GEOLOGY

OF

THE BRITISH ISLES

BY

P. G. H. BOSWELL, GRENVILLE A. J. COLE, ARTHUR MORLEY DAVIES, CHARLES DAVISON, JOHN W. EVANS, J. WALTER GREGORY, ALFRED HARKER, OWEN THOMAS JONES, PERCY FRY KENDALL, LINSDALL RICHARDSON, WILLIAM WHITEHEAD WATTS, H. J. OSBORNE WHITE

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EDITOR: J. W. EVANS

WITH AN APPENDIX:

THE CHANNEL ISLANDS

BY

JOHN PARKINSON

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The British Isles

by

Grenville A. J. Cole, Arthur Morley Davies, Charles Davison, John W. Evans, J. Walter Gregory, Alfred Harker, Owen Thomas Jones, Percy Fry Kendall, John Parkinson, Linsdall Richardson, William Whitehead Watts, H. J. Osborne White.

Preliminary Note by the local Editor.

The completeness of the geological record in the British Isles, the variations in the facies of the different formations from place to place, and the immense volume of the literature that has accumulated, render it impossible for one man to do justice to the Regional Geology of the area. It was therefore decided to divide the work among a number of specialists, each of whom could write with authority on the subject allotted to him and be individually responsible for his contributions. Every effort has, however, been made to secure as much uniformity as was possible in bibliographical and typographical details.

The majority of the illustrations have been taken by permission from the official Reports of the Geological Surveys and the publications of the Geological Society and of the Geologists' Association, the exact source being given in each case. The general maps have been prepared by A. Morley Davies, who has made a careful study of the structural geology of the whole country. He also had the advantage of detailed information supplied to him by other contributors. I am however responsible for the symbols employed on the structural maps, and the system of shading adopted in those showing the distribution of the different formations at the surface. Other maps and diagrams have been specially prepared for the present work by the contributors, who are identified by their initials.
John W. Evans.

I. Morphology.

a. England and Wales.

By Arthur Morley Davies.

The folds and faults of England and Wales are usually grouped in four systems, according to their general axial directions:

1. The Charnian system, with N.W.—S.E. direction;
2. The Caledonian system, with N.E.—S.W. direction;
3. The Malvernian system, with N.—S. direction;
4. The Armorican system, with direction varying from E.N.E.—W.S.W. through E.—W. to W.N.W.—E.S.E.

To each of these systems an age of predominance may be assigned, but the use of any name must not be taken as implying age: it denotes merely direction.

The **Charnian** system is principally developed in the pre-Cambrian rocks of Charnwood Forest (Fig. 8). As both Carboniferous and Triassic strata lap up unconformably against these ancient rocks, and Cambrian strata, present only 24 km. (15 miles) away, are there wanting, it is probable that the folding of the Charnian rocks is itself pre-Cambrian in age. Movement on the same lines, however, was repeated at later periods, notably in post-Carboniferous time, when the boundary-faults of the Leicestershire and Warwickshire coalfields were formed. These are in the near neighbourhood of Charnwood Forest. Other folds and faults with the same axial direction are found at greater distances and separated by areas with other dominant directions, so that their relationship to the Charnian system must be regarded as more doubtful. Such are a) the Eden Valley fault of Cumberland (Fig. 4); b) one set of faults in the Lancashire and Yorkshire coalfields (Fig. 5); c) the post-Carboniferous Woolhope anticline of Herefordshire (Fig. 8); d) part of the system of pre-Bajocian and Bajocian folds, of very slight amplitude, detected in the Cotteswolds by the minute zonal work of Buckman (Fig. 8); e) a series of post-Jurassic pre-Cretaceous folds, with one fault, in the Oxford district (Fig. 8); and f) possibly the post-Eocene folds in the neighbourhood of Lambourn, Berkshire (Fig. 8).

The **Caledonian** system is mainly of post-Silurian age, though movement on these lines seems to have begun in the Ordovician period. It is the dominant system throughout North and Central Wales (Fig. 7). As the folds and faults approach South Wales they become deviated under the influence of the Armorican movement, while as they approach the English border of North Wales they are similarly modified by the Malvernian movement.

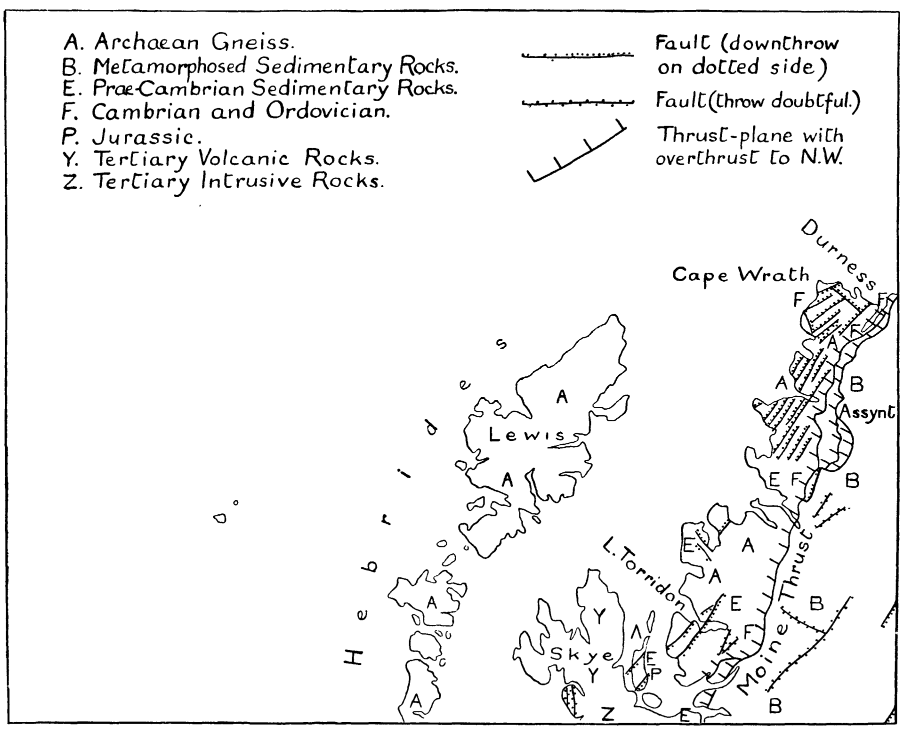

Fig. 1. Tectonic Map of the British Isles—Section I.—Hebrides and North-West Highlands. Region of thrust planes of Caledonian system. A. M. D.
The scale of these structural maps of the British Isles is about 1: 2 650 000 or 42 miles to an inch.

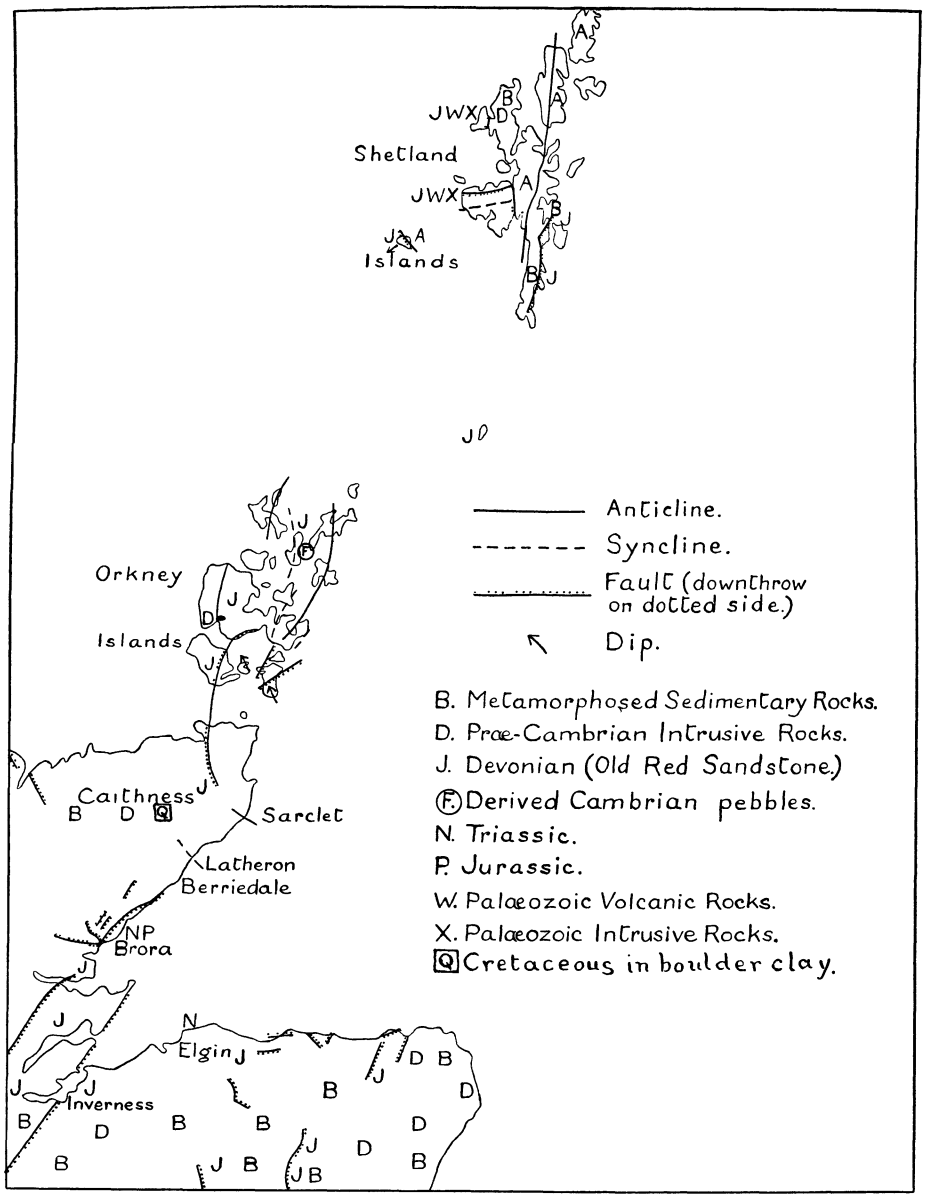

Fig. 2. Tectonic Map of the British Isles—Section II.—North-East-Scotland, Orkneys and Shetlands. Caledonian system dominant. A. M. D.

To this system belong two of the most powerful faults in the country — a) the Dee Valley fault, traceable from Cheshire to Cardigan Bay, and b) the Church Stretton fault, part of a series of faults that form an almost continuous line of fracture from Morecambe Bay to Carmarthen Bay. Beginning with a Charnian direction in Morecambe Bay it extends to the neighbourhood of Manchester, when it curves round into the Caledonian direction, forming first the western boundary fault of the North Staffordshire coalfield, and later the eastern boundary of the

Longmyndian horst. Other important disturbances are c) the faults to which the Menai Straits owe their existence; d) the Snowdon syncline; e) the Harlech anticlinorium; f) the Builth anticlinorium, with its igneous rocks; g) the Berwyn anticlinorium; h) the St. David's anticlinorium.

Besides the many folds and faults in Wales, there also belongs to the Caledonian system a series of post-Carboniferous faults in Northumberland, in close association with the structure of the Southern Uplands of Scotland (Fig. 4), including the well-known 90-fathom "dyke" of the Newcastle district (the term "dyke", as used by Northumbrian miners, meaning simply a fault — not an igneous dyke).

The post-Carboniferous folds of the Lancashire coalfield and the district to the north of it (Fig. 4) may also possibly indicate a revival of Caledonian movements; and in the Yorkshire coalfield there are two intersecting series of faults having respectively the Charnian and Caledonian as their dominant directions.

The **Malvernian** system of north-and-south direction includes more faults than folds. It is of post-Carboniferous and partly of post-Triassic age.

Starting at the northern end in the neighbourhood of Manchester with a series of north-and-south faults, these pass into a series of anticlines and synclines which radiate out southwards and determine the form of the North Staffordshire and adjacent coalfields. They are continued southwards by the boundary faults of the South Staffordshire coalfield (Fig. 8) and parallel faults in the Trias of Worcester-

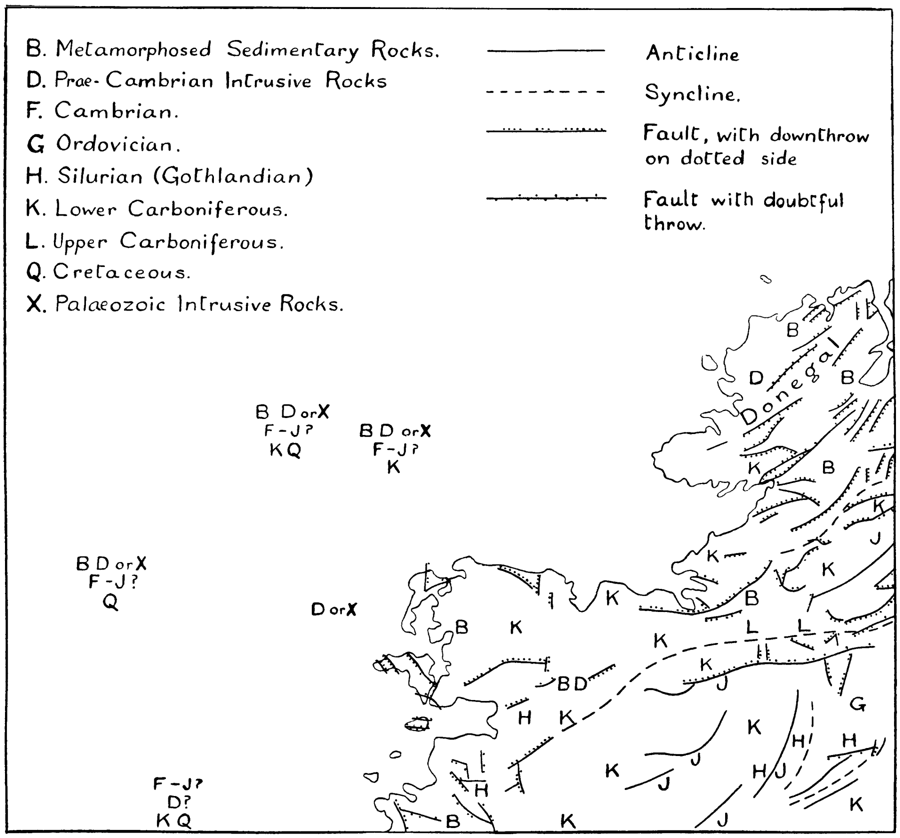

Fig. 3. Tectonic Map of the British Isles.—Section III.—North-West-Ireland. Caledonian system dominant. A. M. D.

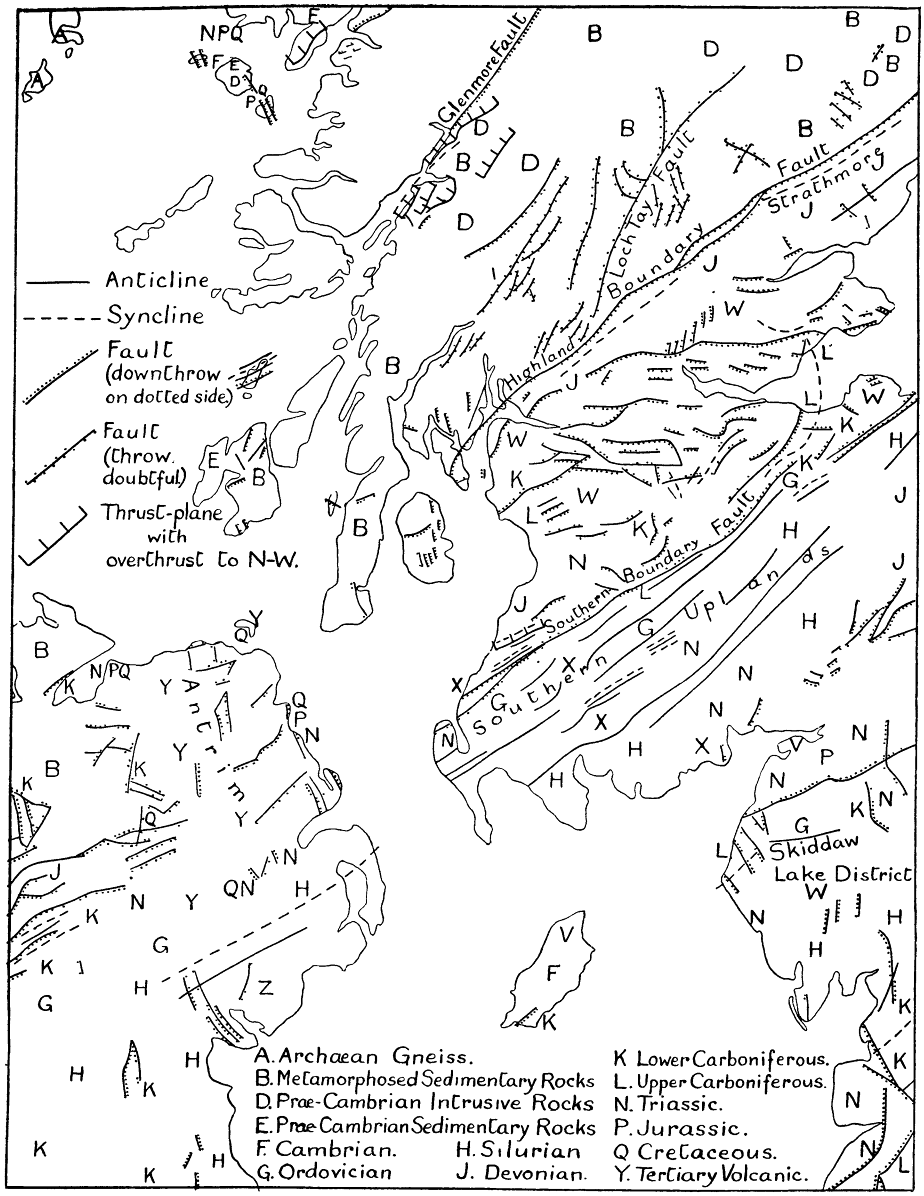

Fig. 4. Tectonic Map of the British Isles.—Section IV.—North-East-Ireland, Scotland (Grampian Highlands, Central Valley, Southern Uplands), England (Lake District) and the Isle of Man. Caledonian system dominant. A. M. D.

shire. But the main feature of this system is the great Malvern fault which for many miles separates the Archaean and Palaeozoic rocks on the west from the Trias to the east. Crossing the Severn it is continued by the syncline of the Bristol coalfield, and ends abruptly against the Armorican folds of the Mendips — unless, indeed, we regard it as continued by the cross-faults of that system, in which case it can be traced on by post-Jurassic faults into the neighbourhood of Yeovil.

The diagrammatic representations of the Pennine chain (Fig. 5) as a simple anticlinė, usually given in text-books, would, if they were correct, justify the extension of the Malvernian system northwards to Northumberland. There is, however, no such simple anticlinal structure. The only indication in the tectonic map of this northward extension is the fact that the Caledonian trend of the west is replaced to the east by an east-and-west trend of folds and faults — much as is the case on crossing the Malvernian system farther south. These east-and-west disturbances are noticeable at intervals throughout the east of England. Such are the folds and faults at the southern margin of the Durham coalfields (Fig. 5), the great Craven fault, the post-Jurassic disturbances of the Vales of York and Pickering, the southern boundary faults of the Carboniferous-limestone area of Derbyshire (Fig. 8) and their post-Jurassic extension eastwards, with probable unmapped disturbances determining the position of the Wash and the north coast of East Anglia, and many minor post-Jurassic disturbances, as in the Cotteswolds and the area north-west of Oxford.

The **Armorican** system is primarily post-Carboniferous in age, but includes slight intra-Jurassic and important post-Jurassic, post-Cretaceous and post-Oligocene revivals. Its greatest development is seen in the South Wales coalfield (Fig. 7) and the Mendip Hills (Fig. 8). The northern margin of the former is partly influenced by Caledonian movement, and a Malvernian interference cuts it off to the east and separates the small coalfield of the Forest of Dean. The Mendip Hills consist of a series of long and narrow domes of Carboniferous limestone with cores of Upper Old Red Sandstone and in one case of Silurian (Gothlandian). They repeat the structure of the South of Ireland, except that (possibly owing to Malvernian influence) the axes are not continuous for such long distances.

The rocks of Cornwall and Devonshire (Fig. 7) also show Armorican folding, and it is in connexion with it that the granitic intrusions, elvan-dykes, and tin- and copper-veins were produced.

As the Palaeozoic rocks of the south-west of England pitch under the Mesozoic strata to the east, evidence of the continuity of folding is seen in the latter. The intra-Liassic denudation of the Radstock district appears to be due to movement parallel to the Mendip axes. It is very probable that when detailed zoning of the Corallian rocks has been carried out, their irregularities of distribution will be found due to similar causes. The faults in the Jurassic rocks of Somerset and Dorset (Fig. 8) have a dominant Armorican trend, and still more strikingly is this the case with the post-Cretaceous and post-Eocene disturbances. These include

(a) The Isle of Purbeck and Isle of Wight, anticlines possibly continuous with that of the Pays de Bray;
(b) the Isle of Purbeck thrust-fault;
(c) the syncline of the Hampshire basin;
(d) the Portsdown anticline;
(e) the Salisbury-Chichester-Worthing syncline;
(f) the anticline of the Vale of Wardour (partly pre-Cretaceous);
(g) the series of anticlines constituting the Wealden axis, one of which is continued into the Bas Boulonnais;
(h) the Pewsey-Kingsclére-Peasemarsh anticline accompanying the steep southern margin of the London Basin, with associated minor folds and faults, including a slight northwardly thrust-fault at the Hog's Back near Guildford.
(i) the series of synclines that form the London basin.

The London basin is not a simple syncline: a minor crumpling brings up the Chalk along the lower Thames, and there is some disturbance of the axial direction

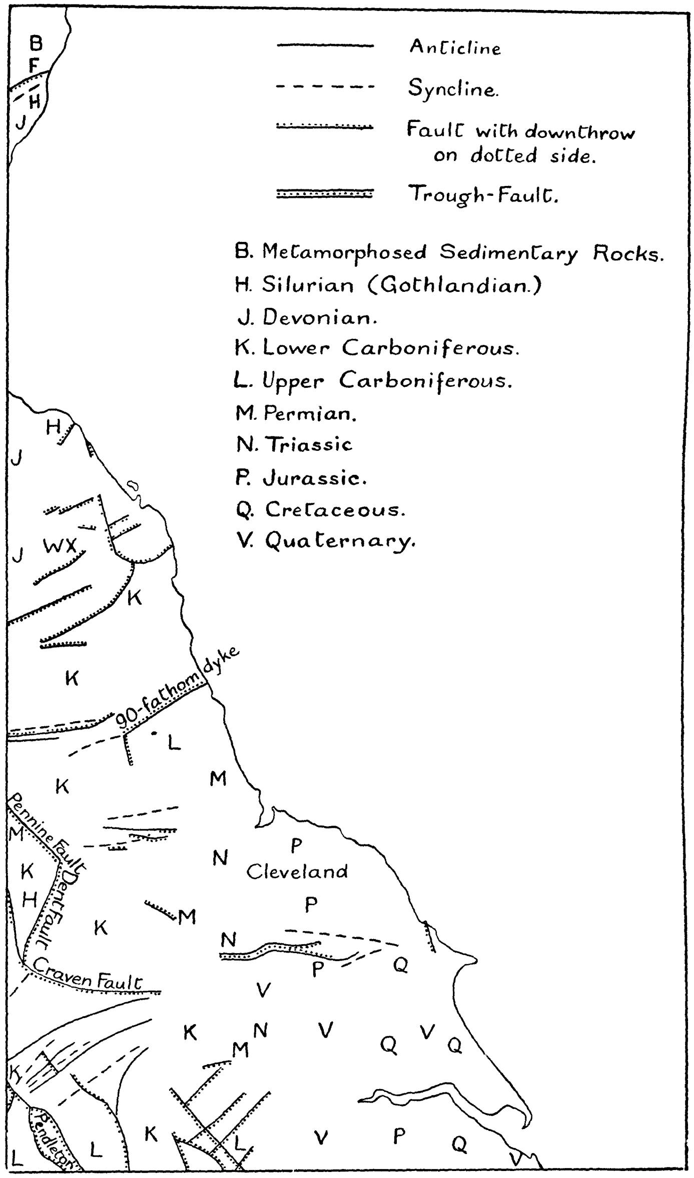

Fig. 5. Tectonic Map of the British Isles.—Section V.—North-East-England. A. M. D

in the centre of the basin, as shown by the Windsor inlier, but the very gentle angle of dip makes determination of the nature of this disturbance very difficult. It is not impossible that it may be connected with the series of folds with Charnian direction near Oxford, as the distribution of Jurassic rocks underneath London suggests an extension of those folds as far as London.

Physiography. The most fundamental fact in the geography — physical, economic and racial—of England and Wales is the contrast between the Palaeozoic areas of the west and north and the Neozoic areas of the south and east. The former consist of a series of separate districts, of high relief, each a deeply dissected ancient peneplain with an epigenetic river-system more or less re-adapted to the rock-structure now exposed; while the latter is an area of low relief and gently-dipping strata, with a river-system in an advanced stage of adaptation to the rock-structure, but in places greatly modified by glacial diversion. The former areas include all the main coalfields, and most of the other sources of mineral wealth, and the

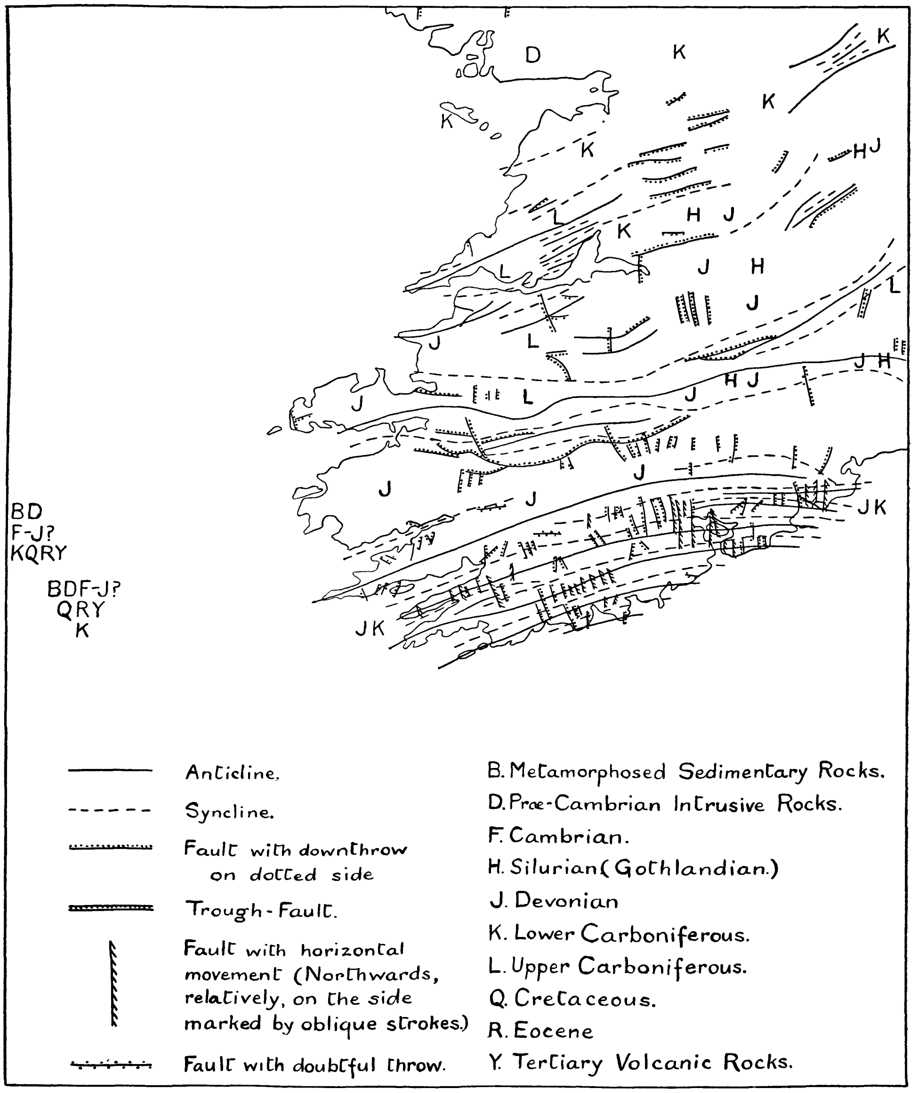

Fig. 6. Tectonic Map of the British Isles.—Section VI.—South-West-Ireland. Armorican system dominant. A. M. D.

majority of the manufacturing towns, and their inhabitants are largely of the races that inhabited the British Isles prior to the Teutonic invasion. The latter are less industrial than agricultural, and their population is mainly Teutonic

The four great Palaeozoic areas are 1) the south-western peninsula of Devon and Cornwall, 2) Wales, with the border counties of Shropshire, Herefordshire, Monmouthshire and part of Gloucestershire, 3) the Pennine area, of Northumbria, Lancashire and Yorkshire, and 4) the Lake District of Cumberland and Westmorland. To these may be added 5) the Isle of Man.

Most, if not all, of these areas were submerged in the Upper Cretaceous transgression, if not previously, and have been re-exposed by Kainozoic erosion. There are also a number of minor areas, less completely stripped of their Mesozoic cover — 1) the Mendip Hills, with the Somerset and Bristol coalfields, 2) the South Staffordshire, Warwickshire and Leicestershire coalfields, and 3) Charnwood Forest.

1) The **South-western peninsula** (Devon and Cornwall) (Fig. 7) may be described broadly as an Armorican synclinal area, with Carboniferous and Permian rocks in the centre, Devonian on the north and, the same, with Silurian, Ordovician and Metamorphic rocks, on the south. The southern limb is complicated by large granite intrusions, igneous dykes and metalliferous veins. The river system is obviously epigenetic, but so complex and intricate in its character, that it has hitherto defied explanation. Tin- and copper-mining have been carried on here from prehistoric times, and china-clay is now extensively produced from the kaolinized granites.

2) **Wales** (with the border counties) (Fig. 7) is an area in which Caledonian structure predominates, the trend lines passing into a Malvernian direction in the north, while in the south they end off against well-marked Armorican folds. The rocks include members of all the pre-Palaeozoic and Palaeozoic systems except undoubted Permian, but Ordovician and Old Red Sandstone cover the widest areas.

Wales is classical as the case in which a mountainous country was first recognized as a deeply dissected plateau, JUKES and RAMSAY having pointed out the uniform gentle slope of the plane surface tangential to the highest mountain-tops. In the west, the river-system has become well-adapted to the rock-structure, but in the South-Wales coalfield the epigenetic character is well shown. Most of the rivers, like the Taff, traverse the coalfield completely from north to south, though in the west the Towy, working on the soft Ordovician shales, has beheaded the transverse river Loughor or Llwehwr. Still more striking is the lower Wye, of which the entrenched meanders cross and recross the boundary between Old Red Sandstone and Carboniferous Limestone, forming deep narrow gorges in the latter and wide vales in the former.

The broad subsequent valleys of Wales are devoted to agriculture, but the rest of the country consists of barren moors, thinly populated, except where coalmining and iron-smelting has drawn together a huge industrial population.

3) The **Pennine area** (Fig. 5) is mainly a series of moorlands of grit, with limestone areas characterized by caverns and underground drainage. The north-to-south trend of the area is believed to have been blocked out in the Kainozoic era, and by no means corresponds to the tectonic structure of the rocks, almost entirely Carboniferous, of which it is composed. The drainage is mainly eastwards and westwards, but in the south the Derwent, working along an outcrop of shale, at the foot of a grit escarpment, has disturbed the simplicity of the river-system.

4) The **Lake district** (Fig. 4) consists of an area of slaty and volcanic rocks, of Lower Palaeozoic age, and has a strikingly radial drainage practically independant of the structure.

The Neozoic part of Britain consists mainly of alternations of escarpments and vales, with a maturely-adjusted river-system showing numerous examples of capture. The principal resistant beds, forming the main escarpments are 1) the Permian Magnesian Limestone (included with the Mesozoic for topographical convenience), 2) certain of the Triassic sandstones, 3) the Marlstone of the Lias, 4) the limestones of the Lower Oolites and 5) the Upper Chalk. Of the two main escarpment-lines of England, one is formed in part (as near Bath) of the Great Oolite, in part (as near Cheltenham and again near Lincoln) of the Inferior Oolite, and elsewhere where neither of these is well-developed, by the Marlstone; the other is the striking Chalk escarpment.

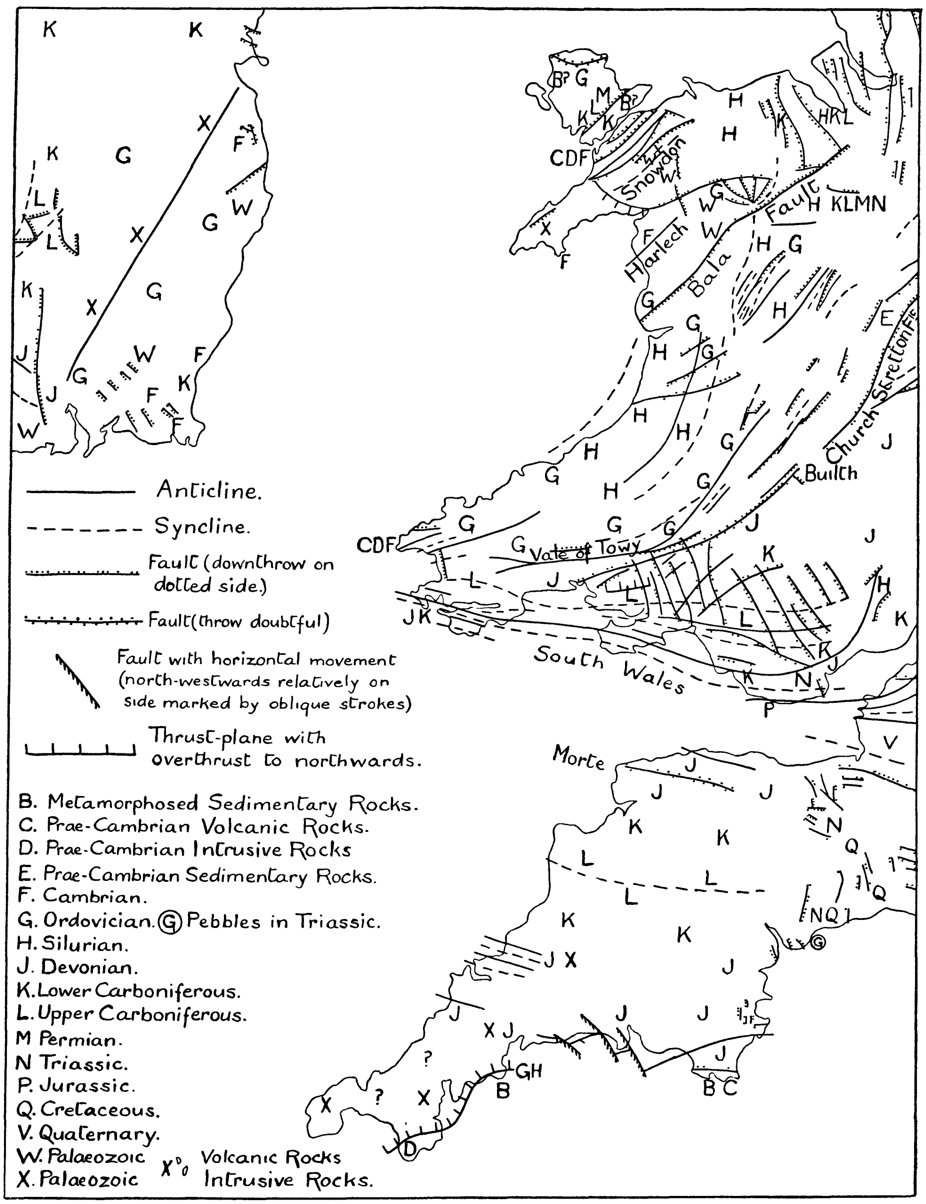

Fig 7. Tectonic Map of the British Isles.—Section VII.—South-East-Ireland, Wales and South-West-England. Meeting of Caledonian and Armorican systems. A. M. D.

Epigenetic drainage is well-shown by the Bristol Avon, which cuts through the Carboniferous Limestone at Clifton in the gorge which gives the standard section of that formation — a gorge 90 metres (300 ft.) deep, though an easier course over the Triassic red marl seems open to it.

Of glacial disturbances of drainage two striking cases may be given. The upper Severn emerges from the Palaeozoic upland of Wales on to the Triassic

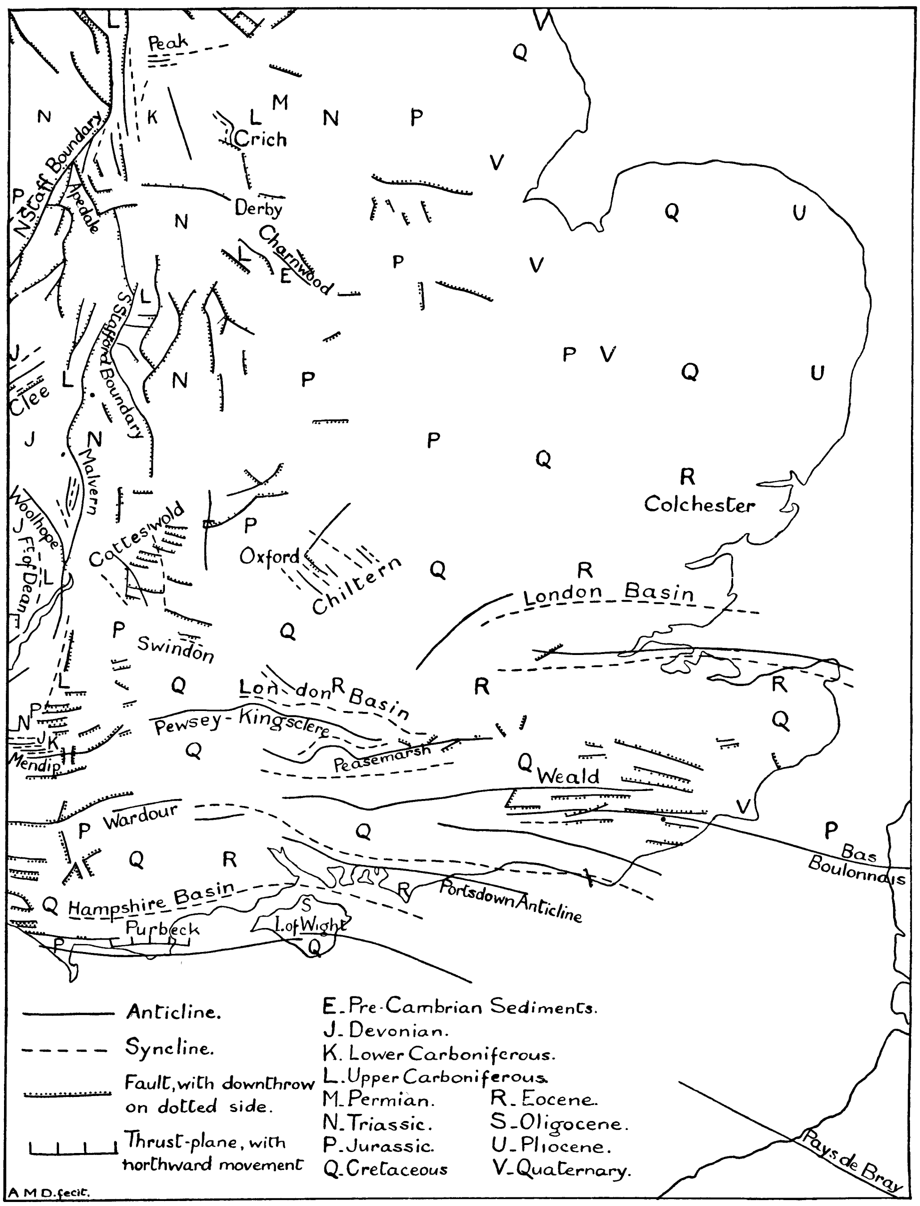

Fig. 8. Tectonic Map of the British Isles.—Section VIII.—England (Central, Southern and Eastern). Malvernian, Charnian and Armorican systems. The London Basin is seen to be composed of two separate synclines, not in line: the connexion between them is obscure owing to slightness of dip. A. M. D.

plain of North Shropshire, where its natural course would appear to be northwards to join the Dee. This was probably its course until the Glacial Epoch, when the Irish Sea ice blocked its course and formed a lake that overflowed southwards and cut the gorge at Ironbridge, through which the Severn was permanently diverted into a valley that had been tributary to the Warwickshire Avon.

The second case is that of the Yorkshire Derwent. The upper waters of this stream were originally gathered into a river occupying the vale of Kimmeridge Clay at the foot of the Chalk Escarpment of the Yorkshire Wolds, and entering the sea near Filey. The North Sea ice dammed up this stream, and made a lake, the alluvial floor of which now forms the Vale of Pickering. This lake overflowed south-westwards into the Vale of York, and in doing so cut the gorge at Malton which now forms its permanent course.

In the south-east of England, the anticlinal dome of the Weald exhibits the effects of mature adjustment of drainage, of which it is a classical example. Its original continuation in the Bas Boulonnais has been severed from it by marine erosion.

The coasts of England afford many fine examples of the effects of marine erosion, of submergence and of accumulation. Drowned river-valleys are characteristic of the southern coasts from Milford Haven round to the mouth of the Thames. Plymouth Sound and Portsmouth Harbour are the two most important ports due to submergence. The original central river-valley of the Hampshire basin (the continuation of the Dorset Frome) has been converted by the combined effects of submergence and erosion into the Solent and Spithead. The Isle of Wight has been separated from the Purbeck peninsula by marine erosion, and its river-system, heading in the south coast, shows that it once extended as land much farther south. Along the Dorset coast, where Upper Jurassic and Cretaceous beds dip steeply landward, the progress of marine erosion has led to a number of beautiful features, of which Lulworth Cove is the finest. This is a nearly circular bay, hollowed out in the soft Lower Cretaceous strata, with a narrow opening to the sea through the hard Portland limestone. Other coves in various stages of growth or destruction are found along the same coast.

Extensive alluvial areas, deposited partly by rivers, partly by the sea, are seen in the Fens of Cambridgeshire and Lincolnshire, in Sedgemoor (Somerset) and elsewhere.

Of accumulations of shingle, the most interesting is the Chesil Bank, which unites the Isle of Portland to the mainland, and extends north-westwards along the coast for 19 km (12 miles). The pebbles decrease in size westwards, although they are all of rocks of westerly origin, but they make their way to Portland apparently along the sea-bottom on a line some distance south of the coast. Another important accumulation of shingle is at Dungeness: this appears to have accumulated entirely since the formation of the Straits of Dover.

b. Scotland.

By J. W. Gregory.

Scotland, the northern part of Great Britain, is separated from England in part by the Tweed and one of its tributaries, in part by the watershed along the Cheviot Hills, whence the boundary is continued westward along a less natural line to the Solway Firth. Scotland is bounded to the east by the shallow basin of the North Sea and to the west by the Atlantic. The continental platform extends westward and bears the numerous Western Isles, of which the most remote is the small island of St. Kilda. At a distance of usually over 160 km. (100 miles) from the mainland the sea floor sinks rapidly to the North Atlantic basin*. The morphology of Scotland both as regards outline and structure has been largely determined by earth-movements, directly by those of recent date, and indirectly by ancient movements which have guided modern denudation. The northernmost part of Scotland is a denuded horst standing between the sunken areas of the North Minch to the west and a series of faults trending approximately from north-east to south-west along the coast of Caithness and Sutherland. The archipelagoes of the Hebrides, Orkneys and Shetlands are all remnants of this once more extended land.

Scotland consists morphologically of three divisions.

1) The largest is the Highlands, which, from the structural standpoint, include the whole country north of a line across Scotland from Stonehaven on the east to the estuary of the Clyde at Helensburgh; the line continues westward across Bute and Arran, the northern parts of which belong geologically to the Highlands (Fig. 4, p. 5). The sharpness of the southern boundary is due to a great fault known as the Highland Boundary Fault, by which the younger rocks to the south have been brought against the older rocks of the Highlands.

2) The second division, the Midland Valley of Scotland (Fig. 4, p. 5), lies to the south of the Highlands and has been formed by a great trough fault. It includes the chief industrial centres, the largest coalfields and the most populous districts of Scotland. The Midland Valley extends across Scotland from the Firths of Forth and Tay on the east to the Firth of Clyde on the west and includes the rich agricultural districts of Ayrshire. Its coastal limits are on the east from Stonehaven to Dunbar, and on the west from the estuary of the Clyde to near Girvan in southern Ayrshire. The Midland Valley is bounded to the south by the "Southern Boundary Fault", which consists of a series of parallel step faults; hence the southern border of the Midland Valley is less sharply defined than the northern.

3) The third element in Scotland is formed by the Southern Uplands, which consist mainly of moorlands, separating the Midland Valley from the Solway Firth and the English Border (Fig. 4).

Geologically the three divisions of Scotland are essentially distinct, both in composition and structure.

The Highlands (Figs. 1, 2, 4) consist in the main of a block of crystalline schists and gneisses, which are generally regarded as of Archean age. The Archean rocks have been invaded by plutonic masses, mainly granites of Palaeozoic and Archean ages. A belt of Pre-Cambrian sandstones (the Torridonian) and of Cambrian and Ordovician rocks lies along the north-western margin of the Highlands, and there is a thin band, probably Cambrian, along the southern border; wide sheets of sedimentary and volcanic rocks, belonging to the Old Red Sandstone, lie upon the Archean block; some comparatively small areas of Carboniferous and Mesozoic rocks have been preserved by trough faults or by a cover of Kainozoic lavas; some sheets of Jurassic rocks rest upon its north-eastern slopes; some small patches of Cretaceous have been preserved beneath the lavas of the Western Isles, and there is a significant Cretaceous outlier on the Highland plateau in Morven. In some of the Western Isles, as Mull, Skye and Eigg, and on the peninsula of Ardnamurchan, vast eruptions of Kainozoic volcanic rocks have been piled upon the older rocks.

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* On it rises the westernmost of the British Isles, the stack of Rockall.

There is accordingly abundant evidence that the Pre-Cambrian rocks of the Highlands have been covered by a long series of later deposits, most of which have been swept away, leaving the country as a dissected block of Archean rocks.

The two southern divisions of Scotland, on the other hand, contain no outcrops of Archean rocks in situ, though pebbles found in the Palaeozoic conglomerates indicate the former extension of the Archean into southern Scotland.

The Midland Valley (Fig. 4) is occupied mainly by Upper Palaeozoic rocks, chiefly Old Red Sandstone, Carboniferous and Permian. The Old Red Sandstone is exposed to the north and south of the valley, beside the boundary faults; while the central area consists of Carboniferous rocks and includes the chief coalfields. The largest area of the Permian rocks is preserved by a basin-shaped depression around Mauchline in Ayrshire. Silurian rocks occur in the inlier at Lesmahagow and in the Pentland Hills. The essential structure of the Midland Valley may be regarded as an irregular geosynclinal of Upper Palaeozoic rocks, dropped by trough faults between the Archean rocks of the Highlands and the Lower Palaeozoic rocks of the Southern Uplands.

The Southern Uplands (Fig. 4) have quite a distinct structure from either of the two other divisions, as they consist mainly of Lower Palaeozoic rocks belonging to the Ordovician and Silurian (Gothlandian). The rocks, though intensely folded, have a predominant dip to the south-east. The oldest rocks, the Arenig (Lower Ordovician), occur along the northern edge of the Southern Uplands. They are followed to the south by the Llandeilo (Middle Ordovician) and Caradoc (Upper Ordovician). The slope downward to the Solway Firth and the lower Tweed is formed mainly by Silurian rocks. This Lower Palaeozoic foundation is capped by sheets of Old Red Sandstone, some Carboniferous rocks, as in the coalfield of Sanquhar, and some Permian and Trias. The Southern Uplands have also been invaded by masses of Devonian granites. Their essential structure however is a broad band of Lower Palaeozoic rocks cut off to the north by faults and having a long and very disturbed dipslope south-eastward.

The three structural divisions of Scotland are more sharply defined than the political and ethnographic divisions. The differences between the Upper Palaeozoic rocks of the Midland Valley and the Lower Palaeozoic of the Southern Uplands are less marked than those of the Highlands and the Midland Valley. Hence there are less striking geographical differences between the two southern areas which are grouped together as the Lowlands, and are both occupied by the same race. Owing to the more favorable agricultural conditions of the eastern as compared with the western Highlands, the Lowland race has crossed the eastern end of the Highland Boundary Fault and has extended northward occupying parts of Aberdeenshire and the adjacent counties; this area, though geologically Highland, is therefore ethnographically Lowland.

The Highlands were once a plateau having its main slope from north-west to south-east, but the old plateau surface has been destroyed by denudation, which has been guided by bands of weakness due to earth movements of at least three dates.

The oldest of these three is post-Cambrian and probably Silurian. It thrust the schists and gneisses of the Highlands westward over the Ordovician, Cambrian and Torridonian rocks. This great overthrust can be traced from the northern coast of Scotland at Loch Eriboll for one hundred miles south-south-westward to Skye (Fig. 1). This line of movement separates a western area of varied geological character, including Lewisian and Moine gneisses, Torridonian Sandstone, Cambrian quartzites and Durness limestones from an eastern area of more monotonous geological character, as it consists mainly of gneisses covered in places by Old Red Sandstone (Figs. 1, 2).

The second movements happened in Devonian times and are known as the Caledonian. A series of faults along the eastern coast of Sutherlandshire and in eastern Ross-shire dropped the Lower Old Red Sandstone against the Archean gneisses (Fig. 2). Faulting at the same date occurred along the line of the Great Glen, which now traverses Scotland from Loch Linnhe to the Moray Firth at Inverness (Figs. 2, 4); and strips of the Old Red Sandstone are preserved in the valley along the course of this fault. The typical Caledonian direction, as seen in northern Scotland, is approximately from north-north-east to south-south-west; but further southward the line trends from east-north-east to west-south-west, as along the boundary faults which border the Midland Valley (Fig. 4). That these faults were formed in Middle Devonian times is indicated by the evidence near Loch Lomond, where the Upper Old Red Sandstone is nearly horizontal, while the Lower Old Red Sandstone is uptilted against the fault. The main strike of the rocks in the Southern Uplands was doubtless determined by the Caledonian movements.

The third series of movements happened in Kainozoic times and was connected with those that formed the Alps and the North Atlantic. These movements broke up the great volcanic plateau of which the islands of Mull, Skye and some of the smaller of the western islands were part. The subsidence, as suggested by MACKINDER, of a submarine rift-valley formed the deeper part of the Little Minch, which separates the Hebrides from Skye; and various faults produced rift valleys, such as the Sound of Mull, and caused rifts and lines of weakness, which have been enlarged by rivers and ice into the glens and lochs of western Scotland.

One of the most striking features in the structure of the Highlands is the contrast between the western and eastern sides of the country. The western coast is skirted by an archipelago of innumerable islands, and the coast is indented by a series of lochs which include fiords. There are, on the other hand, very few islets off the eastern coast, and they are volcanic necks belonging to the Midland Valley. The eastern coast of the Highlands extends in unbroken stretches, of which the longest are in Aberdeenshire and on the north-western side of the Moray Firth, and trend from north-north-east to south-west, parallel to the main Caledonian lines. The intervening coast line of Nairn, Elgin and Banff trends from east to west parallel to an important series of Highland valleys, such as Glens Oykell, Strathconnan, Strathbrae, Strathfarrar, Glengarry, Loch Arkaig, Loch Morar, Loch Eil, etc.

The only important indentations on the eastern coast of the Highlands are at the head of the Moray Firth (Fig. 2), which continues inland as the Firths of Cromarty, Beauly and Dornoch. The connexion of Cromarty Firth with Moray Firth past the town of Cromarty is of post-Glacial date, the former outlet having been into the Dornoch Firth, to the west of Tarbat Ness.

The great difference between the western and eastern coasts of the Highlands is due partly to geological structure and partly to earth-movements. The Archean rocks sink eastward below sea level and are covered by wide sheets of Old Red Sandstones and their associated shales, and by the largest Jurassic areas in Scotland. Fluvioglacial gravels and sands have been laid down along the river valleys and over the low country along the eastern coasts. Hence the Eastern Highlands are bordered by wide plains, which have a better soil, a drier climate and more sunshine than the western districts and thus enjoy great agricultural advantages over the isolated patches of cultivable land on the floors of the western glens. As the prevalent winds are from the south-west, they strike first the high western area which, therefore, receives a heavy rainfall and snowfall. In Glacial times the first glaciers were doubtless formed on the western side of Scotland, and they probably lasted there latest. The material left by pre-Glacial rock decay in western Scotland has been very largely carried eastward and south-eastward and has helped to fill up many of the old valleys in eastern Scotland. The glaciers flowed out to sea in eastern Scotland in great strength, but the tectonic conditions there were not suitable for fiord formation. The many branched lochs of the western Highlands are probably due to the area having been a high plateau shattered by Middle Kainozoic earth movements, and the valleys then begun have been moulded by river and ice into the present lochs and glens.

Kainozoic denudation and fresh movements along the line of Caledonian faults have formed the Great Glen (Figs. 2, 4) and thus broken the Highlands into two main divisions. The main Highland valleys in early Kainozoic times ran from north-west to south-east; the formation of the Great Glen broke these valleys into two series, both still preserving in the main their original direction from north-west to south-east. In the northern Highlands the longest rivers rise on the hills behind the western coast and flow south-eastward to the Moray Firth or the Great Glen; and the level lower courses, or estuaries of these rivers form the lochs such as the Beauly Firth, Loch Garry, Loch Arkaig, Loch Eil on the northern side of the Great Glen.

The southern Highlands, between the Great Glen and the Highland Boundary Fault, consist of a second block with a main slope from north-west to south-east. Its peneplane surface can still be recognised in views across the country from the summits of the chief peaks. The remains of the old consequent drainage is still apparent as in Glen Garry, the former main stream of the Tay, or in the continuous valleys from the hills of mid-Argyll across Loch Fyne and through Hell's Glen to Loch Goil and the Gareloch, and along Loch Eck to the estuary of the Clyde.

The valley system of the Highlands was not originated by the glaciers, but they modified it, especially by the frequent diversion of the drainage; many of the notches on the sides of the valley have been used as overflow channels and cut down to the general base level of the local river system. Thus the Highland plateau has been intersected by many low valleys and passes which afford easy means of intercommunication. The old drainage system has been greatly altered by the formation of large valleys along the strike of the rocks, such as the valleys of the Spey, upper Tay, upper Forth, Dee and Don. These rivers deposited along their valleys and over the eastern plains wide sheets of alluvium, which, combined with the sunny and drier climate, have given the eastern Highlands their special agricultural advantages over the western.

The western Highlands and islands owe some of their most striking geographical features to Kainozoic volcanic activity; the gabbro masses, which form the picturesque mountains of the Coolins in Skye, and the wide sheets of basalts that constitute most of northern Skye both belong to this period. The islands of Rum, Eigg, Mull and the peninsula of Ardnamurchan all contain volcanic masses resting on foundations of Mesozoic or older rocks.

The Midland Valley of Scotland (Fig. 4) is politically the most important of the three divisions of Scotland, although much smaller than the Highlands. It owes its industrial importance primarily to its coalfields, with their beds of coal, iron ore, fire clay and oil shale. Its land moreover, is of higher value agriculturally than that of the Highlands, as the rocks are softer and more readily decompose to soil, while large parts of the country are covered by thick clays and loams deposited during the glacial period; and these superficial deposits often form fertile soils, as they have been enriched by the waste of the extensive basic igneous rocks. As the level of the country is lower than that of the other two parts of Scotland, the soils can be used to better advantage as the climate is warmer.

The floor of the Midland Valley is, however, hilly, for it includes moorlands of Old Red Sandstone, ranges of Silurian sediments and Devonian igneous rocks; and from Renfrewshire to Stirling is a series of plateaus formed of Lower Carboniferous volcanic rocks, the Renfrewshire Hills, the Kilpatrick Hills, the Campsie Fells and the Fintry Hills.

The general structure of the Midland Valley is essentially a disturbed irregular geosynclinal. The Old Red Sandstones form the moorlands on both northern and southern sides; the Carboniferous rocks form most of the middle of the valley. The coal seams occur at two horizons—the Lower Carboniferous Limestone Series, and a higher horizon which corresponds with the Coal Measures of England. The Lower Carboniferous coals are found in numerous scattered basins; the upper or true Coal Measures occur in the Lanarkshire coalfield, a great basin.

The coast of the Midland Valley includes the two great Firths of Forth and Tay on the east, and the Firth of Clyde on the west, though the branches of the last are lochs belonging to the Highlands.

The Southern Highlands (Fig. 4) are geographically the simplest division of Scotland. They are composed mainly of Ordovician and Silurian rocks, which are covered in places by sheets of Old Red Sandstone and of New Red Sandstone, and have been invaded by masses of Devonian granite. The country consists mainly of moorlands used for sheep farms, while the valleys and plains in the south-eastern and south-western districts include much valuable agricultural land and dairy farms. The mineral wealth is of secondary value; there are lodes with ores of lead and silver at Leadhills etc., and a patch of Carboniferous rocks preserved in a depression in the older rocks forms the coalfield of Sanquhar. The country as a whole has its high ground near the northern border and the level falls to the south-east and south-west. The highest summits are remnants of an old peneplane destroyed by river valleys begun in early or perhaps mid-Kainozoic times; the main consequent valleys trend from the N. W. to S. E., and the wind gaps left at their heads are used as the chief routes for roads and railways from the Midland Valley to the English border.

c. Ireland.

By G. A. J. COLE.

The general outline of Ireland is roughly rectangular, its four sides respectively facing the cardinal points of the compass. Considerable variety, however, is discoverable when the details of its coast-line are examined, and features are revealed which connect this or that part of its structure with the west coast of Scotland, the Southern Uplands, or South Wales. Situated as the country is on the great European plateau, which drops on the west of Ireland into oceanic waters, it soon becomes clear that a comparatively recent subsidence has separated Ireland from Great Britain, and that prominent tectonic lines may be expected to pass from one region to the other. It is as difficult to consider Ireland, from a geographic point of view, apart from Britain, as it is to consider the islets off the Irish coast apart from the features of the mainland.

As a matter of convenience, the line indicating a depth of 100 fathoms (183 metres) has been usually accepted as the edge of the continental shelf; and this serves well for western Europe generally. On account, however, of the broad area of shallow water that extends westward from Co. Galway, the line of 300 fathoms (548.5 m.), expresses more accurately, in the case of Ireland, the limit of the Atlantic basin. This line sweeps out westward from off northern Mayo to beyond 27° W. Long., and returns towards the coast of Kerry, after a hook-like bend southward in 26° W. Long. It includes the Porcupine Bank, where rock is known to rise within 159 m. (87 fathoms) of the surface. An elevation of some 600 metres (2000 ft.) would thus add a territory nearly 300 km. (186 miles) in width and some 200 km. (124 miles) from north to south to the existing area of Ireland, while the gain off the coasts of Scotland, England, and France would be very little more than would be occasioned by an uplift of 200 m. (656 ft.).

When we examine the present **coast-line** of Ireland, certain distinct morphological types are met with. These depend partly on the geological structure of each district, partly on recent movements of subsidence or elevation, and partly on the extent to which the rocks are exposed to the battering action of the sea. Thus from Dublin Bay to Carnsore Point in Co. Wexford (Fig. 7) the shore is practically parallel with the strike of the strata, and with the axis of high ground that runs north-east and south-west at some little distance within the coast. Broad bays have been carved out between headlands of more resisting rock; but the coast-line is one of fairly regular erosion, and shows few features due to the subsidence of ancient valleys. The mouths, indeed, of many of the valleys have been cut away by marine erosion. When we pass westward round the granite promontory of Carnsore, we find far more rugged features, where the sea is attacking the country up the strike of the beds, and where rocks of various hardness have thus a prominent influence in producing promontories or recesses (Fig. 6). Near Dungarvan we find a third type of coast, which extends round to the mouth of the Shannon. East-and-west folds dominate the country, hard sandstone weathering out along the anticlines, and limestone or slate forming lower ground along the synclinal hollows. The subsidence of the coast has produced numerous sea-inlets along the lower courses of the rivers. Cork Harbour, with its "passages", represents a system of streams that here cuts across the strike of the folds. The "rias" of western Kerry represent streams that flowed seaward down the hollows worn out along the synclinals. The islets off the coast are the unsubmerged peaks of the former valleywalls.

The violence of the Atlantic storms prevents the accumulation of delta-material on the west Irish coast, except in sheltered inlets. Here the winds pile up blown sand on any alluvial bank or barrier that may rise to the surface of the sea. Fine cliffs have been cut out in the west of Clare (Fig. 6). North of Galway Bay, a fault-line seems responsible for a straight stretch of coast; and thence to the north of Mayo a characteristic region of rugged headlands, irregular sea-inlets, and outlying rocky isles, indicates severe marine erosion combined with features due to subsidence (Fig. 3). The same type recurs throughout the Donegal coast, the milder interval between Killala Bay and Donegal town being due to the presence of limestone along the shore, and the consequent lack of resistance offered to erosion. The long inlets of Mulroy Bay, Lough Swilly, and Lough Foyle, indicate the subsidence which has increased the basin of the North Atlantic in Pliocene or later times, and which limits Ireland in a northerly direction. A far less indented coast, dominated by a scarped edge of basaltic plateaus, continues from Lough Foyle to Belfast Lough (Fig. 4). Here we see how the old valley of the Lagan was entered by the sea when Ireland became cut off from Britain; Strangford and Carlingford Loughs furnish additional evidence of subsidence as we go southward. From Dundalk down to Dublin, still milder features prevail, and signs of uplift, or recovery from the last downward movement, become prominent in the form of raised beaches. Similar beaches occur, indeed, from Lough Foyle eastward and southward, and provide flat land at the heads or on the flanks of many inlets, such as the level shore on which the Lagan alluvium has gathered at Belfast. Close to Dublin, the village of Baldoyle stands on a raised beach that now joins the rocky mass of Howth with the mainland.

When we pass from the coast to the interior of Ireland, we are at once struck with the fact that the **highlands** are grouped upon its margins. The coast-line is almost everywhere picturesque, with mountains rising abruptly from the sea, as in Kerry or Donegal, or forming a wall-like background to a comparatively narrow lowland, as along the Leinster shore. Broad stretches of the interior, however, are devoid of any prominent features, and a great plain, rising in places as plateaus 120 m. (400 ft.) above the sea, stretches between Dublin and Galway, and from Boyle in the north of Roscommon to Nenagh in the north of Tipperary. The lower parts of this level land are often covered by bog, and lakes, which are broad expansions of the rivers that run through them, occupy extensive areas. No clearly defined watershed exists to mark off the river system of the Shannon from that of the Boyne, the Liffey, or the Barrow. The only prominent hills are formed of glacial gravels, deposited as long winding eskers upon the worn-down surface of the plain. The same type of country extends between the ranges of hills as far south as the borders of Cork and Waterford, and as far north as Dungannon and Donegal Bay. Local offshoots of the great central plain thus occur far beyond the limits above assigned to it; and these are found to repeat in their geological structure the far narrower valleys which lie between the ranges of the south of Ireland.

A broad triangular area of broken hummocky country stretches from an apex on the central plain near Longford to the eastern coast, where the base of the triangle extends from Belfast to Drogheda. The axis of this upland thus runs north-east and south-west, and is a continuation of that which forms the Southern Uplands of Scotland (Fig. 4). At its west end it forms a watershed between the river-systems of the Erne and the Shannon. North-west of it, there are two or three areas of high ground. The most important of these lies round about Lough Allen, a region of scarps of stratified rock, rising in terraces, and culminating in Cuilcagh, 667 m. (2188 ft.), where the first waters of the Shannon gather.

Farther west, the Irish plain is broken by the range of the Curlew Hills, and then by the Ox Mountains, which appear as a north-easterly offshoot of the Mayo highlands. South of the line between Dublin and Galway, numerous interruptions of the plain occur, in the form of somewhat round-backed masses, often with basin-shaped depressions in their centres. Such are the Slieve Bloom Mountains, Slieve Aughty, Slieve Bernagh, and the broad upland from Devilsbit Mt. to Slieve Felim. The range of the Galtees and the Ballyhoura Hills has the same structure; Galtymore is 919 m (3115 ft.) in height. Slievenaman (720 m., 2364 ft.) on the borders of Tipperary and Kilkenny forms a bold promontory in the south-east angle of the plain. From its western end a ridge runs towards Kilkenny city, a typical piece of plain-land being thus enclosed. North of Kilkenny, the plateau of the Leinster Coal-field rises in bold terraces to heights of over 300 m. (1000 ft).

The general lowland of the interior is thus greatly broken towards the south; but the intervals between the hills, which often have rivers in their floors, are important for agriculture, and the commercial routes, whether roads, canals, or railways, have been carried along them. In the Galtee range we reach truly mountainous country. This is repeated on the Knockmealdown and Comeragh Mountains immediately to the south, and generally throughout the west of the county of Cork and the whole of that of Kerry. The trend of the ranges is here east and west. Carrauntoohil in Macgillicuddy's Reeks rises 1040 m (3414 ft.) above the sea, and is the highest Irish mountain.

The west of Clare is a country of high plateaus. The county of Galway, with its irregular peaks of stratified quartzite rising among granites and mica-schists, introduces us to a complex highland type, which occurs generally throughout Mayo, and again from Donegal town across to Londonderry. In the latter region, as in the Ox Mountains, a north-east and south-west trend is conspicuous. In a stretch intervening between Ballina and Donegal town, limestone plateaus prevail, resembling those of southern Derbyshire. The high margin of Ireland is maintained across the east of Co. Londonderry and the whole of Co. Antrim by the basalt plateaus, which are tilted down in the latter country to the south-west and attain their highest points (some 450 m., 1500 ft.) along their north-east border. Then we meet the region of hummocky country already referred to as reaching to the coast from Co. Longford. The granite crests of the Mourne Mountains (750 m.), and the older granite ridge from Newry to Slieve Croob on the north-west, diversify this part of the landscape. The coast is actually low from the south of Carlingford Mt. to Dublin; but here the great range of the Leinster granite rises from the sea at Killiney, and forms a high barrier on the edge of the central plain, until it unites with the east-and-west ridge of Slievenaman. The north-east and south-west trend of the Leinster Chain (Fig. 7) clearly links it with the axis of Newry and Slieve Croob, with the Ox Mountains, and with the ridged moorlands of the county of Donegal.

We thus have one series of marginal ridges that suggests the **Caledonian** or **early Devonian chains** of Europe. The country from Longford to the coast of Co. Down expresses the same general structure. In the south, the close-set east-and-west ranges, with valleys running between them, recall the **Armorican** or **early Permian chains.** The protruding masses that break the central plain will be found to be connected with these southern ranges, though they have been influenced in their trend by the pre-existing Caledonian obstacles, and thus have often a north-easterly direction.

The great plain itself merely repeats on a broad scale the features of the long valleys among the southern Armorican ranges. Limestone, which has been removed by denudation from the intervening ridges, remains in these valleys, and also forms the floor of the central plain. Long ages of denudation have worn it down to a general and nearly level surface, a true "peneplain", and this has been uplifted again sufficiently in recent geological times to allow the streams to notch its margins.

The longest river in Ireland, the Shannon, lies almost entirely in the plain, rising in the Lough Allen upland in the west of Co. Cavan, and running southward to western Tipperary, with intervening expansions in the form of lakes. It cuts across the Slieve Bernagh mass, has a more rapid fall towards Limerick, and then enters the submerged part of its valley, the long sea-inlet stretching down to Kerry Head. The courses of the southern rivers among the Armorican ranges will be considered in connexion with the geological structure of the orographic features of Ireland (p. 23).

The two directions of folding that control the main **orographic features** of the Irish area have already been referred to. The whole floor of this area must have been remodelled, like so much of north-west Europe, by the Caledonian earth-movements at the close of Silurian, and therefore in early Devonian, times. Possibly the Dingle Promontory represents a region where the floor of the Silurian sea was at first uplifted more gently, as in parts of South Wales and the west of England, so that the striking unconformity between its deposits and those of the Old Red Sandstone lakes was here for a time avoided. But everywhere else in Ireland there are signs of the formation, by extensive crumpling, of continental land, prior to the deposition of the Old Red Sandstone. The most continuous feature produced by these Caledonian movements is the **Leinster Chain.**

The Ordovician and Gothlandian sediments became raised in the south-eastern Irish area into a huge anticlinal arch, the visible part of which is 150 km. (94 miles) in length (Fig. 7). The little isle of Rockabill off Balbriggan is the last relic of the north-east end of the anticlinal, where it becomes lost in the Irish Channel. The south-west end has been cut into by the Atlantic waves along the coast of Waterford. As the arch rose, numerous subsidiary crumplings went on in the strata forming its cover and its flanks, while a granitic magma, perhaps in successive inflows (Sollas 1891, 1893), followed it from below, and cooled as a strengthening mass along its core. The strata in contact with it were greatly altered, and flake after flake of the schists that were produced was eaten off and became assimilated by the granite, which is thus highly charged with biotite in many places along its margins. The foliation of the schists has taken place along their uptilted bedding-planes, and the gneissic structure that is often traceable in the granite runs parallel with this foliation. Long tongues of schist are included in the granite, as near Wicklow Gap and near Mount Leinster, showing the mode in which the igneous core has attacked its bounding walls. Denudation in Devonian and Carboniferous times reduced the height of the chain, stripped off any Gothlandian strata, carved deep valleys in the Ordovician and Cambrian slates, and exposed the granite in the form of a central moorland. It is doubtful if this moorland was ever covered by marine Carboniferous strata, though the coal-forests probably grew across it. Denudation may have acted continuously on the chain since the Armorican uplift, and at the present day, while the Carboniferous beds near Dublin are being removed, features of the early Devonian topography must be slowly coming to light. The contrast between the central granite and the stratified foothills is very picturesque. The granite, with its large curving joints, and its fairly uniform and crumbling system of decay, forms a rounded moorland ridge, on either side of which the head-waters of numerous rivers, assisted by upland glaciers, have cut out broad basins. When the streams, however, reach the Ordovician slates and sandstones, or the somewhat similar Cambrian beds, they carve their way down along more definite lines, keeping ahead of the results of the lateral and pluvial denudation. Gorges are thus frequent, and waterfalls occur at their heads, as the streams cut backward; until, as may be seen at Glenmacnass in Co. Wicklow, the streams fall steeply from the granite moorland over the actual junction of igneous and stratified material. (On the association of mature and immature features on the Leinster Chain, see G. A. J. Cole, 1912.) The great domes, such as those of Kippure, Tonlagee, Lugnaquilla, and Mount Leinster, are mere protuberances on a granite core that lies mainly 600 m. (2000 ft.) above the sea. The few roads that cross this highland have to ascend passes some 550 m. (1800 ft.) in height. In the foothills, valleys are numerous, and communications are far more easy. A great variety of surface-features is here produced by the juxtaposition of rocks of different hardness and different resistance to the atmosphere, such as quartzite, slate, eurite, and diorite. Woods grow freely in the hollows, and numerous private dwellings, set in their own parks ("demesnes"), characterise eastern Leinster. On the west side of the chain, the overlapping of the Carboniferous Limestone is far more obvious, and this brings the features of the great arable plain abruptly against the granite highland, from Athy down to Goresbridge, as we follow the valley of the Barrow. The same contrast is repeated on the south of Dublin city, where the limestone boundary crosses the strike of the Leinster Chain.

The Newry axis (Fig. 4). The granite axis near Newry recalls the features of the Leinster Chain on a less imposing scale. The reappearance of granite at Crossdoney close to Cavan town shows that a long bar of igneous rock in reality occupies the core of the Caledonian fold from Longford to the sea. The Ordovician and Gothlandian strata have here been much contorted, and their general trend is best realised when we observe that of the granite along the axis of uplift. Carboniferous, and probably Triassic beds, once covered the whole triangular area now exposed by denudation. The region does not become mountainous until we reach the granite of Slieve Croob in Co. Down (535 m., 1755 ft.); but it affords an interesting illustration of what the Leinster Chain must have been like before it had become seriously attacked by denudation.

Western Caledonian masses (Fig. 3, 4). The whole structure of Donegal has been controlled by the Caledonian folding. The Dalradian rocks, already invaded and metamorphosed by older igneous masses, became rearranged along folds with a north-easterly and south-westerly trend. The intrusion of the great central mass of granite from Ardara nearly to Mulroy Bay probably dates from this epoch of compression. Its contact-effects on the old sediments are complicated by earth-pressures accompanying and following its intrusion; and faulting has taken place along the trend of the folds. The line of weakness along which we find the Gweebarra River running south-west, and the great eroded hollow of Glen Veigh running north-east, seems due to one of these earth-fracturings. In the north of Tyrone, the Sperrin Mountains are a Caledonian chain running east and west, possibly influenced by the proximity of the Pre-Cambrian mass immediately to the south.

The Ox Mountain axis (Fig. 3), 100 km. (62 miles) long, running from the north of Manorhamilton to Castlebar, is revealed as a narrow moorland, some 450 m. (1500 ft.) in height, with a core of granite intimately intruded into Dalradian quartzites, schists, and epidiorites. The arrangement of the highly siliceous masses in the portion of the ridge near Sligo suggests that the original strike of the sediments was north and south. The rounded summits rise in marked contrast with the Carboniferous landscapes on either side. Through western Mayo and Galway, the Dalradian masses form an irregular highland country, and the stratification of their quartzites may be seen on the hillsides from a distance of many kilometres. In Donegal and in the Dalradian country generally, these quartzites have weathered out into massive conical mountains, or ridges displaying striking features of bare rock. Muckish, Errigal and Aghla in Donegal, Nephin in central Mayo, Croaghaun in Achill Island, and the Twelve Bens (misnamed Twelve Pins) in Connemara, are alike evidences of the resisting power of the quartzites. Round Killary Harbour, the Silurian masses, standing out upon a Dalradian foundation, form great fort-like bluffs marked by almost horizontal terraces of stratification.

Central Armorican masses. The Armorican folding is seen in the small range of the Curlew Hills (Fig. 3), and in the denuded dome-like uplands that break the central plain. These are described in the Silurian and Devonian pages of the section dealing with Irish stratigraphy. The influence of the pre-existing Leinster Chain on the trend of these Armorican masses is conspicuous. The Upper Carboniferous outlier that includes Slieve Ardagh and the Castlecomer coalfield similarly shows a north-easterly trend.

Armorican ranges of the south (Fig. 6). But throughout the south the characteristic east-and-west Armorican direction controls the orographic features. Owing to the difference in resisting power the Carboniferous strata and the underlying Old Red Sandstone, the latter series forms the ridges, while Carboniferous Limestone remains along the synclinal hollows. These hollows, occupied by streams, are usually well wooded, and are set with numerous farms and market-towns. The Old Red Sandstone slopes above are bare and mountainous, or covered locally by plantations of coniferous trees. The wildest rock-scenery of Ireland occurs amid the Old Red Sandstone of MacGillicuddy's Reeks, where Carrauntoohil reaches 1040 m. (3414 ft.) above the sea. The famous Upper Lake of Killarney lies in this region, and the broad Lough Leane below rests on a limestone synclinal, recalling, with its low shores, all the features of the central plain.

The influence of the rocks brought up by the Armorican folding on the local river-system was pointed out by J. B. JUKES in a memorable paper in 1862. He explained how the main Irish rivers had begun to flow on a great denuded surface of Carboniferous rocks, which sloped generally towards the south. Such a surface, which would now be described as a peneplain, was attributed in JUKES's time to marine denudation. The rivers, as usually happens, were able to cut their way downwards more quickly than atmospheric denudation could reduce the general level of the uplifted peneplain. The peneplain gradually came to show great irregularities of surface, as the Carboniferous rocks were stripped off from the crests of the Armorican folds. Though the "consequent" rivers could cut right across these folds, whether working against limestone, shale, or the underlying sandstone, their "subsequent" tributaries gradually extended up the synclinals in which soft Carboniferous rocks still lay. The Shannon system, aided by general atmospheric denudation, wore out a broad basin in a Carboniferous area, which is now part of the central Irish plain, while the main stream, well fed by its tributaries continued to carve its way across the Devonian and Silurian mass at Killaloe. The general denudation could not remove this mass so rapidly as could the concentrated stream along its own southerly course; and we now find the river apparently sawing its way across a mountain-ridge. In the southern ranges, the tributaries, extending westward up the long synclinals, gradually became the more important portions of the streams; but the main courses are still seen in the abrupt bends of the rivers southward, across the sandstone ranges, shortly before they reach the sea. As JUKES (1862) contended, there was a tendency for the waters of the district to be "always turned down the transverse ravines, because, at whatever rate the ground in the longitudinal valleys sank [through denudation], the erosion of these rivers was able to keep the bottom of the ravines sufficiently below it; while other brooks, being unable to effect this, were ultimately drawn down into the longitudinal valleys, and their water [was] carried out to the ravines." Here we find truly stated the process now known as river-capture. The longitudinal valley of one stream, by extension westward or eastward, may have cut off the head-waters of the transverse part of another stream, and an original consequent transverse valley may now be found divided into several portions which drain into successive and parallel subsequent valleys. The Brinny was thus held by JUKES to be an original transverse stream, of which the Bandon was an exaggerated tributary.

The Finisk River, he urged, once ran south across the folding to the sea parallel with the southern course of the Blackwater; but the lowering of the limestone surface just east of the Blackwater drew off the waters of the Finisk westward into the Blackwater itself. It is obvious that, the greater number of captures a river can effect, the greater will be its flow and its power to maintain its own transverse course across the Armorican folds.

The Lava-plateaus (Fig. 4). The highlands of eastern Londonderry and Antrim are due to successive outpourings of basalt in early Kainozoic times. There are no mountain-ranges in this region, and the volcanic neck of Slemish, a prominent mass of olivine-dolerite, is the only striking feature of the interior. The falling in of the plateaus towards the present basin of Lough Neagh gives the country the structure of a basin, with high marginal escarpments, worn out by atmospheric denudation (HARDMAN 1876).

Finally, the **Mourne Mountains** (Fig. 4) are formed by a knot of granite that broke through the Silurian slates and sandstones of Co. Down in Kainozoic times. Denudation has carved deep valleys in the mass, and has left dome-like crests upstanding, on which crags and pinnacles still remain, in spite of the formation of long grey taluses on their flanks. The surface-forms of this picturesque highland, as viewed from Slieve Donard (852 m., 2796 ft.) or Slieve Bingian (746 m., 2449 ft.), are clearly far less mature than those of the adjacent Newry axis or of the Leinster Chain. Glacial moraines form barriers across several of the valleys, and the lowland along the coast is cumbered with detritus from the hills. South of Carlingford Lough, a mass of granite has invaded gabbro. The granite has become worn down into a basin, while the gabbro forms an upstanding and rugged ring about it, the chief peak of which rises among the black crags of Carlingford Mountain.

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II. British Earthquakes.

By CHARLES DAVISON.

The most complete catalogue of British earthquakes is that published in 1889 by the Mr. W. ROPER. This includes notices of all the more important known earthquakes until the beginning of 1889, though few details are given with regard to any shock. As British earthquakes seldom cause damage to buildings and rarely result in loss of life, they have attracted little notice, and, with a few exceptions, it is now impossible to determine the position of the epicentre of any earthquake before the year 1889. From the beginning of that year, however, they have been continuously studied, and the present section therefore deals mainly with the earthquakes of this period.

During the twenty one years 1889—1909, 250 earthquakes occurred in Great Britain, 50 in England, 27 in Wales and 173 in Scotland. In Ireland and the Isle of Man, none is known to have originated in the same period, though five strong earthquakes originating in England and Wales were felt in the eastern and south-eastern counties of Ireland, and two in the Isle of Man. British earthquakes may be divided into three classes, according to the area included within the isoseismal

4 of the ROSSI-FOREL scale. An earthquake may be regarded as strong when this area exceeds 13 000 km². (5000 square miles), as moderate when it lies between 2600 and 13 000 km². (1000 and 5000 square miles), and as slight when it is less than 2600 km². (1000 square miles). Of the earthquakes here considered, 9 were strong, 7 moderate, and 223 slight, while 11 were earth-sounds without any accompanying tremor. Of the strong earthquakes, only three reached an intensity as high as 8, namely, the Hereford earthquake of 1896, the Inverness earthquake of 1901 and the Swansea earthquake of 1906.

Of the 250 earthquakes, it is possible to associate 199 with known lines of fault or folding. The distribution of the earthquakes among the principal directions of faulting is shown in the following table:

	Caledonian	Charnian	Malvernian	Armorican
England	15	22	6	5
Wales	9	—	5	8
Scotland	128	1	—	—
Total	152	23	11	13

Certain characteristics of all British earthquakes may be first referrred to. 1. So far as our limited survey goes, the growth of any fault is now extremely localized. The epicentres of successive shocks rarely coincide, but their migrations are confined within small limits. 2. Measuring the length of the seismic focus by the difference between the lengths of the longer and shorter axes of the innermost isoseismal, the average length of focus for strong earthquakes is 19.6 km. ($12^1/_4$ miles) and for moderate earthquakes 20.8 km. (13 miles). Slight earthquakes are divisible into two subclasses, one in which the focus is 14.4 km. (9 miles) or more in length, the other in which it is 9.6 km. (6 miles) or less in length. The average length of focus in the former is 19.2 km. (12 miles), in the latter 6.4 km. (4 miles) or less. The grouping of the average length of focus about 19.2 or 20.8 km. (12 or 13 miles) is probably connected with the average distance between the crests of successive crust-folds.

In Scotland nearly all the earthquakes that can be referred to known faults are connected with the two great faults, which bound the Highland district to the north-west and south-east, and the fault, which skirts the southern margin of the Ochil Hills. The first of these, which runs in a southwesterly direction from Inverness, is now growing in two portions, one lying between Inverness and the northeast end of Loch Ness, the other in the neighbourhood of Fort William. In the former district, important earthquakes occurred in 1816, 1888, 1890 and 1901. In most or all of these, the seismic focus probably extended from Inverness to Loch Ness. With the exception of the earthquake of 1888, they were followed by a succession of after-shocks, the foci of which show a marked tendency to migrate to the south-westward, some of them lying beneath the north-east end of Loch Ness. In the neighbourhood of Fort William, five earthquakes, all of them very slight, occurred between 1889 and 1909.

The southern boundary fault of the Highland district is remarkable for the numerous earthquakes in the region immediately surrounding the village of Comrie. The epicentres, though not fixed, are confined to a very short length of the fault. The more important earthquakes in this district occurred in 1801 and 1839, and on each occasion were followed by a great number of after-shocks, that of Oct. 23, 1839, being followed by not less than 334 within the next five years. Since 1845 they have gradually decreased in number and intensity and between 1889 and 1909 only three very slight shocks occurred.

The third fault is that which forms the southern margin of the Ochil Hills, and which, in the neighbourhood of Airthrey, Menstrie, Alva and Tillicoultry has produced 82 earthquakes between Sep. 1900 and the end of 1909. The majority of them were slight, though two attained to the degree 7 of the Rossi-Forel scale.

The Scottish earthquakes differ from those of England and Wales in several respects: 1. with one exception, so far as known, they originated in faults belonging to the Caledonian system; 2. they are invariably "simple" earthquakes, that is, they originate in a single continuous portion of the fault; 3. they are followed by a large number of after-shocks; and 4. they originate in foci that are situated at a comparatively small depth below the surface. This is shown by their great intensity considering the small area disturbed by them, and by the closeness of the centres of the innermost isoseismals to the fault-lines with which the earthquakes are associated. The latter circumstance is no doubt the reason why it is possible so frequently to identify the parent fault.

The earthquakes of Wales are for the most part confined to two districts, the northwest of Carnarvonshire and the three southern counties. The Aber-Dinlle fault, which must extend for some distance under the sea, is responsible for a strong earthquake in 1903 and not less than seven successors. A movement near Bala along the great Bala fault caused a slight shock in 1903. These two faults belong to the Caledonian system. In the south of Wales, there have been three strong earthquakes, two in Pembrokeshire in 1892 and 1893, and one in the neighbourhood of Swansea in 1906. All three were "twin" earthquakes, that is, they originated nearly or quite simultaneously in two detached regions of the parent-fault. In the case of the Pembroke earthquakes, it is difficult to assign the earthquakes to any particular faults, owing to the large number which traverse the crust in that district. The Swansea earthquake was caused by a twin movement along a great fault running nearly east and west from the neighbourhood of Llanelly to that of Llwynypia. The fault lies too deep for recognition by geological methods, but there can be no doubt as to its existence, as two nearly simultaneous movements took place in foci separated by about 22 miles.

In England, the faults which are responsible for recent earthquakes belong chiefly to the Charnian and Caledonian systems. Among the former must be included the fault which bounds the Woolhope anticlinal to the south-west or one very near it, which gave rise by a twin movement, to the Hereford earthquake of 1896; one of the anticlinal faults of Charnwood Forest, which must be continued for several miles under the newer rocks to the south-east, along which a twin displacement occurred in 1893 and simple slips in 1904; and the Pendleton or Irwell Valley fault in Lancashire, which was the seat of the Bolton earthquake of 1889, and of several earth-shakes in the neighbourhood of Pendleton, the fault-slips in the latter case being precipitated by mining operations. To unknown and probably deep-seated Caledonian faults must be attributed the strong twin earthquakes of Colchester in 1884 and Derby in 1903 and 1904. Among Malvernian faults lately in action may be mentioned that which skirts the eastern side of the Malvern Hills, along which a small slip occurred in the neighbourhood of Great Malvern in 1907, and a great fault, which traverses the crust at a considerable depth below the Lake District, and which by a twin movement extending over at least 23 miles caused the Carlisle earthquake of 1901.

The earthquakes of England and Wales possess the following characteristics: 1. they are due to slips along faults of all systems, 2. all the strong earthquakes, with the exception of the Carnarvon earthquake of 1903, were twins; 3. they are seldom followed by after-shocks; and 4. they originate in foci that are situated at a comparatively great depth below the surface, so that it is only occasionally that the parent-fault can be identified.

The Irish area is not at present one of seismic activity, and the few earthquakes that now reach it seem to originate in Great Britain and to be connected with British earth-movements.

III. Stratigraphy.

1. Pre-Cambrian.

a. England and Wales.

By W. W. WATTS.

The Pre-Cambrian rocks of England and Wales make their appearance in a number of isolated inliers, rising from beneath Cambrian or newer rocks. These localities range from Anglesey in the north to the Lizard and the Eddystone Lighthouse in the south, and from Pembrokeshire on the west to Charnwood Forest in Leicestershire on the east.

In any one area a single type of rocks alone may be present, or there may be two or more types of different ages. In the latter case it is generally possible, though by no means easy on account of the disturbance of the rocks, to ascertain the relative ages of the different types. The correlation of separate areas will always be a difficult task and one that must depend on close comparison of lithological characters. Such comparison is rendered exceptionally difficult by the variablility of the types within the areas themselves and also when they are traced from one area to another.

It will therefore be best to indicate in the first place the general characters of the rock-types, treating them in the order dictated by convenience. This order of the groups is not necessarily that of age, nor is it certain that some of the individual groups may not contain rocks of more than one age. This will be followed by a brief description of the separate areas. Finally, the question of correlation will be discussed in the light of our present knowledge of the rock groups.

The following are the chief rock-types:

1. **Foliated rocks,** such as gneisses, schists, granulites, quartzites, and crystalline limestones, mainly derived from the metamorphism of igneous rocks, though some members are undoubtedly altered sediments. This type is conspicuously represented in Anglesey, Malvern, and Cornwall.
2. **Igneous rocks,** mostly of volcanic and hypabyssal types, and of acid or intermediate composition. Certain abyssal rocks in places are associated and appear to be genetically connected with them. Usually pyroclastic rocks occur with the lavas. Shropshire may be regarded as a type locality for these igneous rocks, which are well developed in other parts of the Midland province as at Malvern and Charnwood, while they are also met with in North and South Wales.
3. **Sedimentary rocks,** conglomerates, greywackes, quartzites, grits, and slates, red, green and purple in colour, of great thickness, highly disturbed, and covering large areas of ground where they often give rise to a characteristic landscape. This type of rocks has not yet been recognised with certainty outside the Shropshire area, but reasons will be given for believing that rock-series of different aspect, but corresponding age, may exist in other regions.

Shropshire.

As most of the types of Pre-Cambrian rocks are present in Shropshire, it will be well to begin with a description of that area.

What is probably the oldest rock, is found at the village of Rushton, where a small area, very ill exposed, of quartz-mica-schist was discovered by CHARLES CALLAWAY. Its relation to other rocks is unknown. It does not seem to be part of the plutonic rocks to be shortly mentioned, but to be a representative of the oldest foliated rocks of Anglesey.

Probably later in age there comes a volcanic group called Uriconian, after its typical occurrence at the Wrekin, a mountain from which the Romans named their City of Uriconium. Uriconian rocks occur at a number of places aligned along a fault which runs south-westward from Lilleshall through the Wrekin, Caer Caradoc and other Church Stretton hills, to Warthill Knoll, and possibly on to a group of hills near New Radnor. Where the igneous rocks crop out along the fault, they give rise to hog-backed hills. These are flanked, on the west side at Wrockwardine and on the east side at Cardington, by rounded hills, where the rock is not directly on the line of the fault.

The chief rocks are rhyolitic and andesitic lavas and tuffs, associated with acid intrusions, probably of Pre-Cambrian date, and with basic sills and dykes certainly of much later date. The tuffs vary from coarse breccias, through medium-grained crystal tuffs, to close-grained ashes made of the finest volcanic dust. The fine-grained type is especially well developed at Lilleshall, where the rocks are in the condition of hälleflintas. Near Church Stretton and elsewhere, there are quartz-felspar grits deposited in water, but there is no evidence as to whether the majority of the tuffs were laid down in water or on land. The lavas present the characters of devitrified glassy rhyolites with the usual textures of such rocks, phenocrysts of quartz and orthoclase, spherulites, fluxion structure, and often well-developed perlitic shrinkage cracks. In certain localities the lavas show large pyromerides with concentric cracks and hollow interiors, filled up with quartz. These rocks furnished ALLPORT (1877) with material for his classic memoir on the devitrification of volcanic glasses.

The strike of the Pre-Cambrian rocks is, in general, across the ridges, a structure spoken of by CALLAWAY as "plagioclinal". Both at the north and the south end of the Wrekin there are found plutonic rocks of acid composition. They are aplites, granites with little or no ferro-magnesian constituents. To the north they are intrusive into a series of crystal tuffs; to the south their relations are obscure, and here they sometimes possess a rude foliation.

The Uriconian Rocks are covered unconformably by Cambrian, Ordovician, or Gothlandian, rocks, but their relations to the Longmyndian Group, to be next described, are invariably obscured by faulting. Fragments of rhyolites are, however, frequently found in the Longmyndian conglomerates, so that there is no doubt as to their Pre-Cambrian age.

The outcrop of the Longmyndian Rocks forms the wild, moorland tract called the Longmynd, a high plateau dissected by water-cut valleys known locally as "gutters" or "batches". The rocks dip steeply from east to west and, even if, as is likely, there is repetition by faulting and overfolding, there must be a great thickness of rock. It is generally agreed that the succession is best divided into two Series, an Eastern or older, and a Western or newer Series. The eastern rocks are for the most part grey, green, or purple, in tint, and are largely composed of minerals derived, directly or indirectly, from volcanic rocks and laid down in water; the western ones are usually deep red or purplish-red in colour due to staining by oxide of manganese, with which the pebbles of the conglomerates are often coated. The detailed succession given by CHARLES LAPWORTH (1910) who has been engaged for many years in mapping the rocks, is as follows:

Wentnor Series. (Western Longmyndian.)
7. Ratlinghope Group: red and purple grits and shales, with conglomerates.
6. Bayston Group: red and grey grits, with the three zonal conglomerates of Stanbatch, Darnford, and Haughmond (in descending order); the last rich in pebbles of Uriconian volcanic rocks.

Stretton Series. (Eastern Longmyndian.)
5. Portway Group: purple, grey, and green slates and flags with the Narnells grit and conglomerate band near the base.
4. Lightspout Group: massive grey and green grits and flags, with few shales.
3. Synalds Group: purple shales and occasional flaggy grits and green shales, with the Carding Mill Grit at the base.
2. Burway Group: grey-green flags and shales, having as a basement band the siliceous Buckstone Grit.
1. Stretton Shale Group: consisting of,
   b) Brockhurst Shales: hard grey-blue and dark green laminated shales, with rare calcareous nodules.
   a) Watling Shales: green shales with occasional purple mudstones, flaggy beds, and rare calcareous bands.

J. F. BLAKE claimed to have made out that an unconformity exists between his upper and lower groups (which do not exactly correspond with those given above), but, though there are marked lithological distinctions between the two groups, LAPWORTH has been unable to confirm this observation. The Western Group compares very closely with the Torridonian Rocks of Scotland, and it now appears to be generally admitted that this correlation is justifiable.

The highest beds of the Western Longmyndian pass up with apparent conformity into a volcanic group typically exposed at Pontesford Hill, but occurring also in several isolated localities along a line running south-westward from that hill. These rocks comprise green shales, purple and green grits, andesitic and rhyolitic lavas and tuffs, the latter of intermediate composition and bearing palagonite fragments. Acid and basic intrusions also occur, but no plutonic rocks are at present known. The series is strikingly like the Uriconian even in its peculiar petrological details (BOULTON 1904). These rocks are cut off on the western side by faults, beyond which Upper Cambrian Rocks immediately succeed.

The succession of Pre-Cambrian Rocks in Shropshire would therefore appear to be:

5. Western Uriconian or Pontesfordian Series.
4. Western Longmyndian or Wentnor Series.
3. Eastern Longmyndian or Stretton Series.
2. Eastern Uriconian or Cardingtonian Series.
1. Rushtonian Schists.

Rocks, which have been referred to the Longmyndian underlie Upper Cambrian shales at Pedwardine in Herefordshire, and crop out from beneath the Gothlandian at May Hill in Gloucestershire and at Kington in Herefordshire; in the last locality they are associated with igneous rocks correlated with the Uriconian by CHARLES CALLAWAY (1879).

The Midlands.

Rocks, which are probably Pontesfordian, but possibly Cardingtonian, in age, are found at the Lickey Hills, S. W. of Birmingham, (the Barnt Green Rocks), and at Caldecote near Nuneaton (LAPWORTH 1886). The latter are mostly quartz-felspar tuffs, intruded upon and mingled with basaltic intrusions, all unconformably covered by the basal Cambrian rocks. East of Herefordshire Beacon on the Malvern Hills, there are volcanic rocks (the Warren Hill Series) which must be referred to one or other of these volcanic series. The principal rocks of the Malverns are however the gneisses and schists of the main range. These in places are massive diorites associated with pegmatites, but there also occur foliated gneisses, hornblendic and micaceous schists, and phyllites. The majority of these are considered by CALLAWAY (1880, 1887) to be plutonic and volcanic rocks which have acquired a foliated texture by reason of dynamo-metamorphism. The relationship of these rocks to the volcanic series is not known, but both groups are unconformable beneath Cambrian and younger rocks.

At Charnwood Forest, in Leicestershire, there occurs a great thickness of Pre-Cambrian rocks which seem at first to stand apart from all other British Pre-Cambrian volcanic rocks. They show the following divisions:

3. **Brand Series.**
   b) The Swithland Slates.
   a) Conglomerates, sandstone, and quartzite.
2. **Maplewell Series.**
   e) Bradgate Beds.
   d) Woodhouse Ashes.
   c) Slate Agglomerate.
   b) Beacon Hill Hornstones.
   a) Felsitic Agglomerate.
1. **Blackbrook Series.**
   Fine-grained tuffs and hornstones.

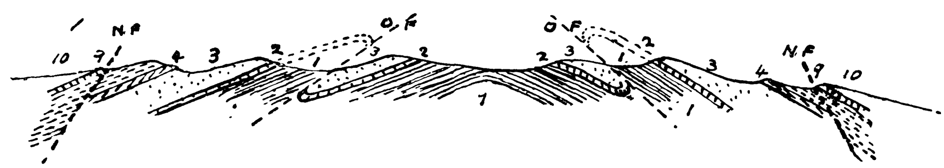

Fig. 9. Generalised section across Charnwood Forest to show the Structure and Faulting. W. W. WATTS.
NF = Normal Faults. OF = Overthrust Faults. 10. Swithland Slates. 9. Brand Conglomerate. 4. Slate Agglomerate. 3. Beacon Hill Beds. 2. Felsitic Agglomerate. 1. Hornstones and Grits.
Reproduced from the Geologists' Association, Jubilee Volume, Geology in the Field, p. 780, 1910; with the permission of the Council.

The lower and middle divisions are pyroclastic rocks of intermediate composition and varying degrees of coarseness, deposited on the flanks of volcanoes and probably sorted and stratified under water. They pass, however, on the western side of the area, into coarse agglomerates and breccias, probably formed above water, and associated with lavas and massive intrusive rocks. The latter are quartz-bearing "porphyroids", related to the dacites in composition and allied to those of the Ardennes. Like them, they are often highly sheared, and in places pass into schists. The Brand Series consists of conglomerates, grits, quartzites, and slates, made up chiefly of terrigenous material transported by water but deposited while vulcanicity was still in progress in the immediate neighbourhood. Worm casts, similar to those found in the upper part of the Eastern Longmyndian Rocks, have been found in the grits. It is possible to institute a close comparison between these Longmyndian rocks and those of the Maplewell and Brand Series, allowance being made for the fact that the volcanoes of the period were situated in the Charnwood district. No representative of the Torridonian has yet been discovered in Charnwood Forest. The "Charnian Rocks" are overlain by the Carboniferous and Triassic rocks, but there can be no doubt as to their Pre-Cambrian age, or as to the correctness of the correlation with the Eastern Longmyndian (see also page 51).

Pembrokeshire (South Wales.)

The Pre-Cambrian rocks of Pembrokeshire are somewhat like those of the Midlands. At St. David's, the rocks are mainly acid tuffs and lavas with intrusions of felsite and rhyolite; there is also an aplite which was at one time supposed, as at the Wrekin, to be part of an older series, named Dimetian by HICKS (1897). This rock is now known to be likewise intrusive into the volcanic series. To the latter the name Pebidian was given by HICKS. J. F. N. GREEN (1908) has recently divided the series into the following:

4. **The Ramsay Sound Series.**
   Schistose and slaty rocks with tuffs.
3. **Caerbwdy Series.**
   Fine grained felspathic rocks and hälleflintas with a bed of conglomerate.
2. **Treginnis Series.**
   Mainly trachyte and andesite with some rhyolite.
1. **Penrhiw Series.**
   Red and green volcanic tuffs and hälleflintas.

The whole Pebidian sequence cannot be much less than 1500 m. (5,000 ft.) thick. The rock types compare closely with those of the Uriconian of Shropshire, except that they appear to have been more highly disturbed. The whole series is covered unconformably by the Cambrian beds which were laid down after the folding and denudation of the Pebidian rocks, and after the intrusion of a set of basic dykes, which have at many localities become epidiorites and hornblende schists.

A somewhat similar succession occurs farther east, near Brawdy and Hayscastle (THOMAS and JONES 1912). The earlier Pebidian tuffs, of acid and intermediate composition, pass up into more distinctly acid rocks which are related to soda-rhyolites and keratophyres. Into these are intruded granites, quartz-porphyries, and diorites, with some later basic dykes. The whole are unconformably covered by Cambrian rocks.

North Wales.

The Pre-Cambrian rocks of North Carnarvonshire present a great volcanic series for the most part of acid composition. It was divided by HICKS into three parts, the plutonic rocks were named Dimetian, the lavas Arvonian, and the tuffs Pebidian; but the whole is now considered to be a single volcanic series. The strip of rocks, which extends from Bangor to Carnarvon, displays a series of grits, breccias, and tuffs, associated with rhyolites, which are probably lava-flows. A mass of aplitic granite at Carnarvon ("Dimetian"), is now correlated with the plutonic rocks of St. David's and the Wrekin. A larger mass of rhyolitic lavas ("Arvonian") crops out near Llanberis. It is associated with a small proportion of ashy sediment, and is unconformably covered by the basement bed of the Cambrian slate rocks of Llanberis. Tuffs and associated rocks similar in character have been described by T. G. BONNEY (1883) at Beaumaris on the Anglesey side of the Menai Straits.

A large area in Anglesey is occupied by gneisses and schists which present a closer resemblance to the Lewisian Archean rocks than any others in England or Wales. The whole of the rocks of the Island are now being mapped and described in detail by E. GREENLY, and parts of them have been dealt with by CALLAWAY, BLAKE, and C. A. MATLEY. Towards the centre of the Island, there occurs an area of crystalline, acid and intermediate, plutonic rocks, in part massive but frequently foliated. There are granite-gneisses and diorite-gneisses, sometimes porphyritic or with augen structure, associated with hornblende-schists and mica-schists. The bulk of the rocks seem to be of igneous origin and to have received a foliated structure partly during injection (CALLAWAY 1897), and partly as the result of subsequent disturbance; but there are undoubtedly some altered sediments associated with them. Into what rocks this plutonic complex was intruded is not certain, but it is flanked by great masses of highly contorted micaceous, chloritic, chloritoid, and glaucophane schists. At least two other groups of Pre-Cambrian rocks occur in Anglesey as well as those just mentioned and the rocks of Beaumaris, an older one named by MATLEY (1899, 1900) the "Green Series", and a newer the "Llanbadrig Series". The former consists of flaggy and phyllitic grits, chloritic and micaceous phyllites, and slates. The latter Series is in the main gritty, it contains irregular bands of quartzite, limestone, and intercalated spilites or "pillow lavas". The rocks have undergone extensive earth-movement, and the limestones, quartzites, and volcanic rocks, have been sheared into lenticular masses ("quartz knobs" etc.). Much overthrusting has obscured the mutual relations of these rocks, but there is evidence which seems to indicate that the two Series are unconformable to one another. It is also clear that they are pre-Llandeilo in age, and therefore almost certainly pre-Cambrian.

GREENLY (1902) has described in south-eastern Anglesey, jaspers, jaspery phyllites, and slates, associated with limestones and pillow lavas. These rocks seem to be also pre-Ordovician, and, though GREENLY declines to refer them to any particular part of the Pre-Cambrian sequence, they may presumably be referred to one or other of MATLEY's groups. Similar rocks also occur on the western side of the Lleyn Peninsula, and at Bardsey Island.

The North of England.

Near Ingleton in Yorkshire, there exists a group of grits, slates, and conglomerates, underlying, probably with unconformity, Ordovician rocks. Though these are probably of Pre-Cambrian age, it has not been found possible to parallel them exactly with any British rocks. Perhaps they may find their representatives in the Longmynd.

The South of England.

In the Lizard district of Cornwall, there exists a series of mica-schists (Geological Survey 1906, 1907, 1908, 1912), granulites, and quartzites, of sedimentary origin, and hornblende-schists of igneous origin. These are associated with serpen-

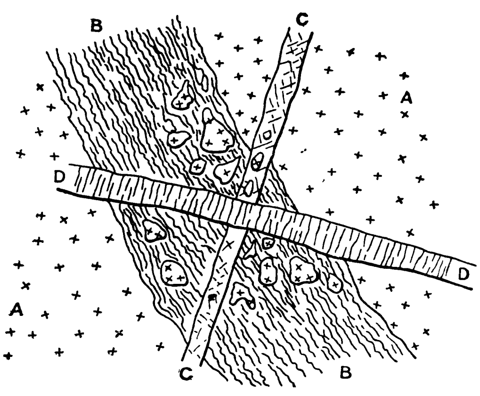

Fig. 10. Plan of dykes in shore at west-end of Coverack, Lizard Peninsula.

Reproduced from the Memoirs of the Geological Survey of England and Wales. Sheet 359—Lizard and Meneage, p. 94, 1912; with the permission of the Director and of H. M. Stationery Office.

The country rock is serpentine (A) which has a weak fluxion foliation almost due north; this is cut by a dyke of gabbro schist (B) running into a north-west direction, perfectly foliated and in places highly schistose. It contains many blocks of serpentine but both these inclusions and the walls of the dyke are almost quite massive. The gabbro-schist is cut in turn by a straight dyke of coarse gabbro pegmatite (C) with crystals of felspar and diallage up to two inches in diameter; it runs north-north-east and shows very little foliation. This dyke also contains inclusions of serpentine. The whole series is crossed in a west-north-west direction by a dyke of olivine dolerite (D) which is in a perfectly massive condition.

tines, gabbros, granulites, and other rocks. This complex appears to be of Pre-Cambrian age, as the rocks seem to be quite distinct from the older Palaeozoic rocks to the north and west. The rocks on which the Eddystone Lighthouse is built are pre-Cambrian gneisses. Again, about the Start Point in Devonshire, BONNEY describes sections of highly folded micaceous and chloritic schists, which he considers to be older than the Devonian rocks, and therefore possibly of pre-Cambrian age. With this group the phyllites of the Dodman in Cornwall may also be compared.

Fig. 11. Kennack Gneiss; Streaky type. Kennack (Lizard Peninsula). ×1/2. Reproduced from the Memoirs of the Geological Survey of England and Wales; sheet 359.—Lizard and Meneage, p. 132, 1912; with the permission of the Director and of H. M. Stationery Office.

The Kennack Gneisses (the Granulite Series of BONNEY) were preceded by doleritic intrusions shown in Fig. 10 and succeeded by red gneissic granite. They are believed to represent an imperfect combination of these two elements.

Summary and Correlation.

From the foregoing description, it would appear to de doubtful whether the Lewisian gneisses are represented at all in England or Wales, except possibly in Anglesey, or at Malvern, or in Cornwall. Probably the chief of the foliated rocks, like those of Rushton and Anglesey, more nearly correspond with the Moinian or Dalradian Systems. The Pebidian System would appear to be of wide occurrence, from Pembrokeshire and Carnarvonshire into Anglesey on the one side, and into Shropshire and perhaps farther east in the Midlands on the other. The Longmyndian and Charnian Rocks appear to have a more limited range, though they may be represented in some of the newer Pre-Cambrian groups of Anglesey, and possibly at Ingleton. The Upper Longmyndian Rocks may be safely correlated with the Torridonian of Scotland. The Pontesfordian Group has not been recognised elsewhere with certainty, though it seems very probable that the acid volcanic rocks of other Midland localities are of this age.

It is clear that the Pre-Cambrian history of England and Wales was one of active vulcanicity and the intrusion of igneous rocks, that marine areas were limited in extent and of restricted duration, and that conditions were highly unfavourable for the preservation of fossils.

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b. Scotland (see plate I opposite p. 40).

By J. W. GREGORY.

The whole of Scotland north of the Highland Boundary Fault may be regarded as a block of Pre-Cambrian crystalline schists and gneisses, with various intrusive rocks many of which are of Pre-Cambrian age. The Pre-Cambrian rocks outcrop over most of the area, though the old foundation is covered in places by piles of Kainozoic volcanic material, by small remnants of once wide sheets of Mesozoic and upper Palaeozoic sediments, by large areas of Old Red Sandstone, and along the north-western edge by a tract of Cambrian and Ordovician quartzites, shales, and limestones. There is also a narrow band of rocks, apparently of Cambrian age, beside the Highland Boundary Fault, which forms the Southern boundary of the Pre-Cambrian area.

The schists and gneisses were first studied in the Southern Highlands; the less crystalline of the schists were then regarded as the metamorphosed continuation of the rocks of the Southern Uplands, which are now known to be Silurian and Ordovician. The coarsely crystalline rocks were at first regarded as older than any of the fossiliferous rocks of southern Scotland.

Prominent attention was attracted to the Scottish Pre-Cambrian rocks in 1819, when MACCULLOCH described the apparent interstratification of fossiliferous limestones and quartzites between two series of gneisses on the shores of Loch Eriboll in north-western Sutherland. He concluded that the gneisses above the fossiliferous rocks were younger in age than the limestones; and as these gneisses rested on red sandstone regarded as Old Red Sandstone and as the fossils in the limestones were identified as Carboniferous, MACCULLOCH regarded the overlying gneisses as altered rocks of Carboniferous or post-Carboniferous age. The fossils however, were subsequently shown by SALTER to be Ordovician and the overlying gneisses were therefore regarded as altered Silurian rocks.

This problem was investigated by MURCHISON who adopted MACCULLOCH's conclusion that the upper gneisses were younger than the fossiliferous limestones;

and this view was supported by Sir ARCHIBALD GEIKIE's discovery of the section at Craig a Knochan, north of Ullapool, where the gneisses apparently rested conformably on the fossiliferous sedimentary series. It appeared therefore that the western gneisses of north-western Scotland were Archean; while the eastern gneisses, which constitute nearly the whole of the Scottish Highlands, were Silurian. This view was opposed by NICOL who regarded the apparently ascending sequence from sedimentary to crystalline rocks as delusive, and explained the undeniable superposition of the eastern gneisses by overthrust faulting. Nevertheless, the authority of MURCHISON and GEIKIE, the simplicity of their explanation of the facts, and NICOL's rejection of the obvious differences between the western and eastern gneisses led to the almost unanimous acceptance of MURCHISON's theory. The first fatal blow to it was struck in 1880 by BONNEY, who showed, that some of the eastern gneisses at Loch Maree, were petrographically identical with the western gneisses. Subsequently LAPWORTH (1883) proved that at Loch Eriboll, the locality for which the Palaeozoic age of the eastern gneisses was first advanced, the eastern gneisses were, as NICOL had held, old rocks which hed been thrust over the fossiliferous sediments; and this conclusion was established beyond doubt by the work of the Geological Survey. The eastern gneisses are therefore to be included in the Pre-Cambrian rocks of Scotland, which comprise four main groups:

4. **Torridonian.** Sedimentary rocks mainly sandstone, grits. conglomerates and shales.
3. **Dalradian.** A varied series of gneisses, schists, crystalline limestones, amphibolites, etc.; they are no doubt a metamorphosed stratified series.
2. **Moinian.** A thick series of granulitic gneisses and mica-schists.
1. **Lewisian.** The basal or "Fundamental Complex"; composed mainly of gneisses, with the characters of altered igneous rocks; they are traversed by a varied series of dykes and are associated with some schists, cherts and limestones of sedimentary origin.

1. **Lewisian System.** The oldest Scottish rocks unquestionably belong to the series of coarse gneisses, which form the foundation of north-western Scotland and the whole of some of the Hebrides. From their resemblance to some of the Laurentian gneisses of Canada they have been called Laurentian. As they are well exposed on the Hebrides they have been named Hebridean; but as they are especially well developed in the island of Lewis, they are now generally known as the Lewisian Gneisses.

These Lewisian rocks underlie all the other Archean groups, and they are therefore regarded as the "fundamental complex". The rocks are very varied in character; they are mostly coarse gneisses, which have the mineralogical characters of gneiss formed from altered plutonic rocks; but as TEALL has pointed out the metamorphism of an arkose would give rise to precisely similar gneisses, and it is therefore not certain that the whole of these rocks were directly of igneous origin; they may include altered gabbro-arkose, diorite-arkose, as well as granitic arkose.

The rocks of the Lewisian complex are divided by TEALL into five groups. 1. rocks of ultra-basic composition, such as banded amphibolites, pyroxenites and peridotites. 2. Rocks in which pyroxene is the predominant ferromagnesian constituent combined with felspar and usually quartz; the series includes pyroxene-granulites, augite-gneiss, and hypersthene-gneiss. 3. Amphibolites, hornblende-schist, and hornblende-gneiss, with or without quartz. 4. Rock rich in biotite, including biotite-schist and biotite-gneiss. 5. Rocks containing both biotite and muscovite, such as muscovite-biotite-gneiss.

In the northern part of the Lewisian district as around Cape Wrath the characteristic rocks are coarse-grained, pink and green gneisses charged with numerous intrusive pegmatites, and bands of schist due to the alteration of basic dykes. Further to the south in the area between Scourie and Loch Broom the characteristic rock is a gray, quartzose pyroxene-gneiss.

The Lewisian rocks are greatly folded and disturbed, but the characteristic strike of their foliation is on an average from west-north-west to east-south-east or from west to east. The rocks have been penetrated by a vast series of dykes and sills of Archean age. These intrusive rocks range from picrites to granites; some of the basic dykes still retain their igneous structure and are diabase or dolerite; but others are now hornblende schists. The Scourie dyke, described by Teall in 1885, shows the gradual passage of sub-ophitic diabase into typical hornblende schist. Dykes of intermediate composition are represented by microcline-mica-schist at Kylesku, and biotite-diorite dykes near Little Assynt. The acid dykes include granite, gneissose granite, and pegmatite.

The altered sedimentary rocks belonging to the Lewisian System are best developed near Loch Maree and the Gairloch. They include platy mica-schist, silvery garnetiferous mica-schist, and some graphitic schist which contains graphite in a fine-grained foliated rock composed of felspar, apparently andesine, mica and quartz. A sedimentary origin is still more evident in the case of some quartz schists, jaspers, cherts, quartz-magnetite rocks, and some of the crystalline limestones. The Lewisian limestones are well developed near Glenelg, as at the locality of Balvaig.

The Lewisian rocks frequently form a broad undulating plateau, which has been worn into an irregular moorland containing a large series of lakes and pools. On this plateau rest isolated hills of Torridon Sandstone and Cambrian rocks, but the continuity of the Lewisian rocks from the Pentland Firth southward to Skye admits of no doubt. In the Scottish central highlands there are many isolated areas of a coarse gneiss resembling the Lewisian. They were described in the Survey Memoir of 1907 as probably inliers, and the same view has been more definitely advanced in recent years. Some of these coarse-grained gneisses appear to be intrusive in some of the later pre-Cambrian rocks, and it has been suggested that others are only coarse-grained varieties of the eastern gneisses. The balance of opinion is however, in favour of the larger of these outcrops being exposures of the Lewisian foundation.

2. **The Moine Gneisses.** From the Pentland Firth on the north to nearly the southern edge of the highlands, and from the great overthrust fault on the west to the Tay Valley on the east, most of the Scottish highlands are composed of a series of siliceous gneisses which weather into flag-like slabs. Many different names have been given to this series of rocks. They are the Younger or Silurian gneisses of Murchison. From their flag like character they have been called the "gneissose flagstones" and the "flaggy schists". Callaway, in 1883, named them the Caledonian gneisses in contradistinction to the Lewisian gneisses. The Geological Survey at first called them the Eastern Schists, but they are shown in the later maps as the "Moine". As the term Caledonian is coming into use in Goodchild's sense, it is perhaps best to adopt for this group of rocks the name of the Moine System. The typical rock is the flaggy granulitic gneiss of the Moine Peninsula of north-western Sutherland; and this rock extends with striking uniformity of character, as far south-eastward as the Tay valley, where, as Barrow has shown, it is represented by the Strowan Flags. In western Scotland the Moine Gneiss occurs as far south as Tyndrum.

The typical Moine rock is a granulitic quartz-felspar schist or gneiss; and it consists mainly of grains of equal size of quartz and alkali-felspar. The foliation is often remarkably regular and the rock breaks along the micaceous divisional planes into thin flat slabs. Some of the cliffs of Moine rocks weather into the aspect of a series of ordinary flags. They have therefore been described as gneissose flagstones. In places, as east of Ullapool, the rock includes pebbles of quartz and felspar, a quarter of an inch in diameter, and such bands were no doubt originally fine grained conglomerates. The rock is holocrystalline, and the mica flakes often run through the grains of quartz and felspar, so that the minerals have crystallized in situ. Nevertheless the foliation closely resembles bedding planes and sometimes even shews false-bedding; hence the foliation may have developed along the old bedding planes, and the layers of biotite may represent argillaceous bands interstratified with the quartz-felspar sands.

The granulitic Moine Gneiss is the most widely distributed rock in Scotland. It is sometimes associated with garnetiferous mica-schists, with mica-schists in which the foliation is less regular, and with "flaser gneiss". It rests unconformably on the Lewisian.

In the neighbourhood of the thrust planes the Moine gneisses have been broken down into mylonites; and in some localities, as near Craig a Knochan, sills of foliated igneous rocks, which are probably post-Cambrian in age, have been crushed into schists with the foliation planes parallel to those in the Moine. In such cases the existing foliation planes in the Moines may have been due to the overthrusting; but in other cases it is clear that the Moines had their present characters before the date of these movements. The folds in the Moines, for example, trend from west-north-west to east-south-east at right angles to the direction of the earth-thrusts.

At Tarskavaig, at the northern end of the Sleat of Skye is an area of Moine composed of siliceous schists, phyllites, and granulitic schists, which are faulted against the Torridon Sandstone.

3. **Dalradian.** The name Dalradian was introduced by Sir ARCHIBALD GEIKIE in 1891. The Southern Highlands of Scotland are composed of a complex series of schists, gneisses and crystalline limestones which have a general strike from east-north-east to west-south-west. They extend across Scotland in a broad belt from Banff, Aberdeenshire and Kincardine on the eastern coast, to Argyll and the Firth of Clyde on the west. The schists are invaded by masses of granites, diorites, quartz-porphyries etc., and they contain bands of hornblende schist due to foliated igneous rocks; but the Dalradian System as a whole consists of altered sediments.

The stratigraphical relations of these rocks have given rise to special difficulties. Sir ARCHIBALD GEIKIE in 1891 grouped these rocks together under the name Dalradian, which he proposed as the name of a petrographic group rather than a distinct geological system; for he considered that these rocks included Palaeozoic and earlier rocks folded together and so altered that their separate elements are inextricably welded. Later work renders it probable that the Dalradian rocks may be regarded as the Scottish representatives of a pre-Torridonian system.

The sequence of the Dalradian rocks is shewn in sections north and south across the Southern Highlands. The Dalradian system has been divided into five series in the following order from north to south:

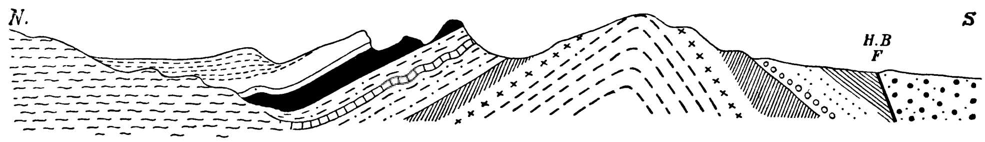
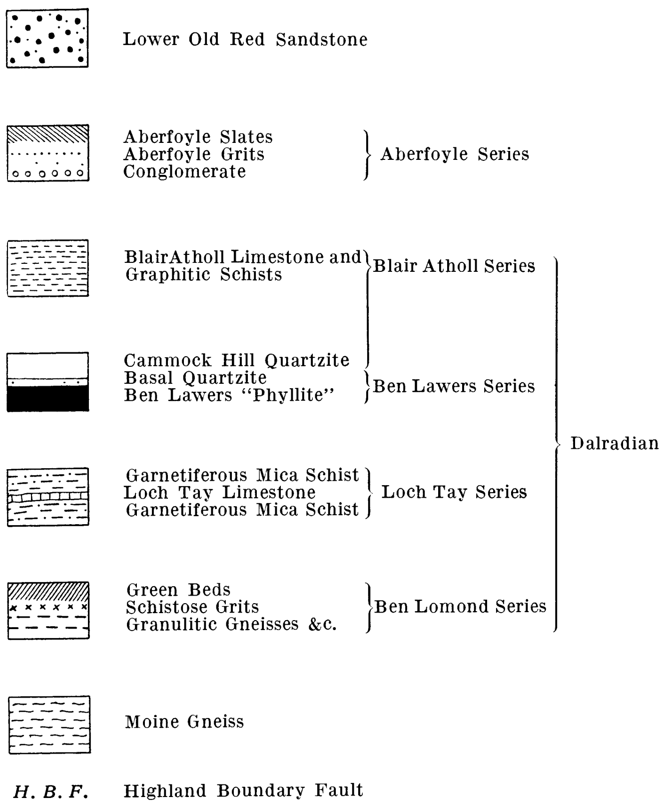


Fig. 12. Diagrammatic Section across the Southern Highlands, secondary folds and faults omitted. J. W. G.



5. Schichallion Series — Quartzites and Boulder Bed.
4. Blair Atholl Series — Graphitic Schists, Blair Atholl Limestone, and Cammock Hill Quartzite.
3. Ben Lawers Series — Ben Lawers "Phyllite", Loch Gair Quartzite.
2. Loch Tay Series — Garnetiferous Mica Schists and Loch Tay Limestone.
1. Loch Lomond Series — Epidotic Schistose Grits (Green Beds), Granulitic and Albite Gneisses, Ben Ledi Schistose Grits.

The names of these series are from typical localities on the main Dalradian band. The sequence of these five divisions can be traced across Scotland, but it is still undecided which is the youngest series and which the oldest member of the system. The southern Dalradian rocks near Loch Lomond dip southward, and they are covered by slates and grits, which rest upon the schists and also dip southward. Further east, as in the Pass of Leny near Callender, the same succession can be recognized, but the slates and grits there dip northward under the schist series.

Nicol concluded that the sequence in the Loch Lomond area was in the original order and that the beds in the Pass of Leny have been inverted; and this conclusion is supported by the comparatively unaltered condition of the southern rocks and by their being more disturbed near the Pass of Leny than near Loch Lomond. The view has however been held, as by Bailey, that the rocks on the southern border are older than the schists to the north of them, and that the beds near Loch Lomond are inverted.

According to Nicol's complete view, the whole of the Dalradian sequence is in ascending order from north to south. It appears to the writer however that there is a descending sequence southward from the unfoliated felspathic quartzites (the Schichallion Quartzites) and the graphitic schists of the Blair Atholl Series — the two northern members of the Dalradian System — to the albite schists and granulitic gneisses of the Loch Lomond Series. Further south, however, the order is reversed and the beds probably follow in an ascending order to the south.

South of the Loch Lomond Gneisses is a band of slates and grits, which is well developed at Aberfoyle and is therefore called the Aberfoyle Series. These rocks are also found in the Peninsula of Cowal, and at Luss on Loch Lomond. This Aberfoyle series is probably post-Dalradian and was deposited unconformably upon the southern edge of the Dalradians.

The typical rocks of the Dalradian Series are as follows: The Schichallion quartzite is a massive felspathic quartzitic grit; it forms the ridge of Schichallion and constitutes the Ben-y-Ghloe Mountains. At its base a boulder bed occurs in several localities along the northern edge of the Dalradian band. The characteristic rocks of the Blair Atholl Series are graphitic schists and crystalline limestone. The characteristic rock of the Ben Lawers Series is known as "phyllite"; it is a calc-sericite-schist. The Loch Tay Series consists of garnetiferous mica schists and gneisses, some quartzitic schists, the Loch Tay Limestone and some bands of amphibolite which represent basic lava flows, sills and earthy limestones. The Loch Lomond Series consists of a series of crushed schistose grits, which in places are albite gneiss and granulitic gneiss. The Loch Lomond granulitic gneisses are associated with bands of epidote chlorite schists, which from their colour are known as the Green Beds and have proved of great value in the field mapping. Some of the granulitic gneisses have been formed from the alteration of grits, and the clastic grains are sometimes still recognisable.

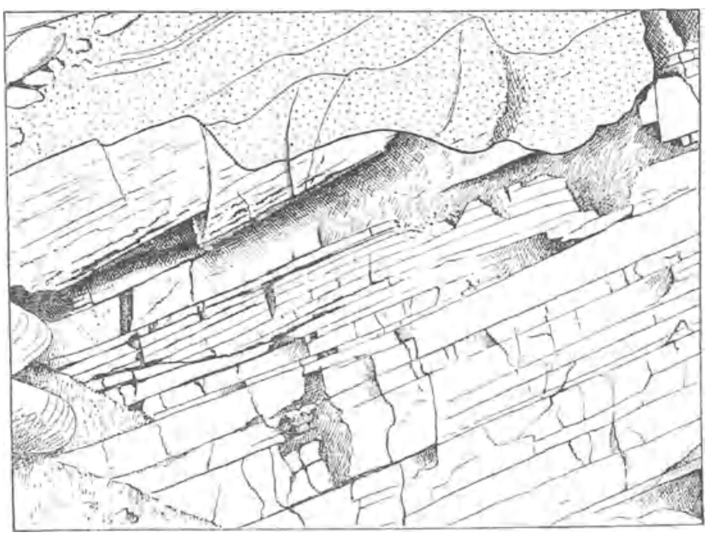


Fig. 13. Main or Blair Atholl Limestone resting on the eroded surface of Moine. Glen Tilt, below Marble Lodge (GEORGE BARROW). Reproduced from the Quarterly Journal of the Geological Society vol. 60, p. 430, 1914; with the permission of the Council and of the author.

4. **The Torridonian.** The Torridonian System consists of a thick series of red sandstones, conglomerates and shales, which range in northwestern Scotland for a length of 184 km (115 miles) from north to south and for a width of about 32 km (20 miles). The beds are often almost horizontal and they are so little altered, that they were originally identified, not unnaturally, as part of the Old Red Sandstone. They are especially well developed at the head of Loch

Torridon and there rise in bold precipices. The Torridon Sandstone often rests on the Lewisian platform and masses isolated by denudation, such as Suilven and Stack Poli, form some of the most striking in aspect of Scottish mountains.

The material of the lowest beds has been in many localities derived from the decomposition of the Lewisian rocks and contains much oligoclase; but most of the Torridon Sandstone is rich in microcline, which is not a characteristic Lewisian felspar. The pebbles in the Torridon conglomerates are also not of common Lewisian types. They include various felsites and other igneous rocks, and pebbles of quartzite, chert, jasper and grit, which do not resemble the Lewisian rocks. The Torridon Sandstone therefore appears to have been formed of sediments derived from some post-Lewisian deposits.

The maximum thickness of the Torridon Sandstone appears to be about 6000 m. (20 000 ft). It is divided into three series, which in descending order are as follows:

3. The Aultbea Series, sandstone and flags with some calcareous bands and shales.

2. The Applecross Series, mainly red arkose with bands of conglomerate composed of pebbles of quartzite and jasper.

1. The Diabaig group which reaches its maximum thickness in Skye; it is mainly composed of fine red sandstone and shales with calcareous lenticles. The lowest part of this series consists of a conglomerate made from the underlying Lewisian.

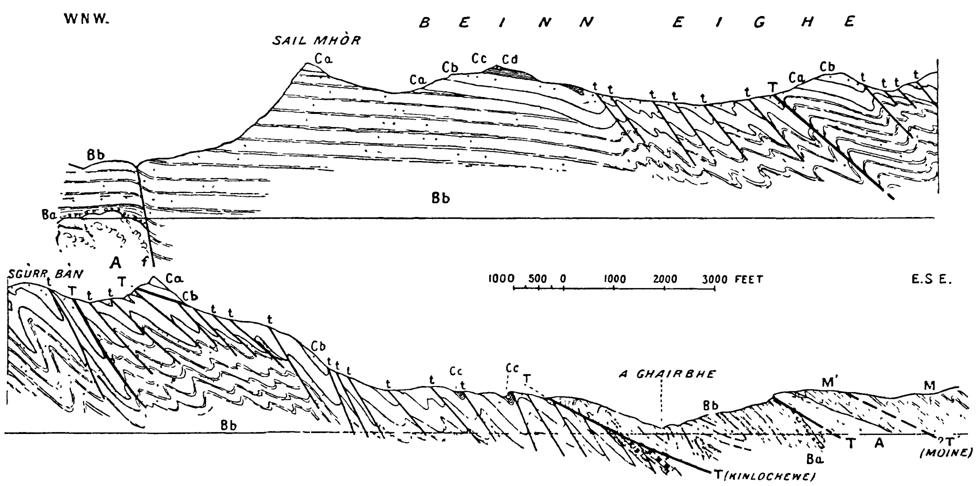
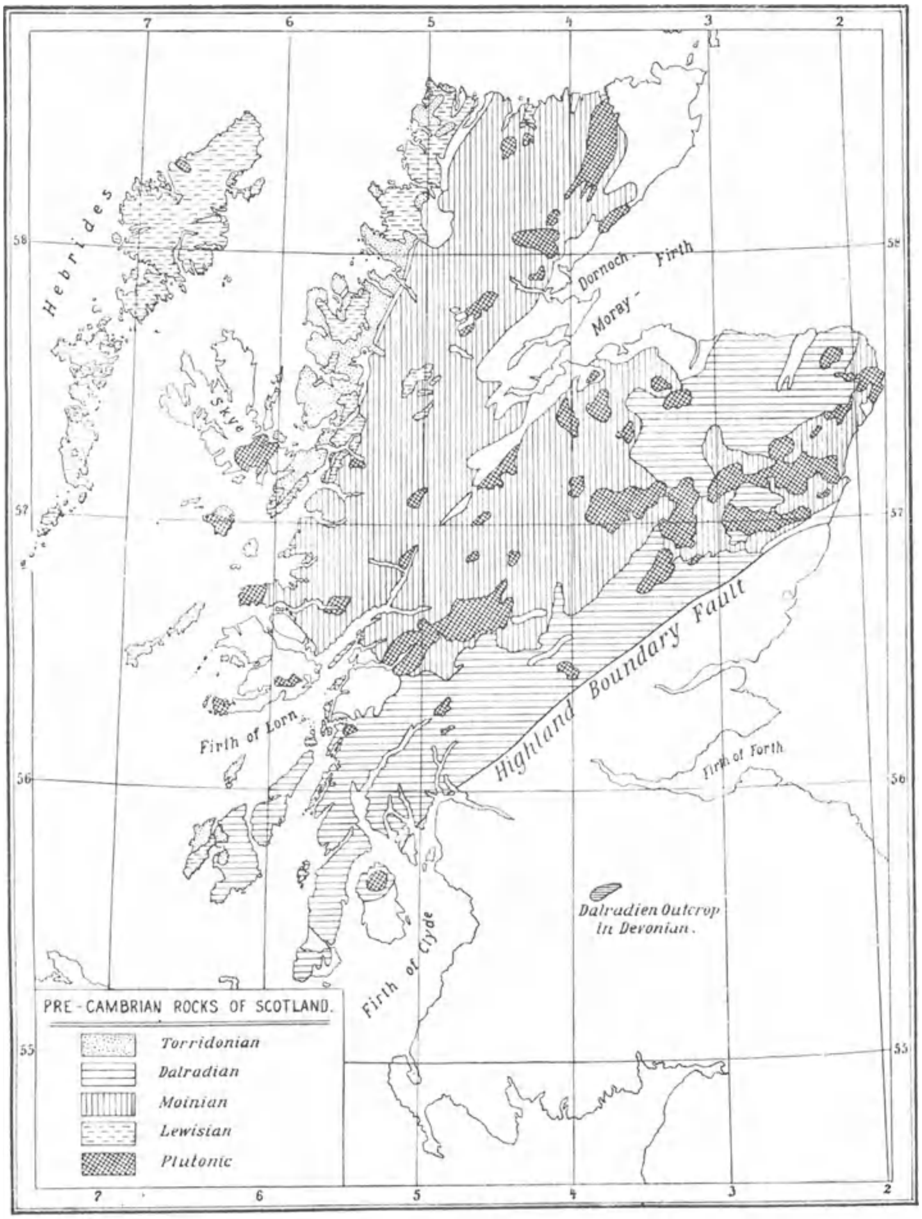


Fig. 14. Section across Beinn Eighe to A Gairbhe, south of Kinlochewe.
A. Lewisian Gneiss. Ba. Diabaig Group (Torridonian). Bb. Applecross group. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. M′. Mylonized Rocks, Phyllites, and Siliceous Schists. M. Moine-schist. T. Thrusts. ?T′. Moine thrust. T. Minor thrusts. F. Fault.
Reproduced from the Memoirs of the Geological Survey of Great Britain—The Geological Structure of the North-Western Highlands of Scotland, 1907, p. 550, with the permission of the Director and of H. M. Stationery Office.

As a general rule the coarsest varieties of the Torridonian rocks are in the north, and they become finer in grain to the south. Some of the rocks in the Torridon Sandstone were clearly formed under water, but the pebbles in many places are faceted; and both the form of the sand grains and the polishing of the pebbles show that they were deposited on land under arid terrestrial conditions. Owing to the remarkable freshness of some of the grains, L. Hinxman has suggested that the



J. W. G.

Carl Winters Universitätsbuchhandlung, Heidelberg.

rocks were rapidly accumulated in a cold climate, while J. G. GOODCHILD regarded the rocks as accumulated under desert conditions. The rocks have smothered an old Archean land surface, which is now being slowly reexposed by the denudation of the sandstones.

The rocks are so little altered that the shales might well have retained any fossils originally present in them; but the only certain traces of fossils that have been discovered hitherto are some spherical bodies and brown fibres, discovered by J. J. H. TEALL; they occur in phosphatic grains found in the upper Torridon shales from Loch Broom.

The relationship of these Archean systems involves many problems on which opinion is still divided. The Lewisian System is unquestionably the oldest though there are some younger gneisses of Lewisian aspect.

The Moinian System, according to the evidence near Glenelg and in Ross-shire, rests unconformably upon the Lewisian, and the base of the Moinian is there a thick conglomerate. The fact that many of the dykes in the Lewisian do not penetrate the adjacent Moinian also gives some evidence in support of the view that the deposition of the two series of rocks was separated by a considerable interval of time. According to BARROW however the Moinian and the Lewisian are parts of one system.

The Moine gneiss has also been regarded as metamorphosed Torridon Sandstones, a view suggested by B. N. PEACH, and several facts concerning the petrography and distribution of the rocks appeared to favour that hypothesis; but the view appears now to be generally accepted that the Moinian is an older system than the Torridonian (GREGORY 1915).

The Dalradian System is a very varied collection of rocks which according to the writer are later than the Moinian and were deposited unconformably upon the southern flanks of a land composed of Lewisian and Moinian rocks. On the other hand, according to P. MACNAIR and some members of the Geological Survey, the Dalradian rocks are earlier than the Moinian and the superposition of the Dalradians upon the Moinian is explained by great overfolds.

According to BARROW the less altered condition of the Dalradian Series is due to the fact that the Scottish Highlands are a great metamorphic aureole, in which the metamorphism is most intense in the centre and the beds become less crystalline to the north-west and the south-east.

The author regards it as most probable that the Lewisian and Moinian Systems formed an ancient land which had been greatly denuded before the deposition of the Dalradian sediments upon its south-eastern border.

Another area of the Lower Archean rocks must have existed in southern Scotland, and the Dalradian sediments were deposited on the north-western slopes of these highlands; the Lewisian and the Moinian rocks formed a foreland, against which the Dalradian beds were intensely puckered by pressure from the south-east. These southern highlands must have been destroyed before the Upper Cambrian, as some beds of that age have been laid down along the south-eastern edge of the Dalradian; but the existence of Archean areas south of the Midland Valley of Scotland in Devonian times is indicated by the large boulders of Schichallion grit found in the Old Red Sandstone conglomerates near Lesmahagow.

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c. Ireland.

By G. A. J. COLE.

In Ireland there is no certain exposure of a rock-floor of a fundamental and "primitive" character. Ancient gneisses occur, but they seem to have resulted in all cases from the invasion of sedimentary rocks by granite. These sedimentary rocks are older than the Arenig series, as may be clearly proved in southern Mayo and northern Galway; and comparison with Scotland and Wales makes it practically certain that they are Pre-Cambrian, like the successive sedimentary series that are now well established in Fennoscandia. The name Dalradian, given to them by Sir A. GEIKIE, is a safe one, pending an accurate delimitation of these early systems. In eastern Tyrone, from north of Carrickmore to the Londonderry border, biotite-gneiss and schist form a moorland country; we probably meet here the oldest rock-masses in Ireland (NOLAN 1879, GEIKIE 1897, Geol. Surv. Mem. Sheet 26). Granite in-

[1] Some of these works were published after the manuscript had been sent to the editor.

vades this series at Fir Mt., and produces a composite rock, the features of which are so similar to those of the gneiss to the south-west that we may conclude that this also had a composite origin. Were the granitic material removed from this ancient gneiss, it might resemble an ordinary Dalradian schist. The later granite in this district is pre-Devonian (COLE 1899) and the proximity of masses of it to the little altered Ordovician slates of Pomeroy goes far to show that it is not one of the "Caledonian" intrusive masses, but is of late Pre-Cambrian age. Above the gneisses and schists are greenish diabases, sometimes massive and crystalline, sometimes volcanic, and with a scoriaceous structure, which form the flanks of the moorland. They are associated with red and green cherts, containing very dubious traces of organisms, and are invaded by the younger granite. Though at one time these rocks were compared with the Arenig series of southern Scotland, it seems probable that they also are Pre-Cambrian. Devitrified rhyolites and rhyolite-tuffs occur in this series at Creggan and other places. Gneisses, probably of intrusive or composite origin, come out to the north-east in connexion with a series of mica-schists and dark crystalline limestones at Torr Head on the Antrim coast. The area of old rocks here, in which the Glendun and Glenshesk valleys have been cut, is mostly occupied by the normal Dalradian series. This series consists throughout western Londonderry of much folded mica-schists and quartzose pebble beds, with occasional slates. Traces of the original bedding are clear in places; but in general the most prominent

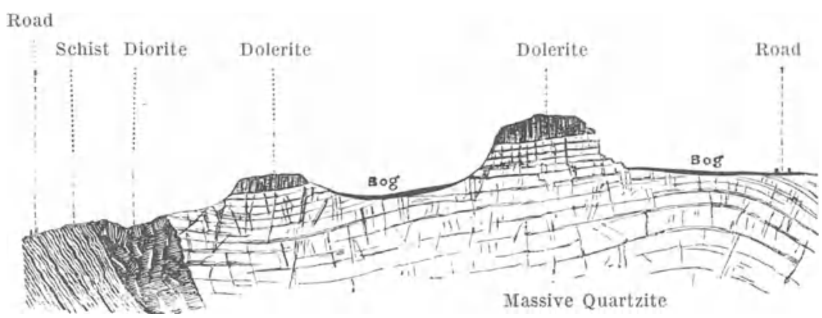

Fig 15. Section through the King and Queen of the Mintiaghs, showing influence of sills of dolerite on the surface features of Co. Donegal, Pre-Cambrian area, Irishowen. Reproduced from the Memoirs of the Geological Survey of Ireland, Nos. 1, 2, 5, 6 and 11. Inishowen, Co. Donegal, p. 31, 1890; with the permission of the Director and of H. M. Stationery Office.

divisional planes are those of cleavage. Disturbances during the Caledonian folding have crumpled these cleavage-surfaces and have sometimes developed a second cleavage (Geol. Surv. 1908). A greater variety of rocks occurs to the west in Donegal. Crystalline limestones, quartzites and mica-schists have been invaded by basic igneous rocks, which, during a general epoch of metamorphism, have passed into an epidiorite state. Great masses of granite, mainly lying in the strike of the Caledonian folds, have risen through this series, and have enriched themselves with biotite on their margins of contact against the schists and epidiorites. The strike impressed upon the region at the close of Silurian times remains recorded in numerous strips of schist included in the granite itself, whereby the igneous rock has locally become a composite gneiss, with a foliation running north-east and south-west. Contact phenomena may be well studied in the southern area of metamorphic rocks near Lough Erne. Great eyes of amphibolite, consisting of quartz, basic felspars, pyroxene, amphibole, and garnet, lie in the granite round Lough Derg near Pettigo, and gneissic features have been produced along the contact-zone. The invading granite has, not unnaturally, been taken in places for a "fundamental gneiss". Yet here, as elsewhere in Ireland, the Dalradian sediments are the oldest traceable series. (HAUGHTON 1862; SCOTT 1862-4; Geol. Surv. 1891; COLE 1900-2.)

In Donegal, the Geological Survey has revealed a sequence in these sediments, which may be thus summarised, in descending order:

4. Quartzites (often forming mountain-crests).
   "Boulder-bed" at base, possibly of glacial origin.
3. Crystalline limestones and schists.
2. Mica-schists, with some black slates.
1. Quartzose and felspathic grits and flags.

The Dalradian rocks reappear in western Mayo and Galway, and their unconformable relation to the Ordovician and Gothlandian strata is clearly seen in Connemara. At Recess in central Galway, a band of limestone has become metamorphosed by contact with diorite into a handsome serpentinous marble, known as Connemara marble. The structure of this rock, which is similar to that of the "Eozoönal" marble of Canada, was relied on by W. King and T. H. Rowney (1866, 1870) in attacking the alleged organic origin of *Eozoön* (See also Sanford and Jones 1865). A large area of intrusive granite occupies the north coast of Galway Bay. The formation of gneiss by the action of the granites on the Dalradian epidiorites was first demonstrated by Callaway (1887) in this region. There is no doubt that the Pre-Cambrian rocks extend south-westward under the sea from the coast of Galway. The Devonian conglomerate of Inch in the Dingle Promontory shows that a schistose mass lay somewhere near at hand in Co. Kerry, from which the pebbles in this conglomerate were derived.

The range of the Ox Mountains in the counties of Mayo and Sligo consists of an elongated mass of Dalradian rocks, including handsome banded gneisses, resulting from granitic intrusions into an older metamorphic series.

It is difficult to determine the character of the Irish area in early Pre-Cambrian times. When the stratified Dalradian beds were being deposited, still older masses of land must have lain near at hand, probably in the west and north, from which the abundant detrital material was derived. There is nothing to show that the conditions of sedimentation were different from those of the present day, and sandy muds, now converted into mica-schists, sandstones, now converted into quartzites, and occasional grits and conglomerates, show that a shore was not far distant. The distinctly bedded limestones may be of chemical origin, if at this remote period there were no organisms capable of accumulating calcium carbonate in their shells. The stratification of the whole series indicates deposition in water, which was probably that of a marine basin. Towards the close of the Dalradian periods — for the rocks probably include more than one system of strata — the "boulder-bed", a coarse conglomerate of remarkable persistence, was formed, and seems to point to glacial action. Drift-ice in this case may have dropped the boulders on the sea-floor during a time of general glacial extension, for striated rock-surfaces have not been found beneath the boulder-bed. It is proper to state, moreover, that no striations have yet been found on the boulders themselves.

The period of Dalradian deposition was followed by earth-movements which allowed of the invasion of the series by an immense number of bosses, sills, and dykes of basic rock. These very probably produced lava-flows, and even lava-plateaus, on the surface, which were worn away before Ordovician times. The whole Dalradian area subsequently suffered from metamorphism, the shales being converted into slates or puckered mica-schists, yet sometimes retaining their stratification; the sandstones passed into quartzites, with less profound modification; the limestones, which were in part dolomitized, lost any trace of original structure; and the basic intrusive rocks, probably in large part originally pyroxenic, became diorites and even hornblende-schists. Masses of granite welled up in certain places, adding greatly to the metamorphism that had already taken place, and here and there forming a floor to the series invaded by them, so as to resemble an earlier and "fundamental" series. One of the most difficult problems is to distinguish these late Dalradian granites from those that long afterwards accompanied the Caledonian folding in the same areas. Pebbles of granite, however, occur in the Gothlandian beds of Connemara, and prove conclusively the intrusion of a granite magma at an early epoch.

The handsome red granites of Galway and of Burton Port in Co. Donegal are connected with the Dalradian series, and are quarried to some extent.

The only Pre-Cambrian crystalline limestone successfully quarried is the serpentinous marble of Co. Galway ("Connemara Green"), which is an exceptionally striking ornamental stone. It results, as above stated, from the alteration of a sedimentary limestone by basic igneous intrusions; bands of olivine were developed in it, which have now passed into serpentine, and the streaky character of the marble forms one of its chief attractions.

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See also Portlock J. E.

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2. Cambrian.

a. Great Britain, including the Isle of Man.

By W. W. WATTS.

The Cambrian rocks make their appearance in numerous scattered areas, for the most part of small size, but the North Wales area and that of the Highlands of Scotland, each covers some hundreds of square miles. The rocks are exposed in many parts of Wales and the border counties, and they are known from borings as far east as Leicestershire and Buckinghamshire. They appear to thin out to the north-west and are not found in Anglesey. They are not known with certainty in southern England, nor are they typically developed in the north of England. They may be present, though they have not been recognised, in southern Scotland, and they appear in force in the northern part of that country.

The rocks present three facies. One, the Welsh or "Merioneth Facies", is characterised by its great thickness, by the presence of coarse-grained rocks, and in that the succession is nearly complete. The other two facies are less distinct from one another, but both differ remarkably from the Welsh facies. That of the Midlands, the "Shropshire Facies", is characterised by the presence of quartzites in the lower part of the succession, followed by deep-water shales. The middle and lower part of the Upper Cambrian are sometimes not well represented. In the Scottish or "Highland Facies", quartzites are present, but the Middle and Upper Cambrian, if present at all, are represented by limestones, which find no parallel elsewhere in British geology.

The rocks will be considered in each group of localities under the following heads, although, in those cases where the rocks have not yielded characteristic fossils, an exact allocation to any particular division may not be possible.

Upper Cambrian	**Transition** Series	Tremadoc Slates.
	Olenus Series.	Lingula Flags.
Middle Cambrian,	**Paradoxides** Series	Menevian Beds.
		Upper Harlech Beds.
Lower Cambrian,	**Olenellus** Series	Lower Harlech Beds.

A. North Wales.

The great dome of Harlech exposes the grandest succession of the Lower Cambrian Rocks known in the country; and round the dome, from Criccieth and Portmadoc to Cader Idris, the Middle and Upper Cambrian Rocks crop out in successive rings, usually broken and distorted, but on the whole fairly complete and regular. An important area of Cambrian rocks is also exposed near Llanberis, and one or two other smaller patches occur in isolated localities in Carnarvonshire.

Where the lowest rocks of the centre of the dome strike out to sea, rocks of Pre-Cambrian type have been found. The general succession of the older Cambrian rocks, as established by Charles Lapworth and Stacey Wilson (Andrew 1910), is the following:

2. **The Menevian Series.**
   Black shales and slates.
1. **The Harlech Series.**
   e) Gamlan Shale Group: grey and purple shales, slates, and flags, with occasional grit bands, 229—366 m. (750 to 1200 feet).
   d) Barmouth Grits: Massive felspathic grits or greywackes, with pebble bands, about 180 m. (600 feet).
   c) Hafotty or Manganese Shale Group: Grey and green shales and flags, some subordinate grits about 300 m. (1000 feet).
   b) Rhinog Grits: very massive, forming the Rhinog and other mountains, 760 m. (2500 feet).
   a) Cefn or Llanbedr Slate Group: blue and purple shales, slates and flags.

The outcrop of the Lower Cambrian Rocks forms a barren and desolate tract almost without habitations, with block-like mountains where the two great grit bands make the surface of the ground. The rocks are thrown into innumerable minor folds and are traversed by joint and fault planes, which determine the conspicuous features of the landscape. A band, important by reason of the presence of carbonate and oxide of manganese, occurs in the Hafotty group between the two main grit bands, and has been much mined in the past.

Hitherto the Harlech beds have not yielded fossils, other than worm tracks or "fucoids" found commonly in the highest division, but from the fact, that the fossiliferous Menevian Beds succeed without unconformity, there can be little doubt that they represent the Lower Cambrian and possibly part of the Middle Cambrian.

When the Cambrian rocks rise up again from under the Snowdon syncline, they are much finer in texture, and constitute the Llanberis Slates, which rest unconformably on the Pebidian rhyolites. Grits, thinner than those of Harlech, are present on several horizons, but the chief rocks are purple and green slates in which a vast series of quarries has been opened all along the line extending from Penrhyn, through Llanberis, to Nantlle. The perfect cleavage of the rocks, due to considerable mineral change, has been connected by HARKER with the presence of the resistant Pre-Cambrian mass of Llanberis, against which the slates have been pressed by earth movement and converted into fine-grained phyllites. The only fossils hitherto found in the Llanberis Slates are two specimens of *Conocoryphe viola*, a species not known elsewhere. A small patch of Cambrian rock also occurs in the south of the Lleyn Peninsula. In Anglesey the Cambrian Rocks appear to be overlapped by Ordovician Rocks, and they nowhere come to the surface.

The Upper part of the Paradoxidian Series, called by BELT and SALTER the Menevian, is a group of dark, almost black, shales and slates indicating the deepening of the sea. They are generally characterised by a small-scale cuboidal jointing. Fossils have been found at several places, and among them, the following are the chief: *Protospongia fenestrata*, *Agnostus punctuosus*, *A. altus*, *Anopolenus salteri*, *Microdiscus punctatus*, *Paradoxides davidis*, and *P. hicksi*. The slates are not so black as the famous "black band" of the Dolgelly Stage, and the colour seems to be due to the presence of pyrites, which tends to collect in bands that weather white. The beds are traversed by numerous intrusions of "porphyry" and "pale diabase". It is in association with these igneous rocks that mineral veins occur, especially the gold-bearing lodes for which the district has been long famous.

The Upper Cambrian Rocks have been divided on lithological grounds into the Lingula Flags and the Tremadoc Slates. The former is characterised by species of *Olenus* and other Trilobites, the latter by *Niobe*, *Shumardia*, and *Asaphellus*, and by *Dictyonema* and *Clonograptus*. The latter division is now often placed in the Ordovician System, but for convenience of description, it is found better to include it in Britain with the Cambrian and to treat it as a Transition Series.

The lower members of the Lingula Flags are coarse-grained flaggy rocks deposited in shallow water, but the highest division is characterized by the presence of a well marked, intensely black band, deposited in deep water. These upper beds were evidently deposited slowly and they may comprise a period much more lengthy than the rest of the Series (FEARNSIDES 1905, 1910). The chief divisions are the following:

3. Dolgelly Stage; 80—200 m. (250—650 ft.).
    - d) Zone of *Peltura scarabaeoides*; sooty-black mudstones.
    - c) Zone of *Agnostus trisectus*; blue-black mudstones.
    - b) *Orusia lenticularis* bands in black slates.
    - a) Zone of *Parabolina spinulosa*; dark flaggy slates.
2. Ffestiniog Stage.
    - c) Band rich in *Lingulella davisi*, 9 to 12 m. (30—40 ft.).
    - b) Tough blue-grey flags.
    - a) Blue and brownish-grey fine-grained flags 575 m. (1900 ft.).
1. Maentwrog Stage.
    - b) Upper, or Pen Rhos Beds: dark blue slates, weathering bright red.
    - a) Vigra Beds: dark grey and blue slates, with hard siliceous beds, known as "ringers".

Among the characteristic fossils of the Lower Lingula Flags are *Agnostus reticulatus*, *A. pisiformis*, *Olenus truncatus*, and *O. cataractes*; of the Dolgelly Beds, *Agnostus obtusus*, *A. rudis*, and *Sphaerophthalmus alatus*.

The Tremadoc Slates occur near the village of that name in Carnarvonshire, from which they are traceable discontinuously to Criccieth on the west and Cader Idris in the south. The highest beds are hidden sometimes by the unconformable overlap of the overlying beds, sometimes by the occurrence of a great overthrust fault (FEARNSIDES 1909, 1910). The sequence is as follows:

6. Garth Hill Beds: grey-blue slates with *Angelina sedgwicki*; over 36 m. (120 ft.) thick.
5. Penmorfa Beds: flaggy mudstones with *Shumardia pusilla*, and a rich fauna of other trilobites like that found in the Shineton Shales.
4. Portmadoc Beds: thick felspathic slates with *Asaphellus homfrayi.*
3. Moel-y-Gest Beds: banded grey slates and mudstones; *Acrotreta* and *Bellerophon*; few fossils 75 m. (250 ft.).
2. Dictyonema Band: blue-grey mudstones, bright-rusting, with abundant *Dictyonema sociale*; about 6 m. (20 ft.)
1. Tynllan Beds: thin bedded rusty shales, with some hard bands containing *Niobe homfrayi*, *Psilocephalus innotatus*, and *Hymenocaris vermicauda*; about 60 m. (200 ft.).

The Tremadoc Series as a whole shows the recurrence of shallower water after the deeper phase indicated by the "Black Band" of the Dolgelly Stage. Volcanic rocks of Upper Cambrian age are known to occur on the north-western slopes of Cader Idris. There are andesitic lavas in the Dolgelly Beds and rhyolitic lavas and tuffs above the *Dictyonema* Band. No Tremadoc rocks have been identified north-west of the Snowdon Syncline.

B. South Wales.

The Cambrian Rocks of South Wales are closely comparable with those of the north of that country, in that there are two fine grained and two coarser-grained series. The Tremadoc Series is not typically developed. The divisions given by HICKS (1892, 1894) at St. Davids in Pembrokeshire are summarized below:

3. Upper Cambrian: Lingula Flags with *Lingulella davisii.*
   - b) Upper Lingula Flags.
   - a) Lower Lingula Flags.
2. Middle Cambrian.
   - b) Menevian Series.
     - 3. Highest Beds with *Conocoryphe.*
     - 2. Zone of *Paradoxides davidis.*
     - 1. Zone of *Paradoxides hicksi.*
   - a) Solva Series.
     - 3. Zone of *Paradoxides aurora.*
     - 2. Zone of *Paradoxides solvensis.*
     - 1. Zone of *Paradoxides harknessi*, *Plutonia* etc.
1. Lower Cambrian.
   Caerfai Series, with *Olenellus*, *Lingulella ferruginea.*

The Lower Cambrian rocks consist of conglomerates, red and purple flaggy sandstones, and red shales and flags, with a thickness somewhat over 450 m. (1500 ft.). Certain crustacean fragments found in this series have been referred by HICKS to *Olenellus*. The Solva Series shows grey, purple, and red sandstones, flags, and slates, with a thickness of 610 m. (2000 ft.). The Menevian Series is as usual made up of dark flags and black slates about 230 m. (750 ft.) thick, in which several species of *Paradoxides* have been recognised. This deeper-water series is followed by the Upper Cambrian, shallow-water, rocks, of which the various members have been correlated with the three divisions of the Lingula Flags, but few fossils, except the characteristic *Lingulella davisii*, have been found in the lower beds. The well-marked fauna of the Dolgelly Beds is represented at Trefgarn Bridge and elsewhere. The rocks referred by HICKS to the Tremadoc Series, occurring on Ramsey Island and at Whitesand Bay are almost certainly of Arenig age.

East of St. Davids, at Brawdy and Hayscastle, Lower and Middle Cambrian Rocks occur, which have been compared by H. H. THOMAS and O. T. JONES (1912) with parts of the Caerfai and Solva Series of St. Davids. Very few fossils have been found in these rocks. J. E. MARR and T. ROBERTS (1885) recognised in this neighbourhood Lingula Flags with *Agnostus pisiformis* and *Parabolina spinulosa.* In the neighbourhood of Carmarthen and Llanarthney, dark shales and mudstones, making their appearance in the cores of sharp anticlinal folds, have been relegated to the Tremadoc. The principal fossils found in them are *Peltura punctata* and *Ogygia marginata* with *Dikellocephalus serratus*, and *Parabolinella rugosa.*

C. The Midlands.

Cambrian Rocks have been detected in the following areas: Shropshire, The Lickey Hills, Nuneaton, Malvern, and at Pedwardine in Herefordshire. The succession, which is not usually complete in any one area, is as follows:

3. Upper Cambrian
    - c) Shumardia Beds.
    - b) Dictyonema Beds.
    - a) Olenus Shales.
2. Middle Cambrian.
    - b) Menevian Shales.
    - a) Paradoxides Limestone.
1. Lower Cambrian.
    - b) Sandstone or quartzite with *Olenellus* and *Hyolithus.*
    - a) Quartzite.

The Quartzite of the Wrekin and Caradoc rests unconformably on Cardingtonian volcanic rocks, with a conglomerate, made from the denudation of them, at its base. In the main it is uniform in texture and it has yielded worm-tracks to CALLAWAY (1877). It passes up gradually into a green glauconitic sandstone (the Comley Sandstone) in which several beds of limestone have been discovered (LAPWORTH and WATTS 1894, 1910). These limestones present many points of comparison with the lowest Cambrian limestones of Oeland. In them have been found the faunas of the *Olenellus* and *Paradoxides* stages. In the neighbourhood of Comley, near Church Stretton, E. S. COBBOLD (1910, 1910, 1911) estimates the Wrekin Quartzite to be about 30 m. (100 ft.), and the Lower Comley Sandstone between 90 and 120 m. (300 and 400 ft.) thick. In the Sandstone two species of *Callavia*, one of *Wanneria* and several other fossils have recently been found. At the top of this occur two limestones in juxtaposition, the lower containing *Callavia callavei*, the upper *Protolenus*, *Microdiscus bellimarginatus*, and *M. lobatus.* Separated by an unconformity occur grits, shales, and flags, considerably over 120 m. (400 ft.) thick carrying *Paradoxides groomi*, followed by *Dorypyge* in the lower part, *Ptychoparia* in the middle, and zones of *Paradoxides rugulosus*, and *P. davidis* in the upper part. Above the last horizon come shales with *Orthis* (*Orusia*) *lenticularis* and other shales with *Dictyonema*, but the relations of these shales to one another and to the beds below are unknown as the complete succession is not exposed.

Near the Wrekin the highest shales are well developed. Low down in the sequence the *Dictyonema* Band occurs, carrying *D. sociale* and *Clonograptus*; then follows a considerable thickness of barren shales, in the upper part of which CALLAWAY (1877) detected the rich fauna of the Shumardia zone, including *Macrocystella mariae*, *Lingulella nicholsoni*, *Asaphellus homfrayi*, *Olenus salteri*, *O. triarthus*, *Agnostus dux*, *Niobe*, and *Shumardia pusilla.* The beds are uncleaved and the fossils beautifully preserved. They enable correlation to be effected with certain parts of the Tremadoc Series of North Wales, although the Niobe beds below and the Angelina beds above have not yet been identified. The highest rocks exposed are unconformably overlapped in some places by the basal beds of the Ordovician and in others by the Gothlandian.

At Pedwardine Farm, near the village of Brampton Bryan, in Herefordshire, richly fossiliferous Dictyonema beds of Tremadoc age have been found.

At the Lickey Hills, south-west of Birmingham, the Barnt Green Rocks (LAPWORTH, WATTS and HARRISON 1898) are followed by a quartzite, the basal beds of which contain fragments derived from the Pre-Cambrian Rocks; but the bulk of the rock is a typical quartzite much quarried for road-metal. No fossils have been discovered, but the fact that it is overlain unconformably by basal Valentian beds, and comparison with the Wrekin and Nuneaton Quartzites, make it practically certain that it is of Lower and possibly Middle Cambrian age.

North and north-west of Nuneaton, the Carboniferous Rocks are underlain by a considerable series of Cambrian Rocks recognised and worked out by LAPWORTH (1886, STRAHAN 1886, LAPWORTH, WATTS and HARRISON 1898) and the Geological Survey. Overlying the Caldecote Volcanic Series come grits and massive conglomerates made up of fragments of the underlying ashes and the rocks intrusive into them. These soft rubbly beds are followed by compact and flaggy quartzites exposed in a large series of quarries where the rock is worked for road-metal. In this division there are two or three seams of shale, and worm-tracks have been found in the quartzites.

The highest division of the Quartzite consists of softer sandy strata, of little use for road-metal, and hence less favourably exposed. In this division however, a band of limestone have been discovered (LAPWORTH 1886, STRAHAN 1886, LAPWORTH, WATTS and HARRISON 1898). It is rich in the remains of *Hyolithus*, *Orthotheca*, *Coleolides*, *Stenotheca rugosa*, and *Kutorgina cingulata.* The genera and species found in these beds at Camp Hill Quarry compare closely with those found elsewhere in the Olenellus Series, and with those of the Etcheminian Series of New Brunswick. In spite of the absence of trilobites this limestone may be safely correlated with part of the Olenellus Series. The quartzites immediately associated with it yield worm-tracks and other markings like those found in the "Fucoid Beds" of North Scotland in which the Olenellus fauna has been found. On this horizon, oxide of manganese occurs and was at one time mined.

The top beds of the Quartzite are interbedded with purple shales and are followed by a thick shale series named, after its occurrence at the village of that name, "The Stockingford Shales". These have been subdivided by LAPWORTH as follows:

3. Grey or Merevale Shales.
2. Black or Oldbury Shales.
1. Purple or Purley Shales.

The recent discovery of *Olenellus* in the Lower Purley Shales by the Geological Survey places the line of division between Lower and Middle Cambrian above the base of these shales, in which *Lingulella ferruginea* and *Acrothele granulata* have also been found. V. C. ILLING has found the species of *Paradoxides*, *Anopolenus*, *Conocoryphe*, *Liostracus*, *Microdiscus*, and *Agnostus* characteristic of the zones of *Agnostus atavus*, *P. hicksi*, and *P. davidis* in the lower part of the Oldbury Shales; while, in the higher part of the same shales he has been able to recognise the characteristic fossils of the Maentwrog, Ffestiniog, and Dolgelly divisions of the Lingula Flags. The highest shales yield *Dictyonema sociale*, and therefore clearly belong to the Tremadoc.

East of Nuneaton, Cambrian Rocks have not been found at the surface of the ground, but borings near Leicester have brought up cores of shales of Stockingford type yielding Upper Cambrian trilobites and associated with characteristic sills of intrusive rock like those of Nuneaton. It is interesting to find these rocks so near to the axis of Charnwood Forest in an unaltered and uncleaved condition. They not only prove the extension of Cambrian Rocks in this direction, but they also clinch the other arguments which have been put forward for the pre-Cambrian age of the Charnian Rocks. Another boring recently carried out at Calvert in Buckinghamshire, has struck Cambrian Rocks beneath the Lower Lias and a small thickness of Trias. The rocks are shales of Stockingford type which have yielded to ARTHUR MORLEY DAVIES perfectly preserved specimens of *Clonograptus*.

At the Malvern Hills, the Cambrian succession combines the characters shown in Shropshire with those of the Nuneaton area (GROOM, 1901). At several localities in these hills, and to the north, caught in faults and overfolds, there occurs a quartzite, "The Malvern Quartzite", which forms the lowest member of the Cambrian System. It contains fragments derived from both the plutonic and volcanic members of the Pre-Cambrian Rocks. It is succeeded by a mass of green glauconitic sandstone known as the Hollybush Sandstone, probably not less than 270—300 m. (900—1000 ft.) in thickness. The lower part is flaggy and shaly, with calcareous layers and a thin band of limestone; the upper part is massive and contains *Kutorgina phillipsi*, and two or three species of *Hyolithus*. These rocks correspond with the Comley Sandstone of Shropshire and the Upper Quartzites of Nuneaton, and therefore they seem to represent the upper part of the Lower Cambrian System.

This division is followed by a considerable thickness of shales, black in the lower part, the "White-leaved-Oak Shales", and grey in the upper part, the "Bronsil Shales"). The black shales have yielded *Sphaerophthalmus alatus*, *Peltura scarabaeoides*, and *Agnostus trisectus*, while *Polyphyma lapworthi*, and *Protospongia paradoxica*, have been found in the lowermost beds. These shales therefore represent at least the Dolgelly Stage of the Lingula Flags, but they probably range much lower, and the sequence may even include part of the *Paradoxides* beds. GROOM parallels them with the Oldbury Shales of Nuneaton. The shales are not less than 150—180 m. (500 to 600 ft.) thick, and include a dark-grey shelly limestone probably discontinuous.

The grey shales, bluish, grey, or yellow in tint, are characterised by *Dictyonema sociale* in the lower part. In the higher beds *Dictyonema* is again found, but it is associated with *Niobe homfrayi*, *Platypeltis crofti*, and an *Agnostus* allied to *A. dux*. These shales may be correlated with the Merevale Shales of Nuneaton, with the lower part of the Shineton Shales, and the Tremadoc of North Wales.

Instrusive camptonites and diabases are frequently found in association with the Midland Cambrian strata, occurring as dykes or sills (LAPWORTH, WATTS and HARRISON 1898). They are found at Nuneaton both in the shales and the quartzites, forming a valuable source of road-metal. They also occur in Shropshire in the Shineton Shales and in the Longmyndian Rocks, at the Lickey Hills, and at Malvern, and they have even been found in Leicestershire and Buckinghamshire. Similar rocks are met with on in the Cambrian of the Highlands of Scotland.

D. The North of England and Isle of Man.

In the Lake District of Cumberland and Westmorland, fossil evidence proves that the upper parts of the "Skiddaw Slates" are of Arenig age. It is therefore highly probable that the bulk of these slates must belong to the Cambrian System. Slabs containing a *Bryograptus* allied to, or identical with, *B. callavei* have been found at Barf. In the Isle of Man the older Palæozoic Rocks are made up of the Manx Slates and the Lonan Flags (Geol. Surv., Distr. Memoir). The order of succession of these two divisions is as yet unknown. No undoubted fossils have been found in them, but the slates present considerable resemblances to the Skiddaw Slates. In all probability part of the Manx Slates must also belong to the Cambrian System.

E. Scotland.

Between the area occupied by the Lewisian Gneisses in the North West Highlands of Scotland and the huge tract of the "Eastern Gneisses", there runs a broad belt of sediments from Loch Eriboll to Loch Carron and the Island of Skye. The western part of this belt consists of Torridonian Rocks, the eastern of rocks, in part at least and possibly altogether, belonging to the Cambrian System. The succession given by the Geological Survey of Scotland (1907) is as follows:

3. **Durness Limestone.** Dolomites and Limestones with certain fossiliferous zones.
2. "**Serpulite Grit**" and "**Fucoid Beds**" yielding the *Olenellus* fauna.
1. **Quartzites** with worm-casts in the upper portion and false-bedded grits below.

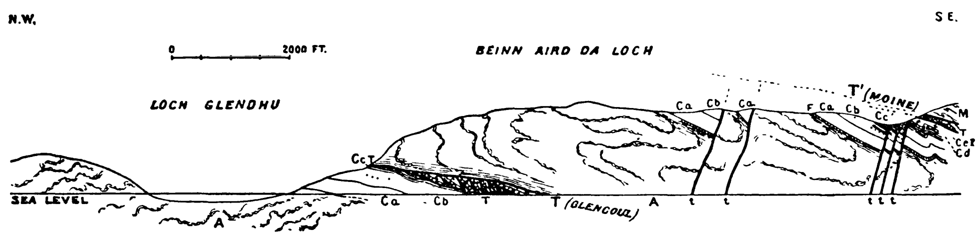

Fig. 16. Section across Loch Glendhu and the North-East Side of Beinn Aird da Loch. Scale about 1 : 40,000.

A = Lewisian Gneiss; Ca = Basal Quartzite (Cambrian); Cb = Pipe-rock; Cc = Fucoid-beds; Cd = Serpulite-grit; Ce I = Ghrudaidh group; M = Eastern Schists; F = Porphyrite Sill. T = Thrusts. T' = Moine-Thrust; t = Minor thrusts.

Reproduced from the Memoirs of the Geological Survey of Great Britain. The Geological Structure of the North-Western, Highlands of Scotland. 1907, p. 500, with the permission of the Director and of H. M. Stationery Office.

The total thickness of these Cambrian strata is about 630 m. (2,100 ft.)

The lower Quartzite is based upon a thin brecciated conglomerate; this is followed by false-bedded flaggy grits and quartzites. The upper Quartzites are fine-grained and perforated by vertical worm-casts and burrows which become more numerous towards the top ("Pipe Rock"). It has been found possible to subdivide this division into five sub-zones each distinguished by its own peculiar type of "pipes".

The next division consists of two zones. The lower is made up of dolomitic shales and mudstones, traversed by numerous worm-casts, usually flattened, and resembling fucoidal impressions. The fossils found in this zone include (Peach 1894) *Hyolithus*, *Coleolides*, *Salterella*, *Paterina* (*Kutorgina*) *labradorica*, *Olenellus lapworthi*, *O. reticulatus*, *O. gigas*, and *Olenelloides armatus*. These fossils, which exhibit a close parallelism with Eastern American forms, are sufficient to establish correlation with the beds of the *Olenellus* Stage found elsewhere. The upper zone consists of a massive band of quartzite and grit, passing upwards into carious dolomitic grit, crowded in patches with *Salterella* ("Serpulite Grit"), and yielding *Olenellus Lapworthi*, *Orthoceras*, and lingulids.

CAMBRIAN SYSTEM.

	Subdivisions.	WALES.		ENGLAND.			SCOTLAND.
		South Wales.	North Wales.	Shropshire.	Nuneaton.	Malvern.	N. Scotland.
Upper.	Tremadoc or Transition Series.	Peltura punctata Beds.	f. Angelina Beds: over 37 m. (120 ft.) e. Shumardia Beds: over 30 m. (100 ft.) d. Asaphellus Flags: over 60 m. (200 ft.) c. Moel-y-Gest Beds; 73m. (240ft.) b. Dictyonema Band: 4,5–6 m. (15—20 ft.) a. Niobe Beds: 58 m. (190 ft.)	c. Upper Shineton Shales. b. Dictyonema Band. c. Lower Shineton Shales.	Merevale Shales.	Bronsil Shales; about 300m. (1000 ft.)	DURNESS LIMESTONE; 460 m. (1500 ft.) g. Durine Stage.
Upper.	Lingula Flags or Olenus Series.	Lingula Flags.	c. Dolgelly Stage; 75 to 180 m. (250—600 ft.) 4. *Peltura scarabæoides.* 3. *Agnostus trisectus.* 2. *Orthis lenticularis;* 1,2 to 1,5 m. (4—5 ft.) 1. *Parabolina spinulosa;* 61 m. (200 ft.) b. Ffestiniog Stage; 610 m. (2000 ft.) c. Maentwrog Stage; 730 m. (2400 ft.)	O. lenticularis Shales; 90-150 m? (300—500 ft.)	Oldbury Shales.	White-leaved Oak Shales; 150 m. (500 ft.)	f. Croisaphuill Stage. e. Balnakiel Stage. d. Sangomore Stage. c. Sailmhor Stage.
Middle.	Paradoxides Series.	Menevian Stage; 230 m. (750 ft.) Solva Stage; 600 m. (2000 ft.)	Menevian Beds. Gamlan Shales; 230-365 m. (750—1200 ft.)	d. *P. davidis.* c. *P. rugulosus.* b. *Dorypyge lakei*, &c. 9 m. (30 ft.) Shales; 90 m. (300 ft.) a. *P. groomi;* 6.5 m. 1 m. (20 ft.)	Purley Shales; 600 m. (2000 ft.)	? Hollybush Sandstone.	b. Eilean Dubh Stage. a. Ghrudaidh Stage.
Lower.	Olenellus Series.	Caerfai Stage; over 460 m. (1500 ft.)	d. Barmouth Grits; 180 m. (600 ft.) c. Hafotty Shales; 305m. (1000ft.) b. Rhinog Grits; 700 m. (2300 ft.) a. Llanbedr Slates.	d. Protolenus Beds. 1,5 m. (5 ft.) c. Olenellus Beds; (3 ft.) b. Sandstones; 90-120 m. (300-400 ft.) a. Quartzite; 30 m. (100 ft.)	b. Hyolithus Limestone. a. Quartzite.	b. Hollybush Sandstone? 335 m. (1100 ft.) a. Quartzite 60-90 m. (200-300 ft.)	LOWER CAMBRIAN; 180m. (600 ft.) c. Serpulite Grit. b. Fucoid Beds (*Olenellus*). a. Quartzite.
		Dimetian and Pebidian.	Bangor and Llanberis Rocks.	Uriconian and Longmyndian.	Caldecote Rocks.	Volcanic and Plutonic Rocks.	Torridonian.

W. W. W.

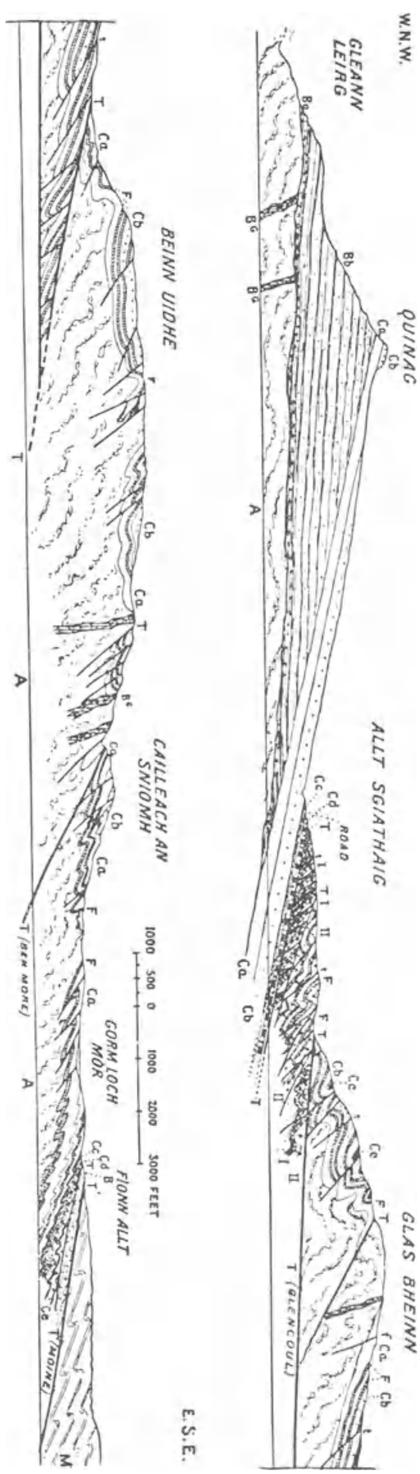

Fig. 17. Section from Quinag by Glas Bheinn Uidhe to Gorm Loch Mór and Fionn Allt. Scale, 1:43,600. A = Lewisian Gneiss; Bg = Dykes in Gneiss; B = Torridon Sandstone; Ba = Diabaig group (Torridonian); Bb = Applecross group; Ca = Basal Quartzite (Cambrian); Cb = Pipe-rock; Cc = Fucoid-beds; Cd = Serpulite grit; Ce = Limestone (Cambrian); Ce I = Limestone (Grudaidh group); Ce II = Limestone (Eilean Dubh group); F = Intrusive Igneous Rocks; M = Eastern Schists; T = Thrusts; T¹ = Moine-thrust; t = Minor thrusts; F = Faults. Reproduced from the Memoirs of the Geological Survey of Great Britain: The Geological Structure of the North-West Highlands of Scotland, 1907, p. 510 with the permission of the Director and of H. M. Stationery Office.

The Limestones have been divided into seven stages. They are mostly dark and light grey dolomites, sometimes granular, sometimes massive, with some bands of true limestones, and occasional bands of chert nodules. Several of the beds are marked by worm-casts, but in certain others, mainly in the higher divisions, well-preserved fossils have been found. These fossils include *Archaeoscyphia*, *Camarella*, *Orthisina festinata*, *Euchasma*, *Maclurea*, *Ophileta*, *Murchisonia* (*Hormotoma* and *Ectomaria*) *Pleurotomaria*, *Piloceras*, *Endoceras*, *Orthoceras*, and *Trocholites*. Trilobites are extremely scarce, only one species, *Bathyurus nero*, has been with certainty determined, but it is possible that *Solenopleura*, *Conocoryphe*, and *Paradoxides* may be present. From the palæontological evidence it would appear that all the calcareous beds, "overlying the *Salterella* dolomites represent the Middle and Upper Cambrian Formations. But owing to the American facies of the fauna, it is impossible to correlate these sub-divisions either with the Welsh or Scandinavian succession".

Along the fault which forms the southern border of the Central Highlands of Scotland from Stonehaven to Loch Lomond, patches of Palæozoic rocks occasionally make their appearance, generally emerging from beneath thrust planes. These include (1) Jaspers and Green Rocks and (2) the Margie Series of shales and limestones. In these rocks fossils, mainly hingeless brachiopods, have been found, which seem to indicate that the rocks are of Cambrian age. Dr. FLETT has found pebbles of Cambrian limestone in one of the Old Red Sandstone conglomerates of Orkney.

Summary and Correlations.

The principal correlations are given in the annexed table (p. 53). There is evidently very considerable variation in faunal as well as lithological facies, the fossils of the Scottish area standing apart from those of Wales and England. The lithological characters of the strata and the overlap which occurs in Anglesey, indicate the presence of a shore-line in that direction, possibly a large island with smaller islands about Llanberis, the Longmynd, and elsewhere in the Midlands. The main land-mass, however, would appear to have lain towards the north-west, with the North-west Highlands of Scotland and Ireland on its margin. Eastward and to the south-east the sea deepened sharply and so far no evidence has been obtained in England of any eastern shore to the trough. The chief period of depression was in Upper Cambrian time and though this was but temporary in North and South Wales, it appears to have lasted till the end of the Period farther east. Volcanic action broke out on the flank of the Harlech anticline in later Cambrian time, the beginning of the long and important volcanic history of the succeeding Period.

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b. Ireland.

By G. A. J. COLE.

No good fossiliferous representatives of the Cambrian system have been found in Ireland; but a series of crushed and folded slates and quartzites in the east of Leinster has generally been referred to the Cambrian. These rocks are exposed from Bray in Co. Wicklow to near Wicklow town, and they also form the promontory of Howth on the north side of Dublin Bay. They reappear at Roney Point in Co. Wexford, and extend south-westward to the south coast of Ireland at Bannow Bay. The radiated or fan-like markings known respectively as *Oldhamia radiata* and *antiqua* characterise the pink and green slates, and are properly regarded as organic in origin, though referred variously to hydrozoa and to worms (J. R. KINAHAN 1858). Undoubted casts of worm-burrows occur at Bray, including *Histioderma*, and SOLLAS (1895 and 1900) and RYAN and HALLISSY (1912) have described other organisms. G. W. LAMPLUGH (Geol. Surv. 1903, 1875, 1869) has suggested, from analogy with the Isle of Man, that the rocks of Bray and Howth are closely linked with those styled Ordovician nearer to the Leinster granite axis, and that the whole may be a descending series. J. F. BLAKE (1888) proposed to place them, however, in analogy with Anglesey, in his Pre-Cambrian Monian system.

The quartzites produce striking features in the northern area near Bray, in contrast with the more easily weathered slates. Knob-like bosses of them form the crests of Howth and Bray Head, and a relic of an uptilted bed, dipping steeply seaward, stands out as the sharp summit of the Great Sugarloaf, 506 m. (1660 ft.) above the sea. The ravines of the Dargle near Enniskerry and of the Dartry in the Devil's Glen near Ashford have been excavated in the slates by streams falling rapidly from the granite chain. The quartzites form striking castellated features along the ridge of the Mountains of Forth, south-west of Wexford town.

These problematic rocks seem to have been laid down in a basin which subsided slowly, allowing of a great accumulation of shore and estuarine deposits.

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3. Ordovician.

a. Great Britain, including the Isle of Man.

I. Sedimentary and Volcanic Rocks.

By W. W. WATTS.

The Ordovician Rocks occupy a large area of ground in three separate districts in Great Britain: 1. The Southern Uplands of Scotland, 2. the Lake District of England, 3. Wales, both North and South, with the Border County of Shropshire. There are also a few smaller regions such as those in Yorkshire and Cornwall. In the large areas the strata generally strike from N. E. to S. W., but this strike swings round to E. and W. in South Wales. No Ordovician rocks have been found east of the longitude of Shropshire either at the surface or in depth.

The rocks present two distinct facies. 1. A deepwater facies represented by shales and mudstones, bearing graptolites: 2. A shallow-water facies of sandstones, grits, and occasional limestones, usually bearing trilobites and brachiopods, but rarely graptolites. Between these two types correlation has been very difficult in the past, but the difficulties are now gradually being overcome, largely as the outcome of the masterly work of CHARLES LAPWORTH on the Moffat and Girvan facies of South Scotland. With either of these types volcanic rocks may be associated, but there are a few areas and some parts of the succession in which important volcanic rocks are not known. Everywhere, however, minute volcanic dust, and the denudation of a freshly formed volcanic material, have provided much of the sediment of which the strata are made.

Miss ELLES has recently shown that there are two distinct trilobite faunas in the Ordovician Rocks. One, characterized by *Asaphus*, *Calymene*, and *Trinucleus* is more generally met with in Britain; the other marked by *Cheirurus*, *Lichas*, and *Encrinurus*, becomes established early in Scotland, but dominates the whole British area by Ashgillian time.

The sub-division of the Ordovician Rocks now usually adopted, is as follows, the nomenclature being that advocated by J. E. MARR (1905. 1907):

4. Ashgillian Series (after Ashgill in the Lake District).
3. Caradocian Series (after Caradoc in Shropshire).
2. Llandeilian Series (after Llandeilo in Carmarthenshire).
1. Skiddavian Series (after the Skiddaw Slates in the Lake District).

The Skiddavian Series has been also called the Arenig or Arenigian Series. Some workers prefer to place the top of the Skiddavian and the bottom of the Llandeilian in a Llanvirn Series. And the "Bala Series" includes at least the greater part of the Caradocian Series. The newer terms are, however, rather more satisfactorily defined and the use of them avoids certain difficulties which are the outcome, in part of our imperfect knowledge of the faunas of the rocks when the names were first given, and in part of the rocks themselves in the type localities when attempts were made to make the terms more precise by means of the definition of faunas discovered elsewhere.

The most satisfactory subdivisions of the system as established on graptolite evidence, are the following:

4. **Ashgillian Series.**
   c) Zone of small climacograptids.
   b) Zone of *Dicellograptus anceps*.
   a) Zone of *Dicellograptus complanatus*.
3. **Caradocian Series.**
   c) Zone of *Pleurograptus linearis*.
   b) Zone of *Dicranograptus clingani*.
   a) Zone of *Climacograptus wilsoni*.

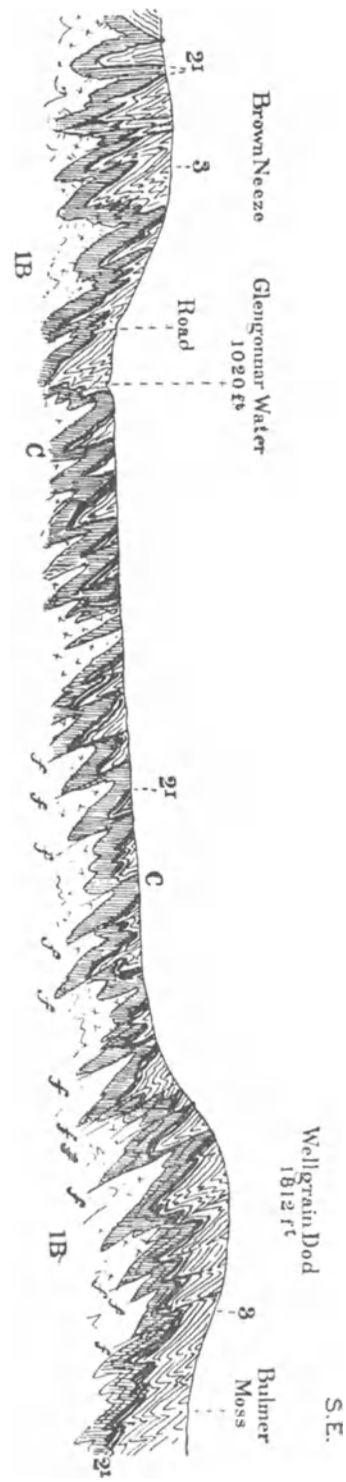

Fig. 18. Section exposed in the Clowgill Burn, Glengonner Water, Lanarkshire. Horizontal Scale, 6 in. = 1 mile, or 1:10,560; Vertical Scale about 1:15,000.
1B = Arenig volcanic rocks; C = Radiolarian chert; 2^1 = Glenkiln Shales; 3 = Caradoc; f = Fault.
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2. **Llandeilian Series.**
   c) Zone of *Climacograptus peltifer.*
   b) Zone of *Nemagraptus gracilis.*
   a) Zone of *Didymograptus murchisoni.*
1. **Skiddavian Series.**
   c) Zone of *Didymograptus bifidus.*
   b) Zone of *Didymograptus hirundo.*
   a) Zone of *Didymograptus extensus.*

A. Scotland.

The discovery of the value of graptolites as zone fossils was made in the Southern Uplands of Scotland, in the Moffat district (Lapworth 1878), where the Middle and Upper Ordovician Rocks are represented by an attenuated succession of shales very highly disturbed. The succession was first worked out in the shale facies, and, when the sequence had been independently made out in the shelly and trilobitic facies of Girvan it was found that the two facies could be closely correlated. The classification of Lapworth (1878, 1882, 1889) was later extended by the Geological Survey of Scotland (1899) and applied to the Southern Uplands as a whole. They found it convenient to treat the area under the following heads:

1. The Northern Belt, which extends S.W. from the Lammermuir Hills to Port Patrick.
2. The Central Belt, from St. Abbs Head, through Moffat, to the Mull of Galloway.
3. The Girvan Area, in Ayrshire and on its coast.

The Skiddavian Series. The succession in the Northern Belt and the Girvan area, the base of which is not seen, begins with a volcanic series of lavas and tuffs the "Ballantrae Rocks", from 150-460 m (500 to 1500 ft.) thick. It is not impossible that part of this volcanic series may be older than Ordovician. This is followed by mudstones with *Tetragraptus*, about 1.2 m. (4 ft.) thick, and that by radiolarian cherts 20 m. (70 ft.) in thickness. Similar cherts are associated with mudstones and thin volcanic tuffs in the Central Belt. The lavas are diabases and spilites frequently exhibiting the well-known "pillow structure", the spaces between the spheroids being filled up with fine-grained shale and limestone. Sometimes chert fragments occur in the tuffs as though the cherts had rapidly consolidated on the sea-floor. The fossils include *Didymograptus extensus*, *Phyllograptus typus*, *Dichograptus*, and *Trigonograptus*, a large series of hingeless brachiopods, and *Caryocaris wrighti*.

The Llandeilian Series is represented by the Glenkiln Shale Series in the Central Belt, and by the Barr Series in Girvan. In the Central Belt the following divisions are present:

4. Thin black shales: *Dicranograptus zic-zac*, *Climacograptus peltifer;* 0.6 m. (2 ft.).
3. Orange-coloured mudstones, radiolarian cherts, and fine volcanic rocks; 1.2 m. (4 ft.).
2. Black shales with cherty ribs: *Nemagraptus gracilis*, *Didymograptus superstes;* 2.4 to 3.7 m. (8 to 12 ft.).
1. Radiolarian cherts, mudstones, and volcanic tuffs.

Fig. 19. Generalized Section across the "Score" at Hartfell Spa.

1 & 2c = Arenig and Glenkiln cherts and mudstones; 2I = Glenkiln Black Shales; 2c = Glenkiln cherts and mudstones; 3II = Lower Hartfell Shales; 3II' = Barren Mudstones; 4III = Lower Birkhill Shales; 4 = Llandovery and Tarannon greywackes and shales; Ts = Volcanic agglomerate; f = Faults.

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Horizontal Scale roughly 1:4800 or about 13 inches to the mile. Vertical Scale about 1:3350 or nearly half as large again.

In the Northern Belt some of the shales pass into about 300 m. (1000 ft.) of grits and greywackes. In the Girvan area, the *Nemagraptus* beds are sometimes replaced by the Stinchar Limestone Group, 20 m. (60 ft.) thick, and the Benan Conglomerate 150 m. (500 ft.) thick comes in at the top of the series. *Didymograptus murchisoni* has not yet been found in Scotland but in all probability the lower radiolarian cherts &c. (1) belong to that zone. There is a rich graptolite fauna in the black shales (2) in addition to the zone fossil, *Nemagraptus gracilis*, such as *Thamnograptus*, *Dicellograptus*, *Leptograptus*, *Diplograptus*, and *Climacograptus*. Hingeless brachiopods are common, with *Hyalostelia*. In the Girvan area graptolites are less common, but a *Didymograptus superstes* and *Nemagraptus* have been found. Corals, hinged brachiopods, gastropods, and fourteen genera of trilobites have also been found at this horizon.

If the zone of *Dicellograptus complanatus* and the "Barren Mudstones" of the Upper Hartfell be relegated to the Ashgillian, only the lower 12 m. (40 ft.) of the black, flaggy, graptolitic, Hartfell Shales is the equivalent of the Caradocian Series in the Central Belt. In this there are three zones:

3. Zone of *Pleurograptus linearis.*
2. Zone of *Dicranograptus clingani.*
1. Zone of *Climacograptus wilsoni.*

In the Northern Belt there are greywackes, calcareous conglomerates, and shales with Lower Hartfell graptolites, with local unconformities and volcanic rocks, the total thickness being over 300 m. (1000 ft.). In this area occur the lead-ores of the Leadhills, which are confined to the Caradocian and Ashgillian Rocks. In the Girvan area the Balclatchie mudstones, grits, and conglomerates, 30 m. (100 ft.) thick, containing abundant trilobites and brachiopods, and *Glossograptus hincksi*, are followed by the Ardwell Group of flagstones and shales about 400 m. (1200 ft.) thick, yielding *Dicranograptus ramosus*. To these succeed the Whitehouse Group, with *Pleurograptus linearis* and trilobites, about 100 m. (300 ft.) thick, the Barren Flagstones, 240 m. (800 ft.) thick, with *Orthograptus truncatus*, and the lower part of the Drummuck sandstones and mudstones.

Marr (1904) has suggested that the "Starfish Bed" in the Drummuck green mudstones may be the equivalent of the *Staurocephalus* Limestone as it contains the zone fossil *Staurocephalus globiceps*. The succeeding mudstones are thus correlated with the Ashgill Shales. In the Moffat region, the top of the Hartfell sequence consists of barren mudstones with a black bed at the base and another at the summit. The former yields *Dicellograptus complanatus*, and the latter *D. anceps*. In the Northern Belt, there are micaceous shales, conglomerates and limestones, with trilobites, brachiopods etc., 240 m. (800 ft.) thick.

In the Southern Uplands the replacement of fine sediment by coarse grits, flags, and conglomerates, together with the greatly increased thickness of the divisions when traced in that direction, clearly indicate that the land of the period was situated to the north and west. The extreme thinness of the shales, combined with the presence of radiolarian cherts associated with the very finest sediment, all show that the sea of the period must have sloped very steeply downwards towards great depths along narrow and restricted belts.

B. The English Lake District.

In this area the Ordovician rocks display three lithological divisions:

3. Coniston Limestone Series.
2. Borrowdale Volcanic Series.
1. Skiddaw Slates (in part).

In certain parts of the succession the subdivisions are clearer, or have been more fully described, in the inlier of Ordovician rocks which occurs under (Marr, Nicholson 1891) Cross Fell, East of the Lake District proper; and as careful correlations have been made, these two areas will be, as far as possible, considered together.

It has been already pointed out that part of the Skiddaw Slates includes the equivalent of the Tremadoc Rocks. Hence the Skiddavian Series comprises only the upper division of the Skiddaw Slates. The subdivisions given by (Marr 1894, Elles 1898, 1904) Miss Elles are as follows:

d) Ellergill Beds (probably on the horizon of *D. bifidus*).
c) Upper Tetragraptus Beds.
b) Dichograptus Beds.
a) Lower Tetragraptus Beds.

The fauna includes many species of *Dichograptus*, *Didymograptus* (including *D. extensus*), *Phyllograptus*, and *Tetragraptus* in the lower part of the Skiddavian sequence; and *Diplograptus*, *Climacograptus*, and *Glossograptus* in the upper part. *Didymograptus bifidus* has been recorded from both parts. The Manx Slates of the Isle of Man are probably in part of Skiddavian age.

The Llandeilian Series in the Cross Fell inlier begins with the "Millburn Beds" from which *Didymograptus murchisoni* and *Glyptograptus dentatus* are recorded. The Millburn Beds are succeeded by volcanic rocks which are correlated with the Borrowdale Volcanic Series of the Lake District. These volcanic rocks were formerly known as the "Green Slates and Porphyries". In this series it has not been found possible to establish divisions founded on organisms, but the following lithological groups have been distinguished (HARKER [1902] and MARR [1900]):

e) Shap Rhyolite and Yewdale Breccia Group.
d) Shap Andesite Group.
c) Scawfell Tuff and Breccia Band, with Kentmere-Coniston Slate-band.
b) Eycott and Ullswater Basalt Group.
a) Falcon Crag Andesite Group.

The Falcon Crag andesites bear hypersthene or augite: the Eycott Group contains no olivine but hypersthene and magnetite: the Scawfell Group has both basic and acid fragments and the rocks carry garnets; the Shap Andesites bear augite but no hypersthene: the highest beds are rhyolites and pass up into the volcanic rocks associated with the Coniston Limestone. Cutting the bedded volcanic rocks numerous intrusive rocks occur which are described on pp. 74—75.

The Coniston Limestone Series or Caradocian, has been divided by MARR (1892) into the following divisions:

b) Sleddale Stage.
    5. Applethwaite Beds; 30 m. (100 ft.).
    4. Conglomerate; 3 m. (10 ft.).
    3. Yarlside Rhyolite.
    2. Stile End Beds; 15 m. (50 ft.).
a) Roman Fell Stage.
    1. Corona Beds; 30 m. (100 ft.).

The Corona Beds have only yielded indentifiable fossils in the Cross Fell inlier, the characteristic form being *Trematis corona*. Other fossils include *Homalonotus rudis*, *Strophomena grandis*, and *Bellerophon* (*Protowarthia*) *bilobatus*. The Stile End Beds consist of calcareous ashes with abundant, but badly preserved, fossils. The Applethwaite Series is made up of calcareous, very fossiliferous, shales with limestone bands. A white horny limestone with Orthocerata frequently occurs at the summit.

The fossils of the Sleddale Stage include *Beyrichia* (*Tetradella*) *complicata*, *Cheirurus bimucronatus*, *Harpes doranni*, *Illaenus bowmanni*, *Lichas laxatus*, *Remopleurides colbyi*, and many species of *Orthis*, and *Strophomena*. In the north of the Lake District, on Caldbeck Fell, a group of shales, the "Drygill Shales", appears to represent the whole of the Caradocian Series.

Above the Coniston Limestone Series, there comes a thin limestone specially characterised by the presence of *Staurocephalus globiceps*, with other trilobites and cystideans. This is taken by MARR (1905, 1907) as the base of his Ashgillian

Series. It is followed by the Ashgill Shales, with trilobites and gastropods, and these by the Phyllopora Beds. Among the chief fossils confined to the Ashgillian Series, are the following: *Encrinurus sexcostatus*, *Cheirurus octolobatus*, *Cyphoniscus socialis*, *Remopleurides longicostatus*, and *Ampyx tumidus*. *Acaste brongniarti*, and *Phillipsinella parabola*, are common in the Series, while *Chasmops* and *Phacops* proper are not present.

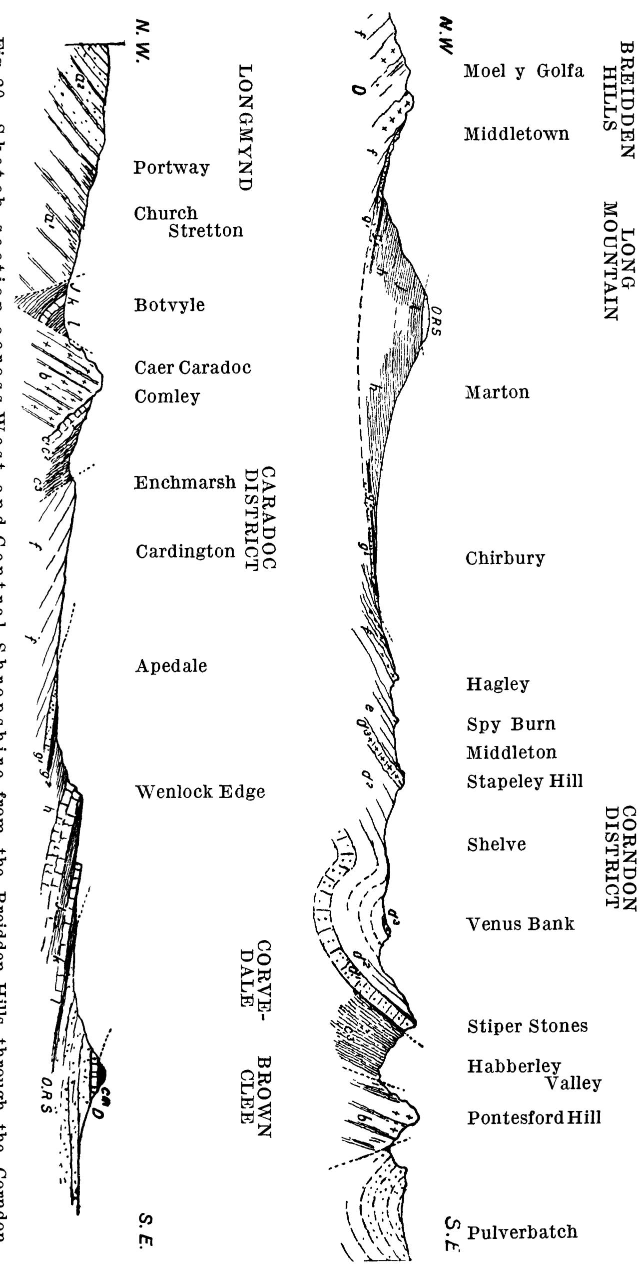

Fig. 20. Sketch-section across West and Central Shropshire from the Breidden Hills through the Corndon District, the Longmynd and the Caradoc District to the Brown Clee Hill (C. Lapworth and W. W. Watts). Total distance about 43.5 kilometres or 27 miles. Scala about 1:140,000.

D =	Dolerite		
cm =	Coal Measures,		Carboniferous
O.R.S. =	Old Red Sandstone		Devonian
l =	Upper Ludlow Rocks,	Downtonian	Gothlandian or Silurian
k =	Aymestry Limestone	Salopian	
j =	Lower Ludlow Rocks		
i =	Wenlock Limestone		
h =	Wenlock Shale		
g^2 =	Purple Shale	Valentian	
g^1 =	Upper Llandovery Sandstone, Conglomerate and Limestone		
f =	Chirbury Series		Ordovician
e =	Middleton Series		Ordovician (continued)
d^3 =	Stapeley Ashes		
d^2 =	Hope Shales, Mytton Flags		
d^1 =	Stiper Quartzite		
c^3 =	Shineton Shales		Cambrian
c^2 =	Comley Sandstone		
c^1 =	Quartzite		
b =	Uriconian Volcanic Series		Pre-Cambrian
a^2 =	Western Longmynd or Red Sandstone Series		
a^1 =	Eastern Longmynd or Grey Shale Series		

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In the Cross Fell inlier (MARR and NICHOLSON 1891) the Sleddale Stage is only represented by a shale series (the "Dufton Shales") which rests on fossiliferous Corona Beds. The shales appear to represent the whole of the Stage. They pass up into by the Keisley Limestone, the equivalent of the Staurocephalus Limestone, which is followed by Ashgill Shales. In the Cautley district MARR has recently described volcanic rocks in the Ashgillian, occurring above beds with *Phacops robertsi* which in the absence of a constant limestone band he takes for the base of the Series. In these and in the *Staurocephalus* Beds which follow *Dicellograptus anceps* occurs. Inliers of Ordovician rocks crop out from beneath the Carboniferous of the Pennine Chain in the neighbourhood of Settle and Ingleton, and the "pencil slates" of Cronkley Scar in Teesdale are probably also of Ordovician age.

From this account it will be gathered that the chief vulcanicity in the North of England dates to the Llandeilian Epoch, probably beginning not far from the time of deposition of the zone of *Didymograptus murchisoni*. There was, however, some volcanic activity both before and after this time as beds of lava and ash have been described in the Upper Skiddaw Slates, in the Coniston Limestone Series, and in the Ashgillian.

C. Shropshire and the Borderland of Wales.

In this region there are four distinct Ordovician areas, one on the east side of the Longmynd, the Caradoc area, one on the west, the Shelve area, one at the Breidden Hills, and one about Welshpool. Three of these areas display only the two higher Series, but the Shelve area gives a full succession from the Skiddavian to the Caradocian, and probably the Ashgillian. The succession of the subdivisions in the Shelve area, as given by LAPWORTH (1894, 1910), is the following, but he has not correlated any part of the succession with the Ashgillian Series:

4. **Ashgillian Series.** (Upper Chirbury Series).
   - ? Whittery Shales.
3. **Caradocian Series.** (Lower Chirbury Series).
   - e) Whittery Ashes.
   - d) Hagley Shales.
   - c) Hagley Ashes.
   - b) Aldress Shales.
   - a) Spy Wood Grit.
2. **Llandeilian Series.** (Middleton Series).
   - d) Black Flags with *Nemagraptus gracilis.*
   - c) Meadowtown Limestone.
   - b) Betton Shales, with *Didymograptus murchisoni.*
   - a) Weston Flags and Shales.
1. **Skiddavian Series.** (Shelve Series).
   - e) Stapeley Ashes.
   - d) Hope Shales.
   - c) Shelve Church Beds, with *Dichograptidae.*
   - b) Mytton Flags.
   - a) Stiper Stones Quartzite.

The basal Quartzite appears to succeed the Tremadoc Shales conformably. It is at times conglomeratic, but for the most part is compact, with occasional shale bands. Only obscure traces referred to *Lingula* have been found in it. Following this is a thick series of shales and flags, made of ashy material, yielding few fossils among which *Ogygia selwyni* and *Obolella* (*Monobolina*) *plumbea* are conspicuous. LAPWORTH has found *Didymograptus extensus* and *D. hirundo* in these beds. The rocks have long been famous for the supplies of lead, zinc, and barytes that they yield, some mines in the district having been worked for lead by the Romans. The highest beds of this Stage at Shelve Church are pale flags yielding abundant examples of *Dendrograptus diffusus*, *D. flexuosus*, and other *Cladophora*, with *Euomphalus corndensis*. The Hope Shales contain few fossils, chiefly graptolites, among which *Didymograptus bifidus* is important. In the higher beds there are a few intercalations of ash. But a great volcanic outburst put an end to the shale period, giving rise to thick beds of andesitic ash, accompanied by the outpouring of lava of intermediate composition.

The Llandeilian division begins with shales and grits in which *Ogygia corndensis* occurs. The shales which follow have yielded *Didymograptus murchisoni* abundantly, accompanied by *Orthis (Dalmanella) testudinaria*. They are followed by calcareous flags and limestone which, at Middleton and Meadowtown, are rich in fossils, especially *Ogygia buchi*, *Asaphus tyrannus*, and *Trinucleus lloydi*. The latest member of the Llandeilian is the series of black flags in which, on certain horizons, *Nemagraptus gracilis* and *Leptograptus flaccidus* occur abundantly. In the Llandeilian Epoch there was little vulcanicity in this area, but there are thin beds of ash among the sediments.

The Caradocian Series begins with a bed of calcareous grit containing graptolites, trilobites, and brachiopods, together with abundant examples of *Beyrichia (Tetradella) complicata*. It is followed by a barren group of shales and mudstones containing a few diplograptidae, and in one thin band very rich in *Dictyonema*. The succession is closed by two andesitic ashes (sometimes associated with lavas), and two shale series with only rare and unimportant fossils. It is not certain where the base of the Ashgillian Series should be drawn in this region, but if the correlations to be given in the Caradoc and Welshpool areas are correct, it should come either at the base or at the top of the Whittery Ash. The Ordovician rocks are unconformably covered by the lowest beds of the Gothlandian, so that the top of the sequence is not known.

While the Shelve succession is complete, so far as it goes, the lower horizons are not known on the eastern side of the Longmynd. In the Caradoc area, the base of the Caradocian Series rests unconformably on Cambrian or older rocks. The divisions of the rocks that are present, however, compare so closely with those just described, that there seems no doubt as to this remarkable overlap. A comparative table is annexed:

Shelve District.		**Caradoc District.**
	Ashgillian Series.	
Whittery Shales.		Trinucleus Shales.
	Caradocian Series.	
Whittery Ash.		Acton Scott Beds.
Hagley Shales		Cheney Longville Flags.
Hagley Ash.		Soudley Sandstone.
Aldress Shales.		Harnage Shales.
Spy Wood Grit.		Hoar Edge Grit.

In this district the rocks are rich in brachiopods and trilobites. Graptolites are scarce except in the Harnage Shales where they afford a close comparison with those of the Aldress Shales. Bastard limestones occur in the Hoar Edge division, and at the base of the Cheney Longville Flags there is another limestone called from the abundance of *Orthis alternata* in it, the "*Alternata* Limestone". The Soudley Sandstone is much used for building and was clearly the division that MURCHISON had in mind when he named the whole group the Caradoc Sandstones. The Acton Scott beds are calcareous and yield many species of corals. The Trinucleus Shales contain *Orthograptus truncatus* and evidently compare with those to be presently mentioned which have been placed by WADE in the Ashgillian Series.

Part of the Shelve sequence reappears on the west of the Long Mountain syncline in the Breidden Hills. Here a series of barren shales comparable with the Aldress Shales underlies an ash which may be correlated with the Hagley Ash. Fossils occur in the ash and the associated beds, including *Climacograptus scharenbergi*, *Cryptograptus tricornis*, and *Beyrichia (Tetradella) complicata*, which establish the position in the Caradocian Series. According to WADE (1911), the Ashgill Shales make their appearance near Buttington in the south of the Breidden area.

In the Welshpool area WADE (1911) has made out the following divisions:

3. **Ashgillian Series.**
   Gwern-y-Brain Stage.
   2. Black Shales.
   1. Limestone.
2. **Caradocian Series.**
   b) Gaer Fawr Stage.
   2. Limestones and ashy grits.
   1. Grits and flags.
   a) Pwll-y-Glo Stage.
1. **Llandeilian Series.** (?)
   Shales of Trilobite Dingle.

The lowest division consists of purple shales full of *Trinucleus concentricus*, with *Asaphus powysi*, associated with *Climacograptus scharenbergi*, *Amplexograptus perexcavatus*, and *Mesograptus foliaceus*. This stage seems to find its nearest parallel with the *Nemagraptus* flags in the Shelve District.

Shales and mudstones follow containing some graptolites, *Asaphus powysi*, varieties of *Trinucleus concentricus*, and *T. fimbriatus*, with Orthides and lamellibranchs. The Gaer Fawr Stage presents considerable resemblance to the Caradoc Rocks of the type area. They are over 300 m. (1000 ft.) thick and have yielded a rich harvest of fossils also closely related to those found in corresponding rocks in the Caradoc area. Among the more important are the following: *Acaste alifrons*, *A. apiculatus*, *Trinucleus elongatus*, *Bellerophon (Protowarthia) bilobatus*, lamellibranchs, and species of *Orthis*, *Plectambonites*, *Rafinesquina*, *Strophomena*, and *Triplecia*.

WADE refers the highest Ordovician Rocks in the area to the Ashgillian Series and correlates them with the "Trinucleus Shales" of the Caradoc district. There is a thin and crystalline, but unfossiliferous, limestone at the base, followed by about 15 m. (50 ft.) of shales. The limestone may be compared with the Staurocephalus Limestone, and the shales with the Ashgill Shales. Among the fossils found in the shales are the following: *Mesograptus modestus* cf. var. *parvulus*, *Orthograptus truncatus* cf. var. *socialis*, many Entomostraca, *Orthis hirnantensis*, *O. sagittifera*, *Siphonotreta micula*, and *Bollia lata*. As has been pointed out, if these rocks are correctly referred to the Ashgillian Series, they carry with them the "Trinucleus Shales" of the Caradoc district.

No Ordovician rocks have hitherto been found in association with the Cambrian or pre-Cambrian patches of the Midlands east of Shropshire. The pebbles in the Bunter Conglomerate, however, are sometimes fossiliferous and among the fossils are brachiopods and trilobites characteristic of the Grès Armoricain and the Grès de May, and contained in quartzites indistinguishable from those in France on the horizons mentioned. While it is not impossible that these pebbles may have drifted from the south, it is at least possible that they may have been derived from concealed Ordovician rocks in the Midlands themselves.

D. North Wales.

The Ordovician rocks of North Wales are characterised by the presence of vast quantities of volcanic and intrusive material which occur in thick sheets that, by reason of their resistance to denudation, give rise to an impressive mountain group, many members of which exceed 1000 metres (3,300 ft.) in height. The principal mountain lines are 1, the range running from Penmaenmawr to Yr Eifl in the Lleyn Peninsula, 2, the Carnedds, Glyders, Snowdon, and Moel Hebog to Llwyd Mawr, 3, the group of the Manods and Moelwyns, 4, the chain of the Arenigs, Arans, and Cader Idris, and 5, the Berwyn Hills.

In many cases the Ordovician rocks are separated from the underlying Cambrian by thrust planes, but where a natural junction exists there is generally a marked unconformity, concealing the highest part of the Cambrian sequence. In no single section are all the members of the sequence typically represented, so it is necessary to take several localities in order to get a view of all the rocks.

W. G. Fearnsides (1905) has worked out the succession at Arenig in considerable detail, and this may be taken as typical of the Skiddavian Series. It is as follows:

2. Llandeilian Series.
- f) Rhyolitic ashes.
- e) Massive ashes.
- d) Acid andesitic ashes.
- c) Daer Fawr Shales; (equivalent to the zone of *Didymograptus murchisoni*).
- b) Platy ashes.
- a) Great agglomerate.

1. Skiddavian Series.
- f) Shales; zone of *Didymograptus bifidus*.
- e) Filltirgerrig or hirundo beds. zone of *D. hirundo*.
- d) Erwent or Ogygia Limestone.
- c) Henllan or Calymene Ashes.
- b) Llyfnant or extensus flags. zone of *D. extensus*.
- a) Basal Grit.

Unconformity.

This succession brings out a very remarkable fact. The rocks which have come to be called Arenig, forming the lower part of the Ordovician System, are not those to which Sedgwick originally applied that term. He used it to signify the main volcanic group of the mountain, and this is now shown to occur in what has come to be called Llandeilian. It is for this reason mainly that the term Skiddavian is preferred to the older word.

The basal grit is in places conglomeratic, and in places a quartzite. It is very variable in thickness and does not seem to occupy invariably the same position in the sequence. Sometimes it is torn into phacoids by earth-movement as seen to the north near Criccieth. The extensus flags yield *Loganograptus logani* and a *Tetragraptus* as well as the zone fossil. They are followed by beds containing ashy matter which increases in quantity when traced southwards. The *Calymene* of the next division is related to or identical with *C. parvifrons*, and it is associated with a few large gastropods. The most abundant trilobite in the Ogygia Limestone is *O. selwyni*, often of large size; *Orthis carausii (O. proava)* is characteristic of the lower, and *Obolella (Monobolina) plumbea* of the higher part of this stage. The hirundo beds are slightly ashy and contain *Didymograptus patulus*, *Tetragraptus serra*, with *Azygograptus suecicus* and *Aeglina*. This fauna dies out with the change in lithology and is replaced by one in which *Didymograptus bifidus*, *Cryptograptus tricornis*, and an *Ogygia*, like *O. peltata*, are important: in places the rocks contain pyroclastic felspars.

The early volcanic outbursts of the Llandeilian Epoch gave rise to platy ashes of intermediate composition derived from a hypersthene andesite magma. In these occurs a coarse agglomerate with fragments of large size. The mudstones that follow are very inconstant, but yield fossils such as *Mesograptus foliaceus*, *Diplograptus angustifolius*, and *Dicellograptus moffatensis*, which suggest the higher part of the zone of *Didymograptus murchisoni*, but the zone fossil has not hitherto been found. The succeeding ashy beds determine the higher summits and precipices of the mountain: some thin lavas and agglomerates occur in them. The Massive Ashes are intermediate in composition and contain botryoidal pyrolusite which is mined. The volcanic episode closes with a series of rhyolitic ashes containing about 73 per cent of silica.

The volcanic rocks terminate abruptly against a thin, richly fossiliferous, brachiopod, monticuliporoid, and cystoid, limestone, called the Derfel Limestone. The fossils include *Trinucleus concentricus*, *Lichas laxatus*, *Orthis actoniae*, *O. (Dalmanella) testudinaria*, and *Plectambonites sericea*. The fauna is similar in aspect to that of the middle part of the Caradoc rocks in Shropshire. The junction with the beds below seems to be a natural one without fault, but it has not yet been found possible to assign the limestone to its exact position in the Ordovician sequence. The section is closed by a vast thickness of black shales or slates in which no fossils have been found in situ, though a species of *Dicranograptus* has been collected from drift boulders of a precisely similar rock in the black shale area.

The intrusive rocks of this area, as of the Shropshire district and so many other localities in North Wales, comprise hypersthene andesites and andesitic dolerites. Where it is possible to ascertain the age of these intrusions they seem to be not later than the Upper Gothlandian.

It is unfortunate that the above description cannot be completed by a satisfactory account of the rocks in the Bala district; but the strata here are very highly disturbed, and little recent work has been published upon them. According to RUDDY (1897), the section begins with ashes and fossiliferous shales, followed by the "Bala Limestone" containing *Treplecia spiriferoides*, *Orthis (Herbertella) vespertilio*, *O. (Platystrophia) biforata*, and *O. actoniae*, with *Trinucleus concentricus*, and *Tentaculites anglicus*. These strata are followed by a considerable thickness of barren shales capped by the "Hirnant Beds", including a limestone, which yield *Orthis hirnantensis*, *O. sagittifera*, *Lingula ovata*, and *Homalonotus bisulcatus*. The Geological Survey placed the limestone exposed at Rhiwlas, north-east of Bala, on the same horizon as the Bala Limestone, but this correlation has not met with assent. MARR (1907) classifies these upper beds with his Ashgillian Series, thus:

Ashgillian Series.
c) Hirnant Limestone.
b) Shales.
a) Rhiwlas Limestone.

The Ordovician rocks dip under the syncline east of Bala Lake and reappear to form the Berwyn Hills, where their structure is that of an irregular and much broken dome. Towards the centre there are limestones and ashes with shales all usually correlated with the Llandeilian Series. The outer rocks have been classed by P. LAKE and T. T. GROOM (1908) as follows:

2. **Ashgillian Series.**
b) Glyn Grit.
a) Dolhir Beds.

1. Caradocian Series.

e) Graptolitic Slates.
(Gap)
d) Bryn Beds.
c) Craig-y-Pandy Ash.
b) Teirw Beds.
a) Cwm Clwyd Ash.

The Caradocian Rocks consist mostly of sandstone and grit. In both the Dolhir and the Glyn beds, there are layers of nodules passing up into beds of limestone, in each case followed by shales. Trilobites, brachiopods, and lamellibranchs are abundant in the Ashgillian Series, but graptolites have not yet been found in it. The lowest beds of the Gothlandian System follow with apparent conformity.

Ordovician Rocks similar to those described in detail extend to the south and west as far as Cader Idris and Towyn, and to the north and west as far as the Moelwyns and Snowdon, whence they pass south-west to the Lleyn peninsula and northeast to Conway. Near Blaenau Festiniog and the Manods and Moelwyns the rocks about the middle of the system are of very great importance for the valuable slates that they yield. In the Moelwyns also there is a Skiddavian volcanic series intercalated among beds with extensiform graptolites.

In the Snowdon area it was supposed by RAMSAY (1866, 1881) and the Geological Survey that the ashes of Arenig (now known to be of Llandeilo age) had thinned out, and that the Lower and Middle Ordovician divisions were reduced to a thin series of slates and grits in which no fossil horizons were known. On the other hand it was thought that the Bala Beds (Caradocian and Ashgillian) had thickened out enormously and included an immense series of tuffs and lavas. The basis for correlation in the Snowdon syncline was found in the fossiliferous calcareous ash at the summit of the Mountain, which was considered from its fossils to be the equivalent of the Bala Limestone.

According to RAMSAY the succession on Snowdon itself and the immediately adjoining mountains is the following:

5. Columnar felspathic lava.
[4. Andesitic lava].
3. Felspathic, sandy, and calcareous ashes, (with fossils like those of the Bala Limestone).
2. Three beds of felspathic porphyry, which southward converge into one.
1. Slates and fossiliferous grits.

The andesitic lava (4) was discovered by Sir A. GEIKIE in 1891. When the slates and fossiliferous grits (1) are traced to the northward, there come in below them three older volcanic groups as indicated in the Geological Survey map and described by HARKER (1889), who also points out that the main Snowdon lavas are thinning out rapidly in the same direction. He traces the geographical distribution of each of the five sets of Snowdonian lavas and shows that the eruptions shifted on the whole southwards, the final activity being probably centred somewhere near to Mynydd Mawr. He names the lavas as follows:

e) The Upper Snowdon lavas, (corresponding with 5. above).
d) The main Snowdon lavas, (corresponding with 2. above).
c) The lavas of Glyder Fach, Capel Curig, and Conway Mountain.
b) The lavas of Pen-yr-Oleu-Wen and Carnedd Llewellyn.
a) The lavas of Dwygyfylchi and Y Drosgl.

The finding of *Didymograptus geminus* or *murchisoni* by FEARNSIDES (1903) as a nearly continuous zone from Criccieth northward to a point close under the western crags Snowdon itself, where it underlies the main Snowdoman volcanic group throws some doubt on the view of RAMSAY as to the age of these main ashes, and makes it practically certain that the divisions a), b), and c) above, must come below the Caradocian Series. This view is confirmed by the work of Miss ELLES (1909) in the Conway district, where she has found the following succession:

3. **Ashgillian Series.**
    b) Deganwy Mudstones.
    a) Bodeidda Mudstones.
2. **Caradocian Series.**
   Upper Cadnant or *Dicranograptus* Shales.
    b) Zone of *D. clingani.*
    a) Zone of *Climacograptus wilsoni.*
1. **Llandeilian Series.**
   Lower Cadnant or *Dicranograptus* Shales.
    b) Zone of *D. brevicaulis* and *Mesograptus multidens.*
    a) Zone of *Climacograptus peltifer.*
   Conway Volcanic series.

The Conway Volcanic series would seem to be the continuation of the Main Snowdon lava series, (d) of the table given above, and if so, it hardly seems that any portion of the Snowdon volcanic rocks will come into the Caradocian Series. It is noteworthy that FEARNSIDES (1910) prefers to treat the Snowdon group by itself, and though he has not published his work in the Criccieth area, he remarks that sooty black shales like those of Conway "have recently been recognised as overlying the highest Snowdonian lavas in the Dwybach river west of Criccieth. They also appear in the quarries of black slate close to Dodwyddellan, and may be represented by the sooty barren shales of the Bala district."

It therefore appears certain that if the structure of the complicated area of North Wales, as expressed many years ago upon the Geological Survey Map, is to be trusted, and if the conclusions founded upon it and given above are sound, considerable revision will have to be made in current ideas as to the position of the Snowdon Volcanic Group.

The Cadnant Shales (ELLES 1909) are only divisible into the Llandeilian and Caradocian Series on palæontological grounds, the lithology not affording any assistance.

The Bodeidda Mudstones contain some fossiliferous bands, in which occur *Trinucleus seticornis*, var. *bucklandi*, var. *portlocki*, and var. *arcuatus*, *Acaste brongniarti* (?), and *Calymene blumenbachi*. The Deganwy or Phacops Mudstones yield *Dalmannites mucronatus*, *Orthograptus truncatus* var. *abbreviatus*, *Orthoceras vagans*, *Chonetes laevigata*, and *Ctenodonta varicosa*.

Lower Skiddavian Rocks (FEARNSIDES 1910) belonging to the graptolitic facies, are found near Aberdaron, in the Lleyn Peninsula, near Carnarvon, and on the Menai Straits. Upper Skiddavian Rocks, with deposits of ironstone and manganese, are also found in the Lleyn, while beds with *Didymograptus murchisoni* are found near Carnarvon and on the Menai Straits. They are replaced by the "*Neseuretus* Beds" of brachiopod type, resting unconformably on the pre-Cambrian Rocks in central Anglesey. At Llangwyllog, in Anglesey, the *D. murchisoni* beds occur, followed by the zone of *Nemagraptus gracilis*, but farther to the north-west, the latter overlaps on to older rocks and passes into conglomerate and pebbly grit. The Snowdon volcanic rocks occur in the Lleyn about Pwllheli, and Caradocian shelly rocks exist in Anglesey.

E. Central Wales and its Borders.

The Ordovician Rocks in this tract serve to link up the facies of South Wales with that of North Wales on the one hand and that of Shropshire on the other. Skiddavian (FEARNSIDES 1910) rocks are met with near Builth and at Llanwrtyd and Llangadock. The age of the lowest rocks is unknown, but they are succeeded by dark graptolitic shales with *Placoparia*. Above these comes an andesitic series which would seem to occur on the same horizon as in Shropshire. The Llandeilian rocks are shallow-water calcareous flags with trilobites, followed by graptolitic shales at Pencraig. Any higher rocks which may be present are concealed by the Gothlandian unconformity.

H. LAPWORTH (1900) records blue-black shales underlying the Valentian rocks of the Rhayader area; and O. T. JONES (1909) has recognised about 1040 m. (3400 ft.) of strata underlying the Gothlandian Rocks as probably belonging to the Ashgillian Series. The lowest flags and thin shales yield *Dicellograptus anceps*, and *Orthograptus truncatus* with other characteristic fossils, but the overlying mudstones, grits, and conglomerates have so far proved unfossiliferous.

F. South Wales.

Ordovician Rocks occur along three main belts in South Wales: 1, north of the anticlinal axis of St. David's from Whitesand Bay and Ramsay Island to Cardigan and beyond; 2, from near St. Bride's Bay to New Quay Road south of that anticline; 3, from Haverfordwest through Carmarthen and Llandeilo to Llandovery. The chief characteristic in most of the districts is the presence of an important series of shales, the *Dicranograptus* Shales, the lower part of which seems to belong to the Llandeilian, and the upper part to the Caradocian, and it is scarcely possible to draw any line between the two series either on palæontological or lithological evidence: consequently the lines drawn below must be only accepted as provisional. On the other hand, the South Wales (HOPKINSON and LAPWORTH 1875; MARR and ROBERTS 1885; REED 1895; CROSFIELD and SKEAT 1896; Geological Survey 1907, 1909) rocks will probably in the end throw much new light on the Ashgillian Series.

4. **Ashgillian Series.**
    - c) Slade Beds.
    - b) Red Hill Beds.
    - a) Shoalshook Limestone.
3. **Caradocian Series.**
    - b) Robeston Wathen Limestone.
    - a) Mydrim Shales; (Upper *Dicranograptus* Shales).
2. **Llandeilian Series.**
    - e) Mydrim Limestone.
    - d) Hendre Shales; (Lower *Dicranograptus* Shales).
    - c) Llandeilo Limestones and Flags.
    - b) *Asaphus* Ash.
    - a) *Didymograptus murchisoni* Beds.
1. **Skiddavian Series.**
    - b) *Didymograptus bifidus* Beds.
    - a) Tetragraptus Beds.
        2. Zone of *D. hirundo*.
        1. Zone of *D. extensus*.

The lowest of the three Skiddavian divisions is conformable with the *Peltura punctata* beds previously described, and contains *Ogygia selwyni*, *Dendrograptus*, *Callograptus*, and *Dictyonema*, in addition to the forms mentioned above. The middle division yields the same genera, with *Aeglina grandis*, *Ogygia peltata*, *Trinucleus gibbsi*, and *Ampyx salteri*. The bifidus zone contains *Barrandea homfrayi*, *Illaenus hughesi*, *Placoparia cambrensis*, with *Nemagraptus*, *Climacograptus*, and *Diplograptus*. Some andesitic volcanic rocks occur, either in the Skiddavian Series or below it, near to Llangynog.

H. H. THOMAS (1911) has brought forward evidence which goes to prove that the great volcanic series which occurs on Skomer Island and the neighbouring mainland, belongs to the zone of *D. extensus.* At its maximum development this series is not less than 900 m. (2900 ft.) thick and consists for the most part of thin subaerial lava flows, with a few intrusive rocks, mostly basic, and a persistent band of sediments towards the middle of the series. The igneous rocks range from soda-rhyolites to olivine dolerites. The soda-rhyolites, soda-trachytes, skomerites, and marloesites, present affinities with the alkaline rocks of Pantelleria. The mugearites, basalts, and dolerites, belong to the sub-alkaline class. The order of extrusion appears to be a succession from acid to basic and back again from basic to acid in rhythmic sequence. The rocks present affinities with those associated with the lowest Ordovician of Southern Scotland, and with those in Cornwall.

It is in association with the zone of *Didymograptus murchisoni* that the volcanic group occurs in the neighbourhood of St. David's and about Fishguard, and a poorer representative of it is found near Carmarthen in the *Asaphus* Ash, and other beds on about the same horizon. The Llandeilo Limestone is a series of calcareous flags rather widely distributed on this horizon. It yields the well-known fossils *Asaphus tyrannus*, *Calymene cambrensis*, *Trinucleus concentricus* var. *favus*, with many species of *Orthis*, *Rafinesquina*, and *Plectambonites*. In the Fishguard region, the Llandeilian succession is the following: ashes and tuffs associated with *D. murchisoni*, slates and flags, felsitic tuffs, beds with *Siphonotreta micula*, and graptolitic shales in ascending order.

The Dicranograptus Shales which in the southern outcrop follow the Llandeilo Limestone, have been separated into the Hendre Shales and the Mydrim Shales, generally separated by the Mydrim Limestone. The Hendre Shales contain *Dicellograptus sextans*, *Climacograptus scharenbergi*, and *Cyrtograptus tricornis.* The Mydrim Limestone yields *Nemagraptus gracilis*, *Didymograptus superstes*, and *Leptograptus validus.* It seems to represent the zone of *N. gracilis.*

The Mydrim Shales contain in their lower part, a mixture of Hartfell and Glenkiln graptolites, but towards their summit yield forms characteristic of the zone of *Dicranograptus clingani.* In the upper part of the Shales *Orthograptus truncatus* and *Climacograptus minimus* have been found. The Robeston Wathen Limestone contains abundance of *Halysites catenularia*, but trilobites are few and fragmentary *Illaenus Bowmanni* has, however, been found, with *Orthis actoniæ.* This limestone has generally been paralleled with the Bala Limestone.

The Shoalshook Limestone is coarser and more arenaceous than that of Robeston Wathen, and yields *Staurocephalus globiceps*, *Calymene blumenbachi*, *Encrinurus sexcostatus*, *Cybele verrucosa*, *Cheirurus bimucronatus*, *Trinucleus seticornis* var. *bucklandi*, *Ampyx tumidus*, *Homalonotus rudis* and *Orthis actoniae.* In fauna and character it therefore approaches the *Staurocephalus* Limestone in the Ashgillian Series of the north of England. The Redhill Stage consists of barren olive-green mudstones with rare fossils occurring in isolated patches. The fossils found include *Trinucleus concentricus*, *Illaenus bowmanni*, *Homalonotus bisulcatus*, *Plectambonites sericea*, and *Orthis (Dalmanella) elegantula.* The Slade Beds, the highest of the sequence, are similar to the last, but are varied by thin limestones. In these beds are found *Illaenus murchisoni*, *Glauconome disticha*, *Orthis (Dalmanella) testudinaria*, *Leptaena rhomboidalis*, and *Phyllopora hisingeri.* The two last Stages correspond to the Ashgill Shales.

ORDOVICIAN SYSTEM.

		SCOTLAND.		ENGLAND.	
	Zones.	Girvan.	Moffat & Central Belt.	Lake District and Cross Fell.	Shropshire.
Ashgillian.	b. *Dicellograptus anceps*. a. *D. complanatus*	UPPER DRUMMUCK BEDS; ? 120 m. (400 ft.) b. Ladyburn Shales. a. "Starfish Band".	UPPER HARTFELL SHALES; 18 m. (60 ft.) b. *Dicellog. anceps.* Barren Mudstones. a. *D. complanatus.*	c. *Phyllopora* Beds. b. Ashgill Shales. a. *Staurocephalus* Limestone.	UPPER CHIRBURY SERIES. Whittery and *Trinucleus* Shales.
Caradocian.	c. *Pleurograptus linearis*. b. *Dicranograptus clingani*. a. *Climacograptus wilsoni*.	e. Lower Drummuck Beds. d. Barren Flagstones; 245 m. (800 ft.) c. Whitehouse Stage; 150 m. (500 ft.) b. Ardwell Stage; 365 m. (1200 ft.) a. Balclatchie Stage; 30 m. (100 ft.)	LOWER HARTFELL SHALES; 12 m. (40 ft.) c. *Pleurog. linearis.* b. *Dicranog. clingani.* a. *Cl. wilsoni.*	CONISTON LIMESTONE SERIES. d. Applethwaite Beds; 30 m. (100 ft.) c. Conglomerate; 3 m. (10 ft.) b. Stile End Beds; 15 m. (50 ft.) a. Roman Fell Stage; 30 m. (100 ft.)	LOWER CHIRBURY SERIES. c. Hagley Beds. b. Aldress Shales. a. Spy Wood Grit.
Llandeilian.	c. *Climacograptus peltifer*. b. *Nemagraptus gracilis*. a. *Didymograptus murchisoni*.	BARR SERIES. d. Benan Conglomerate; 150 m. (500 ft.) c. *Didymog. superstes* Beds; 9 m. (30 ft.) b. *Nemag. gracilis* Beds; 1.8 m. (6 ft.) (and Stinchar Limestone; 18 m.) (60 ft.) a. Sandstones and Radiolarian Cherts.	GLENKILN SERIES. d. *Climacog. peltifer*; 60 cm. (2 ft.) c. Radiolarian Chert &c.; 1.2 m. (4 ft.) b. *Nemag. gracilis*; 2.4-3.6 m. (8—1.2 ft.) a. Radiolarian Cherts and Volcanic Tuffs.	Borrowdale Volcanic Series. Millburn Beds.	MIDDLETON SERIES. c. *Nemag. gracilis* Beds. b. Meadowtown Limestone. a. *D. murchisoni* Beds.
Skiddavian.	c. *Didymograptus bifidus*. b. *Didymograptus hirundo*. a. *Didymograptus extensus*.	c. Radiolarian Cherts and Tuffs; 21 m. (70 ft.) b. Black Shale (*Tetrag. bryonoides*); 1-1.2 m. (3—4 ft.) a. Ballantrae Rocks; 460 m. (1500 ft.) (lavas and tuffs).	Radiolarian Cherts and Volcanic Tuffs; 45-60 m. (150—200 ft.)	d. Ellergill Beds. c. Upper *Tetragraptus* Beds. b. *Dichograptus* Beds. a. Lower *Tetragraptus* Beds.	SHELVE SERIES. d. Stapeley Ashes. c. Hope Shales (*D. bifidus*). b. Mytton Flags (*D. hirundo*) (*D. extensus*). a. Stiper Quartzite.
				Lower Skiddaw Slates.	Shineton Shales.

W. W. W.

ORDOVICIAN SYSTEM.

	Zones.	WALES. Conway.	WALES. The Berwyns and Arenig.	WALES. Welshpool.	WALES. South Wales.	IRELAND. Killary area.
Ashgillian.	b. *Dicellograptus anceps.* a. *D. complanatus.*	b. Deganwy Mudstones; 24 m. (80 ft.) s. Bodeidda Mudstones; 107 m. (350 ft.)	b. Glyn Grit. a. Dolhir Beds.	GWERN-Y-BRAIN SERIES; 15 m. (50 ft.) b. Shales. a. Limestone.	c. Slade Beds. b. Red Hill Beds. a. Shoalshook Limestone.	
Caradocian.	c. *Pleurograptus linearis.* b. *Dicranograptus clingani.* a. *Climacograptus wilsoni.*	Upper Cadnant Shales; about 30 m. (100 ft.) b. *Dicranog. clingani.* a. *Climacog. wilsoni.*	e. Graptolitic Shales. Gap. d. Bryn Beds. c. Craig-y-Pandy Ash. b. Teirw Beds. a. Cwm Clwyd Ash.	c. Gaer Fawr Beds; 300 m. (1000 ft.) b. Pwll-y-Glo Beds; 90 m. (300 ft.) a. Trilobite Dingle Shales; ? 300 m. (1000 ft.)	b. Robeston Wathen Limestone. a. Mydrim Shales.	Mweelrea Grits; 3600 m. + (12 000 ft.)
Llandeilian.	c. *Climacograptus peltifer.* b. *Nemagraptus gracilis.* a. *Didymograptus murchisoni.*	2. Lower Cadant Shales; about 64 m. (210 ft.) b. *Dicranog. brevicaulis.* a. *Climacog. peltifer.* 1. Conway Volcanic Series; over 600 m. (2000 ft.)	d. Rhyolitic Ashes. c. Andesitic and Massive Ashes. b. Daer Fawr Shales. a. Andesites and Ashes; 150 m. (500 ft.)		e. Mydrim Limestone. d. Hendre Shales. c. Llandeilo Limestone. b. Ash. a. *D. murchisoni.*	
Skiddavian.	c. *Didymograptus bifidus* b. *Didymograptus hirundo.* a. *Didymograptus extensus.*		d. *D. bifidus*; 6-9 m. (20—30 ft.) c. *D. hirundo.* b. *D. extensus*; 45-60 m. (150—200 ft.) a. Basal Grit; 30 m. (100 ft.)		c. *D. bifidus.* b. *D. hirundo.* a. *D. extensus.*	Doolough Slates and Leenane Grits. *Didymograptus extensus, Diplograptus dentatus*; 760 m. (2500 ft.) Bencroff Slates. *Tetragraptus, Dichograptus and Didymograptus extensus*; 18 m. (60 ft.)
			Shumardia Shales.		*Peltura punctata* Beds.	Dalradian schists.

W.W.W. G.A.J.C.

G. Cornwall.

The so-called "killas" or clay-slates of south Cornwall have been variously referred to the Devonian System and to the Lower Palaeozoic Rocks (? "Ordovician" of the Geological Survey 1907, 1912; Ussher 1910). In the absence of fossils from all but a part of the rocks there found, it is impossible to be certain as to the age of the group as a whole, and the tectonic structure is so complicated that the succession of the individual members of the series has not yet been made out. Along the southern border of the clay-slates, a great series of thrusts has brought up "augen" of fossiliferous rocks, some of which are Gothlandian and others of Ordovician age. To the latter are referred the "Veryan Series" of limestones and radiolarian cherts, and also the "Gorran Quartzite". From the Quartzite the following fossils have been obtained, among others not admitting of precise identification: *Cheirurus sedgwicki*, *Calymene tristani*, *C. cambrensis*, *Phacops mimus*, *P. incertus* (?), and *Asaphus powysi* (?). These fossils seem to indicate a horizon about the middle of the Ordovician, a determination which finds some confirmation in the occurrence of radiolarian cherts and pillow lavas in the beds below. The beds "evidently correspond either with the Angus [? Angers] Slates or the Grès de May of Brittany and Normandy" (Survey 1907). It is interesting to note that fossiliferous quartzite pebbles derived from the Grès de May and the Grès Armoricain occur in the Budleigh Salterton conglomerate of the Devonshire Trias.

Summary and Correlations.

The Ordovician Rocks were deposited on narrow continental shelves, the flanks of a group of partly or wholly submerged volcanic islands, and on the floor of steep-sided troughs. As is to be expected in a volcanic area changes in depth occurred with remarkable suddenness, and deposition was in certain places and at particular times remarkably slow. A great continental area seems to have occupied the north Atlantic, along the southern shore of which migration between America and Europe could take place. At least one important island was maintained through out part of the period in Anglesey and to the west of it, and probably another where the Longmynd now is. It is not improbable that east of Shropshire much of England was land so that the Ordovician trough was a narrow syncline.

Volcanoes were in action in south-east Carnarvonshire during the early part of the Skiddavian Epoch, but the great outburst, of which evidence remains in almost every area where Ordovician Rocks are exposed, was in the Llandeilian Epoch, and expecially in the early part of it on the horizon of *Didymograptus murchisoni*. During the Caradocian Epoch vulcanicity died down almost everywhere in Wales except in the Berwyns, but it continued on a small scale in Shropshire and the Lake District. In the last area the latest volcanic action was prolonged into the Ashgillian Epoch. The Ordovician Period was brought to an end by far-reaching earth-movement giving rise to extensive land areas.

II. Some Intrusive Rocks, presumably of Ordovician age[1].

By A. Harker.

A. The English Lake District.

Of the numerous igneous intrusions in the English Lake District and the bordering country some are anterior and others posterior to the main crust-movements of the region. This criterion of age does not give decisive results in every case, but it suffices to divide the intrusive rocks into an older and a younger series.

[1] Other intrusive rocks supposed to be of Ordovician age are referred to by W. W. Watts.

The older are doubtless related to the Ordovician Volcanic Series of the district, being of slightly later date. The younger rocks are partly of Old Red Sandstone age, partly Tertiary, and will be considered later.

The Ordovician intrusive rocks show a considerable range of petrographical variety, but the dominant rock-types in all the larger masses are of acid composition. The most important set is in the neighbourhood of Ennerdale and Buttermere (RASTALL 1906), where several irregularly laccolitic intrusions occur near the boundary of the Skiddaw Slates and the Volcanic Series. The largest mass measures $5^1/_2$ by 3 kilom. ($3^1/_2$ by 2 miles), and passes under the Volcanic Series. Here the chief type is an acid biotite-granophyre; but smaller masses of basic augitic rocks, of slightly earlier intrusion, occur on its border and in the neighbourhood. Another acid rock, a microgranite, makes two boss-like intrusions near Threlkeld and the mouth of St. John's Vale. None of the rocks of this series have typical abyssal characters. The acid types are usually granophyres, the basic ones dolerites, while intermediate types have been styled quartz-porphyrites, augite-porphyrites, etc. In some cases, however, e. g. at Blea Crag in Langstrath (WALKER 1904), intermediate varieties have been produced by admixture between a basic rock and an acid magma intruded slightly later.

A special feature of many of the acid and intermediate rocks is the presence of garnet. This mineral is found, e. g., in a group of spherulitic quartz-porphyry dykes on Helvellyn and Armboth Fell and elsewhere, and in dykes and sills of quartz-porphyrite and andesite in various localities. It is possible that the garnet in these rocks is of secondary origin, as it doubtless is in the lavas and volcanic breccias of the district, in which it is of frequent occurrence.

The smaller intrusions, when they have the sill or stratiform habit, tend to show a certain definite distribution in the Ordovician succession, the more basic and heavier rock-types occurring in the lower members and the more acid and lighter at higher horizons. In the Skiddaw Slates a group of very basic intrusions is found to the north of Skiddaw and along a belt extending westwards towards Cockermouth. The rocks are of coarse texture, and consist principally of hornblende ('hornblende-picrites' of Bonney). Numerous irregular sheets of basic dolerites occur in the Skiddaw Slates and near the base of the Volcanic Series, beside some small boss-like masses such as that of Castle Head near Keswick. More acid rocks are found as sheets at higher horizons in the Volcanic Series, and the sills in the Coniston Limestone group are all of quartz-porphyry and allied types.

B. The Isle of Man.

Distinct from the Carboniferous and later igneous rocks, there is in the Isle of Man (LAMPLUGH 1903) a considerable variety of older igneous rocks, the age of which cannot be fixed precisely by direct evidence. They have been affected by the pre-Carboniferous crust-movements of the region, but in different degrees. This fact, together with petrographical considerations, makes it probable that these older igneous rocks do not all belong to one age. The earliest are probably Ordovician, while the later may perhaps be assigned to the Old Red Sandstone, but decisive criteria are not applicable in every case.

There is considerable variety of basic dykes, with some of mean acidity, distributed generally but not uniformly over the Manx Slates tract. They have as a rule a N.E.—S.W. direction, parallel to the main axes of disturbance. They are later than the folding of the slates, but are affected by a second set of crust-movements, and are often much crushed and schistose. The rocks include diorites, hornblende- and mica-lamprophyres, porphyritic dolerites, and augitic lamprophyres, etc.

In addition there are acid intrusions, which are later than the majority of the dykes, and later than the crust-movements already mentioned, but are affected by a third set of movements. These intrusions occur mainly along the central belt of the island. The biotite-granite of Dhoon has a boss-like habit. It is accompanied by a set of N.E.—S.W. dykes of microgranite and quartz-porphyry. The Foxdale granite, which seems to have a laccolitic habit, is less crushed than that of Dhoon, and is probably younger. It is rich in muscovite and microcline, and sometimes contains garnet, being closely similar to the Dublin granites on the prolongation of the same axis. There is an attendant group of dykes of corresponding composition. A small intrusive boss at Oatland, near Santon, is very little affected by crushing, and is probably to be correlated with the 'Newer Granite' plutonic complexes of Scotland. It has a border of dark basic rock, rich in hornblende and partly uralitized augite, and through this there has broken an intrusion of biotite- and hornblende-granite.

C. The Assynt District, Sutherland and Ross.

In the Assynt district of the North-West Highlands of Scotland, situated in the western parts of the counties of Sutherland and Ross, there occurs a series of rocks rich in alkalies and embracing an assemblage of types not found elsewhere in Britain. (Horne and Teall 1902; Teall 1900, 1907; Shand 1906, 1909.) The age of these cannot be determined with precision; but they are younger than the Cambrian dolomites (Durness group) and older than the great system of overthrusts that has affected this region. It is possible that they are contemporaneous with the Ordovician igneous rocks of other parts of Britain; but they are of very different nature, and constitute a small but distinct petrographical province. There is no indication of surface volcanic activity, but only of intrusion: the rocks comprise firstly a plutonic complex and secondly a series of intrusive sills and dykes.

The plutonic complex forms Cnoc na Sroine and other low hills to the north and east of Loch Borolan, on the borders of Sutherland and Ross, and extends under the peat which covers the neighbouring low ground. The boundaries are in many parts concealed, but the probable area is about 7 by 5 kilom. ($4^1/_2$ by 3 miles), excluding two or three smaller detached areas. The intrusion invades dolomitic limestones, which have been metamorphosed near the contact and transformed to forsterite-marble, pencatite, etc. The igneous rocks, in common with the Cambrian strata, have been in part modified by crushing and shearing, and in certain places affected by overthrusting. Owing to this, as well as to imperfect exposure, the relations of the various rock-types which compose the plutonic complex are not completely revealed. In many places there is a gradual transition from one type to another; but in some places the change is a rapid one, and probably indicates that the complex has been built up by several distinct intrusions. The most acid type appears in the central part of the area, which is also the highest ground, and the most basic types on the border, which is lower ground. Shand supposes that the several types constitute the upper and lower layers of a stratified laccolitic mass, the denser and more basic rocks forming the base.

Cnoc na Sroine is composed of a quartz-syenite, which extends to Alltnacealgach on Loch Borolan and for nearly 2 kilom. ($1^1/_4$ mile) to the north-east. It consists of albite and orthoclase, either separate or in perthitic intergrowth, with quartz. This rock passes into a quartzless syenite, often containing some melanite. Then come rocks richer in the dark minerals and containing some nepheline or its alteration-products. One variety is a melanite-syenite: another (ledmorite), exposed in the Ledmore River, is rich in green pyroxene, with less melanite. A good nepheline-syenite (with melanite) occurs to the north of Cnoc na Sroine, and various peculiar types are found as dyke-like masses on the outskirts of the area. The most basic, seen to the south of Ledmore, is a melanite-pyroxenite, composed of augite, melanite, magnetite, etc.

The south-eastern part of the area, beyond Allt a' Mhuilinn, is not geologically continuous with the rest, being overthrust and much crushed. Here occurs the borolanite type, composed of orthoclase and melanite with green mica and alteration-products after nepheline and sodalite. It often contains ovoid white or reddish spots, up to 2 or 3 cm. ($^3/_4$ or 1 inch) in diameter, which TEALL believed to be pseudomorphs after leucite; but SHAND has given reasons for regarding them as merely crushed porphyritic felspars. The borolanites are often severely crushed, and then acquire a granulitic structure, while the melanite is destroyed.

The minor intrusions that may be attached to this series of rocks are very numerous. They are most developed to the north of the plutonic centre, extending beyond Inchnadamph, a distance of about 10 kilom. ($6^1/_4$ miles). They assume mostly the form of intrusive sills or sheets, but dykes are also found. There is a wide range of petrographical types; and it is clear that, although the assemblage has unmistakable affinities with the plutonic complex, some of the types must have been derived by further differentiation. There are hornblendic lamprophyres, which fall under spessartite and vogesite. A mica-porphyrite occurs on the hill Canisp and elsewhere, and hornblende-porphyrites are numerous in the neighbourhood of Inchnadamph. There are rocks consisting almost wholly of alkali-felspars, in particular a porphyritic albite-rock. A more acid type contains quartz in addition and very numerous little needles of ægirine, thus approximating closely to grorudite.

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b. Ireland.

By G. A. J. COLE.

At one time, the crystalline Dalradian rocks of Ireland were regarded, with these of Scotland, as metamorphosed Ordovician strata, a fact that must not be forgotten when memoirs, maps and sections by various authors are examined. Even at the present time, much has to be done to separate adequately the Irish Ordovician zones from the overlying Gothlandian, and, in the south-east, from the slaty series of Howth and Bray.

On both flanks of the Leinster Chain, the foothills are formed largely of shales, slates, and thin beds of a more sandy character, much contorted, but with a general north-east and south-west strike. These are the remains of a great Caledonian anticline, in the midst of which the Leinster granite has arisen. Near the granite the slates have been altered into andalusite-mica-schist. A relic of the crest of the anticlinal dome rests horizontally on the summit of Lugnaquilla Mountain, in the highest part of the granite chain. This series of strata is possibly in part of Cambrian age (Geol. Surv. 1903); but Ordovician fossils occur in the slates near Rathdrum, and at Ballymoney on the Wexford coast. Among the graptolites are *Coenograptus gracilis*, *Dicranograptus ramosus*, and *Diplograptus foliaceus*. *Primitia m'coyi* SALT. occurs near Courtown, as in the Bala beds of Portrane and the Chair of Kildare (see below). Arenig, Llandeilo and Bala beds are all represented on the east side of the Lenster chain (Geol. Surv. 1887, 1869; ELLES 1910). Ordovician shales, with some minettes and volcanic ashes among them, occur as inliers in a

Gothlandian area from Duleek to Balbriggan. Two other detached areas, at Portrane north of Dublin and on hilly ground north of Kildare town, include richly fossiliferous limestones of Upper Ordovician age. At Portrane, andesitic lavas and ashes are succeeded by Middle Bala shales, above which are limestones with fossils like

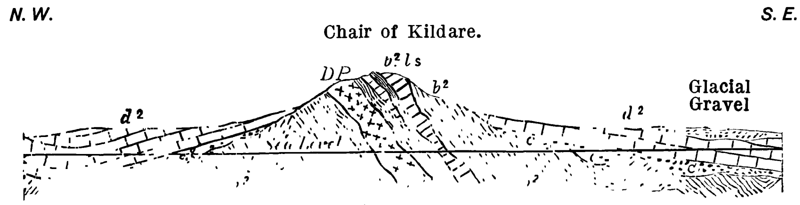

Fig. 21. Section showing relation of the Ordovician outlier of the Chair of Kildare to the rocks of the Central plain. Horizontal scale, one inch to 1 mile = 1:63360; vertical scale, about four inches to 1 mile = 1:15340.

d² = Carboniferous Limestone
c = Old Red Sandstone
b² = Ordovician slates and sandstones
b² ls = Ordovician limestone (Bala Series)
DP = Porphyritic andesite.

Reproduced from the Memoirs of the Geological Survey of Ireland, No. 119, p. 4, fig. 2, 1858; with the permission of the Director and of H. M. Stationery Office.

those of the Keisley Limestone in the English Lake District. Among the trilobites in the limestones are *Stygina latifrons* Portl., *Trinucleus seticornis* His., *Cybele rugosa* Portl., *Remopleurides* sp., *Harpes* sp., etc. Similar rocks occur in the adjacent island of Lambay. In the Kildare ridge, a large number of Middle and Upper Bala fossils have been discovered, including *Primitia m'coyi* Salt., *Illaenus bowmanni* Salt., and *Sphaerexochus mirus* Beyrich. These and other forms occur also at Portrane. The Kildare series also began with a volcanic phase, when andesites and basalts were erupted. Above these rocks are red and grey limestones of Keisley Limestone age. The grits above these may be Gothlandian. (Geol. Surv. 1858 and 1875; Gardiner and Reynolds 1896; Seymour 1907.)

Numerous igneous rocks, both intrusive and contemporaneous, occur along the strike of the Ordovician area of Leinster, notably on the south-east of the granite. Diorites, andesites, trachytes and rhyolites (felsites), and corresponding tuffs, form rougher features in a country mainly composed of shales and slates. South-west of Waterford town, the "felsites" cover a wide area down to the coast. Some of them are clearly intrusive, and have been crushed so as to resemble tuffs. These may be of early Devonian age. (Hatch 1889; Reed 1899, 1900; Kilroe and Mc. Henry 1901; Thomson 1908.)

The strata associated with the felsites along the Waterford coast may possibly include some of Arenig age; but so far the fossils found belong to Llandeilo horizons. The limestone and shale series of Tramore contains *Monticulipora petropolitana* Pand. in nodular bands, *Climacograptus bicornis* Hall, *Dicranograptus ramosus* Hall, *Diplograptus*, and *Didymograptus*. Numerous Ordovician trilobites are recorded. The fauna is somewhat specialised, and some thirty species, including the *Monticulipora* mentioned above, have not been found elsewhere in the British Isles. (Jukes 1852; Geol. Surv. 1865; Reed 1899.)

Numerous areas of Ordovician and Gothlandian shale and sandstone appear as inliers throughout southern Ireland in the cores of anticlinal domes. Surrounded by a rim of Old Red Sandstone, which overlies them with striking unconformity, they often weather down into hollow lands surrounded by scarps of the more resisting series. Farming is carried on in these upland basins, which are reached across barren and forbidding hills. A good example of this structure is seen in the country south of Carrick-on-Suir, where the Devonian terraces of the Comeragh Mountains look down on an Ordovician and Gothlandian plateau, itself raised high above the sea. Another case occurs west of Galtymore, where the core of an Armorican upfold has been hollowed out for some 25 km. (16 miles). Gothlandian rocks rise high in the ranges of Tipperary and round the Shannon at Lough Derg, and appear again in the heart of the Slieve Bloom Mountains near Maryborough. In recent years, these rocks have been placed by the Geological Survey in the Gothlandian system, on the evidence of graptolites found in certain zones; but it is quite possible that some Ordovician beds may ultimately be traced among them, in addition to those already observed by the Survey upon Slieve Bernagh.

A complete Ordovician and Gothlandian succession can be made out in the country round the inlet of Killary Harbour, lying partly in northern Galway, and partly in southern Mayo. There has been some difference of opinion in the interpretation of district, and much remains obscure in the moorland country northward between this the mountainous masses of Mweelrea (Muilrea) and Croagh Patrick. Successive discoveries of fossils have, however, led to the following conclusions. A true Arenig series was recognised by J. R. Kilroe in 1894 in a limited area of slates south of Bencroff, on the south side of Killary Harbour (Kilroe 1907), and Arenig grits, slates and cherts are now known also on the west shore of Longh Mask, where they include volcanic tuffs. Above the slates occur massive grits and conglomerates, probably of Upper Arenig age. Above these are the Mweelrea grits, some 3600 m. (12 000 ft.) thick, with here and there Llandeilo fossils. Organic remains, however, are so scarce that Carruthers and Maufe have suggested a continental origin for most of these felspathic sandstones and pebble-beds. Llandeilo grits and ashes, with *Pliomera (Amphion)*, among other trilobites, occur west of Lough Mask, pointing to a sea in this direction, and these are succeeded by Llandeilo limestones (once regarded as of Bala age). Bala beds may occur on the heights of Mweelrea and east of Killary Harbour (Carruthers and Maufe 1909; Gardiner and Reynolds 1909, 1910, 1912; Reed 1909).

In the north west of Ireland, the Ordovician and Gothlandian systems have been very generally removed by denudation. An interesting patch remains at Pomeroy, in Co. Tyrone, where Bala fossils were long ago indicated by Portlock (1843). Recent investigations (Fearnsides, Elles and Smith 1907), confirm the Upper Bala (Ashgillian) age of the sandstone and shale series containing *Dicellograptus anceps*, *Strophomena grandis*, *Str. siluriana*, *Lichas hibernicus*, and *Trinucleus seticornis;* but a higher series of shales, from which Portlock had collected *Monograptus*, corresponds with those of Birkhill in Britain, and is thus of Llandovery age. The whole series of strata rests towards the north against the old igneous and metamorphic rocks of the axis of Tyrone, already described as Pre-Cambrian.

The hummocky land from the coast of Co. Down to the central Irish plain near Longford is formed of Ordovician strata on the north, succeeded as we go southward by Gothlandian beds with Ordovician inliers, much like those of the Scottish Southern Uplands. These shales, slates, and sandstones, into which the Newry granite and the Kaïnozoic granite of Mourne have intruded, occupy almost all the country southward, until we reach Balbriggan on the Dublin coast. The Ordovician series in Co. Down was compared with the Glenkiln shales (Llandeilo) and Hartfell Shales (Bala) of southern Scotland by Swanston and Lapworth (1876—77) and Clark (1902), and characteristic graptolites were described.

The Irish area in Ordovician times was practically marine. The Arenig beds of the Killary Harbour district probably had representatives, now lost to us, farther south and north. Yet the highland of Dalradian rocks no doubt rose to westward above the sea, and furnished much of the mud in which the early graptolitic fauna is embedded. Coarse conglomerates were at times rolled down by rivers from the heights, and sandstones accumulated in the Mayo area, to which, as we have seen, a continental origin has been ascribed. Continental land must have long remained where the North Atlantic now spreads its waters.

In the Ordovician limestones, which often contain corals, we see evidences of fairly warm waters, and the volcanic action of Bala times doubtless built up islands, comparable to those of the Pacific at the present day. These, however, must have always been subordinated to the great andesitic and rhyolitic piles farther to the east in what is now the mountain-land of Wales.

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See also J. E. PORTLOCK above.

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4. Gothlandian or Silurian.

a. Great Britain.

I. Sedimentary and Volcanic Rocks.

By OWEN THOMAS JONES.

The principal exposures of Silurian rocks occur in Wales, the Lake District and Scotland; smaller areas are found along the borders of England and Wales and scattered among the newer rocks in the Midland district of England. They have been penetrated also in deep borings in the south east of England.

Classification. A threefold division of the rocks is generally adopted by British geologists but so far opinion is not unanimous in regard to the names given to certain of the divisions and the lines of demarcation between them. The task of constructing a scheme of classification which will apply to the whole of the British Isles is rendered exceedingly difficult by the fact that they occur in two radically distinct lithological and faunal developments. One facies is characterized by relatively coarse deposits of great aggregate thickness and containing a shelly fauna of brachiopods, trilobites etc.; the other is typically represented by fine-grained deposits of small thickness and containing a graptolite fauna almost exclusively.

For some years therefore two schemes of classification have been in existence side by side — the older founded mainly by Sir RODERICK MURCHISON having reference to the shelly facies; the other suggested by CHARLES LAPWORTH being based upon the graptolite fauna of the rocks.

A brief history of these classifications is necessary in order to understand their signifiance.

MURCHISON (1839) arranged the rocks in the Welsh borders into the groups

Ludlow

Wenlock

Caradoc

the last being assigned to the Lower Silurian. It was shown later by SEDGWICK and Mc COY (1853) that the Caradoc could be divided into two portions; the upper division, referred to by MURCHISON as the Horderley and May Hill rocks, was shown to be intimately allied to the Wenlock, and they proposed for them the name May Hill Sandstones. The lower division was regarded by SEDGWICK as equivalent to his Bala group as developed in North Wales.

This was confirmed later by RAMSAY and AVELINE (1854), officers of the Geological Survey, who remapped the Caradoc rocks of Shropshire. The upper Caradoc formed an impersistent base to the Wenlock rocks and consisted of a sandstone group with Pentameri followed by a group of purple and green shales almost devoid of fossils. It is to these shales that much of the confusion in the nomenclature at the present day is due.

AVELINE mapped these shales throughout Wales and found that near Llandovery they overlay a sandstone group with Pentameri like the upper Caradoc of Shropshire. Near that town there was a lower sandstone group not found in Shropshire but also containing species of *Pentamerus*. These two groups were subsequently included by MURCHISON in a new formation (Llandovery) which he regarded as a transitional formation between the lower and upper Silurian; the purple and green shales were excluded from this formation. AVELINE also traced these shales throughout Wales as far as Conway in North Wales; and they were ultimately given the name of Tarannon shales from their marked development on an upland tract of that name in Central Wales.

From his investigations among the graptolitic rocks of the South of Scotland (Moffat etc.) LAPWORTH (1882) showed that the Tarannon shales as developed at Conway were in the main equivalent to his Gala group in the south of Scotland and he considered that the groups Birkhill and Gala there established were equivalent to the Llandovery and Tarannon rocks of Wales. He proposed the name Valentian for this series (after the Roman name of that part of the South of Scotland where these rocks are well developed).

It was established however by Mrs. SHAKESPEAR (WOOD 1906) that the shales mapped by AVELINE were of widely different ages at Tarannon and Conway. At the latter place they were the equivalents of the Gala group: in the former district although of much greater thickness they formed only the uppermost subdivision of the Scottish Valentian rocks, and it was proposed to redefine the term Tarannon to include all those rocks included in it by AVELINE and thus make it equivalent to the Gala rocks of Scotland. This course only increased the confusion; for it is certain that, where the shelly facies is in question, the upper Llandovery is largely equivalent to the Tarannon as thus defined and not to the upper Birkhill of South Scotland, as has been commonly supposed, and the overlying purple and green shales are probably represented by the highest (Dolgau) group of that formation. The term Tarannon is therefore used in two widely different senses according as it is applied to the shelly or the graptolitic facies. In the following article the term will be discarded and the more natural plan will be followed of extending the Llandovery to include this subsidiary and unimportant group of purple and green shales.

The higher Silurian rocks (Wenlock and Ludlow) when traced away from the typical region towards the west and north-west undergo marked lithological and faunal changes. The massive limestones interspersed with the shales disappear and their place is taken by shales; also the abundant shelly fauna is gradually replaced by one of graptolites. It then becomes impossible to identify the original subdivisions of MURCHISON which were based to a large extent upon lithological characters.

LAPWORTH therefore proposed as a more natural classification to include the beds above the Valentian in a series which he called Salopian, while for the highest Silurian rocks he proposed the term Downtonian.

More recently Miss ELLES (1900) and Mrs. SHAKESPEAR (WOOD 1900) established a zonal classification of these rocks by means of graptolite species and were able to define with some precision the limits of MURCHISON's groups in terms of the zonal classification. LAPWORTH's proposal also received full justification; the graptolites were found to persist though in diminished numbers throughout the Salopian but did not survive that period. The Downtonian series includes therefore all the post- graptolitic Silurian rocks and the passage beds into the Old Red Sandstone.

These two classifications are set out side by side in order to show their relation to one another.

Lapworth: Newer classification	Murchison: Older classification	
Downtonian	Ludlow, including the Passage beds	Ledbury Shales (Passage beds into Old Red Sandstone) Downton Sandstone
Salopian		Upper Ludlow shales Aymestry Limestone impersistent Lower Ludlow shales
	Wenlock	Wenlock Limestone impersistent Wenlock shales Woolhope Limestone impersistent
Valentian	Llandovery (or Llandovery-Tarannon of some authors)	Purple and green shales (Tarannon of some authors) Upper Llandovery Lower Llandovery.

1. **The Valentian Series.** The Valentian rocks exemplify to a marked degree the contrast between the shelly and the graptolitic facies, and the boundary between these can be traced with some precision in south Britain. South-east and south of this line the fauna consists of brachiopods, corals, lamellibranchs, gastropods, cephalopods, and trilobites, while graptolites are exceedingly rare or wanting. In the tract which lies west and north-west of the line the groups of organisms enumerated above are of rare occurrence, their place being taken by a great variety of graptolite forms, by means of which the rocks have been subdivided in considerable detail. The change of fauna is in general accompanied by a change in the lithology of the rocks; where shelly fossils prevail the rocks are mainly conglomerates, sandstones, and sandy mudstones reaching an aggregate thickness of 900-1200 m. (3000-4000 ft.). All the rocks are somewhat calcareous and are blue-grey in colour.

Where the graptolitic rocks are typically developed they are of extreme tenuity and are composed of finely-divided sediment such as shales and mudstones. Calcareous matter when present is confined to layers of nodules at certain horizons; Its place is taken generally by iron pyrites which occurs abundantly disseminated throughout the rocks. This gives the rock a prevailing dark-blue or black colour and causes them to become deeply ironstained on weathering. The rocks of the higher members, as also in the shelly facies, are lighter in colour and generally coarser in grain.

The Valentian series falls naturally into two subdivisions or stages which vary to a certain extent independently in lithological and faunal characters and in certain districts there is evidence of physical discontinuity between the upper and lower stage. Also the Upper Valentian rocks of the shelly facies have a far wider distribution than the lower and not uncommonly rest on Pre-Cambrian rocks. For these reasons it is convenient to consider separately the distribution and characters of these subdivisions.

Lower Valentian Stage. The rocks of this stage are known in different areas under a multitude of names. In the shelly facies it includes the Lower Llandovery rocks and others referred to that group such as the Haverford Group of Haverfordwest; the Powis Castle and Cloddiau Groups of Welshpool and the Mulloch Hill and Saugh Hill Groups of Girvan. In the graptolitic facies it comprises the Birkhill rocks of South Scotland; the Skelgill rocks of the Lake District; the Gwastaden and Caban groups of Rhayader; the Fachdre, Dolgadfan and Twymyn beds of the Tarannon district; the Pont Erwyd Stage of Central Wales; part of the Gyffin Shales and Castle Grits at Conway and similar shales with grits at Corwen and again near Llansawel in Carmarthenshire.

The shelly facies has long been known at Llandovery and Haverfordwest; at the base there are grits and conglomerates resting on Upper Bala or Ashgillian rocks without any evidence of unconformity. These are followed in the Haverfordwest district by shales with lamellibranchs, brachiopods and trilobites and these in turn by sandy mudstones containing numerous characteristic fossils namely *Nidulites favus*, *Lindstroemia subduplicata*, var. *crenulata*, *Atrypa marginalis*, *Meristina crassa*, *Orthis mullochiensis*, *Barrandella undata*, *Stricklandinia lens*, *Plectambonites duplicatus*, *Phacops* cf. *elegans*, numerous gastropods and other less important fossils. At Haverfordwest these beds are succeeded by a group of massive sandstones containing similar fossils; this group has not been identified elsewhere. The occurrence of *Mesograptus modestus*, var. *parvulus* and *Climacograptus normalis* in the shales near the base is important as it enables the lowest beds of the shelly facies to be correlated directly with the lower horizons of the graptolitic facies. The sequence at Llandovery is very similar to the above. The total thickness of sediments in the Haverfordwest-Llandovery belt is 450 to 600 metres (1500-2000 ft.); but there is reason to suppose that these rocks do not extend far eastward or southward beyond their outcroup, having been removed over those areas before the formation of some part of the Upper Valentian or, alternatively, they were never deposited over much of this southern and eastern area.

The graptolitic type of Lower Valentian is best developed in the Lake district (MARR and NICHOLSON 1888) (Skelgill Group) and in the Southern Uplands of Scotland (LAPWORTH 1878) (Birkhill Group). In these districts the groups have been subdivided minutely into zones characterised by certain species of graptolites. In the Lake District bands containing certain trilobites alternate with the graptolitic layers and trilobite zones have been worked out for the upper part of the sequence. The graptolite fauna of the rocks of these typical areas has since been obtained in most other regions where the facies prevails. The lithological characters of the rocks vary however somewhat widely in different districts; these variations follow a well marked law and will be dealt with below. A general classification of the graptolitiferous Lower Valentian rocks may be drawn up as follows (the older classification being slightly rearranged in accordance with the most recent information):

Lower Valentian or Birkhill Stage	Upper Birkhill Sub-Stage	Zone of *Monograptus (= sedgwicki) spinigerus* ,, ,, *Cephalograptus cometa*
	Middle Birkhill Sub-Stage	,, ,, *Monograptus convolutus* ,, ,, *Monograptus leptotheca* ,, ,, *Monograptus fimbriatus*
	Lower Birkhill Sub-Stage	,, ,, *Monograptus cyphus* ,, ,, *Monograptus acinaces* ,, ,, *Monograptus atavus* ,, ,. *Diplograptus acuminatus*

In the Lake District the two trilobite zones of *Encrinurus punctatus* and *Phacops glaber* intervene between the middle Birkhill graptolite zones and the zone of *Ampyx aloniensis* between the upper Birkhill zones. The zone of *Rastrites maximus* is now removed from the Lower and united with the Upper Valentian.

The Lower Birkhill rocks of these areas consist of dark ironstained shales with some white seams of thin siliceous bands.

The Middle Birkhill is a group of pale greenish blue mudstones with dark shale bands in which most of the graptolites occur the mudstones having occasionally a scanty trilobite fauna.

The Upper Birkhill rocks are composed mainly of thin papery shales.

In Central Wales (H. Lapworth 1900, Wood 1906, Jones 1909 and 1912) the lower substage is of much greater thickness and contains in places massive grits at the base (Gwastaden Grits of Rhayader, Pen-y-Ddinas Grits of Llansawel etc.). At Rhayader the Upper Birkhill substage occurs partly in the form of massive grits underlain by the Caban Conglomerate, which rests unconformably on various zones of the Lower Birkhill.

In certain parts of the British Isles the distinction between the shelly and the graptolitic facies is not so clear as elsewhere. Bands of dark shale with a graptolite fauna alternate with calcareous sandstones, mudstones or conglomerates containing a typical shelly fauna and thus form an intermediate or compound facies. The best instance is afforded by the Lower Valentian rocks of Girvan in Ayrshire (C. Lapworth 1882). The Lower Valentian succession is as follows

Saugh Hill Group including:
- a) Zone of *Monograptus sedgwicki*
- b) Saugh Hill Sandstones (unfossiliferous)
- c) Zone of *Diplograptus modestus* (= Zones of *M. fimbriatus*, *M. cyphus* and *M. acinaces*)
- d) Woodlands conglomerate, limestone and mudstone (shelly fauna)

Mulloch Hill Group divided into:
- a) Zone of *Diplograptus acuminatus*
- b) Mulloch Hill Sandstones and conglomerate (shelly fauna).

The representatives of these divisions in the general scheme of classification can be readily seen.

A compound facies is less perfectly developed in more southerly districts

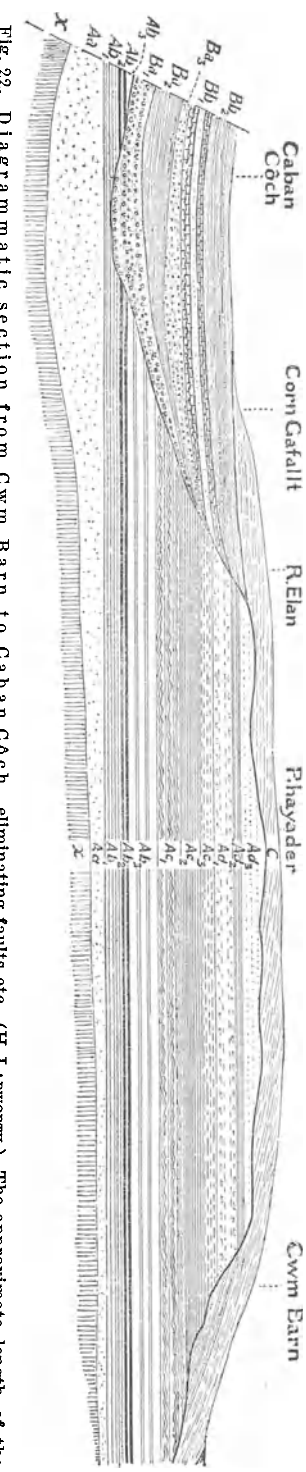

Fig. 22. Diagrammatic section from Cwm Barn to Caban Côch, eliminating faults etc. (H. Lapworth.) The approximate length of the section is 7 miles. The Gwastaden Beds are plotted horizontally.

CABAN GROUP
- C = Rhayader Pale Shales
- Bb_2 = Gafallt Shales
- Bb_1 = Monograptus sedgwicki Grits
- Ba_3 = Upper Conglomerate
- Ba_2 = Intermediate Shales
- Ba_1 = Lower Conglomerate

GWASTADEN GROUP
- Ad_3 = Pale Grey Mudstones
- Ad_2 = Zone of *Monograptus convolutus*
- Ad_1 = Calcareous-Nodule Beds
- Ac_3 = Zone of *Monograptus fimbriatus*
- Ac_2 = Zone of *Monograptus cyphus*
- Ac_1 = Zone of *Monograptus tenuis*

GWASTADEN GROUP
- Ab_3 = Diplograptus modestus Beds
- Ab_2 = Rottenstone Beds
- Ab_1 = Micaceous Flags and Grits
- Aa = Cerig Gwynion Grits
- x = Blue-black shales (Ordovician)

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in Britain, e.g. Corwen (Lake and Groom 1893, 1908) and Welshpool (Wade 1911), where part of the succession yields a shelly fauna while another part yields graptolites.

Upper Valentian. The Upper Valentian may be defined as including all the beds between the Lower Valentian and the base of the Salopian. Two distinct facies can be distinguished which prevail generally over the same areas as those of the Lower Valentian, but the rocks of the shelly facies have a much wider distribution in the south and east of Wales and the Welsh borders, where they not uncommonly rest on Pre-Cambrian rocks.

The Upper Valentian rocks of the shelly facies are known under various names. They include the "Upper Llandovery" of Llandovery together with the overlying group of purple and green shales often referred to the "Tarannon", the May Hill Sandstone of Gloucestershire, the Millin and Rosemarket groups of South Pembrokeshire and the Cefn group of Welshpool.

The Gala and Hawick rocks of south Scotland; the Dailly Series and Cámregan Group of Girvan; the Browgill Beds of the Lake District; the Tarannon Series of Tarannon and other groups correlated with the latter in Central and North Wales belong mainly to the graptolitic facies. It is commonly agreed at present to include the zone of *Rastrites maximus* in the base of the upper Valentian.

Shelly Facies. The rocks of the shelly facies exhibit considerable variation when traced laterally but in general they consist of fossiliferous calcareous sandstones and sandy mudstones followed as a rule by purple and green shales almost devoid of fossils. Near Tortworth in Gloucestershire (Morgan and Reynolds 1901), the Mendip hills in Somersetshire (Reynolds 1907) and Marloes in Pembrokeshire these rocks are remarkable as affording evidence of volcanic activity, the only instance known in the south of Great Britain of vulcanicity during the Silurian period. This occurrence compares however with the much greater development of Silurian volcanic rocks in the southwest of Ireland. Basic pyroxene-andesites, associated with coarse ashy conglomerates and fine tuffs are interbedded with fossiliferous rocks and indicate volcanic activity at two different horizons.

The characteristic fossils include *Palaeocyclus praeacutus*, *Coelospira hemisphaerica*, *Stricklandinia lirata*, *Pentamerus oblongus*, *Barrandella globosa*, *Catazyga haswelli*, *Stropheodonta compressa*, *Illaenus aemulus*, and *Phacops weaveri*, but some of these are restricted in their distribution and indicate sub-facies. In the belt that extends from Shropshire through Llandovery towards Pembrokeshire, *Pentamerus oblongus* is extremely abundant; while at Tortworth, in the Mendips and at Marloes in Pembrokeshire this form is exceedingly rare its place being taken by *Stropheodonta compressa* and other forms.

Graptolitic facies. West and north-west of the areas considered above the graptolitic facies prevails, e. g. in North and Central Wales, the Lake District and the south of Scotland, but in the Girvan district of Ayrshire there is a partial return to a shelly facies, the Camregan group being in part a calcareous sandstone with brachiopods, trilobites etc. The graptolitic rocks of the Tarannon district were divided by Mrs. Shakespear (Wood 1906) into several distinct zones, some of which can be recognized over wide areas.

These are as follows:

Zone of *Monograptus crenulatus*
„ „ „ *griestonensis*
„ „ „ *crispus*
„ „ „ *turriculatus*
„ „ *Rastrites maximus.*

The zone of *Monograptus crenulatus* comprises the purple and green shales to which the name Tarannon was originally applied by Aveline. In addition to the zonal graptolites *Monograptus becki*, *M. runcinatus*, *M. discus*, *M. nodifer*, *M. nudus*, *M. priodon*, *M. exiguus*, *Retiolites geinitzianus*, *Climacograptus extremus*, *Petalograptus palmeus*, *var. tenuis* are characteristic and commonly occurring forms.

Conditions of deposition of the Valentian rocks. The graptolitic type of the Valentian appears to have been deposited in a trough which was in all likelihood gradually subsiding during lower Valentian times, while its margins were being slowly uplifted. The districts where the same facies or subfacies occurs are found to lie along successive belts south-eastward or north-westward of the axis of the trough, which ranged from N.E. to S.W. These belts are in general concave towards the centre of the trough and indicate shallower water or the approach to a shore-line away from that direction. The regions where the Valentian rocks are represented by the least thickness of sediments are the Lake District and North Wales; in the former district the Lower Valentian is composed of 20 m. (65 ft.) and the Upper Valentian of about 90 m. (300 ft.) of fine graptolitiferous shales and mudstones. Farther south in Central Wales these subdivisions expand to 275 m. (900 ft.) and nearly 1100 m. (3500 ft.) respectively. Still farther south-eastward the Lower Valentian in particular increases greatly in thickness for at Rhayader the total thickness of that subdivision is about 900 m. (2900 ft.). This is due however in part to a local unconformity at the base of the Caban Group of that district; the overlying rocks being composed of coarse boulder-beds, grits and subordinate shales. In this district also there is evidence of overlap at the base of the Upper Valentian.

In the next belt, on which the Haverfordwest-Llandovery development lies, the lower and upper subdivisions are each represented by 450-600 m. (1500-2000 ft.) of sediments but there is reason to suspect a physical and palæontological break between them; the total thickness of sediments is therefore less than at Rhayader but part of the sequence may be unrepresented. Then follows still farther east and south a different facies, which lies on a curved line extending from Shropshire to the south side of the Pembrokeshire coalfield. The Lower Valentian is absent; the Upper Valentian which is of comparatively small thickness, is composed of coarse sandstones or limestones with some shales, and rests upon older rocks generally Pre-Cambrian. This littoral type is fairly general over the southeast of Wales, May Hill, Malvern etc. and is probably prevalent over much of the Midlands where these rocks occur.

Still farther east is the distinct subfacies of Tortworth and the Mendips, which ranges to Marloes in South Pembrokeshire; it is characterized by the occurrence of basic volcanic rocks.

There appears good reason for supposing therefore that while the central trough was subsiding during Lower Valentian times its eastern margin was being gradually elevated, so that in Upper Valentian times land prevailed over the eastern area. It is interesting to note however that in the East of England (Chilham in Kent) typical graptolitiferous Upper Valentian shales have been met with in a deep boring through the Mesozoic rocks; these probably belong to the continental province extending from Brittany into the Ardennes rather than to the British province of Valentian rocks.

Northwest of the centre of the trough the same general change takes place but it cannot be traced in so detailed a fashion. In the Moffat district about 30 m. (100 ft.) of graptolite shales represent the Lower Valentian and 900-1200 m. (3000-4000 ft.) of coarse grits, conglomerates and shales the upper stage. It was shown by Lapworth that as the graptolite shales are traced northwestward they are gradually replaced by arenaceous sediments and the total thickness of the group increases correspondingly. In the Girvan district, still farther northwest, the lower subdivision is composed of 275 m. (900 ft.) of shelly sandstones and limestones alternating with graptolite shales; there are some unconformities in the series indicating local earthmovements and these may also have removed an unknown thickness of deposits.

On the whole the trough seems to have been gradually filling up with coarse sediments during Upper Valentian times; though subsidence must have continued pari passu, to allow of the accumulation of so great a thickness of coarse sediments under somewhat uniform shallow-water conditions.

2. **The Salopian Series** includes the highest graptolitiferous strata, or their equivalents under different facies, so far as these have been determined. There are still certain regions, where the upper limits of the Salopian has not been recognised with certainty; reference will be made to these at a later stage.

The rocks of the series admit of a broad division into two lithological types or facies, but these are not so sharply marked off by their organic contents as those of the Valentian rocks. These two facies may be referred to as a) the calcareous facies, b) the non-calcareous facies. It is convenient also to subdivide the series into two stages which will be described as Lower and Upper Salopian; the former corresponds in general with the Wenlock of MURCHISON while the latter includes the Lower Ludlow and the Aymestry Limestone group of the older classification.

a) The calcareous facies; the lithological characters and organic contents of the rocks of this facies were described in detail by MURCHISON. These rocks prevail in Shropshire and along the borders of England and Wales; Wenlock, Ludlow, Malvern, Woolhope, May Hill, Usk being well known localities, they are found also around Tortworth (in Gloucestershire), Cardiff and as small inliers in the neighbourhood of Birmingham, (Walsall, Dudley, Lickey). Approximately the same type is developed in the extreme southwest of Pembrokeshire (Marloes etc.), and if one may judge from the limited exposures of Silurian rocks in south Cornwall the calcareous facies seems to be dominant there also. Its western limit is probably related to a peculiar belt of disturbance which forms an arc, concave to the northwest, and ranges from the east side of the Longmynd (Church Stretton) through Old Radnor towards the middle of the Pembrokeshire coalfield. This line is indicated on geological maps by severe post-Carboniferous disturbances and is probably a structural feature of great antiquity.

Salopian rocks appear also to be somewhat sharply limited eastwards for they are absent in borings beneath the newer strata of the Midlands east of a line drawn from Birmingham to the Mendip hills in Somerset. They reappear however farther east as at Ware in Hertfordshire, and various localities recently discovered in East Kent (Cliffe etc.). Their distribution is analogous to that of the Upper Valentian and it is therefore possible that the subterranean Salopian rocks of the east of England belong to a different province from those of the west as suggested in connection with the preceding stage.

b) The non-calcareous facies occupies the eastern portion of North and Central Wales and the border region; a large area in the Lake District and the surrounding tracts, a narrow belt in the southern Uplands of Scotland near the English borders and smaller areas near Girvan in Ayrshire, Lanarkshire and the Pentland Hills.

The classification of the rocks of the calcareous facies is set out in tabular form on pp. 98-9. The limestone beds which intervene between the shales are relatively impersistent, but have acquired an importance out of all proportion to their thickness through the abundance and variety of their organic remains. Where they are well developed their superior hardness among the softer strata gives them great prominence in the landscape; they generally form well-wooded escarpments, while the intervening shales give rise to long strike valleys or low undulating tracts of a monotonous character. This type of scenery is strikingly exhibited along Wenlock Edge and around the domes of Woolhope and May Hill. The shale bands can scarcely be distinguished from one another by their lithology, but their fauna is somewhat different. The Wenlock shale usually contains numerous brachiopods and trilobites, the commonest being *Atrypa reticularis*, *Orthis rustica*, *Dalmanella elegantula*, *Scenidium lewisi*, *Plectambonites segmentum*, *P. transversalis*, *Phacops caudatus*, *P. stokesi*, *Calymene blumenbachi* and *Cardiola interrupta*. The Lower Ludlow shale contains many of the above fossils but in addition *Rhynchonella nucula*, *Wilsonia wilsoni*, *Chonetes striatella*, *Phacops downingiae*, *Lingula lata* and others are characteristic. In the higher portion of these shales known locally as the Leintwardine flags a thin band has long been known from which starfishes (*Lapworthura* and *Palaeocoma*) have been obtained together with remains of Merostomata (*Pterygotus* and *Eurypterus*). As indicated later these rocks have in places also yielded some graptolites by means of which the position of the shales and the intervening limestones were determined on the graptolitic scale.

The bands of limestone are readily distinguished from one another by their lithological and faunal characters; they were therefore selected by MURCHISON to define the limits of his groups.

The Woolhope Limestone is generally a blue flaglike limestone with thin bands of shale; occasionally it is partly represented by nodular limestone; it is characteristic of the southeastern portion of the calcareous area and becomes replaced by shales towards the north west. Its fossils are intimately related to those of the overlying Wenlock shale, but in some districts *Stricklandinia lirata* and *Barrandella globosa* survive from the Valentian. The trilobite *Illaenus barriensis* occurs in several localities and may be regarded as a characteristic fossil.

The Wenlock Limestone is, however, the best known and most distinctive member of the calcareous facies on account of the variety and abundance of its organic remains and their beautiful state of preservation. It is a bluish grey argillaceous limestone in even beds of no great thickness, alternating with thin bands of shale. In some of the beds brachiopods and trilobites occur in profusion, while others are almost made up of the remains of corals and crinoids. Among the most characteristic fossils may be enumerated *Acervularia luxurians*, *Omphyma turbinatum*, *Favosites gothlandicus*, *Actinocrinus*, *Periechocrinus*, *Crotalocrinus*, *Sieberella galeata*, *Meristina tumida*, *Strophonella euglypha*, *Horiostoma discors*, *Phacops caudatus*, *Phacops musheni*, *Orthoceras*, *Phragmoceras*, *Gomphoceras*.

The calcareous material dies away rapidly and becomes replaced by shales in a southwesterly direction its most typical development being around Wenlock from which town it derives its name.

Aymestry Limestone. The highest band of limestone attains its maximum development near the place after which it is called. Away from that neighbourhood especially towards the west and south west the massive beds of earthy limestone become interspersed with numerous shale bands until the group is finally reduced to a few thin calcareous beds or nodules. It usually contains a profusion of the brachiopods *Conchidium knighti*, and *Dayia navicula*, which are often associated with *Wilsonia wilsoni*, *Lingula lewisi* and other fossils; the first named species appears to be confined to this horizon. In some localities traces of graptolites have been found in the limestone. It has been proved recently that near Ludlow 12 to 45 m. (40-150 ft.) of shales (Mocktree Shales) over-lying the limestone contains a very similar fauna including *Monograptus leintwardinensis*, and must therefore be grouped with the Aymestry limestone in the Salopian; this is the highest level at which graptolites have yet been recorded (ELLES and SLATER 1906) in Britain.

The non-calcareous facies. Owing to the absence of the distinctive limestone bands in the west and northwest of the Silurian area it was for a long time impossible accurately to identify the divisions established farther east by MURCHISON. This has now been accomplished for many districts by means of the graptolite fauna, which has been very completely investigated of recent years by Miss ELLES (1900) and Mrs. SHAKESPEAR (WOOD 1900). The former established a detailed zonal classification of the Wenlock (Lower Salopian) rocks of Wales and the borderland while the latter extended the classification to the Lower Ludlow rocks and Aymestry Limestone (Upper Salopian). By means of these detailed researches and the work of previous observers in Wales (WATTS, 1885 and 1890, LAKE 1895), the Lake District (MARR 1892) and the South of Scotland (LAPWORTH 1880) the divisions of the Salopian rocks established in these different districts can now be correlated, and the history of deposition of the sediments and their lateral variation can be followed in detail.

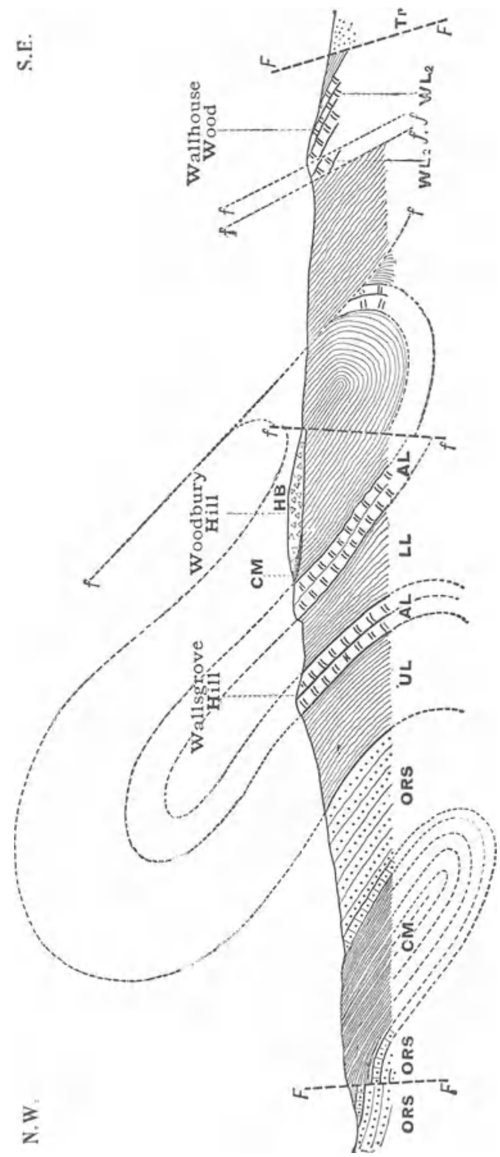

Fig. 23. Section across Woodbury and Wallsgrove Hills, and the adjacent portion of the Wyre-Forest Coalfield. (T. T. GROOM.) Scale: 4 inches = 1 mile, or 1:15840.
Tr = Trias; HB = Haffield Breccia; CM = Coal Measures; ORS = Old Red Sandstone and Passage-beds; UL = Upper Ludlow; AL = Aymestry Limestone; LL = Lower Ludlow; WL_2 = Wenlock Limestone; FF = Faults; ff = Hypothetical faults. Reproduced from the Quarterly Journal of the Geological Society, vol. 56, p. 174, 1900; with the permission of the Council and of the author.

The Lower Salopian rocks of Builth, the Long Mountain and the Dee Valley in North Wales have been divided into six graptolite zones, based principally upon species of the genus *Cyrtograptus*:

Zone	of	*Cyrtograptus*	*lundgreni*
,,	,,	,,	*rigidus*
,,	,,	,,	*linnarssoni*
,,	,,	,,	*symmetricus*
,,	,,	*Monograptus*	*riccartonensis*
,,	,,	*Cyrtograptus*	*murchisoni.*

The zonal fossils are accompanied by species of *Monograptus* the most abundant forms being allied to *Monograptus flemingi.* It is the presence of these and of the genus *Cyrtograptus*, that gives to the Lower Salopian graptolite fauna its distinctive features. At certain horizons, where a small amount of calcareous matter is intercalated among the argillaceous sediments, a few species of brachiopods, trilobites cephalopods etc. were obtained e. g. *Atrypa reticularis*, *Orthis rustica*, *Wilsonia wilsoni*, *Chonetes minima*, *Phacops musheni*, *Acidaspis prevosti*, *Orthoceras primaevum*, *Cardiola interrupta* etc. An important result of this detailed zonal work was the detection of breaks in the succession due to repeated overlaps produced by irregular subsidence or tilting of the area during the deposition of sediment. The zones detected in the above areas can be recognized over the greater part of Britain where the facies prevails.

Upper Salopian. The Upper Salopian graptolitiferous rocks were investigated in the Builth and Long Mountain areas of Central Wales and Shropshire, where the rocks belong to the non-calcareous facies, and also in the Ludlow district, where the limestone bands of the Silurian are represented. Five main zones were established, which are characterized by various species of *Monograptus*, that genus together with certain species of *Retiolites* beeing the only graptolites which survive into the Upper Salopian.

These zones were as follows:

Zone of *Monograptus leintwardinensis*
" " " *tumescens*
" " " *scanicus*
" " " *nilssoni*
" " " *vulgaris*

The separation of the Upper from the Lower Salopian of these areas is in general arbitrary, as there is no marked change of lithological characters at the boundary and many of the graptolite forms are common to both stages. The distinction is based upon the absence of the genus *Cyrtograptus* and *Monograptus flemingi* and its allies from the Upper Salopian together with the presence in that stage of *Monograptus colonus* and its allies. Spinose forms of *Monograptus* are also specially characteristic of the upper division; this is probably due to the adverse conditions under which the graptolites of that period were maintaining a struggle for existence. Only twenty-seven forms of *Monograptus* and two of *Retiolites* were recognized. These have for the most part an extended vertical range and a limited geographical distribution. The zonal divisions are in consequence unevenly developed and some of the zones have been detected in only one or two areas. In the highest zone only the zonal graptolite and a variety of it have been found, but it happens that these have a wide geographical distribution so that the zone has been recognized over an extensive area. In addition to the graptolites various shelly fossils occur commonly in thin calcareous bands among the argillaceous sediments; they consist principally of brachiopods, together with some polyzoa, corals, trilobites and cephalopods.

Relatively few species occur, but they are represented by numerous individuals. The brachiopod *Dayia navicula* is abundant in certain bands and is often associated with *Spirifer crispus*, *Scenidium lewisi*, crinoid stems and other remains. The well known form *Pentamerus* (*Conchidium*) *knighti* was found on one horizon on the same slabs of rock with *Monograptus leintwardinensis*, so that it is impossible on palæontological grounds to separate the Aymestry limestone of which this brachiopod is characteristic from the underlying shales. The calcareous bands occur less frequently as the strata are traced away from the Ludlow district towards the west and north-west.

Lateral Variation and Conditions of Depositions of the Salopian rocks. It will be convenient to trace the variation in lithological characters and thickness of these rocks as they would present themselves in a general traverse from south-east to north-west across the general strike from the neighbourhood of Bristol to the south of Scotland.

Near Tortworth the Salopian rocks are imperfectly developed and consist of calcareous mudstones with abundant shelly fossils; they increase in thickness towards the May Hill and Malvern regions where the limestone bands and especially the lower ones are clearly marked. The Lower Salopian is represented by over 300 m. (1000 ft.) of calcareous mudstones and limestones; the upper by 180 to 210 m. of similar rocks. Farther northwest occurs the typical calcareous development of the Wenlock-Ludlow area: the Lower stage is composed of a thickness of 450 to 600 m. (1500-2000 ft.) of calcareous mudstones; the lowest (Woolhope) limestone band is poorly represented. The Upper Salopian has increased to over 300 m. (1000 ft.), largely owing to the great development of its chief calcareous member the Aymestry Limestone. A few kilometres to the north-west of this area the calcareous facies dwindles away almost completely and gives place to the facies developed along the eastern borders of Central Wales (Builth, Long Mountain etc.). The total thickness of sediments remains much the same, but the strata consist of shales with arenaceous flagstones sometimes containing calcareous matter; some coarser gritty sediments occur occasionally in the higher members. Small breaks and overlaps in the succession have been detected, proving irregular subsidence and slight tilting of the area during deposition.

This type forms a transition to that developed in North Wales where the Salopian rocks generally have long been known under the name of the Denbighshire Series. The Lower Salopian has a thickness of about 500 m. (1700 ft.) and consists of slates (Pen-y-glog and Moel Ferna) with a band of grits; the slates contain principally a graptolite fauna while the grit has yielded *Meristina tumida* and other shelly fossils. The Upper Salopian has increased greatly in thickness, and is composed of over 900 m. (3000 ft.) of flags, mudstones and sandstones containing certain of the characteristic graptolites including the highest zonal form *M. leintwardinensis*. Certain shelly fossils also occur notably *Dayia navicula*, *Cardiola interrupta*, *Rhynchonella nucula*, *Acidaspis hughesi*, and fine examples of *Actinocrinus pulcher*. The uppermost limit of the Salopian has not been definitely fixed but it is believed that representatives of the highest (Downtonian) series may occur.

The North Wales type is developed also in the Lake District; the Lower stage (Brathay Flags and possibly the Lower Coldwell Beds) is composed of fine-grained flags and some grits containing chiefly a graptolite fauna. The Upper Salopian (comprising the Middle and Upper Coldwell Beds, Coniston Grits and Bannisdale Slates) has however expanded greatly and attains the enormous thickness of nearly 3,600 m. (12,000 ft.) of flags, slates and grits. In these most of the zonal forms of graptolites have been observed, including *Monograptus leintwardinensis* or a variety of it; also many of the common Upper Salopian shelly fossils have been obtained e. g., *Pterinea tenuistriata*, *Phacops downingiae*, *Cuculleal cawdori*, *Protaster miltoni* and other forms.

The Lake District development marks the greatest thickness of sediments met with in the Salopian of Britain; farther north-west Scottish rocks which may be referred to the Lower Salopian are developed in the southern uplands (Riccarton and Raeberry beds) where they consist of over 900 m. (3000 ft.) of mudstones, shales and marls with conglomerates, grits and some limestone nodules; they are sparingly fossiliferous but most of the characteristic graptolite forms have been obtained from them. In the Girvan district of Ayrshire the Lower Salopian consists of flagstones, grits and conglomerates, known as the Bargany and Straiton beds which attain a thickness of at least 490 m. (1600 ft.) the highest beds being concealed by Carboniferous rocks.

In Lanarkshire and the Pentland Hills the division of the series into stages is difficult and the separation of the Salopian from higher Silurian strata has not been satisfactorily accomplished. The lower rocks, which may tentatively be referred to the Lower Salopian consist of over 600 m. (2000 ft.) of sandstones and grits associated with green, red, purple and grey shales and mudstones indicating peculiar conditions of deposition; some beds contain eurypterids and starfish. The part that may be attributed tentatively to the Upper Salopian consists of about 450 m. (1500 ft.) of red and green shales with *Platyceras simulans;* they have also yielded the scorpion *Palaeophonus.* These are followed by a remarkable set of deposits which will be described under the Downtonian.

The Salopian rocks seem therefore to have been deposited in a trough-like area coinciding roughly with that in which the Valentian sediments were laid down; on the margins of the trough the calcareous and argillaceous deposits with shelly organisms were formed while the arenaceous materials accumutated near the centre. As the transportation of these coarse deposits necessitated strong currents it is probable that they were carried in the direction of the trough rather than across its margins, where the quiet and comparatively clear waters necessary for the formation of the argillaceous and calcareous deposits prevailed. The whole area of deposition must have been slowly sinking the central parts more quickly than the margins. It is probable also that the boundaries of the marine area were being uplifted concurrently with the subsidence of the trough. In Lanarkshire and some other parts of Scotland the area of deposition seems to have been at times under lagoon conditions with still water and rapid evaporation resulting in the formation of red and green shales and marls closely resembling those of the Devonian.

3. The **Downtonian Series.** The rocks of this series have a relatively limited distribution at the surface, and are only found in certain regions, either forming a fringe along the base of the Old Red Sandstone, or emerging from beneath an unconformable cover of later deposits. They may have been deposited over much of the Silurian area and have since been removed; some evidence of this has been obtained in North Wales, where fossiliferous pebbles of undoubted Downtonian rocks resembling those of the Lake District were obtained in the conglomerates at the base of the Carboniferous rocks and appear to have been derived from the denudation of the highest Silurian sediments. On the other hand the somewhat peculiar and variable characters of the rocks render it possible to suppose that they may have had originally a restricted distribution. The typical development of the series is that of the Ludlow district, where it has been exhaustively studied by Miss Elles and Miss Slater (1906).

The classification of these rocks which immediately overlie the Aymestry Group is there as follows:

Downtonian Series.	Temeside Group [stage]	Temeside Shales with *Lingula cornea & Eurypterus*
		Downton-Castle Sandstones with *Lingula minima*
	Upper Ludlow Group [stage]	Upper Whitcliffe Flags with *Chonetes striatella*
		Lower Whitcliffe Flags with *Rhynchonella nucula*

The fossils mentioned are those which occur most abundantly, and are not necessarily confined to the beds with which they are linked.

The Whitcliffe Flags consist of highly fossiliferous calcareous blue or olive-green flags and shales which attain a maximum thickness of 85 m. (280 ft.). In addition to the fossils mentioned above *Orthis lunata*, *Spirifer elevatus*, *Goniophora cymbae-*

formis, *Orthonota amygdalina*, *Pterinea retroflexa*, *Orthoceras bullatum*, *Homalonotus knighti* and *Beyrichia kloedeni* occur abundantly; *Pterygotus problematicus* has also been obtained from these beds. At the top is the well-known Ludlow Bone-bed which, though only reaching a maximum thickness of about 15 cm. (6 inch.) and is frequently scarcely more than a centimetre, has been observed at numerous localities and appears to cover a wide area. It is composed of a mass of minute brown or black organic fragments firmly compressed together and cemented by relatively small amounts of calcite and ferruginous material. The organic remains are those of fishes, Crustacea, Brachiopoda and perhaps Annelida; they are to some extent rolled and worn. Small coprolites also occur. *Onchus murchisoni*, and other fishes are represented by spines, while *Pterygotus*, *Leperditia* and other crustacea occur as small fragments. Besides this well-known bed, other bone-beds have been recognized in the area containing somewhat different fossils.

The Downton Castle Sandstones consist of massive yellow sandstones associated with micaceous sandstones and shales, they have a maximum thickness of about 15 m. (50 ft.) and are only sparingly fossiliférous. Near the base and only separated from the Ludlow Bone-bed by about a metre (3 ft.) of unfossilifereous beds is a band containing abundant *Platyschisma helicites* and *Modiolopsis complanata* which passes laterally into another bone-bed (Downton Bone-bed), containing organic remains similar to those of the former with *Thelodus parvidens* and the small seed-like plant-remains known as *Pachytheca sphaerica.* At a higher level occurs another layer of coarsely micaceous friable sandstone full of fish fragments belonging to the cephalaspid species *Eukeraspis pustulifera* and the Acanthodian genus *Climatius.* This band may be described as another bone-bed and like the others varies much in texture and thickness within short distances, but it does not seem to be present everyhere over the area.

The Temeside shales form the highest members of the Silurian and consist of grey, greenish and olive shales with thin sandstones; they have a maximum thickness of 36 m. (120 ft.). They contain small indeterminate lamellibranchs and *Lingula cornea* occurs fairly commonly. In the upper portion of these shales is the Temeside Bone-bed which is a grey micaceous carbonaceous grit, in which fragments of bone and fish-spines are disseminated; it is coarser than, and very different in appearance from, the Ludlow Bone-bed. It yielded two species of *Pterygotus*, two species of *Onchus*, and abundance of *Pachytheca sphaerica.*

The uppermost bed referred to the Silurian is a grey micaceous grit at the top of which is a layer crowded with carbonaceous fragments but in which bones are rare *Onchus* having been recognized together with *Pachytheca*, *Leperditia* and *Lingula cornea.* The succeeding beds are purple-red sandstones with shaly partings, which differ in lithology from anything below and are considered to belong to the Old Red Sandstone.

It is doubtful whether the detailed subdivisions established in the Ludlow district could be recognized far from that area though it is probable that the major groups will be identified approximately.

Lateral variations and conditions of deposition of the Downtonian Series. When traced to the south-west into South Wales the highest Silurian rocks pass into sandstones with subordinate shales. Some of the sandstones are highly micaceous and split up into thin flags which have been used extensively in the locality for roofing, and are known as Tilestones. Many of the fossils of the Ludlow district occur; the prevailing forms are thick-shelled lamellibranchs and certain gastropods, *Orthonota amygdalina* and *Holopella gregaria* being the most characteristic. The various divisions thin out gradually westward probably due in part to repeated overlap within the series, and ultimately the highest members become concealed by overstep at the base of the Old Red Sandstone. The rocks occupying the position of the Downtonian series when the Silurian rocks emerge from beneath the Old Red Sandstone in South Pembrokeshire consist of massive greenish sandstones with very scanty organic remains, *Lingula* and traces of other horny brachiopods being the only fossils that occur.

It is probable that Downtonian rocks fringe the Old Red Sandstone of eastern Wales, as a great thickness of brown shales with flagstones and sandstones succeeds the graptolitic deposits of the Salopian but no details are available in regard to their lithological and faunal characters.

In North Wales also it is possible that the highest portion of the Denbighshire Series belong to the Downtonian though this has not been satisfactorily proved.

An important development of the series occurs in the Lake District where over 600 m. (2000 ft.) of greenish and grey sandstones and flags known as the Kirkby Moor Flags represent the higher Silurian rocks. The series is not complete owing to the overstep at the base of the unconformably overlying Carboniferous rocks.

The thin calcareous bands among the arenaceous sediments yield abundant fossils such as *Lingula cornea*, *Chonetes striatella*, *Orthonota amygdalina*, *Grammysia cingulata*, *Holopella gregaria*, *Orthoceras ludense*, *Lituites ibex* and numerous others.

These fossils make it clear that the Kirkby Moor Flags represent only the lower portion of the Downtonian as developed at Ludlow for not only are the above forms characteristic of the Whitcliffe Flags of that district but there is an entire absence in them of the bone-beds and *Eurypterus*-bearing strata which are so marked a feature of the higher or Temeside stage. It is obvious that as in the case of the preceding series the Downtonian has expanded greatly in thickness in this region.

In Scotland strata referred to the Downtonian occur at the top of the Silurian sequence in Lanarkshire and the Pentland Hills south of Edinburgh. They attain a thickness of over 600 m. (2000 ft.) and consist of red, chocolate-coloured and yellow sandstones, mudstones and shales with some conglomerates, the red colours predominating towards the top. On account of these characters they were at one time assigned to the Old Red Sandstone but they are separated by an unconformity from that formation. One of the bands of shale yielded some years ago numerous remains of fish and Merostomata; many of the genera of fish were new and of great interest; the genus *Thelodus* which occurs abundantly in the higher bone-beds of the Ludlow district is represented by *T. scoticus*. The Merostomata include species of *Eurypterus* and *Stylonurus*; the phyllocarids *Dictyocaris* and *Ceratiocaris* and the myriapod *Archidesmus* also occur. Sandstones and shales referred to the Downtonian also occur near Stonehaven, where they rest unconformably on the Cambrian and pass up into the Lower Old Red Sandstone; they have yielded *Cyathaspis*, *Dictyocaris*, *Ceratiocaris*, Merostomata and *Archidesmus*. They are associated with volcanic rocks. The Downtonian were formed during the final stages in the filling of the Silurian trough of deposition and it is possible that parts of the area of deposition were separated off from others or even from connection with the open sea and were thus converted into isolated basins where an approach to continental conditions prevailed. This would probably account for the incoming of red and green sediments which are usually associated with continental conditions. There is in some areas evidence of earth-movements having occurred immediately after the deposition of these rocks and before the formation of the Old Red Sandstone; it is probable also that in other regions farther south slow movements of uplift were in progress during the closing stages of the Silurian, leading to the

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great Caledonian earth-movements which closed the period in Britain. The trend of these movements from north-east to south-west is approximately the same as that of the Silurian trough of deposition. This is probably not an accidental coinci-

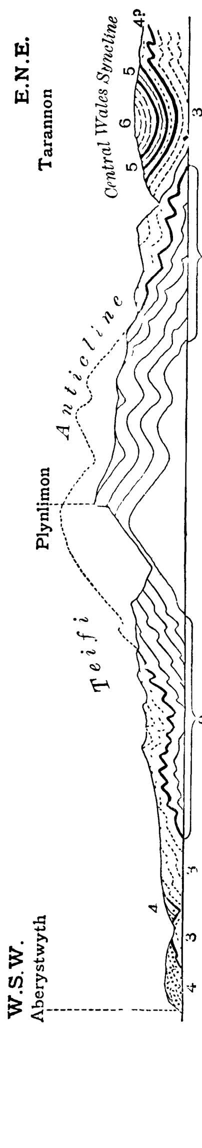

Fig. 25. Diagrammatic section across Central Wales (plate II, section 2), showing the principal axes of folding and the general nature of the small-scale folding (O. T. JONES). Horizontal scale: 1 inch = 5 miles, or 1:316,800; vertical scale, exaggerated about 5 times, say 5000 feet to the inch, or 1:60,000.

1 = Dicranograptus Shales; 2 = Upper Bala; 3 = Lower part of the Valentian; 4 = Aberystwyth Grits; 5 = Purple and Green Beds; 6 = Wenlock-Ludlow Beds; 7 = Old Red Sandstone.

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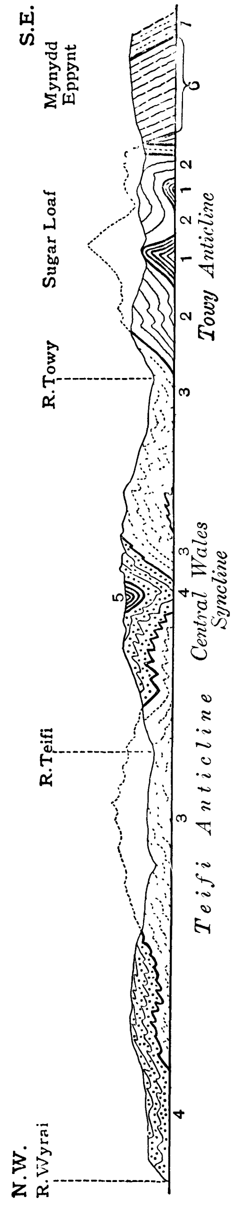

Fig. 26. Diagrammatic section across Central Wales (plate II, section 1), showing the principal axes of folding and the general nature of the small scale folding (O. T. JONES). Horizontal scale; 1 inch = 5 miles, or 1:316,800; vertical scale, exaggerated about 5 times, say 5000 feet to the inch, or 1:60,000.

1 = Dicranograptus Shales; 2 = Upper Bala; 3 = Lower part of the Valentian; 4 = Aberystwyth Grits; 5 = Purple and Green Beds; 6 = Wenlock-Ludlow Beds; 7 = Old Red Sandstone.

Reproduced from the Quarterly Journal of the Geological Society, vol. 68, p. 338, fig. 1, 1912; with the permission of the Council and of the author.

dence; it appears more likely that the gradual formation and deepening of the central portions of the trough while its margins were being slowly elevated were due to the same crustal strains that in their full development gave rise to the Caledonian mountain ranges of northern and central Britain.

	WEST OF ENGLAND.				IRELAND.	
	Shropshire. Wenlock and Ludlow.	Herefordshire. May Hill and Woolhope.	Herefordshire. Malvern.	Gloucestershire. Tortworth.	East coast. Balbriggan.	West coast. Dingle promontory.
Downtonian.	Temeside and Upper Ludlow Groups. Micaceous shales and sandstones with "bone-beds". Average 305 m. (1000 ft.).	? Top absent. Shale with some sandstone. About 60 m. (200 ft.).	Ledbury and Upper Ludlow Groups. Grey and purple shales and yellow sandstones. 122 m. (400 ft.).	Absent.	Absent.	? Part of Dingle Beds.
Upper Salopian.	Aymestry and Lower Ludlow Groups. Soft sandy shales and flags with limestone (Aymestry). 300-400 m. (1000-1300 ft).	Aymestry and Lower Ludlow Groups calcareous shales with Aymestry limestone. 180 m. (600 ft.).	Aymestry and Lower Ludlow Groups calcareous shales with Aymestry limestone. 230 m. (750 ft.).	15 m. (50 ft.). ?	Absent.	Croaghmarhin Beds. 300 m. (1000 ft.).
Lower Salopian.	Wenlock Group, calcareous shales with band of Limestone (Wenlock). 550-610 m. (1800-2000 ft.).	Wenlock Group, grey shales with Wenlock Limestone above and Woolhope Limestone below. 350 m. (1150 ft.).	Wenlock Group, grey shales with Wenlock and Woolhope Limestones. 280 m. (930 ft.).	Wenlock Group, calcareous shales and sandstones with two bands of limestone. 190 m. (620 ft.).		Clogher Head Beds, sandstones, slates, rhyolites, and volcanic ashes. (915 m. 3000 ft.). Ferriters Cove Beds, calcareous flags with some rhyolites and ashes. 425 m. (1400 ft.). (Probably Llandovery in part).
Upper Valentian.	Purple and Green Shales. Pentamerus Limestone and Sandstone. 75-150 m. (250-500 ft.). Unconformity.	May Hill Sandstone, grey and brown sandstones. 122 m. (400 ft.). Unconformity.	May Hill Sandstone Group, grey sandstones and shales with grey and purple sandstones and conglomerates. 305 m. (1000 ft.). Unconformity.	Upper Llandovery Group, Ashy limestones and calcareous sandstones with two bands of pyroxene andesite, 18 and 36 m. (60 and 185 ft.). 244-260 m. (800-850 ft.).	Grey grits with some black slates. 700 m. (2300 ft.).	Smerwick Beds. 610 m. (2000 ft.).
Lower Valentian.	Absent.	Absent.	Absent.			
Underlying Rocks.	Ordovician — Pre-Cambrian.	? Pre-Cambrian.	Cambrian.		Ashgillian volcanic series.	

O. T. JONES. G. A. J. COLE.

	SCOTLAND.		NORTH OF ENGLAND.	WALES.				
	Girvan.	Moffat, Lanark, Pentlands etc.	Lake District.	North Wales. Conway and Corwen etc.	Central Wales. Tarannon and Plynlimon.	Eastern Wales. Rhayader.	Eastern Wales. Llandovery.	Eastern Wales. Builth.
Downtonian.	Absent.	Upper Groups of Lanark and Pentland Hills. Conglomerates, red and green mudstones. 820 m. (2700 ft.) at maximum.	Kirkby Moor Flags. Sandstones and flags with calcareous bands. over 610 m. + (2000 ft.).	? Removed by denudation. Pebbles in Carboniferous Conglomerate.	Absent.	Absent.	Absent.	Calcareous flags shales and Sandstones. ? 610 m. (2000 ft.).
Upper Salopian.	Absent.	Lower Groups of Lanark and Pentland Hills and Raeberry Group. Mudstones, shales, sandstones and marls. 610 m. (2000 ft.).	Bannisdale Slates. Coniston Grits. Upper and Middle Coldwell Beds. Grits, sandstones, flags and shales. 3350 m. (11,000 ft.).	Upper Denbighshire Flags and Grits. Sandstones, mudstones.	? thickness	Absent.	?	Mudstones shales and flags, usually calcareous. 380 m. (1250 ft.).
Lower Salopian.	Straiton Group. Conglomerates, grits, flags and shales. 152 m. (500 ft.).	Riccarton Group. Conglomerates, grits, shales, mudstones. 300-460 m. (1000-1500 ft.).	Brathay Flags. Fine laminated flags. 305 m. (1000 ft.).	Lower Denbighshire Flags and Grits. Moel Ferna Beds. Slates, flags and grits. Total thickness of Salopian about 1500-1800 m. (5000-6000 ft.).	? thickness	Absent.	?	Shales and flags generally calcareous. 509 m. (1640 ft.).
Upper Valentian.	Drumyork, Bargany, Penkill and Camregan Groups. Sandstones, flags and shales; lower beds calcareous. 700 m. (2300 ft.).	Hawick and Gala Groups. Conglomerates, grits, shales and mudstones. 915-1220 m. (3000-4000 ft.).	Browgill Beds. Reddish purple and pale grey shales with some thin grits. 60 m. (200 ft.).	Gyffin Shales of Conway and Pale Slates of Corwen with grits at base viz:— Conway Castle or Corwen Grits.	Tarannon Series of Tarannon, or Ystwyth Beds of Plynlimon; mudstones and shales with bands of grit at intervals over 1000 m. + (3200 ft.).	Rhayader Pale Shales. Blue and grey slates with some grits. ? Overlap.	Upper Landovery. Purple and green shales over sandstones and mudstones. ? 460 m. (1500 ft.). ? Break.	Upper Llandovery. Dark shales and sandstone. ? about 30 m. (100 ft.) Unconformity.
Lower Valentian.	Saugh Hill Group. ? Unconformity. Mulloch Hill Group. Conglomerates. Sandstones and Shales. 260 m. (850 ft.).	Birkhill Group. Black shales and grey mudstones with clay seams. 23 m. (75 ft.).	Skelgill Beds. Alternations of grey and black shales with pale mudstones. 15 m. (50 ft.).	Valentian (undivided) Total thickness 140-280 m. (450-900 ft.).	Lower shales of Tarannon, or Pont Erwyd beds of Plynlimon: shales, mudstones and flags with some grits 275m. (900 ft.).	Caban Group. conglomerates, grits and shales. (Unconformity) Gwastaden Group. mudstones, shales, flags and grits. 915m. (3000ft.).	Lower Llandovery. Sandy mudstones, shales, grits and conglomerates. ? 460 m. (1500 ft.).	Absent.
Underlying Rocks.	Drummuck Beds or Upper Bala.	Upper Hartfell or Upper Bala.	Ashgill Beds. (Ashgillian or Upper Bala).	Upper Bala.	Plynlimon Beds (Upper Bala).	Upper Bala.	Upper Bala.	Llandeilo Beds.

O. T. JONES.

II. Intrusive Igneous Rocks.

By ALFRED HARKER.

Newer Granite group of Scotland.

There is a great group of igneous intrusions which may be assigned to an epoch slightly earlier than that of the lowest Old Red Sandstone. These rocks are known in the Scottish Highlands by the name of the "Newer Granites", although they are not all of acid composition. They are younger than the great crust-movements and foliation of the region; but, on the other hand, pebbles of some of them are found in the conglomerates of the Lower Old Red Sandstone. The largest masses occur in the neighbourhood of the Dee valley (counties of Aberdeen and Kincardine with parts of Forfar and Perth), but others farther north in Sutherland and Caithness and to the westward through the county of Inverness. Their distribution is indicated on the map (fig. 27). Some of the masses have a general stratiform habit, though with much irregularity in detail, and this seems to be true of some very large bodies, such as that which makes the Cairngorm Mountains. Others have apparently an abrupt boss or stock-form. According to BARROW, all these intrusions in the Highlands, breaking through strata already highly metamorphosed, have produced in them very little change.

Petrographically the rocks of the "Newer Granite" group are largely biotite- and hornblende-granites and quartz-diorites; but there are also more acid granitic rocks and on the other hand numerous basic diorites and some peridotites. At many of the centres rocks of different kinds are intimately associated in "plutonic complexes". There the more acid types usually prevail, and occupy especially the central area, while the more basic varieties occur on the border. There is sometimes a gradual transition, sometimes a sharp boundary, between the different associated rocks. Wherever a definite sequence can be detected, the more acid type is of later intrusion than the more basic.

On the borders of Caithness and Sutherland intrusions belonging to this group range from acid to ultrabasic, including the typical 'scyelite' of Judd. In Sutherland masses of hornblende-granite occur also at Beinn Laoghal, Lairg, and elsewhere. In Nairn and the north-eastern part of Inverness there are granitic and other intrusions at Loch Moy, Abriachan, Stratherrick (quartz-diorite) and other places. In Banffshire intrusions at Ben Rinnes and elsewhere show an intimate association of quartz-diorite with biotite-granite, veined by muscovite-granite and pegmatite. A smaller boss at Netherley is of diorite with variable composition, more basic in the centre. In the north-eastern part of Aberdeenshire considerable masses of biotite-granite occur at Pitsligo and Peterhead, and numerous large intrusive masses, younger than the main crust-movements, are scattered along a belt of country extending south-westward from here nearly across Scotland. The complex west of Ellon includes not only diorites, but gabbros and norites, and there are ultrabasic as well as basic rocks in the ridge at Belhelvie. The large masses of Hill of Fare, Kincardineshire, Lochnagar, and Cairngorm are mainly of biotite-granite, sometimes graduating into quartz-diorite, and there are slightly earlier intrusions of basic diorites. The complex of Glen Tilt and Beinn Dearg, in Perthshire, includes basic diorites and granites. Near the head of Loch Linnhe is the basic diorite of Glen Loy, intersected by the granite (containing some muscovite) of Banavie. Other rocks in the West of Scotland assigned to this group are the quartz-diorite of Strontian, at the head of Loch Sunart, and the biotite-granite which makes the south-western promontory of the Isle of Mull. At Garabal Hill, near the head of Loch Lomond, is a complex including periodite, augite- and mica-diorites, tonalite, and hornblende- and biotite-granites (DAKYNS and TEALL 1892). Another plutonic complex is found at Carn Chois, N. of Comrie, in Perthshire.

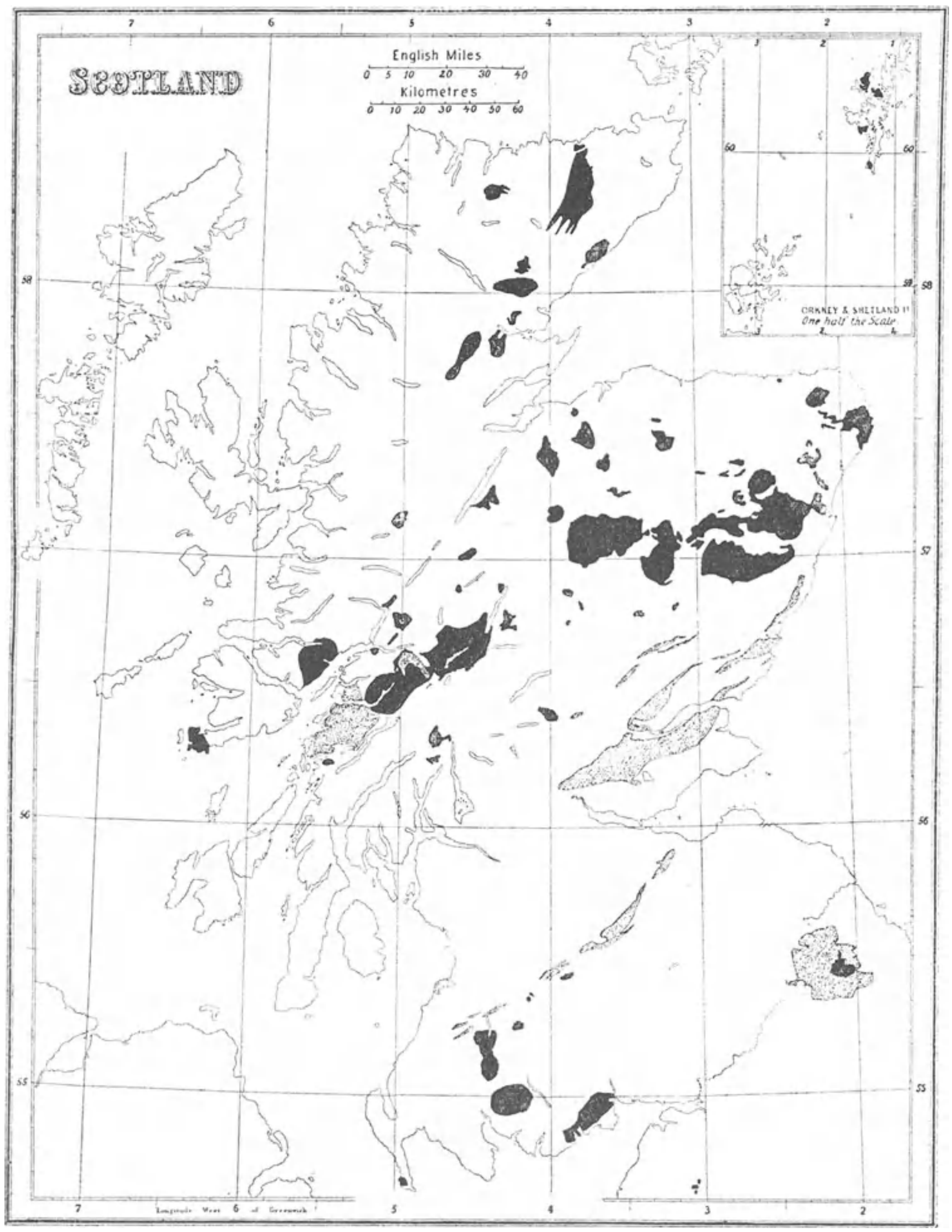

Fig. 27. Map to show the distribution of the Newer Granites of Scotland and of the volcanic and plutonic rocks of Lower Old Red Sandstone age (ALFRED HARKER). The plutonic intrusions are indicated in black and the volcanic districts by stippled areas.

In the South of Scotland occurs the important set of the 'Galloway Granites', which break through Lower Palaeozoic strata, and have caused important metamorphism. There are three chief masses: the Loch Dee intrusion of tonalite, with some quartz-hyperites and quartz-augite-diorites on its margin; that of Cairnsmore of Fleet, mainly of biotite granite; and that of Criffel, of the tonalite type, with oligoclase as the dominant felspar (Geol. Surv. 1899, pp. 607—25). Some smaller intrusions occur in other places, e. g. in the Lammermuir Hills, in the South-East of Scotland, but it is not possible to distinguish in every case these earlier intrusions from those of true Lower Old Red Sandstone age. The intrusion of Oatland, in the Isle of Man (p. 76), may not improbably be assigned to the 'Newer Granite' group.

In many parts of the Scottish Highlands there are minor intrusions, mostly dykes, which are to be regarded as satellites of the 'Newer Granites', and similar dykes accompany the Galloway intrusions. They are petrographically like the minor intrusions of the Old Red Sandstone age itself, to be noticed below, the common types being porphyrites, more acid felsites, and various lamprophyres (minette and spessartite).

The acid volcanic rocks in the Downtonian of Stonehaven (see p. 96) and others of similar character found at Rhynie may possibly be connected with these intrusives.

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b. Ireland.

By G. A. J. COLE.

Gothlandian rocks of the Llandovery stage have been represented on the Geological Survey maps of Co. Dublin and Co. Meath since 1901, occupying a considerable area between the Boyne and Skerries. C. I. GARDINER (1899) traced beds of Llandovery and Wenlock age, 700 m. (2300 ft.) thick, above Bala lavas and ashes, on the coast north of Balbriggan. The Llandovery beds contain fossils of the *Monograptus gregarius* and *spinigerus* zones of the Birkhill Shales; the age of the beds styled Wenlock rests on the presence of a form closely resembling *Monograptus riccartonensis*. It is believed that the grits of Dunmurry, on the south-east of the Kildare Ordovician inlier, may be of Llandovery age.

The uplifted regions of Gothlandian shales, slates, and sandstones forming the cores of the Armorican ranges of southern and central Ireland have been already referred to when similar Ordovician inliers were discussed. A notable area is exposed in the west of the Dingle Promontory in Co. Kerry, where Llandovery, Wenlock, and Ludlow beds are well represented along the sea-coast, and at several points inland. The Llandovery and Wenlock series, which are here not easily separated by their fossils, contain numerous rhyolitic lava flows and ashes, and also andesitic tuffs. The ashes continue into the Lower Ludlow stage (Geol. Surv. 1863; GARDINER and REYNOLDS 1902). The debatable Dingle Beds have been generally held to succeed the Ludlow, but A. McHENRY (1912) made the striking suggestion that they are identical with the "Smerwick Beds" of the north side of the Dingle promontory, and should, like those beds, be regarded as of Llandovery age (see p. 131). In the region round Killary Harbour, there is a local unconformity between the Ordovician and Gothlandian, and Bala beds may be absent; but the Owenduff series of grits and conglomerates, above the Mweelrea Grits, is of Llandovery to Wenlock age. Highly fossiliferous sandstones, corresponding with it, and containing *Pentamerus oblongus*, occur in the lowland to the north at Cregganbaun. J. R. KILROE found a zone of Wenlock (? Llandovery) age, rich in corals, high up on the south side of Croagh Patrick, among rocks previously regarded as Dalradian. South of Killary Harbour, Llandovery, Wenlock, and Ludlow sandstones and slates overstep the Dalradian schists (CARRUTHERS and MAUFE 1909; KILROE 1907).

Near Pomeroy, in Co. Tyrone, the Ordovician rocks pass up into Llandovery flagstones and shales, with *Diplograptus vesiculosus*, *Dimorphograptus confertus*, *Monograptus sedgwicki*, *M. triangulatus* and numerous other species of *Monograptus* An unfossiliferous series above may represent the Tarannon beds (FEARNSIDES, ELLES and SMITH 1907). *Monograptus* was recorded here by Portlock (1843).

The upland country that spreads north-east from Longford to the coast of Co. Down is largely composed of Gothlandian shales and sandstones. The rocks are greatly crumpled, and Ordovician inliers appear, as in southern Scotland, on the crests of anticlinals here and there. Graptolites of Lower Llandovery (Birkhill and Gala) age have been described from Coalpit Bay near Donaghadee in Co. Down, and from other places (SWANSTON and LAPWORTH 1876-7).

R. CLARK (1902) has added some new localities, and has recorded the early plant *Berwynia carruthersi* from the Llandovery beds of Coalpit Bay.

The Gothlandian sea spread somewhat farther than the Ordovician; but there is no evidence that it passed across the whole Dalradian land. Beach-conditions are observable in the north of Co. Galway. A volcano manifested itself near Dingle in the sea that covered the whole of southern Ireland, and subsidence seems to have continued here at the close of Ludlow times, possibly as a consequence of the local weakening of the crust during the Wenlock epoch.

Economic Products.

Slate. Though it is difficult to rival the slates of N. Wales, good green slates are raised from Silurian strata at Clashnamuth near Carrick-on-Suir, and at Kilmoganny in Co. Kilkenny. Quarries are also worked in the Silurian slates of Killaloe on the lower Shannon.

Clay. The Ordovician shales near Waterford have been successfully crushed into a clay for brickmaking.

Road-metal. The basic intrusive rocks in the Silurian areas are commonly used for road-metal.

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See also PORTLOCK, J. E.

5. Devonian.

a. Great Britain.

I. Sedimentary Rocks.

By JOHN W. EVANS.

A. South Devon and Cornwall.

On the south of the wide syncline that traverses the county of Devon the rocks have been thrown, under the influence of powerful pressure from the south and south-east, into numerous plications, which often pass at the apex into thrusts; while minute disturbances of the same character give rise to a "thrust cleavage" which has to a large extent obliterated the original lamination of the rock. The bedding is frequently difficult to discover, except when it is revealed by bands of different composition, or lava flows, and the apparent thickness of the rock is increased by its plicated state. The geological structure, and the nature of the succession must therefore often be inferred from a comparison with less altered localities, or ascertained by fossil evidence. The lithological character is however not sufficiently persistent to constitute a safe guide, and all traces of organisms are frequently destroyed by cleavage, or the metamorphic action of great masses of granite. Where the structure can be satisfactorily determined, it is usually found that the major flexures are essentially simple, though complicated by powerful dip and strike faults and overthrusts.

The lowest Devonian beds which have at present been recognised in this area are the Dartmouth Slates, consisting of pink, purple and green slates with grit-beds and more or less calcareous bands. They outcrop in an anticline crossing the southern projection of Devonshire in an east and west direction, and appear again at Rame Head in East Cornwall beyond Plymouth Sound with a west-south-west strike, which carries them out to sea, only to be brought back more than once within the coast line by powerful oblique faults. As the St. Austell granite boss is approached, they are faulted out of sight, but emerge to the north-west of the granite in an anticlinal dome, intersected by the coast at Watergate Bay. Their relations with older rocks is still uncertain.

With the exception of *Bellerophon trilobatus* Sow. and *Loxonema*, which are confined to the South Coast, the Dartmouth slates have yielded only a fish fauna of Lower Old Red Sandstone facies, including *Pteraspis cornubica* M'COY, *Cephalaspis carteri* M'COY, spines, coccostean plates and on the North Coast *Phlyctaenaspis*, *Climatius* and *Parexus*.

The Dartmouth slates are overlain conformably by the Meadfoot Beds[1].

The base consists of slates with arenaceous bands, and contains no fossils, but the slates with sandy and siliceo-calcareous bands which succeed have yielded a marine fauna, though *Pteraspis* is still found. The fossils reported to occur include *Rhynchonella pengelliana* DAVIDSON, *Rh. papilio* KRANTZ, *Spirifer hystericus* SCHLOTH., *Sp. primaevus* STEIN., *Sp. subcuspidatus* SCHNUR, *Rensellaeria strigiceps* RÖMER, *Orthis circularis* Sow., *O. personata* ZEILER, *O. vulvaria* PHILL., *Orthotetes umbraculum* SCHLOTH., *Stropheodonta gigas* M'COY, *Atrypa aspera*, SCHLOTH., *Bellerophon trilobatus* Sow., *Pleurotomaria cancellata* PHILL., *Alveolites labechei* MILNE-EDWARDS, *Pleurodictyum problematicum* GOLDF., *Phacops ferdinandi* KAYSER, *Neritopsis cornubicus* UPFIELD GREEN (a fossil of uncertain affinities) and *Lodanella mira* KAYSER. These may however represent more than one horizon.

The higher Meadfoot Beds of the Paignton and Torquay anticlines contain a somewhat different fauna, including *Chonetes sarcinulata* SCHLOTH., *Rhynchonella daleidensis* F. RÖMER, *Spirifer hystericus*, *Sp. paradoxus* SCHLOTH. and *Pterinea costata* GOLDF.

It is believed that strata of Meadfoot age are also represented in the metamorphic aureole of the St. Austell granite and on the shores of St. Austell Bay, and extend to the north-west coast on both sides of the anticline of Dartmouth Slates.

West of St. Austell Bay and south of the rocks last described is a great tract of almost unfossiliferous strata, known as "killas" by the miners, which have been mapped as the Manaccan or Grampound Grit[2], and Portscatho, Falmouth and Mylor Series, but their relations and the question to what extent they are of Devonian age are still in dispute (HILL 1906, 1912, 1913; GREEN 1908, 1912, 1913). On the south they are in contact with rocks shattered by thrust faulting and containing Ordovician and Silurian fossils.

The Meadfoot Beds are is succeeded by the Staddon Grits, consisting mainly of reddish grits and sandstones with associated shales and slates. They are usually placed in the Lower Devonian, but at Warberry Hill in the Torquay anticline the rocks attributed to this series are stated to contain *Spirifer cultrijugatus* F. RÖMER and

[1] Near Start Pont the Meadfoots are faulted against crystalline schists (see p. 33), believed by some authors to be of Devonian age.

[2] Recently an Orthis allied to *O. personata* ZEIL. of the Siegener Grauwacke but more coarsely costate has been described from the Grampound Grit (THOMAS 1912).

Orthotetes umbraculum SCHLOTH., the former suggesting the base of the Middle Devonian[1]. The Staddon Grits also outcrop on the north of the anticlinal axis that traverses the south of Devon, reappear in the Staddon Heights on the shores of Plymouth Harbour, and continue through Cornwall, passing north of the St. Austell Granite to the North Coast, where they form the Denzil Downs and the cliffs of Trenance Point.

At a higher horizon are the dark grey slates of Daddyhole near Torquay with *Calceola sandalina* LAMK., *Pentamerus biplicatus* SCHNUR, and *Cyrtia whidbornei* DAVIDSON. *Calceola* is also found in the shaly limestones overlying the slates in the same neighbourhood, but not in the dark slaty limestone of Hope's Nose, where *Cyathophyllum heterophyllum* FRECH, *Heliolites porosa* GOLDF., *Athyris rugata* DAVIDSON, *Atrypa aspera* SCHLOTH., *Kayseria lens* HALL, *Pentamerus biplicatus* SCHNUR, *Productella subaculeata* MURCH, *Rhynchonella parallelepipeda* BRONN, *Rh. procuboides* KAYSER, *Orthotetes umbraculum* SCHLOTH., and *Spirifer curvatus* SOW. are met with. The more massive limestones in the same neighbourhood are characterized by *Heliolites porosa* GOLDF., *Cystiphyllum vesiculosum* GOLDF., *Striatopora cristata* BLUMENB., and, at Lummaton Hill, the Upper Devonian coral, *Phillipsastraea hennahi* LONSD. Here the upper portion is locally replaced by a shelly limestone containing numerous fossils, including *Orthoceras robertsi* WHIDB., *Macrochilina arcuata* SCHLOTH., *Holopella tenuisulcata* SANDB., *Bellerophon lineatus* GOLDF., *Conocardium clathratum* D'ORB., *Actinopteria texturata* PHILL., *Stringocephalus burtini* DEFR., *Merista plebeia* SOW., *Retzia longirostris* KAYSER, *Spirifer verneuili* MURCH., *Sp. undiferus* F. RÖMER, *Sp. nudus* SOW., *Cyrtina heteroclyta* DEFR., *Atrypa aspera* SCHLOTH., *A. flabellata* GOLDF., *Pentamerus brevirostris* PHILL., *Rhynchonella acuminata* MARTIN, *Rh. pugnus* MARTIN, *Rh. cuboides* SOW., *Orthis striatula* SCHLOTH., *O. eifeliensis* de VERN., *Orthotetes umbraculum* SCHLOTH., *Stropheodonta interstrialis* PHILL., and *Productella subaculeata* MURCH. The shells were probably deposited in hollows worn by marine currents in the limestones.

Thick beds of strongly cleaved crystalline limestone also occur in the neighbourhood of Plymouth. It is largely made up of stromatoporids and corals including *Stromatopora concentrica* GOLDF., *Acervularia goldfussi* DE VERN., *Heliophyllum helianthoides* GOLDF., *Cystiphyllum vesiculosum* GOLDF., *Calamopora goldfussi* D'ORB., *Pachypora cervicornis* BLAINV., *Heliolites porosa* GOLDF., *Phillipsastraea hennahi* LONSD., *Pleurodictyum problematicum* GOLDF., accompanied by *Stringocephalus burtini* DEFR., and other brachiopods, nearly all of which are found at Lummaton.

Though usually described as Middle Devonian, the Torquay and Plymouth limestones may equally well be referred to the base of the Upper Devonian.

No continuous succession of the Upper Devonian is known, but at Saltern Cove near Torquay the Büdesheimer Schiefer are represented by mudstones with nodular and lenticular limestone, which have yielded: *Tornoceras auris* QUENST., *T. simplex* v. BUCH, *T. ausavense* STEIN., *Gephyroceras orbiculum* BEYR., *G. calculiforme* BEYR., *Orthoceras schlotheimi* QUENST., *Pleurotomaria turbinea* STEIN., and *Buchiola retrostriata* v. BUCH; and the horizon of the Adorfer Kalk occurs at Petit Tor Combe, Ilsham and Lower Dunscombe (near Chudleigh) as a shaly limestone with *Manticoceras intumescens* BEYR. and *Beloceras multilobatum* BEYR. Red and green slates with *Entomis serratostriata* SANDB., and *Posidonomya venusta* MÜNST. are found in a number of localities in South Devon and appear to occupy a still higher position.

The succession in Cornwall above the Staddon Grits cannot be exactly correlated with that in South Devon. There is, in the first place no really

[1] Other rocks in the same neighbourhood contain Meadfoot fossils though lithoogically similar to the Staddon Grits.

satisfactory palæontological evidence for the occurrence of Middle Devonian rocks in Cornwall. The slates mapped as of that age have yielded near Bedruthan Steps on the north coast *Pteroconus mirus* HINDE, of uncertain affinities, *Pachypora reticulata* BLAINV., *Palasteriscus devonicus* STÜRTZ, *Polypora ripisteria* GOLDF., *Orthis arcuata* PHILL., *Orthoceras aff. cochleiferum* SANDB., as well as fish remains, referred by Dr. SMITH WOODWARD to the typically Lower Devonian *Pteraspis* and *Climatius*; and the whole assemblage might be of that age. At Porthcothan to the north-east, on the other hand, the fossils include *Conularia complanata* SLATER, var., *Asteropyge punctata* SALTER non STEIN., *Phacops* cf. *granulatus* MÜNST., *Ph. latifrons* BRONN, and, in the same neighbourhood, *Orthoceras robertsi* WHIDB.; a fauna which might be Upper Devonian. The occurrence, however, of *Kophinoceras* at Cant Hill on the north of the River Camel suggests the occurrence of Middle Devonian rocks at that locality.

Further to the north-east the Upper Devonian is well exposed in the cliffs on both sides of Padstow Harbour. It is strongly cleaved but lies in gentle undulations striking a little south of east. Near Tintagel it is highly metamorphosed by a concealed extension of the Bodmin Moor granite. The following horizons have been described but the succession is not in every case free from doubt.

7. Pale greenish-grey slates of Bounds Cliff with salmon-coloured bands of thin grits and lenticles of lava.
6. Purple and green slates of Daymer Bay with *Posidonomya venusta* MÜNST., *Tentaculites*, *Trimerocephalus anophthalmus* FRECH, *Phacops latifrons* BRONN, and *Entomis serratostriata* SANDB.; metamorphosed near Tintagel into the Tredorn Phyllites.
5. Thin black slate, the Trembley Cove Beds of the Tintagel area.
4. Pillow lava.
3. Blue black soft slate of Daymer Bay with *Chonetes hardrensis* PHILL., *Modiella pygmea* CONR., *Orthoceras commutatum* C. G. GIEBEL and *Tornoceras* cf. *auris* QUENST., represended by the Barra Nose Beds near Tintagel.
2. Grey slate of Port Quin with *Allorisma concinna*, I. THOMAS, *Buchiola retrostriata*? v. BUCH, several species of *Cheiloceras* including *Ch. Verneuili* MÜNST., *Trimerocephalus pentops* I. THOMAS and small gastropods (= Nehdener Schiefer).
1. Striped calcareous grey slates containing: at Dinas Head, black chert with radiolaria and silicified *Phillipsastraea;* in Trevone Bay, *Buchiola retrostriata* v. BUCH, *Styliola*, *Tentaculites*, *Anarcestes lateseptatus* BEYR., *Tornoceras simplex* v. BUCH, *Cheiloceras globosum* MÜNST., *Mimoceras compressum* BEYR. and *Trimerocephalus trinucleus* THOMAS = *T. laevis* SALTER, ? MÜNST. (= Büdesheimer Schiefer); in Booby's Bay, *Buchiola retrostriata* v. BUCH, *Tentaculites*, *Conularia complanata* SLATER var. and *Anarcestes* cf. *nöggerathi* v. BUCH and seams of black grit and phosphatic nodules enclosing *Conularia*, which are found also in the immediately underlying similar but less calcareous beds, south of Treyarnon Point.

The base of the grey slates is obscured by sand, but in the metamorphosed area, where they are represented by the Woolgarden Phyllites, they rest on grey-green and blue-grey slates passing laterally into mica schist. The former yield near Delabole a large variety of *Spirifer verneuili* MURCH., and fish remains resembling *Psammosteus*.

Inland no continuous definite succession can be made out, but the occurrence of the pillow lava affords an indication of the geological structure, the main outcrop extending south-eastward to similar volcanic rocks near Plymouth (vide p. 126), which, however, are usually considered to belong to a lower horizon. In the valley of the Tamar the highest strata of the North Coast are represented near South Petherwin by greenish calcareous slates, and limestone, succeeded by massive sandstone, blue slates and calcareous sandy shales. The fossils include: *Phacops latifrons* BRONN, *Ph. granulatus* PHILL., *Proetus dunhevidensis* THOMAS, *Asteropyge punctata* SALT., *Tornoceras lineare* MÜNST., *Clymenia laevigata* MÜNST., *C. undulata* MÜNST., *C. striata*, MÜNST , *Actinopteria subradiata* PHILL., *Aviculopecten* *transversus* Sow., *Posidonomya venusta* MÜNST., *Buchiola retrostriata* v. BUCH, *Sanguinolites sulcata* MÜNST., S. *elliptica* PHILL. (upper beds only), *Murchisonia angulata* PHILL., *Bellerophon trilobatus* Sow., *B. hiulcus* Sow., *Capulus compressus* GOLDF., *Loxonema römeri* KAYSER, *Athyris concentrica* v. BUCH, *Orthis interlineata* Sow, *O. striatula* SCHLOTH., *O. resupinata* MART., *Atrypa desquamata* Sow., *Chonetes hardrensis* PHILL., *Rhynchonella acuminata* MART. *var. mesagona* PHILL., *Rh. ferquensis* GOSSELET, *Spirifer verneuili* MURCH., *Ambocoelia urei* FLEM., *Orthotetes crenistria* PHILL. var. *arachnoidea* PHILL., *Productella productoides* MURCH.

Still higher are the green and black slates of the inliers north of Petherwin and Launceston containing *Phacops latifrons* BRONN and *granulatus*, *Entomis serratostriata* SANDB., *Sanguinolites elliptica* PHILL., *Bellerophon hiulcus* Sow; *Clymenia* sp., *Ambocoelia urei* FLEMM., *Orthis* n. sp., *O. interlineata* Sow., *Athyris* n. sp. and *Aulocystis entalophoroides* SCHLÜTER.

The junction with the Carboniferous is usually a line of fault, often a thrust, bringing the Devonian above the Carboniferous. Sometimes the Carboniferous appears to overlie the Devonian conformably, but there is in reality a break, for the beds that cover the Devonian are high above the base of the Carboniferous, and the Devonian inliers represent higher horizons the further north they are found.

B. North Devon and West Somerset.

The strongly cleaved Devonian rocks to the north of the great syncline exhibit throughout a more arenaceous facies. They extend, with one break, in a band about 24 km. (16 miles) wide on the south of the Bristol Channel from the Quantock Hills on the east, to the estuary of the Taw (ETHERIDGE 1867, HAMLING 1909). In the north they form an anticline with a west-north-west and east-south-east strike but in general they dip to the south-south-west with local undulations and faulting.

The lowest rocks are believed to be the Foreland Grits, which extend eastward along the coast from Lynmouth to Minehead. They consist of red and grey quartzose grits, interbedded with reddish slates, and resemble the arenaceous beds of the Lower Old Red Sandstone. They are faulted against the Lynton Slates, but are presumably of earlier date, for a small patch of the latter is seen resting on the grits. They are as a rule unfossiliferous, but plant remains recently discovered near Porlock have been refered by W. N. EDWARDS to the Lower Old Red Sandstone genus *Psilophyton* (EVANS 1914).

The Lynton Beds consist of bluish grey irregular slates with interstratified grits and more or less decalcified calcareous bands. They appear to include more than one horizon between the Hunsrückschiefer and the summit of the Lower Devonian. In the immediate neighbourhood of Lynmouth, especially on the east they contain fish remains, among which *Pteraspis* has been recognised by SMITH WOODWARD (1901). Further west numerous fossils have been collected, among which the following have been stated to occur: *Spirifer primaevus* STEIN., *Sp. hystericus* SCHLOTH., *Sp. canaliferus* STEIN., *Orthis arcuata* PHILL., *O. longisulcata* PHILL., *Chonetes sarcinulata* SCHLOTH., *Orthotetes umbraculum* SCHLOTH, *Orthot. hipparionyx* VANUX. (= *proximus* VANUX.), *Pterinea spinosa* PHILL., *Pt. fasciculata* GOLDF., *Modiomorpha lamellosa* BEUSH., *Ctenodonta krachtae* RÖMER, *Megalodon cucullatus* Sow., *Bellerophon striatus* BRONN, *Pachypora cervicornis* BLAINV. and *Alveolites suborbicularis* LAM. The highest beds contain *Orthis arcuata* PHILL. and *Chonetes sordida* Sow. (which has been identified with *Ch. hardrensis* PHILL.).

The Hangman Grits, which succeed the Lynton Slates and resemble the Foreland Grits, form the Quantock Hills and a ridge of high ground terminating in Hangman Point on the north coast to the west of Lynmouth. At some horizons casts of indeterminable lamellibranchs, gastropods and brachiopods including *Myalina*, *Natica* and *Spirifer* are found, as well as the "corduroy plant" of the Middle Old Red Sandstone (p. 117). They are usually placed in the Lower Devonian, but are probably, in great part at least, Middle Devonian. To the southward they pass upwards into the Combe Martin Beds, red and grey slates containing *Stringocephalus burtini* Defr. and lamellibranchs and gastropods. These are succeeded by the Ilfracombe Beds, a thick series of silver grey slates with intercalated limestones. The fossils reported include the following: *Stromatopora concentrica* Goldf., *Cystiphyllum vesiculosum* Goldf., *Cyathophyllum caespitosum* Goldf., *C. helianthoides* Goldf., *Pachypora cervicornis* Blainv., *Tentaculites*, *Trimerocephalus trinucleus* Thomas, *Athyris concentrica* v. Buch, *Atrypa desquamata* Sow., *Cyrtia heteroclyta* Defr., *Merista plebeia* Sow., *Orthis interlineata* Sow., *O. striatula* Schloth., *Rhynchonella cuboides* Phill., *R. pleurodon* Phill., *R. pugnus* Sow., *Spirifer canaliferus* Stein., *Sp. curvatus* Schloth., *Sp. verneuili* Murch., *Sp. nudus* Sow., *Orthotetes crenistria* Phill., *O. umbraculum*, *Strophomena rhomboidalis* Wahl. and *Megalodon cucullatus* Sow. Tuffs and possibly lavas occasionally occur. The absence of *Calceola sandalina* Lam. and *Stringocephalus burtini* Defr. and the occurrence of *Spirifer verneuili* Murch. at a comparatively low horizon and of *Rhynchonella cuboides* Phill. point to the conclusion that the greater part, if not the whole, of the Ilfracombe beds must be referred to the Upper Devonian.

To the southward they are succeeded by the grey Morte Slates which include occasional calcareous nodules and arenaceous bands, the latter containing rounded grains. They are highly cleaved and yielded no fossils till Hicks discovered near Woolacombe Bay and Ilfracombe some distorted brachiopods and lamellibranchs. These he believed to be characteristic of Silurian (Gothlandian) rocks, and accordingly contended that the slates represented a faulted inlier of that age; but the doubts raised by the unsatisfactory condition of the fossils, the absence of anything that could be accepted as graptolites and the dissimilarity to the Silurian of the Mendips, South Wales and South Cornwall have been justified by the recent discovery of a well preserved *Spirifer verneuili*[1] (Evans and Pocock 1912).

Next in order are the Pickwell Down Sandstones consisting of friable red, purple, brown and green grits, sandstones and shales, containing iron ore at the base, traces of fish remains, and fossil wood. They pass upwards into the Baggy and Marwood Beds, grey, green or yellowish sandstones, flags and shales, with a fauna consisting chiefly of lamellibranchs, including *Leptodomus constricta* M'Coy, *L. semisulcata* Sow. *Myophoria deltoides* Phill., *Ctenodonta antiqua* Sow., *Cucullaea unilateralis* Sow., (including var. *trapezium* Sow.), *Ptychopteria damnoniensis* Sow., *Bellerophon subglobatus* M'Coy, the myriapod *Cariderpestes*, phyllopods, *Lingula squamiformis* Phill. and plant remains. These are succeeded by the Pilton Beds, grey flags and shales with calcareous bands. The rocks included in this series appear to graduate upwards into the base of the Carboniferous, the stratigraphical break occurring at a higher level than on the south of the syncline. Only five forms are common to the Baggy and Marwood beds, *Leptodomus constricta* M'Coy, *Sanguinolites mimus* Whidb., *Ptychopteria damnoniensis*[2] Sow., *Actinopteria rudis* Phill. and *Lingula squamiformis* Phill. The lowest beds are characterized by *Rhynchonella laticosta* Phill., *Rh. pleurodon* Phill., and *Spirifer urei* Fleming.

[1] In West Somerset Hicks found at Treborough in slates usually referred to the Ilfracombe Beds, highly cleaved fossils, which according to Whidborne belonged to the horizon of the "lowest beds" of the Rhenish Devonian; and at Oakhampton in rocks mapped as Morte Slates others corresponding to the higher beds of the Lower Devonian; but at the latter of these localities *Sp. verneuili* Murch. is said to have been found (Ussher 1910).

[2] Phillips however made the Pilton fossil, which only occurs in the lower beds, a separate species, "*cancellata*".

At a higher horizon *Strophalosia productoides* Murch. and *Chonetes hardrensis* Phill. are common. Among other fossils in the beds which are regarded as Devonian may be mentioned *Phacops latifrons* Bronn, *Pleurotomaria gracilis* Phill., *Aviculopecten transversus* Sow., *Spirifer verneuili* Murch., *Sp. obliterata* Phill., *Spiriferina cristata* Schloth. var. *octoplicata* Sow., *Orthis interlineata* Sow., *Leptaena rhomboidalis* Wilckens and *Productus praelongus* Sow. The plants *Knorria dichotoma* Haugh., *Archaeopteris hibernica* Forbes and *Sagenaria veltheimiana* Sternb. are also stated to occur.

C. South-east of England.

Upper Devonian rocks somewhat similar to those of North Devon, the Boulonnais and the Bassin de Namur exist below the Thames valley. The Frasnian is represented in a boring in London by mottled red, purple and greenish shales very calcareous in places, with thin seams of quartzite. They dip at 35° (probably to the south) and contain *Spirifer verneuili* Murch., *Rhynchonella boloniensis* d'Orb. (? *Rh. ferquensis* Goss.). In a boring at Southall red and mottled clays and coarse sandstone have yielded *Holoptychius* and *Bothriolepis*, while at Turnford near Cheshunt dark chocolate coloured beds have been reached, with *Spirifer verneuili* Murch., *Rhynchonella cuboides* Sow., *Leptaena rhomboidalis* Wilck., *Ptychopteria damnoniensis* Sow. and *Actinopteria texturata* Phill., which indicate a Lower Pilton horizon (Whitaker 1889, Proctor 1913, Smith Woodward 1913). Other borings have yielded similar rocks but no fossils.

D. South Wales and the Welsh Border.

To the northward of the Bristol Channel and its continuation in the low ground near Glastonbury the Devonian is represented by rocks of the Old Red Sandstone facies. These are exposed in the anticlines of the Mendips in north-east Somerset, and reappear in Gloucestershire, whence they extend northward to the neighbourhood of Wenlock in Shropshire, 52° 36′ N., and westward through Wales on the north of the South Wales Coal-field into Pembrokeshire, where they are overlapped by the Carboniferous. They are also seen at intervals on the south of the Field. On the east they are bounded by a line of disturbance running northward from near Bristol to beyond Bridgenorth but similar rocks underlying the Coal Measures have been proved by boring near Northampton (Geol. Field, p. 452).

The Old Red Sandstone of this area consists of a Lower and Upper portion, which are usually apparently conformable, but their organic contents are entirely distinct, and the palæontological break must represent a considerable interval of time.

In Shropshire and Montgomery the highest beds of the Gothlandian (Silurian), present considerable resemblance to the Old Red Sandstone but still contain *Lingula cornea* Sow.[1], associated with *Cyathaspis banksi* Huxley and Salter and *Cephalaspis murchisoni* Egert. They are succeeded conformably by the Red Marls the lowest division of the Old Red Sandstone. On the south, on the other hand, there is usually a distinct break; the base of the Old Red consists of gritty or conglomerate beds, and the uppermost portion of the Gothlandian is missing.

The Red Marls are usually about 1000 m. (over 3000 ft.) in thickness and consist of red and green argillaceous rocks, usually more or less sandy, with intercalated beds of sandstone. They also contain calcareous or dolomitic material, known as "cornstones", which are not of organic origin. The cornstones occur sometimes as concretions (locally known as "race"); sometimes as conglomeratic

[1] *Lingula* is frequently associated with Old Red Sandstone conditions, see pp. 109 and 111 and Frech, Lethaea Geognostica vol. 2, p. 224.

aggregates of these concretions in a gritty matrix, as if the argillaceous material had been washed out by a strong current, and sometimes as compact limestones. They are frequently found at the same horizon in distant localities.

The fossils of the Red Marls include *Pteraspis rostrata* AGASS., *Pt. crouchi* LANK., *Cyathaspis maccullоughi* SMITH WOODWARD, *Palaeaspis sericea* LANK., *Eukeraspis*, *Cephalaspis lyelli* AGASS., *C. salweyi* EGERT., *Psammosteus*, *Climatius* (?) *ornatus* AGASS., *Protodus*, *Pterygotus*, *Pachytheca* and *Nematophycus* (a mass of apparently endless tubes). An isopod, *Praearcturus gigas* H. WOODWARD, has been described from the cornstones.

On the north the Red Marls are succeeded conformably by the Senni Beds, green and red sandstones and marls with cornstones. They are sometimes more than 200 m. (650 ft.) thick. They contain *Pteraspis*, and *Cephalaspis*, and are of Lower Old Red Sandstone age. In the east they have not been separated from the Upper Old Red Sandstone Beds above. In the south-west the Cosheston Sandstones and the Ridgeway Conglomerate occupy a similar position.

The lowest beds of the Upper Old Red Sandstone are the Brownstones; brown, red or green gritty sandstones and red marls, which contain remains of plants with Upper Old Red Sandstone affinities, and pass up into the conglomeratic Plateau Beds. Although there is no apparent discordance[1] between the Upper and the Lower Old Red Sandstone, the former overlap not only the Senni Beds, but the Red Marls and rest in the peninsula of Gower, at Tortworth, and in the Mendips on the Gothlandian rocks. The pebbles have been found to consist of subangular quartzites and red jasper, the latter being the result of the jasperization of various rocks, including a perlitic felsite, in a manner similar to that which is believed to take place under desert conditions. At the same time the sand of the finer grained rocks is characteristically rounded. Near Bristol the Brownstones are represented by strata containing a considerable amount of carbonate of lime. To the north-east and east of the South Wales Coal-field the highest beds consist of yellow, red and grey sandstones similar to the Kiltorcan beds of Ireland, and contain *Archanodon* (*Amnigenia*) *jukesi* FORBES, *Holoptychius*, *Glyptopomus*, *Bothriolepis macrocephala* EGERT. (at Farlow in Shropshire), *Conchodus*, *Ceraspis*, *Strepsodus*, *Sauripterus anglicus* SMITH WOODWARD and rhizodont teeth and scales[2]. On the north of the Coal-field the uppermost beds consist of grey grits or quartzites, the latter yielding at Penlan near Kidwelly remains of plants including *Artisia approximata* BRONGN., a calamitic pith-cast, *Stigmaria ficoides* STERNB., and *St. inaequalis* GÖPP.

The Upper Old Red Sandstone of the south of Pembroke is represented by the Skrinkle Sandstones, quartzitic sandstones and breccias of subangular quartz fragments. At several places it includes marine intercalations in its upper part.

At Sandtop Bay in Caldy Island off the south-east coast of Pembroke, there is a thin bed of tubular organisms described by SALTER as *Serpula advena*, associated with calcareous marls, and sandstones with lenticles of detrital limestone, made up of crinoids, bryozoa, and probably lamellibranchs, with palatal fish teeth similar to Carboniferous types. At Skrinkle Bay on the adjoining mainland greenish grey soapy shales with *Modiola* and *Lingula* occur. At West Angle Bay at the entrance to Milford Haven there are several marine bands, of which the principal is conglomeratic at the base and sharply marked off

[1] Near Milford Haven there appears to be in places considerable difference in dip between the Lower Old Red Sandstone and the Carboniferous, and as the Upper Old Red Sandstone is elsewhere conformably overlaid by the Carboniferous, an uncomformity is inferred between the Lower and Upper Old Red in this area, though it has never been actually observed.

[2] I am informed by D. M. S. WATSON that in the Bristol Museum there is a specimen of *Bothriolepis*, probably near *hydrophila*, from the calcareous rocks near Clevedon, as well as a *Phyllolepis* from the yellow sandstones.

from the underlying rock; it consists of sandstones with plant remains, and shales and limestone containing marine forms, chiefly lamellibranchs. The highest marine band commences with a break indicated by borings penetrating the underlying red marl and similar breaks occur in the band itself. It contains a bed of dark grey shale with lenticular limestones, both crowded with lamellibranchs. Then follow grey shales, mud-stones, and sandstones with marine fossils, and finally a sandstone of Old Red type, containing brachiopods and crinoids, which is taken as the summit of the formation. SALTER (1859) notes the occurrence in the Upper Old Red Sandstone of this neighbourhood of *Serpula*, *Ptychopteria damnoniensis* SOW. (of the Marwood type), *Cucullaea unilateralis*, var. *trapezium* SOW., *Rhynchonella laticosta* PHILL. and *Bellerophon trisulcatus*.

Taking the Old Red Sandstone beds as a whole the arenaceous beds appear to become thicker to the north-west, as if they were derived from hills in that direction.

The green colour which characterizes certain beds is explained by the presence of dark green chlorite and yellow epidote (Mem. Geol. Surv., Sh. 231, p. 6). It is characteristically developed in parts of the Red Marls and the Senni Beds, but is sometimes found in the lower part of the Brownstones. It appears to result from the presence of organic matter, being associated with plants and worm borings, the latter sometimes U-shaped like those of *Arenicolites didymus* of the Cambrian.

E. North Wales, the Isle of Man and Lake District.

Between the South Wales area and the Cheviot Hills on the borders of England and Scotland, the Lower Old Red Sandstone appears to be absent, but the Upper Old Red Sandstone may be represented in Denbigh and Anglesey in North Wales, the Isle of Man and the Lake District, by red rocks consisting of conglomerates, sandstones and occasional marls and cornstones, underlying, in the Lake District with some discordance, the base of the Carboniferous, which belongs to a higher horizon than in South Wales. They are frequently included in that formation, but I prefer to retain them in the Upper Old Red until distinct evidence of their age is forthcoming (see also pp. 140, 143).

F. The Scotch Border.

In the Cheviot Hills, however, the Gothlandian is overlaid unconformably by volcanic rocks of Lower Old Red Sandstone age, which will be described later (pp. 122—125) and these again are covered with marked discordance by Upper Old Red Sandstone, which occupies a large area on the west and extends northwards to Dunbar and Eyemouth, resting unconformably on Ordovician, Silurian and Lower Old Red Sandstone. It commences with Red Conglomerates and Sandstones, (cream coloured and green in patches), which gradually become finer and are ultimately interstratified with marls. Rounded sand-grains frequently occur. The fossils include *Bothriolepis obesa* TRAQ., *B. leptocheira* TRAQ., scales of *Holoptychius nobilissimus* AGASS. and fragments of *Archaeopteris hibernica*. The upper portion, the Cornstone Series is of a less pronounced red colour, and rarely yields rounded sand grains; it contains flakes and concretionary masses of calcareous matter, which tends to pass into haematite. Sun-cracks and rain-pitted surfaces are common (GOODCHILD 1903). Similar beds occur at the base of the Carboniferous in Northumberland and are usually placed wholly or partially in that formation instead of in the Devonian.

Fragments not only of the Lower Old Red Sandstone volcanic rocks but also of the granite, dykes and sills intrusive in them can be recognised in the conglomerates of the Upper Old Red Sandstone.

G. The Midland Valley of Scotland.

The Old Red Sandstone rocks outcrop over a considerable area on both sides of the great north-east and south-west trough, that extends from the Firth of Clyde to the Firth of Forth and gives rise to the Midland Valley of Scotland. They are usually separated by powerful strike faults from the older rocks on the north-west and south-east, while in the centre they are covered by Carboniferous strata.

The south-eastern outcrop stretches from the south of Edinburgh south-westward to the coast of Ayr, but is interrupted by downthrows which bring in Upper Old Red and Carboniferous rocks. The uppermost beds of the Gothlandian (see p. 96) are mostly red in colour and present considerable resemblance to the passage beds in the South Wales area. They are referred to by the Survey as Downtonian but GOODCHILD, who believed that they occupied a somewhat higher horizon, termed them Lanarkian. They were formerly included in the Lower Old Red Sandstone, but the base of the true Lower Old Red the "Caledonian" of GOODCHILD, a thick series of conglomeratic sandstones and volcanic rocks, rests unconformably upon them.

The Lower Old Red Sandstone on the north-west margin of the Midland Valley is well seen on the east coast between the Firth of Tay and Downie Point, south of the great boundary fault of the Highlands and extends to the south-west to the north-east of Ireland. HICKLING (1908, 1912) gives the following downward succession in Forfarshire:

Edzell Shales (? 300 m. — 1000 ft.), fine sandstone, shales and marls,
Arbroath Sandstone (365 m. — 1200 ft.), coarse sometimes pebbly, with red flags and a band of limestones nodules.
Auchmithie Conglomerate (240 m. — 800 ft.) with well rounded quartzite pebbles and interstratified sandstones.
Red Head Series (460 m. — 1500 ft.), thin bedded sandstones and shales passing up into thicker bedded sandstone with volcanic rocks near the base.
Cairnconnan Grits, (610 m. — 2000 ft.), coarse sandstones with bands of conglomerate.
Carmyllie Series (300 m. — 1000 ft.), compact sandstones, flags and shales with interstratified lavas.
Dunottar Series (1500 m. — 5000 ft.), coarse red and grey sandstones, and conglomerates with large well rounded pebbles.
The beds above the Cairnconnan Grits constitute the Strathmore Sandstones.

The Dunottar sandstones and conglomerates are best seen south of Stonehaven (CAMPBELL 1911), where they rest conformably on the Downtonian. They include in the higher portion basalt and andesite flows. The conglomerates consist at first mainly of the early Palaeozoic rocks of the Highland border and the "newer granites". Later on the ancient crystalline rocks of the Highlands are also represented. The Auchmithie conglomerate consists of similar materials. The conglomerates and sandstones which succeed the lava flows are made up for the most part of volcanic materials and pass downwards into ashes and agglomerates. The surface of lava flows and fragments appears to have been oxidized to a deep red before they were covered by succeeding flows or deposits. The hollows in the lavas and agglomerates are frequently filled with a greenish matrix which seems to consist of fine volcanic dust mixed with arenaceous material. The Carmyllie flags resemble this matrix in appearance and apparently also in composition (HICKLING 1908, 1912 and JOWETT 1913).

In the lower beds the sandstones are usually dull red or grey, the shales red or blue and the colouring is comparatively uniform. Towards the summit of the Lower Old Red Sandstone red becomes the dominant colour and is of a brighter hue, while a curious mottling makes its appearance especially in the Edzell shales, which show small circular patches, or more rarely bands, of yellow, grey or green.

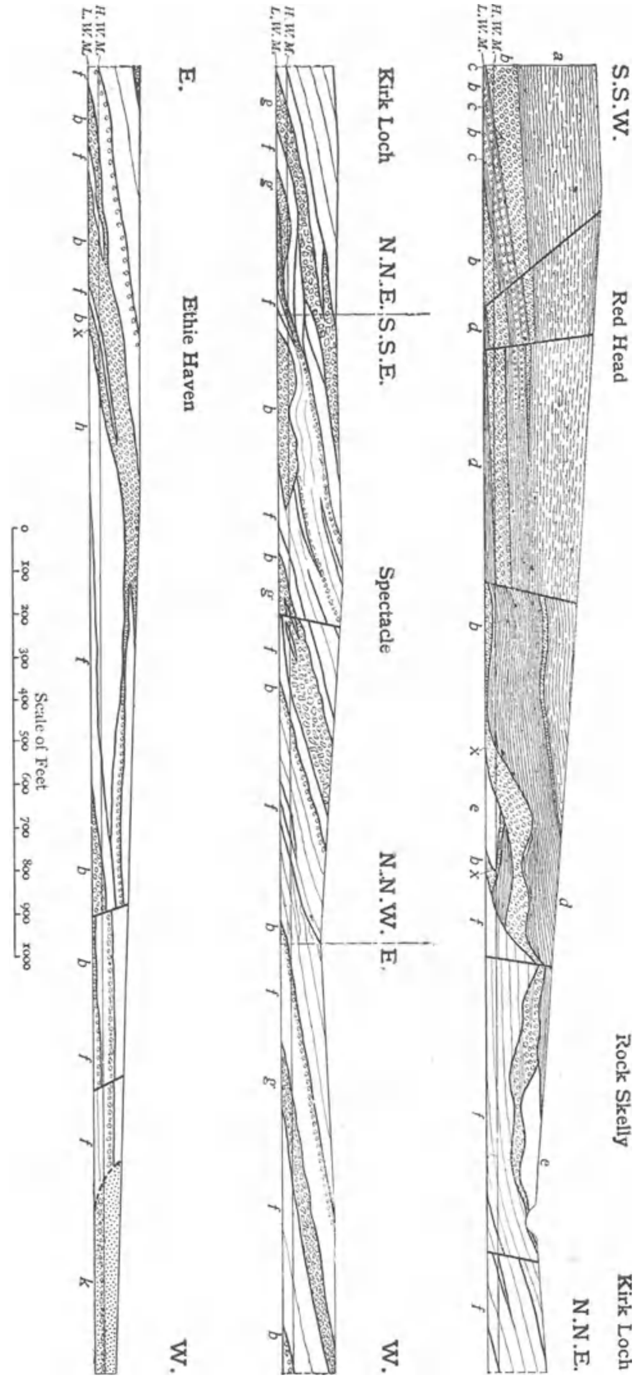

Fig. 28. Diagrammatic section along the coast of Forfarshire from the Red Head to Ethie Haven and the south-western corner of Lunan Bay (A. Jowett). Scale about 1:5400, nearly 12 inches to the mile.

k = Upper Old Red Sandstone: motled red sandstone and sandstone-breccia.
h = Olivine-basalt with plagioclase phenocrysts and olivine in the ground mass.
g = Masses of slaggy lava cemented by fine sediment.
f = Olivine-basalt with olivine phenocrysts.

Lower Old Red Sandstone:
e = Olivine-basalt, with glomero-porphyritic aggregates of olivine, augite and labrodorite.
d = Red shale with bands of fine conglomerate.
c = Finer sediments; materials nearly all volcanic.
b = Coarse conglomerate; materials nearly all volcanic.
a = Red and Grey sandstone.

x = Local unconformity.

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Most of the fossils occur in the Carmyllie and Cairnconnan series. They include the Acanthodi *Mesacanthus mitchelli* Egert., *Ischnacanthus gracilis* Pow., *Parexus incurvus* Agass., *P. falcatus* Pow., *Climatius reticulatus* Agass., *Cl. macnicoli*

POW., *Cephalaspis lyelli* AGASS., *Protodus scoticus* E. T. NEWTON, *Farnellia tuberculala* TRAQ., the Merostomata *Pterygotus anglicus* AGASS., *Pt. minor* H. WOODW., *Stylonurus scoticus* H. WOODW., *St. powriei* PAGE, *St. ensiformis* H. WOODW., *Eurypterus brewsteri* H. WOODW., the myriapods *Kampecaris forfarensis* PAGE and *Archidesmus macnicoli* PEACH; and the plants *Parka decipiens* FLEMING, (DON 1913[1]) and *Zosterophyllum myretonianum* PENHALLOW (HICKLING 1908, 1912, 1913).

A much higher plant horizon is stated (MACNAIR 1908) to occur in green-grey flags near the summit of the Strathmore Sandstones in the counties of Perth Stirling and Dumbarton and to be characterized by *Psilophyton princeps* DAWS. and *Arthrostigma gracile* DAWS., the former of which occurs in the Lower Devonian and the latter in the lower Middle Devonian of Canada.

The Upper Old Red Sandstone of the Midland Valley is usually found on the inner borders of the Lower Old Red Sandstone, which had already been thrown into well marked anticlines and synclines and worn to an irregular plain, when the Upper Old Red, which is still nearly horizontal, was laid down upon them. As in the border counties, it consists of conglomerates and red or mottled sandstones, succeeded by the Cornstone Series consisting of less deeply coloured beds with intercalated calcareous material, usually at definite horizons. Everywhere there is evidence of conformity with the overlying Carboniferous. *Holoptychius nobilissimus* AGASS. has been found below the dolerite sills of Salisbury Crags near Edinburgh and in Fife and other localities, *Sauripterus favosus* AGASS. at Clashbennie in Forfar, and *Bothriolepis leptocheira* at the Heads of Ayr. At Dura Den in Fife numerous fish remains have been found in sandstones belonging to the Cornstone Group including *Phyllolepis concentrica* AGASS., *Glyptopomus minor* AGASS., *G. kinnairdi* HUXLEY, *Gyroptychius heddlei* TRAQ., *Holoptychius flemingi* AGASS.,, *Phaneropleuron andersoni* HUXLEY, and at an horizon about 15 metres (50 ft.) higher, *Bothriolepis hydrophila* AGASS.

H. The Lorne Area.

In the neighbourhood of Oban on the Firth of Lorne, is a tract of rocks of Lower Old Red Sandstone age, extending from Loch Creran on the north to Loch Melfort on the south, including the islands of Seil and Lunga. Coarse breccias and massive conglomerates are succeeded by volcanic grits, tuffs, fine sandstones and shales containing *Psilophyton*, *Pachytheca*, *Mesacanthus mitchelli* EGERT., and *Cephalaspis lornensis* TRAQ., and *C. lyelli* AGASS., and these again by lavas and agglomerates.

I. Northern Scotland.

In the northern valleys of the Grampians, the shores of the Moray Firth, Caithness, and the neighbouring portion of Sutherland, the Orkneys, and Shetlands, are extensive deposits which are referred to as the Middle Old Red Sandstone or Orcadian. They are best developed in Caithness where they are known as the Caithness Flags. The following downward succession is described in the Memoir to accompany sheets 110 and 116 of the Geological Survey of Scotland. The thickness attributed to the Thurso Flagstone Group is probably excessive.

6. **John o'Groats Sandstone Group** (About 610 m., 2000 ft.) with *Tristichopterus alatus* EGERT., *Microbrachius dicki* TRAQ., *Dipterus macropterus* TRAQ., and *Mesacanthus peachi* EGERT. Yellow and red false-bedded sandstones with thin phosphatic blue flags and black bituminous shales.
   (Almost complete change in the type of deposit and fish fauna).

[1] An important paper by DON and HICKLING will shortly be published by the Geological Society.

5. **Thurso Flagstone Group** (over 1830 m., 6000 ft.) with *Estheria membranacea* PACHT., *Homosteus milleri* TRAQ., *Thursius pholidotus* TRAQ., *Coccosteus minor* MILLER, *C. decipiens* AGASS., *Glyptolepis paucidens* AGASS., *Osteolepis microlepidotus*, PANDER, *Cephalaspis magnifica* TRAQ., and *Dipterus valenciennesi* SEDGW. and MURCH.[1] Blue phosphatic and grey calcareous flags with pale mudstones, bituminous matter in bands and nodules, concretionary red and yellow sandstones and "boulder" beds.
4. **Achanarras Band.** (At Niand on the east coast and Achanarras south of Thurso), (not more than 3 m., 10 ft. in thickness) with *Diplacanthus striatus* AGASS., *D. tenuistriatus* TRAQ., *Glyptolepis paucidens*, *Osteolepis macrolepidotus* AGASS., *Diplopterus Agassizi* TRAILL,[2] *Rhadinacanthus longispinus* AGASS., *Mesacanthus*, resembling *M. pusillus* AGASS., *Cheiracanthus murchisoni* AGASS., *Pterichthys milleri* AGASS., *Pt. productus* AGASS., *Coccosteus decipiens* AGASS., *Homosteus milleri*, *Dipterus valenciennesi*, *Cheirolepis trailli* AGASS., and the supposed marsipobranch, *Palaeospondylus gunni* TRAQ. Dark bluish-grey calcareous flag.
(Large accession to fish fauna and further change in type of deposit).
3. **Passage Beds Group.** — (including the Noss Head, Castle Sinclair, Field, and Papigoe Beds in descending order) (About 760 m., 2500 ft.) with *Coccosteus decipiens*, *Dipterus valenciennesi* and *Thursius macrolepidotus* SEDGW. and MURCH., grey calcareous and dark shaly flags, hard blue and lenticular black limestone and sandy beds.
(Change in type of deposits and first appearance of *Coccosteus*).
2. **Wick Flagstone Group** (about 1830 m., 6000 ft.) with *Dipterus valenciennesi*, *Thursius macrolepidotus* and *Osteolepis* sp.; consisting of:
Wick Flags, Dark flags with pale grey sandstones and smooth fissile limestones containing fish remains.
Red Beds, Sandstones and shales.
Helman Head Beds, Black slates with *Thursius macrolepidotus*, and sandstones.
Upper Conglomerate, Conglomerate, sandstone and breccia.
(Local unconformity and change in type of deposits; first appearance of fish fauna.
1. **Basement Group** (about 460 m., 1500 ft.). Purple, green, and chocolate mudstones, passing down into sandstones, conglomerate, arkose, and breccia.

The Basement Beds are unfossiliferous, unless plates of *Pterygotus* found in the neighbourhood of Sarclet come from them. Local basement conglomerates or breccias also occur at higher horizons. The Wick flagstone group is characterized by the presence of *Thursius macrolepidotus* and absence of *Coccosteus decipiens*. The Passage beds contain both, and their lithological characters combine those of the Wick and Thurso group. Of the fifteen forms of fish found in the Achanarras bed, ten are confined to this horizon, two, *Coccosteus decipiens* and *Dipterus valenciennesi*, occur both in the Passage Beds and Thurso Group and two, *Homosteus milleri* and *Glyptolepis paucidens*, are found in the latter only. The John o'Groats Sandstones are distinct both in fauna and lithology from the lower beds.

At Cromarty, Lethen, Clun, Tynet Burn, Gamrie and other points on the shores of the Moray Firth, a coarse basement conglomerate is followed by dark shales with calcareous nodules containing fish, and these are covered by red sandstones and shales. The fauna is closely allied to that of the Achanarras horizon in Caithness, for all except two — *Palaeospondylus gunni*, and *Glyptolepis paucidens* — of the forms constituting the latter are found in the Moray Firth, and of the southern forms only *Glyptolepis leptopterus* AGASS. and *Gyroptychius microlepidotus* AGASS. are definitely missing in the Achanarras fauna, though the identification of *Mesacanthus pusillus* (AGASS.) is still uncertain. The only other horizon of the Middle Old Red Sandstone represented in the Moray Firth Area is that of the Thurso Group at Hillhead Quarry, Dalcross, Invernesshire, where

[1] D. M. S. WATSON informs me that he has found *Dipterus macropterus* high in the Thurso Group at Brimsness, associated with *Homosteus* and *Coccosteus decipiens*.
[2] A specimen collected by WATSON is in the Manchester Museum. He also found *Estheria membranacea* in the same bed.

Coccosteus minor, *Homosteus milleri* and osteolepid scales occur in small calcareous nodules in shale and sandstone (WATSON 1908). With the Moray Firth Middle Old Red Sandstone may be placed a number of outliers in the Grampians in the neighbourhood of Rhynie and Cabrach on the southern margin of the basin of the Deveron, Tomintoul on the upper waters of the Avon a tributary of the Spey, and Drynachan Lodge on the Findhorn. At Rhynie they consist of conglomerates of well rounded pebbles and sandstones with pipes and "galls" of red clay, Moray Firth fish and "corduroy" stems (see p. 108 and *infra*).

The Middle Old Red Sandstone is nowhere seen overlying the Lower Old Red, but the basement conglomerates of the Moray Firth Area contain pebbles of granite of the Lower Old Red type. In the neighbourhood of the river Spey these conglomerates are in some places mainly composed of a fine gray sandstone which may have been derived from Lower Old Red or Downtonian rocks then subject to denudation in that district. The possibility of the Basement Group in Caithness being of Lower Old Red Age must not be overlooked, while on the other hand, as suggested by HICKLING, the highest strata assigned to of the Lower Old Red sandstone in Forfarshire may conceivably be of Middle Old Red Sandstone age.

The Middle Old Red Sandstone of the Orkney Islands corresponds to the higher beds of Caithness. The Stromness Flags, which are chiefly developed in the west of Mainland with a thickness of about 400 m. (1300 ft.), consist, except where there is a local conglomeratic base resting on older rocks, of either dark blue flags with alternations of more sandy beds, in which rounded sand grains are met with, or calcareous or bituminous flags. The fossils are all common either to the Achanarras horizon in Caithness or to the Moray Firth Area.

The Rousay Flags, which mainly occur in the north and east and have a thickness of about 460 m. (1500 ft.), are similar in lithological characters to the Stromness Flags and have yielded most of the species of the latter, and in addition *Coccosteus minor* and *Thursius pholidotus*, which are characteristic of the Thurso group. *Estheria membranacea* is also common to the Rousay beds and the Thurso Flags. At the summit of the Rousay beds a specis of *Asterolepis*, a genus elsewhere confined to the Upper Old Red Sandstone, makes its appearance.

The fossils of the Orkney flags are usually met with in thin bedded fissile calcareous bands. The more argillaceous beds are apt to contain concretions, which give the rock a fretted appearance on weathering. The flags are often ripple marked and sun-cracked so that they must have been laid down in very shallow water.

The Rousay beds are covered conformably by the Eday Sandstones, yellow with thin fossiliferous flags below, and red and unfossiliferous above. The total thickness is about 150 m. (500 ft.). The fossils include *Tristichopterus alatus*, *Microbrachius dicki* and *Dipterus macropterus*, all found in the John o'Groats sandstones. A single specimen of the long-lived *Coccosteus decipiens* has also been found. The red sandstones sometimes contain layers of coarse gravel and local conglomerates, as well as flows of a vesicular olivine dolerite.

A remarkable feature is the accumulation of small specimens of *Osteolepis macrolepidotus*, *Dipterus valenciennesi*, *Glyptolepis paucidens* and *Coccosteus decipiens* at the summit of the Rousay Flags. A simular phenomenon occurs in the flagstone beds in the Eday sandstones.

The Middle Old Red Sandstone is characterized by distinct plant types including "*Lycopodites*" *milleri* SALTER and *Ptilophyton thomsoni* DAWSON, the stem of which was described as *Caulopteris peachi* by SALTER. It appears to range from the Wick Group to the Thurso Group in Caithness and occurs at Gamrie in the Moray Firth and Stroma and Stromness in the Orkneys. "Corduroy" stems showing a fluted surface without nodes, similar to those found in the Hangman Grits and at Rhynie, occur in the Thurso group in Caithness. Plant remains in the John o'Groats sandstone have been compared with *Sprochnus* (of Stur not Kuetzing) and *Rhacophyllum.*

The Old Red Sandstone occurs in Shetland on both sides of the central axis of metamorphic rocks of Mainland. A little west of Lerwick it is faulted down against the crystalline rocks and there is an upward succession eastward across Bressay Sound to the islands of Bressay and Noss, in which the following have been distinguished: (Flett 1909).

Bressay and Noss Series	Thin flaggy sandstones and grey shales of Noss. Grey micaceous thin bedded sandstones with fish remains, and coarser, less micaceous, gritty seams, often obliquely bedded, with rounded clay galls, fragments of plants and shreds of fine shale, Cullingsburgh Voe, Bressay. Brownish and grey sandstones often conglomeratic or breccia-form, West Bressay.
Lerwick Series	Grey micaceous sandstones with plant remains and *Estheria membranacea,* Nabb, south-east of Lerwick. Reddish and grey sandstones often current bedded, sometimes with large rounded pebbles of quartzite, granite etc.
	Rovey Head Conglomerate.
	Red Flags of Brenista.
	Basement Breccia.

As the Lerwick series contains *Estheria membranaca* and plant-remains similar to those of the Middle Old Red Sandstone of Caithness and Orkney, it is presumably of the same age. In the Bressay flags however at an horizon several thousand feet higher an undetermined species of *Asterolepis*, *Holonema ornatum* Traq., and a scale which may belong to *Holoptychius* have been found. *Asterolepis* though it occurs high up in the Middle Old Red of Orkney is mainly Upper Old Red, and *Holonema* only occurs elsewhere in the Upper Devonian Chemung Beds of North America. The Bressay flags may therefore be provisionally placed low down in the Upper Old Red.

The only evidence of the age of the red sandstones of West Shetland is the identification of plant remains in rocks metamorphosed by intrusions with those in the Lerwick series (Peach and Horne 1884).

The Upper Old Red Sandstone of the Moray Firth, Caithness, and the Orkneys, rests unconformably on the Middle Old Red, but there is not the same degree of discordance as between the Upper and Lower Old Red Sandstone south of the Grampians. The lowest palæontological horizon which has been recognized in the Upper Old Red Sandstone of the Moray Firth, is found in the Nairn Sandstone and is characterized by the fish *Psammosteus tesselatus* Traq., resembling *P. paradoxus* Agass. of Russia, *Asterolepis maxima* Agass.[1], *Polyplocodus leptognathus* Traq., *Coccosteus magnus* Traq. and *Holoptychius decoratus* Eichw. A higher horizon occurs in the Alves or Scaat Craig Beds, south of Elgin[2], where *Bothriolepis major* Agass. allied to *B. panderi* Lahus.[3], *Psammosteus pustulatus* Traq., *Polyplocodus* sp., *Cosmacanthus*[4] *malcolmsoni*, Agass., *Conchodus ostraeiformis* M'Coy, *Holoptychius giganteus* Agass., *H. nobilissimus* Agass. and *H. decoratus* Eichw. are found, the last of which is the only form common to the Nairn Beds. It does

[1] At a locality west of Nairn Watson found smooth osteolepid scales with *Asterolepis maxima*, suggesting a transition between Middle and Upper Old Red Sandstone.

[2] The Scaat Craig horizon appears to occur also on the Findhorn river.

[3] W. Taylor of Lhanbryde has found at Whitemire, between Alves and Nairn, *Asterolepis maxima* and *Bothriolepis major* together.

[4] The other species of *Cosmacanthus* are found in rocks in the North of Ireland, usually considered to be of Carboniferous age.

not occur in the quarries, also referred to the Alves Beds, between Alves and Nairn, where the only fossils common to Scaat Craig are *Bothriolepis major*, *Holoptychius giganteus* and *H. nobilissimus*, which are here associated with *Psammosteus taylori* TRAQ., and *Sauripterus crassidens* TRAQ. similar to *S. favosus*, from Clashbennie. These may indicate a somewhat higher horizon, also represented on the north of the Moray Firth, where *Ps. taylori* and the same two species of *Holoptychius* are found. In Quarry Wood close to Elgin above beds with *Ps. Taylori* and *S. crassidens* is a fine grained sandstone, the Rosebrae Bed, containing a small variety of *B. major* together with *B. cristata*, TRAQ., *Phyllolepis concentrica*, *Phaneropieuron andersoni* and *Glyptopomus minor*, the three last species indicating the horizon of the lower and principal fish bearing beds at Dura Den.

At Dunnet Head in the North of Caithness an unfossiliferous yellow and brown sandstone with grit beds is faulted against the Middle Old Red Sandstone and is believed to represent the Upper Old Red. In the Island of Hoy, one of the Orkneys, rocks of a similar character occur resting on the eroded edges of the Middle Old Red Sandstone.

Climatic and topographical Conditions.

The close of the Silurian was marked by the gradual retirement of the sea and the coming in of the conditions that gave rise to the Old Red Sandstone type of sedimentation. North of the Bristol Channel and of a line passing south of the Mendips and 14 miles north of London there is no evidence of a marine environment before the commencement of the transgression of the sea that attained its maximum in the Lower Carboniferous Period. The prevailing red colour of the rocks is to be attributed to exposure to the oxidizing and desiccating effects of the atmosphere in a comparatively warm climate. The conditions under which the Red Marls were laid down were probably somewhat similar to those that prevail in portions of the Bolivian Plateau and the interior of South Australia, where a nearly level surface is covered after heavy rainfall with an expanse of shallow waters, which during periods of drought dry up or contract to much smaller dimensions. The Carmyllie Flags appear to have been laid down in a lake of somewhat more permanent character but of limited extent. The conglomerates and much of the sandstone are of fluviatile origin, but some of the latter may have been accumulated by the wind. The marls would seem to consist for the most part of wind-borne dust, which has been arrested by the water surface, damp ground or vegetation. The "race" can be paralleled by the concretions in the loess and by the kankar of India; and the more continuous cornstones by the calcareous deposits in shallow depressions in arid areas, but the desert conditions which prevailed may have been due more to the fact that the vegetation that then existed was by its nature confined to lakes and swamps, than to deficiency in the rainfall.

Early in Old Red Sandstone times we have evidence of important earth movements resulting in the formation of a series of north-east and south-west depressions in Lorne, the Midland Valley of Scotland, the Cheviots and the South Wales area, while the intervening tracts were elevated into mountains in which powerful but intermittent torrents wore out deep gorges and accumulated the débris in alluvial fans. (T. G. BONNEY, Rep. Brit. Assoc. 1886, p. 617; EVANS, 1892 and Geol. Mag. 1903, p. 549; GOODCHILD 1898 and WALTHER, Die Denudation in der Wüste (1890) and later works).

The time occupied by the deposition of the Lower Old Red deposits was comparatively short to judge by the little change that took place in the fish fauna; while the fact that *Pteraspis*, which is so characteristic of them, occurs in the lower beds of the marine Lower Devonian and never in the Gothlandian leaves no doubt of their Devonian age.

After the last volcanic eruptions in the Central Valley and a period of quiet during which the deposits became progressively finer in grain, a new series of earth movements appears to have commenced, which may have been connected with the major and minor intrusions that constituted the later stages of Lower Old Red Sandstone igneous activity.

The Basement Beds of the Middle Old Red Sandstone consist mainly of torrential deposits, but sheets of water appear to have been subsequently formed, which were more persistent than those of the Lower Old Red Sandstone and gave rise to abundant vegetation, transmuted in process of time into the bitumen that is now characteristic of the Caithness Flags. The conditions that then prevailed may be compared to those of Lake Chad in Central Africa at the present day. At the time when the Achanarras Band were laid down, the area under water was enlarged so as to include the Moray Firth, the Orkneys and possibly the Shetlands, but the continued existence of arid conditions in the adjoining land areas is rendered probable by the presence in the flags of rounded sand grains. The southern area was soon again left dry, its fish fauna being preserved in the calcareous concretions that were formed as the waters evaporated. The same process was subsequently repeated in Caithness and the Orkneys. It is illustrated by an observation of J. R. Buchanan (Nature vol. 88, 1911, p. 107).

The prolonged period that elapsed between the deposition of the Lower and Middle Old Red Sandstone is evidenced not only by the erosion which must have taken place but by the striking change in the fish fauna. There are only three families common to both: the *Cephalaspidae*, *Coccosteidae* and *Acanthodidae* and these all continue into the Upper Devonian or Upper Old Red Sandstone of Europe or America[1]. The six remaining families of the Middle Old Red, the *Asterolepidae*, *Osteolepidae*, *Rhizodontidae*, *Holoptychiidae*, *Ctenodontidae* and *Palaeoniscidae* are also found in the Upper Old Red Sandstone, to which it is therefore much more closely linked than to the Lower. It must be nearly contemporaneous with the Russian Middle Old Red Sandstone of the Baltic Provinces, which overlies unconformably pre-Devonian rocks and is covered conformably by marine limestone of Givetian age; for the forms common to the Scotch and Russian deposits include *Osteolepis macrolepidotus*, *Gyroptychius microlepidotus* (= *angustus*), *Diplopterus agassizi* (= *macrocephalus*), *Dipterus valenciennesi* and *Estheria membranacea*. It is also linked with the Middle Devonian of the Eifel by the genera *Dipterus*, *Pterichthys* and *Osteolepis*[2].

During the Upper Old Red times strongly arid conditions at first prevailed, but later there seems to have been a gradual amelioration of the climate. In the Moray Firth area the Nairn Sandstone can be correlated with the Wenden deposits on the banks of the Aa in Livonia, while the Alves or Scaat Craig Beds near Elgin correspond as a whole with those of the Sjass River in the Government of St. Petersburg and the Psammites de Condroz in Belgium.

[1] The Middle Old Red Sandstone Acanthodidae show characters intermediate between those of the Lower Old Red Sandstone and later forms.

[2] The presence of these freshwater forms in marine deposits presents no difficulty, as at the present time many fish live both in fresh and salt water. On the other hand the fact that several of the Old Red Sandstone fish families extend upwards into the undoubtedly fresh-water deposits of the Carboniferous is a confirmation of the view that they were fresh-water types. It is probable that the Old Red Sandstone fish, like their living allies, ***Polypterus***, ***Ceratodus***, ***Protopterus*** and ***Lepidosiren***, were to a greater or less extent air breathers and able to live through periods of drought. ***Estheria*** still survives and is frequently found in more or less saline pools in arid areas, though it also occurs in fresh water.

In Northumberland and the South of Scotland, where the lowest Carboniferous beds are of fresh water origin, it is not easy to define the upper limit of the Old Red Sandstone in the absence of fish remains; which are quite distinct in the two formations.

In the south of England the relation of the Devonian to the underlying rocks is uncertain. There is however clear evidence that the recession of the sea extended to this region in early Devonian times, represented by the Dartmouth Slates and Foreland Grits. Afterwards the sea advanced over the whole area but retreated again at the close of the Lower Devonian, so that in the south the water became shallow and further north land conditions prevailed during most of the time occupied by the deposition of the Hangman Grits. Gradually the sea again advanced but it did not extend over all the south-western area until late in the Middle Devonian, at the same time as the submergence of the Bassin de Namur and the Boulonnais. The maximum of marine conditions occurred early in the Upper Devonian and it was followed by a recession of which the extreme point is marked by the terrestrial Pickwell Down and Southall Beds, which were followed by the estuarine or littoral Baggy and Marwood Beds and the marine Pilton Beds[1], only a portion of which can be claimed for the Devonian. The absence of the highest Devonian rocks in South Devon and Cornwall is probably due to their removal before the deposition of the Lower Culm.

There is little to be said in reference to the economic products of the Devonian rocks. The "killas", the more or less altered slates in which the Cornish mineral veins occur, may be of Devonian age, but the minerals date from a later period. The altered slates of Tintagel are extensively worked for roofing purposes; the Red Marls, when not too calcareous, are employed for brick making; the sandstones make a useful and handsome building stone and the Carmyllie and Caithness flags are utilized for paving purposes.

II. Igneous Rocks of Devonian Age.

By ALFRED HARKER.

Both the Old Red Sandstone and the marine Devonian formations of Great Britain afford evidence of contemporaneous volcanic activity, as well as igneous intrusion belonging to approximately the same age. We shall consider separately the Old Red Sandstone igneous rocks (with some older ones) of Scotland and the North of England and those associated with the Devonian strata of the South-West of England. In the intervening country, including the Old Red Sandstone of South Wales and the Welsh Border, there are no igneous rocks known to be of this age.

Lower Old Red Sandstone Igneous Rocks.

The Lower Old Red Sandstone age was characterized by volcanic outbreaks in several parts of Scotland, and also by intrusions which followed and were related to these. The outbreaks were distributed with reference to the N.E.—S.W. Caledonian axes. Three principal areas may be distinguished: (a) the Lorne and Glencoe district in northern Argyllshire, with Beinn Nevis a little farther north: (b) extensive districts along both sides of the Midland Valley of Scotland, including

[1] The characteristic forms, *Ptychopteria damnonensis* and *Cucullaea hardrensis* are also found in the Psammites de Condroz of Belgium. The Pön sandstone and the rocks of the Grey Hook in Spitzbergen, the fauna of which has been described by KAYSER, appear to have been laid down under similar conditions.

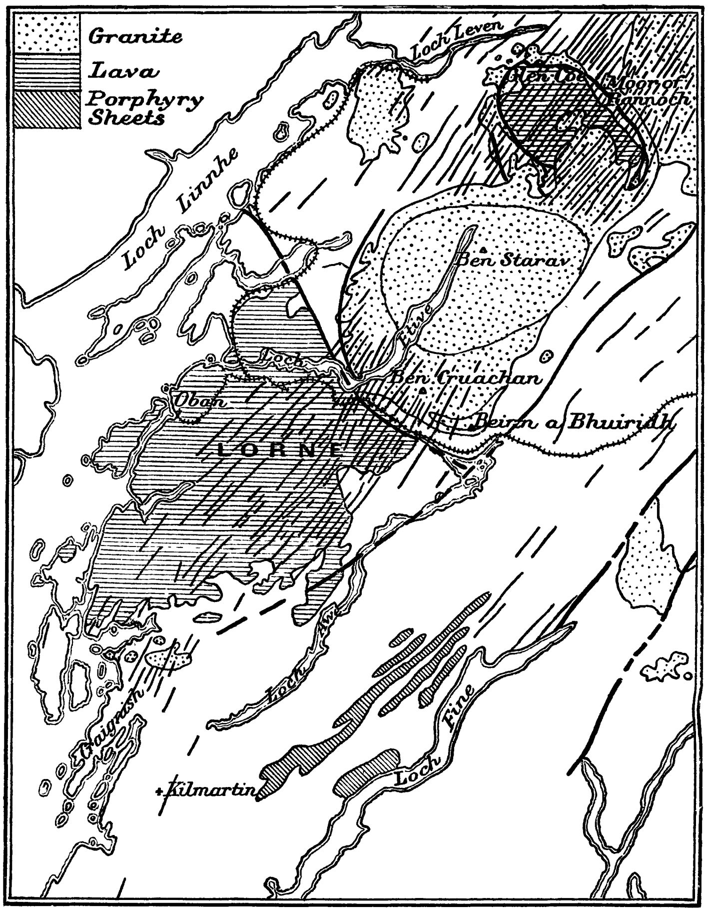

Fig. 29. Sketch-map of the volcanic district of Northern Argyllshire: after Clough, Maufe and Bailey (from Quart. Journ. Geol. Soc., vol. 65, p. 614, 1909, with the permission of the Council of the Geological Society). Scale 1:633,600 or ten miles to the inch.

on the one side the Ochil and Sidlaw Hills, with a prolongation north-eastward into Forfarshire, also, far to the south-west, part of Arran; on the other side the Pentland Hills with smaller centres extending south-westward into Ayrshire: (c) the Cheviot Hills, on the border of Scotland and England, to which may be added a district on the coast near St. Abb's Head. (See map. fig. 27, p. 101) (Geol. Survey maps and Memoirs; Geikie, 1897).

In the Cheviots igneous action manifested itself in these areas under three successive phases (I) Volcanic, (II) Plutonic, (III) Minor Intrusions: in the Lorne and Glencoe district the same three phases are represented, but there is a partial overlapping in time of the second and third: in the Midland Valley plutonic intrusions are wanting.

(I) **Volcanic Phase.** Although the volcanic rocks here considered are of Lower Old Red Sandstone age, it is not possible to correlate very exactly those of the several areas. In Glencoe the volcanic series, with an estimated thickness of over 1100 m. (3500 ft.), rests directly upon the old crystalline schists. Near Oban and elsewhere in the Lorne district there is sometimes a certain thickness of sediments below the lavas; but the base is made by a conglomerate containing blocks derived from older lava-flows now destroyed. In the Midland Valley, the volcanic rocks,

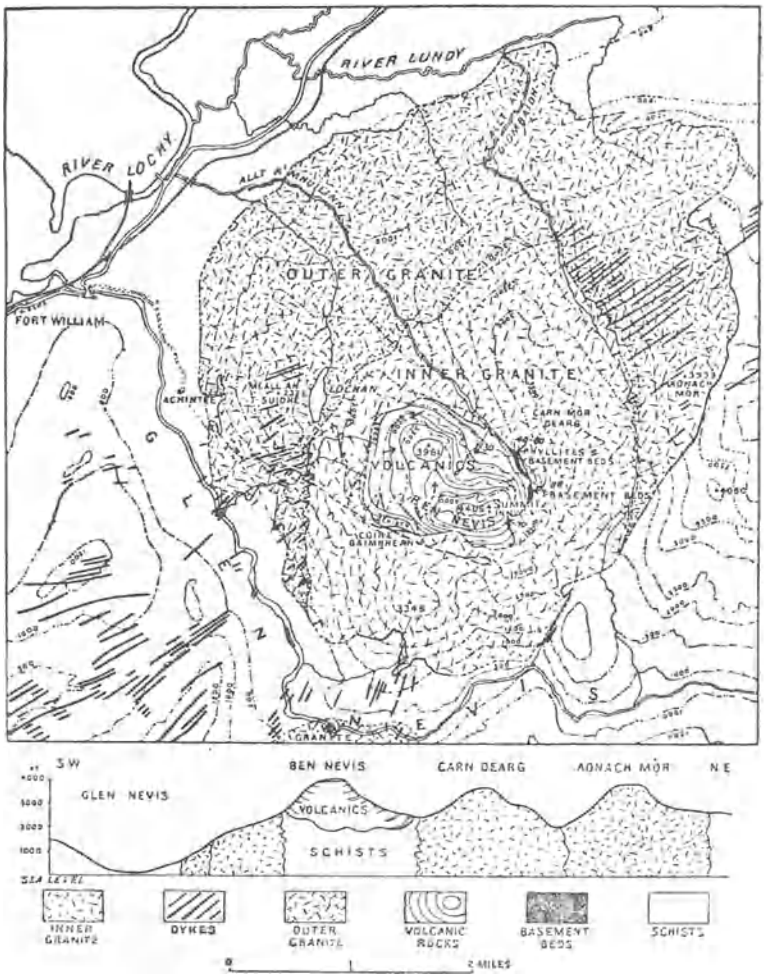

Fig. 30. Geological Map and Section of Ben Nevis: after MAUFE (from Summary of Progress for 1909, with the permission of the Director of the Geol. Survey). Scale about 1:101,000.

more than 2000 m. (6500 ft.) thick in the Ochill Hills, overlie a considerable succession of stratified rocks. In general the volcanic accumulations were of subaqueous formation, but in some districts, such as Glencoe, probably subaerial. They alternate with ordinary sediments, but these latter are of trifling importance where the volcanic series is most fully developed.

Tuffs and breccias occur interbedded with the predominant lavas, but only in relatively small amount; and it is evident that volcanic action here was not in general of the explosive type. In some districts the old volcanic vents are indicated by cylindrical "necks" of agglomerate or tuff piercing the lavas. It is possible that other volcanic centres are represented by some of the small boss-like intrusive masses which are numerous in some districts. A different type of volcanic mechanism is revealed in Glencoe (CLOUGH, MAUFE and BAILEY, 1909). The lavas in this district are confined mainly to an elliptic area measuring about $14^1/_2$ by 8 km. (8 by 5 miles), which is bounded by a curved fault, and has been let down more than 300 m. (1000 ft.) in the midst of the crystalline schists. This subsidence is believed to be partly of the age of the volcanic outpourings, and it is proved to be partly contemporaneous with a broken ring of intrusions which follows the outer edge of the fault (fig. 29).

Petrographically the Old Red Sandstone volcanic rocks have no very wide range of variety. The prevalent lavas are basic pyroxene-andesites (usually named "porphyrites" by the older geologists), graduating into olivine-basalts. In the Lorne district the lower part of the series is of basic augite-andesites, followed by porphyritic hypersthene-andesites, with a few intercalations of tuffs. These are followed by acid tuffs interstratified with basic lavas; then less acid tuffs with dacites or rhyolites and some hornblende- and mica-andesite; finally hypersthene-andesites with some more basic andesites and andesitic agglomerates. In the Glencoe district again the sequence does not follow any evident law, and indeed the different flows seem to have issued from different centres. Hornblende-andesites are here more prominent, and in the small volcanic area of Beinn Nevis they prevail exclusively. On the Forfarshire coast, S. of Montrose, the lavas are olivine-basalts, with a few enstatite-basalts (fig. 28) (Jowett, 1913); and farther north, in Kincardineshire, pyroxene-andesites and basalts still preponderate, though there are some hornblende-biotite-andesites and one flow of rhyolite, while all the tuffs are of acid composition. In this part of Scotland, near the Highland Border, vulcanicity, characterized by the same petrographical types, had already broken out in Upper Silurian (Downtonian) times (Campbell, 1911). In the Pentland Hills the rocks are usually much altered. They are chiefly andesitic, including pyroxene-andesites and others with hornblende and mica; but olivine-basalts are abundant, and on the other hand trachytes occur, besides some rhyolites. Geikie has remarked that the fragmental materials which fill the vents, and so represent the latest products, are in general of more acid composition than the lavas through which they have broken. The lavas of the Cheviot Hills (Teall, Geol. Mag. 1883, 1885) are mostly hypersthene-andesites, but augite-andesites are also found, and one type contains abundant biotite. Some of the lavas approach dacite in composition, and a trachyte is also recorded.

(II) **Plutonic Phase.** Wherever the volcanic are accompanied by plutonic rocks, the latter are seen to break through and metamorphose the former, and they must therefore be assigned, in each district, to a somewhat later epoch of the Lower Old Red Sandstone age.

Some of the plutonic masses have a special interest in relation to the mechanism of intrusion. The granite of Beinn Cruachan, which divides the Lorne and Glencoe districts, and that of Beinn Nevis seem to be of cylindrical form with approximately vertical walls, but also with a defined upper surface. It is suggested that in each case a cylindrical block of the country rocks has subsided, and its place bas been occupied by the granitic magma which rose concurrently along the boundary. Moreover, the intrusion has, in each case, been effected in two stages; for there are two distinct granites, the younger piercing the older. In Beinn Nevis (Maufe, 1909) the relations are even more remarkable, for the summit, making the highest point in the British Isles, consists of hornblende-andesites. These rest on a portion of the Highland crystalline schists, and represent a cylindrical plug which has subsided in the granite magma (Fig. 30).

The Beinn Cruachan mass is part of a string of intrusions extending about 75 km. (47 miles) in a north-easterly direction, and including Black Mount and the Moor of Rannoch. The dominant rock varies between hornblende-granite and quartz-diorite, but more basic varieties also occur. Both at Beinn Cruachan and at Beinn Nevis the inner granite is of more acid composition than the outer. These rocks, containing orthoclase and plagioclase felspar in fairly equal proportions, fall into the monzonite family, as understood by BRÖGGER, and more basic types of this family are found in the same district. An olivine-monzonite (kentallenite) occurs associated with the acid intrusion of Ballachulish, and also makes small intrusive masses in Glen Orchy and elsewhere. In the Cheviot Hills there is a relatively basic granite with both biotite and augite.

Finally, there are plutonic intrusions assigned to the Lower Old Red Sandstone age in the English Lake District (Cumberland and Westmorland). The several exposures of the Skiddaw granite are doubtless parts of one continuous mass, underlying the metamorphosed slates. The rock is a muscovite-biotite-granite with a variable amount of the white mica. This mineral is wanting in the southern part; while on the northern border the granite passes into a quartz-mica-rock (HARKER, 1895). The Eskdale-Wastdale mass also underlies the neighbouring rocks, producing notable metamorphism in the Ordovician volcanic series. It is a biotite-granite in the south, but farther north contains muscovite in addition (DWERRYHOUSE, 1909). The porphyritic biotite-granite of Shap Fell appears to have the form of a boss (HARKER and MARR, 1891). There is no evidence of volcanic outpourings in connection with these intrusions.

(III) **Phase of Minor Intrusions.** The minor intrusions which occur in the Lower Old Red Sandstone volcanic districts, and are disposed about the plutonic centres, are mostly dykes of moderate dimensions, with some sills. In the Lorne and Glencoe districts, and at the neighbouring centre of Beinn Nevis, there is a partial overlapping of the plutonic and dyke phases. Most of the dykes are younger than the outer granite and older than the inner mass, although there are also later dykes, younger than any plutonic intrusion. These dykes have a N.E.—S.W. direction and are most thickly crowded on the N.E. and S.W. sides of the plutonic centres. In the Cheviot district the dykes have roughly radial grouping round the granite. In the English Lake District the best marked set of dykes of this age is that which surrounds the Shap granite, with a radial arrangement.

Petrographically these minor intrusions fall into three groups: (a) hornblende- and mica-porphyrites, with allied types of intermediate acidity; (b) quartz-porphyries, with allied acid types; (c) hornblende- and mica-lamprophyres (spessartites, minettes, etc). It is the rule, though not without exceptions, that the three groups have followed this order of succession. In the Lorne and neighbouring districts the porphyrite dykes and sheets preponderate, but the acid and basic rocks also occur. In the Cheviots mica-porphyrites and quartz-felsites are both well represented, and in the English Lake District quartz-porphyries and mica-lamprophyres, with transitional varieties (HARKER, 1892).

Middle Old Red Sandstone Igneous Rocks.

In the Old Red Sandstone of the West of Shetland there is a succession of volcanic and plutonic rocks, followed by minor intrusions (PEACH and HORNE, 1884), which closely resembles that which has been described in the Lorne District. The evidence of the age of these rocks is inconclusive, but they have been correlated with the Bressay Flags on the east coast which are apparently of late Middle Old Red Sandstone age. The olivine-basalt lava in the yellow sandstones of Shapinsay in the Orkneys (FLETT, 1895) and the andesite lava of Rhynie and the Gollochy Burn, south of the Moray Firth, also appear to be referable to about the same period (MACKIE, 1913).

Upper Old Red Sandstone Igneous Rocks.

Although the wide-spread igneous action in the Old Red Sandstone was limited to the Lower division of that system, there was at a later time a revival of activity on a much smaller scale and confined to isolated districts. In the island of Hoy, one of the Orkney Isles, a small volcanic group, consisting of bedded tuffs and lavas, occurs at the base of the Upper Old Red Sandstone. Another locality where volcanic rocks occur in the Upper Old Red Sandstone is in the island of Arran. They are found on the north side of North Glen Sannox, and consist of altered olivine-basalt lavas. Precursors of the Carboniferous lavas are also to be found in the Upper Old Red Sandstone of Berwickshire (Geikie, 1897).

Devonian Igneous Rocks of S. W. England.

The Palæozoic igneous rocks of Cornwall and Devonshire, involved in the folding and faulting which have affected the strata of this region, have had their original geological relations partly obscured. Nevertheless it has been recognized that there are Devonian igneous rocks, to be distinguished from the older (Ordovician) and the younger (Carboniferous and Permian), and that they comprise both contemporaneous and intrusive occurrences.

In North Devon igneous rocks are almost wanting, but in South Devon both interbedded and intrusive igneous rocks of this age are found, from Torquay westward. The true volcanic rocks are in some force near Torquay and Plymouth, and can be followed north-westward across Cornwall to Pentire Point and Port Isaac. Volcanic action began in the later part of the Middle Devonian with the Ashprington Volcanic Series, continued in the Upper Devonian, when it attained its maximum, and did not become extinct until the time of the Lower Culm.

Petrographically the rocks are of basic composition, but their true nature is much obscured by secondary alteration and often also by crushing. The lavas are mainly of the spilite type, sometimes showing the peculiar "pillow" structure. When crushed and cleaved they resemble the "Schalstein" of German petrographers. The ferro-magnesian minerals are destroyed and the original felspars replaced by albite or albite-oligoclase, probably as a solfataric change (Dewey and Flett, 1911). The associated intrusive diabases and proterobases are also albitized and often crushed. There are also some picrites, mostly hornblendic. The slates in contact with the diabase intrusions, notably in the Padstow district of North Cornwall, are in places thoroughly albitized and converted to rocks of the adinole type.

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References to the Old Red Sandstone also occur in the explanations of other sheets and in the Summary of Progress (see especially contributions by R. G. CARRUTHERS, H. B. MAUFE and under TRAQUAIR, 1909).

b. Ireland.

By G. A. J. COLE.

The Devonian system in Ireland is represented almost entirely by freshwater or terrestrial deposits of the Old Red Sandstone type. In the south, these resemble those of South Wales; but it is possible that the Dingle Beds, which appear to rest conformably on the Ludlow series in the Dingle Promontory, correspond with the passage beds of Ludlow town and the earlier part of the Welsh Old Red Sandstone, while the mass of sandstones and conglomerates of Kerry, Cork, and Waterford are of a somewhat later date.

The Dingle Beds proper are known only in the Dingle Promontory, and are a series of grits, sandstones, and slates, 3000 m. (10 000 ft.) thick, unfortunately devoid of contemporaneous fossils. A few fossils occurring in pebbles have been held to be derived from Llandovery strata, and in any case they show that the Lower Devonian upheaval had already begun in adjacent areas. The great earthfolds ultimately reached the Dingle area, and the characteristic conglomerates of the Old Red Sandstone overlie the Dingle Beds and the Ordovician strata with striking unconformity. Hence G. H. KINAHAN and others relegated the Dingle Beds to the Gothlandian. A. MCHENRY (1912) has now suggested that, by reversed folding, their present position is misleading, and that they really underlie the Wenlock series, and are of Llandovery age (see p. 103). JUKES, on lithological grounds, connected certain grits in the lower part of the Old Red Sandstone of Glengariff with the Dingle Beds, under the name of Glengarriff Grits; but the unconformity characteristic of the Dingle Promontory has not been proved to occur within Devonian strata elsewhere in southern Ireland. The division that has been attempted between an upper and a lower series on HULL's general map of Ireland, since its first issue in 1878, and on some later editions of the maps of the Geological Survey, cannot be regarded as more than a suggestion (JUKES 1866, KINAHAN 1878, 1879, HULL 1879, 1882). It is of course possible that the base of the Old Red Sandstone in the Glengarriff area, which is not seen, may rest conformably on Gothlandian rocks; but its general unconformity on these strata is conspicuous round the Gothlandian exposures in the north of Co. Cork. If the Old Red Sandstone of southern Cork and southern Kerry is of the South Welsh type, its highest beds may be found overlapping the lower ones against a slope of the Caledonian landsurface, which descended originally from the north, while its true base may be, as KINAHAN evidently felt to be the case, conformable on a Ludlow series down below. For a general account of the southern Irish Old Red Sandstone see JUKES (1866).

The Old Red Sandstone of Ireland consists mostly of brownish to purplish conglomerates, with numerous pebbles of quartz-rock and quartzite, and intercalated grits and sandstones. Except for a few plant-stems, it is almost devoid of fossil remains, until we reach its highest series. It thickens in the southern region from about 1000 m. (say 3000 ft.) in Co. Waterford to more than 3000 m. (10000 ft.) in Cork and Kerry. As shown above, it is not clear if we must add another 3000 m. by the inclusion of the Dingle Beds. The Old Red Sandstone overlying the Dingle Beds in the Dingle area is 1300 m. (4300 ft.) thick. The folds into which the country has been thrown by the Armorican earth-movements, together with the resistance of the conglomeratic beds to denudation, have caused the Old Red Sandstone to stand out in a fine serie of east-and-west ridges, which include in Kerry the grandest rock-scenery of Ireland. The unconformity of the strata on the Older Palæozoic slates is well seen on the north of of the Suir at Waterford, and in many of the inliers of Gothlandian or Ordovician rocks that occur within the Old Red Sandstone domes.

These domes, produced by the Armorican folding, are a characteristic feature of the interior of Ireland, the Old Red Sandstone coming up in the form of somewhat barren hills from beneath the Carboniferous Limestone Series, which overlies it conformably throughout the region.

At the top of the typical Old Red Sandstone conglomerates there occurs a series of yellowish fine-grained sandstones, 150 to 300 m. (500 to 1000 ft.) thick, known as the Yellow Sandstone Series or Kiltorcan Beds. This is perfectly conformable to the Old Red Sandstone beds below, and has been styled on Geological Survey maps the Upper Old Red Sandstone. It has thus no similarity to the beds so styled in the Cheviots, except that it passes up conformably into the Lower Carboniferous strata. These gently deposited beds have preserved at Kiltorcan quarry, near Ballyhale in Kilkenny, an interesting freshwater fauna and a terrestrial flora of late Devonian age. The most abundant fossil is the large fern

Archaeopteris hibernica. Long striated stems known as *Filicites* occur, with *Bothrodendron*, *Sagenaria*, *Lepidodendron*, and *Sphenopteris.* The fauna is composed of the earliest known freshwater mollusc, *Archanodon Jukesii*, a small *Belinurus (B. kiltorkensis)*, a large isopod *(Oxyuropoda ligioides* CARPENTER and SWAIN), fragments of *Eurypterus*, and of a few Devonian placoganoid fishes, including *Coccosteus disjectus* SMITH WOODWARD, and *Glyptolepis. Archanodon* has also been found near Clonmel, and a little east of Cork city, in the latter case with *Archaeopteris*, and the flora is represented at one or two places near Fermoy. (Geol. Surv., LAMPLUGH 1905, W. BAILY 1861, 1869 and 1875—7, JOHNSON 1911, COLE 1901, CARPENTER and SWAIN 1908.)

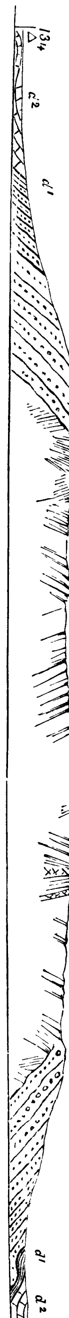

Fig. 31. Section east of Slievenaman, Co. Tipperary, showing relations of the Older Palæozoic strata to the overlying deposits. Horizontal scale, one inch to 1 mile, 1:63 360; vertical scale, two inches to 1 mile, 1:31 680. d² = Carboniferous Limestone; d¹ = Lower Limestone Shale; c³ = Kiltorcan Beds; c² = Old Red Sandstone; b = Gothlandian or Ordovician. Reproduced from the Memoirs of the Geological Survey of Ireland, No. 156, p. 5, fig. 3, 1858; with the permission of the Director and of H. M. Stationery Office.

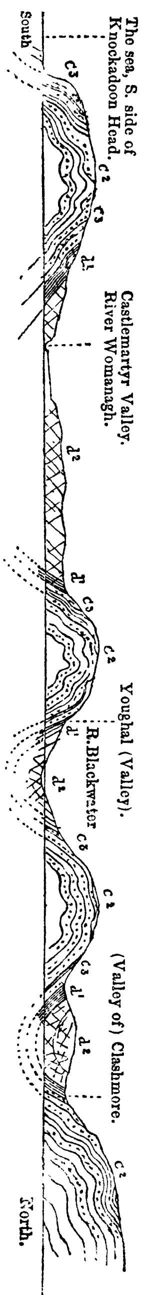

Fig. 32. Typical section across the folded strata of southern Ireland, east of Cork City. Horizontal scale, half an inch to one mile, 1:126 720. Vertical scale, one inch to 1000 ft., 1:12 000. d² = Carboniferous Limestone; c³ = Kiltorcan Beds; d¹ = Lower Limestone Shale; c² = Old Red Sandstone. Reproduced from the Memoirs of the Geological Survey of Ireland, No. 188, p. 8, fig. 1, 1861; with the permission of the Director and of H. M. Stationery Office.

Considerable discussion has arisen over the fauna of the Coomhola Grits, (JUKES, 1866, p. 106, and 1868, p. 68., LAMPLUGH, Geol. Surv., Mem. on country around Cork, 1905, p. 13) which are beds of sandstone occurring at various levels in the Carboniferous Slate, but more abundantly in the lower part of it. JUKES assigns to them in places a thickness of 900 m. (3000 ft.). The typical section in them is at Ardnaturrish, on the eastern shore of the approach to Glengarriff Harbour, in Bantry Bay. The lower horizon contains a fauna that includes *Curtonotus* (several species), *Cucullaea hardingi*, and *Avicula damnoniensis;* and it is probable that we have here marine beds of Upper Devonian age, heralding the return of the sea across the Old Red Sandstone region. The classification of these beds, and, indeed, of all the series in Ireland between the Ludlow Series and the top of the Carboniferous Limestone, has been complicated by certain views of JUKES, followed by KINAHAN, to which reference will be made when the Carboniferous strata are described (p. 172).

Beds of the ordinary Old Red Sandstone type occur on the margin of Clew Bay, and on the north side of the plain along the Curlew Hills. A large outcrop of similar red conglomerates and sandstones stretches from Enniskillen to Pomeroy in the county of Tyrone. These latter are the Fintona Beds, which have often been correlated with the Dingle Beds of Kerry (J. NOLAN, 1880; E. HULL, 1882, p. 206). They rest, however, unconformably on the Silurian beds of Pomeroy, and there seems no adequate reason for cutting them off from the main Old Red Sandstone series of the south. A small exposure of very coarse quartzite-conglomerate occurs on the Antrim coast at Cushendun. Another patch lies on Dalradian rocks at Fanad in the county of Donegal, and is said to have been brought into its present position along a thrust plane.

The igneous rocks directly associated with the Old Red Sandstone cannot be compared in importance with those of Scotland. Sphaerulitic and fluidal rhyolites, with some ashes, occur at Lough Guitane and at other points near Killarney; altered trachytes and andesites, also with fragmental products, in the Curlew Hills; and altered andesites, of the Scottish porphyrite type, in the Fintona Beds east of Omagh. But an immense number of "felsite" dykes, running generally north and south, cut the Caledonian folding throughout the northern half of Ireland, and do not penetrate the Carboniferous strata. These, if we may judge by the analogy of the Kainozoic dykes, provided passages for the outflow of trachytes and andesites of various types, which were denuded away before the overflow of the Carboniferous sea. On the Waterford coast, again, there are a number of igneous rocks intruded into the Silurian slates at an epoch later than the Caledonian folding of that area. These have been referred to the Old Red Sandstone; but F. R. C. REED (1900), after careful discussion, believes that they cannot be later than Gothlandian. We must always remember that where Gothlandian rocks, as, for instance, in the county of Down, have been involved in the Caledonian folding, the great intrusions of granite that are associated with the anticlinal arches must be of early Devonian age.

Lakes probably gathered in the hollows of the early Devonian land, though it is now difficult to trace their boundaries in the Irish area. Broad fans of siliceous detritus accumulated on and spread across the land-surface. In the south, the succession and type of deposits resemble those of South Wales, though the unconformity of these deposits on the Older Palæozoic rocks is far more marked in Ireland. When the Dingle Beds became steeply uptilted, the typical Old Red Sandstone conglomerate spread across their denuded edges. The mountain ranges of Dalradian rocks, with their characteristic Caledonian trend, must have supplied an enormous amount of detrital material to the hollow regions of the land. In some parts of the south, muds were accumulated; but on the whole the Devonian deposits indicate beaches and terrestrial taluses of varying coarseness, in which conglomerates predominate, mainly composed of the rocks best calculated to resist prolonged weathering action. A large part of the material consists of subangular stones (quartzite and vein-quartz and jasper), cemented in a sand. Where true pebbles occur, they were doubtless well rounded in the torrents that streamed down from the mountains, before they came under the influence of waves along the margins of the lakes. The Lower Devonian and older granites supplied some of the material; but the stones now left to us must represent only a portion, naturally selected, of the waste-materials from the Dalradian, Ordovician and Gothlandian rocks. The Upper Old Red Sandstone of the Kiltorcan and Cork type is found to underlie marine beds, which herald the inflow of the Carboniferous sea over a very wide area in central and southern Ireland; and we may be led to believe that one great estuarine flat occupied the region from the west of Kerry to the east of Waterford. North, however, of the Caledonian axis of Cavan and Newry, the Old Red Sandstone was probably laid down in a basin which may have been the south-westerly prolongation of that of the Midland Valley of Scotland.

	The Rhine	Ardennes	Cornwall	South Devon
Carboniferous		Calcaire d'Étroeungt	(Palæontological break)	(Palæontological break)
Upper Devonian and Upper Old Red Sandstone	Clymenien-Kalk | Pön-Sandstein Nehdener Schiefer Adorfer Kalk Büdesheim. Schiefer Plattiger Kalk Kalke u. Dolomite mit *Rhynchonella cuboides*	Psammites de Condroz Schistes de Famenne Schistes de Matagne Calcaires, Marnes et Schistes } de Frasnes	Green and black slates, north of Petherwin South Petherwin Beds (sandstones and limestones) Purple and green slates of Daymer Bay Black slates of Daymer Bay Grey slates of Port Quin Striped calcareous slates of Trevone Bay Slates of Booby's Bay Slates south of Treyarnon Point ? Delabole Slates ? Slates of Porthcothan	Red and Green Slates with *Entomis serratostriata* and *Posidonomya venusta* Shaly limestone of Petit Tor Combe and Lower Dunscombe Mudstone with nodular and lenticular limestone of Saltern Cove Lummaton Shell Bed Massive limestones of Torquay and Plymouth
Middle Devonian and Middle Old Red Sandstone	Kalke und Dolomite mit *Stringocephalus burtini* Crinoiden Zone *Calceola* Mergel und Kalke *Cultrijugatus* Stufe	Calcaire de Givet Schistes et Calcaires de Couvin	Staddon Grits (usually placed in the Lower Devonian)	Hope's Nose Limestone Shaly limest. and slates of Daddy Hole Staddon or Warberry Grits
Lower Devonian and Lower Old Red Sandstone	Ober-Coblenzschicht. Unter-Coblenzschicht. Hunsruck-Schiefer Taunus-Quarzit Gedinne-Schichten	Grauwacke d'Hierges, Poudingue de Burnot Grès de Vireux, Grauwacke de Montigny, Grès d'Anor Schistes de St. Hubert, Schistes d'Oignies	Upper Meadfoot Beds Lower Meadfoot Beds Dartmouth Slates (including Falmouth Slates according to Upfield Green)	Base not seen
Gothlandian or Silurian		Schistes de Mondrepuits Arkose d'Herbes Poudingue de Fépin	(Portscatho [and Mylor] according to Upfield Green)	

Note There is considerable difficulty in correlating the Devonian rocks of the British Isles both among themselves and with those of the Continent of Europe and there is ample room for difference of opinion.

North Devon and West Somerset	South Wales and border counties			Ireland (except north)
	South-west	North-east	South-east	
(Palæontological break) Upper Pilton Beds	Cleistopora (K) zone of the Carboniferous (included in the Devonian by some geologists)			Carboniferous Slates
Middle and Lower } Pilton Beds Baggy and Marwood Beds	Skrinkle Sandstones } Marine bands near the top	Yellow and Red Sandstones and grits with plant and fish remains Conglomerates		Coomhola Grits
Pickwell Down Sandstones		Brownstones (with plant remains)		
Morte Slates (placed by some in the Middle Devonian, by HICKS in the Gothl.				Kiltorcan Beds or Yellow Sandstone Series Red sandstones
Ilfracombe Beds				
Combe Martin Beds ? Hangman Grits (usually placed in the Lower Devonian)	(Great palæontological break, and probably structural discordance near Milford Haven)	(Great palæontological break but apparent conformity In some places there is an overlap so that the Upper Old Red Sandstone may rest on the Gothlandian)		(There is no evidence of a break in the succession, but the Upper Old Red Sandstone appears to overlap the Lower to the northward)
Lynton Slates	Ridgeway Conglomerate	Senni Beds (In some places absent; in others not yet separated from the Brownstones above)		Red Sandstones (The lowest portion of these sandstones in the south-east may be represented in the south-west by the Dingle Beds, which are conformable to the Gothlandian, and are covered unconformably by the Old Red Sandstone)
Foreland Grits	Cosheston Sandstones Red Marls (with sandstones and cornstones) Basement conglomerates or grits			
	(slight unconformity)		Passage Beds from Gothlandian	
	Gothlandian			

In this table I have placed many of the British strata at higher horizonts relatively to those of other countries than is usual, but in most cases similar correlations have been made by other writers. J. W. E.

	Ireland (north)	Cheviots and adjoining areas	South-west of Midland Valley of Scotland and Lorne	North-east of Midland Valley of Scotland
Upper Devonian and Upper Old Red Sandstone	The Upper Old Red Sandstone of the North of Ireland is frequently described as the „Basement Beds" of the Carboniferous, and the same is the case with the Upper Old Red Sandstone of the Isle of Man, North Wales, and the North of England.	Cement stones Cornstone Series		(at Dura Den) Zone of *Bothrolepis hydrophila.* Zone of *Glyptopomus minor.*
		Red and mottled sandstones.		
			[There is no Upper Old Red Sandstone in Lorne.]	
		(Great palæontological and structural discordance)		
Middle Devonian and Middle Old Red Sandstone	The old Red Sandstone of the North of Ireland resembles that of the Midland Valley of Scotland except that there is no apparent break between the Upper and Lower Old Red Sandstone.			
Lower Devonian and Lower Old Red Sandstone		Volcanic Rocks		Strathmore Sandstones: Edzell Shales, Arbroath Sandstone, Auchmithie Conglomerate, Red Head Series
			Sandstones and conglomerates	Cairnconnan Grits Carmyllie Series Dunottar Series
Gothlandian or Silurian		(unconformity)	(unconformity) Downtonian [Ther is no Downtonian in Lorne]	Downtonian (unconformity)

Moray Firth	Caithness	Orkneys	Shetland	Russsia
Rosebrae Bed with *Glyptopomus minor* Beds with *Psammosteus taylori* Scaat Craig Beds with *Ps. pustulatus* Nairn Beds with *Ps. tesselatus* and *Asterolepis maxima.*	Dunnet Head Sandstone	Sandstone of Hoy	Bressay and Noss Series: Flaggy sandst. and shales Thin bedded micaceous sandst. with coarser seams, fish and plant remains Sandst. often conglomeratic with some shales.	Sjass River Beds Wenden deposits Limestones with *Spirifer archiaci* and *Sp. verneuili* and *Rhynchonella cuboides.* Dolomite and limest. with *Spirifer anosoffi*
Sandstones Fish Beds Conglomerate	John o'Groats Sandstone Group (Break) Thurso Flagstone Gr. (? slight break) Achanarras Band Passage Beds Group Wick Flagstone Group Upper Conglomerate (Break) Mudstones Basement Conglom.	Eday Sandstones (Break) Rousay Flags Stromness Flags	Lerwick Series: Grey micaceous sandst. with plant remains and *Estheria membranacea.* Sandstones with rounded pebbles. Rovey Head Conglomerate Red flags of Brenista Basement Breccia	Sandstones with *Asterolepis* (?) *Osteolepis*, *Dipterus* and *Estheria.*
				Red Sandstones of the Dniester and of Poland with *Pteraspis* passing down into the Gothlandian.

J.W.E.

The volcanic action of Devonian times has left few lava-flows in the Irish region; but the immense number of dykes (p. 133) of various compact types found in the exposed Dalradian and Silurian areas of the north, cutting the Caledonian folds, but not the Carboniferous strata, shows how extensive in reality was the igneous basin down below. At least an equal number of these dykes must be concealed by the mantle of Lower Carboniferous strata; and we may assume that any lava-flows to which they gave rise outside the margins of the Old Red Sandstone basins became denuded away before the Carboniferous sea invaded the district. The Caledonian continent, towards the close of Devonian times, had suffered greatly from continuous denudation. The enormous accumulations of material in the lowlands and lake-basins sufficiently indicate the lowering of its surface. The passage from conglomerates and grits to the Yellow Sandstone type of deposit, which was no doubt laid down in shallows by sluggish streams, suggests that the surrounding country had assumed the character of a peneplain. The torrents of earlier times were now replaced by meandering streams, moving this way and that over the surface of a land that was ready to admit the sea. Subsidence of the lake-floors commenced early in the period, and thus allowed a great thickness of deposits to accumulate; and this subsidence affected at the same time the adjacent land, and combined with denudation in bringing the Caledonian ranges nearer to the sea-level. To this day, in the south of Mayo, where the Lower Carboniferous beds have only recently been removed from the crests of the Dalradian hills, we may trace in the level tops of these hills the last relics of the Devonian peneplain.

Economic Products.

Granite. A number of Irish granites in the Dalradian areas may represent intrusions that accompanied the Armorican folds; and on the east of the country, a definite early Devonian age can be assigned to the granites of the Leinster Chain and of the Newry Axis. The former is a muscovite-granite, which becomes charged with biotite near its junctions with the Ordovician rocks. It is extensively used for building in Dublin, most of the stone coming from Ballyknockan in Co. Wicklow. The Newry granite is rich in biotite; it is fine-grained, with occasional patches of schistose rocks which have been only partially absorbed, and it forms a good grey ornamental stone.

Slate. Massive slate and roofing slate have been raised from the Devonian strata of Valencia Id., Co. Kerry.

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6. Carboniferous.

a. Great Britain (including the Isle of Man).

I. Sedimentary Rocks.

By PERCY F. KENDALL.

The Carboniferous rocks are the most important of all the British strata, not only from the thickness that they attain and the great area that they occupy, but from the fact that they form the greatest repository of minerals of economic value. Coal, oil, ironstone, building-stone, limestone, brick- and pottery-clays or shales, fire-clay, alum shale, lead veins, chert and other valuable substances of lesser importance are obtained from this great formation.

The geological interest of these rocks is not inferior to their economic value, as they present a nearly continuous record of a vast lapse of geological time during which great variations of physiographical and climatic conditions affected the British area. Marine conditions varied from the clear-water reef-conditions of some of the limestones to frequently recurring lagoon-phases. Estuarine conditions are thought to be represented at some stages, while the "Millstone Grit" was laid down mainly as a series of deltaic flats at or near the debouchure of great rivers. Terrestrial or swamp conditions are indicated by coal-seams and their seat-earths. In the early stages the region from the Tyne northward seems to have experienced conditions of desiccation that recurred at a late stage in the Coal Measure period over the greater part of Britain.

The lithology varies very greatly, not only in the vertical sequence, but also when the rocks are followed from south to north. Thus the massive marine limestones of the Bristol area and the southern Pennines become interstratified with shales and sandstones with coal-seams in the North of England, and in Scotland their equivalents constitute the most important coal-bearing division. The old lithological classification into 1. Carboniferous Limestone with Yoredale Series, 2. Millstone Grit, and 3. Coal Measures is applicable only to a portion of the Pennine Region, and attempts to press into these compartments the strata outside that area have led to the greatest confusion. The Yoredale phase of deposition descends to lower and lower horizons as the series is traced to the northward from the titular region, while to the southward its homotaxial equivalents are rocks whose contemporaneity is on palæontological grounds steadfastly denied by authorities of acknowledged competence. The Millstone Grit, another characteristic Pennine type, almostly completely loses its identity in Northumberland by reason of the occurrence of similar rocks both higher and lower in the sequence, while, in a southerly direction, it dwindles and disappears in the Midlands. The rocks called Millstone Grit in the South West Province differ from the type lithologically and are not restricted to a specific horizon but appear both below and above the position assigned to it in the classification referred to.

Two broad palæontological divisions are recognised. An

Upper Carboniferous comprising the Coal Measures and Millstone Grit, and

Lower Carboniferous including the Pendleside Series, the Yoredale Rocks, Carboniferous Limestone and, locally, some Basement beds.

The fish fauna furnishes no evidence for further subdivision though two categories of fishes — estuarine and marine — may occur. Fresh-water lamellibranchs show in many areas a definite vertical succession in the Upper Carboniferous. Lee however suggests that the distribution is affected by local conditions and hence that a fauna may reappear above its proper horizon, but Hind and Stobbs regard the order as invariable. Only one departure from the sequence they establish is known to the writer, viz: in the West of Scotland (Geol. Surv. Mem. Glasgow 1911, p. 72, 92) and this exception can hardly be regarded as invalidating the rule.

The marine Invertebrata are of paramount importance in the Lower Carboniferous or Avonian where they furnish materials for zonal discriminations of the greatest value, whereas, in the Upper division they are of little value except in their relation to other criteria.

Palæobotany on the other hand is of comparatively little value in subdividing the Lower Carboniferous, but the Upper can be divided into four more or less sharply defined stages by means of the succession of plants.

Relation of the Carboniferous Rocks to the subjacent strata.

The Upper Devonian rocks of Devon and Cornwall and the London area were largely of marine origin. Elsewhere in Britain continental conditions with terrestrial surfaces and inland waters mainly prevailed. The wide spread submergence that had commenced before the close of the Devonian Period brought about a general transgression of the Carboniferous deposits over a diversified suite of rocks. In North Devon the Upper Pilton Beds, — a very early, perhaps the earliest, phase of the marine Carboniferous — succeed in apparent conformity the latest Devonian. In the Mendips, South Wales and Scotland, the Carboniferous is probably conformable on the Upper Old Red Sandstone. Elsewhere the Carboniferous rests in strong unconformity on rocks of various earlier geological dates.

Even before the recognition of a zonal sequence it became clear that the surface of pre-Carboniferous rocks was not a plain, but a country of fairly high relief, and though tectonic movements during the deposition of the Carboniferous rocks—in some cases with an amplitude of thousands of feet—make exact measurement difficult, if not impossible, it is certain that inequalities of great magnitude must have existed.

The study of the zonal distribution of the Invertebrate fossils in which Garwood, Marr, Hind and Vaughan have achieved great success, and the palæobotanical work of Kidston and Arber enable the progressive submersion of old land features to be studied in greater detail. The broad results of these investigations show that at an early stage a great insular, or peninsular, mass occupied a large part of Central and North Wales, much of the Irish Sea, and the Wicklow mountains, with a narrow isthmus extending to the eastward across the Midlands, which was not finally overwhelmed until a late stage of Coal Measure time. The region to the north was very irregular in relief so that while some parts succumbed to the earliest marine invasion, others, e.g. the Isle of Man, and the northern moiety of the Pennine Chain, remained above water until the Viséan stage[1].

Lower Carboniferous Palæontology.

The first definite attempt to establish a zonal succession was that of GARWOOD and MARR (1895) who recognised six zones in the Lower Carboniferous of the Northern Pennines. They were followed by HIND and HOWE (1901) who defined a series of zones characterised by species of Goniatites in a group of shales black limestones and sandstones to which they gave the name of the Pendleside Series. They found strata with the Pendelside fauna only in the country South of the Craven faults. In 1904 VAUGHAN presented the results of a minute examination of the Lower Carboniferous Series of Bristol; but this important paper was not published till the succeeding year. The distinctive feature of his work was the recognition of an evolutionary sequence of corals and brachiopoda in which, not merely varietal or specific, but even generic limits were overpassed.

In the appended table (p. 142) VAUGHAN's zones[2] are placed in sequence with those of HIND and HOWE, while GARWOOD's recent amplification of his early work is brought into parallelism.

In the Pendleside Series of HIND and HOWE reliance is placed on the invariable sequence of the Cephalopod fauna, but the occurrence of these animals seems to have been entirely dependent upon special conditions of sedimentation, that were on the other hand inimical to the coral fauna upon which VAUGHAN mainly relied. Consequently the task of bringing the two series of zones into sequence is one of great difficulty, but, as in Ireland and in Derbyshire, the two faunas alternate, the Pendleside in the shales, and the uppermost Avonian in the limestones, it seems probable that they were contemporary rather than successive. The Pendleside phase has a wide geographical development in the West of Ireland, the Isle of Man, North Wales, the Pennine Chain south of the Craven faults, South Wales, and North and South Devon and Cornwall. It is not recognisable as such in Scotland, the Northern Pennines, or in the Bristol-Mendip area.

A. Avonian (Carboniferous Limestone).

Stratigraphical details.

In considering the development of the Avonian Series and its equivalents it is convenient to divide the area of Great Britain into six Regions:

1. The Southern including Devon and Cornwall
2. The South-West Province of VAUGHAN including the Mendip and Bristol areas, the Forest of Dean, Clee Hills and South Wales.
3. The Midland comprising Derbyshire, North Staffordshire, Shropshire, North Wales, Anglesey and the Isle of Man.
4. The Mid Pennine Region, including the country between Pendle and Clitheroe (53^0 52′ N.) in Lancashire, and the Craven faults.
5. The Northern region extending from the Craven faults northward to the Tweed Valley.
6. Finally the region of the Scottish Midlands extending from Dunbar to the Clyde.

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[1] The term Tournaisian and Viséan are here used as aquivalent to VAUGHAN's Clevedonian and Kidwellian and therefore not strictly in the sense in which they are employed in Belgium.

[2] For the most authoritative account of these zones see VAUGHAN 1910.

Series	Zone	(Hind and Howe) / (Vaughan)	Garwood (1912) In the North West Province		Garwood subdivisions		
Penaleside Series	Posidonomya Zone, P.	(Hind and Howe) 5. *Glyphioceras bilingue* 4. *Glyphioceras spirale* 3. *Glyphioceras reticulatum* 2. *Posidonomya becheri* 1. *Prolecanites compressus*					
Viséan or Upper Avonian	Dibunophyllum Zone, D. *Dibunophyllum* aff. *turbinatum*	(Vaughan) D_3 Subzone of *Cyathaxonia*	D_3? Dy	13. Botany Beds with *Phillipsastraea*	k. *Dibunophyllum muirheadi*	Upper	D. *Dibunophyllum*
		D_2 Subzone of *Lonsdalia floriformis* (*Lonsdalia* subzone)	D_2	12. *Saccammina carteri* 11. *Girvanella* Nodular Bed	i. *Lonsdalia floriformis*	Upper	
		D_1 Subzone of *Dibunophyllum* θ and φ (θφ subzone)	D_1	10. *Chonetes* aff. *comodes* and *Cyrtina septosa* 9. *Davisiella llangollensis*	h. *Cyathophyllum murchisoni*	Lower	
	Seminula Zone, S. *Seminula ficoidea* and its allies	S_2 Subzone of *Productus cora* mut. S_2	S_2	8. Bryozoa Band	g. *Nematophyllum minus*	Upper	C. *Productus curruguto-hemisphaericus*
				—	f. *Cyrtina carbonaria*	Middle	
		S_1 Subzone of *Productus semireticulatus* mut.	S_1		e. Gastropod Bed	Lower	
	Syringothyris Zone. C. *Syringothyris* aff. *laminosa*	$(C_2 + S_1) = \delta$		7. *Clisiophyllum multiseptatum*	d. *Chonetes carinata* c. *Camarophoria isorhyncha*	Upper	B. *Michelinia grandis*
		C_2 Upper Caninia Zone	C_2	6. *Spirifer furcatus* 5. BrownberPebbleBd with *Syring. cuspidata* 4. *Thysanophyllum pseudovermiculare*	b. *Seminula gregaria*	Lower	
Tournaisian or Lower Avonian		C_1 Lower Caninia Zone	C_1	3. *Productus globosus* and Algal Band		Upper	A. *Athyris glabristria*
	Zaphrentis Zone, Z. *Zaphrentis* aff. *phillipsi*	Z_2 Subzone of *Zaphrentis* aff. *cornucopiae* (Matley and Vaughan 1906 [Ireland], p. 301).		2. *Camarotoechia proava* 1. *Vaughania cleistoporoides*	a. *Solenopora*	Lower	
			Z_2?	Shap Conglomerate			
		Z_1 Subzone of *Spirifer* aff. *clathratus* β. passage to Z_1	Z_1?	Pinskey Gill Beds with *Spirifer pinskeyensis*			
	Cleistopora Zone, K. *Cleistopora* aff. *geometrica*	K_2 Subzone of *Spiriferina* cf. *octoplicata*					
		K_1 Subzone of *Productus bassus*					
		K_m Phase of *Madiola lata*					

Beds with *Lithostrotion* = Viséan (Garwood zones C. and D.)

Beds without *Lithostrotion* = Tournaisian (Garwood zones A. and B.)

1. **The Southern region** includes the country South and West of Sedgemoor (51° 10′ N.). Two areas of Lower Carboniferous exist respectively in North and South Devon. The severe folding, crushing and thrusting, to which the rocks have been subjected in the development of the Hercynian chain, render the elucidation of the succession extremely difficult.

In North Devon the black slates of the Upper Pilton have yielded to VAUGHAN a fauna suggesting a low horizon in the Zaphrentis zone and recalling the horizon of Z. delépini (Hor. β) in Belgium. These are separated by a considerable break, represented elsewhere by the greater part of the Carboniferous Limestone[1], from the Codden Hill Cherts containing radiolaria with *Prolecanites compressus* and *Cyathaxonia* and belonging to the *Cyathaxonia* or D_3 Subzone. These cherts are closely allied to those described by DIXON and VAUGHAN (1911) in South Wales. They are followed by black shales and limestones with the following "Pendleside" zone-fossils (1) *Posidonomya becheri* and *Nomismoceras rotiforme*, (2) *Glyphioceras reticulatum* and (3) *Glyphioceras spirale*. These are followed by *Gastrioceras listeri* of the Millstone Grit, but the earlier Millstone Grit zone-fossil *G. bilingue* has not been found. These are succeeded by the grits and shales of the Middle Culm. A similar succession and most of the same fossils are found in South Devon, but there are no representatives of the Pilton Beds. (HINDE and FOX 1895, HAMLING and ROGERS 1910).

2. **South-Western Province** (of VAUGHAN) furnishes perhaps the only complete sequence of marine Avonian. The rocks are prevailingly calcareous, though shales sandstones and grits or conglomerates appear at different horizons in various parts of the district, but especially along the northern margins.

The limestones seem without exception to have been formed in shallow water and many of the shales, especially such as are characterised by the *Modiola* fauna, to have accumulated under lagoon conditions, i. e. in shallow salt water with incomplete connexion with the sea. The dolomitic condition is very frequent, especially at the "laminosa" horizon. The dolomitization is generally considered to have been in the main contemporaneous, but in some cases it has clearly been due to percolation after consolidation, as the dolomitic changes traverse blocks, so that one end may have 23 % of Magnesium Carbonate and the other only 1,7 %.

Oolitic structure is present at certain horizons, especially at C and S_2. A remarkable type of "pseudo-breccias" in C_2 occurs in the Gower Peninsula.

[1] The nearest point at which typical Carboniferous Limestone has been found is at Cannington Park in West Somerset Lat. 51° 9′ N and Long. 3° 5′ W, where S_1 occurs.

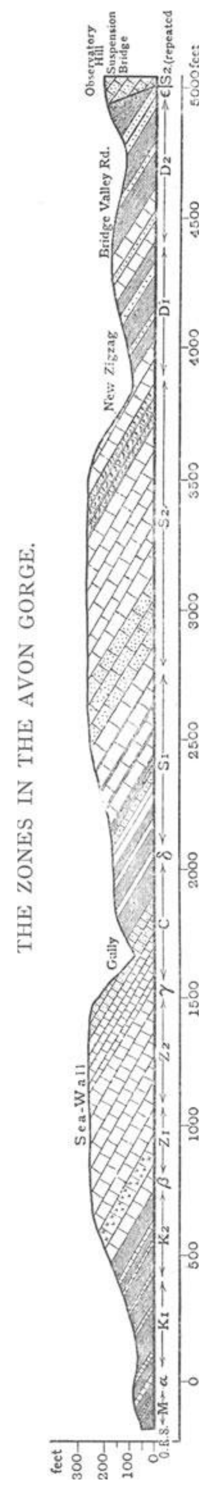

Fig. 33. Section illustrating the palæontological sequence in the Carboniferous Limestone in the Bristol Area (A. VAUGHAN). Horizontal and vertical scale about 1:8,900 or 7,1 inches to the mile.

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They have been carefully described and discussed by DIXON (1911). They appear from the descriptions to bear considerable resemblance to beds on the C_2 S_1 horizon at Ingleton, and DIXON suggests that they have originated by the partial early recrystallisation of a calcareous mud. Some of them have undergone subsequent dolomitization.

Chert appears in the Mendips at the passage γ from Z_2 to C_1, as well as in S_1. In the Gower Peninsula, where alone D_{2-3} is represented in this Province, chert also appears, and it is interesting, and possibly significant, that the horizon D_{2-3} is cherty in North Wales, Derbyshire, Wensleydale, and Northumberland.

The variation in thickness of the Avonian in this region is very remarkable, the general tendency is to increase of thickness from north to south and east to west. This is in part due to the invasion of the upper zones by sheets of coarse grit or sandstone, the so called "Millstone Grit", that appear at lower and lower horizons pari passu with the reduction of thickness; in part, again, it is due to attenuation of the zones; and probably, as to the remainder, to intraformational unconformity. DIXON and VAUGHAN have shown that in the Tenby area from West Williamston to Pendine a plane of unconformity, succeeded by a lagoon-phase, cuts in a west to east direction from the top of C to the top of Z, and is succeeded by overlapping lagoon-phases that, at Pendine, bring S with an intervening conglomerate, on to Z_2.

The following thicknesses have been estimated

		Abergavenny 30 m. (100 ft.)	
			Mitcheldean 180 m. (600 ft.)
			Bristol 685 m. (2250 ft.)
Tenby 365 m. (1200 ft.)	SW. Gower 1130 m. (3700 ft.)		Mendips 920 m. (3020 ft.)

DIXON ascribes these variations in a series of essentially shallow water deposits to earth movements of depression towards the south or south-west and elevation in a northerly direction, but the direction of the axes of movement changed, so that, whereas in the movements during the deposition of K_m to C the axis of tilting was roughly N.W. — S.E., the later movements were parallel to an axis roughly S.W.—N.E.

3. **The Midland Province.** This region is characterized in the Pennine area by the enormous development of the Dibunophyllum zone in all its three divisions, and, consequently, though the deep valleys that trench the anticlinal axis of Derbyshire expose about 460 m. of Upper Avonian Limestone, it is composed wholly of the D_{1-3} divisions. Black limestones occur near the base of the visible portion, and again in the upper part of D_2 and lower part of D_3, where also chert, chiefly in nodules, is largely developed.

On the reappearance of the series in North Wales it is found, to include, besides all the subzones of the Dibunophyllum zone, a representative of S_2, with a basal layer containing *Daviesiella (Chonetes) llangollensis* resting on a red conglomerate[1] 90 m. (300 ft.) thick that in some localities is charged with pebbles of Downtonian rock of a type that is not known in Wales. LOMAS (1908) gives a revised correlation of the beds that does not materially alter the classification.

[1] These and other red rocks at the base of the Carboniferous are referred by some authors to the Upper Old Red Sandstone, see p. 112.

From this it appears that the Viséan subzones comprised almost entirely by the D_{1-3} have a thickness of 390 m. (1275 ft.). The local interruption of the lower beds by a ridge 180 m. (600 ft.) high of the floor of pre-Carboniferous rocks was illustrated by LOMAS who pointed to its coincidence with the axis of the Berwyn anticline.

The upper part of the Dibunophyllum series, D_3, is often sandy and even somewhat conglomeratic. A most notable feature of this horizon is the extensive and valuable beds of chert that occur at the top. At Pentre near Gronant (53° 20′ N.) 21 m. (70 ft.) of these black chert is exposed, but this is not the full thickness. It is extensively worked for use in the Potteries (Stoke-on-Trent) for grinding calcined flints. The close general resemblance of the development just described to that found in Derbyshire has prompted the inference, that not only do the two areas belong to one province, but the Southern Pennine development would, like that of North Wales, commence with the Viséan. This does not seem a justifiable inference, as North Wales may have been much nearer to the shore-line and we shall see later that Tournaisian rocks are present at the next emergence of the Lower Carboniferous in the Pennine anticline.

Anglesey is considered to be within the Midland Province. Here a great basal series of sandstones and conglomerates (180 m., 600 ft., thick) are exposed in Lligwy Bay. They are succeeded by 210 m. (700 ft.) of limestone with intercalations of conglomerate and sandstone. GREENLY has recognised in this series the whole of the Dibunophyllum subzones. In a southerly direction the limestones, reduced to 140 m. (450 ft.), overlap the sandstones and rest on Archaean rocks.

A remarkable feature recorded by I. E. GEORGE, and confirmed and explained by GREENLY, is the occurrence in the top of the limestone of "potholes" filled with tough yellow sandstone. They are regarded as infilled solution-hollows produced under contemporaneous subaerial conditions.

Similar "potholes" 12 m. (40 ft.) deep are found at Ifton near Newport, Monmouthshire (DIXON and VAUGHAN). They are filled with "Millstone Grit". Others have been noted by Professor O. T. JONES at Haverford-west (1906) and evidences of unconformity at or about the same horizon are noted by SIBLY and by WEDD (1908) in Derbyshire.

The Carboniferous Series in the Isle of Man is generally attributed to the facies of the Midland Province. In the south of the Island a massive

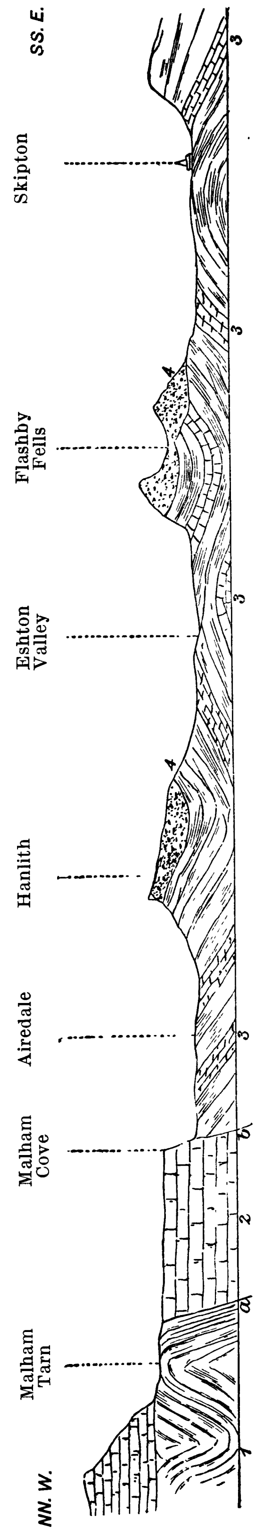

Fig 34. Diagrammatic section from Malham Tarn, 54° 6′ N, to Skipton, 53° 57′ N; (W. H. HUDLESTON). Explanation of signs:— 1 = Silurian Grits; 2 = Carboniferous Limestone; 3 = Yoredale Series; 4 = Millstone Grit; a = North branch of the Craven Fault; b = South branch. The surface of the valleys is for the most part thickly covered with glacial clays, sand and boulders. Horizontal scale 1 in = about 1,77 miles, or 1:112 000; vertical scale exaggerated. Reproduced from the Proceedings of the Geologists' Association, vol. 7, p. 435 (1882) with the permission of the Council.

conglomerate rests in striking unconformity upon the Manx Slates. Upon this succeeds about 60 m. (200 ft.) of white limestone with a D_2 fauna[1] passing up into D_3 with abundant *Cyathaxonia*, and this division is followed by Pendleside shales and limestones. At Poolvash a remarkable variant occurs; the "top of D_2 is represented by knoll-like masses without any definite bedding planes." The knolls are of various sizes, some being diminutive, and when unaltered by metasomatic changes are crowded with fossils" (HIND 1907). They appear to protrude through the bedded D_3 limestones and are surmounted directly by normal Pendleside beds. The Peel Sandstones in the north of the island have been referred to the lower part of the Carboniferous series. They rest upon the ancient rocks, but their relations to the Carboniferous Limestone are not seen in any section. Bands of calcareous conglomerate have yielded remanié fossils attributed by DAWKINS to the Carboniferous, but GILL (1903) identifies well-known Ordovician species and his determinations are confirmed by the fact that the matrix precisely resembles the peculiar Keisley Limestone that contains the fauna described.

4. **The Mid Pennine Region.** This is the area where the Avonian reappears between Pendle Hill (53° 51′ N.) and the Craven Faults (54° 1′—11′ N.).

The district is much folded, the strata on some axes being vertical or even slightly overturned, and this, together with the fact of an extensive cover of Glacial deposits, would suffice to make the task of correlation difficult; but, beside this, the rocks vary greatly in lithology and fossil-contents even when traced along the strike.

The base is nowhere visible. WILMORE states (1907, 1910) that the series extends from zones at least as low as Z, up to the junction of D_2 or D_3 with the Pendlesides.

The most remarkable feature of this region is the occurrence of the "reef-knolls" of TIDDEMAN (1891). These are semi-ovoid or hemispherical masses of limestone forming rows or irregular groups of hills up to 60 m. (200 ft.) or more, in height. They are commonly crowded with well-preserved shells, especially brachiopods, and in some knolls examples may be found still retaining the colour markings. TIDDEMAN describes the structure of the knolls as quaquaversal[2], and supposes that they were shell-banks accumulating upon a sinking sea-floor, hence that their form is an original feature. DAKYNS (1899) supported this opinion.

These views have been opposed by MARR, HIND and WILMORE. MARR (1899) denies the abundance of fossils, holding that the rock is abnormally crystalline and that the fossils are thereby rendered conspicuous. He attributes the mounds and their structure to thrusting movements breaking up thin layers of limestone embedded in shales and piling them together in a kind of "Schuppen-struktur". He traces a connexion between their distribution and lines of over-thrust. WILMORE cites examples of minor thrust-planes and folds in knolls, and, mentions that in certain cases, e. g. Gerna near Downham (53° 52′ N.), the shales lying at the foot on one side are of Pendleside age, while those on the other are on a lower stratigraphical horizon.

VAUGHAN has recognised a special fauna in these knolls, as well as in equivalent beds at Wetton (Staffordshire) and Rush (Ireland). He states that

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[1] GARWOOD has, however, found a C fauna, at Derbyhaven.
[2] According to VAUGHAN, this dœs not extend to the interior of the knolls, which is structureless.

these "Brachiopod Beds" with the "knoll" phase appear, in part, to represent D_3, and that D_y is not typically developed in the localities exhibiting this peculiar phase. He believes that a knoll phase occurs at more than one horizon.

The present writer, after examination of many of the knoll-areas, is inclined to favour the reef theory of TIDDEMAN, perhaps with modification, and to regard such a case as that of Gerna as a strike-section of a lenticular mass. The abnormal abundance of fossils is beyond dispute. In some places, e. g. in Mill Gill, Wensleydale (the type section of the Yoredales of PHILLIPS) miniature knolls rise about 1 m. (4 ft.) from the surface of the Great Scar Limestone, which here contains *Cyathaxonia*, and black shales with *Posidonomya becheri* are bedded round about and over the knolls. The difference between these and the typical knolls is one of scale, which may of course be most material.

The Mid Pennine Province extends in a westerly direction to Kendal and Arnside where the series may include a part of the Tournaisian.

5. **The Northern Region** presents three types or Sub-regions. (a) The Kirkby Stephen and Shap escarpment on the Western Side of the Vale of Eden. In this area limestones greatly predominate. At Pinskey Gill near Ravenstonedale (54° 30′ N.L.) a Tournaisian fauna, perhaps older than any in the South West Region,

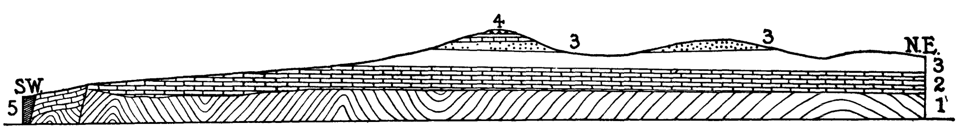

Fig. 35. Section across Ingleboro and the Craven Faults (A. R. DWERRYHOUSE).

5 = Coal Measures; 4 = Millstone Grit; 3 = Yoredale Series; 2 = Carboniferous Limestone; 1 = Older Primary.

Reproduced from the Proceedings of the Geologists' Association, vol. 22, 1911, p. 38, with the permission of the Council and of the author.

shows some doubtful Devonian affinities. An important datum in this area is provided by the Fell Sandstones in the S_1 zone. (b) The Northumbrian fault-block (KENDALL 1911). This is a block of country walled by a system of faults extending from the North Sea at the mouth of the Tyne (55° 1′ N.) round to the sea again at Filey (54° 10′ N.), the whole series forming a figure like a reversed 3 (ε). Within the fault-blocks no marine horizons below C_2 S_1 have been recognised but extensive Basement beds of sandstone and conglomerate, expanding on Roman Fell (54° 34½′ N, 2° 23′ W) to 150 m. (500 ft.) thick, occur. The upper part of this series contains materials entirely of local origin and is referred by all observers to the Carboniferous series. The lower part contains a great diversity of derived fragments (hence styled polygenetic) and is by many geologists referred to the Upper Old Red Sandstone. These pebbles are different from any rocks exposed in the adjacent pre-Carboniferous areas, and the writer suggests that they may have derived from a Pre-Cambrian series lying to the North of the Ingletonian rocks of Ribblesdale. These lower beds also contain thin bands of dolomitic limestone a fact of some significance when the series is compared with the succession further north.

A typical section is seen on Ingleborough (54° 10′ N.).

Coarse Pebbly Grit	Millstone Grit	18 m. (60 ft.)
Shale	Yoredale Rocks	280 m. (930 ft.)
Main Limestone		
Sandstone with some Shale		
Limestone with Shale		
Shale and sandstone		
Middle Limestone		
Sandstone and Shale		
Simonstone Limestone		
Sandstone and Shale		
Hardraw Scar Limestone		
Shales and Limestone		
Great Scar Limestone	Carboniferous Limestone	180 m. (600 ft.)
Basement Bed (impersistent)		
Silurian and older rocks		

The rocks are displayed in magnificent sections that have been studied by generations of geologists, but the palæontological succession has not yet been fully worked out and much difference of opinion exists as to the zones represented. Thus HIND in 1909 placed the Great Scar Limestone in S_2 and the whole of the Yoredales in D_1. GARWOOD (1907) carried D_1 up to and including the Hardraw Scar Limestone. D_2 is made to embrace the strata between this horizon and the Main Limestone. The Main Limestone and strata up to the Millstone Grit he refers to D_3. S. SMITH (1911) in a review of the succession north of the Tyne places the Hardraw Scar Limestone in D_2, the strata up to the Main Limestone in D_{2-3} and the Main Limestone D_3. All the remaining beds are designated by the symbol D_Y. JOHNS in 1908 referred the upper part of Great Scar Limestone to D_2 in which subzone he also included the Main Limestone, but later, in 1910, he announced the occurrence of *Cyathaxonia* in the top of the Great Scar Limestone of Wensleydale and pronounced the fauna of the Main Limestone to "indicate a higher level than anything recorded from Bristol or South Wales". This was before the recognition of D_{2-3} in Gower. Until researches now in progress are completed it would be premature to express any definite opinion upon this question of correlation.

Since the foregoing was written GARWOOD's full statement has appeared (1912). Some of his results are embodied here.

The Yoredale Rocks though containing many important beds of limestone are predominantly sandstones and shales. Some coal-seams, even of workable dimensions, occur, each with its seat-earth, and these increase in number and importance northward. The number of limestones also increases, but whether, as some think, these are intercalary in the shales or whether they are due to penetrations of shale into the limestones has not yet been determined, but the latter, in view of the other changes noted seems the more probable.

6. **Northumberland and the Tweed Valley.** This sub-region lying to the north of the fault block exhibits a great contrast to the areas just described as will be seen from the following table adapted by SMITH (1911) from the works of LEBOUR and GUNN. The terms Tuedian and Bernician are adopted by LEBOUR for the Lower Carboniferous series:

	Tyne and Rede	Tweed
Bernician		
Calcareous division	1200 m. (4000 ft.)	520 m. (1700 ft.)
Carbonaceous division	760 m. (2500 ft.)	275 m. (900 ft.)
Tuedian		
Fell Sandstone Series	180 m. (600 ft.)	180 m. (600 ft.)
Cement Stone Series	180 m. (600 ft.)	760 m. (2500 ft.)

The correlation of this succession with that of the fault-block and with VAUGHAN's system of zones is shown in the following compilation from the works of GUNN, GARWOOD and SMITH:

Wensleydale (GUNN, 1898)		Northumberland (SMITH, 1911)	(GARWOOD)	(1910)	(1912)
			Botany Beds		D_3
	Dy	Fell Top Limestone	Fell Top Limestone	D_3	
		Robsheugh ,,			
		Thornbrough ,,			
		Corbridge ,,		Dy	
		Little ,,			
Main Limestone		Great ,,	Dryburn or Great ,,	D_3	D_2
Undersett Lmst.	D_{2-3}	Four Fathom ,,	Lowdean or 4 Fath. ,,	D_2	
Acre Limestone		Acre ,,	Acre ,,		
		Eelwell ,,	Eelwell ,,		
Hardraw Scar L.	D_2	Oxford ,,	Oxford ,,		
	D_1	Fourlaws ,,	Fourlaws ,,	D_1	D_1
		Redesdale ,,	Redesdale ,,		
		Redesdale Ironstone .	Carbonaceous	S_2	S_2
			Division		S_1
			Fell Sandstones . . .	S_1	C_2
			Cement Stones and .	C	C_1 γ
			Lower Freestone . .		Z(?)

Apart from the question of zones there is a general agreement in correlating the Hardraw Scar with the Oxford Limestone, so that only the comparatively small Redesdale and Fourlaws limestones, if even these, can be regarded as calcareous equivalents of the massive Great Scar Limestone of Ingleborough. The limestone beds are separated by shales and sandstones with occasional coal-seams some of which are of workable thickness, especially the Lickar Coals between the Great and Little Limestones. The Acre limestone is packed with *Saccammina carteri*, a fossil that also characterizes a bed near the top of the Great Scar Limestone in Wensleydale.

The Carbonaceous division of the Bernician may represent a phase of which a mere trace is developed at Ingleton in the form of an eroded fragment of a coal-seam with its underclay, that is intercalated in the Great Scar Limestone. In Northumberland this Carbonaceous division, also known as the Scremerston Series, consists of sandstones, shales, and thin limestones with thin impure limestones. The coal-seams are of considerable importance, 16 seams exceed one foot in thickness and of these six are of workable dimensions. Most of the seams have a limestone roof and two contain a thin parting of limestone.

The Fell Sandstones contain minor beds of shale and some small coal-seams and besides plant remains they yield the interesting lamellibranch *Archanodon jukesi*. The Cement Stone Series consists of "reddish and white sandstones and green and dark-coloured shales and thin magnesian limestones (Cement Stones)". The fauna in the Tweed Valley where they attain their maximum consists, according to GARWOOD, mainly of land and fresh water lamellibranchs, gastropods and fishes, with a varied assemblage of arthropods, including Arachnida und Crustacea. No brachiopods or corals occur but an *Orthoceras* is recorded. According to GARWOOD the most characteristic fossil is *Spirorbis helicteres*, he also notes the occurrence of *Syringothyris cuspidata* and *Orthotetes crenistria*, either at the summit of this series, or at the base of the Fell Sandstone. It is in either case clear that occasional irruptions of the sea came into this area. *Mitcheldeania gregaria* has been found in limestones in many places and *Athyris glabristria* PHILL. (*royssii* auct.) occurs near the borders of Cumberland in beds referred by GARWOOD to some part of the C. zone.

A digression may now be conveniently made to consider briefly the relation of the Yoredale Rocks to the Pendleside series. HIND insists that the two are quite independent, the Pendleside series being the newer. Correlation is difficult because the two types have never been found in clear succession but JOHNS holds that the Pendleside Limestone is the same as the Main Limestone, and points out that in Mill Gill, Wensleydale, the top of the Great Scar Limestone with a Cyathaxonia fauna (whether the true D_3 fauna or not has not been made clear) is directly succeeded by shales crowded with *Posidonomya becheri* which he considers to mark the incoming of the Pendleside fauna. The characteristic goniatites have not been found and until this defect is supplied the question cannot be decisively settled. HIND's contention involves great stratigraphical anomalies, for example, on Ingleboro, 284 m. (930 ft.) of Yoredale Rocks intervene between the Great Scar Limestone and the Millstone Grit, and in full view, 32 miles away, stands Pendle with 450 m. (1500 ft.) of Pendleside Beds occupying a precisely similar homotaxial position. The palæontological argument for difference of age is much weakened by the discovery in Ireland (MATLEY and VAUGHAN 1908, Ireland) of rocks with a Pendleside fauna interbedded with typical D_3 beds. Similar relations appear to hold in parts of Derbyshire (SIBLY 1908), and the present writer inclines to the opinion expressed by VAUGHAN that the faunal differences depend more upon differences of conditions than of age. It has long been believed by TIDDEMAN and others that the Craven faults, that constitute the boundary between the Yoredale country and area within which the Pendleside Series occurs, were moving in Carboniferous times with consequent marked effects upon deposition. Many observers, e. g. WILMORE (1910), GARWOOD and CARRUTHERS have commented upon the great palæontological contrasts presented upon the two sides of this great system of dislocations, and it seems more probable that the two series of strata were contemporaneously deposited than that, without perceptible unconformity, the whole Pendleside series should be absent from the Northern area and all the Yoredale Rocks from the Southern one.

HIND's argument that, as the Yoredale fishes differ from those of the Pendleside Series, the rocks must be of different ages, is neutralized by the fact that TRAQUAIR can find no significant differences between the fish faunas of different parts of the Lower Carboniferous Series.

7. **The Scottish Lowlands.** This region is enclosed between great trough-faults forming the "Rift", or Midland, Valley of Scotland. It is the general opinion that these faults were in operation in Old Red Sandstone time and that the movement continued at least during the deposition of the Carboniferous strata. The succession of Lower Carboniferous rocks is in all essentials the same as in Northumberland as will be seen from the following table:

	Northumberland		Scotland
Bernician . .	Calcareous division with Lickar Coals	Carboniferous Limestone Series	Upper Limestone Group Edge Coal Group (Coal and Ironstone Group of Glasgow) Lower Limestone Group
	Carbonaceous division (Scremerston Coals)		Carbonaceous Group and Midlothian Oil-shale
Tuedian . . .	Fell Sandstones	Calciferous Sandstones	Upper Series with Fell sandstones near Dunbar
	Cement Stone Series		Cement Stone Group (including the Ballagan Group of Glasgow)

The sections near Dunbar approximate most closely to the Northumbrian type, and towards Glasgow the lithology changes so greatly that without the connecting links, furnished by the intervening area of Midlothian, correlation would be difficult, if not impossible.

The Calciferous sandstones consist mainly of green clays and shales with bands and nodules of argillaceous dolomite (Cement Stones) and some sandstones, especially in the upper part near Dunbar, where they clearly correspond with the Fell Sandstones.

The occurrence of dolomitic limestones and gypsum in the Ballagan beds have by many writers, particularly GOODCHILD, been regarded as affording indications of an arid climate.

Beds of limestone containing a marine fauna occur in the upper part of the series, and in the Glasgow area the Hollybush Limestone, about 90 m. (300 ft.) below the summit of the Calciferous Sandstones has yielded a considerable suite of fossils including *Productus giganteus* and *P. latissimus* characteristic members of the D. fauna.

The Carbonaceous group, contrary to the general practice, is in the table attached to the Carboniferous Limestone series in order to make clear its relation to the Bernician series of Northumberland. It contains several small coal-seams near Dunbar that may correspond with the Scremerston Coals of Northumberland and the group is considered to be represented in Midlothian by the very important Oil Shales.

On lithological grounds it just as ill-deserves the name, for, while limestones do occur, they are few in number and very thin, rarely attaining a thickness of 6 m. (20 ft.) and in the upper division seldom so much as 1,5 m. (5 ft.). The great bulk of the formation consists of sedimentary materials — shales and sandstones with coal-seams.

The Lower Limestone Group includes six principal limestones on the East Coast near Dunbar and three limestone horizons in the Glasgow area. The correlation of these two districts is somewhat difficult. The following scheme exhibits the probable relation to Northumberland.

Northumberland		East Lothian
Lickar Coals	=	Edge Coals
		Barness Limestone
		Chapel Point ,,
Acre Limestone	=	Skateraw ,,
Eelwell Limestone	=	Longcraig Upper Limestone ,, Middle ,, ,, Lower ,,
Woodend (or Fourlaws) Limestone	=	Linkhead or Cove Upper Limestone
Dun (or Redesdale) Limestone	=	Cove Lower Limestone

The Skateraw Limestone contains a persistent band of *Saccammina carteri*. Several coal-seams occur in this series.

The Edge Coals of Midlothian, the equivalents of the Coal and Ironstone Series of Glasgow, constitute an important series, with seams varying in thickness up to about 1,5 m. (5 ft.) in the east, but much thinner in the west. In Midlothian there is a general tendency for the seams to become thinner from north to south. Cannel occurs throughout this region, and in the Glasgow area a valuable seam of anthracite is worked. Its formation is attributed to the proximity of a dolerite sill. Valuable ironstones also occur.

The Upper Limestones constitute a series bearing a strong general resemblance to the Lower Limestones and like them containing workable coal-seams, but the limestone bands themselves are very thin, despite which, however, they are very constant, the Index Limestone, which is taken as the base of the series, and the Castle Cary Limestone that marks the summit, extend quite across from the East Coast to Glasgow. The abundance of *Productus latissimus* characterizes the lower part of this series.

Though not included in the Carboniferous Limestone in any scheme of classification, the lower part of the Roslin Sandstone must find a place, either there or in the Pendleside Series, and in the absence of any specific evidence it seems more appropriate to group it on stratigraphical grounds with the former, for, as we have seen, the term Pendleside Series probably connotes rather a special palæontological phase than a specific and constant stratigraphical horizon.

The palæontological succession in the Carboniferous rocks of Scotland has long engaged the attention of geologists, and a broad division into an upper, and a lower, series was put upon a satisfactory basis by the labours of KIDSTON upon the plants and of TRAQUAIR upon the Fishes. These two workers found themselves in close agreement in drawing a line of separation at some distance above the base of the Roslin Sandstone or Millstone Grit. Below this line no further subdivision has been found practicable by them. The invertebrate fossils, until the publication of the results obtained by GARWOOD, HIND and VAUGHAN in England, were almost equally unproductive of bases for subdivision or of correlation with the sequence of Lower Carboniferous in other parts of Britain. It is now found however that the general zonal distribution applies, with some modification to the Scottish rocks. The true horizon of the Calciferous Sandstone is still uncertain but the occurrence of the Hollybush Limestone with a D_2 fauna about 73 m. (240 ft.) from the top of the upper division affords a valuable datum. It shows further that as already remarked the name "Carboniferous Limestone" must bear a different connotation in Scotland and in England, the entire Scottish series so designated, as well as a large part of the Calciferous Sandstone, lying on the horizon of the Yoredale Series of Yorkshire[1].

G. W. LEE (1912, pp. 95—6) refers the whole series from this limestone up to the top of the Upper Limestones to D_2. He remarks that "this D_2 phase in Central Scotland appears to have persisted during a longer period than in England. Our Upper Limestones therefore, though from stratigraphical evidence known to be higher up in the sequence than the top part of the English D_2 zone, still contain a fauna which, in our present knowledge, has D_2 affinities." With reference to sub-zones D_3 and P he states that "species characterizing these sub-zones have not yet been met with in Scotland as distinct assemblages, though marine beds of the same age are doubtless present." It may be remarked however that mutation D of *Zaphrentis delanouei* found by CARRUTHERS in the Lower Limestones and *Z. omaliusi var. ambigua* mut. σ from the same series were found by VAUGHAN (1908, Ireland) to be confined respectively to the P. and D_{3b} horizons at Loughshinny in Ireland. The lower part of the Roslin sandstone may be the stratigraphical equivalent of the highest Yoredales and Pendlesides.

Outlying occurrences of Lower Carboniferous rocks in the West of Scotland are of interest as aiding any attempt to reconstruct the geographical conditions of the period. JUDD records the occurrence of Carboniferous plants (*Lepidodendron aculeatum*) from Ardtornish in Argyllshire and similar evidence has been obtained from Bridge of Awe in the same district. The occurrence of a *Modiola* related to, if not identical with, *M. macadami* is also noted.

[1] *Syringothyris* has been found by PEACH and HORNE in Liddisdale at the base of the Fell Sandstones. The Cement Stone group below must therefore be of Tournaisian age.

B. The Millstone Grit.

This is, of all the members of the Carboniferous series, the most difficult to reduce to any systematic arrangement.

Many causes conspire to complicate the task. In the first place palæontology gives little aid in the endeavour, except so far as the definition of a base, cutting across the lithological lines, may be said to be an assistance; but, even with this reservation, it must be admitted that the presence of well-preserved fossils of diagnostic value is exceptional. Lithology, again, is often a source of error, rather than a helpful guide; and finally, the stratigraphy is confused by the wedging out of massive beds of sandstone as might be expected in deltaic accumulations laid down in areas undergoing a general movement of depression varied by long periods of quiescence or even of elevation.

To all this must be added the fact that the Grit formations of Scotland and the Pennine Region are of an origin and provenance absolutely distinct from the Farewell Rock of the South-Western Province, and in large measure also from each other.

The grits of the Northern area extending from Charnwood (52° 43′ N.) and the neighbourhood of Birmingham to the Midland Valley of Scotland are essentially arkoses, derived from the waste of crystalline rocks lying to the north, north-west or north-east. "The Farewell Rocks" of the South-Western Province, on the other hand, are quartzose grits and conglomerates whose materials have come from an entirely different source, at present not definitely ascertained, though probably to be sought in Central Wales. To the first of these alone the name Millstone Grit should be applied.

The grits of the southern portion of the Pennine range were classified by Hull and Green (1864) into four main arenaceous groups with intervening shales, and they numbered them, very oddly, by ordinals commencing with a First Grit or Rough Rock at the top and concluding with a Fourth Grit or Kinderscout Grit. To this series is added an additional lower member Farey's or the Shale Grit formerly grouped with the Yoredale Series.

The grits are well-defined as separate beds or groups of beds of sandstone or more or less conglomeratic grit, composed of sharp and generally subangular grains of quartz with felspar, mostly microcline, often in a very fresh and little altered condition, though upon exposure the felspar may be reduced to a kaolin mud, with the concurrent production of crystal-terminations upon the quartz grains as well as a hackle of minute facets upon the pebbles. Sorby (1847, 1858—59) studied the current bedding of the grits in an area near Sheffield and found that, while the direction varied considerably, the predominant direction indicated that the materials were distributed by currents coming from the north or north-east. His studies of the contained stones supported this conclusion. Recent researches by Albert Gilligan (1912), of the Leeds University, have resulted in the identification of pebbles conforming to types well-known in the Highlands of Scotland, thus confirming in some measure Sorby's conclusion that the materials were of northern, probably of Scandinavian, derivation. He finds that the main substance of the grits consists of quartz and microcline — other felspars rarely being present. The constitution of the rock thus resembles in a remarkable way the pre-Cambrian Torridon Sandstone of the North-West Highlands of Scotland, but the extremely fresh condition of the felspar, and the angularity of the particles, coarse as well as fine, no less than the common occurrence of fragments of pegmatite, forbid the inference that the Millstone Grit was derived from that source, but favours the opinion that both rocks, separated though they are by so wide an interval of time, came from a common source. No area of pegmatite of adequate magnitude to be the source of this immense mass of material exists in North Western Europe and the conclusion appears to be unavoidable that some tract of crystalline rocks at present submerged beneath the waters of the Atlantic provided both the Torridon Sandstone and the Millstone Grit. GILLIGAN considers that the fresh and unaltered condition of the felspar and the distribution of the sheets of Millstone Grit indicate that it was borne by a large river from an area of low rainfall lying in the direction named. The shales intervening between the grit beds appear to be mainly of fresh water origin, though fresh water shells have been discovered at only two or three localities. There are, however, true marine shales distinguished both by their fauna and by lithological peculiarities. It is probable that one such marine band occurs in each main bed of shale. The most notable of these occur above the Kinderscout Grit (Sabden Shales of the Geological Survey), beneath the Rough Rock, and in unassigned positions near the middle of the series.

At Eccup near Leeds, in the Middle Series, blue shales occur crowded with marine lamellibranchs, gastropods, cephalopods, brachiopods, crinoids and crustaceans. *Brachymetopus ouralicus*, the last of the British trilobites, occurs in these beds. At a slightly lower horizon is an arenaceous limestone, the Cayton Gill Bed, extending from Harrogate (54° N.) up the Nidd Valley. Its fauna has been discussed by HIND (1907) who comments upon the reapparition of a brachiopod fauna of Lower Carboniferous aspect 300 m. (1000 ft.) above the base of the Grits. He assigns it to "a late *Dibunophyllum*" stage. GARWOOD seems to have overlooked these two beds, when expressing the opinion (1912) that his Botany Beds, occupying an undefined position in rocks referred to the Millstone Grit in Teesdale, yield "the highest truly marine fauna yet met with in the North of England". In some sections, e. g. at Marsden (53° 35′ N.), each bed of Grit is surmounted by a coal-seam with its seat-earth. The coals in the Millstone Grit have been mined in some of the more remote valleys of the Pennine Chain, where transport from the regular coalfields is difficult and costly.

The Grit series varies not only in thickness but in its constituent members as it is traced from north to south.

In Scotland it is represented by a portion of the Roslin Sandstone, which near Edinburgh consists of shales, marls, fireclays and pebbly sandstones attaining a total thickness of 225 m. (740 ft.) of which, however, on the evidence of the plants, the lower 72 m. (235 ft.) is assigned to the Lower Carboniferous. Two beds of pebbly grit occur in the portion assigned to the Millstone Grit and a similar one in the lower division, besides which the same type appears in the Lower Carboniferous and recurs in the Lower Coal Measures. The pebbles are mostly of vein-quartz, a notable difference from the grits of the Pennine area, but in some sections conglomeratic beds contain fragments of Carboniferous Sandstone and, at one place, angular fragments of volcanic rock.

In the Glasgow area fireclays of a remarkable character occur in the lower part of the series, that at the famous Glenboig works consists of about four-fifths of kaolin, some quartz, felspar, hornblende and biotite. A rhombohedral carbonate occurs in minute crystals identified by GREGORY as sideroplesite.

A very notable palæontological feature of the beds in the Glasgow area attributed to the Millstone Grit is the apparition, near the base of the series, of a marine fauna, of which fully 50 per cent of the forms (e. g. *Meekella*) were until recently unknown elsewhere in Britain, though they had been previously recognised in the Upper Carboniferous of Nebraska and some of the species had been found in Russia and China. Many of the typical lamellibranchs have since been found in a limestone, presumably belonging to the Carboniferous Limestone, in a bore at Stirling, and others at various horizons in the Carboniferous Limestone Series and Calciferous Sandstone Series. It should, however, be noted that the plant evidence would place the division between Upper and Lower Carboniferous above the horizon of the Marine Bed in the Millstone Grit.

In Northumberland the series consists of alternations of grits and shales with a total thickness of 150 m. (500 ft.). Grits lithologically indistinguishable occur both in the Lower Carboniferous and in the Coal Measures. GARWOOD (1912) assigns some of the beds mapped as Millstone Grit in Teesdale to a horizon below his "Botany Beds", which contain a D_3 fauna.

In North Yorkshire a coarse typical Millstone Grit appears below the highest Yoredale limestone (the Main Limestone) on Ingleborough, while the summit of the mountain is formed of the Kinderscout Grit. Further south the full Millstone Grit series attains great magnitude, but the correlation with the typical development is at present impracticable, for instead of the four or five grits of the southern extremity of the Pennine Chain, ten or twelve beds of grit are found, separated by larger or smaller beds of shale.

This multiplication of the grit-beds has been ascribed to the intercalation of wedges of shale penetrating from the north. In view, however, of the proofs that the grit materials were derived from a northerly source, it seems much more likely that the sheets of grit were of the nature of deltaic sand-flats spread out by a river flowing from the north and dwindling to a free edge in a southerly direction.

In South Derbyshire the interpretations of the geological surveyors do not support this view, but in Staffordshire the grits die out as they are traced to the south and west. The Second Grit does not penetrate beyond Cheshire and the Fourth and Fifth next disappear, then the First Grit or Rough Rock, so that, when the Millstone Grit is last seen, only the Third Grit separates the Pendleside Series from the Coal Measures, and no palæontological evidence is available to determine how much of the over-and under-lying shales should be attributed to the Grit Series. A little further south the series dies out altogether and the Coal Measures rest upon pre-Carboniferous rocks.

The physiographical conditions attending the deposition of the Millstone Grit appear to have been estuarine or deltaic. A great river seems to have entered the area of the North of England from the north or north-east bearing the detritus of some large area of crystalline rocks, most probably from a district of mountainous land lying beyond Scandinavia and the Highlands of Scotland. The fresh and unweathered condition of the felspar suggests that the chief agent in the disintegration of the parent-rock was change of temperature and not ordinary pluvial denudation. The Scottish area was probably in a different drainage system. The area of deposition was undergoing a general movement of subsidence during which dark, frequently carbonaceous and micaceous, shales with drifted plant-remains were laid down. At times a more rapid subsidence brought in marine conditions, and at others, more stable conditions permitted the gradual encroachment of the sandbanks cumbering the actual channel. These spread out over broad stretches and grew by deposition upon their margins so as to form great flat expanses of grit. As BARROW (1905, p. 30) remarks "The First and the Third Grit are not single beds but a series of interlacing lenticles of grit, which together build up a minor sub-formation which is just as regular in its thickness as is any one of the sub-divisions of many other formations."

At other times a complete equilibrium was established when vegetation crept out over the sandy flats and formed the thin coals that frequently occur as a capping to a bed of grit. These coals invariably, in the writer's experience, rest upon a bed of fire-clay or gannister crowded with rootlets. Sometimes the vegetable matter was insufficient in quantity to form a coal-seam or it underwent contemporaneous decay and only the rootlet bed remained. All these features in miniature can be observed in a reservoir that is being silted up.

The thickness of the Millstone Grit series in the Pennine area varies very greatly. In the neighbourhood of the Burnley Coalfield it reaches its maximum 838 m. (2770 ft.), it diminishes to 365 m. (1200 ft.) at Axe Edge (53° 12′ N.) and in the next 32 km. (20 miles) is further reduced to about 122 m. (400 ft.). This however takes no account of that portion of the shales below the Third Grit assignable to the Grit Series. In North Wales the series attains a thickness of about 200 m. (650 ft.) and includes cherty beds with *Productus* and other marine forms.

Extensive local movements caused unequal depression of the area of deposition, and into these as catch-pits the grit materials would be poured and the wide-spread uniformity of character of the Rough Rock shows that the hollows were quite filled up and levelled by deposition.

The Millstone Grit of the Bristol-South Wales area is quite distinct lithologically and stratigraphically from that of the Pennine region. It consists, where most complete, of two beds of course siliceous grit with pebbles of vein-quartz, and an intermediate shaly division with occasional sandstones. These rocks are overlain by Coal Measures with a flora characteristic of the Middle Division while they are underlain in the Gower Peninsula by rocks with a Pendleside fauna. The value of these stratigraphical landmarks is however diminished by the fact that in Gower the grits have given place to shales, and STRAHAN (1910) states that "no line, stratigraphical or palæontological, save of the most arbitrary description can be drawn for the top of the Pendleside." Furthermore, grits of an exactly similar character occur both in the Carboniferous Limestone and at various horizons in the Coal Measures.

In the Bristol-Mendip area the Avonian D_2 zone is succeeded by 30 m. (100 ft.) of limestone containing a late D fauna, followed by 300 m. (980 ft.) of "Millstone Grit" in the upper part of which a fauna and flora suggestive of Coal Measures is found, and above this the undoubted Coal Measures referred by NEWELL ARBER to the Middle division. The equivalence of this grit is thus quite uncertain and, as in South Wales, the same lithological type occurs both below and above the series.

C. The Coal Measures.

This great series, the chief repository of coal in Britain, is also locally the greatest in respect of thickness of the Carboniferous rocks, attaining in South Wales, where it reaches its maximum, a thickness computed to be 2500 m. (8200 ft.) (STRAHAN and POLLARD 1908). Lithologically the Coal Measures are essentially shales, but in most areas, there is also a notable amount of sandstone. Ironstones though of small thickness and local in distribution are economically of great importance. Limestones are rarely developed, except the peculiar *Spirorbis* limestones that characterize some of the unproductive higher measures. Coal seams range at varying intervals throughout the succession except in the highest members of the series. Finally, in a category by themselves, are the various types of "seat-earth" known as underclay, fireclay and gannister.

The whole Coal Measure series may be regarded as characteristically a fresh-water formation, but occasional marine bands occur in the Lower and Middle parts, and these have proved of great service in determining the horizon of rocks found in deep bore-holes. Marine faunas are not, however, sufficiently clearly individualized, as a rule, to furnish intrinsic evidence of age, and it is only when their associations are observed that they yield decisive evidence. The marine bands, which rarely amount to 6 m. (20 ft.) thick are usually fine blue shales of a soapy texture, readily distinguishable, even in the absence of fossils, from the normal shales of the Coal Measures, and this difference of texture furnishes an additional argument in favour of, fresh-water origin of the bulk of the strata, which is still further supported by the fact, insisted upon by GREEN (1878), that the assumed fresh-water shells (*Carbonicola*, *Anthracomya* &c.) never occur in the same layer as the unquestioned marine forms, even though the layers may be in contact. One exception to this rule is known in the Yorkshire Coal-field where CULPIN has found a single example of *Lingula mytiloides* on a surface bearing *Carbonicolæ*.

STRAHAN has argued that *Carbonicola* is not a fresh-water shell. He says: "the Coal Measures [? of South Wales] were almost certainly not fresh-water. The *Anthracomya* is known to have lived by side with true marine molluscs, and the *Carbonicola*, though allied to a great fresh-water family, is always found in close attendance upon the *Anthracomya*."

This opinion is not shared however by those palæontologists such as WARD, HIND, STOBBS and LEE who have studied closely the genera mentioned.

Coal seams and their seat-earths present many interesting problems that can in general be merely hinted at here.

The mineral character of the seams shows every variation from the extreme of bituminous to a very pronounced type of anthracite.

In the Scottish coal-fields the blazing Coals are the dominant types, but anthracite occurs in the Glasgow district as a consequence of the proximity of an igneous intrusion (sill), and in Arran three anthracitic seams are known.

The seams in the English coal-fields vary from extremely bituminous to hard steam and coking coal; the South Wales coalfield, on the other hand, is distinguished by the occurrence of anthracite, besides other types. Cannel (or parrot) coal occurs in all areas.

The seams vary in thickness from mere films of no economic use or importance up to 2 or 3 m. (7 or 10 ft.) and in only one instance is the latter greatly exceeded, namely, by the famous Thick Coal of South Staffordshire. This seam known also as the Ten Yard Seam attains a maximum thickness of 12 m. (40 ft).

The question of the mode of origin of coal seams has been much discussed and the present is not the place for entering at length into controversial matters, but as the subject has been reopened by recent writers, a brief statement may be given here of the reasons, admirably arrayed by BOWMAN (1841), BINNEY (1846) GREEN (1878) and never yet categorically answered, that have induced the writer to adopt the in situ or growth-in-place theory of the origin of the coal in all the British coal-fields with which he has a personal familiarity.

GREEN's summary argument may be briefly stated as follows: 1. The quantity of ash is very small. 2. The seams are constant in character and thickness over wide areas. 3. They are often of great extent. 4. Remains of aquatic animals are entirely absent from the coal. 5. Each seam rests upon a seat-earth of some kind, which he considers to be an ancient soil.

The reasons for this last opinion are as follows: 1. It is not a laminated or bedded deposit. 2. It is crowded with roots and rootlets. 3. Other fossils are only in rare instances found in it. 4. It has the chemical characters of an exhausted soil. Some beds of a coal-like substance, viz. cannel, display the exact opposite of the features detailed above, being of limited extent; show great variations of thickness; yield a high percentage of ash; are only in fortuitous and exceptional relation to a seat-earth; and, finally, as an almost invariable character, contain remains of aquatic animals e. g. ostracods, molluscs, and fishes. The fact that cannel is in every respect the reverse of true coal constitutes at the same time evidence of its sedimentary origin and against the "drift" origin of ordinary coal.

As an illustration of the constancy of some seams it may be mentioned that, while it is highly probable that the chief seams in the Yorkshire coalfield are represented in Lancashire, North Staffordshire, and North Wales, one small seam near the base of the series is so clearly characterized that the correlation is quite certain. This is the seam known in Yorkshire as the Halifax Hard Bed, in Nottinghamshire as the Alton Coal, in North Staffordshire as the Crabtree, and in Lancashire as the Gannister Seam, or Mountain Mine. Its maximum thickness is less than four feet and it declines to about one and a half feet near Leeds.

The seam has a floor of gannister (i. e. a siliceous seat-earth), a roof of black shale with a rich marine fauna, and in the area adjacent to the Pennine Chain, in Yorkshire and Lancashire, it contains the remarkable nodules known as "coal-balls" that constitute the principal source of our knowledge of the structure of the coal flora.

It is not absolutely certain that the seam can be identified in the coal-fields near Chester, though it is highly probable that it extends there. If this identification is correct the seam must have had an area of between 13 000 and 15 000 qkm. (5000 and 6000 sq. m.). The difficulty of explaining so equable a distribution of drifted vegetation over so vast an area, applies, though in less degree, to the gannister floor upon which the seam rests.

Spore-coals, as Huxley pointed out, are of very common occurence, and Lomax (1912) has made further studies that confirm and extend the application of his observation, but more exhaustive investigation is still needed, for many seams can, even without the aid of the microscope, be seen to contain layers mainly or perhaps entirely constituted of macrospores.

These spore-coal layers are usually an inch or less in thickness, of a dull aspect, and are very tough. The Beeston Bed of the neighbourhood of Leeds contains two such layers of a distinct brown colour, and at one colliery the portion of the seam containing them is hand-picked for sale as steam-coal. Another seam, the Haigh Moor, has a spore-band about half an inch thick, known as the "dull-streak", that can be traced over many square-miles.

The splitting of coal seams, i. e. the separation of a seam by a wedge or lens of sedimentary material, is a phenomenon of common occurrence in nearly all the British coalfields. An excellent explanation of its cause was given by Bowman (1840), though he failed to take accoumt of the effects of the compression of the peaty mother-substance.

The Gannister Coal is a case in point. At Todmorden (53 ° 42′ N.) it consists of two elements in direct superposition, but near Halifax and elsewhere in Yorkshire they are separated by a considerable interval, while in the south of the same coalfield, in South Derbyshire, the two seams again coalesce.

The most famous example however, is that of the Thick Coal of South Staffordshire. This seam subdivides on the north of a large fault crossing the coalfield, and by successive splits is resolved into 14 seams in a distance of 7 km. ($4^1/_2$ miles), the intervening strata attaining a thickness of about 150 m. (500 ft.) (see Geol. Surv., Coalfield Mem., South Staffordshire).

Another feature commonly observed in most of the British coalfields is the occurrence of "washes", the name usually given to areas in which the coal seam is replaced by shales, sandstones, or conglomerates. Sometimes these have the form of a regular river-system with meanders and tributaries. Another species of "wash" is broad and irregular, resembling more an area over which a river has operated by shifting meanders. This type can be shown in certain areas to be in such relation to the major faults as to indicate that movement of the faults was the cause or accompaniment of the washes. The Haigh Moor Seam of the Yorkshire coalfield is much subject to washes and in a series of Collieries ranging for 8 km. (5 miles) in a south-west and nord-east direction the seam is extensively "washed" on the down-throw side of a fault, almost even up to the line of dislocation, while it is quite intact up to the brink of the fault on the upthrow side.

Another evidence of contemporary earth-movement is afforded by the thickening of the Coal Measure strata in synclinal areas, as in the North Staffordshire Coalfield where a certain group of strata thickens from 600 m. (2000 ft.) on an anticline to 1200 m. (4000 ft.) in the adjacent syncline.

The anthracitic character of much of the coal of the South Wales Coalfield is of immense economic importance and of great geological interest: it was formerly ascribed to the internal heat of the earth, because, as a general rule, the seams in the deeper portions of the great basin are more anthracitic than those above them. The whole subject are been carefully considered by the geologists who have recently resurveyed the field (STRAHAN and POLLARD 1908, pp. 66, 70). Their conclusions are as follows:

"1. The seams are not all similarly anthracitic, and though each seam is generally more anthracitic than the one above it; there are many exceptions to this rule".

"2. The anthracitic character was not due to faults, but existed before the faults were formed." Faults with a throw of hundreds of feet throw anthracitic against non-anthracitic seams.

It may be remarked that this statement is not quite conclusive, as the faults may have been produced by successive movements and the anthracitization have affected at an early stage of the faulting only certain of the lower seams.

"3. The anthracite existed as such before the coalfield was reduced by denudation to its present dimensions." Some seams are anthracitic right up to the outcrop. This may be taken to prove that the change was pre-Triassic, for the disturbances and denudation took place before the deposition of the Trias; moreover, pebbles of bright coal, neither crushed nor deformed, occur in the Pennant Grit.

"4. The percentage of ash diminishes pari passu with the decrease of bituminous matter," whereas, had the normal percentage been present originally, it might be expected that the anthracite, having lost more volatile matter, would show a higher proportion of ash.

The following extremes of composition (excluding cases of probable error) are noted:

Bituminous Coal		Anthracite	
Ash	Carbon	Ash	Carbon
11,0	87,19	6,6	92,64
0,9	87,93	0,7	93,20

The inverse ratio, which may be said in general terms to exist between the degree of anthracitization and the quantity of ash present, though apparently contradicted by these figures, is however borne out decisively by a more comprehensive review and it lends some support to the view that the anthracitic change is due to an original difference of conposition; but a much more extended study of the nature of the ash is needed before a plenary acceptance of this hypothesis is permissible. The mineral nature of coal-ash is very imperfectly known. Some of it may be, no doubt, attributed to the original plants, while other parts may be mere mineral detritus, and others again may occur in the form of veins of calcite, iron pyrites etc. filling-in joints that, occur much more abundantly in bituminous than in anthracitic coal. THORPE (1878) found that careful separation of the bright from the dull or "mineral charcoal" layers in two typical bituminous coals disclosed great differences in the percentages of ash respectively characterizing the two types, bright coal giving 2,8 and 2,2 %, against 9,5 and 6,3 in the dull layers. It may further be noted that the alkalies constitute the principal ingredients in the ash of most plants, while they are almost entirely absent from coal. On the other hand salts of calcium and magnesium, relatively rare in modern plants, are predominant elements of coal-ash.

It appears to the present writer probable that the degree of anthracitization depends rather upon physical conditions set up at an early stage of conversion of the vegetable matter into coal than to "original" differences in the chemical compositions of the mother-substance. In the case of the Halifax Hard Seam the presence in it of petrifactions of the undistorted plant structures in the form of coal-balls shows beyond question that the mineralizing materials were introduced by percolation from an overlying shell-bed.

The distribution of the anthracitic seams in South Wales throws little light upon the problem. The degree of anthracitization increases in general from south to north and at both ends of the coal-field it becomes more pronounced as the thickness of the measure diminishes, but the anthracitic area does not by any means coincide with the region of least thickness.

STRAHAN (1901) has described a case in which a seam of coal passed gradually into dolomite.

One other interesting feature of the coal seams remains to be mentioned. Well rounded blocks of foreign rock occasionally occur embedded in the seams, or, more rarely, in roof or floor. They are most frequently of a hard grey quartzite and the largest blocks weigh several hundredweights each. Such masses can not have been rolled into the position in which they are found and some agent of flotation such as ice, or entanglement in tree-roots, must have operated. As to the latter, it may be observed that the only roots of arborescent vegetation found in association with these seams are the divergent rhizophores (*Stigmaria*) of the giant lycopods and these are entirely unsuited to the involution of large stones. It is a remarkable circumstance that no boulders at all comparable are noted from the sedimentary elements of the Coal Measures, such as the sandstones, where, if any where, far-transported blocks might be expected. This may be due to lack of observation rather than to non-existence, for the mass of sandstone and other sedimentary materials excavated is but a small fraction of the tonnage of coal raised; moreover, the occurrence of a boulder in a coal seam is much more likely to attract attention than the like occurrence in a quarry.

The classification and correlation of the Coal Measures is attended with considerable difficulties, the first of which arises from the fact that, in the absence of any palæontological guide, the strata were subdivided at well-marked lithological changes, or according to the character or frequence of coal seams, the nature of their seat-earths, or other, more or less arbitrary, criteria.

The application of palæobotany to the problem has brought about a much needed change by enabling lines to be drawn at the horizons at which notable changes of the flora take place. The study of the animal remains has also yielded results of great value in exploration, but, as might be expected from the conditions attending the deposition of the Coal Measures, the animals are much more affected by local influences than the plants.

In North Staffordshire HIND has found the lamellibranch mollusca to be distributed with such constancy that they can be used as indices with much confidence, the succession in ascending order being as follows: 1. *Carbonicola robusta*, 2. *Anthracomya williamsoni*, 3. *A. adamsi*, 4. *A. wardi*, 5. *A. phillipsi*, 6. *A. calcifera*. In Scotland however the distribution is not constant, and it is suggested by LEE (1912) that the distribution of these species is determined more by suitability of conditions than by time. In East Lothian the molluscan sequence appears to be the same as in North Staffordshire but a marked divergence may be noted in the Glasgow area.

The classification by plant evidence is in large measure due to the labours of KIDSTON who divides the Coal Measures into four horizons as follows:

4. Radstockian Series = Upper Coal Measures.
3. Staffordian „ = Transition Series.
2. Westphalian „ = Middle Coal Measures.
1. Lanarkian „ = Lower Coal Measures (including the Millstone Grit).

The necessity for adopting a new terminology is apparent from a consideration of the confusion that would arise when correlations were attempted of areas in which a palæontological classification had been effected with others in which the terms Upper, Middle and Lower Coal Measures had merely a stratigraphical and local foundation.

The zoological indices are more irregular in their distribution and are less frequent in their occurrence than the plants, and to the present writer it seems better to employ KIDSTON's terminology and to use the evidence of the mollusca as a useful or even an indispensable supplement.

A few broad features of the floral sequence may be summarized from data kindly furnished by KIDSTON:

Radstockian (= Stephanian, or true Upper Coal Measures). *Pecopteris arborescens* and *P. polymorpha.*
Staffordian. A flora transitional from the Westphalian to the Radstockian.
Westphalian Great abundance of *Sigillaria* especially *S. boblayi.*
Lanarkian. Chiefly characterised by rarity of *Sigillaria* the flora being much poorer than that of the Westphalian and many species common in the latter being absent.

While upon this subject the floral characteristics of the Lower Carboniferous may fitly be mentioned. The Lower Carboniferous is characterized by the great rarity of *Sigillaria*, and the abundance of *Lepidodendron* especially *L. rachiopteris.* Sphenopteroid species are also very characteristic. The Calciferous Sandstones of Scotland have the same general features and are specially notable for the occurrence of *Telangium affine* LIND. and HUTT. sp., and *Adiantites antiquus.*

A brief mention may now be made of the distribution in the various coal-fields of Great Britain, so far as has been ascertained, of the floras, as thus defined, KIDSTON's views being adopted, except in certain specified instances.

The Culm Measures of Devon are separable into a lower division presenting a well-marked Pendleside fauna and surmounted by a series containing a Westphalian flora.

The Somersetshire Coal Measures present anomalous stratigraphical relations due to severe tectonic disturbances. They include a lower Farrington and an upper Radstock Series both referable to KIDSTON's Radstockian.

The Bristol Coal-field is still under consideration. No Lanarkian representatives have been definitely recognised, but a series of measures below the lowest workable seam may belong to that horizon. The Westphalian, according to ARBER, includes all the workable coals.

The great South Wales Coal-field is provisionally classified by KIDSTON as follows:

Upper Pennant = Radstockian.
Lower Pennant = Staffordian.
White Ash = Westphalian.
Basal Sandstones and Grits = Probably Lanarkian.

The Forest of Dean contains representatives only of the Farington subdivision.

The little Dover Coal-field is referred by ARBER to the Staffordian, all the three divisions recognized in Staffordshire, being according to him, present.

The South Staffordshire Coal-field shows the overlap of Westphalian on to Lower Palæozoic rocks. It is succeeded by Staffordian.

North Wales. All the seams at present worked are in the Westphalian, but KIDSTON fully endorses WALCOT GIBSON's ascription of an upper unproductive series to the Staffordian.

North Staffordshire furnishes a full sequence from the Lanarkian up to the Keele Series, the equivalent of the basal Radstockian.

In Lancashire a similar sequence is found up to the Ardwick Series, which is referable to the Staffordian. The Whitehaven Coal-field has yielded evidence of Westphalian and Staffordian (probably Lower) measures. And the equivalents of the Keele Series occur at Jockey's Sike in Cumberland.

Turning now to the Eastern Coal-fields, we find that though South Leicestershire is very imperfectly known at present the presence of Westphalian is certain.

The great Coal-field of Yorkshire, Derbyshire and Nottinghamshire is mainly constituted of Lanarkian and Westphalian, but traces of Staffordian have survived pre-Permian denudation at Conisboro in Yorkshire, and explorations through the newer rocks at Gedling and Thurgarton show that at the former place the Staffordian is present and at the latter the full Staffordian and Lower Radstockian (the Keele Series).

The Coalfield of Northumberland and Durham has not yet been fully studied. The Westphalian and Lanarkian certainly occur and STOBBS (1906) has found a fauna suggestive of Staffordian.

In all the Scottish Coal-fields the Lanarkian is worked; and the Westphalian, also, is found in Fife and in the little Border Coalfield of Canonbie, where in addition a representative of the Keele Series (Lower Radstockian) has been identified. It is probable that the Staffordian will be detected by closer investigation.

Lithological Characters. The Lanarkian and Westphalian divisions present no marked characters beyond those due to the development of a Millstone Grit facies, to the prevalence of gannister seat-earths in the coalfields of the Pennine Region and North Wales, and to the Pennant Series of sandy and gritty rocks that forms a parting, inconstant in position, between Higher and Lower Productive Measures in South Wales.

In South Wales this Pennant series mounts higher in the sequence as it is traced from west to east, but its approximate position is within the Staffordian, whereas in the Bristol and Somerset field it lies between the Staffordian and Radstockian.

The Staffordian and Radstockian present great abnormalities in the strong colouration and the generally barren character of the rocks and the occurrence of peculiar fine-grained limestones, often crowded with *Spirorbis* and Ostracoda, that are commonly, though (as GIBSON points out) erroneously, designated by the term *Spirorbis* limestones. Such limestones are by no means restricted to this series but are found in the Lower Carboniferous of Scotland.

Throughout the Midland area, and North Wales these Measures were for a long time confounded with the Permian rocks, but the recognition of plants of Carboniferous type in some of them led to a revision of the whole series, and the recent resurvey of the North Staffordshire Coal-field by DE RANCE, GIBSON and others has afforded a welcome opportunity for a close investigation of the whole series. The area was peculiarly well fitted for the purpose as, though the rocks are almost destitute of workable coal-seams, they are largely exploited for ironstone, and the clays are employed for "seggars" in the great pottery industries that have flourished in the district for more than two centuries.

GIBSON classifies the rocks as follows

Keele Group. 210 m. (700 ft.). Red and purple sandstones and marls with occasional coal-seams and thin black grey or limestones.
Newcastle under Lyme Group. 90—105 m. (300—350 ft.). Grey sandstones and shales with four thin seams of coal and at the base an entomostracan limestone.
Etruria Marl Group. 245—335 m. (800—1100 ft.). Chiefly mottled red and purple marls and clays. Thin bands of green grit very characteristic. Limestone bands occur near the summit and near the base one thin coal-seam with a laminated ironstone.
Black Band Group. 90—120 m. (300—400 ft.). Grey sandstones, marls and clays. Numerous thin coal seams and Black-Band ironstone. Thin bands of limestone throughout.

KIDSTON refers the Keele Group to the Lower Radstockian and the remaining three divisious constitute the type of his Staffordian.

An exactly similar series has been identified by GIBSON in North Wales, and at Thurgarton in Nottinghamshire. CANTRILL (1895) has recognised a portion of the series in the Forest of Wyre and at other localities in Shropshire, Warwickshire and South Staffordshire. In the Warwickshire Coalfield VERNON (1912) has found a series comparable to that of North Staffordshire.

In the coal-field of South Lancashire occur the Ardwick Series described long ago by BINNEY and later, with sections coloured as in nature, by BROCKBANK and DE RANCE. They consist of marls brilliantly coloured red and green with many beds of *Spirorbis* limestone, which were formerly extracted by mining. They probably represent the Etruria Marls, and they attain a thickness of at least 250 m. (800 ft). At Bradford Colliery near Manchester the Black Band Group is well represented.

In Scotland a great series of barren measures generally of a red colour surmount the Productive Coal Measures and probably represent some part of the Staffordian or Radstockian, but palæontological proof of the occurrence of rocks of this age is lacking, except in Ayrshire where the Radstockian flora seems to be represented.

The relations of the Red and Gray Rocks of Central England to the Westphalian on the one hand and the Permian on the other are not always clear, as sections showing the contacts are seldom available and the outcrops are often concealed by Drift. In general it may be said that the whole Coal Measure sequence from the lowest to the highest is in strict conformity. The notable cases of discordance are found in the Flintshire Coal-field and in the Coalbrookdale Coal-field near Shrewsbury, the so-called Simon Fault. This was interpreted by some of the earlier observers as a "wash", i. e. a great trough eroded in the "Middle" Coal Measures and filled in with "Upper" Coal Measures. CLARKE however has shown that the older beds were folded and denuded, and the newer series laid across the plain of erosion.

While the Coal-Measure sequence is in general uninterrupted, it is becoming more and more clear that in the Midlands and on the South side of the great central barrier a basal unconformity is by no means infrequent, and the failure to detect the Lanarkian flora in any part of the South Western, and Southern regions is probably due to a break in the succession. Thus, VAUGHAN considers that there is an unconformity at the base of the Coal-Measures in the Clevedon area, DIXON has shown that at Titterstone Clee the Coal-Measures rest on Lower Carboniferous rocks; and SIBLY has ascertained that the Radstockian of the Forest of Dean lies in strong unconformity upon "Millstone Grit", which is of Lower Carboniferous age, and overlaps the underlying Tournaisian so as to come on to the Old Red Sandstone.

The Permian rocks are usually in strong discordance upon the Carboniferous no matter what division they may rest upon, most examples quoted of the contrary, being cases in which stained Carboniferous rocks have been mistaken for Permian. CANTRILL however speaks of a gradual passage into the Trias.

The deposition of the Coal Measures above the Westphalian in Central England probably took place under conditions markedly different from those of the earlier series. The general poverty of the fauna and flora, the entire absence of distinctively marine forms, and the strong colouration with peroxidized iron, point to climatic conditions of a desert or semi-desert type, as GREEN observed. He concluded that these strongly coloured rocks were probably laid down in lakes having no overflow to the sea. The *Spirorbis* or ostracod (entomostracan of WARD) limestones commonly contain a high percentage of magnesia and in some cases, eg. in the Ardwick Limestone, the iron content is high enough to give them the character of ores of Iron of sufficiently high grade to have justified their extraction, if the mode of their occurrence had been favourable to mining.

These rocks are usually of a compact smooth texture and reddish or grey colour. They sometimes show a curious brecciated structure, with fragments and matrix almost identical in colour and texture. *Spirorbis pusillus* is not an invariable component of these limestone, some beds being found from which it is practically absent, but *Carbonia* is much more general. The habits of the *Spirorbis* must have been markedly different from those of the modern animal attributed to the same genus. The latter is exclusively of marine habitat, its favorite position being on the fronds of *Fucus* and *Laminaria*, whereas the Carboniferous examples have not been recorded as associates of marine animals. A common mode of occurrence is attached to ferns. The fauna of the *Spirorbis* limestones includes, besides *Carbonia*, the small lamellibranchs *Anthracomya phillipsi* and *A. calcifera*. Fish remains are of rare occurrence. These associations seem to negative decisively any idea that the *Spirorbis* of the Coal Measures was a marine form.

It is interesting to observe that the conditions, whatever they were, that induced the formation of these limestones, were not confined to the period of the Staffordian and Radstockian: one occurrence is noted below the position assigned to the top of the Westphalian in North Staffordshire. In the Midland Valley of Scotland limestones with the colour and texture of the typical *Spirorbis* limestones occur in the Upper Red Barren Measures, and in the Ayrshire basin the characteristic annelids are found.

The Calciferous Sandstone Series of Northumberland and of the Midland Valley of Scotland contains many beds of "cement-stone", for the most part fine-grained dolomites (see Mem. Geol. Surv., Glasgow, for analyses), without recognisable fossils, but in East Lothian *Spirorbis helicteres* occurs in profusion in certain bands. The Lower Carboniferous rocks of this area in their strong colouration and the frequent occurrence of gypsum suggest deposition in an area of desiccation. The climatic condition of the later Coal Measure times was a recurrence of a perhaps equally wide-spread phase.

The Coal-fields and their Economic Resources.

The resources of the British coal-fields have been exhaustively considered by a Royal Commission to whose Final report in 1905 reference should be made, as well as to the works of HULL, and GIBSON that embody much of the geological information.

The Kent Coal-field or Coal-fields, lying beneath an unconformable cover of secondary rocks, is known from one colliery that has just commenced operations and from a small number of borings; the data are altogether inadequate for the correlation of seams even between adjacent bores. Any estimate of either the area or productiveness is therefore premature. It is not certain that the measures proved lie in a single basin. ARBER recognises the equivalents of the Staffordian series and of the Keele Beds.

Cornwall and Devon. The Upper Culm Measures in these two counties are mainly shaly, of unknown thickness, and contain thin beds of inferior coal (locally called "culm"). So far as the plants have been studied the flora appears to be Westphalian.

The Bristol and Somerset Coal-fields. The group of coalfields lying between the Mendip Hills and the Severn are arranged roughly as an inverted ⊥ in consequence of the interference of two systems of folds — the E.-W., Armorican and the N.-S., Malvernian. The general succession is:

Radstockian	Radstock Series
	Farrington "
	Pennant Sandstone Series
Staffordian	New Rock Series
	Vobster "

A large part of the known coal-fields is under an unconformable cover of Triassic and Jurassic rocks and it is probable that other detached basins yet remain to be discovered. The Upper Series about 914 m. (3000 ft.) thick, contain 22 seams, the Pennant Sandstone 525 m. (1725 ft.) contains 5 seams and the Staffordian, 660 m. (2000 ft.) thick, 36 seams.

The output in 1903 amounted to 14 million tons. The estimated quantity of available coal (after allowance for waste in working etc.) in seams of one foot and upward at a depth not exceeding 1220 m. (4000 ft.) is 4 000 000 000 tons.

The South Wales Coal-field is practically all exposed, except where covered by the sea, and where, in South Glamorgan, a small area is concealed under secondary rocks.

The succession varies progressively in a west to east direction. The general sequence is, as already statet, according KIDSTON:

Upper Pennant (Supra-Pennant)	Radstockian
Lower Pennant (Pennant and Red Ash) .	Staffordian
White Ash or Lower Coal Series	Westphalian
Basal Sandstones and Grits	? Lanarkian

A lithological classification and correlation is rendered extremely difficult by the fact already mentioned that the Pennant phase runs athwart the stratigraphy, its base and summit being on lower horizons in the west than in the east.

The area of the field is 2600 qkm. (1000 sq. m.). The maximum thickness of the Coal Measures is upwards of 2500 m. (8400 ft.) (STRAHAN 1910). The number of seams varies from place to place, in Pembrokshire 10 seams with 8.4 m. (28 ft.) of coal, Carmarthen 18 to 34 with 14.2 to 26.5 m. (47 to 88 ft.); Glamorgan 24 to 48 with 20 to 38 m. (66 to 124 ft.) and Monmouth 11 to 21 with 11.8 to 14.3 m. (38 to 47 ft.). The total available coal remaining in 1905 was 26 470 000 000 tons. Of this quantity 30°/₀ is bituminous, 22°/₀ Anthracite, 47°/₀ Steam Coal. The output in 1903 was 42 millions of tons.

The Forest of Dean Coal-field has an area of 88 qkm. (34 sq. miles), wholly exposed.

A threefold division has been adopted, but the whole of the Measures, 843 m. (3765 ft.) in thickness, belong to the Radstockian. A thick sandstone, suggestive of the Pennant of South Wales but of course on a higher horizon occurs in the Lower division.

SIBLY has shown (1912) that the so-called Millstone Grit in this area is of Avonian (probably Tournaisian) age and that the Coal Measures rest unconformably upon it and pass transgressively on to the Old Red Sandstone.

The available coal remaining in 1905 was 258 533 000 tons. The output, which appears to be declining, is less than one million tons per annum.

Coal-fields of the Midlands. These coalfields, in which for the most part the Coal Measures rest unconformably upon pre-Carboniferous rocks, are the subjects of a report to the Royal Commission by LAPWORTH. They are only partially exposed, the greater part being concealed beneath Triassic and small tracts of Liassic rocks. On the West occur the little isolated fields of 1. Coalbrookdale, 2. the Forest of Wyre, 3. the Clee Hills, 4. Shrewsbury, 5. Le Botwood, 6. Dryton. Except at Coalbrookdale and the Clee Hills, no Lower Carboniferous rocks are present. In most of these the Measures belong exclusively to the Staffordian and Radstockian, the latter in unconformable relation to various divisons of the Carboniferous. DIXON has shown that at Titterstone Clee they rest on Avonian. This group of coalfields is estimated to contain 275 000 000 tons of available coal in the visible and 46 000 000 tons in the concealed parts.

The Warwickshire Coal-field is exposed to the extent of about 245 qkm. (62 sq. m.) but there is, concealed beneath newer rocks, a considerable area that can not be computed. VERNON (1912) recognises Westphalian, Staffordian and Radstockian (Keele Beds) with a maximum thickness of 850 m. (2800 ft.). The measures thin towards the south and the seams come closer together. Nine workable seams are known. The available coal remaining in 1903 was 375 000 000 tons in the visible field and 751 600 000 tons in the concealed extension.

The South Staffordshire Coal-field. The succession is substantially the same as in the Warwickshire Coalfield. The total proved area is 3875 qkm. (1495 sq. m.) but it is probable that it will be considerably extended by further exploration. The available coal remaining amounts to 1 400 000 000 tons.

The Leicestershire and South Derbyshire. The Measures in this field are very difficult to correlate with those in adjacent areas and even between one part of the field and another. A Westphalian flora has been recognised, and an unproductive series succeeding Millstone Grit is probably of Lanarkian age. The visible coal-field extends to about 78 qkm. (30 sq. m.) and the concealed portion to 140 qkm. (54 sq. m.). The available coal in the visible field is estimated at 433 800 000 tons and in the concealed portion 1391 000 tons.

The North Staffordshire Coal-field. The stratigraphy has already been described. The Coal Measures in three separate areas, the Potteries, Cheadle and Shaffalong fields, respectively 208 qkm. (80 sq. m.), 47 qkm. (18 sq. m.) and 5 qkm. (2 sq. m.) in area. The southern portion is concealed beneath a cover of Triassic rocks and the whole area is cut off on the west by a great fault with a downthrow of 640 m. (2100 ft.). The total available coal in 1905 is estimated at 4 368 000 000 tons.

The Cheshire Coal-fields. Two small coalfields have been proved in this county, one on the Pennine side near Stockport, and the other on the shore of the Dee estuary. The available coal is estimated at 291 080 000 tons.

The North Wales Coal-field. This is situated in the counties of Flint and Denbigh on the shores of the Dee estuary. The full Coal Measure sequence is doubtless present. The available coal is estimated at 1 736 000 tons.

The Lancashire Coal-field. This field contains representatives of every division of the Coal Measures up to the Etruria Marl. It abuts on the west upon the Pennine Chain, on the north it surrounds the anticline of Rossendale, and on the south and west it descends below the great unconformable cover of Permian and Trias of the Cheshire Plain, beneath which, but at a depth prohibitive of profitable working, the coal measures extend from all the surrounding Coalfields. In the Burnley area the Coal Measures probably attain their maximum thickness in England, though lacking the Ardwick series (= Etruria Marls).

The available coal is estimated at 4 238 500 000 tons. The total area of the Coalfield is about 564 qkm. (217 sq. m.).

Ingleton Coal-field. This little field forms a shallow basin lying against the South Craven fault. It is partly covered by Permian rocks. Several coal seams occur and two collieries have recently been started but no reliable estimate of its productiveness can be made.

The Yorkshire, Derbyshire and Nottinghamshire Coal-field. This is by far the largest and most productive Coal-field in Britain. The visible coal-field has an area of 1980 qkm. (760 sq. m.), but Coal Measures have now been proved as far East as the Trent at Scunthorpe. The further extension is conjectural but the present writer in a report to the Royal Commission gave his grounds for the belief that the true boundaries would coincide on the north with a remarkable post-humous fold running through Market Weighton, on the south with a similar fold extending in a southeasterly direction from Charnwood towards Cambridge, while on the east the basin would either terminate on the flanks of a low anticline whose axis runs through Willoughby and Louth in Lincolnshire, or would extend under the North Sea. The nature and position of this boundary he regarded as immaterial, as in either case no Coal Measures at workable depth would be found to the east of the assumed boundary. The Commissioners include in the "proved" coalfield not only the uncovered portion but also that part of the concealed field enclosed within lines joining the north-east and south-east corners with Haxey (11 miles east of the visible coalfield).

The estimate of available coal in this area is 26 500 000 000 tons. The area of "unproved" coalfield beyond this is computed by the writer at 10 100 qkm. (3885 sq. m.) with a possible 35 000 000 000 tons of available coal. The Commissioners regarded the south-eastern extension as too hypothetical to be included in the area for which they considered an estimate possible; they therefore reduced the area to 6630 qkm. (2550 sq. m.) and the estimate of available coal to 23 000 000 000 tons. Even thus reduced it is clear that this gigantic field must constitute the principal coal reserve of Great Britain; it is indeed the only British coalfield that is capable of any very large increase of its output; all the other coalfields have practically reached their limit or are actually declining; on the other hand new collieries are starting here, generally on the expectation of an annual output of one to two millions of tons. The full sequence of Coal Measures from the Lanarkian to the Radstockian is present, but the higher divisions (Upper Staffordian and Keele Series) only in bore holes.

The Northumberland and Durham Coal-field. This great coal-field is fully exposed save for the belt on the east and south covered by the Magnesian Limestone. The Coal Measures include Lanarkian and Westphalian with some representative of the lower part of the Staffordian in the south-east. Regarded as a coalfield however, the Lickar and Scremerston series in the Lower Carboniferous must be included. The estimates of the Royal Commission also include the extension of the field out to the three mile limit beneath the sea. The total available coal is estimated to be 5 271 000 000 tons.

The Whitehaven Coal-field. This coal-field is divisible, like the last, into three tracts—the exposed area, the undersea area, and the sub-Permian area. Workings now extend at Whitehaven to a distance of four miles under the sea. The Coal Measures include Staffordian and Westphalian but no Lanarkian has yet been identified. The total available coal to a distance of 5 miles under the sea is estimated to be 1 527 700 000 tons.

The Scottish Coal-fields. In all the coal-fields of Scotland the Lower Carboniferous contains a notable percentage of workable coals and the term coal-field in this region does not connote merely Coal Measures. The general development of the members of the Coal Measure Series in Scotland has already been mentioned à propos KIDSTON's classification and need not be repeated here.

In the absence from the Report of the Royal Commission of separate estimates of area and productiveness of the Scottish Coal Measures and the Lower Carboniferous rocks respectively it is impossible to give any detailed treatment field by field as was done in England and Wales. The gross available coal from all divisions is computed to be 14 681 000 000 tons. The increase of output is extremely slow in several areas, e. g. Lanarkshire; the thicker seams are practically exhausted, so that in the near future the output will begin to decline. The concealed or partially proved coalfields are of small extent.

II. Igneous Rocks.

By ALFRED HARKER.

During Lower Carboniferous times igneous activity broke out in numerous districts in the southern half of Scotland and also, on a more restricted scale, at certain isolated centres in England. The course of events was in some respects different from that which was followed in the Ordovician and Old Red Sandstone times, and subsequently in the Tertiary, in so far that there are in Britain no large plutonic intrusions of Carboniferous age. Here igneous action was represented only by lavas and fragmental volcanic accumulations and by intrusions of moderate dimensions in the form of plugs, sills, and dykes. On a broad view it appears that the more important groups of intrusions succeeded the surface volcanic outbursts: but the sequence is a complicated one, and there were also intrusions accessory to the volcanic eruptions themselves. Moreover the visible evidence sometimes admits of ambiguity, or at least of difference of opinion, as regards the extrusive or intrusive nature of particular sheet-formed bodies of rock.

A. Carboniferous Igneous Rocks of Scotland.

We shall begin with the Scottish area as in every respect the most important. Volcanic action was mostly confined, except in the west, to the Lower Carboniferous, and was most energetic in the earlier division, represented by the Calciferous Sandstone Series. Sir A. GEIKIE remarks that the earlier eruptions were of the "plateau" type, in which continous tracts of volcanic materials were built up by discharges from numerous vents; while the later eruptions were of the "puy" type, in which the accumulations lie round isolated vents, and are sometimes exclusively fragmental. At no stage is there any indication of fissure-eruptions: the actual sites of the volcanoes can often be identified, and many of them are of small size.

The region affected consists of a broad belt of country along the "Midland Valley" of Scotland (Forth and Clyde) and a narrower and more scattered belt near the border of Scotland against England (see map, fig. 36). The eruptions were not always synchronous in different districts: as a rule they began earlier, and ceased earlier, in the eastern and south-eastern part of the region than in the western. Some of the fragmental volcanic deposits are of submarine origin; but in general the volcanoes appear to have stood above water until they were gradually submerged.

Petrographically the volcanic rocks, and those intrusive rocks which are intimately connected with them, are predominantly basic in composition, and they possess decided, but not very strongly marked, alkaline affinities. Analcime and nepheline occur in some types, but the latter mineral is seldom more than an unimportant accessory constituent. The basalts, which are the prevalent rocks, have

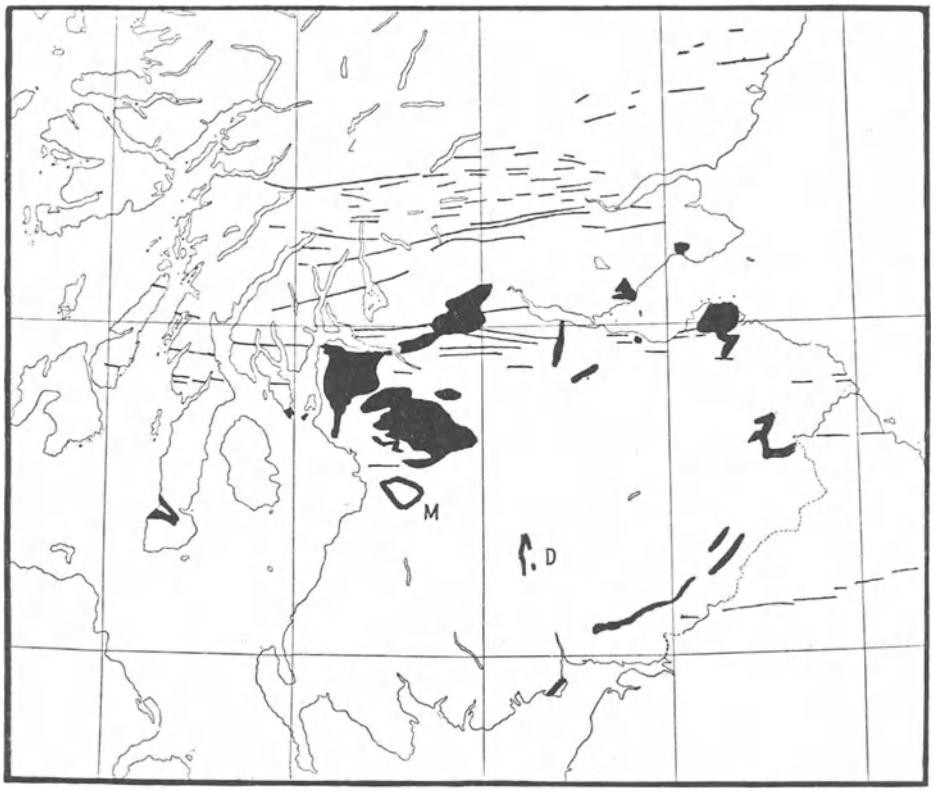

Fig. 36. Sketch-map showing the distribution of the Carboniferous and Permian volcanic rocks of Southern Scotland. (ALFRED HARKER.)
The Permian, or supposed Permian, are found chiefly in two districts: M = Mauchline (Ayrshire), and D = Dumfriesshire.
Volcanic rocks black. The principal E.—W. dykes of quartz-dolerite are also indicated.

as a whole a composition between gabbroitic and essexitic. They are often conspicuously porphyritic, with large crystals of augite, olivine, or labradorite. Associated with the basalts is the more alkaline type mugearite, rich in oligoclase and sometimes in orthoclase. The more felspathic types which have been styled trachytes (but are mostly orthophyres) are not so generally abundant. They consist of a soda-orthoclase with green augite and sometimes doubtfully a little nepheline.

(I) **In the Calciferous Sandstone Series.** The igneous rocks in the Calciferous Sandstone Series of southern Scotland include, besides fragmental deposits, a succession of sheets which are partly lava-flows, partly intrusive sills. The distinction between extrusions and intrusions is here perhaps not of great importance, for there is evidence that the sills were intruded near the surface of the ground at an epoch little later than that of the lavas.

The Midland Valley belt begins in the county of Haddington or East Lothian. The earliest volcanic accumulation in the neighbourhood of North Berwick is a green ash enclosing large blocks. Above is a series of sheets of porphyritic olivine-basalts of several types, becoming generally less basic upwards, and having sheets of mugearite intercalated among them. Farther west these rocks are overlain by thick sheets of so-called trachytes, which build the Garlton Hills. The whole covers an area of more than 100 qkm. (40 sq.m.). About Dunbar the sites of numerous volcanic vents are marked by "necks" of agglomerate, sometimes invaded by intrusions of basalt. Elsewhere are intrusive stocks which probably mark the sources of both lavas and sills. Some are of basic nature, while North Berwick Law and the Bass rock are trachytic stocks, and Traprain Law is a laccolite of like composition.

In Midlothian similar lavas and tuffs occur, but only as scattered outliers. Both at Edinburgh and in the Mid-Calder district porphyritic olivine-basalts are overlain by mugearites. There are old volcanic vents at Arthur's Seat and other places near Edinburgh, and some of the basic intrusions in the neighbourhood are referable to the same age. On the north side of the Forth a series of lavas and tuffs occurs in the upper part of the Calciferous Sandstone Series about Kirkcaldy and Burntisland in Fife. The lavas are basic, mostly porphyritic olivine-basalts, while numerous volcanic necks occur as before.

In the west of Scotland are much larger tracts of volcanic rocks, representing collectively a broken and eroded plateau which has probably had an original area of 5000 to 7500 qkm. (2000-3000 sq. m.). It extends on both sides of the Clyde, covering a considerable part of the counties of Stirling, Dunbarton, and Renfrew, with the west of Lanarkshire and the north of Ayrshire. In addition there are outlying relics in the islands of Cumbrae, Bute, and Arran, and near the southern end of the Cantyre peninsula. The succession is well displayed in the Campsie Fells in Stirlingshire, where the maximum thickness is probably 600 to 900 m. (1800-2700 ft.). It is made up of porphyritic olivine-basalts and mugearites of types found also in the eastern area, underlain by another type of olivine-basalt, only micro-porphyritic. The sequence, however, varies in different localities, owing to the overlapping of flows from different centres of eruption. There are numerous volcanic necks, some of agglomerate, others of basalt and trachydolerite, and at Fintry is an intrusion, probably a laccolite, of a trachytic phonolite. A similar succession is met with in the neighbouring Kilpatrick Hills, in Dunbartonshire, where the more felspathic basalts are often amygdaloidal, and contain various zeolites. In the Cathkin Hills, south of Glasgow, the succession shows non-porphyritic olivine-basalts succeeded by others with porphyritic felspar.

The volcanic rocks of the Scottish border belt are less fully known. There is a considerable development in the lower part of the Calciferous Sandstone Series in the Tweed Valley district of Berwickshire and Roxburghshire. The lavas are basalts, including both porphyritic and micro-porphyritic types. The western limit of the volcanic plateau is determined by erosion, and beyond it the older strata are pierced by basaltic plugs and agglomerate necks, which probably represent the vents of Carboniferous volcanoes. Some other intrusions in the neighbourhood are possibly to be related to this volcanic epoch. The most interesting is the sheet which makes the Eildon Hills, near Melrose, consisting of trachytic rocks containing riebeckite (McRobert, 1914).

A similar but thinner volcanic group makes a belt running south-westward through the southern parts of Roxburgshire and Dumfriesshire, along Liddesdale and across lower Annandale, and is seen again on the Solway coast south of Criffell.

(II) **Of Carboniferous Limestone and Later Age.** In much of the Scottish Carboniferous tract true volcanic action did not outlast the Calciferous Sandstone Series, and later igneous activity took the form of intrusion only. There are, however, certain areas where superficial vulcanicity was prolonged into the Carboniferous Limestone age.

One of these areas includes Linlithgowshire (or West Lothian) with parts of eastern Stirlingshire and western Fife. The chief volcanic district is found in the Bathgate Hills and the neighbourhood of Linlithgow and Bo'ness. The group begins with tuffs in the upper part of the Calciferous Sandstones, and these are followed by a series of olivine-basalt lavas (with intercalated later sills) in the Lower Limestone Group of the Bathgate Hills. Corresponding lavas occur in the Kinghorn district of Fife. A higher group of lavas and tuffs is found in the Upper Limestones of the Bo'ness district and elsewhere, and this also is represented on the north side of the Forth in the Saline Hills. To the east of the Bathgate Hills the lower members of the Carboniferous Limestone Series are pierced by volcanic necks of agglomerate and basalt, which may be assigned to this age.

In some of the western districts of Scotland vulcanicity continued, not only throughout the Carboniferous Limestone Series, but even into part of the Coal Measures. This is seen in northern Ayrshire. The volcanic rocks are basalt lavas and tuffs, but we have no detailed account of their petrography.

The intrusive rocks, excluding those already mentioned as being intimately associated with the volcanic outpourings, fall into three groups:

a) Analcime-basalts, monchiquites, limburgites, etc.
b) Analcime-dolerites, teschenites, picrites, etc.
c) Quartz-dolerites and tholeiites.

The first two groups have alkaline affinities which serve to link them with the volcanic rocks, but they are of distinctly later age, being mostly intruded into the Carboniferous Limestone. In the eastern districts (from East Lothian and Fife to eastern Stirlingshire, and perhaps as far as Glasgow) these alkaline intrusions are probably to be referred to the age of the Carboniferous Limestone Series, since they do not penetrate higher strata. In Ayrshire and Renfrew rocks of similar petrographical nature must be of later age, for they are intruded into the Coal Measures and even into strata which have been assigned to the Permian. The quartz-dolerites (c) are younger than the alkaline intrusions, in the eastern districts at least. They are intrusive in strata up to the Coal Measures, and their geological relations connect them with the crust-movements at the close of Carboniferous times.

(a) A number of sheets and irregular intrusions of analcime-basalt and monchiquite occur near North Berwick and elsewhere in East Lothian. In a plug at Kidlaw the analcime is in crystals of 3 mm. ($^1/_8$ inch) diameter. A sill at Chesters, near Haddington, between monchiquite and limburgite, contains doubtful nepheline. In West Lothian again there are sills of analcime-basalt in the Bathgate Hills. The dykes and sheets of monchiquite found in some parts of western Scotland belong probably to a later date.

(b) The coarser-grained intrusions of alkaline rocks have a wider distribution than the preceding group, and form sheets up to 65 m. (200 ft.) in thickness. They include ophitic analcime-dolerites, teschenites (with hornblende), and picrites. Analcime-dolerites with olivine occur near Anstruther in eastern Fife, at Gosford Bay and elsewhere in East Lothian, at several places in Mid-Lothian, and at Mochrie's Crag in West Lothian. Teschenite sills are seen at Gullane in East Lothian, at Salisbury Crags, Carcraig, Mons Hill, and other places near Edinburgh, in the Bathgate Hills, and at Necropolis Hill, Paisley, and Cathcart near Glasgow. Rocks which may be termed essexite-dolerites occur on the islet Craigleith at the mouth of the Forth, at Corstorphine near Edinburgh, and in a boss at Lennoxtown in Stirlingshire. Picrites are less abundant, and are found usually in intimate association with the teschenites. On the islet Inchcolm, near Edinburgh, a picrite sill, 20 m. (60 ft.) thick, is bordered above and below by teschenite, and a like association is seen at Bathgate in West Lothian.

(c) The third group includes doleritic rocks, free from olivine, having interstitial micropegmatite or sometimes glass. They may be termed quartz-dolerites and sometimes tholeiites. The intrusions take the form partly of sills, partly of dykes with an E.-W. direction (see fig. 36). The sills are found chiefly in the Midland Valley of Scotland. There is a complex of them about Stirling, and they reappear in the Kilsyth and Croy district of Dumbartonshire. In Linlithgowshire (West Lothian) sills occur at Cocklerue and in the Bathgate Hills, and again along a belt extending from Torphichen into the northern part of Lanarkshire. Others are found near Old Cumnock and elsewhere in Ayrshire. The dykes are developed in the same districts as the sills, where they attain widths of 40 or 50 m. (120 or 150 ft.) but they have a somewhat wider distribution, being found northward as far as Loch Etive in Argyllshire and Loch Tay in Perthshire. Westward scattered examples are known in Bute, Cantyre, Islay, and Jura. Eastward the belt widens, for dykes of this group are found as far north as Forfarshire and Kincardineshire and as far south as the English border of Berwickshire. The distribution therefore does not correspond with that of the alkaline Carboniferous rocks.

The quartz-dolerite group further passes into the north of England. It includes probably one or two dykes, such as that at Hett in Durham, and also the "Great Whin Sill". This latter can be followed for 120 km. (75 miles), from the Farne Islands off the coast of Northumberland to the escarpment of the Eden Valley in Westmorland, and has a maximum thickness of 50 m. (150 ft.). A still further extension is possible, though not proved, for quartz-bearing basic intrusions of doubtful age are known at several places even as far as St. David's Head in South Wales (ELSDEN, 1908).

B. Carboniferous Igneous Rocks of England.

(I) **In the Carboniferous Limestone.** Evidence of a marine volcanic episode in the Carboniferous Limestone is found in three isolated districts: (a) Isle of Man, (b) Derbyshire, (c) Somerset (see fig. 37). All the rocks are of basic composition. Those of the second district at least show no sign of alkaline affinities, and it is probable that we are to recognize here a petrographical province distinct from that which occupied the southern half of Scotland.

(a) Isle of Man. The volcanic rocks occur on the coast near Castletown, at the southern end of the island. They consist of basaltic tuffs and agglomerates and porphyritic olivine-basalts, resembling certain Scottish types. They have been greatly disturbed by subsequent crust-movements. The confused relations of the tuffs and agglomerates to the limestone can be explained only by overthrusting. The same explanation is applicable to certain dyke-like ribs of basalt in the midst of the agglomerate, sometimes in a highly inclined posture: these appear to be, not dykes, but broken portions of lava-flows.

(b) Derbyshire. The igneous rocks of Derbyshire attain no great development. The volcanic group consists of basalts and spilites, with basaltic tuffs and ashy limestones, and there are also volcanic necks composed of agglomerate. The rocks occur about three centres. — Miller's Dale, Matlock, and Tissington. In this last place volcanic action continued from the Carboniferous Limestone into the Yoredale Series. Closely related to the volcanic centres are a number of intrusive sills of olivine-dolerite.

(c) Somerset. Spilites and spilitic tuffs are found in the Carboniferous Limestone at several places in the neighbourhood of Weston-super-Mare in northern Somersetshire, and give evidence of contemporaneous volcanic action of a sporadic kind. The spilites are lava-flows, but it is possible that certain coarser doleritic rocks may be intrusive sills. This district is probably to be connected with that next to be mentioned.

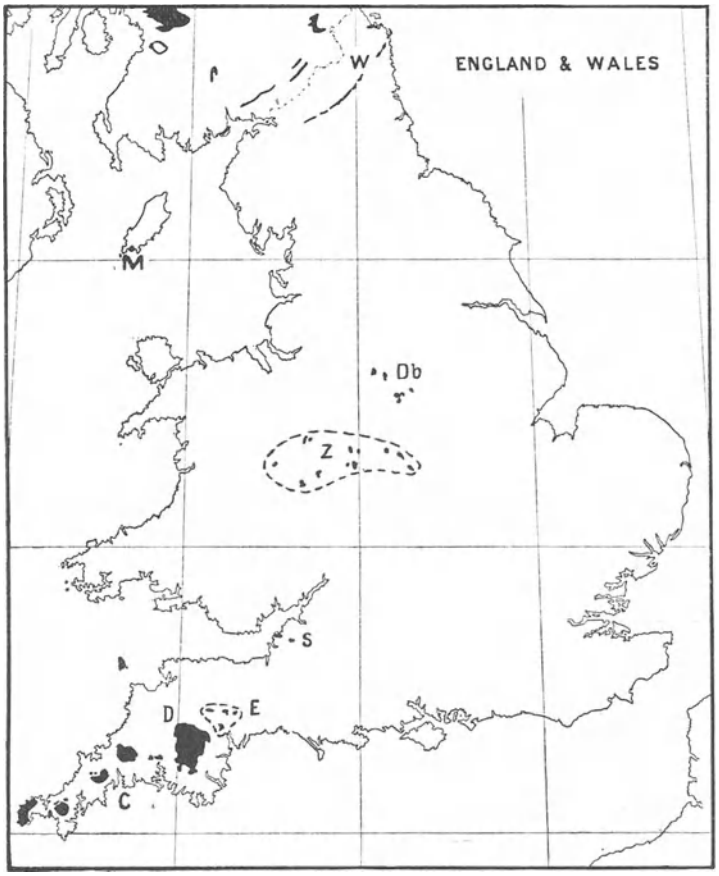

Fig. 37. Sketch-map showing the distribution of Carboniferous and Permian igneous rocks in England.

M = Isle of Man; Db = Derbyshire; S = Somerset; the three volcanic districts of Carboniferous Limestone age. W = Whin Sill (quartz-dolerite); C and D = Cornwall and Devonshire granites; E = Permian volcanic rocks of the Exeter district; Z = intrusions in the Coal-Measures of the Midlands, perhaps to be referred to a Tertiary age.

(II) **In the Culm Measures of Cornwall and Devon.** Although the stratigraphy is in some places not free from doubt, it seems to be established that in certain parts of the south-western counties volcanic action was prolonged from the Upper Devonian into the Lower Culm. The lavas resemble the Devonian spilitic types, and tuffs are also represented.

(III) **Intrusions in the Coal Measures of the Midland Counties.** No contemporaneous volcanic rocks are found in the Carboniferous between Derbyshire and Somerset; but there are numerous basic sills and laccolites, which are intruded mostly in the Coal-Measures, and have sometimes been assigned to a late Carboniferous age. Most of them are olivine-dolerites. These occur especially in the South Staffordshire coal-field, but also in the neighbouring counties, Shropshire and Leicestershire (fig. 37). Some of these rocks have a decided suggestion of alkaline affinities in the occurrence of some orthoclase or interstitial analcime and a purplish pleochroic augite. There is no direct evidence of their Palæozoic age, and it is possible that they are Tertiary. In Warwickshire is found a group of hornblendic sills of variable characters, some being diorites and others of a camptonitic variety.

Other rocks of doubtful age may be mentioned in this connection: viz. a dyke of analcime-dolerite near Hereford, one of monchiquite near Chepstow in Monmouthshire, and one of nepheline-basanite at Butterton in Staffordshire. The first two occur in Old Red Sandstone, but the last intersects the Trias, which points with much probability to a Tertiary age.

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See also GEIKIE, Sir ARCHIBALD, JONES, O. T., and LAMPLUGH, G. W.

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b. Ireland.

By GRENVILLE A. J. COLE.

The Carboniferous System assumes great importance in Ireland, since Mesozoic strata were either not laid down upon its surface, or have been stripped away by denudation to a degree unknown in England. The valuable coal-seams of the Upper Carboniferous have, however, suffered severely by this denudation, and the Carboniferous Limestone now forms the most characteristic rock exposed.

South of a line from Queenstown to Glengariff, the lower series are argillaceous, and the Armorican folding has converted them into dark slates known as the Carboniferous Slate. These rocks follow conformably on the Old Red Sandstone, and include at their base the Coomhola Grits with their marine fossils, which have already been referred to under the Devonian System. While it is clear that the Carboniferous Slate represents the "Lower Limestone Shales" of other areas, it is uncertain how far into the Carboniferous period this muddy type of deposit continued. It seems probable that the Carboniferous Slate includes fairly high zones of the Limestone series, as JUKES always maintained (1864). In reading some of the Irish literature on the correlation of these strata and of the Old Red Sandstone, we must bear in mind the views held by JUKES (1866—68) towards the close of his career as to the contemporaneity of the systems styled Devonian and Carboniferous by other geologists. These views, which proved to be entirely unsustainable, were too faithfully repeated by G. H. KINAHAN (1878), who ignored the existence of a Devonian system. JUKES, in the first of the papers here referred to, gives an excellent and comprehensive account of the Lower Carboniferous rocks of southern Ireland. The Carboniferous Slate is from 900 m. to 1500 m. (3000 to 5000 ft.) thick in the south of Co. Cork. It contains *Productus semireticulatus*, *Spirifer pinguis*, *Spirifer striatus*, *Sanguinolites plicatus*, *Bellerophon striatus*, *Phillipsia pustulata*, and other species characteristic of Carboniferous Limestone horizons; but zonal determinations in it are still much to be desired. The ordinary grey Carboniferous Limestone, resting on Lower Limestone Shale, as it does in South Wales, appears in the synclinals near Cork city. In places the rock has been altered into a red or pink marble.

The succession from this point throughout central Ireland as far north as the Curlew Hills and the Newry axis is as follows (HULL 1877):

Upper Carboniferous	5. Coal-Measures. 4. Sandstone and shale series, representing the Millstone Grit and Pendleside series of England.
Lower Carboniferous (Avonian)	3. Sandstone, shale, and limestone series, of Yoredale or Upper Limestone Shale age. 2. Carboniferous Limestone, which may be 900 m. (3000 ft.) thick. 1. Lower Limestone Shale.

The fossils of the Lower Carboniferous series have been recorded by KELLY (1855—7), GRIFFITH (1844—60) and M'COY (1844); M'COY's brachiopoda have been revised by DAVIDSON (1864—8), and the cephalopoda have been carefully investigated by A. H. FOORD (1897). But the establishment of palæontological zones has not as yet been carried far. The clayey limestone, or "calp" type (JUKES 1857), has been generally assumed to include middle horizons of the main Carboniferous Limestone; and it is true that the limestone above it is often far more pure, and weathers out in scarps and plateaus in the western areas, in contrast to the gentler slopes formed by the underlying series. The calpy beds are probably, however, local developments of a type that recurred throughout Lower Carboniferous times, wherever portions of the Caledonian land rose above sea-level, and sent down detritus into the ocean. A detailed study has recently been made of the Lower Carboniferous succession between Rush and Skerries on the Dublin coast (C. A. MATLEY and A. VAUGHAN 1906—9). There is a general agreement here with the succession established by VAUGHAN for the Bristol area in England, even to the occurrence of shallow water conditions following on the Zaphrentis beds.

5. Limestones and shales, passing up into shales, with *Posidonomya becheri.*
4. Argillaceous limestones and shales, with *Cyathaxonia rushiana* and *C. contorta* (VAUGHAN).
3. Limestones (Dibunophyllum zone).
2. Sands, shales, and conglomerates.
1. Slates with *Zaphrentis* cf. *phillipsi* (Upper Zaphrentis zone).

Thus, while the lowest or Cleistopora zone of the Lower Carboniferous series is not seen in this area, the succession is a satisfactory one, through strata some 600 m. (2000 ft.) thick, up into the Upper Carboniferous Pendleside Series, represented by No. 5 above (W. HIND and J. A. HOWE 1901.)

The bare plateaus of almost horizontal limestone in north-western Clare have similarly been compared with the English and Belgian sequence (DOUGLAS 1909). Brachiopods of the Cleistopora zone occur in sandy shales at the base, following

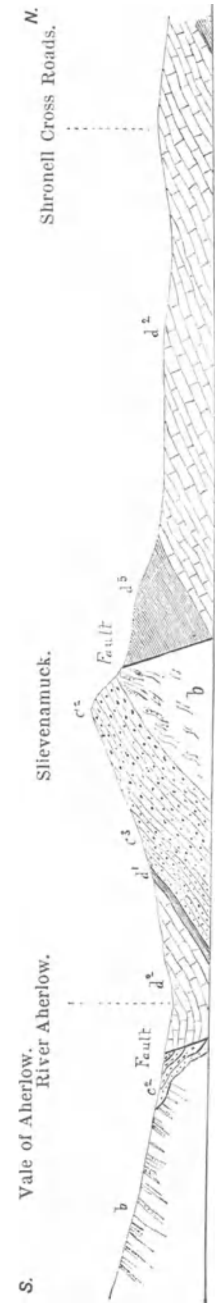

Fig. 38. Section of strata north of the Galtee Mountains. Horizontal scale, one inch to a mile = 1:63,360; vertical scale, three inches to one mile = 1:21,120.

d^5 = Upper Carboniferous Shales; d^2 = Carboniferous Limestone; d^1 = Lower Limestone Shale; c^3 = Kiltorcan Beds; c^2 = Old Red Sandstone; b = Llandovery Series.

Reproduced from the Memoirs of the Geological Survey of Ireland, No. 154, Limerick and Tipperary, p. 10, fig. 1, 1861; with the permission of the Director and of H. M. Stationery Office.

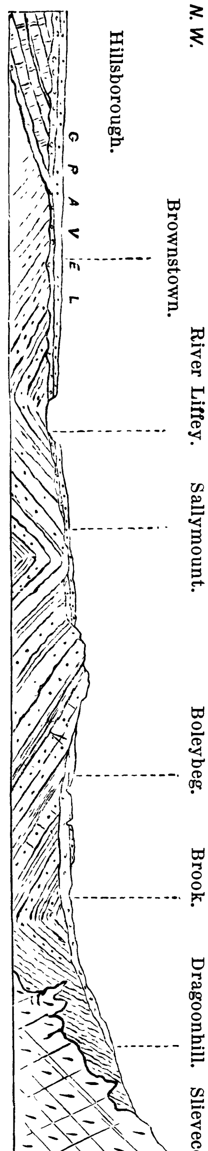

Fig. 39. Section, about 16 km. (10 miles) long, showing on the right the Leinster granite intrusive in folded Ordovician rocks, and on the left Carboniferous Limestone overlying these rocks unconformably. Glacial deposits cover the lower ground. Scale about 1:100,000.

Reproduced from the Memoirs of the Geological Survey of Ireland, No. 120, Kildare, Wicklow, and Dublin, p. 8, 1880; with the permission of the Director and of H. M. Stationery Office.

on the Old Red Sandstone. The Zaphrentis zone is followed by a shallow-water Syringothyris zone, with abundant large cephalopods. The Lower Carboniferous is here complete, closing with the top of the Dibunophyllum zone, in which *Caninia* and other zaphrentids are abundant. Beds or nodular layers of chert are a common accompaniment of the Carboniferous Limestone, especially above the lower zones. The limestone has been locally modified into a brownish dolomite in many places. The Carboniferous Limestone has been much worn away by prolonged denudation, since the material passes into solution, and is also of inferior hardness when compared with many other rocks. In the Sligo area, and in the terraced highland of the Burren in northern Clare, scarps of Carboniferous Limestone remain some 450 m. (1500 ft.) above the sea. But in the great part of Ireland, and even among the steep Armorican folds of the south, the limestone has given rise to lowland and fairly level country. The great peneplain of central Ireland owes its uniform character to the presence of the limestone, and a series of very shallow synclinals may be traced in it, with Old Red Sandstone and Silurian ranges protruding along the anticlines. This level country rises in plateaus, but is covered in many places with drift, on which broad bogs have established themselves. In other places, the solvent action of the rivers has formed the shallow lakes that are so characteristic a feature of the plain. Subterranean water-ways and disappearing or emerging streams are frequent, especially in the west, and their exploration gives rise to an increasing literature.

In the north of Ireland generally, the basal Carboniferous beds include much sandstone, which is often of a red colour and which forms bleak uplands where it is lifted on the slopes of the Dalradian country. At Ballycastle, on the north coast of Co. Antrim, seams of coal are included in this series, accompanied by one thin band of limestone. The beds of the Ballycastle Coal-field, some 400 m. (1300 ft.) thick, were deposited in a hollow of the Dalradian schists, and have been broken through and faulted by Kainozoic dykes of basalt. The laccolitic dolerite of Fair Head separates the field into an eastern and a western division. The highest strata are probably of the age of the "Carboniferous Limestone" of the basins of the Forth and Clyde, and the series should be compared with the Lower Carboniferous of Scotland, rather than with that of any other part of Ireland (Hull and Baily 1871, Arber 1912). Among the marine fossils are *Lingula squamiformis*, *Rhynchonella pleurodon*, *Productus giganteus*, *Murchisonia angulata*, *Bellerophon uri*, and *Orthoceras steinhaueri*. The Lower Carboniferous Sandstone of the north has been compared with the Yellow Sandstone series of Devonian age in the south (NOLAN 1880); but its fossils ally it rather with the Avonian Series and, as above observed, sandy beds occur in the northern area, both near the base and much higher in the Carboniferous series. The Carboniferous Limestone facies is, however, well developed in the mountainous country round the source of the Shannon, and as an "Upper Limestone" above a series of shales and sandstones near Lough Melvin and Lough Erne. Hence the region in which Lower Carboniferous coal seams are likely to occur is very limited. A boring has failed to detect coal in the sandstones of Dungiven, only 17 km. (11 miles) south of the latitude of Ballycastle.

Unless, as previously hinted, some beds of the Carboniferous Slate represent high Avonian zones, the Yoredale and Upper Limestone Shale Series of central England are preserved in the south of Ireland only in the neighbourhood of the coal-fields. In the area of the Leinster Coal-field we have these horizons represented by a cherty "Upper Limestone", and WHEELTON HIND (1905) urges that in some western districts what are called "Upper Limestone Shales" belong to the Upper Carboniferous Series. This view is borne out by the work of DOUGLAS in Clare, previously quoted.

In the counties of Leitrim and Fermanagh, there are considerable beds of sandstone below the horizon of the Millstone Grit, sometimes 300 m. (1000 ft.) thick, and probably representing part of the Carboniferous Limestone series of the south. A few thin coal-seams, not good enough to work, occur in these shore-deposits (W. B. WRIGHT 1912).

The Upper Carboniferous strata include the Pendleside series of WHEELTON HIND, which was traced by him in several parts of Ireland (1905 and HULL 1877, KINAHAN 1878). A large part of the areas formerly mapped as Coal Measures have been in later years referred to Millstone Grit and Pendleside horizons. WHEELTON HIND regards the Pendleside Series in Co. Clare as 24 m. (80 ft.) thick, and as deposited in the western end of a basin which deepened across central England. These beds have been styled Upper Limestone Shales, but are succeeded above by a generally marine Millstone Grit, with *Glyphioceras reticulatum*. The following fossils are among those regarded as characteristic, and as proving here the presence of the Pendleside Series above the Carboniferous Limestone: *Glyphioceras diadema*, *Dimorphoceras gilbertsoni*, *Pterinopecten papyraceus*, *Posidoniella laevis*. The Millstone Grit Series contains workable coals at Dungannon, round Lough Allen, and perhaps in the Leinster Coal-field. The Skehana anthracite seam, 60 cm. (2 ft.) thick, appears round the margin of the high Leinster Coal-field, and seems to underlie a large part of it. Thinner seams occur in still lower beds. The fauna associated with this horizon is marine and estuarine. The same beds recur in the Slieve Ardagh Coal-field in Co. Tipperary. Poor coals have also been found in them over a wide area in northern Kerry and in western Limerick and Clare. The lower coal-seam worked at Arigna near Lough Allen is probably on a Millstone Grit horizon. The Dungannon coals of the Tyrone Coal-field, which have still to be developed, lie in shales and sandstones with marine fossils.

The true Coal Measures, representing on the whole terrestrial and freshwater conditions in the Irish area, remain, as has been pointed out, only in a few favoured localities[1]. The coals in them are anthracitic south of the line connecting Dublin and Galway, and of ordinary household typhes north of this line. In the Leinster Coal-field the Jarrow coal was in parts 2 m. (6 ft.) thick. Its disposition has been accounted for by the suggestion that it was laid down in a curving channel, excavated by

[1] The plants are described in several memoirs of the Geological Survey on the coalfields. See also T. JOHNSON.

river-action in lower strata. This coal-field is preserved as a high synclinal basin, the margin of which is formed by a series of scarped sandstones. Some 600 m. (2000 ft.) of coal-bearing strata are here recorded.

Attention was called in 1865 by W. B. Brownrigg to a very interesting series of amphibian remains from the Coal Measures of the Jarrow colliery in the Leinster Coal-field. These were described by T. H. Huxley and E. P. Wright (1866), and include the genera *Urocordylus*, *Ophiderpeton*, *Dolichosoma*, *Ichthyerpeton* (shown by Lydekker to include *Erpetocephalus)*, *Keraterpeton*, and *Lepterpeton*, all of which were then new to science; also *Anthracosaurus*, which was already known from Scotland. *Ichthyerpeton hibernicum* was added by Lydekker in 1891.

Small mines also extract anthracite on the adjacent plateau of Slieve Ardagh, where Coal Measures overlie the Millstone Grit horizons. The outlier near Carrickmacross is unimportant. The upper coal at Arigna in the Connaught Coal-field lies in true Coal Measures, which here remain only as a capping to the highest hills. The mining is carried on at about 300 m. (1000 ft.) above the sea.

At Coalisland, north of Dungannon in the Tyrone Coal-field, Coal Measures occur in a small triangular exposure; the Annaghone seam here is nearly 3 m. (9 ft.) thick. (Geol. Surv. Mem. and Hardman 1875—7). A number of other coals occur, and the dip of the strata, combined with their downthrow by faulting to the east, leads one to suppose that they may ultimately be traced under the Triassic sandstones to the east. The form of the boundary of the Coal-field, however, which was determined by denudation soon after the Armorican uplift, does not leave hope for any very large extension in this direction. Excellent fire-clay is obtained from the Carboniferous shales of this area, and the coal raised is mostly consumed in the furnaces connected with this industry.

While many of the dykes that traverse Carboniferous strata in northern Ireland are evidently connected with the Kainozoic volcanic activity, there are evidences in two or three places of contemporaneous volcanic action. The chief of these lies east of Limerick city, where lavas, ashes, and intrusive sheets occur in the Carboniferous Limestone (Mc Henry and Watts 1895 and Mem. Geol. Survey). Activity probably continued into Upper Carboniferous times. The lower series of lavas was poured out about the middle of the Carboniferous Limestone epoch. The igneous rocks include pinkish trachytic types (orthophyres), andesites, and olivine-basalts, passing into limburgites. They form a number of low hills, on several of which picturesque feudal castles stand.

North of Philipstown in King's County there is a second but smaller volcanic area of Carboniferous Limestone age, where basalts and limburgites are associated with volcanic tuffs. Andalusite-schist has been brought up in these tuffs from some unseen mass below (Haigh, 1914).

The invasion of the Irish area by the Carboniferous sea was remarkably complete. We can realise, by the sandy nature of its first deposits in the north and west, that land lay not far off in the Atlantic area. The presence of coal-seams at Ballycastle, and the virtual absence of the limestone, indicate in this one place the actual shore-line. But Carboniferous outliers occur on the crest of Slieve League in the far west of Donegal, and on the great flat-topped hills near Killary Harbour. Even if the Connemara mass was not completely submerged, the rocks that have been dredged up so abundantly from the Atlantic off the western Irish coast show that we cannot mark out a limit to the Carboniferous overflow in that direction. A considerable region of Caledonian land must have remained for a long time in about latitude 51° N., to furnish the muddy material now known as the Carboniferous Slate. The Leinster Chain and the Newry axis stood out for a while as bold promontories; but the higher strata of the Carboniferous Limestone series now conceal the earlier shore-deposits at most points, by overlap as the subsidence went on. In the Dublin district, however, copious admixtures of mud, and even coarse conglomerates formed of older Palæozoic rocks, occur at various levels in the limestone, and we may conclude that the topography was much what it would be at the present day, were a subsidence of 150 m. (500 ft.) to let in the sea over lowlands. The addition of mud to the sea does not seem to have appreciably limited the marine fauna, and even such delicate forms as crinoids continued to flourish. The so called "calp" beds are, indeed, limestones rather than shales. The Leinster Chain had already been so far worn down as to expose its core of granite, fragments from which are found in the Carboniferous Limestone south of Dublin. Detrital mica occurs freely here in many places, and masses of the metamorphic Ordovician schist also remain just as they were washed down. A "calpy" or argillaceous type of limestone occurs very frequently through Ireland, and the handsome pure grey limestone must be mainly looked for in what has been styled the Upper Limestone series.

Gradually, as the sea spread, very few islands remained above its surface. Then came the first intimation of the Armorican movements, in the upward swing of the whole area, giving rise to an epoch in which shales and sandstones were the predominant deposits, while the once abundant brachiopods and molluscs moved elsewhere, and perhaps far eastward, into purer waters. The forests began to manifest themselves about the horizon of the Millstone Grit, and the type of coal-field known in Scotland and northern England, with good seams in the Lower Carboniferous series, is found in Ireland only in the north at Ballycastle. But in true Coal Measure times land was so far prevalent that we may regard the whole Irish area as clothed with forests of Carboniferous trees.

By the close of the Carboniferous period, denudation had already acted on the uplifted land. A depression appears to have arisen in the north of the area., whereby the region of accumulation in later periods remained in the north, and especially in the north-east, while that of exposure and denudation lay in the south and west. The continental character given to the region by the Upper Carboniferous uplift, and soon after by the Armorican movements, seems to have been remarkably preserved through succeeding periods; and consequently the Mesozoic and Kainozoic deposits have none of the rich variety of those of France and England.

The Armorican folding probably produced a far less mountainous country than that of Lower Devonian times. The old crumpled Caledonian hill-barriers were still effective down below, with their schistose boundaries and granite cores, and checked the free rise of the Armorican folds. In an endeavour to wrinkle themselves over the older topographic features, the Armorican folds became greatly influenced by the Caledonian trend. A general highland, however, was produced, the surface of which was almost everywhere composed of Carboniferous strata. It must have been a long time before denudation began to reveal the domes of Old Red Sandstone with Silurian cores that are now such conspicuous features in the limestone plain. As JUKES long ago pointed out, these did not appear through the Carboniferous covering until the present river-systems had begun to establish themselves on a plain of denudation, which was tilted somewhat to the south. We know that the main streams of these systems are pre-Glacial. Is it possible that any of them have descended to us from the conformation of the country in Permian times? The answer to this question depends on what view we take of the westward development of the Cretaceous ocean. If much of Ireland can be shown to have sunk below the Senonian sea-level, the river-systems at once become limited in antiquity to Kainozoic times.

Economic Products.

Coal. Ordinary Coal for household purposes occurs in the high Upper Carboniferous outliers round Lough Allen; at Ballycastle, in Lower Carboniferous shales and sandstones; and in Upper Carboniferous beds at Dungannon and Coalisland west of Lough Neagh. In the last-named locality, it is possible that a good deal of coal, including the continuation of a seam nearly 3 m. (9 ft.) thick, remains to be discovered beneath the Pliocene clays and Triassic sandstones between Coalisland and the lake. The Dungannon coals still remain unexplored.

In southern Ireland, the coal is anthracitic. The great outlier of Upper Carboniferous beds forming the Leinster coal-field contained several good seams which have been almost worked out. An almost untouched seam 0,6 m. (2 ft.) thick underlies, however, part of the field, and promises well for the future. Coal is also worked to the south-west on the plateau of Slieve Ardagh.

The large area of Upper Carboniferous strata in the counties of Limerick and Clare yields only a few occasional small seams of anthracite.

Iron-Ore. Concretionary iron-carbonate is common in the Upper Carboniferous shales, as round Lough Allen; but it is not easily worked, owing to the amount of material that must be removed during its extraction. There are numerous iron ore zones at Lough Allen, below that in which the coal occurs.

Fireclay is worked at Coalisland in Co. Tyrone from Upper Carboniferous strata, and a variety rich in silica occurs near Ballycastle in Co. Antrim.

Barytes is mined near Clonakilty in Carboniferous strata, and at other places in the south-west of Co. Cork; also near Glencar in Co. Sligo.

Limestone and **Marble.** The common grey Carboniferous limestone is very largely used for building, as well as for conversion into lime. Owing to its cheapness, it is too generally employed as a road-metal. Excellent stone of uniform grain, for buildings in which carved work is required, comes from the country near Ballinasloe in the central plain.

A crushed and iron-stained variety from Little Island, Cork, makes a handsome red marble when polished. Grey marble, with pink and red calcite veins, is quarried at Midleton, Co. Cork. Black varieties, coloured by carbon, are quarried at Kilkenny city and at Menlo near Galway.

Sandstone. The Lower Carboniferous beds of Mount Charles, west of Donegal town, and of other places in the northern counties, provide good yellowish sandstone for building. The very hard well bedded sandstones of the Upper Carboniferous series in the west of Clare, and similar stones from the Kilkenny Coal-field, have been used as paving-stones. The casts of animal tracks on their surfaces are an advantage in preventing their becoming slippery. They also make good slabs for steps and landings.

Slate is worked in the Carboniferous Slate series near Clonakilty, Co. Cork.

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See also MCHENRY, A. above.

7. Permian.

a. Great Britain, including the Isle of Man.

I. Sedimentary Rocks.

By PERCY F. KENDALL.

The Permian rocks of Britain present two strongly contrasted lithological facies that may be broadly described as the Eastern, or Magnesian Limestone, and the Western, or Red Rock facies.

The first of these characterized by the great predominance of limestone, generally magnesian, and by pale yellow sands when arenaceous members are present extends in a continuous outcrop from Cullercoats on the east coast 2 km. ($1^1/_2$ miles) north of the Tyne to the neighbourhood of Nottingham.

The western type consists of bright red sandstones, marls and breccias or conglomerates, with a local development round the Irish Sea of thin magnesian limestone. This type extends from Arran and the south-western peninsula of Scotland to Ireland the Vale of Eden, Cheshire and the Midlands.

No rocks of Permian age appear in South Wales or the Mendip area, nor have any been met with in borings in the east or south-east of England, but the western facies is in doubt represented by certain of the Red Rocks of Somerset, Devon and Cornwall, which, though yielding no unequivocally significant fossils, are yet connected with the Permian by their association with volcanic rocks as well as by their stratigraphical relations with the Carboniferous and Triassic rocks.

The interval between the Carboniferous and Permian periods in Britain was marked, as elsewhere, by vast earth movements producing in the south the great foldings of the Armorican Chain and further north folds, though of less amplitude still of large dimensions, (Hull 1868). These, so far as affects the present discussion, may be briefly outlined. The great boundary faults of the Scottish "rift valley", usually referred to as the Midland Valley, had made a large further movement, whereby the Central Highlands and the Southern Uplands were raised above it. In England an anticline of great magnitude and nearly E. to W. in direction, the Howgill anticline of Marr (1910), extended from the neighbourhood of Richmond (Yorkshire) to near St. Bees Head (Cumberland) and perhaps to the Isle of Man and County Down Ireland, while, in the opposite direction, the post-Jurassic folds of Cleveland indicate its continuance to the North Sea. The Pennine fold was initiated at this period, as well as a great S.W.—N.E. set of undulations that crosses the Pennine system about its centre. At the southern end the Pennine fold gives place to a diverging series of disturbances, for the most part posthumous movements of much earlier systems, such as the Charnian folding.

Faulting accompanied the folding, and, while some of these faults cannot be proved to have had any prior existence, some were renewals of the activity of earlier dislocations and in a few cases the disturbances continued to operate down to much later geological periods — even, as earthquake records show, to the present time.

Denudation went on concurrently with these crust movements, and anticlines and fault-features of great magnitude were worn down prior to the deposition of the Permian rocks upon their sites.

Near Clitheroe in the Ribble Valley red rocks, presumably of Permian age, rest upon the Viséan, and Hull (1868) has argued from the great thickness of the Yoredale (Pendleside) rocks, the Millstone Grit, and Coal Measures of the adjacent area, that no less than 6000 m. (20 000 ft.) of Carboniferous rocks were removed prior to the deposition of the Permian rocks at this place. This is probably an overestimate but denudation even more drastic has affected other areas; thus the Permian rocks of the western side of the Lake District rest upon pre-Carboniferous rocks, as do those of Belfast Lough, of Dumfries, and of some parts of the Midlands, while the Upper Permian rocks of the Vale of Eden and the Ingleton area contain fragments of pre-Carboniferous rocks that must have been exposed to denudation by movements of the adjacent faults. The Permian rocks in different parts of Britain can be found to rest upon every rock of older date back to the Archaean.

Local details and succession. It will be convenient to consider first the eastern type of Permian, both because the continuity of the outcrops and the general uniformity of characters permit a simple and comprehensive treatment, and also because the similarity to the development in Germany brings the eastern Permians into clear relation, to the continental sequence.

Throughout their range the Eastern Permians rest with marked unconformity upon different members of the Carboniferous series. The most constant member of the series, the Magnesian Limestone, is selected for first consideration. This division, despite local variations, especially of its upper division, ranges completely through from Cullercoats (55° 2′ N.), to Nottingham (52° 57′ N.) a distance of 233 km. (145 miles).

This rock was admirably described by Sedgwick (1836) and further descriptions and correlations have been given by Howse (1857), Kirkby (1861), Binney (1855, 1857), Woolacott (1909), Garwood (1910) and others.

The chemical constitution of the rock varies from nearly pure carbonate of lime as at Knottingley (Yorkshire) Roker and Fulwell near Sunderland (54° 55′ N.) to a true dolomite at Hartlepool (54° 39′ N.). The subjoined table by Kirkby (1861), somewhat abbreviated, gives a general correlation and description of the strata.

Subdivisions	Durham	South Yorkshire
1. Bunter Schiefer	(Howse) Red Sandstone overlying the Magnesian Limestone in the S.E. portion of the County Thickness 15m. (50 ft.)	(Geol. Survey) Red Sandstone and Marl near Doncaster and Tickhill. Thickness ? 15 m. (50 ft.)
2. Upper Limestone	Yellow, concretionary, and Crystalline Limestone of Marsden, Roker etc. Thickness 75 m. (250 ft.)	Brotherton Limestone and Lower Red Marl and Gypsum of Brotherton, Knottingley etc. Thickness 37 m. (120 ft.)
3. Middle Limestone	Shell- and cellular Limestone (Fossiliferous and Pseudo-brecciated Limestone of King) of Tunstall and Humbleton Hills. Claxheugh etc.. Thickness 45 m. (150 ft.)	Small-grained dolomite of Vale of Went, Roche Abbey, Warmsworth etc. Thickness 60 m. (200 ft.)
4. Lower Limestone	Compact Limestone of Ferry Hill, Whitley etc. Thickness 60 m. (200 ft.)	Lower Limestone of Pontefract, Hampole, Micklefield etc. Thickness 37 m. (120 ft.) (4 and 5)
5. Kupfer-Schiefer	Marl Slate of Claxheugh, Ferry Hill etc. Thickness 3 m. (10 ft.)	
6. Rotliegendes	Lower Red and Yellow Sandstone of Tynemonth, Claxheugh etc. Thickness 30 m. (100 ft.)	Lower Red, Yellow and Variegated Sandstone of Pontefract, Hickleton etc. Thickness 0—30 m. (0—100 ft.)

Lebour (1886) gives for Durham the following scheme:

Red Marly Sandstones and Marls, with lenticular beds of anhydrite, gypsum and salt, and fetid limestone in variable bands towards the base	Upper Permian (Rauchwacke)
Thick Magnesian Limestone	Middle Permian
Marl Slate, with Fish Bed	” ”
Yellow Sands	Lower Permian

The limestone varies in texture from a fine close-grained rock, to deposits with the cavities lined with crystals of dolomite. Concretionary structures of great diversity occur — especially in the non-magnesian rock at Roker and Fulwell in Durham. Brecciated structures are described in detail by LEBOUR (1884) and WOOLACOTT (1909). These are found in some places in the form of bedded masses when they are in great part at least the products of fault thrusts and in others of vertical sheets and wedge-shaped masses filling fissures in the rocks described by LEBOUR under the name of "breccia-gashes" and ascribed to the falling in of solution hollows.

GARWOOD considers that "both the lime and magnesia in the Durham beds appear to have existed in the original deposit". GREEN (1882) attributes the concretionary structures, as well as the cavernous condition of much of the Magnesian Limestone, and the contortions of the bedding, to the readjustments that would take place when calcium was replaced by magnesium. Much of the cavernous structure observed, especially in the Lower Limestone of Yorkshire, has been shown by ERNEST GUY (1911) to be due to the solution of irregular inclusions of gypsum, anhydrite and barytes that are found in the limestone in deep borings. "Suture-lines" are very common in the porous limestones. They are alway accompanied by a thin film of marl and are regarded by the present writer (1907) as the effects of irregular solution, the marl being the insoluble residue.

While the Magnesian Limestone maintains a general constancy of lithological character through its range from north to south there are significant local modifications. About the mouth of the Tees there are extensive intercalations of anhydrite and gypsum, and in the neighbourhood of Mansfield (53° 2′ — 53° 8′ N.) a sandy facies of the Upper and Middle beds is developed (SHERLOCK 1911) that has been mistakenly attributed to the Bunter and hence has led to the assumption of an unconformity between the Permian and Trias there. SHERLOCK's inference that the Upper Limestone and Marl of the northern part of the outcrop are the time-equivalent of the Bunter of South Nottinghamshire does not follow as a necessary corollary and is not likely to be admitted.

The Yellow Sands that form the base of the Permian in Durham are fine pale yellow or sometimes red sands and are believed by LEBOUR (1884, 1905) and others to be of aeolian origin and to exhibit dune-bedding.

Throughout Yorkshire sandy basal beds are often absent but to the west of Leeds they are well developed as well as near Doncaster.

From Conisborough (53° 25′ N.) to Nottingham the Lowest-Permian rock, resting directly on the Carboniferous is commonly a breccia ("Poxon-stone").

In Durham the Marl Slate is very generally present, even when the Yellow Sands are missing. It yields in some places well-preserved fishes and some plant remains. In Yorkshire, in the same position, are found occasional small patches of chocolate-coloured marl, sometimes containing gypsum etc., as at Knaresboro' (54° 1′ N.). This marl appears to have no connexion with the Marl Slate. Borings in Southern Yorkshire show the occasional presence of dark marly limestone regarded by GIBSON (1907) as Marl Slate. It has not yielded any trace of the fish fauna of the Marl Slate. Near Nottingham shales and flaggy sandstones with plant-remains and mollusca have been referred to the Marl Slate.

Above the Middle Magnesian Limestone of the table there occurs with great constancy through the greater part of Yorkshire a series of red and blue marls with gypsum and anhydrite and at Barlow (53° 42′ N.) a bed of rock salt. No definite parting appears in the sequence in Durham, but about the mouth of the Tees many intercalations of marl with gypsum and anhydrite occur in the upper part of the Magnesian Limestone.

The Magnesian Limestone is almost everywhere surmounted by a series of Marls with gypsum, and sometimes anhydrite, besides, in a few localities, rock-salt. The classification of these Marls has led to great divergence of opinion — in Yorkshire, where, at the outcrop, they contain few if any intercalations of sandstone, they have been classed by the Geological Survey with the Permian but the great series of Marls and Sandstones with gypsum, anhydrite and rocksalt round the estuary of the Tees have from the impossibility of drawing any line of separation been referred by the Surveyors to the Upper Trias, and herein they have been supported by WILSON (1876). The testimony of recent borings in South Yorkshire, and in Lincolnshire supports the opinion of LEBOUR (1886) that the Tees beds are of Permian age and in any case not Upper Trias. The gradual passage in the Whitehouse boring from Magnesian Limestone with intercalations of red and blue marl, anhydrite and gypsum, upward through red marl with anhydrite and gypsum to red marl with red sandstone renders any attempt to divide the series purely arbitrary and in a boring at Scunthorpe the difficulty was increased by the fact that red sandstones with very rare pebbles passed down into sandy marls, sandstones and gypseous marls with recurrences of sandstones having the exact lithological features of those above the marl series, and thence into red gypseous marls with a thick bed of anhydrite, that is constant over several hundreds of square miles, and traces of rock salt.

There is on the eastern side of the Pennine Chain in the judgment of the writer, a perfect passage from the Permian into the Trias and the Bunter division of the Trias does not, as commonly supposed, come to an end near Tadcaster (53° 50′ N.) but continues to the Tees.

The Permian series appears to thicken continuously in an easterly direction. In Yorkshire the increase is about 4.7 m. per kilometre (25 ft. per mile).

The Eastern Permians have yielded a large fauna including *Fenestella retiformis*, *Lingula credneri*, *Productus horridus*, *Camarophoria schlotheimi*, *Spirifer alatus*, *Bakewellia antiqua*, *Schizodus obscurus*, *Nautilus*, *Palaeoniscus;* and plants such as *Sphenopteris naumanni*, *Alethopteris goepperti* and *Ulmannia selaginoides*.

The Western Type. Borings in the northern end of the Isle of Man penetrated St. Bees Sandstone — here regarded as Trias — "passing down into red marls with intercalations of sandstone (Permian), brown coarse-grained sandstone with partings of marls, and fine "brockram" (conglomerate) at the base (Permian)". These rest upon highly inclined Lower Carboniferous rocks. (LAMPLUGH 1903). The evidence here of passage from the Trias down into the Permian is interesting. Across the Southern Uplands of Scotland there are several belts of red sandstone, sometimes with associated conglomerates, that have with much probability been assigned to the Permian series. They lie unconformably on Palæozoic rocks, either Carboniferous or older, and in several cases, as for example in Loch Ryan, and Nithsdale, occupy deep valleys eroded in the complex of the Southern Uplands. The only fossils found are reptilian or amphibian foot prints, and these are considered by HICKLING (1909) to be of Permian types. In the Nith valley these rocks are associated with basic lavas similar to those found in other areas of supposed Permian rocks. In the Island of Arran, similar rocks have been observed, but the red rocks of Arran are probably referable to several geological periods, the Upper Old Red Sandstone of the Western side of the island being closely similar in character to the supposed Permian. GEIKIE (1897) regards the volcanic vents that pierce the Coal Measures of Fifeshire as of Permian age (pp. 192—193), and WATSON (1909) attributes the Red Sandstones of Elgin with the reptiles *Gordonia* and *Elginia* to the Permian, as these reptiles have close affinities with those found in the Upper Permian of other areas. HICKLING (1909) corroborates this reading on the ground of the resemblance of fossil footprints in these rocks to those found at Mansfield and elsewhere in undoubted Permian rocks.

In Cumberland and Westmorland the Permian series attains its maximum development in Britain. The succession in the Vale of Eden is of particular interest from the evidence that it furnishes of the physical conditions of the period and their changes. This valley is bounded on the east by the Pennine escarpment which owes its existence to a tremendous series of faults truncating the Permian and later rocks. The succession from west to east is: Carboniferous Limestone and Millstone Grit, covered unconformably by massive calcareous conglomerates, "Lower Brockram", usually dolomitized; bright-red Penrith Sandstone about 300 m. (1000 ft.); "Upper Brockram" interbedded in the upper part of the Penrith sandstone; Hilton Plant Beds with *Noeggerathia* 45 m. (150 ft.); Magnesian Limestone 0—6 m. (0—20 ft.); Marls with gypsum, having locally, a basal conglomerate, 90 m. (300 ft.); St. Bees Sandstone (Trias) 600 m. (2000 ft.). (Goodchild 1893). The succession here, save for the Brockrams and Penrith Sandstone, is fairly comparable with the succession in Durham, but the great thickness of bright-red sandstone has no parallel in the Yellow Sands.

The Penrith Sandstone is strongly current-bedded and its sand-grains are coarse, extremely well rounded and often most accurately "graded" into minor beds of equal sized grains. These are characteristics of wind-sorting and support the view that the rock is an æolian accumulation. The large size of the sand-grains, and the inclusion of a large proportion of felspar grains suggested to the writer (1910) that the materials had been derived from the Millstone Grit of the Pennine Chain. Marr observes that the current bedding inclines from east to west.

The materials of the Lower and Upper Brockrams respectively furnish evidence of contemporaneous movements of the adjacent fault zone. The Lower Brockram consists exclusively of fragments of Carboniferous Limestone and the writer infers that it represents gravel-fans washed by torrential rains from the uplifted fault country, when the displacement had exposed only that division of the Carboniferous series. The Upper Brockrams were laid down after the deposition of 300 m. (1000 ft.) of Penrith Sandstone, which should have covered up an equivalent portion of the faulted area, yet these Brockrams consist in large measure of the Basement Conglomerate of the Carboniferous series, with occasional pebbles of the underlying Ordovician rocks. This is interpreted to mean that between the formation of the two Brockrams a great further movement of the faults took place bringing the base of the Carboniferous up within the action of surface erosion.

In this region the "Marls with Gypsum" extend unconformably across the beds below and in places rest upon the Penrith Sandstone. Whether this is to be regarded as evidence of a limiting unconformity or merely as a local consequence of further movement of the faults cannot be decided without a wider survey.

The western side of the Lake District furnishes one admirable section of the Permians at Barrowmouth (54° 30′ N.) figured by Murchison and Harkness (1864) who show Magnesian Limestone with a basal breccia resting upon an eroded surface of Carboniferous sandstone. The limestone contains a few fossils and is succeeded by red and green marls with gypsum, covered by St. Bees Sandstone (Trias).

To the south of this point the St. Bees Sandstone overlaps on to Ordovician rocks and when the Permian rocks reappear, the lithological type is repeated near Furness Abbey (54° 8′ N.) and again at Skillaw Clough (53° 43′ N.), beyond which the limestone phase is no doubt represented by the fossiliferous marls with septaria that occur in parts of Lancashire and Cheshire.

On the little Ingleton Coal-field, at the foot of the Craven fault-block (54° 7′ N.) a succession is found, having the same general significance as the series in the Vale of Eden. A Lower Brockram rests on Coal Measures, and the pebbles include many fragments of Carboniferous Limestone and a few of a *Spirorbis* limestone, no doubt from the Upper Coal Measures, a type that is not known to occur nearer than Manchester. In another section an Upper Brockram is seen which contains pebbles of Millstone Grit., Carboniferous Limestone, and pre-Carboniferous slate. This has been interpreted, in accordance with the Brockrams of the Vale of Eden, as indicating that while the Lower Conglomerate was being deposited only the Carboniferous rocks were exposed along the fault-scarp, and that a further movement of the faults brought up the platform of older rocks before the Upper Brockram was deposited.

At Clitheroe, in the Ribble valley (53° 49′ N.), red rocks attributed to the Permian rest upon the Carboniferous Limestone on the crown of a denuded anticline. As this outcrop is overlooked by heights capped by Millstone Grit it seems probable that, as Sir A. GEIKIE suggested in the case of the Nith valley, the deposits had been laid down in a kind of fiord. The Coalfield of Lancashire is fringed on the north and east by Permian rocks of a distinctive type, described by BINNEY (1845). A thin Basal Breccia is overlaid by the Collyhurst Sandstone, a bright-red sandstone, identical in appearance with the Penrith Sandstone except for the paucity of felspar. This is succeeded by chocolate-coloured marls, the Collyhurst Marls, with calcareous bands and concretions and many fossils such as *Schizodus* and *Bakewellia*. Often an Upper Breccia intervenes between the Sandstone and the Marls and on the South Side of Manchester a few feet of Marl come below this breccia.

At Stockport (53° 22′ N.), a few miles further south, two thick beds of marl with an intervening sandstone are seen below the Upper Breccia in some sections, while in others the Upper Breccia rests in bold unconformity upon the Collyhurst Sandstone. The movement, of which this is the record, appears to synchronise with those of the faults in the Vale of Eden and at Ingleton.

In the neighbourhood of the Mersey estuary marls have been encountered in boreholes, and in some cases a red sandstone exactly like the Collyhurst Sandstone has served as the type of the "Lower Mottled Sandstone" formerly attributed to the Trias; it now, however, appears certain that it is of Permian age.

On the Welsh border, e. g. near Wrexham (53° 3′ N.) and Oswestry (52° 52′ N.), red sandstones and marls, perhaps in part of Permian age, crop out (GIBSON 1901). The Permian rocks of the Midlands, including the country from the Welsh border to Charnwood and from Staffordshire to the Malvern Range, present a most perplexing problem on account of the rarity of fossils and the presence of red rocks of various geological ages. The difficulty of classification is increased by the fact that similar conditions seem to have persisted, or to have recurred at intervals, from the time of the Upper Coal Measures to that of the Trias, and that throughout that time the Archæan and Older Palæozoic rocks were exposed to denudation, so that the constituents of conglomerates do not always form a safe criterion of age. To add to the difficulty, the older rocks have been very largely stained with iron by percolating water and hence many Carboniferous rocks have been ascribed to the Permian. Fossils are extremely rare, and no invertebrates have yet been discovered; moreover no volcanic rocks occur in the Permian rocks here as they do in Scotland and Devon.

The western portion of the area has been described by WICKHAM KING (1899), the Malvern area by GROOM (1910) and Leicestershire by H. T. BROWN (1889) and the Geological Survey in a recent memoir (FOX-STRANGWAYS 1907). WICKHAM KING accepts a classification into Lower, Middle, and Upper Permian.

The Lower Permian consists of red sandstones interstratified with red marls 260 m. (850 ft.)[1]. These are succeeded, probably unconformably, by Middle Permian conglomerates, calcareous sandstones and marls, and those in turn by the Upper Permian marls and breccias (the "Trappoid Breccias" of some authors). The Trias (Bunter) lies unconformably upon the Permian.

The conglomerates and breccias exhibit a general tendency to thin out, and pass into sandstones from south-east to north-west. The pebbles in the Middle Permian include rocks from the Archæan, Cambrian, Gothlandian, Old Red Sandstone, Carboniferous and Lower Permian. The Upper Permian "Trappoid Breccia" is composed mainly of Archæan rocks and a general review of the Permian rocks of this area favours the suggestion that they are the degradation products of a series of anticlines from which first the Palæozoic rocks were stripped and later the Archæan cores were exposed. The transport of the materials was mainly from south-east to north-west. The total absence of Ordovician rocks is significant, especially in view of the fact that the Grès de May, with Ordovician fossils, constitutes a conspicuous element in the overlying Bunter.

Ramsey supposed that these Permian breccias and conglomerates were of Glacial origin but this view is no longer entertained by local workers, and the striations often found upon the stones are ascribed to friction during earth-movements. It may be remarked that one single striated stone has been recorded from the Lower Brockram of the Vale of Eden but diligent search has failed to yield a second.

In Leicestershire, on the south west side of the Archæan massif of Charnwood, rocks referred to the Permian have been mapped. At Swadlincote bright red sandstone covered by marl rests unconformably upon Coal Measures and is succeeded by an unconformable cover of Trias. The Charnwood axis is an example of posthumous folding; its latest movements appear to be of Cretaceous date.

At Exhall (52° 28′ N.) a sandstone attributed to the Permian has yielded fragments of *Lepidodendron*, *Calamites* and casts of a shell "considered to be of Permian type and more allied to *Strophalosia* than to any other genus" (Howell 1859). The latter is of importance as the only example of an invertebrate fossil from the Permian of the Midlands, but great doubt must attach to the record from the improbability of Permian beds yielding such an association of plants. The *Calamites* was identified by Forbes as *C. mougeotii* but Salter considered it to be *C. suckovi.* Both are Carboniferous species.

The great Armorican folds of the Mendip area separate the Permian area of the Midlands from that of Somerset and Devon, but it must not be assumed that the two regions were discontinuous in Permian times. Probably a connexion existed to the East of the Mendips, as was almost certainly the case in the Bunter period.

The interval between the southernmost Permian exposure in Worcestershire (at Haffield) and the most northerly in Somersetshire is 113 km. (70 miles). The Permian outcrops in Somerset and Devon extend from north to south parallel to that of the Trias and send offshots along some of the synclinal folds of the Armorican system. The whole series of the "New Red Sandstone" has undergone recent revision by the Geological Survey with the result that the Permian is held to include only two divisions — the Lower Sandstone and Breccia, and the Lower Marls.

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[1]) Lapworth and Watts (1910) refer this division to the Keele Series of the Upper Coal Measures and Cantrill (1895) would unite King's three divisions as "Coal Measure Passage Beds".

The former consist of red sandstones with breccias and conglomerates, sometimes becoming mere incoherent sands and gravels. The pebbles are of quartz, grit chert, and limestone, with occasional fragments of slate.

The Lower Marls are dark-red green-spotted marls with intercalations of sandstone, the whole reaching a thickness of perhaps 150 m. (500 ft.) or more. Igneous rocks are associated with the Permian in the neighbourhood of Exeter (see p. 190). The relations with the Trias cannot often be discerned, the junctions being frequently faulted, but in some places, e. g. in the Quantock Hills, conformable junction has been observed, it should however be borne in mind that the lowest division of the overlying Trias is the famous Budleigh Salterton Pebble Beds in which the sudden influx of fossiliferous pebbles of the Grès de May, and Grès Armoricain attest a great physiographical change.

In any attempt to reconstruct the physiography of Britain during the Permian period much will depend upon the correctness of the correlation of the strata. The eastern type of Permian forms a continuous outcrop and it is therefore comparatively safe to carry the stratigraphical lines through the whole outcrop. On the west however the great variation in lithology and general paucity of fossils makes the synchronism much more problematical. One important guiding line is, however, available: the Magnesian Limestone of Cultra in Ireland contains the brachiopod *Productus horridus* which according to all authorities is quite characteristic of the Lower Magnesian Limestone of Yorkshire. This, then, is a datum — and the present writer ventures to refer to the same line the Magnesian Limestone of Barrowmouth and of the Vale of Eden and, with much doubt, the Collyhurst Marls of the Manchester district. The temptation is great to carry the parallel further and correlate the Penrith Sandstone with the Yellow Sands, and the Plant bed with the Marl Slate (vide GOODCHILD). The Marls above the Magnesian Limestone in the Vale of Eden would then represent the Saliferous Marls of the Tees. The writer prefers to limit himself to the single correspondence of the Lower Magnesian Limestone.

The earliest phase of the Permian physiographical development was represented by an arid country traversed by the denuded folds of Carboniferous rocks of the Armorican system and with protrusions of older rocks in the western area, the Scottish Highlands and Southern Uplands, Ireland, Wales, the Midlands and Devon. Into the deep valleys that intersected the country, gravel fans were swept by occasional torrential rains. These formed the brockrams and non-calcareous conglomerates and breccias. Meanwhile the wind bore hither and thither the finer rock débris disintegrated chiefly by sun and chill; thus the detritus of the Millstone Grit, a true arkose, with its felspar still undecomposed was worn down to the smooth, polished grains of large size, that characterise the red Permian sandstones of the western area. The fault scarps of the northern Pennine, and of Ingleton overlooked the sandy tracts and contemporary movements brought up the fault-blocks more swiftly than accumulation could bury their bases. Whether the sands were actual dry land deposits or were blown into lacustrine areas cannot with certainty be determined, but the marly layers in which the vertebrates left their footprints must have been deposited in water. The Plant-beds of the Vale of Eden, and the Marl Slate, must have been water-deposited. The frequent current or cross bedding may be sand-dune bedding or may have been effected by water. It is noteworthy that the Permian Rocks contain no mica and no doubt this soft mineral would be reduced to indistinguishable flour by wind action. The Magnesian Limestone and the Collyhurst Marls bear unequivocal witness to the influx of salt-water, the general impoverished character of the fauna telling of unfavourable conditions, probably of super-salinity. The western area must have had some waterway joining it to the eastern sea and though it is not clear where it was situated it may be supposed to have been a narrow strait incapable of equalising the loss by evaporation, so that the conditions were progressively less favourable from north to south in the western region.

The concentration in the east increased till it reached at the time of the Middle Marls of Yorkshire, the stage of precipitation of calcium sulphate. When the temperature was low, gypsum was deposited, but at times it rose to or above 30° C (86° F) and anhydrite was thrown down. The culmination of this phase was reached with the formation of a bed of rock-salt at Barlow. The waters sweetened again after this so that a fresh influx of marine life came in and the Upper Magnesian Limestone was formed, but it is noticeable that the fauna shows signs of further impoverishment in the absence of those elements of the Permian fauna least tolerant of abnormal salinity such as *Productus* and other brachiopods, and cephalopods. This recurrence of phase continued through the deposition of the Upper Marls with gypsum, anhydrite and rocksalt.

The area about the mouth of the Tees was through the greater part of the Permian period experiencing exceptional conditions, attested by the enormous deposits of anhydrite interbedded with the Magnesian Limestone, and by the great bed of rock salt. This completed the phase and the Triassic period brought new conditions that will be discussed by another pen.

The **economic products** of the British Permian are of interest and of great value. The Penrith Sandstone is a building stone of much beauty but generally too soft to command a market in competition with the Triassic sandstones that accompany it. The old castle of Penrith at Penrith is built of the Permian stone which shows beautifully the recrystallization of the quartz grains at the expense of silica from the decomposition of grains of felspar.

The Magnesian Limestone yields a fine durable stone that has been employed for many famous buildings both ancient and modern.

The Permian gypsum is used to a small extent for Plaster of Paris, and the salt at Tees mouth is also worked.

By far the most valuable mineral product of Permian age is the Cumberland haematite. This occurs as enormous ore-bodies filling partially or completely huge cavities in the Carboniferous limestone, where that rock has been traversed by water percolating through from the Permian strata or by the ferriferous waters from which these were deposited.

Many minerals occur in the Magnesium Limestone, for example, barytes, strontianite, zincblende and ores of copper, but they are not present in workable quantities.

The Magnesian Limestone is distinguished, where not covered with Boulder-clay, by a bright-red clayey-soil, the insoluble residue derived from the solution of the limestone. This suggested to William Smith the name "Redlands Limestone" which he gave to this rock in his famous "Table of the Strata".

II. Igneous rocks.

By Alfred Harker.

A. Permian (or Late Carboniferous) Igneous Rocks of South-Western Scotland.

It has been remarked above that igneous action was prolonged in general to a later stage of the Carboniferous in the west than in the east of Scotland; and further that there occur in the west numerous intrusions of alkaline igneous rocks, comparable with types found in the east but of later age. These late Palæozoic igneous intrusions are found mostly in Ayrshire. In the middle of that county, in the district of Mauchline, there occurs also a volcanic group of strongly alkaline character and of late age. It is associated with red sandstones, which Sir A. GEIKIE has assigned to the Permian, while others have regarded them as the uppermost part of the Coal Measures. Since the alkaline intrusions of Ayrshire break through all strata up to and including the Mauchline lavas, they may be referred to the same cycle of igneous activity as that volcanic group.

The volcanic group of Mauchline (fig. 36) presents a ring-shaped outcrop measuring about 12 by 8 km. ($7^1/_2$ by 5 miles), and has a thickness of 90 m. (280 ft.), including numerous thin lava-flows associated with tuffs. Volcanic action at this epoch was doubtless more extensive than is indicated in this small area. Sir A. GEIKIE (1897) supposes that the rocks continued into Dumfriesshire, where again lavas are found in association with strata believed to be Permian. Moreover, he assigns to this age numerous volcanic necks, which pierce the Carboniferous strata, not only in the south-western districts but also in Eastern Fife (GEIKIE 1902). Near Mauchline (TYRRELL 1912) the lavas present some variety of interesting types: olivine-basalts, analcime-basalts (including some with nepheline), nepheline-basalts, monchiquites, and limburgites.

The intrusions, which have a somewhat wider distribution, have the form of sills and small bosses. They are found about Old Cumnock, Lugar, Patna, Dalmellington, Ardrossan, Troon, etc. The rocks are teschenites, picrites, theralites, essexites, and allied types, with one occurrence of analcime-syenite, at Howford Bridge near Mauchline, and some monchiquites.

In this place may be mentioned certain basic dykes, with more or less marked alkaline affinities, which are found in large numbers in some parts of the south-west of Scotland. They are most abundant in Argyllshire and in the islands of Jura, Islay, and Colonsay. They cut the quartz-dolerite dykes where they encounter them, but are sometimes cut by Tertiary dykes of basalt and andesite. Owing chiefly to their general N.W.—S.E. direction, these Argyllshire dykes have often been supposed to be of Tertiary age, but they differ from the known Tertiary dykes in petrographical characters, and resemble rather the late Palæozoic intrusions. The majority of them are olivine-dolerites, often with purplish pleochroic augite, and analcime-dolerites (crinanites), but more specialized types are found in the outlying districts. Monchiquite dykes occur in Colonsay, and both monchiquites and camptonites in the S.W. of Mull and in the Ardmucknish peninsula, north of Loch Etive.

Another district of dykes having pronounced alkaline characters, and of doubtful age, is the Orkney Isles (FLETT 1900, 1914), in the far north of Scotland. These dykes intersect the Old Red Sandstone, and have a general E.N.E.—W.S.W. direction. They are camptonites, with some monchiquites and alnöites and one bostonite.

B. Granites of Cornwall and Devonshire and their associated Dykes.

The granites of Cornwall and Devon (see fig. 37, p. 173) are the largest intrusive masses of igneous rocks in England. The principal distinct bodies, enumerated from east to west, are those of Dartmoor (Devonshire), Bodmin Moor or Brown Willy, St. Austell or Hensbarrow, Carn Menelez (near Camborne), Land's End, and the Scilly Isles. Smaller masses occur elsewhere in Cornwall, and there is one making Lundy Island, lying N.W. of Devonshire. These granites break through and metamorphose the Devonian and Culm strata. They are related to the Armorican system of crust-movements, and may be assigned to a late Carboniferous or Permian age. Some of the granite masses seem to underlie the bordering strata in a manner suggestive of a dome-shaped upper surface, but the junction is sometimes rather steeply inclined.

The rock is in general a muscovite-biotite-granite with large porphyritic crystals of orthoclase, and very much of it contains tourmaline. Pinite pseudomorphs after cordierite, andalusite, and other special minerals are found locally. The tourmaline is in great part connected with pneumatolytic action, and as a last stage the granite may be converted to a tourmaline-quartz-rock. A different kind of pneumatolysis has in some districts converted the granite along joint-planes into greisen, and to this kind of action belong the tinstone-veins. Still another pneumatolytic change is that which has resulted in the formation of kaolin.

The slates bordering the granite have been metamorphosed to hornfels and mica-schist, often with andalusite or cordierite, and the impure calcareous bands have become lime-silicate-rocks ("calc-flintas"). A pneumatolytic action, involving boric acid, has often given rise to tourmaline in the metamorphosed slates, and in some places to axinite in the more calcareous beds.

The important metalliferous ores of Cornwall are connected with the granite, and occur near the borders of the several intrusions (see various Mem. Geol. Survey). The tin and copper lodes run mostly E.N.E.—W.S.W. Silver and lead ores were deposited subsequently in the same lodes, but more especially in the "cross-courses", which intersect and displace the principal set of lodes.

Two groups of dykes occur in this region, and must be supposed related to the granite: (a) quartz-porphyries and (b) mica-lamprophyres.

(a) The quartz-porphyries, locally termed "elvans", are probably slightly posterior to the granite, which some of them intersect. The dykes are very numerous in the south-western part of Cornwall, near the granite masses of Land's End and Carn Menelez, and have there a general E.N.E.—W.S.W. direction. Near the granites of St. Austell and Bodmin Moor the direction is more nearly E.—W. Other dykes of this group occur near the Dartmoor granite in Devonshire. The rocks are often partly sericitized, and some contain tourmaline or pinite pseudomorphs after cordierite.

(b) The mica-lamprophyre dykes are probably of slightly later age, and are much less numerous, but a number of them are known about Falmouth and Truro, and they occur again near Newquay in North Cornwall. They tend generally to have a N.—S. direction.

C. Permian Volcanic Rocks of Devonshire.

In the Permian of England intercalated igneous rocks are found only in the south-west, and there only in feeble development. They occur in the Exeter district (fig. 5), to the N. and N.W. of the city, and represent, at least in part, contemporaneous lava-flows. The rocks, which are mostly much decomposed, show some variety. They are apparently the effusive equivalents of lamprophyric magmas, and some of them are very rich in potash. They have been described (Teall 1902, Ussher 1902) as basic trachytes or orthophyres; viz. biotite-trachyte (approximating to minette), augite-trachyte, olivine-trachyte, and transitional forms between these and basalts.

At Cawsand, on the west side of Plymouth Sound, a rhyolite is found associated with Permian breccia, probably as an intrusion (Flett 1907, Ussher 1907). It may be related to the lavas of the Exeter district.

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b. Ireland.

By G. A. J. COLE.

The first invasion of the eastern sea into the land that was depressed in the Irish area at the close of Carboniferous times is traceable in three small tracts of Permian strata in a limited district of the north. Magnesian limestone, like that of north east England, occurs on the shore near Holywood in Co. Down. It contains, among other fossils, *Productus horridus*, *Bakewellia antiqua*, and *Schizodus*

Schlotheimi (W. King 1852 and Mem. Geol. Surv. 1871). Certain shales, with intercalated unfossiliferous magnesian limestone bands, rest on Silurian rocks near Moira, in the Lagan valley. These are also probably Permian. Fossiliferous yellowish dolomitic limestones, now much concealed by vegetation, occur in three or four places between Carboniferous and Triassic strata near Tullyconnell, not far from Stewartstown, west of Lough Neagh (King 1851). E. Hull (1873) has described boulder beds, formed of blocks of Carboniferous limestone in a reddish sandy ground, near and underlying the city of Armagh. He compares these with the Permian "brockram" beds of north-west England, and suggests for them a glacial origin. They are overlain by red Triassic sandstone

The proposed correlation of the lower beds of marl and sandstone in the Lagan valley south-west of Belfast with the St. Bees Sandstone of Cumberland, which is sometimes regarded as Permian, makes it possiblè that part of these beds is of Permian age (Mem. Geol. Survey 1904); and in any case it is probable that the Triassic strata of northern Ireland still conceal several relics of the Permian terrestrial and marine sedimentary series.

The Armagh "breccia" shows how the Carboniferous Limestone was exposed to denudation in the land area to the south.

Economic Products.

There is no direct evidence of the age of the metalliferous lodes of Ireland, which are very possibly of Devonian age; but, as those of Cornwall have been discussed with the Permian igneous rocks with which they are believed to be connected, it will be convenient to consider here the Irish ores of the same general character.

Copper. In the middle of the nineteenth century, the mining of copper was an important Irish industry. Large quantities of copper pyrites were raised annually from lodes in the Vale of Ovoca in Co. Wicklow, and in the south of Co. Waterford. One Mine in Co. Wicklow yielded 7500 tons of copper ore in 1842; and the joint Waterford mines raised 9000 tons in 1843. Other mines were worked in the west of Co. Cork beyond Castletown Berehaven. Attempts are being made to reopen some of these lodes, which were formerly so highly profitable. A mine has also been recently worked at Beauparc on the River Boyne.

Lead and Zinc. Small mines of galena have been opened from time to time in many parts of the country, and zinc-blende commonly occurs with the lead-ore. At Silvermines, in Co. Tipperary, at the junction of the Old Red Sandstone and the Carboniferous Limestone, a considerable lode of zinc carbonate occurs, with argentiferous galena and iron pyrites. Mining has now ceased in this locality. Galena, associated with cerussite, is occasionally worked at the junction of the mica-schist and granite above Laragh in central Wicklow.

Gold. The abundance of prehistoric gold ornaments in Ireland points to the working of local alluvial gold. Though the quartz veins and other rocks that have been examined are not by any means rich in gold (Lyburn, 1901), a good deal of gold has been procured by the washing of river-gravels between the hill of Croaghan Kinshelagh and Shillelagh in Co. Wicklow. These deposits were worked by the Government from 1796 to 1803, but without much profit. Traces of gold have been reported from the Dalradian areas of eastern Londonderry and Donegal.

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8. Trias.

a. England and Wales.

By LINSDALL RICHARDSON.

In England the Triassic rocks belong to the Bunter and Keuper divisions: no representative of the German Muschelkalk has as yet been identified.

The outcrop of the Trias in England is comparatively narrow in the South-western District, but expands in the Midland Counties and bifurcates at the southern end of the Pennine Range — one extension projecting into Yorkshire, and the other (considerably dissected) into Lancashire, Westmorland and Cumberland.

The landscape where the Bunter Sandstones and Pebble-Beds prevail is usually diversified; but where the Keuper Beds occur it is relatively tame, being generally lowland. This lowland, however, is rich agricultural ground and usually pleasingly undulating — particularly if the "Arden Sandstone", is present.

Bunter. — The Bunter Beds have a more restricted geographical extent than the overlying Keuper Beds. Their subterranean limits are fairly well known owing to numerous deep borings. Generally speaking, the lower the subdivision, the more limited its extent. This is because the earliest deposits were accumulated in the deepest hollows and the later deposits generally successively overlapped the preceding.

In England there were two distinct areas in which Bunter rocks accumulated. The one was situated in portions of the counties of Dorset, Devon and Somerset, and the other in the Midlands and on both sides of the Pennine Hills.

South-Western Area. — In this area the Permian marls are succeeded at once by a pebble-bed, about 24 m. (80 ft.) thick, called the "Budleigh-Salterton Pebble-Bed". Between Budleigh and Burlescombe the pebbles are mostly of quartzite; but between the latter place and Williton, near Watchet, mainly of Carboniferous Limestone.

The pebbles of the Pebble-Bed at Budleigh Salterton have been examined by SALTER and VICARY, DAVIDSON, BONNEY and O. A. SHRUBSOLE (1903), and while some may be matched in Devon and Cornwall rocks, the majority of the now well-rounded fragments must have been derived from Ordovician rocks similar to those of "Normandy and Brittany or the south of Cornwall" (JUKES-BROWNE, 1911).

The precise manner in which the pebbles were transported and distributed is a little obscure, but the most generally held view is that they were brought by a river flowing northwards from the Calvados district of Normandy. H. H. THOMAS found, after an examination of the sandy matrix of the Pebble-Bed, that its constituents supported such a conclusion (1902).

The Carboniferous-Limestone pebbles of the other section of the Pebble-Bed, that situated between Burlescombe and Williton, must have come from the opposite direction. E. C. MARTIN (1908) suggests that two rivers conjoined near Burlescombe — the one coming from a northerly direction and the other from a southerly direction. Further investigation, however, appears desirable.

Above the Budleigh Pebble-Bed are sandstones, pebbly in the lower portion, but less so in the upper.

Midland and North of England Area. In the Midland District, Cheshire, South Lancashire and South Yorkshire, the lowest subdivision of the Bunter is known as the "Lower Mottled Sandstone". This sandstone is usually of a reddish-brown colour, but is sometimes bright red, yellow, striped or variegated. In thickness it varies greatly, attaining its maximum at Bridgnorth, where it measures some 190 m. (650 ft.). It is absent — except at Polesworth — from around the Warwickshire Coal-field; under Market Bosworth, in Leicestershire, a deep boring proved it to be represented by merely a thin pebble-bed, but near Nottingham it is represented by some 8 to 30 m. (25 to 100 ft.) of orange-coloured sandstone. Near Selby this sandstone, together, with the overlying Pebbly Sandstone (see table p. 202), is said to be 189 m. (620 ft.) thick; but in North Yorkshire the Pebbly Sandstone has disappeared, and the stratigraphical position of the orange-coloured sandstone is occupied by red clays and shales with layers of gypsum and rock-salt between 60 and 120 m. (200 and 400 ft.) thick. On the other side of the Pennines the Lower Mottled Sandstone is continuous into Lancashire, but under Carlisle its place is taken by clays and shales with gypsum and rock-salt, similar to those in North Yorkshire.

In the Midland District, Cheshire and South Lancashire the middle division of the Bunter is very pebbly, and, what is very interesting, pebbles of rock similar to the Ordovician quartzite of the Budleigh-Salterton Pebble-Bed occasionally occur. The Pebble-Beds are finely exposed at Kinver Edge, near Kidderminster, where most of the pebbles are curiously pitted (READE 1895); but as regards actual quantity the pebbles are most abundant in Staffordshire, where a great mass of them occurs banked up against the Palæozoic rocks. In Cheshire and South Lancashire the middle division (pebbly portion) is thicker, 180 to 210 m. (600 to 700 ft.), but the pebbles are fewer in number and the quantity of associated sand greater. In the parts of North Lancashire, Westmorland and Cumberland, where the Triassic rocks occur, the equivalents to the Pebble-Beds of the Midlands are sandstones, inseparable as regards lithology from the equivalent of the overlying Upper Mottled Sandstone. On the other side of the Pennines the equivalent of the Pebble-Beds is seen as a pebbly sandstone in the cliff below Nottingham Castle (LAMPLUGH and GIBSON, 1910); but it does not appear to continue further north than Knaresborough, being unrecognisable in the northern part of Yorkshire.

The Upper Mottled Sandstone varies in thickness in the Midland District, Cheshire and South Lancashire from 90 to 150 m. (300 to 500 ft.). It has a wider geographical extent than either of the underlying subdivisions, extending as far south as the Bromesberrow district of Gloucestershire. On the west side of the Pennines, the equivalent to the Upper Mottled Sandstone cannot be separated from the sandstone which is the time-equivalent of the Pebble-Beds of the Midlands The whole mass is called the St. Bees or Garstang Sandstone — usually the former. In this district footprints of reptilian animals, ripple-marks and dessication-cracks have been observed. In Nottinghamshire and South Yorkshire the Upper

Mottled Sandstone is not represented; but in North Yorkshire, red and white sandstone, some 120 to 150 m. (400 to 500 ft.) thick, has been paralleled therewith.

The Bunter Beds do not contain any building-stone of repute; but they are important in connexion with questions of water-supply, for their yield is considerable.

Keuper. — From the table on p. 203 it will be seen that the Keuper Series is divisible into two parts: a Lower in which sandstone predominates and an Upper in which marl preponderates.

The Keuper rocks are finely exposed in the cliff-sections between Sidmouth and Seaton on the English Channel. Thence they extend inland, giving rise to the rich vale-land around Taunton. In Somerset, Glamorganshire, and South Gloucestershire the portions of the Keuper, which are near to or rest upon the Palæozoic rocks, are usually conglomeratic. The constituent rock-fragments—mainly of Carboniferous Limestone — vary much in size, being sometimes between 0.6 and 0.9 m. (2 to 3 ft.) in diameter. The majority are well-rounded, but many are best described as subangular, and it may be that a considerable quantity of the material accumulated as screes before being reached by the waters of the Keuper sea. The cementing material is generally calcareous and usually dolomitic, on which account the rock is locally known as the "Dolomitic Conglomerate". This conglomerate is well seen in many places in the Mendip country and particularly by the side of the Bridge Valley Road at Clifton. In this neighbourhood it has yielded the remains of *Thecodontosaurus* and *Palaeosaurus* and has been considerably used for building-purposes. The Conglomerate is essentially a marginal deposit of the Keuper and this is partly shown by the fact that the Tea-green Marls become "Dolomitic Conglomerate" when in contact with the Palæozoic rocks. Also, if Old Red Sandstone is the neighbouring Palæozoic rock, then the "Dolomitic Conglomerate" is very arenaceous.

The Keuper Marls are for the most part red, but in places are variegated with greenish spots and have greenish layers traversing their upper portion. Attempts have been made, especially by G. Maw (1868) and G. T. Moody (1905) to account for the several colours. Thus the latter author writes: — "The ease with which iron is deposited from solution in exchange for calcium and magnesium, affords strong evidence in favour of the view that variegation in rocks has in many cases resulted primarily from the passage of chalybeate water through calcareous strata. Subsequently, when conditions were favourable, owing to subsidence of water, air has been introduced and the ferrous carbonate has been converted into ferric oxide." In Gloucestershire and counties to the north, the uppermost 3 to 10 m. (11 to 35 ft.) of rock is of a more uniform greenish colour, and this portion is called the "Tea-green Marls". It is interesting to note that if the overlying Rhætic Black Shales are thick, so are — relatively speaking — the Tea-green Marls and vice versa. In parts of Somerset and Glamorgan above the Tea-green Marls are Grey Marls which pass downwards into the Tea-green Marls and upwards into the Sully Beds (Rhætic).

The upper portion of the Keuper is magnificently exposed in the cliffs of Aust, Sedbury, Garden and Wainlode on the banks of the Severn, and at Glen Parva in Leicestershire.

At various distances between 35 and 65 m. (110 to 215 ft.) below the top of the Keuper in Gloucestershire, Worcestershire and Warwickshire, is a prominent bed of sandstone called the "Arden Sandstone" by C. A. Matley (1912). It is well exposed in the neighbourhoods of Pendock (near Tewkesbury) (Richardson 1905) and Inkberrow and at many places in Warwickshire. Murchison and Strickland (1840), the Rev. P. B. Brodie, and subsequently others, have obtained a considerable number of animal and plant-remains from this Arden Sandstone, such as *Estheria minuta*, *Hybodus*, *Acrodus*, labyrinthodont remains, *Equisetites*, *Voltzia*, etc.

The lower or sandstone-portion of the Keuper Series is composed of beds of usually red sandstones, which are important from a water-supply standpoint.

These sandstones have yielded many interesting remains of the animal and plant life of the period, notably near Bromsgrove in Worcestershire, whence L. J. WILLS (1910) has obtained and described a most interesting collection, including *Schizoneura*, *Yuccites*, *Voltzia*, *Equisetites*, teeth of *Ceratodus*, the scorpions *Mesophonus perornatus* gen. and sp. nov., *M. bromsgroviensis* gen. and sp. nov., *Mesophonus* sp. and *Mytilus*-like shells; and in the neigbourhood of Birkenhead, where the footprints of reptiles abound.

The neighbourhood of Charnwood Forest and Mount Sorrel is most interesting because in the numerous quarries that have been opened in search of slate and road-metal frequent views are afforded of the junction of the Keuper with the older rocks (WATTS 1902). In one of the Mount-Sorrel quarries the granite rock beneath some recently-removed marl exhibited groving which it is thought could only have been accomplished by the wind-driven sand of the desert.

The Upper Keuper Marls of Worcestershire and Cheshire contain vast quantities of salt, the brine-springs of Droitwich and Stoke in Worcestershire, and the salt-workings at Nantwich and other places in Cheshire, being well-known. Gypsum occurs in the Watchet district of Somerset, at Penarth (near Cardiff), Aust Cliff in Gloucestershire, and abundantly in the Midland Counties, where masses are often obtained sufficiently pure to be of use to the sculptor. In the Bristol district, as at Yate, celestine (strontium sulphate) occurs and is largely dug for export to Germany to be used in connexion with the process of beet sugar refining. The marl itself is extensively ground for brick-making purposes, and in a few places — as at Emborough to the north of the Mendip Hills — certain portions are worked for fullers' earth.

The abundant occurrence of footprints in the sandstone of the Birkenhead district has stimulated the search for them in other parts, and the discovery of the sand-grooved rocks at Mount Sorrel has given added interest to the attempt to discover the precise conditions under which the British Triassic rocks, and, of recent years, particularly the Keuper, were formed.

In England, at the time of formation of the Lower Mottled Sandstone there were apparently three distinct areas of accumulation of rock-forming material. Two were situated on either side of the Pennine Range, namely, in the Carlisle and North Yorkshire districts, and were lakes in which red clays and shales with layers of gypsum and rock-salt were formed. The surrounding conditions were most likely those of a desert, for the Lower Mottled Sandstone, which was presumably being accumulated contemporaneously in the Midland district, Cheshire, South Lancashire and parts of Nottingham and South Yorkshire, contains beds of "Millet-seed Sandstone", whose grains were doubtless rounded by the action of desert winds. If any rock were formed in the South-Western district, its amount appears to be a negligible quantity.

The pebble-beds, pebbly sandstone and sandstones of the Midlands also suggest the action and therefore presence of water. The pebbles must have been introduced thereby and the footprints and dessication-cracks in the St. Bees Sandstone point in the same direction.

T. G. BONNEY (1900) holds that the pebbles of the Western-Midland pebble-beds, and particularly the predominant quartzites, were brought by a river which flowed from the direction of the present western side of Scotland; but it may be that, as our knowledge of the buried Archæan and Palæozoic rocks of the Midland and South-eastern Counties increases, a nearer source of origin will be discovered.

SUBDIVISIONS OF THE BUNTER SERIES.

	South-Western District.	Midland District with Cheshire and S. Lancashire.	N. W. District.	Nottinghamshire and S. Yorkshire.	North Yorkshire.
BUNTER SERIES.	Sandstone coarse, current-bedded, red, with pebbles: 91 m. (300 ft.) Conglomerate or "pebble-beds": 25 m. (80 ft.)	Upper Mottled Sandstone Sandstone, generally soft bright-red, yellow, white and variegated. 90 to 150 m. (300 to 500 ft.). No fossils discovered as yet (This subdivision has the widest geographical extent of the three composing the Bunter, extending through Lancashire, Cheshire, Shropshire and Worcestershire into Gloucestershire.)	St. Bees or Garstang Sandstone with occasional pebble-beds. (Footprints of reptilian animals, ripple-marks and dessication cracks.) 300 to 450 m. (1000 to 1500 ft.).	(Upper Mottled Sandstone said to be unrepresented).	Sandstone, red and white: 120 to 150 m. (400 to 500 ft.).
	Budleigh-Salterton Pebble-Bed: 21 to 24 m. (70 to 80 ft.)	Pebble-Beds and pebbly sandstones: 90 to 120 m. (300 to 400 ft.). [Extend over a large area with an average thickness of 90 m. (300 ft.), thinning out in Warwickshire, but thickening in Cheshire and S. Lancashire, 180 to 210 m. (600 to 700 ft.). In this district the pebbles are smaller and the quantity of associated sand greater].		Pebbly Sandstone, white. (Near Nottingham this deposit and the underlying sandstone are only 90 m. (300 ft.) thick, but near Selby 190 m. (620 ft.). The pebbly sandstone dies out between Selby and Knaresborough.)	(The pebbly sandstone of the Nottinghamshire and South Yorkshire district has disappeared.)
	(Presumably not represented.)	Lower Mottled Sandstone. Sandstone, reddish-brown but sometimes bright-red, yellow and striped or variegated, much current-bedded. Thickest at Bridgnorth 200 m. (650 ft.). (Practically limited to Staffordshire, Shropshire, Cheshire, South Lancashire and the Vale of Clwyd, being overlapped by the Pebble-Beds to the northward, eastward and southward.)	Red clays and shales with beds of gypsum and rock-salt: 30 to 90 m. (100 to 300 ft.).	Lower Mottled Sandstone, orange-coloured: 8 to 30 m. (25 to 100 ft.).	Red clays etc., as in the N. W. District: 60 to 140 m. (200 to 450 ft.).

SUBDIVISIONS OF THE KEUPER SERIES.

	South-Western District.	Midland District.	Cheshire and Lancashire.	Nottinghamshire.	Yorkshire.	Carlisle.
KEUPER SERIES.	Grey and Tea-green Marls. Red and variegated marls with gypsum and pseudomorphs of salt, and thin sandstone layers in the lower 45 m. (150 ft.); 350 m. (1150 ft.). (At Lyme Regis a boring proved 400 m. (1300 ft.) without reaching the base.)	Teagreen Marls red and variegated marls. Arden Sandstone *Estheria minuta* 6 to 9 m. (20 to 30 ft.) Red and variegated marls with gypsum and rock-salt. Total thickness in Shropshire, 450 to 550 m. (1500 to 1800 ft.); Staffordshire, 210 to 240 m. (700 to 800 ft.); Warwickshire and Leicestershire 180 m. (600 ft.) and less.	Tea-green Marls. Marls with layers of gypsum and beds of rocksalt 20 to 30 m. (70 to 100 ft.), worked at Northwich: over 600 m. (2000 ft.).	Tea-green Marls. Red and variegated marls with gypsum passing down into the sandstones mentioned below.	Tea-green Marls. Red and variegated marls: 120 m. (400 ft.).	Tea-green Marls. Red marls with gypsum: 290 m. (1000 ft.).
	Red and grey sandstone with seams of marl, and breccia 0.6 m. (2 ft.) thick at the base: 23 m. (75 ft.).	Where fully developed: a. Sandstone locally called "Waterstones" and containing Labyrinthodont remains. b. Sandstone, fine-grained, useful for building - purposes, c. Sandstone, coarse with breccias and cornstones: total 180 m. (300 ft.)	a. Waterstones. Brown micaceous sandstones with red and grey shales at the base (at Liverpool 60 m. — 200 ft.). b. Sandstone, red white and yellow quarried for building-stone. Rich in foot-prints: 60 m. (200 ft.). c. Conglomerate: 120 m. (400 ft.).	Sandstones soft, brown with dessication-cracks, ripple-marks and conglomerate at base resting sometimes upon White Sand with occasional pebbles and at others directly and unconformably upon an eroded surface of the Bunter.	Sandstones, red and white passing down into the Bunter Sandstone: 60 to 90 m. (200 to 300 ft.).	Kirklinton Sandstone: 150 m. (400 ft.).

The geographical distribution of the Upper Mottled Sandstone indicates the steady extension of the Bunter area of accumulation.

In Nottingham a slight uplift appears to have taken place in closing Bunter times, for the Upper Mottled Sandstone is said to be lacking and the irregular development of the basal Keuper rocks also points to a non-sequential relationship between Keuper and Bunter.

The geographical distribution of the Keuper Sandstone testifies to the continued extension of the Triassic area of accumulation and the Keuper Marls to a still greater.

At present opinions are divided as to whether the Keuper Marls were formed mainly under inland sea or mainly under desert conditions (Beasley 1906; Bosworth 1908, 1912; Lomas 1907); but probably the nearest present-day parallel is to be found in the Salt-Lake district of Utah.

b. Scotland.

By P. G. H. Boswell.

The Triassic rocks, which are probably of Keuper age, occur in three areas of Scotland. In the southern part seven small tracts are met with, (Dumfriesshire, Wigtownshire, Ayrshire, and Isle of Arran) lying unconformably upon older rocks. The supposed Triassic rocks consist chiefly of unfossiliferous red sandstones, in early times referred to the Trias, later to the Permian, but now once more by general opinion to the Trias. The table compares the general succession of the beds here with that in the northern Scottish localities.

Southern Division.	Eastern Division.	Western Division.
Thin bedded sandstones with beds of clay 90m. (300 ft.)	Concretionary cream coloured limestones passing into chert etc. (= cherty rock of Elgin) 4 m. (13 ft.)	Soft reddish argillaceous and sandy beds, conglomerates and cornstones, with gypsum 60 m. (200 ft.)
Massive breccias and conglomerates 90 m. (300 ft.)	Yellow and light coloured sandstone, lacustrine ? (= Elgin reptiliferous sandstone) 15 m. (50 ft.)	Red and variegated clays and marls, with cornstones 60 m. (200 ft.)
Soft red current bedded sandstones, and breccias 150 m. (500 ft.)		Coarse breccias and conglomerates, matrix calcareous 150 m. (500 ft.)

It is possible that only the upper breccias and sandstones are of Triassic age, the lower beds perhaps representing the Penrith sandstone of Permian age. In the southern part of the Island of Arran a considerable area of these red sandstones is found, they are underlain by conglomerates, and are succeeded by red shales and marls. A clue to their age was given by the investigation of an agglomerate filling a Tertiary volcanic neck here, large masses of the sedimentary rocks surrounding the volcano at the time being preserved in the tuff, while denudation destroyed the upper portion of the rocks. One such mass showed a succession of strata from the red marl through Rhætic shales to Lower Lias.

On the western coast of Scotland small exposures of Triassic rocks occur at the base of the Jurassic in the islands of Skye, Raasay, and Mull, and on the mainland at Morvern and Ardnamurchan (Argyleshire) and at Gruinard Bay in Rosshire. The general succession according to J. W. Judd (1878) is indicated in the table. The beds of this area are of rather a different type, being characterised by the calcareous element present. The occurrence of gypsum in occasional layers of marl associated with concretionary limestones in Mull is noteworthy, but no rock-salt has yet been found. Some casts of *Cyrena (?)* have been met with in sandstones in Morvern.

On the eastern coast of Scotland two small patches of Trias are found, on each side of the Moray Firth, one in Sutherland, near Dunrobin Castle, and the other in Elginshire. The series is similar at each locality but the sandstones of the latter locality, first thought to be part of the Upper Old Red Sandstone upon which they rest, have acquired considerable importance on account of the reptilian fauna yielded by them. The fauna of the lower portion is most nearly allied to that of the Karroo Beds of South Africa, Texas and Russia. The upper beds (Lossiemouth Beds) contain an undeniably Triassic fauna, e. g. *Telerpeton elginense*, *Hyperodapedon gordoni*, *Stagonolepis robertsoni*, *Ornithosuchus woodwardi* etc. (HUXLEY 1859, NEWTON 1877, 1893, 1894, WATSON 1909). The deposits of this eastern area were probably laid down in a fresh-water lake, and JUKES-BROWNE (1911) considers it likely that its outlet was by way of an outflowing stream entering the western basin, which probably became saline in later Keuper times. The age of the southern deposits is too doubtful to permit speculation upon the Triassic geography of the area.

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c. Ireland.

By G. A. J. Cole.

The continental type of Trias, common in England, must have prevailed over a large part of Ireland; but long-continued denudation has removed the deposits from all but the north-east area. An important outlier, capped in part by basalt, and resting on Upper and Lower Carboniferous strata, occurs between Carrickmacross and Kingscourt near the Monaghan border. Here both the Bunter sandstone type and the Keuper marls are represented. At the southern end of this outlier, the latter contain a bed of gypsum nearly 20 m (65 ft.) thick, which bas been worked from time to time commercially.

Red Triassic sandstone, with thin greenish partings of clay, have been protected by basalt at Scrabo Hill, west of Newtownards in Co. Down. The rock has been quarried as building-stone, though it is rather friable. Great Kainozoic dykes and sheets of basalt penetrate the strata, and a cap of basalt occurs, which may be part of a former sheet (Mem. Geol. Survey 1904). Throughout northern Ireland, indeed, the easily denuded Triassic deposits probably owe their preservation to a covering of basalt, even though this has now in some cases disappeared. At Scrabo, the bedding of the sandstones is very distinct, the parting of the strata being assisted by the occasional layers of clay. In these layers, ripple marks, suncracks, and rain-prints are abundantly preserved; but no fossils have been found.

From Scrabo, a thin strip of sandstone runs westward, to connect the outlying mass with a considerable area in the Lagan valley. The lowest beds near Belfast, found only in borings, are marls; and above them are sandstones which have been correlated with the St. Bees Sandstone of north-west England (Mem. Geol. Survey Ireland, 1904).

Hence the marly part of the lower series, at any rate, may be of Permian age. The Bunter is represented by sandstones with a few pebble-beds; and the overlying red and greenish grey marls and shales often contain gypsum, and are no doubt of Keuper age. At Carrickfergus and Kilroot, north-east of Belfast, beds of rock-salt occur in the marls, one bed being 30 m. (100 ft.) thick.

Red Triassic strata appear frequently on the margins of the basaltic plateaus of Antrim and Londonderry, and are therefore presumed to underlie a very large tract of country. They were denuded away before Cretaceous times in the Dalradian area south of Ballycastle, but are conspicuous on the steep slopes of Murlough Bay, where they rest on Lower Carboniferous sandstones. East of Limavady and Dungiven, they form, as they do near Belfast, gentler and sloping country at the foot of forbidding basaltic cliffs. Farther south, at Moneymore and Cookstown, the red soils formed from their broad outcrop are a feature of the lowland under Slieve Gallion. A considerable outcrop remains south of Dungannon, stretching towards Caledon. In this area, *Estheria minuta* (= *portlocki*) and the fish *Palaeoniscus* have been found (Baily 1877).

The continental type of Triassic deposits is the only one found in Ireland. Arid conditions probably prevailed through part of each year, while copious but merely seasonal rains spread pebbles at intervals over the plains. The lakes and pools of the "vlei" type, that were established here and there, were liable to sudden extensions over their low shores, and then shrank back again in times of desiccation. The stratification and ripple-marking of the Scrabo Hill sandstones and muds, associated with sun-cracked surfaces, point to these alternations of overflow and retreat. The deposits of gypsum and rock-salt indicate the general dryness of the climate.

Economic Products.

Rock-Salt. Beds of rock-salt are mined in the Triassic marls near Carrickfergus on Belfast Lough. At the Duncrue mine, one bed is 25 m. in thickness.

Gypsum. Gypsum occurs in small layers and veins in the Triassic marls near Belfast, and in a considerable bed in similar strata in an outlier near Carrickmacross in Co. Monaghan (p. 206).

Clays. The Triassic clays are used for brickmaking near Carrickmacross and Belfast.

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9. Rhætic.

a. England and Wales.

By LINSDALL RICHARDSON.

The Rhætic Series extends all across England from the Devonshire to the Yorkshire Coast. The beds crop out at or near the top of a small ridge, which is, however, very well-marked except in the neighbourhood of Chard, where their outcrop is concealed by the Cretaceous rocks, in the neighbourhood of the Mendip Hills, where they frequently assume a littoral facies, and in portions of certain Midland Counties, where they are buried beneath a thick accumulation of Drift. In advance of the main escarpment are several others, notably at Berrow Hill, near Tewkesbury, (RICHARDSON 1905); Knowle near Birmingham; Needwood Forest and north of Abbots Bromley, near Burton-on-Trent; Whitchurch, near Market Drayton; and probably near Carlisle.

In Gloucestershire and counties further north the Tea-green Marls are succeeded at once by the well known black Pteria contorta Shales. The line of demarcation between them is very sharply-defined and not infrequently there are signs that the top-portion of the Tea-green Marls was eroded previous to the deposition of the succeeding Black Shales. The reason for this sudden change in the lithic characters is apparent when the Upper Keuper and Rhætic Beds of the south-western Counties and Glamorganshire are studied. There the Tea-green Marls are succeeded by what ROBERT ETHERIDGE, Sen. (WOODWARD 1904), called the "Grey Marls" — marls and marlstones of various shades and combinations of the colours green, grey, brown and black.

Sully Beds. — On the Bristol-Channel littoral, on the Somerset side in the neighbourhood of Lilstock and Watchet and on the Glamorgan side around Sully, the uppermost 4 m. (14 ft.) of these Grey Marls contain fossils that link them with the succeeding Contorta Shales. To these rocks the term "Sully Beds" has been applied and while for cartographical purposes they may be associated with the Keuper, for scientific purposes they must be regarded as Rhætic. It was from these beds near Watchet that BOYD DAWKINS obtained teeth, which proved to belong to the oldest known British mammal, *Microlestes*, along with specimens of *Chlamys valoniensis*, *Protocardia rhaetica*, etc. (DAWKINS 1864.)

Lilstock, near Watchet, is an excellent place for studying these Sully Beds; while at the type-locality, Sully, they contain in abundance *Ostrea bristovi* RICHARDSON and specimens of *Pteria* (*Avicula*) *contorta* PORTLOCK, the teeth of *Sargodon*, *Lepidotus*, etc.

But although the gap between the Tea-green Marls and the Rhætic Black Shales is to a considerable extent bridged over on the Bristol-Channel littoral, there is still a non-sequence between the Sully Beds and Black Shales. The surface of the former was considerably channelled previous to the deposition of the latter, and in places, as at Goldcliff, near Newport, sand with vertebrate-remains was washed down into holes which were possibly made by percolating water (RICHARDSON 1905).

Westbury Beds. — These beds, or the Contorta Shales, extend all across England; but they vary considerably in thickness from place to place. Between the English Channel and Stratford-on-Avon hard bands are of common occurrence in the shales; but between that town and the Yorkshire Coast they are the exception. At Lilstock, in West Somerset, the Westbury Beds are 9.6m (32 ft.) thick (RICHARDSON 1911) in the railway-cutting at Chilcompton, near Radstock, 2 m. (6 ft. 6 inch.); while in places near the Mendips they are represented in part by conglomerates only a few inches thick. Interesting deposits, teeming with vertebrate-remains, lie horizontally upon the upturned Carboniferous Limestone near the viaduct north of Shepton Mallet, fill up fissures in the Limestone in the picturesque neighbourhood of Holwell, and, markedly conglomeratic, crop out in the sides of the lanes near Butcombe — a locality between the Mendip Hills and Broadfield Down. In Vallis Vale, near Frome, some of the thin layers of black shale are rich in the remains of *Pollicipes* and *Chiton* (MOORE 1861) and most of the limestone-pebbles in a thin conglomerate are bored by a species of *Polydora* (BATHER 1909). In the Bridgend-Pyle district of Glamorganshire the Westbury Beds are largely replaced by sandstone, which is extensively worked at the Quarella Quarries for building-stone, and at Pyle is rich in specimens of *Natica pylensis* TAWNEY (TAWNEY 1865).

The Contorta Shales in this country are separable into two portions: an upper, in which mollusks predominate, being particulary noticeable in two impure limestone-beds called "*Pecten*-Beds"; and a lower, in which vertebrate-remains preponderate, occurring principally in layers called "bone-beds". In the neighbourhood of the junction-line between these two subdivisions in the South-West of England is a thin layer which is particularly rich in specimens of *Pleurophorus elongatus* MOORE and small gastropods. It is probably the bed that was pierced in the making of the canal near Beer Crocombe, pieces of which rock yielded to MOORE so unique a series of fossils. MOORE (1861) called the bed the "Flinty Bed". It occurs at between 0.3 and 0.6 m (1 and 2 ft.) above the layer which is richest in vertebrate-remains, including *Ceratodus* teeth — the layer which is known as the Bone-Bed. In certain parts of Gloucestershire (RICHARDSON 1903) and Worcestershire (RICHARDSON 1904), however, this Bone-Bed has passed laterally into a non-vertebratiferous sandstone, which has relatively speaking, greatly increased in thickness (RICHARDSON 1903). In West Somerset and Monmouthshire *Cardium cloacinum* is a useful zonal fossil, particularly fine specimens occurring in a limestone-bed near the top of the Black Shales.

It has been found that, while the component layers of the Westbury Beds above the Bone-Bed are persistent over large areas, the same cannot be said of those below. They appear and disappear in an at first sight inexplicable matter. Thus at Blue-Anchor Point there is 6.6 m. (22 ft.) of deposit between the Bone-Bed and Sully Beds. They contain hard beds, some of which are rich in a number of rare lamellibranchs — *Pteromya crowcombeia* MOORE, for example. The Wedmore Stone is one of these sub-Bone-Bed Rhætic limestones, which, near the historic country-town whence it derives its name, is sufficiently thick and hard to have been worked for building-purposes. At Aust Cliff, the Bone-Bed — which contains rolled pieces of Tea-green Marl — rests directly and non-sequentially upon the Tea-green Marls; at Garden Cliff 2 m. (6 ft. 5 inch.) of deposit intervenes; at Denny Hill, near Gloucester, it reposes directly on the Tea-green Marls again (PARIS 1904); at Dunhampstead, in Worcestershire, 1.25 m. (4 ft. 1 inch.) of deposit intervenes; at Marl Cliff on the borders of Worcestershire and Warwickshire, 0.6 m. (2 ft.) (RICHARDSON 1903, 1904); while at Wigston in Leicestershire, Bone-Bed and Tea-green Marls are again in apposition (RICHARDSON 1909).

It has been suggested that this irregular geographic distribution of the sub-Bone-Bed Rhætic deposits is due to the surface of the marl having been flexured in closing Keuper times and deposition being subsequently made in the hollows so that each successive bed has an increasingly wide extent (RICHARDSON 1904).

A detailed study of the Westbury Beds suggests that their accumulation was slow and that the aggregation of vertebrate-remains was due, not to any sudden killing-off of countless fish and reptiles, but rather to paucity of sediment.

Cotham Beds. — The top-beds of the Contorta Shales in places exhibit features indicative of incipient crust-oscillations. These crust-oscillations rapidly produced conditions suitable for the formation of beds totally distinct from the Black Shales, namely, to a series of greenish-yellow marls and limestones with the curious but well-known Cotham Marble, with its arborescent markings, at or near the top. Ostracods abound in the marly beds that immediately underlie a limestone which is locally rich in *Estheriae* (*E. minuta* var. *brodieana* JONES, and plant-remains (*Lycopodites*), (SOLLAS 1901); while the Cotham Marble or its equivalent is locally prolific in specimens of *Pseudomonotis fallax* auct. and insect-remains — the "Insect Bed" of BRODIE (1845).

The Cotham Beds, like the underlying Westbury Beds extend all across the country and are quite distinct from the Langport Beds or White Lias proper. The Cotham Beds were formed slowly. The Cotham Marble has a curiously irregular surface, is occasionally bored by *Lithophagi*, and at Aust and Sedbury Cliffs was broken up and its tabular fragments enclosed in a very similar matrix to that of the fragments themselves (VAUGHAN 1903). This conglomeratic marble has been called "False Cotham" (SHORT 1904).

Langport Beds. — These beds, or the White Lias proper, are an interesting series of white, pale-grey and cream-coloured limestones with decidedly subordinate partings of marl. The top-bed is often of sufficient thickness and hardness to have gained a distinctive appellation — generally the "Sun-Bed" in Somerset north of the Mendip Hills and "Jew Stone" to the south. The beds are particularly rich in specimens of *Dimyodon intus-striatus* EMMR. (GRÖNWALL 1906) and in the south-western counties, in *Volsella minima* MOORE non SOW., and *Lima praecursor* QUENSTEDT. In the railway-cutting at Charlton Mackrell, Somerset, they are 6 m. (20 ft.) thick; but even here, where the subdivision is so thick, the individual limestone-beds are often irregularly channelled, sometimes bored, and not uncommonly have oysters and *Plicatulae* adherent to their surfaces. Ostracods are not infrequent, and in the neighbourhood of Charlton Mackrell a branching coral is abundant near the middle of the subdivision.

The White Lias is well-developed at Culverhole in Devonshire (RICHARDSON 1906), and in Mid and East Somerset (WRIGHT 1860); but in West Somerset and Glamorganshire it has attenuated and in South Gloucestershire died out altogether — the Cotham Marble and Ostrea Beds being in apposition near Wickwar. Near Stratford-on-Avon, however, the White Lias reappears (RICHARDSON 1912) and is continuous northwards to somewhere between Church Lawford and Wigston in

Leicestershire, apparently then disappearing not to reappear in the more northern counties (WILSON 1882). In times past, in Warwickshire, the stone has been extensively worked for road-metal and for burning for lime. The subdivision in this county does not exceed 3 m. (10 ft.) in thickness and is characterized by an abundance of specimens of *Dimyodon intus-striatus* and radioles of the echinoid *Diademopsis tomesi* WRIGHT. The surface of its top-bed is often very ferruginous, waterworn and sometimes bored and is immediatily succeeded by the Lower Lias.

Watchet Beds. — In West Somerset and Glamorganshire, above the true White Lias are certain marly beds to which the term "Watchet Beds" has been applied. They are immediately succeeded by the Lower Lias.

Table. — Rhætic Series.

Series	Stage	Deposits		Approximate thickness in England	Sequence of the maxima of the principal fossils of the Rhætic
Lias	Lower	Paper Shales (and occasional limestone at base)		0.3 m. (1 ft.)	*Volsella*
Rhætic	Upper	I. Watchet Beds ('Marly Beds of the White Lias')		2.31 m. (7 ft. 7 inch.)	*Volsella* & *Ostrea liassica*
		II. Langport Beds (White Lias proper)		0 to 7.5 m. (25 ft.)	*Ostrea liassica* *Volsella minima* (MOORE non Sow.) *Dimyodon intus-striatus*
		III. Cotham Beds	1. Cotham Marble	0.83 m. (2 ft. 9 inch.) to 5.8 m. (19 ft.)	*Pseudomonotis fallax*
			2.		Ostracoda
			3.		*Estheriae* & *Lycopodites*
			4.		Ostracoda common below Bed 3
	Lower	IV. Westbury Beds (Black Shales)	5a.	0.3 m. (1 ft.) to 14 m. (47 ft.)	
			5b. Cardium cloacinum Bed[1]		*Cardium cloacinum* *Actaeonina* & *Natica oppeli*
			6.		
			7. Pecten Bed[2]		*Chlamys valoniensis*
			8.		*Ophiolepis damesi*
			9.		
			10.		
			11.		
			12.		
			13. Pleurophorus Bed		*Pleurophorus elongatus*, '*Chemnitzia*' spp., *Heterastraea rhaetica*
			14.		Relatively barren
			15. Bone-Bed Infra-Bone-Bed deposits		*Ceratodus latissimus* *Mytilus cloacinus* Vertebrate-remains (*Acrodus minimus*, etc.)
		V. Sully Beds (Fossiliferous Grey Marls)		0 to 4.3 m. (14 ft.)	*Ostrea bristovi*
Keuper	Upper	Grey and Tea-green Marls Red Marls		about 3.3 m. (11 ft.) to 35 m. (115 ft.)	

[1] Or Upper Pecten Bed.
[2] Or Lower Pecten Bed.

The **Ostrea-Beds** of the Lower Lias extend right across England. At Culverhole, near Lyme Regis, they rest upon the White Lias; in Mid and East Somerset generally upon the White Lias, whose top-bed — Sun Bed or Jew Stone — is often waterworn and considerably bored; in West Somerset and Glamorganshire upon the Watchet Beds; at Sedbury and Aust Cliffs and in North Gloucerstershire and Worcestershire upon the Cotham Beds; in Warwickshire upon the White Lias, and in counties to the north upon the Cotham Beds — the subdivision, certain layers of which, contain *Estheriae*.

Except for the road-metal, lime and local building-stone yielded by the true White Lias and the Quarella Sandstone of Bridgend, the Rhætic Beds are not productive of anything of commercial value.

The principal sections of the Rhætic Beds in England are: Culverhole, near Lyme Regis; Blue Anchor and Lilstock in West Somerset; Dunball railway-cutting, near Bridgewater; quarries near Queen Camel; Milton Lane, Wells; Holwell and Vallis Vale, near Frome; railway-cutting, Chilcompton; Aust, Sedbury (RICHARDSON 1903), Garden and Wainlode Cliffs on the Severn; Crowle and Dunhampstead railway-cutting, in Worcestershire; quarry in the White Lias near Ettington, Warwickshire; and Wigston, near Leicester. In Glamorganshire there is the fine and very accessible section at Lavemock Point, the exposure of the Sully Beds at St. Mary's Well Bay, Sully; and the interesting sections in the sandstones on Stormy Down and at Pyle.

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b. Scotland.

By P. G. H. BOSWELL.

Except for the masses of Rhætic and Lower Lias rocks found in the volcanic agglomerates of Arran (mentioned under Scottish Triassic Rocks), the occurrence of these beds is confined to small areas on the east and west coasts of Scotland. The table on p. 237 gives a general comparison of the two areas with one another and with the corresponding deposits in England.

Undoubted Rhætic black fossiliferous shales occur in association with Keuper Marls and Lower Lias beds in the neck of a Tertiary volcano in Arran.

On the eastern coast of Scotland, near Dunrobin Castle in Sutherlandshire, coarse sandstones and conglomerates lie upon rocks similar to the Elgin sandstones and cherts (Trias), and contain fragments and pebbles of the latter. JUDD regards these as probably of Rhætic age, and it is noteworthy that masses included in the Boulder Clay on the South side of Moray Firth contain fossils similar to those of the Scanian Rhætic. In the Western area (islands of Skye, Mull, etc.) it is not possible at present to separate the Rhætic from the Lower Lias (zone of *A. planorbis*). In the Summary of Progress of the Geol. Survey for 1910, a section on the mainland at Morvern is recorded where nearly 100 m. (320 ft.) of Triassic sandstones and pebble beds, with marls and cornstones near the top, pass into white calcareous sandstones, which in turn pass into Lower Lias of the b u c k l a n d i zone. Thus there is a complete transition through the Rhætic, but such fossils as occur are not zonally determinative.

Lying above the Triassic strata of Skye and Mull JUDD (1878) describes 120 m. (400 ft.) of oolitic limestones, calcareous grits and conglomerates, with seams of coal, as Infra-Lias, the upper part of this series being equivalent to the p l a n o r b i s zone of the Lower Lias. The western facies then shows a prevalence of littoral and brackish-water conditions, a distinctly transitional phase.

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c. Ireland.

By G. A. J. COLE.

The beds of the Rhætic stage, have been preserved in several places, connecting with perfect conformity the Triassic and the Lower Jurassic strata (TATE 1863, 1864). It is probable however, that the Rhætic overflow, which heralded the arrival of the Jurassic sea, did not spread far westward of Lough Foyle. The Rhætic series in Co. Londonderry is not completely seen, and its thickness is uncertain. *Avicula contorta* marks these beds throughout north-eastern Ireland. At Larne they contain concretionary spheroids which resemble an oolitic structure. There is also a well known section at Collin Glen four miles south-west of Belfast, now somewhat obscured. *Pteria* (*Avicula*) *contorta*, *Protocardia rhaetica*, *Modiola minima*, and several fish, are among the fossils recorded. With the Rhætic subsidence, and the spread of the sea as far west as Londonderry, a more humid climate doubtless set in; but the conditions on the land must have depended greatly on whether the prevalent winds blew from the north-western continent or from the great sea that had now asserted itself across central Europe.

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10. Jurassic.

a. England and Wales.

By A. M. DAVIES.

I. The Lower Jurassic or Lias.

The term "Lias", so familiar to geologists as the name of the Lower Jurassic series, is an old quarryman's term for a hard limestone, still applied locally to beds of various ages. The presence of thick beds of "white Lias" and "blue Lias" in Gloucestershire and adjacent counties led WILLIAM SMITH and other early stratigraphers to adopt "Lias" as the name of that geological horizon, and gradually the term was stretched to cover higher and higher beds. First, the clays overlying the Blue Lias were included, the strata next above these being for a time confused with the Inferior Oolite. When this mistake was rectified, it was done by throwing into the Lias all the beds below the true Inferior Oolite, the limestones and ironstones that had been mistaken for the latter receiving the inappropriate name of Marlstone. Thus came about the triple division of the Lias still recognized on the Geological Survey map—Lower Lias limestones and clays (**g** 1) Middle Lias or Marlstone (**g** 2) and Upper Lias clays (**g** 3).

The recognition of the Rhætic stage (**fg**) below led to the removal of the White Lias from the "Lias" as extended; while at the top a series of sandy beds were taken as a transition series between Lias and Inferior Oolite, and mapped as Midford Sands (**g** 4).

Zonal work, initiated by WILLIAMSON in 1834, extended by OPPEL, WRIGHT, TATE and BLAKE, BEEBY THOMPSON, S. S. BUCKMAN and others, has led to modifications of the above scheme. The zonal palæontologists drew the base-line of the Middle Lias below the armatum-zone; but this being an unmappable line in the midst of a clay-series the Survey extended the Lower Lias to the top of the capricornus-zone, their Middle Lias being thus equivalent to the Domerian stage of the Italians, while their Lower Lias is equivalent to Hettangian, Sinemurian and Pliensbachian or Charmouthian (in the restricted sense, after deducting Domerian). The zonal work of BUCKMAN showed that the change from Upper Lias Clay to "Midford Sands" was not contemporaneous in different places, and he therefore insisted on the necessity for using distinct local names for these sands. The Upper Lias and Midford Sands proper correspond to the Toarcian stage, though locally the sandy facies extends upwards into the Aalenian. Owing to the large number of zones in the Toarcian, BUCKMAN has lately (1910) proposed to divide it into a lower Whitbian stage, corresponding approximately to Upper Lias clays, and an upper Yeovilian, answering approximately to Midford Sands. A list of zones is given in the accompanying tables (p. 235—237).

A. Lower Lias (Hettangian, Sinemurian and Charmouthian).

These formations crop out along a band from the coast of Dorset at Lyme Regis and Charmouth, to the coast of Yorkshire at Whitby, and through the greater part of this course they show very uniform characters — excepting only in the neighbourhood of the anticlinorium of the Mendip Hills. They consist of alternating beds of grey argillaceous limestone and grey shale, below, and of grey shale with only occasional bands of limestone above. The Blue Lias, in which limestone is as common as shale or predominates over it, corresponds to the Hettangian and bucklandi-zone of the Sinemurian. The limestones are largely worked for hydraulic cement, both on the coast, as at Lyme Regis and Aberthaw in South Wales, and inland, as at Harbury and Rugby in Warwickshire, Barrow-on-Soar in Leicestershire, and many other places. Northwards, however, the limestone becomes very much less in amount, and in Yorkshire these beds are of no value for hydraulic cement. In addition to the zonal ammonites, many fossils are obtained from the Blue Lias, particularly *Gryphaea arcuata* LAMARCK, *Plagiostoma giganteum* J. SOWERBY, *Cardinia listeri* J. SOWERBY and other species, *Pleurotomaria anglica* SOWERBY, *Belemnites acutus* MILLER, *Pentacrinus basaltiformis* MILLER, *Ichthyosaurus communis* CONYBEARE etc. Brachiopoda are not abundant, but *Rhynchonella calcicosta* QUENSTEDT is found in the marmorea-zone and *Spiriferina walcotti* SOWERBY abounds in the gmuendense zone of Radstock.

The semicostatum or turneri zone at the top of the Blue Lias is not usually distinguished from the zones above and below, but from the Vale of Belvoir in Leicestershire northwards to the Humber, it has the character of a very ferruginous limestone passing into an ironstone which supports large iron and steel works at Frodingham in Lincolnshire.

The clays and shales from the oxynotus zone up to the capricornu zone are fairly uniform in character, except that the oxynotus zone is generally more pyritic. These clays make good bricks and there are many openings into them at intervals along the outcrop, but the workings are much shallower than those into the Blue Lias below; hence their thickness and characters are less known, except on the sea-coast. Among the fossils characteristic of the Sinemurian clays are *Pentacrinus briareus* MILLER, *Cardinia* spp., *Hippopodium ponderosum* SOWERBY, (a senile form of *Cardinia*) and *Pleurotomaria anglica* SOWERBY. In addition to the zonal ammonites, there may be mentioned *Xipheroceras planicosta* J. SOWERBY, enormous numbers of which, along with a few examples of *Asteroceras smithi* J. DE C. SOWERBY make up a bed of limestone in the obtusum zone. A separate stellare-zone can be recognized at Lyme Regis, with *Asteroceras stellare* SOWERBY; while at the base of the same zone, one characterized by *Microderoceras birchi* J. SOWERBY can be distinguished; but these zones are not traceable inland. The Charmouthian clays contain more abundant brachiopods than the beds below, *Cincta numismalis* LAMARCK and other species of *Cincta*, along with *Rhynchonella rimosa* VON BUCH and *Spiriferina verrucosa* VON BUCH being common in the jamesoni zone: it is in the abnormal facies of the Radstock area that brachiopods are most abundant, however. Other Charmouthian fossils are *Crenatula ventricosa* SOWERBY, *Goniomya hybrida* MÜNSTER, *Leda* spp., and *Belemnites clavatus* BLAINVILLE. In the neighbourhood of the series of anticlinal folds of Armorican direction which form the southern margin of the South Wales coalfield, the Lower Lias undergoes a very remarkable change, being reduced locally to less than one-tenth of its normal thickness. The zones become thinner and also more calcareous, and at the same time many breaks in the sequence of zones ("non-sequences") are found locally. Thus in South Wales, near Dunraven Castle, the Hettangian loses its argillaceous character and passes into massive and in part conglomeratic limestones, composed of material derived from the wear and tear of the Carboniferous Limestone. The upper part (Southerndown beds) is about 15 m. (50 ft.) the lower (Sutton beds) about 12 m. (40 ft.) thick, so that in this case there is little diminution of thickness. The Sutton beds include the only good building-stone in the Lower Lias: the fossils include nine species of corals. A very similar facies is found near Shepton Mallet in Somerset, close to the Carboniferous Limestone of the Mendip Hills.

It is in the neighbourhood of Radstock in Somerset that the most remarkable attenuation of the Lower Lias is seen. The folding movements of the Mendip Hills must still have been in progress, since the imperfections in the sequence are so many and so local. Thus either the armatum-zone (with remanié fossils from the raricostatum-zone) or the raricostatum zone rests upon obtusum or semicostatum-zone at Radstock, and directly upon Palæozoic at Vobster. The armatum or jamesoni-zone upon Palæozoic at Mells; the spinatum-zone upon Palæozoic at Whatley, though elsewhere Toarcian rests upon Charmouthian without any Domerian between[1]. At Nunney again, the whole of the Lias is missing, the garantiana-zone (Vesulian) resting directly on Rhætic or Palæozoic. Besides the absence of zones, individual zones in this district are thin, often from a few centimetres to a metre only in thickness; and they are mainly limestones and marls.

B. Middle Lias (Domerian).

The Middle Lias is fairly constant in character throughout England. The lower part (algovianum and margaritatus zones) consists of sandy micaceous clays; the upper part (spinatum zone) is a rockbed, usually forming a well-marked escarpment, and in several areas constituting a most valuable iron-ore. Among the fossils of the two lower zones are various species of *Amaltheus*. At the top of the clays, which perhaps represent the algovianum zone on the Dorset coast there is a starfish-bed with *Ophioderma egertoni* BRODERIP and *O. milleri* PHILLIPS. The spinatum zone is richly fossiliferous. Ammonites of the genus *Paltopleuroceras* occur, though not abundantly — *P. spinatum* BRUGUIÈRE etc. *Terebratula punctata* J. SOWERBY and *Rhynchonella tetraedra* SOWERBY occur in "nests" in enormous numbers. Other fossils include *Gryphaea gigantea* SOWERBY, *Pseudopecten aequivalvis* SOWERBY, *Rhynchonella acuta* J. SOWERBY, *R. media* J. SOWERBY, *Zeilleria cornuta* J. DE C. SOWERBY and *Z. subquadrifida* OPPEL.

The spinatum-zone or "Marlstone" yields the iron-ore of Cleveland in North Yorkshire, of which 6 million tons are raised annually, and that of Leicestershire and North Oxfordshire. Elsewhere it forms a good building stone, particularly in the fine escarpment of Edge Hill on the border of Oxfordshire and Warwickshire (Hornton Stone).

Resting upon the top of the Marlstone, in the district around Banbury only, is an extremely thin layer containing a very special fauna of which *Tiltoniceras acutum* TATE and *Dactylioceras holandrei* WRIGHT (non D'ORBIGNY) are the two chief species. This is known as the Transition-bed or acutum zone, and the only other representative of it known in England is in the bottom portion of the thin "Junction-bed" of Down Cliffs, Dorset, described below.

C. Upper Lias (Lower Toarcian).

This formation consists of grey shale or clay, with frequent septarian and other nodules. It is particularly well-exposed on the Yorkshire coast near Whitby, where the upper portion is very pyritous and, on decomposition, yields alum, while the lower portion contains beds with the hard, anthracitic form of lignite known as jet; hence the terms Alum-Shale and Jet-rock. Both these were of economic value for many years, but alum is now made more cheaply from Coal-Measure shales, or the by-products of coal-gas, while carved jet ornaments are no longer fashionable. Inland, the lower beds are often exposed in open workings for the marlstone iron-ore, and the top beds are dug for brick-clay, but the middle portion is rarely seen. On the Dorset coast, the whole of the Lower Toarcian and some of the zones above and below are represented by a remarkable junction-bed, less than 1 m. thick, in which four very distinct layers can be recognized: a brown layer with pebbles of lower beds (spinatum and in places acutum zone), a greenish layer (falciferum zone),

[1] Unpublished information from J. W. TUTCHER, Bristol.

a pink layer (bifrons zone) and a white layer (striatulum zone). All these are not always present, and the state of preservation of the fossils shows that throughout the whole period represented the small amount of sediment deposited was subject to erosion and reconstruction.

Among the characteristic fossils of the lower part of the Upper Lias (tenuicostatum to falciferum zone) are various species of *Dactylioceras* and *Harpoceras*, *Phylloceras heterophyllum* J. SOWERBY, *Nautilus astacoides* YOUNG and BIRD, *Belemnites vulgaris* YOUNG and BIRD, *Inoceramus dubius* SOWERBY, and *Posidonomya bronni* VOLTZ. The "Leptaena beds" of Somerset and Gloucestershire have yielded small species of the brachiopods *Cadomella* and *Koninckella*. The upper beds of the Upper Lias (the old bifrons zone) yield species of *Hildoceras*, *Dactylioceras*, *Peronoceras*, *Lytoceras* and *Phylloceras*, *Belemnites ilminstrensis*, PHILLIPS, and *Leda ovum* SOWERBY.

II. Middle Jurassic.

A. The Bridport, Yeovil, Midford and Cotteswold Sands and associated beds (Upper Toarcian).

Above the clays of the Upper Lias there usually come, in the South of England a series of fine yellow sands with bands and nodules of calcareous sandstone. These are mapped as Midford Sands (**g** 4), but as they begin and end at very different palæontological horizons in different areas, local names are very desirable. As the table (p. 235) shows, the change from clay to sand began earlier and earlier northwards. On the Dorset coast, the Bridport sands are partly Upper Toarcian and partly Aalenian. Inland, the Yeovil sands begin at the same horizon, but, owing to a non-sequence, only the Toarcian portion is present. The upper part of the Yeovil Sand passes locally into thick beds of shelly limestone, which include the much-valued and beautiful building-stone of Ham Hill.

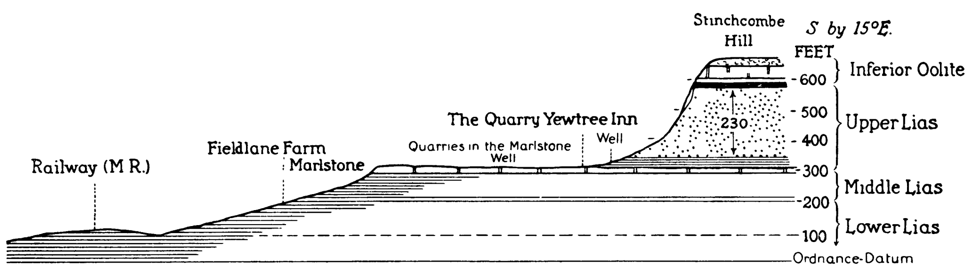

Fig. 40. Section across the escarpment at Stinchcombe, South Cotteswolds (L. RICHARDSON). Vertical scale, 1 inch = 400 feet; horizontal scale, 3 inches = 1 mile.
Reproduced from the Proceedings of the Geologists' Association, vol. 20, p. 528, pl. XXVIII, 1908; with the permission of the Council.
The principal division of the Inferior Oolite shown is the Lower Freestone; the greater part of what is indicated as Upper Lias is the Cotteswold Sands.

The Yeovil and other sands are easily eroded, but like other calcareous sands, they stand in good vertical faces; consequently their outcrop is marked by deeply-worn steep-sided lanes of very picturesque appearance.

Farther north, in the Bath district, the Midford Sands proper begin two zones earlier than the Yeovil sands and are likewise followed non-sequentially by much later beds (Vesulian — garantiana zone). Below the sands, is a thin "Cephalopod-bed", containing ammonites of four distinct zones: struckmanni, striatulum, lilli and bifrons. The Cotteswold Sands of Gloucestershire are of still earlier date than the Midford Sands (Lower Toarcian), and are overlain by thin beds of iron-shot limestone and marl (Cephalopoda-bed), which contain the whole Upper Toarcian in the thickness of little over 1 metre. These thin beds contain an abundant fauna of ammonites, lamellibranchs and brachiopods. It will be noticed that the term "Cephalopod-bed" refers to deposits of different age in different areas.

Beyond the Cotteswold Hills, no deposit of Upper Toarcian age is known until Yorkshire is reached. There the Alum Shale is succeeded by the striatulum-shales and the grey and yellow sands of Blea Wyke. The striatulum-shales contain *Grammoceras striatulum* Sow., *Belemnites voltzii* PHILLIPS, *Trigonia literata* YOUNG and BIRD, etc. The lower part of the grey sands contain nodules with *Lingula beani* PHILLIPS and *Orbiculoidea reflexa* Sow., while the upper part abounds in *Serpula deplexa* BEAN. The yellow sands are noted for the casts of *Terebratulae* generally known as *T. trilineata* YOUNG and BIRD. A very remarkable fact is the sudden disappearance of the whole of the Upper Toarcian on crossing the important Peak Fault from south-east to north-west. The probable explanation of this is that the fault was in process of growth during later Toarcian time, so that there was less deposition and more erosion on the upthrow side than on the downthrow.

B. The Lower Inferior Oolite, Northampton Sands and Lower Estuarine beds (Aalenian).

On the Dorset coast the lower zones of the Aalenian are represented on the coast by the upper part of the Bridport Sands; inland, they are altogether wanting. The upper zones consist of a thin and variable series of limestones, some beds of which are locally very fossiliferous and have for many years been famous for their ammonites. The same statement applies to the Bajocian and Vesulian beds above. Owing to the rapid local variation in thickness, in lithic character and in abundance of fossils, these strata were long united together under the general name of Inferior Oolite, with little attempt at distinction of zones, until the minute palæontological and stratigraphical work of BUCKMAN revealed the highly condensed character of the sequence (BUCKMAN, 1893, 1910). These characters are the result partly of paucity of sedimentation, partly of almost contemporaneous erosion. The variations in thickness of the zones are indicated in the table. In the Sherborne district there is a marked eastwardly thickening of the zones. Among the most characteristic fossils may be mentioned for the opaliniforme zone: *Rhynchonella stephensi* DAV., *Aulacothyris blakei* WALKER, *Zeilleria whaddonensis* S. BUCKMAN, *Canavariella* spp. For the Scissum-zone: *Lioceras opalinum* REINECKE, *Volsella sowerbyana* D'ORB. For the Ancolioceras zone: *Amusium personatum* GOLDF. For the murchisonae zone: *Zeilleria anglica* OPPEL and many ammonites of the family *Hildoceratidae* (sub-families *Hyatteinae* and *Graphoceratinae* of BUCKMAN). For the bradfordensis zone: *Rhynchonella ringens* DAV. and other ammonites of the same subfamilies. For the concava zone: *Ludwigella concava* Sow., and *Lucya marginata* S. BUCKM.

The concava zone is intimately associated with the overlying discites-zone, being in places welded on to it in the same block of stone. Nevertheless the boundary between Aalenian and Bajocian is drawn here by BUCKMAN, because, although Hildoceratids do not die out until the discites zone (and are still abundant in it), that zone contains the first representatives of the new ammonite fauna of the Sonniniae.

Thin calcareous representatives of the Aalenian are also known at Dundry Hill, near Bristol, but it is in Gloucestershire that the beds of this stage attain their greatest development, and here they include the valuable building-stones of the Stroud and Cheltenham district. Above the Cotteswold Cephalopod-bed come successively ferruginous oolite, sandy limestone, oolitic limestone (not of much value as building-stone) and "Pea-Grit". The last is a coarse pisolite with *Hemipedina bakeri* WRIGHT, *Acrosalenia lycetti* WRIGHT and other Echinids, *Terebratula pisolithica* S. BUCKMAN, *Rhynchonella oolithica* DAVIDSON and other brachiopods, lamellibranchs and gastropods; at the top is a Coral-bed.

Next above comes the Lower Freestone, a thick mass of oolitic limestone which includes the principal Cotteswold building-stones. This is followed by the Oolite Marl, characterized by *Terebratula fimbria* Sow., and also with a coral-bed at top; and this by the Upper Freestone, with *Rhynchonella tatei* DAV., not so extensively quarried as the Lower Freestone.

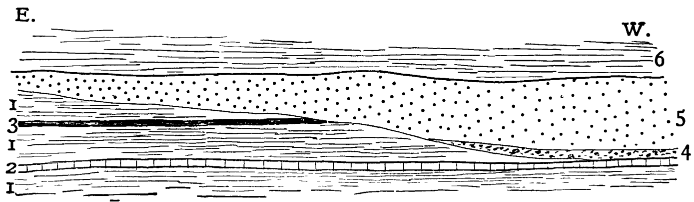

Fig. 41. Boulby alum-works, eastern quarry. (R. H. RASTALL.)

6 = Shale of the Estuarine Series
5 = Sandstone of the Estuarine Series;
4 = Conglomerate;
3 = Impure coal;
2 = Ironstone;
1, 1, 1 = Alum Shale.

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The brachiopod fauna of the Cotteswold Aalenian is strikingly different from that of Dorset — a fact that, in conjunction with the very imperfect development of the Aalenian in the intervening region, shows that movements of upheaval along the Mendip axis were still in progress, with the result that the northern and southern areas were separated. Dundry Hill, although on the northern side of the visible Mendip Hills, belongs to the Dorset province.

Eastwards from the Cotteswolds the Aalenian is also feebly developed, only the scissum-beds having any wide extension. In Oxfordshire, locally, scissum-beds are intercalated between the Vesulian *Clypeus*-grit and the Upper Lias (fibulatum-zone); but in Northamptonshire the marine Scissum-beds (Northampton Sands) are followed sequentially by an estuarine series of sands which represent some part of the upper Aalenian.

The Northampton Sands are divided into a lower Ironstone series, from which is obtained the valuable ironstone for the blast-furnaces of Kettering, Wellingborough and other places, and an upper variable series of sands and limestones. The Ironstone series has yielded many fossils, including *Lytoceras wrighti* S. BUCKMAN (*Amm. jurensis* auct.), *Lioceras opalinum* REINECKE, *Tmetoceras scissum* BENECKE, *Astarte elegans* Sow., etc. The variable series is but slightly fossiliferous.

The Lower Estuarine beds consist of very fine white or lightly-coloured sands, including beds full of vertical carbonized plant impressions, with some clayey beds used for terra-cotta manufacture.

In the Stamford district these beds are overlain by beds of highly-fissile sandy limestone, known as the Collyweston Slate, which is still much prized as a beautiful roofing-stone, being even exported to America. This represents the highest zone of the Aalenian, contains many fossils, including *Malaptera bentleyi* MOR. and LYC., *Gervillia acuta* SOW., and *Trigonia pulla* SOW. Estuarine beds with marine sands below continue onwards through Lincolnshire, but little detail is known about them, until the Yorkshire coast is reached. There both the Estuarine beds and marine sands, though in the same relative position, appear to belong to higher zones than in Northamptonshire. The marine sands are known as the "Dogger", a term having reference to the concretionary masses of sandstone which they contain.

Nerinea cingenda PHILLIPS and other gastropods, *Astarte elegans* SOW. and other lamellibranchs are found in the Dogger. The Dogger is much thinner on the west (upthrow) side of the Peak Fault than on the East, and rests directly on an eroded surface of the Alum Shale (L e d a o v u m beds) (see Figs. 41 and 42). The Dogger contains locally a bed of magnetic ore, formerly mined extensively at Rosedale, but now worked out.

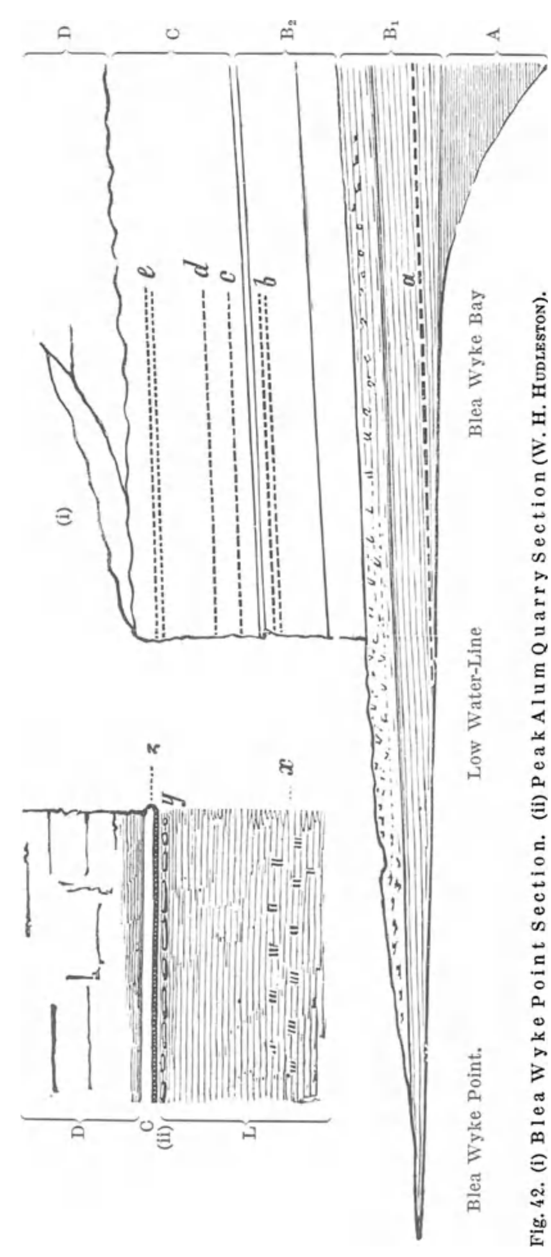

Fig. 42. (i) Blea Wyke Point Section. (ii) Peak Alum Quarry Section (W. H. HUDLESTON).

Explanation of (i).

A = Striatulum Shales. The little bay is hollowed out of these beds; B = Blea Wyke Beds, consisting of: B_1 = Grey Sands, 26 ft.; B_2 = Yellow Sands, 25 ft.; C = The Dogger, 33 ft.; D = The Lower Estuarine Beds; *a* = Main *Lingula* Bed; *b* = *Terebratula* Bed; *c* = Lower Nodule Bed; *d* = Upper Nodule Bed; *e* = *Nerinaea* Bed.

Explanation of (ii), Representing Contact of Oolite and Lias in Peak Alum Quarry, and Showing Rapid Thinning of Beds within half a mile. L = Alum Shale of Upper Lias; x = *Leda ovum* bed; *y* = Line of Clay Ironstone Nodules; C = Dogger, 3 ft., with *z*, Nodule Bed, at its base; D = Lower Shale and Sandstone.

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Above the Dogger come the Lower Estuarine beds — sandstones with upright *Equisetum columnare* BRONGNIART, shales, and occasional coal-seams. In part of Yorkshire they contain a marine intercalation, the Eller Beck bed, with *Astarte minima* PHIL., and *Gervillia acuta* SOW.

C. Middle Inferior Oolite and Middle Estuarine beds (Bajocian).

The Bajocian strata of Dorset resemble the Aalenian in their thinness and want of continuity. The uppermost zones in particular are largely wanting through late Bajocian denudation. In one famous quarry, long closed, a single bed, only 0.5 m. (2 ft.) thick, contained three zones, each with a distinct and abundant fauna, viz. sauzei, Witchellia and Shirbuirnia; and the fauna of the last-named is scarcely known from any other locality in England. Like the Aalenian, the Bajocian strata of the Sherborne district thicken to the east.

Characteristic of the discites zone are the earliest species of *Sonninia*, e. g. S. *(Euhoploceras) spinifera* S. Buckman and the last of the *Hildoceratidae*, e. g. *Hyperlioceras discites* Waagen; also *Belemnites blainvillei* Voltz, *Trigonia striata* Sow., *Rhynchonella forbesi* Dav., and *Terebratula cortonensis* S. Buckm.; of the post-discites zone, *Sonninia ovalis* Quenst. and *Astarte excavata* Sow.; of the Shirbuirnia zone, *Sonninia fissilobata* Waagen and many other of the Gingen ammonites; of the Witchellia zone, besides species of the index genus, *Emileia brocchii* Sow., and *Lima proboscidea* Sow.; of the sauzei-zone, *Otoites sauzei* d'Orb., *Sonninia propinquans* Bayle, *Astarte excavata* Sow.; of the blagdeni zone, *Poecilomorphus cycloides* d'Orb., *Sphaeroceras brongniarti* Sow., and *Teloceras blagdeni* Sow.; and of the niortense zone, *Strenoceras niortense* d'Orb., *Normannites braikenridgei* Sow., *Terebratula phillipsi* Morris and *Glossothyris curviconcha* Oppel.

Owing to the late Bajocian denudation and consequent overstep of the garantiana zone, Bajocian beds are not again found until Dundry Hill, near Bristol, a famous fossil-locality. Here the discites and post-discites zones are represented by grey limestones, 0.4 m. (1 ft. 4 in.) thick, and the Shirbuirnia, Witchellia and sauzei-zones by ironshot oolites, respectively 0.475 m. (1 ft. 7 in.), 0.35 m. (1 ft. 2 in.), and 0.3 m. (1 ft.) thick. Higher Bajocian zones are wanting.

In the Cotteswolds, the Bajocian strata are limestones, for the most part inferior as building-stones to the Aalenian "freestones", and known as "ragstones", with some sandy beds. The several "grits" in this and the Vesulian series are misnamed, being fragmental limestones, not arenaceous. The Lower Trigonia grit receives its name from the abundance of *Trigoniae*, such as *T. sculpta* Lycett and *T. striata* Sow. The Gryphite Grit is marked by the presence of *Gryphaea sublobata* (auct. non Deshayes). The beds higher than the Gryphite Grit are restricted in geographical distribution, and indeed the whole of the Bajocian strata may be locally absent,for they were thrown into a series of gentle folds and planed down to a level surface before the deposition of the basal beds of the Vesulian. The separation of the Cotteswold and Dorset areas, as shown by the distinctness of the brachiopod-faunas, continued through the Bajocian age as in the Aalenian.

From the Cotteswolds, no Bajocian strata are found until Northamptonshire and Lincolnshire, where the beautifully oolitic Lincolnshire limestone is found, yielding famous building-stones at Ketton, Stamford, and elsewhere. The limestone attains considerable thickness, only some beds being suitable for building-stone, while others make good lime. Probably several zones, from discites upwards, are present, but fossils are not abundant, and ammonites and brachiopods are very scarce, so that much zonal research remains to be done. *Nerinaea cingenda* Phillips, *Ceromya bajociana* d'Orb., *Pholadomya fidicula* Sow. and *Pygaster semisulcatus* Phillips are among the fossils recorded. The Lincolnshire limestone forms the very straight and well-marked escarpment running north and south through the county, breached at Lincoln in a wide gap by the river Witham.

Between Lincolnshire and North Yorkshire the overstep of Cretaceous beds conceals the continuation of the Bajocian, and in the latter area they have an estuarine facies. They constitute the Middle Estuarine Series, with marine strata at bottom (Millepore Oolite) and top (Scarborough Grey Limestone). The "Millepore" Oolite is so named, inaccurately, from the abundance of a bryozoon, *Cricopora straminea* PHILLIPS. *Lima duplicata* SOW., and *Pygaster semisulcatus* PHILLIPS are among the other recorded fossils.

The Middle Estuarine Series are massive sandstones and shales, which have yielded an abundant flora of ferns and cycads, including *Pecopteris dentata* LINDLEY and HUTTON, *Taeniopteris major* LINDLEY and HUTTON, *Nilssonia compta* PHILLS., and *Otozamites beani* LINDLEY and HUTTON.

The Scarborough Grey Limestone has yielded ammonites attributed to the species *blagdeni* and *humphriesianum*, and though more exact identifications are desirable, they appear to indicate a high Bajocian horizon. Other fossils include *Belemnites giganteus* SCHLOT., *Trigonia costata* SOW. etc.

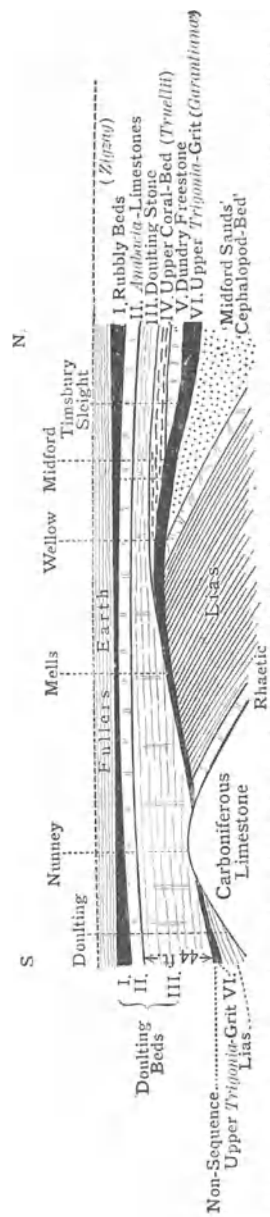

Fig. 43. Sketch-section showing the relations of the Inferior-Oolite Beds of the Bath-Doulting district to the deposits above and below them (L. RICHARDSON).

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D. Upper Inferior Oolite, Lower Fuller's Earth, and Upper Estuarine beds (Vesulian).

With the beginning of the Vesulian age, a widespread depression occurred, and free communication was once more established between the Cotteswold and Dorset areas. The garantiana beds therefore transgress widely over the various divisions of the Bajocian, Aalenian and Toarcian and even rest upon the Carboniferous limestone at Nunney in the Mendips (Fig. 43). At Vallis at the eastern end of the Mendip Hills, the truelli zone overlaps the Garantiana zone and rests directly upon Carboniferous Limestone, while in a few places, the still higher schloenbachi-zone overlaps the garantiana and truelli zones (Chideock and Stoke Knap in Dorset; Chipping Norton in Gloucestershire and adjacent parts of Oxfordshire).

On the Dorset coast, the garantiana beds are thin, richly fossiliferous limestones, with *Astarte* (*Crassinella*) *obliqua* DESHAYES, flat evolute species of *Parkinsonia*, *Garantiana* spp., *Terebratula sphaeroidalis*, auctt., 0.1 m. (4 inch.). On this rests the truelli zone, 0.55 m. (2 ft.) of grey limestone, the home of the well-known and well-preserved *Parkinsonia parkinsoni* SOW. and *P. dorsetensis* S. BUCKMAN; *Astarte obliqua* and *Terebratula sphaeroidalis* also occur here. The schloenbachi zone consists of 1.4 m. ($4^1/_2$ ft.) of limestone with *Parkinsonia schloenbachi*

SCHLIPPE, *Terebratula phillipsi* MORRIS, *Aulacothyris carinata* LAM., *Acanthothyris spinosa* D'ORB., and Echinids such as *Collyrites ringens* AGASSIZ and *Stomechinus bigranularis* LAM. Above this are 1.5 m. (5 ft.) of limestone belonging to the zigzag zone, with species of *Zigzagiceras* and *Morphoceras*. Then a lithological change takes place, and the clayey series known as Fullers Earth begins with the fusca-zone. At an uncertain height above the base is the 6—9 m. (20—30 ft.) thick zone of *Ostrea acuminata* SOWERBY, well-exposed at Langton Herring.

Inland in Dorset, the Upper Inferior Oolite is exposed in the Sherborne district, where the lower zones, like those of the Aalenian and Bajocian, thicken towards the East. The change from limestone to clay begins some way up in the fusca zone; but the evidence of a deep boring at Stowell, farther east, appears to show that in that direction this change begins several zones lower. Over a very large area, extending from Doulting (south of the Mendips) to the Cotteswolds the Upper Trigonia Grit is deposited upon the bored and otherwise eroded surface of beds of very various earlier dates. This bed takes its name from the abundance of *Trigonia duplicata* Sow., *T. producta* LYC. and other species. It also yields *Terebratula globata* auctt., and *Holectypus depressus* LESKE.

The higher part of this zone yields a good building-stone (freestone) at Dundry. At the base of the truelli zone comes the uppermost of the four Coral-beds of the Cotteswolds, with *Spiriferina* (?) *oolithica* MOORE, *Thecidella triangularis* D'ORBIGNY, *Zellania davidsoni* MOORE and other microzoa. This bed is found at intervals from Stroud to the Mendips. Above this bed, in Somersetshire, comes the valuable building-stone of Doulting; but in the Cotteswolds and thence eastwards to Oxfordshire, its place is taken by the Clypeus Grit, with finely-preserved specimens of *Clypeus ploti* KLEIN, also *Terebratula tumida* DAV., *T. cheltensis* S. BUCKM., *T. cotteswoldensis* S. BUCKM., *Nerinaea guisei* WITCHELL.

From Dorset to Gloucestershire the calcareous beds of the Vesulian are overlain by the clays known as the "Fullers Earth". The true Fullers Earth of economic value — a soapy, non-plastic clay, which falls to pieces in water — is limited to a small area around Bath. The upper part of the Fullers Earth Clay of Dorset belongs to the Bathonian (Bradfordian or Bathian) stage; but only the lower part (fusca-zigzag zones) appears to be represented by clay in the Bath and Gloucester district. The characteristic fossils of this clay are *Rhynchonella smithi* WALKER, *Terebratula globata* auctt., *Aulacothyris cucullata* S. BUCKMAN, and *Ostrea Knorri* VOLTZ. *Ostrea acuminata* SOWERBY characterizes a higher horizon — the highest Vesulian

In passing from the Cotteswolds towards Oxfordshire the Fullers Earth clay thins away and is replaced by a sandy limestone, the Chipping Norton Limestone, and other sandy beds characterized by *Trigonia signata* AG. At the same time there come in above the limestone a thick series of marly beds characterized by *Neaera ibbetsoni* MORRIS, *Kilvertia* (*Exelissa*) *pulchra* LYCETT, and many other special forms. These are the "Neaeran beds" of WALFORD (1906), and resemble those described from l'Indre, France, by COSSMANN and BENOIST. These beds extend into Northamptonshire and Lincolnshire where they directly overlie the Lincolnshire Limestone and are the sole representatives of the Vesulian: they are known here as the Upper Estuarine beds, and contain in addition to the special marine fauna a few freshwater shells such as *Cyrena cunninghami* FORBES, and plant-remains. In Yorkshire the Upper Estuarine series reappears, after being hidden by Cretaceous overstep; but here they consist of shales and thick sandstones, with ill-preserved plant-remains and freshwater shells only.

E. The Great Oolite Series (Upper Bathonian, Bradfordian or Bathian).

On the Dorset coast a thick, undivided mass of clay, the "Fullers Earth" 45 m. (150 ft.) intervenes between the thin limestones of the Inferior Ooolite and the Forest Marble. The portion of this clay below and including the zone of *Ostrea acuminata* SOWERBY, has already been described under the Vesulian stage. The overlying clay (Upper Fullers Earth) belongs to the Bradfordian stage and is about 8 m. (26 ft.) thick.

About 16 km. (10 miles) inland, an earthy limestone makes its appearance immediately above the acuminata zone, and forms the base of the Bradfordian. This is called the Fullers Earth Rock, and can be traced to the Mendip district; coming between two thick clays, it generally forms a distinct feature on the ground. Among its fossils are *Ornithella ornithocephala* J. SOWERBY, *Ostrea sowerbyi* MORRIS and LYCETT, *O. subrugulosa* MOR. and LYC. *Macrocephalites morrisi* OPPEL and *Teloceras subcontractum* MOR. and LYC. As it is traced northwards, the clay below becomes thinner, while that above thickens; it is possible therefore that the Fullers Earth rock is not a constant palæontological horizon, and that the "Upper Fullers Earth Clay" of Bath, in which the economic Fullers Earth occurs, may really be of the same age as the Lower Fullers Earth Clay of Dorset: the fossils found in it appear to indicate this. Again, ammonites apparently identical with those of the Fullers Earth Rock are found in the Great Oolite of Minchinhampton, which has 25 m. (83 ft.) of Fullers Earth Clay below it.

The Great Oolite proper is a mass of oolitic and shelly limestones, in part false-bedded, which at Bath attains a thickness of 16 m. (50 ft.), but in 9.5 km. (6 miles) to the south disappears completely. The exact mode of disappearance is not clear, but it is probably due in part to the lateral change of the lower beds into Fullers Earth, and in part to the denudation of the upper beds. The limestones include the famous Bath stone, a very valuable freestone. Fossils are not very abundant in the Bath district, but some beds yield corals such as *Calamophyllia*, and others Bryozoa and small gastropods. Farther north, at Minchinhampton near Stroud, the upper beds of the Great Oolite are richly fossiliferous, yielding *Purpuroidea morrisi* BUV., *Patella rugosa* SOW. and other gastropods, and *Teloceras subcontractum* MOR. and LYC., and other ammonites, but these last are very rare. In the same district the lowest beds begin to take on the character of "Stonesfield Slate", that is of fissile, sandy, thin-bedded limestones. This facies is best developed at Stonesfield in Oxfordshire, where the beds have been worked for roofing purposes from the time of the Roman occupation. The presence at Stonesfield of a single ammonite, *Perisphinctes gracilis* J. BUCKMAN, not known elsewhere suggests that a lower zone may here be represented. Other fossils include the famous mandibles of small, primitive mammalia, *Phascolotherium bucklandi* BROD. and others; remains of *Ornithosauria*, *Dinosauria* and *Crocodilia*; fish teeth — various forms of *Ganodus*, *Hybodus*, *Strophodus*, etc.; *Belemnites aripistillum* LHWYD, *B. bessinus* D'ORB.; *Nerinaea stricklandi* MOR. and LYC. and many other gastropods; *Trigonia impressa* SOW., and many other lamellibranchs; insect-remains and plant-remains. The Stonesfield Slate at Stonesfield immediately overlies the Neaeran beds.

The Stonesfield Slate is not recognisable far north-eastwards from Stonesfield; but beds of oolitic and shelly limestone corresponding to the Great Oolite occur along the outcrop to Lincolnshire, resting upon the Upper Estuarine beds. They are locally quarried for lime or building-stone, but nowhere attain the thickness or excellence of quality of the Bath stone.

F. Bradford Clay, Forest Marble, Blisworth Clay and Cornbrash.

On the Dorset Coast, the Upper Fullers Earth Clay is overlain by a very fossiliferous band with *Rhynchonella boueti* Dav., *Ornithella digona* Sow. and *Dictyothyris coarctata* Park. This is the equivalent of the Bradford Clay, a zone only seen elsewhere at Bradford-on-Avon in Wiltshire, where it is 3 m. (10 ft.) thick and immediately overlies the Great Oolite, attached to the surface of which are abundant fine specimens of *Apiocrinus parkinsoni* Schlot.

Above the Bradford Clay in both places and extending continuously between and northwards to Buckingham are beds of thin-bedded, often false-bedded limestones, sometimes oolitic, alternating with beds of clay. These constitute the "Forest Marble", the latter name referring to the fact that some of the limestones are often hard and blue and capable of taking a polish, so that they were formerly used as ornamental stones, while the first part of the name is taken from the Forest of Wychwood in Oxfordshire where this formation is well shown. From among the abundant fossils may be mentioned *Ostrea sowerbyi* Lyc., *Chlamys vagans* Sowerby, *Epithyris* (*Terebratula*) *marmorea* Oppel, and *Acrosalenia spinosa* Ag. In North Oxfordshire the lower half of the Forest Marble is all clay and includes a band of bright green clay of striking appearance. Marble has been worked at Buckingham, but east of that place the whole formation becomes clayey, and is known as the Blisworth Clay or Great Oolite clay. This continues along the outcrop into Lincolnshire.

In Yorkshire the Bradfordian appears to be entirely absent, unless represented by part of the Upper Estuarine Series, or by the lower part of the Cornbrash.

The Cornbrash is a clayey limestone, never oolitic, weathering to a brown or yellow colour and a very rubbly consistency. It varies from 1 to 9 m. (3 to 30 ft.) in thickness, and is easily recognized in the field by its difference from the underlying marbles and oolitic limestones of the Great Oolite Series, and the clays and calcareous sandstones above. The character of its outcrop depends in large measure on the nature of the overlying Kellaways beds: where these are soft clays and sands the Cornbrash has a wide extension along the dip-slope of the Great Oolite escarpment, and in these cases it weathers down into the rich corn-growing soil, from which it takes its name. Where the true Kellaways Rock lies above it, its outcrop is narrow and inconspicuous.

Fossils are abundant. *Pholadomya deltoidea* Sow., *Pseudomonotis echinata* Sow., *Chlamys vagans* Sow., *Rhynchonella concinna* Sow., *Waldheimia* (*Ornithella*) *obovata* Sow., *Waldheimia lagenalis* Schloth., *Nucleolites clunicularis* Lhwyd, and *Anabacia complanata* Defr. are the commonest. From Yorkshire to Bedfordshire and Northamptonshire, *Macrocephalites macrocephalus* Schlotheim is recorded, but not from farther south, while *Clydoniceras discus* Sow. is found from Dorset to Lincolnshire but not from farther north. It is probable therefore that the Cornbrash is a deposit the period of formation of which came gradually later in time from south to north.

III. Upper Jurassic.

Unlike the Middle Jurassic rocks below, which consist mainly of shallow-water limestones and sands, and the Upper Cretaceous rocks above, consisting mainly of pelagic limestone (chalk), the Upper Jurassic and Lower Cretaceous rocks are mainly argillaceous. Between the Cornbrash and the Cenomanian there is scarcely any portion of the series that is not represented somewhere in England by a deposit of clay. In no place, however, is the whole clayey; everywhere there are intercalations of limestone and sandstone, and upon these alternations in lithic character was based the original classification of these rocks, which is still adopted in England although its imperfections are generally recognized. Since the actual duration of each interruption of the general argillaceous deposit varied from place to place, the divisions usually recognized have not a fixed time-value, and do not correspond strictly to palæontological zones. On a geological time-scale the terms Kellaways Rock, Oxford Clay, Corallian, Kimmeridge Clay, Portland Sand and Stone, Lower Greensand and Gault have a different value in different parts of England, and must not be equated with such terms as Callovian, Oxfordian, etc., as defined palæontologically. Thus much of the English Oxford Clay is Callovian, and much of the Yorkshire Corallian is Oxfordian in the sense in which those terms are understood out of England.

In the accompanying table p. 240—243, an attempt has been made to correlate the Upper Jurassic and Lower Cretaceous strata throughout Great Britain, and I must gratefully acknowledge the kind help given to me by S. S. BUCKMAN in the preparation of this table. At the present time, however, any such correlation must be provisional. In the near future, the number of zones will probably be much increased, and many alterations in the correlation made[1].

The Upper Jurassic and Lower Cretaceous strata have in general a gentle dip to the south-east, and their main outcrop extends in a broad band across England from the coast of Dorset to that of Yorkshire. This general disposition is broken across by folds in an east-and-west direction, of which the two most important are the anticlines of the Weald and of the Isle of Wight and Purbeck peninsula.

Considered from the point of view of the conditions of deposition, three areas may be distinguished in England — (1) North Yorkshire, where there is an almost unbroken marine sequence from the Cornbrash up to the Chalk; (2) the Weald of Kent, Surrey and Sussex, where there is also an unbroken sequence, but where the transitional strata from Jurassic to Cretaceous are of fresh-water origin; (3) the rest of the outcrop and most of the area where these strata are concealed beneath newer systems: here there was a land-area during the time of transition from the Jurassic to the Cretaceous period, and consequently there is an unconformity between the Lower Cretaceous and Upper Jurassic. This unconformity reaches its extreme in Devonshire and under the London area, where Lower Cretaceous strata rest upon rocks of Palæozoic age, the Jurassic strata having been entirely denuded away before the Gault transgression. The Upper Jurassic and Lower Cretaceous strata, as here described, are thus defined palæontologically: — They begin with the re-appearance of an abundant ammonite-fauna, after the very scanty representatives of the ammonites that characterize the Bathonian; starting with *Macrocephalites*, soon followed by *Cadoceras* and *Kepplerites*, and the typical Cardioceratids and Cosmoceratids. In the south of England this palæontological boundary corresponds with the top of the Cornbrash, but farther north it gradually splits up that formation, until in Yorkshire it appears to be at the base of it.

At the top, the end of the Lower Cretaceous period ought, on palæontological grounds, to coincide with the almost complete disappearance of the *Hoplitidae* and the incoming of the genus *Mortoniceras*; but this would involve the splitting up of the thin band of Red Chalk, and the separation of the Upper Gault of south-east England from the Lower Gault — a separation which no one has attempted to express on the map. For convenience, therefore the zone of *Mortoniceras rostratum* Sow. is included in the Lower Cretaceous.

[1] While this part is passing through the press an important contribution to the zoning has been made by H. SALFELD (1914). Some of his results have been incorporated in the text and table of correlation, but it has not been possible to do so fully.

The boundary between Jurassic and Cretaceous has been the subject of much dispute. In the South of England it is usual to draw it at the level where the more calcareous freshwater Purbeck beds are followed by the more arenaceous freshwater Wealden beds, but the flora, the fishes and the reptiles of the Wealden all have a Jurassic character. In Yorkshire the line must be drawn somewhere in a continuous series of clays, and it has been drawn by PAVLOW at the level where the Jurassic Olcostephani are replaced by the Cretaceous Hoplitidae — a level not marked by any lithic change, and one which splits into unequal parts a well-marked belemnite zone.

A. Kellaways Rock and Oxford Clay.

The term Kellaways Rock is applied to beds of calcareous sandstone, either resting directly upon the Cornbrash or separated from it by a variable thickness of clay (Kellaways Clay). It receives its name from a village in Wiltshire, where it was quarried for road-metal in the early years of the nineteenth century and which became famous for its fossils. Now these quarries are abandoned, as are the equally fossiliferous exposures at Scarborough, and it is only exceptionally that any exposures of the rock are found. In Yorkshire the rock-facies extends upwards into higher zones than in the more southern localities. Along large parts of the outcrop the stone passes into soft sands (in which large rounded masses or "doggers" of concretonary sandstone may be developed), or thins away altogether.

The typical Kellaways Rock is highly fossiliferous, some of the most characteristic species being *Cadoceras sublaeve* Sow., and other species, *Proplanulites koenigi* Sow., *Sigaloceras calloviense* Sow., *Patoceras calloviense* MORRIS, *Gryphaea bilobata* Sow., *Goniomya v-scripta* Sow., *Ostrea flabelloides* LAM., *Rhynchonella varians* SCHLOTHEIM.

The "Kellaways Rock" of Yorkshire includes also the duncani and athleta zones, but elsewhere these are represented by part of the Oxford Clay. Shaley clays with compressed nacreous fossils (as at the famous railway-sections, long overgrown, at Christian Malford, Wilts.) constitute the jason zone; stiff blue clays with pyritic fossils (as at Oxford and Peterborough), constitute the duncani zone. These make up the Lower Oxford Clay. In these clays occur many species of *Cosmoceras: C. duncani* Sow., *C. elizabethae* PRATT, *C. jason* REINECKE, &c. At Christian Malford remains of *Belemnoteuthis antiquus* PEARCE, were found in which the outline of the body is preserved with the ink-bag, arms with horny hooks, eyes, fins, funnel etc.

The middle Oxford Clay is of very uniform character, dark bluish-grey clay with some gypsum and many pyritic fossils. Two zones can be recognised; the lower, of *Peltoceras athleta* contains few fossils: *Aulacothyris bernardina* d'ORB., and *Gryphaea bilobata* Sow.; in the higher, species of *Quenstedticeras* are the most characteristic ammonites: *Q. lamberti* Sow., *Q. mariae* D'ORB., and *Q. sutherlandiae* Sow., with *Creniceras renggeri* OPPEL, *Hecticoceras hecticum* REIN., and *Belemnites hastatus* BLV. Recent work shows that these beds contain the characteristic fauna of the renggeri-zone of the Jura Mountains.

The upper Oxford Clay is of similar appearance, but more shaly in places, less pyritic and gypseous, the actual shells of the Ammonites being more frequently preserved. It contains species of *Cardioceras*, s. str., but not *C. cordatum* Sow., Perhaps the most characteristic fossil is *Gryphaea dilatata* auctt., (non Sow.), of very large size. Others are *Pleuromya recurva* PHILL, and *Modiola bipartita* Sow.

In Yorkshire, only this last zone is represented by clay in the coast-section, though the records of fossils suggest that other zones may take on the Oxford Clay facies in some places.

Occasional bands of septaria, or beds of argillaceous limestone occur throughout the Oxford Clay. In the Weymouth district the septaria are of a bright red colour with white calcite-veins: they are polished for ornamental purposes. The clays are much used for brick-making throughout their outcrop, but especially in the Peterborough district, where the presence of bituminous matter in certain beds was found to facilitate greatly the process of burning, and where easy access to London has led to the development of an enormous brick-making industry.

B. Corallian Rocks and Ampthill Clay.

The Jurassic strata higher than the Oxford Clay have a discontinuous outcrop owing to the overstep of Cretaceous beds. From Weymouth to Oxford, wherever the next succeeding series is seen, it consists of very variable limestones, sands and sandstones, with occasional clays, collectively called the Corallian rocks. In the lower portion sands usually predominate, and to this have very generally been given the names: "Lower Calcareous Grit" (taken from the Yorkshire sequence) and "zone of *Ammonites perarmatus*"; but the ammonites found, usually as internal casts, belong to other species of *Aspidoceras*, such as *A. catena* SOWERBY[1]. Among other common fossils of the Lower Corallian are *Cardioceras vertebrale* Sow. *Belemnites abbreviatus* MILLER, *Ostrea gregaria* Sow.

The Upper Corallian is more calcareous in general character, and at many places, such as Steeple Ashton in Wiltshire, corals are very abundant, the limestone then being termed "Coral Rag", a term which is often loosely applied to the whole Upper Corallian. Other beds are of oolitic limestone, "Coralline oolite", another term often used in an equally wide sense. The occurrence of local unconformities, pebbles derived from Palæozoic rocks, and false-bedding, indicate shallow-water conditions of deposit. To these strata the term "zone of *Ammonites plicatilis*" is commonly applied, but many species have been included under that name, and more careful study is needed. At least the zone of *Perisphinctes martelli* can be recognised.

Among the most characteristic corals are *Thecosmilia annularis* FLEMING, and *Thamnastraea arachnoides* PARKINSON. Echinoids are locally abundant, Calne in Wiltshire being a famous locality: *Cidaris florigemma* PHILLIPS, *Hemicidaris intermedia* FLEMING, and *Nucleolites scutatus* LAM. are common species. Gastropods also abound locally, such as *Pseudomelania heddingtonensis* Sow., and *Nerinaea goodhalli* Sow. Lamellibranchs are represented by *Pecten articulatus* SCHLOTH. and *Trigonia clavellata*, Sow. — the latter especially characterising the Trigonia-beds of Weymouth. *Exogyra nana* SOWERBY is enormously abundant in some beds.

At two localities — Abbotsbury near Weymouth (Fig. 44), and Westbury in Wiltshire — there occur deposits of oolitic iron-ore which appear to belong to a higher horizon than any other Corallian rocks. They are characterised by *Waldheimia lampas* Sow. and contain other species with Kimmeridgian affinities[2].

A few miles east of Oxford, the typical Corallian facies ends abruptly, and from thence — except for a local reappearance at Upware in Cambridgeshire (Fig. 45) — it is seen no more until Yorkshire. Along the intervening outcrop, the Oxford Clay is followed by a grey or black clay with much gypsum, the Ampthill Clay. The most characteristic fossil is *Ostrea discoidea* KITCHIN. Usually, as at Elsworth and St. Ives, there is a rock-bed with ferruginous oolite-grains at its base, and in such cases there are clear indications of a non-sequence. This Elsworth

[1] From information by S. S. BUCKMAN.

[2] According to H. SALFELD's recent results, the Abbotsbury ore belongs to the cymodoce zone of the Kimmeridgian.

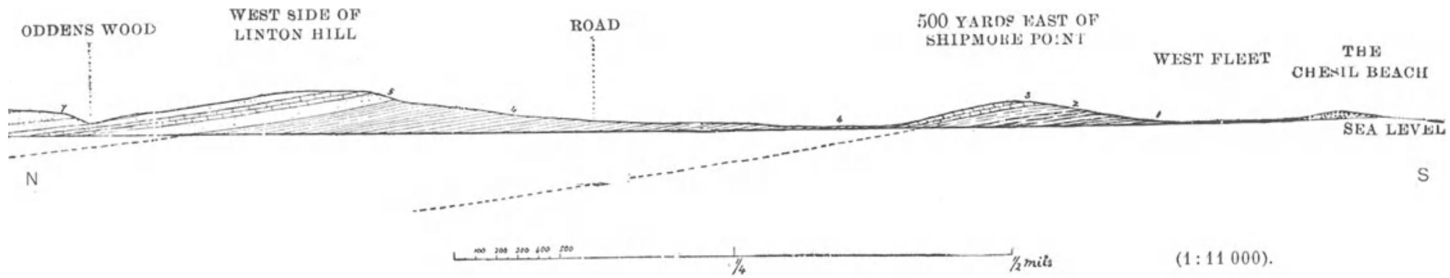

Fig. 44. Section from east of Abbotsbury south through Linton Hill to the Chesil Beach, Dorset (A. Strahan), continued to the north in Fig. 51, p. 254.

7 = Trigonia Beds.	Corallian	4 = Oxford Clay.	1 = Fullonian (Fuller's Earth Clay).
6 = Osmington Oolite.		3 = Cornbrash.	
5 = Lower Calcareous Grit.		2 = Forest Marble.	

Reproduced from the Memoirs of the Geological Survey U.K.—The Jurassic Rocks of Britain, vol. 5, p. 93, 1895; also, Isle of Purbeck and Weymouth, p. 36, 1898; with the permission of the Director and of H. M. Stationery Office.

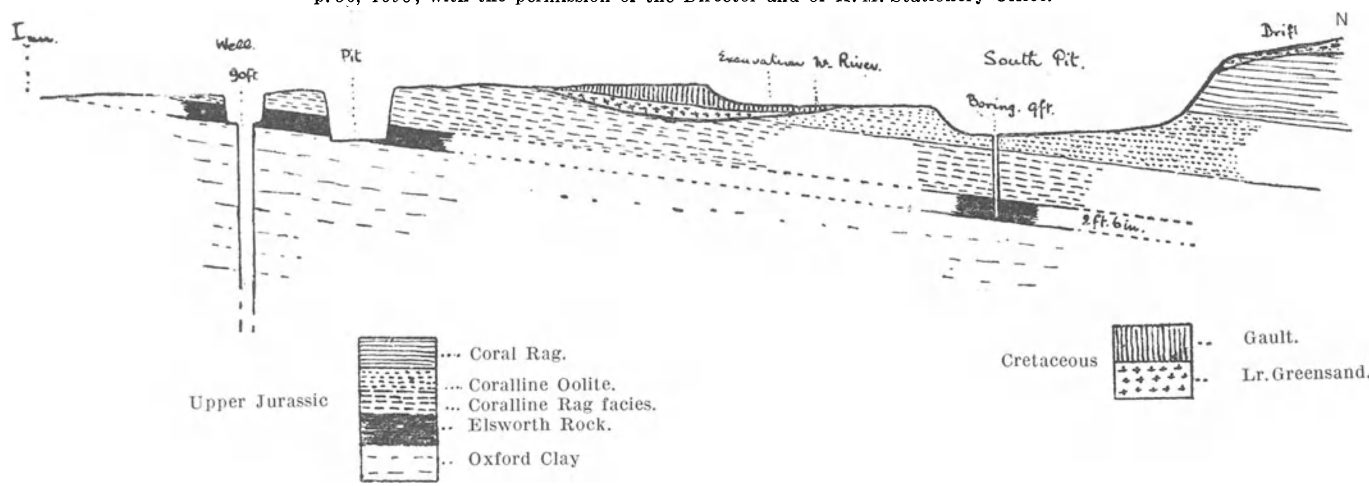

Fig. 45. Diagrammatic Section of the Strata near the South Pit, Upware (P. Rigby and W. G. Fearnsides).
Reproduced from the Geologists' Association, Jubilee Volume.—Geology in the Field, p. 137, 1910; with the permission of the Council.

Rock also underlies the Coralline Oolite of Upware (Fig. 45). It is the base of the martelli zone, and rests on varying zones of the Upper Oxford Clay.

Until the ammonites of the Corallian rocks and Ampthill clay have been more fully worked out, any correlation, such as that in the accompanying table, must be taken as provisional.

In Yorkshire, the Corallian facies reappears, and a great thickness of strata is exposed on the coast and inland. They represent here a longer period of time than anywhere else in England: including as they do the whole of the cordatus zone below, and probably a part of the serratum zone[1] at the top. A large number of divisions can be recognized, but broadly it may be stated that there are three masses mainly of sandstone (the Lower, Middle and Upper Calcareous Grits) separated by two masses mainly of limestone. Both limestones take on a Coral facies locally, but more particularly the upper; the usual Coral Rag species being found.

Oolitic limestones also occur, a famous fossil-bed being that at the base of the Upper Limestone at Malton, from which many fine gastropods and lamellibranchs have come.

C. Kimmeridge Clay.

In everything except thickness, the Kimmeridge Clay is remarkably uniform in character from one end of England to the other. The lower beds are dark clays, often gypseous, with occasional phosphatic nodules and septaria and bands of argillaceous limestone. The upper beds are distinctly shaly and bituminous, often contain lignite, and also contain septaria. On the Dorset coast, a band of oil-shale or "Kimmeridge Coal" in these higher beds has been worked, and yielded from 30 to 60 litres (85 to 170 gallons) of crude oil per ton, with various by-products; but the workings are now abandoned.

At the base of the Kimmeridge Clay, *Rhynchonella inconstans* DAV. non Sow., is abundant. In the next beds above, *Ostrea deltoidea*, Sow. is the most characteristic fossil, with *Belemnites nitidus* DOLLFUS, and *Amoeboceras serratum* Sow.

About the middle, *Exogyra virgula* DEFRANCE is extremely abundant, though it ranges below less plentifully. In the highest portion, *Orbiculoidea latissima* DAVIDSON, occurs with ammonites of the *pallasianus* type. Where Portlandian beds of the South-of-England type are present, the upper Kimmeridgian becomes sandy and glauconitic and passes upwards gradually into the Portland sands.

The thickness of the Kimmeridge Clay varies enormously. It is thinnest in the Midlands where it probably does not exceed 30 m. (100 ft.) In Yorkshire it is three times, on the Dorset coast ten times as thick, while in the Sub-Wealden boring near Hastings it attained a thickness of about 380 m. (1250 ft.).

D. Portlandian of the South of England.

The Kimmeridge Clay of the Dorset Coast becomes sandy at the top and passes up into a series of fine, glauconitic sands, the Portland Sands, among which occur beds of calcareous sandstone or sandy limestone. Fossils are not abundant in these beds, but *Exogyra bruntrutana* THURMANN, *Trigonia pellati* MUNIER-CHALMAS, *Mytilus autissiodorensis* COTTEAU etc. may be found.

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[1] This is usually called the alternans zone, but *Amoeboceras alternans* v. BUCH really belongs to a lower horizon according to SALFELD.

Above the Portland Sands comes the Portland Stone series, famous for its building-stones; but the actual valuable oolitic freestone layers only amount to a thickness of from 3 to 6 m. (10 to 20 ft.), while beneath them are about 9 m. (30 ft.) of limestone containing many bands and nodules of black chert. Above the freestones is about 1 metre of "roach" — an oolitic limestone full of casts of *Cerithium portlandicum* SOWERBY and *Trigonia gibbosa* SOWERBY, used for rougher building work. Ammonites attaining a great size characterize the Portland Stone series — *Perisphinctes giganteus* SOWERBY, the Freestone beds and *P. pseudogigas* BLAKE, the cherty series.

Inland, in the Vale of Wardour, and the Swindon and Aylesbury districts, there are indications of an unconformity between the Lower and Upper Portland beds, in the occurrence of a bed of lydite pebbles with phosphatic casts of Portlandian and Kimmeridgian ammonites and other fossils. At Swindon and Aylesbury the Portland sands below this lydite-bed are replaced by a glauconitic sandy clay the Hartwell Clay, containing a fauna of distinct character including ammonites (*Perisphinctes* or *Virgatites* ?) of the *pallasianus* group, *Astarte hartwellensis* Sow., A. *saemanni* DE LORIOL, *Perna bouchardi* OPPEL, *Waldheimia boloniensis* SAUVAGE and RIGAUX and others.

Above the lydite-bed in the Vale of Wardour come the sandy glauconitic building-stones of Chilmark, above which come the cherty beds and a diminished representation of the freestones of the coast. Farther inland the Upper Portland beds become thinner and disappear altogether a few miles north-west of Aylesbury.

E. Purbeck-Beds.

This series, mainly of freshwater calcareous strata, is magnificently developed on the coast of the so called Isle, more correctly a peninsula, from which it takes its name. It is as much as 120 m. (400 ft.) thick, and is divided into three divisions, of which the Lower and Upper are purely freshwater and terrestrial in origin, while the Middle contains two marine horizons. The presence of the strictly Jurassic echinid *Hemicidaris* in these marine intercalations justifies the reference of the whole series to the Jurassic system.

The Lower Purbeck beds consist of marls and limestones, with many ostracods, such as *Cypris purbeckensis* FORBES, the isopod *Archaeoniscus brodiei* MILNE EDWARDS, and freshwater Mollusca including *Planorbis fisheri* FORBES. At the base resting directly on Portland limestone is a "dirt-bed", or ancient soil from which rise up the stumps of the fossil cycads which grew in it. A second and more important dirt-bed occurs from 2 to 5 m. (6 to 17 ft.) higher.

These dirt-beds vary much in thickness, never exceeding 0.3 m. (1 ft.), and not being present everywhere. Where the basal dirt-bed is wanting, Purbeck and Portland limestones may be united in a single block.

The Middle Purbeck beds also begin with a dirt-bed, which in Durlston Bay has yielded jawbones of 24 species of small mammals, including species of *Plagiaulax* and *Triconodon*. Above come limestones (Lower Building Stones) and cherty beds with *Chara*, insects, ostracods and freshwater Mollusca, followed by the "Cinder-bed", an impure limestone composed chiefly of shells of *Ostrea distorta* Sow., with *Trigonia gibbosa* Sow., and *Hemicidaris purbeckensis* FORBES. There follow more freshwater limestones (Upper Building Stones), after which is a second marine intercalation, the *Corbula* beds, with *Corbula alata* Sow. and a mixture of marine and freshwater Mollusca. The Middle Purbeck series ends with the "Beef beds", dark shales with bands of fibrous calcite ("beef"). *Cypridea granulosa* Sow., is an ostracod strictly confined to the Middle series.

The Upper Purbeck beds are entirely of freshwater origin, consisting of limestones and clays, in which *Unio valdensis* MANTELL and *U. compressus* Sow., are very characteristic stells. *Cypridea punctata* FORBES, is a very characteristic ostracod, though not absolutely confined to the Upper series. An important feature is the occurrence of beds of Paludina-limestone or Purbeck marble, with *Vivipara carinifera* Sow. These were extensively worked in the Middle Ages as an ornamental stone. The Middle Purbeck limestones are very extensively mined near Swanage.

The three series, greatly reduced in thickness, re-appear inland in the Vale of Wardour, with such characteristic features as the main dirt-bed and the Cinder-bed; but in the Swindon and Aylesbury districts the beds are very greatly reduced in thickness and neither dirt-beds nor marine intercalations are found. Possibly only Lower Purbeck beds are present, but the occurrence at Aylesbury of an unconformity or contemporaneous erosion within the series, as well as the presence of *Cypridea punctata* FORBES, suggests the possibility of the Middle or Upper beds being also represented. A little gypsum occurs in the Upper Purbeck beds of Dorset, and in the centre of the Wealden anticline, valuable gypsum deposits have been found in the uppermost beds.

F. Speeton Clay.

On the Yorkshire coast, the Kimmeridge Clay is followed by another series of clays which pass up conformably into the Upper Cretaceous beds. Inland these clays rapidly disappear by reason of the Upper Cretaceous overstep, and in Specton Cliff the sequence is greatly obscured by drift and slipping. The fauna also differs greatly from any comparable fauna in the south of England. Consequently the relations of the Speeton Clay were long imperfectly understood.

At the base is a thin bed of phosphatic nodules (so called "Coprolite-Bed"), in which occur phosphatic casts of *Virgatites* cf. *scythicus* VISCHNIAKOV, and various *Olcostephani*, with *Belemnites magnificus* D'ORB, and *B.* cf. *absolutus*, FISCHER. This bed is thus comparable to the *virgatus*-zone at the base of the Russian Volgian.

Above it come about 10 metres of clay, with several fossil-beds, the whole characterized by *Belemnites lateralis*, PHILLIPS. These are followed by a second layer of phosphatic nodules, the "Compound Nodular Band", in which appear for the first time ammonites of the family Hopliditae, particularly *Neocomites regalis* PAVLOV (BEAN MS), and *Hoplites amblygonius* NEUM. and UHL. With these are *Olcostephanus gravesiformis* PAVLOV, *Holcodiscus rotula* Sow., and *Pecten cinctus*, Sow. *Bel. lateralis* PHILL. still occurs.

The imperfect understanding of the Speeton section was largely due to confusion between the two phosphatic bands, coupled with the belief that the nodules were derived fossils indicating an unconformity. It appears more probable that they only indicate two prolonged phases of non-deposition. The "Coprolite-Bed" may thus represent the whole or a large part of the Portlandian age. The clays between the two nodule-bands are correlated by PAVLOV with the catenulatus-nodiger and riasanensis zones of the Volgian of Russia, and the stenomphalus and gravesiformis zones of the Petchorian, which he includes in the

Lower Cretaceous. For the purposes of English stratigraphy it appears more convenient at present to take the "Compound Nodular Band" with its new hoplitid fauna as the lowest zone of the Lower Cretaceous system, although even this, in respect of its belemnites, shows close affinity with the beds below.

G. Spilsby Sandstone.

In Lincolnshire the Kimmeridge Clay is surmounted by a bed of phosphatic nodules similar to the Lower nodule-bed of Speeton, but upon this rests a sandstone (Spilsby Sandstone), which has yielded *Belemnites lateralis* Phillips, and allied species, *Craspedites subditus* Trautschold, *Aucella volgensis* Lahusen, and many other lamellibranchs.

Above this Spilsby Sandstone comes the Claxby Ironstone, which will be described among the Lower Cretaceous beds later.

H. The Underground Extension of the Jurassic Rocks in Eastern England.
(Fig. 46.)

The exploration of the east and south-east of England by deep borings has shown that that area was more or less occupied by land during large portions of

Fig. 46. Sketch-map to illustrate the underground distribution of Upper Jurassic and Lower Cretaceous rocks in South-East England.
All localities marked are the sites of deep borings (SOU = Southall; RICH = Richmond; STR = Streatham; CL = Cliffe).

the Jurassic period. Thus, nowhere at any great distance from the outcrop are Rhætic, Hettangian or Sinemurian strata known. At Calvert in North Buckinghamshire and Brabourne and Dover in Kent, the oldest Jurassic deposits are Charmouthian (jamesoni zone in the two former places, capricornu zone in the third). Above these Charmouthian beds the sequence is very incomplete. Thus at Calvert the lowest zone of the Domerian is at once overlain by a high zone of the Vesulian (Chipping Norton Limestone). At Brabourne the Domerian is perhaps complete, but only the bifrons and striatulum zones of the Toarcian have been recognized, and only 13 m. (43 ft.) of oolitic limestone intervene between them and the Bathonian. At Dover the sequence is perhaps complete up to the falcifer zone but that is at once followed by 8 m. (27 ft.) of sands, above which come Bathonian limestones.

In the London district, Bathonian strata (apparently bathonica and digona zones) rest directly upon the Old Red Sandstone, and are overlain by Cretaceous rocks.

The Oxford Clay has been found at Dover and Brabourne, and northwards to Chatham, but under the London Basin it has been removed by pre-Cretaceous denudation. Southwards, higher and higher Jurassic strata come in, the topmost member everywhere being incomplete through denudation. Thus at Fredville Corallian rocks appear, and attain a thickness of over 100 m. (342 ft.) at Brabourne. A little north of Dover the Kimmeridge Clay comes in and becomes more complete to the south-west, where Portland and Purbeck beds are also found.

Quite apart from this southerly increase in completeness of the sequence, there is a marked thickening of the strata from east to west, due to the original conditions of deposit. Thus the Lower Kimmeridge Clay thickens from 60 to 100 m. (200 to 340 ft.) in the 16 km. (10 miles) between Brabourne and Pluckley; and there is evidence of similar thickening in the other beds. This is explained by Lamplugh and Kitchin as due to the accumulation of sediment in an area which underwent great depression about a N.W.-S.E. axis to the east of Dover. At Dover itself shallow-water, current-influenced conditions persisted through a large part of the Jurassic period, indicating that the axis of depression was approximately coincident with a shore-line.

b. Scotland.

I. Lower and Middle Jurassic.

By P. G. H. Boswell.

The **Jurassic** rocks of Scotland occur only in isolated masses on the west coast (Skye, Raasay, Mull, Morvern etc.) and on the borders of the Moray Firth (Sutherland, Ross, Cromarty and Elgin), and are but the vestiges of the former wide extent of the beds. They are usually faulted in among the older rocks, with intense crumpling along the junctions, and their preservation is often due to the covering of Tertiary lavas. Nearly all the chief zones of the Lias are represented on the west coast, where the formation reaches a thickness of 360 m. (1200 ft.), but on the east no certain Upper Lias has been identified, though some of the Estuarine sandstones and shales of the lower part of the Oolites may belong to this division (Judd, 1873, 1878). The chief zones recognized are shown in the table, but recent surveying of Mull and the adjacent mainland (Summaries of Progress of the Geological Survey 1909—1911) has resulted in the recognition of the smaller divisions of the system present in England. In the Lower Lias of the Morvern area, which consists of 30 m. (100 ft.) of very fossiliferous limestones and shales, surmounted by shaly sandstones, bucklandi and obtusus zones have been recognized, while in that of Mull, resting on unfossiliferous quartz conglomerate (probably

Triassic), the following beds were found: hard shelly limestones, 18 m. (60 ft.) of bucklandi zone, rusty micaceous sandstones of semicostatus zone, thick calcareous sandstones representing armatus and capricornu zones, thick white sandstones (? margaritatus or algovianum zone), dark shale, 9 m. (30 ft.), of tenuicostatum and bifrons zones, yielding also *D. commune*. It is probable that much of the Upper Lias is here denuded away, for sandy limestones, 21 m. (70 ft.), belonging to the Lower Oolites rest upon an eroded surface of the former. Index ammonites are sporadic but the following zones are indicated; bradfordensis, concava, discites and blagdeni zones, with suggestions of sauzei and Dumortieria zones. Ammonites characteristic of scissum zone were found in the coast section and Ardnadrochet Glen.

The lithological characters of the strata are indicated in the table, the "roof bed" of the Brora coal being a calcareous sandstone of the age of the Kellaways Rock. There are indications of the proximity of a shore line and it seems likely that these marine and estuarine deposits of the eastern and western areas were laid down in a gulf of the Jurassic sea connected with the English basin by way of North Ireland and the North Channel (Jukes Browne, 1911).

II. Upper Jurassic.

By A. M. Davies.

The alternation of marine and estuarine conditions that characterize the Middle Jurassic strata of Yorkshire are found in Scotland in the Upper Jurassic also. Strata of this age occur along both the east and west coasts, but a much fuller sequence is seen on the east coast. Their position on the present coast-line is in no way connected with their original littoral character, but is due to the powerful faults which have both determined the position of the present coast-line and preserved on their downthrow side Mesozoic rocks removed by denudation from the rest of the country. The Jurassic land lay to the north, not to the west, of the area of deposition.

On the east coast, the Bathonian coal of Brora is immediately followed by a representative of the Kellaways Rock, with many characteristic fossils of the koenigi zone. The calloviensis zone, is represented by black shales with crushed bivalves such as *Nucula nuda* Phill. Marine conditions continue through the ornatus and renggeri zones. The former is clayey with the usual fossils but with an admixture of shallow water forms, the latter sandy and containing plant-remains in addition to marine fossils. Among the latter may be mentioned *Quenstedticeras sutherlandiae* Murch., of which the type comes from Braamberry Hill in this area.

With the cordatus zone estuarine conditions set in, and there is a great thickness of sandstones with some seams of coal, but with several marine intercalations.

These appear to be followed non-sequentially by alternations of estuarine and marine beds of Kimmeridgian age (serratum and pseudomutabilis zones). These include, along with finely laminated argillaceous strata, the so-called "brecciated beds", full of angular blocks of Old Red Sandstone often of very large size. According to Judd, who has given the fullest account of these beds, they indicate the occasional occurrence of violent floods, and possibly river-ice was the agent by which the large blocks were carried out to sea.

The highest strata of all are unfossiliferous estuarine sandstones.

On the west coast of Scotland, only the *cordatus-renggeri* zones appear to be present, represented by dark blue clays with septarian nodules.

LOWER JURASSIC ROCKS OF BRITAIN.

Stages	Older Zones	Modern Zones	Dorset Coast	South Somerset (Yeovil &c.)	North Somerset (Bath and Radstock)	Gloucestershire	Oxfordshire
Next overlying Stage and Zone			Aalenian-aalensis		Vesulian-garantiana	Aalenian-aalensis	Aalenian-scissum
Upper Toarcian (Yeovilian)	*jurensis*	*Dumortieria moorei*	Lower part of Bridport Sands 60 m. (200 ft.)	Ham Hill Stone 27 m. (90 ft.)	absent	Cephalopod-bed 1 m. (3 ft.)	absent
		Dumortieria sp.		Yeovil Sands 24 m, (80 ft.)	Midford Sands 30 m. (100 ft.)?		
		Phlyseogrammoceras dispansum	Blue Clay ("Upper Lias") of Down Cliffs 21 m. (70 ft.)	Upper Lias Clay 36 m. (120 ft.) or less			
		Pseudogrammoceras struckmanni					
		Grammoceras striatulum	*		Cephalopod-bed (limestone, oolitic above, non-oolitic below) 0.5—1 m. (18 in.— 3 ft.)	Cotteswold Sands 80 m. (265 ft.)	
Lower Toarcian (Whitbian)	*bifrons* or *communis*	*Haugia variabilis*	Junction bed of Down Cliffs * (4 zones or fewer) 1 m. (3 ft.) or less				
		Lillia lilli					
		Collina brauniana				Upper Lias Clay 5 m. (16 ft.)	Blue Clay 4—12 m. (13—40 ft.)
		Peronoceras fibulatum					
		Cymbites subcarinatus					
	serpentinus	*Harpoceras falciferum*				Fish- and Insect-beds	absent ?
		Harpoceras exaratum					
	annulatus	*Dactylioceras tenuicostatum*		"Leptæna"-beds 0,5 m. (18 in.)	Clay-	"Leptæna"-beds	
Domerian	*acutus*	*Tiltoniceras acutum*	*	?	?	?	Transition-bed- 0.1 m. (0—4 in.)
	spinatus	*Paltopleuroceras spinatum*	Yellow sands with doggers 23 m. (75 ft.)	Sandy ironshot limestone - 3 m. (10 ft.)	These zones are poorly developed and in part absent	Rock-bed } 60 m. (200 ft.)	Banbury Iron-Ore
	margaritatus	*Amaltheus margaritatus*	Laminated micaceous sands, etc. 21 m (70 ft.)	Clays 45 m. (150 ft.)?		Micaceous Sandy clays	Sandy Clays
		Seguenziceras algovianum	Blue clays 58 m. (190 ft.)				
Charmouthian	*capricornus*	*Aegoceras capricornu*	Green-Ammonite beds 32 m. (105 ft.)	Probably the same general characters and thickness as on the Dorset coast		Clays 100 m. (330 ft.)	Grey Clay 70 m. (230 ft.) ?
	henleyi	*Liparoceras striatum*			Limestone 0,5 m. (18 in.)		
	ibex	*Acanthopleuroceras valdani*	Belemnite-beds 24 m. (80 ft.)		Clay 1,5 m. (5 ft.)		
	jamesoni	*Uptonia jamesoni*			Limestone 0,5 m. (18 in.)		
	armatus	*Deroceras armatum*			Limest. and clay- 1 m. (3 ft.)		
	raricostatus	*Echioceras raricostatum*	Black Marls 57 m. (190 ft.)		Limestone 0-1 m. (0-3 ft.)		
Sinemurian	*oxynotus*	*Oxynoticeras oxynotum*			absent ?		
	obtusus	*Asteroceras obtusum*			Limestone 0,3 m. (1 ft.)		
	turneri	*Arnioceras semicostatum*	"Blue Lias" shales and limestones 32 m. (105 ft.)		Clay 0—3 m. 0—10 ft.)		
	bucklandi	*Coroniceras gmuendense*			Spirifer-marl 0,3 m. (1 ft.)	"Blue Lias" clays and limestones 75 m. (250 ft.)?	absent ?
		Coroniceras rotiforme			Limestone 0-1 m. (0-3 ft.)		
Hettangian	*angulatus*	*Schlotheimia marmorea*			Limestone 0-1 m. (0-3 ft.)		
		Waehneroceras megastoma					
	planorbis	*Psiloceras planorbis*			Limestone and shale 0—3 m. (0—10 ft.)	Shales and limestones 12 m. (40 ft.)	
	Ostrea beds						
	Pleuromya beds						

LOWER JURASSIC

Stages	Older Zones	Modern Zones	Northamptonshire	Lincolnshire
Next overlying Stage and Zone			Aalenian-scissum	
Upper Toarcian (Yeovillian)	*jurensis*	*Dumortieria moorei*	absent	absent
		Dumortieria sp.		
		Phlyseogr. dispansum		
		Pseudogr. struckmanni		
		Grammoc. striatulum		
Lower Toarcian (Whitbian)	*bifrons* or *communis*	*Haugia variabilis*		
		Lillia lilli	Upper Leda ovum Beds 4—7 m. (13—23 ft.)	Shales with septaria 11,5 m. (38 ft.)
		Collina brauniana	Lower and Middle Leda ovum Beds 22 m. (72 ft.)	
		Peronoceras fibulatum	Unfossiliferous Beds 23 m. (75 ft.)	Shales 2,5 m. (8 ft.)
		Cymbites subcarinatus	Upper Cephal.B.(Argill.limest.) 2 m. ($6^1/_2$ ft)	
	serpentinus	*Harpoceras falciferum*	Lower Cephal. Bed 1 m. (3 ft.)	Shales with septaria 12 m. (40 ft.)
		Harpoceras exaratum	Fish Bed (shale and limest. 0,6 m. (2 ft.)	
	annulatus	*Dactyl. tenuicostatum*	absent ?	Shales with fish and insect-limestone 2,5 m. (8 ft.)
Domerian	*acutus*	*Tiltoniceras acutum*	Transition-bed	absent ?
	spinatus	*Paltopleur. spinatum*	Marlstone rock-bed 0,2 m. (8 in.)	Marlstone rock-bed 2—6 m. (6—20 ft.)
	margaritatus	*Amaltheus margaritatus*	Clays and limestones 6—12 m. (20—40 ft.)	Blue and grey micaceous sh. w. cementstones-2—11 m. (6—36 ft.
		Seguenzic. algovianum	Sandy micaceous shales 18—24 m. (60—80 ft.)	
Charmouthian	*capricornus*	*Aegoceras capricornu*	Clay-thickness uncertain	Clays with septaria 18 m. (60 ft.)
	henleyi	*Liparoceras striatum*		Ironstone (Pecten bed) 1,2 m. (4 ft.)
	ibex	*Acanthopleur. valdani*		Clay 27—42 m. (90—140 ft.)
	jamesoni	*Uptonia jamesoni*		
	armatus	*Deroceras armatum*		
	raricostatus	*Echioceras raricostatum*	Clay 1 m.	
Sinemurian	*oxynotus*	*Oxynoticeras oxynotum*	Clay 6 m. (20 ft.)	
	obtusus	*Asteroceras obtusum*	Clay 6 m. (20 ft.)	
	turneri	*Arnioc. semicostatum*	Clay	Frodingham Iron-Ore 1,5—9 m. (5—30 ft.)
	bucklandi	*Coronic. gmuendense*	Argillaceous limestone and shales	
		Coroniceras rotiforme		
Hettangian	*angulatus*	*Schlotheimia marmorea*		
		Waehneroc. megastoma		Argillaceous limestone and shales 50 m. (160 ft.)
	planorbis	*Psiloceras planorbe*		
	Ostrea beds		? Shales 6 m. (20 ft.)	Clays with limestone bands 6 m. (20 ft.)
	Pleuromya beds			

ROCKS OF BRITAIN.

Yorkshire	Scotland — East Coast	Scotland — West Coast
Aalenian-murchisonae ?	Vesulian ?	Aalenian-scissum ?
absent ?	absent	probably present
Blea Wyke beds: Yellow sands 8 m. (26 ft.) Grey sands 12 m. (40 ft.)		absent ?
absent ?		
Striatulus-shales 20 m. (65 ft.)		
Shales- 4 m. (13 ft.) +	absent	Blue shales with nodules, jet and pyrites in places 18—30 m. (60—100 ft.)
Alum Shale (grey shale with much disseminated marcasite 27 m. (90 ft.)		
Hard-dark shale 20 m. (65 ft.)		
Jet-rock 7 m. (23 ft.)		
Grey shale 9 m. (30 ft.)	absent	Scalpa beds: sandy limestones and calcareous grits with Raasay iron-ore
absent ?		
Clevel. Ironstone and Upper Kettleness beds 9—16 m. (30—52 ft.)		
Lower Kettleness beds (micaceous sandy shales) 19 m. (62 ft.)		
Staithes beds (sandy shales) 14 m. (46 ft.)		
Shale with ironstone-doggers 36 m. (120 ft.)	(Upper zones absent ?) Dark blue micaceous shales 24 m. (80 ft.) +	Pabba beds sandy micaceous shales (Scalpa and Pabba beds: 150 m. (500 ft.))
Shales with ironstone-doggers 40 m. (130 ft.)		
Blue shale with ironstone-doggers 27 m. (90 ft.)		
Blue shale with sandy bands 13 m. (42 ft.)	absent ?	absent
Shale with limest. bands 2,5 m. (8 ft.)		
Shale with some limestone-bands 17 m. (56 ft.)	absent ?	absent
Shale with thin bands of earth and shelly limestone 54 m. (180 ft.)	alternations of sandst. a. micaceous shale 27 m. (90 ft.)	limestones and shales 120 m. (400 ft.)
Blue shale with limestone-bands 9 m. (30 ft.)	Estuarine beds: sandst. shales and thin coals 120—150 m. (400-500 ft.)	Calcareous sandston. with coral-bands. Ostrea irregularis 60 m. (200 ft.)
Blue Clay with limestone-bands ? 17 m. (56 ft.)		

MIDDLE JURASSIC ROCKS OF BRITAIN.

Stages	Older Zones	Modern Zones	Dorset		Somerset and Wilts	Gloucestershire
Upper Bathonion (Bradfordian)		*Clydoniceras discus* Sow.	Cornbrash 9 m. (30 ft.)		Cornbrash 6 m. (20 ft.)	Cornbrash
		Epithyris marmorea Oppel	Forest Marble 24 m. (80 ft.)		Forest Marble 18—30 m. (60—100 ft.)	Forest Marble 22—33 m. (72—110 ft.)
		Ornithella digona J. Sow.	Rhynchon. boueti-bed 0,35 m. (14 in.)		Bradford Clay 3 m. (10 ft.)	Bradford Clay 1—2,5 m. (3—8 ft.)
		Epithyris bathonica, S. Buckman	Upper Fuller's Earth Clay 9 m. (30 ft.)		Great Oolite 16 m. (52 ft.)	Great Oolite: Kemble beds 9 m. (30 ft.); Whitelimestone 3 m. (10 ft.); Lower beds 7,5 m. (25 ft.); Stonesfield Slate 4.5 m. (15 ft.)
		Teloceras subcontractum Morris and Lycett	Fuller's Earth Rock (where present) 10 m. (33 ft.)			
Lower Bathonian (Vesulian)	Ammonites parkinsoni	*Ostrea acuminata,* Sow.	Lower Fuller's Earths Clay 20—35 m. (65—115 ft.)		Fuller's Earth Clay 40—45 m. (130—150 ft.)	Fuller's Earth Clay 25 m. (80 ft.) thinning to 0.3 m. (1 ft.)
		Oppelia fusca Quenstedt				Chipping Norton Limestone 6 m. (20 ft.)
		Zigzagiceras zigzag d'Orb.	1—10 m. (3—33 ft.)	Upper Inferior Oolite (variable beds, mainly limestones.)		
		Parkinsonia schloenbachi Schlippe	0,1—1 m. (4—40 in.)		Rubbly beds and Anabacia limestones 4 m. (13 ft.)	Clypeus Grit 2—4.5 m. (6—15 ft.)
		Strigoceras truellii d'Orbigny	0,1—6 m. (4 in.—20 ft.)		Doulting Stone 13 m. (43 ft.)	
		Garantiana garantiana d'Orb.	0,15—9 m. (6 in.—30 ft.)		Upper Trigonia Grit 1,5 m. (5 ft.)	Upper Trigonia Grit 0,6-3,6 m. (2-12 ft.)
Bajocian (restricted)	Ammonites humphriesianus	*Strenoceras niortense* d'Orb.	0,1—1 m. (4—40 in.)	Middle Inferior Oolite (variable beds, mainly limestones.)	absent	absent
		Teloceras blagdeni Sow.	0,075—0,7 m. (3—28in.)			
		Otoites sauzei d'Orbigny	0,1—1,8 m. (4 in.—6 ft.)		0,5 m. (1½ ft.) — Ironshot Oolites of Dundry	T. phillipsiana and Bourguetia beds 7 m. (23 ft.)
		Witchellia	0,4—4 m. (16 in.—13 ft.)		0,5 m. (1½ ft.) — Ironshot Oolites of Dundry	Ironshot limestone T. wrighti 1,2 m. (4 ft.)
		Shirbuirnia	0—0,2 m. (0—8 in.)		0,5 m. (1½ ft.) — Ironshot Oolites of Dundry	Notgrove Freestone 3-9 m. (10-30 ft.) Gryphite Grit 1.5 m. (5 ft.)
		post-discites	0,2 m. (8 in.)		?	T. buckmani Grit 3,6 m. (12 ft.)
		Hyperlioceras discites Waagen	0,1—2 m. (4 in.—6 ft.)		Grey limestone and marl-beds 1,5 m. (5 ft.)	Lower Trigonia Grit 2 m. (6 ft.)
Aalenian	Ammonites murchisonae	*Ludwigella concava* Sow.	0.1—2 m. (4 in.—6 ft.)	Lower Inferior Oolite (variable beds, mainly limestones.)		Snowshill Clay 0.4 m. (16 in.) Harford Sands 1,5 m. (5 ft.)
		Brasilia bradfordensis S. Buckman	0,025-0,675 m. (1-27 in.)		Grey limestones 2 m. (6 ft.)	Upper Freestone 2—6 m. (6—20 ft.) Oolite Marl 1,5—3 m. (5—10 ft.)
		Ludwigia murchisonae Sow.	0,375-3,3m. (15 in.-11 ft.)			Lower Freestone 13-39 m. (43-130 ft.) Pea Grit 1—6 m. (3—20 ft.)
		Ancolioceras	0—0,75 m. (0—30 in.)			Lower Limestone — 3-7.5m. (10-25ft.)
		Tmetoceras scissum Benecke	Bridport Sands (upper part) 12 m. (40 ft.)		Bluish clay-stone (of Dundry) 0.1 m. (4 in.)	Sandy ferruginous beds — 3-7.5m. (10-25ft.)
		Cypholioceras opaliniforme S. Buckman				Hard ironshot stone — 3-7.5m. (10-25ft.)
		Pleydellia aalensis Zieten				Top of Cephalopod bed

MIDDLE JURASSIC ROCKS OF BRITAIN.

Stages	Older Zones	Modern Zones	Oxfordshire	Northamptonshire and Lincolnshire	Yorkshire	Scotland East Coast	Scotland West Coast
Upper Bathonian (Bradfordian)		*Clydoniceras discus* Sow.	Cornbrash (lower part) less than 4 m. (13 ft.)	Cornbrash (lower part, in Northants only) 1 m?	absent	absent or represented by part of the Estuarine beds	absent or represented by part of the Estuarine beds
		Epithyris marmorea Oppel	Forest Marble limestone above 5 m. (16 ft.); clay below 5 m.	Blisworth Clay 5.5 m. (18 ft.)			
		Ornithella digona J. Sow.	?	?			
		Epithyris bathonica, S. Buckman	Great Oolite Limestone 19 m. (62 ft.) Stonesfield Slate 8 m. (26 ft.)	Great Oolite Limestone 4—10 m. (13—33 ft.)			
		Teloceras subcontractum Morris and Lycett					
Lower Bathonian (Vesulian)	Ammonites parkinsoni	*Ostrea acuminata*, Sow.	Neæran beds 4.5 m. (15 ft.)	Upper Estuarine beds 4,5—10 m. (15—33 ft.) represent some of these zones	Upper Estuarine beds 15—60 m. (50—200 ft.) represent some of these zones	Estuarine beds (sadstones, and clays with Brora coal, 1 m at the top.) 70 m. (230 ft.) + (base not seen).	Estuarine beds (sandstones, shales and thin coals) 250 — 300 m. (800—1000 ft.) Marine limestones at base 13 m. (43 ft.)
		Oppelia fusca Quenstedt	Chipping Norton Limestone and Trigonia signata beds 6 m. (20 ft.)				
		Zigzagiceras zigzag d'Orb.					
		Parkinsonia schloenbachi Schlippe	Clypeus Grit 4 m. (13 ft.)				
		Strigoceras truellii d'Orbigny					
		Garantiana garantiana d'Orb.	absent				
Bajocian (restricted)	Ammonites humphriesianus	*Strenoceras niortense* d'Orb.					White sandst. w. plant-remains 18 m. (60 ft.)
		Teloceras blagdeni Sow.		Lincolnshire Limestone 24—30 m. (80—100 ft.) (represents discites and some higher zones)	Scarborough Grey Limest. 6 m. (20 ft.)		Alternations of Sandstone and shale with marine fossils 48 m. (160 ft.)
		Otoites sauzei d'Orbigny			Middle Estuarine beds 15—30 m. (50—100 ft.)		
		Witchellia					
		Shirbuirnia					
		post-discites					
		Hyperlioceras discites Waagen			Millepore Oolite 4,5-9 m. (9-30 ft.)		
Aalenian	Ammonites murchisonae	*Ludwigella concava* Sow.		Collyweston Slate 0,6—3 m. (2—10 ft.)	Lower Estuarine beds (w. Eller Beck bed about middle) 45-90 m. (150-300 ft.)		Sandy micaceous shales 36 m. (120 ft.)
		Brasilia bradfordensis S. Buckman		Lower Estuarine beds 4,5 m. (15 ft.) (represent some portion of these zones)			
		Ludwigia murchisonae Sow.			"Dogger" (variable beds) 1-12 m. (3-40 ft.)		
		Ancolioceras					
		Tmetoceras scissum Benecke		Northampton Sands variable beds 9 m. (30 ft.), Ironstone beds 9 m	absent		
		Cypholioceras opaliniforme S. Buckman		absent	absent (or part of Blea Wyke beds?)		
		Pleydellia aalensis Zieten					

UPPER JURASSIC AND LOWER

	SERIES		ZONES		YORKSHIRE	LINCOLNSHIRE	NORFOLK &c.
LOWER CRETACEOUS	Albian		*Belemnites minimus* Lister	*Mortoniceras rostratum* Sowerby	Red Chalk 9 m. (30 ft.)	Red Chalk 4 m. (13 ft.)	Red Chalk 1,5 m. (5 ft.)
				Hoplites lautus Sowerby			
				Hoplites interruptus Bruguière	Speeton Clay, A (Passage Marls) 2 m.	Carstone 6—12 m. (20—40 ft.)	
			Belemnites brunsvicensis Strombeck	*Douvilléiceras mammillatum* Schlotheim	?	?	Carstone [ferruginous sandstone] 12 m. (40 ft.) Snettisham Clay [marine fossils and ferns] 0-9m.(0-30ft.)
	Aptian			*Hoplites deshayesi* Leymerie	Speeton Clay, B 44 m. (145 ft.)	Tealby Limestone 4 m. (13 ft.) passing southward into Roach Ironstone 11 m. (36 ft.)	
	Neocomian		*Belemnites jaculum* Phillips	*Simbirskites speetonensis* Young and Bird	Speeton Clay, C 1—6; 24 m. (80 ft.)	Tealby Clay 21—25 m. (70—80 ft.)	Sandringham Sands 30 m. (100 ft.)
				Simbirskites subinversus M. Pavlow	Speeton Clay, C 6—7; 5 m. (16 ft.)		absent
				Neocomites regalis Pavlow	Speeton Clay, C 8—11, D 1 (part), 7,5 m. (25 ft.)	Claxby Ironstone 1,5—4,5 m. (5—15 ft.)	
UPPER JURASSIC	Purbeckian (Aquilonian)		*Belemnites lateralis Phillips*	*Olcostephanus gravesiformis* Pavlow	Speeton Clay, D 1—3, 3 m. (10 ft.)	Spilsby Sandstone 2—14 m. (6—46 ft.)	
				Craspedites fragilis Trautschold	Speeton Clay, D 4—8, 8 m. (26 ft.)		
	Portlandian (sensu anglico)	Portlandian (sensu gallico)		*Perisphinctes giganteus* Sowerby	?	?	
				Perisphinctes pseudogigas Blake	?	?	
				Perisph. eastlecottensis Salfeld	?	?	
				Perisph. pectinatus Phillips			
	Kimmeridgian (sensu anglico)			*Olcostephanus pallasianus* d'Orbigny	Coprolite-bed, E 0,1 m. (4 in.)	Phosphatic nodule-band	Kimmeridge Clay
		Kimmeridgian (sensu gallico)		*Aulacostephanus pseudomutabilis* de Loriol	Kimmeridge Clay 150 m. (500 ft.) +	Kimmeridge Clay 90 m. (300 ft.) phosphatic nodules at base	
				Rasenia cymodoce d'Orbigny			
				Amœboceras serratum Sowerby	Upper Calcareous Grit 9-14 m. (30-46 ft.)		
	Corallian (sensu anglico)	Sequanian		*Perisphinctes martelli* Oppel	Upper Limestone and Coral Rag 12—15 m. (40—50 ft.) Middle Calcareous Grit 5-25m. (16-80 ft.)	Ampthill Clay (selenitic clay) 7 m. (23 ft.)	Ampthill Clay (selenitic clay)
		Oxfordian (sensu gallico)		*Aspidoceras catena* Sowerby	Lower Limestone 0—18 m. (0—60 ft.) Passage beds 0—12 m. (0—40 ft.)	absent	absent
				Cardioceras cordatum Sowerby	Lower Calcareous Grit 15-40 m(50-130ft.)		
	Oxfordian (sensu anglico)			*Cardioceras* sp.	Oxford Clay 6—45 m. (20—150 ft.)	Oxford Clay 90 m. (300 ft.)	Oxford Clay
		Callovian (sensu gallico)		*Crenic. renggeri* Op.	Kellaways Rock 3—30 m (10—100 ft.)		
				Peltoc. athleta Phill.			
				Cosmoceras duncani Sowerby			
	Callovian sensu (anglico)			*Sigaloceras calloviense* Sow.		Kellaways Rock 0—1 m Kellaways Clay 6 m. (20 ft.) Cornbrash 1—2 m. (3—6 ft.)	Kellaways Rock Cornbrash 2—6 m. (6—20 ft.)
				Propl. koenigi Sow.			
				Macrocephalites macrocephalus Schlotheim	Dark Shales 2-3 m.(6-10 ft.) Hard ferruginous limestone and calcareous shales- 1-3 m. (3-10 ft.)		

CRETACEOUS ROCKS OF BRITAIN.

CAMBRIDGE-SHIRE	BEDFORD-SHIRE	BUCKINGHAM-SHIRE & OXFORD-SHIRE	WILTSHIRE & BERKSHIRE	VALE OF WAR-DOUR. &c.
Partly absent from denudation Gault Clay 30—55 m. (100—180 ft.)	Upper Gault, in part removed by denudation Gault Clay 45—55 m (150—180 ft.)	Gault Clay with phosphatic nodules 50—60 m. (160—200 ft.)	Malmstone and micaceous sands 37 m. (120 ft.) Grey Gault Clay 27—52 m. (90—170 ft.)	Malmstone and micaceous sands- *Exogyra columba* 32-36 m. (105-120 ft.) Grey sandy micaceous Gault Clay 12 m. (40 ft.)
Brown, yellow and white sands with phosphatic nodules at base. *H. deshayesi* and derived Jurassic and Lower Cretaceous fossils 4-20m (13-65 ft).	WoburnSands [with rare Brachiopod limestone] 75 m Beds of Fullers Earth 4 m. (13 ft.) in middle portion: phosph nodules with derived Jurassic fossils at base	Thin basement bed 0,1 m. (4 in.) Variable sands 0-15m. (0-50 ft.) + resting on Purbeck, Portland or Kimmeridge series	Thin basement bed 0.1 m. (4 in.) Faringdon beds (Sponge-gravels and sands) 0-30 m. (0-100 ft.) *Bel. speetonensis*, resting on Kimm. Clay	Sands 10 m. (33 ft.)
absent	absent	Freshwater (Wealden) Ironsands of Shotover and Brill 15 m. (50 ft.) resting on Purbeck or Portland beds		Wealden Clays 10 m. (33 ft.)
		Middle and Lower Purbeck beds (marls and thin-bedded limestones) 4—5 m. (13—16 ft.)	Purbeck marls and thin-bedded limestone 6 m. (20 ft.)	Upper Purbeck clays and marls 6 m. (20 ft.) Middle Purbeck marls and sandstones *Archaeoniscus* 4 m. Low. Purb. limest. shal. and dirt-beds 16.5 m.
		Creamy limest. 3,5 m. ($11\frac{1}{2}$ ft.) Sands 1,5 m. (5 ft.) Rubbly limest. 2,5 m. (8 ft.) Glauconitic sands3m. (10ft.) Pebble-bed with derived Kimmeridge ammonites Hartwell Clay [sandy glauc.] 4 m. (13 ft.) + ?	Chalky limestone 1—2 m Oolitic limestone with *Trigonia*-casts 2 m Sands and calcareous sandst. 8 m. (26 ft.) Limestone ("cockly bed") 2,5 m. Pebble-bed with derived phosphatic casts Swindon Clay 4-6 m. (13-20 ft.) Marly Sandst., *E. Bruntrutana* 1-3 m. (3-10 ft.) Sands with doggers 12 m. (40 ft.)	[illegible] 3-5m. [illegible] *[illegible]astraea oblonga* (silicified) 2-8 m. Ragstones 2.5 m Lower Build. stones (oolitic and sandy limest.) 5.5m. Pebble-bed Portland Sands 12 m. (40 ft.]
UpperKimmeridge Clay (bituminous shale) *Orbiculoidea latissima Exogyra virgula* 5 m. (16 ft.) Lower Kimm. Clay black clays, phosphatic nodules at base *Ostrea deltoidea* 38 m. (125 ft.)		Upper Kimmeridge Clay (shaley, with lignite) 15 m. (50 ft.) Lower Kimmeridge Clay (selenitic) *Ostrea deltoidea*. 15 m. (50 ft.)	Kimmeridge Clay 90 m. (300 ft.)	Kimmeridge Clay (thickness uncertain) Westbury Iron-Ore 3 m. (10 ft.)
Coral Rag 3 m. (10 ft.) Oolitic Limestone 6 m. (20 ft.) + Elsworth Rock (limestone with ferruginous oolite grains) 3 m. (10 ft.)	Ampthill Clay 18 m. (60 ft.) Elsworth Rock (inconstant) at base	Ampthill Clay, with Elsworth Rock at base, passing westwards into Coral Rag and Oolite	Coral Rag, falsebedded sands, loamy clay and oolitic limestone (variable) 10 m. (33 ft.)	Sandsfoot Clay 7 m. Sandy, shelly and oolitic limestones 18 m. (60 ft.)
absent	absent	absent ArngroveStone (*Rhaxella*-chert) locally 2 m. (6 ft.)	Sands and calcareous sandstones 5 m. (16 ft.)	Clays and sands with doggers 8 m. (26 ft.)
Oxford Clay dark blue and grey clays with bands of septaria; occasionally with much selenite) ? 150 m. (500 ft.)	Oxford Clay	Oxford Clay 120 m (400 ft.)	Upper Oxford Clay 90 m. (300 ft.) Middle Oxford Clay 30 m. (100 ft.) Lower Oxford Clay 34 m. (110 ft.)	Oxford Clay 125 m. (400 ft.) ?
	Kellaways Rock (Calcareous sandst. and sands) 3 m. (10 ft.)	Sands 2 m. (6 ft.)	Shelly clay and calcareous sandstone 19 m. (62 ft.)	
Upper part of Cornbrash-less than 2—5 m. (6—16 ft.)	Kellaways Clay (se-[illegible] ft.) Upper part of Cornbrash 1 m.	Clay 0-4 m. (0-13 ft.) Upper part of Cornbrash less than 4 m. (13 ft.)		

UPPER JURASSIC AND LOWER

	SERIES			ZONES	DEVONSHIRE	DORSET COAST
LOWER CRETACEOUS	Albian		*Belemnites minimus* Lister	*Mortoniceras rostratum* Sowerby	Glauconitic Sands with layers of chert- 37 m. (120 ft.) *Exogyra conica, Neithea 4-costata* (resting on Lias, Trias or Permian)	Glauconitic Sands with layers of stone *Ex. conica, Neithea 5-costata* 24 m. (80 ft.)
				Hoplites lautus Sowerby		Sandy Gault Clay with few fossils 20 m. (65 ft.)
				Hoplites interruptus Bruguière		
			Belemnites brunsvicensis Strombeck	*Douvilléiceras mammillatum* Schlotheim		White and ferruginous sands 45 m. (150 ft.) Atherfield Clay 15 m. (50 ft.)
	Aptian			*Hoplites deshayesi* Leymerie		
	Neocomian		*Belemnites jaculum* Phillips	*Simbirskites speetonensis* Young and Bird		Wealden Shales Wealden Sands with lignite 60—600 m. (200—2000 ft.)
				Simbirskites subinversus M. Pavlow		
				Neocomites regalis Pavlow		
UPPER JURASSIC	Purbeckian (Aquilonian)		*Belemnites lateralis* Phillips	*Olcostephanus gravesiformis* Pavlow		Upper Purbeck freshwater shales and limest., *Vivipara, Unio,* etc 8—19 m. (26—62 ft.) Middle Purbeck marine and freshwater limestones *Hemicidaris purbeckensis, Ostrea distorta,* etc. 16-51 m. (52-170 ft.)
				Craspedites fragilis Trautschold		Lower Purbeck marls and dirt-beds 27-52 m. (90-170 ft.)
	Portlandian (sensu anglco)	Portlandian (sensu gallico)		*Perisphinctes giganteus* Sowerby		Freestones (oolitic limestones) *Perisph. giganteus* 9 m. (30 ft.)
				Perisphinctes pseudogigas Blake		Cherty series (limestones with nodules and bands of chert) 20 m. (65 ft.)
				Perisph. eastlecottensis Salfeld		Portland Sands (glauconitic) *Trigonia pellati, Exogyra bruntrutana* 40 m. (130 ft.)
				Perisph. pectinat. Phill.		
	Kimmeridgian (sensu anglico)			*Olcostephanus pallasianus* d'Orbigny		
		Kimmeridgian (sensu gallico)		*Aulacostephanus pseudomutabilis* de Loriol		Upper Kimmeridge Clay (dark bituminous shales with cementstones) *Orb. latissima, Exogyra virgula* 195 m. (640 ft.)
				Rasenia cymodoce d'Orbigny		Lower Kimmeridge Clay *Ostrea deltoidea, Rhynch. inconstans* 120 m. (400 ft.)
				Amœboceras serratum Sowerby		Sandsfoot Grits 5—6 m. (16—20 ft.)
	Corallian (sensu anglico)	Oxfordian (sensu gallico)		*Perisphinctes martelli* Oppel		Sandsfoot Clay 8 m. (26 ft.) *Trigonia* beds *T. clavellata* 4,5 m. (15 ft.) Osmington Oolite 18 m. (60 ft.)
				Aspidoceras catena Sowerby		Bencliff Grits 3 m. (10 ft.) Nothe Clay 12 m. (40 ft.) Nothe Grits *G. dilatata* auctt. 11 m. (36 ft.)
				Cardioceras cordatum Sowerby		
	Oxfordian (sensu anglico)			*Cardioceras* sp.		Upper Oxford Clay (bluish-grey clay with red septaria) 75 m. (250 ft.)
		Callovian (sensu gallico)		*Crenic. renggeri* Opp.		Middle Oxford Clay with pyritized fossils *Bel. hastatus.* 25 m. (80 ft.) ?
				Peltoc. athleta Phill.		
				Cosmoceras duncani Sowerby		Lower Oxford Clay (thin shales with fragile fossils) 25 m. (80 ft.) ?
	Callovian (sensu anglico)			*Sigaloceras calloviense* Sow. *Propl. koenigi* Sow.		Clays with occasional calcar. sandst. *Cadoceras sublaeve, Proplanulites koenigi* 25 m. (80ft.) ?
				Macrocephalites macrocephalus Schlotheim		?

CRETACEOUS ROCKS OF BRITAIN.

ISLE OF WIGHT	WEST WEALD	EAST WEALD	WEST COAST OF SCOTLAND	EAST COAST OF SCOTLAND
Sandstones 18-25 m. (60-80 ft.) Sandy micaceous clay 13-16 m. (43-52 ft.)	Malmstone 40 m. (130 ft.) Sandy marls 15 m. (50 ft.)	Upper Gault Clay (pale grey marl, phosphatic nodules at base) 24 m. (80 ft.)		
Upper Gault Clay 20—25 m. (65—80 ft.)	Gault Clay 30 m. (100 ft.)	Lower Gault Clay (dark clay) 8 m. (26 ft.)		
Lower Gault Clay 6 m. (20 ft.)		Low. Gault Clay (dark clay, phosph. nodules at base) 3,5 m. (11 ft.)		
Carst. 22 m. (72 ft.) Sandrock Ser. 25-57 m. (80-190 ft.) Ferugin. Sands ("Crackers" at base) 75-157 m. (250 to 515 ft.) Atherfield Clay (Perna Bed at base) 18-25 m. (60-80 ft.)	? Ferrug. Sands ("Folkestone Sands") 30 m. (100 ft.) Bargate Stone and Pebble-beds 15 m. (50 ft.)? Sands and chert-beds 90 m. (300 ft.) Atherfield Clay 18 m. (60 ft.)	Greensand with phosphatic nodules 2 m. (6 ft.) Folkest. beds 18,5 m. (60 ft.) Sandgate beds 24,5 m. (80 ft.) Hythe beds 18,5 m. (60 ft.) Atherfield Clay 8 m. (26 ft.)		
Wealden Shales 150 m. (500 ft.) Wealden Sandstone 140 m. (460 ft.)	Weald Clay 270 m. (900 ft.) Tunbridge Wells Sands 115 m. (380 ft.) Wadhurst Clay 48 m. (160 ft.) Ashdown Sands 150 m. (500 ft.)	Weald Clay 115 m. (38 ft) Tunbridge Wells Sands 45 m. (150 ft.) Wadhurst Clay 30 m. (100 ft.) Ashdown Sands 120 m. (400 ft.)		Glauconitic sandstone (in glacial drift)
		Purbeck beds (limestones and shales with gypsum) up to 170 m. (560 ft.)		
		Portland Stone and Sand (known only in borings) 40 m. (130 ft.)		
		Kimmeridge Clay (known only in borings) 380 m. (125 ft.) ?		Estuarine sandstones (unfossiliferous) 35 m. (115 ft.) "Brecciated beds" coarse shelly limestones and carbonaceous shales 170 m. (560 ft.) Marine and estuarine sandstones 130 m. (430 ft.)?
		Corallian rocks (known only in borings) 100 m. (330 ft.)		
		Oxford Clay (known only in borings) 50 m. (160 ft.)	Dark blue clays with septarian nodules thickness uncertain	Limestones, clays and sandstone 60 m. (200 ft.) ? Estuarine sandst. with marine bands 150 m. (500 ft.) Fine grained sandst. with plants and marine fossils 8 m. (26 ft.)
				Sandy shales 75 m. (250 ft.) laminated black shales 23 m. (75 ft.) calcareous sandstone 2 m. (6 ft.)

Zonal Position of the principal Iron-Ores and Building-Stones of the Jurassic Rocks of Great Britain.

Iron-Ores.	Zones.	Building-Stones.
	Upper Purbeck	Purbeck Marble
	Middle Purbeck	Swanage
	Lower Purbeck	
	giganteus	Portland
	peudogigas	Chilmark
	pectinatus	
	pallasianus	
	pseudomutabilis	
Abbotsbury	cymodoce	
Westbury	pseudocordatus	
	serratum	
	martelli	Oxford
	catena	
	cordatum	
	renggeri	
	athleta	
	ornatum	
	calloviense	
	koenigi	
	macrocephalus	
	discus	
	marmorea	Frome,etc.
	digona	
	bathonica, subcontractum	Bath, Corsham etc.
	gracilis	Stonesfield*
	acuminata	
	fusca	BradfordAbbas
	zigzag	
	schlœnbachi	
	truellii	Doulting, Dun-[dry
	garantiana	
	niortense	
	blagdeni	
	sauzei	
	Witchellia	Cotteswolds
	Shirbuirnia	
	post-discites	
	discites	Lincolnshire

Iron-Ores.	Zones.	Building-Stones.
	concava	Collyweston*
Eller Beck	bradfordensis	Painswick
Rosedale	murchisonae	Cheltenham
Northampton-shire	scissum	Duston
	opaliniforme	
	aalensis	
	moorei	Ham Hill
	Dumortieria	
	dispansum	
	struckmanni	
	striatulum	
	variabilis	
	lilli	
	braunianum	
	fibulatum	
	subcarinatus	
	falciferum	
	exaratum	
	tenuicostatum	
Raasay	acutum	
Cleveland, Leicestershire, Banbury	spinatum	Hornton
	margaritatus	
	algovianum	
	capricornu	
	striatum	
	valdani	
	jamesoni	
	armatum	
	raricostatum	
	oxynotum	
	obtusum	
Frodingham	semicostatum	
	gmuendense, rotiforme, marmorea	Hydraulic limestone, Dorset to Nottingham
	megastoma	Sutton Stone
	planorbis	

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* Collyweston and Stonesfield yield roofing "slates".

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c. Ireland.

By G. A. J. COLE.

The only Jurassic strata in Ireland are of Lower Liassic age. Middle Liassic fossils bave been found in the boulder-clays of Co. Antrim and even of Co. Dublin. In Co. Dublin *Hildoceras bifrons* of the Upper Lias is also recorded (TATE 1870, SOLLAS and PRAEGER 1895). These drifted specimens may, however, have come from Scottish sources or from the Irish Channel. The Irish beds are all closely connected with the protective covering formed by the north-eastern basaltic plateaus; but even here only a part of the Lower Lias remains preserved. The epoch of denudation that prevailed also in parts of England before the Cretaceous strata were laid down has destroyed any higher Jurassic beds in Ireland. Lower Liassic limestones and shales are well seen on the coast just north of Larne in Co. Antrim. The zones that remain are those of *Psiloceras planorbis*, *Schlotheimia angulata*, and *Arietites bucklandi*. The lowest beds graduate conformably into the Rhætic marls. At Collin Glen, south-west of Belfast, shales and limestones occur under the Cretaceous glauconitic sands, and contain *Aegoceras intermedium*, *Gryphaea arcuata*, *Lima gigantea*, and *Modiola minima*. The zone of *Psiloceras planorbis* is traceable on Cave Hill, and small patches of Lower Lias, much squeezed in places by landslide movements, occur at various points round the basalt and chalk escarpment (TATE 1863 and 1870). The occurrence of Liassic beds near Lough Foyle shows that the Jurassic sea spread as far westward as that of Rhætic days.

The highly altered calcareous shales of the Lias at Portrush, into which a sheet of Kainozoic dolerite has intruded from below, formed the subject of a historic controversy between the vulcanists and the Wernerian school. The history of this is well summarised by PORTLOCK, 1843. Impressions of ammonites are clearly seen at Portrush on the surface of a black flinty rock, which is the product of contact metamorphism of the shales. The mineral characters of this rock have been studied in detail by PORTLOCK 1843 and others (LACROIX 1893, COLE 1906, THOMSON 1907).

The Jurassic period was mostly marked by elevation in Ireland, and the Scottish deposits of the same age again and again suggest the nearness of a shoreline. We must not, however, forget the large area over which marine Jurassic strata at one time existed in England, and from which they have now entirely disappeared. It is very doubful, however, if marine conditions prevailed in the Jurassic period in any part of Ireland later than Upper Liassic times.

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11. Lower Cretaceous.

Great Britain.

By A. M. DAVIES.

A. Speeton Clay.

Above the "compound nodular band", which is taken as the base of the Lower Cretaceous at Speeton (Fig. 47) are 36 m. (120 ft.) of clays with *Belemnites jaculum* PHILLIPS and other belemnites of more southerly type than those in the zones above and below. Associated with these are boreal ammonites of the genus *Simbirskites*, by means of which finer zonal divisions have been recognized. In the highest zone occurs the southern echinid *Echinospatagus cordiiformis* BREYN. (*Toxaster complanatus* AG.). Other fossils of the jaculum zone are *Exogyra sinuata* Sow. and *Terebratula sella* Sow.

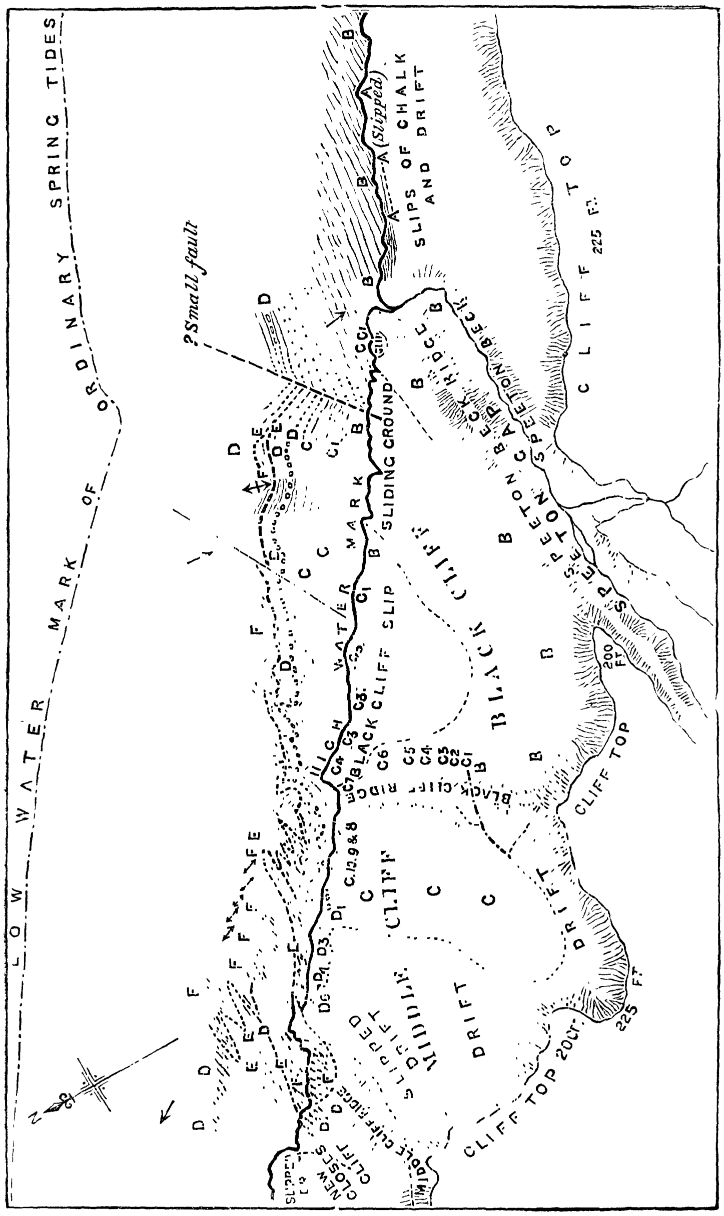

Fig. 47. Ground-plan of the Coast at Speeton showing the course of the beds on the shore and in the foot of the cliff (G. W. LAMPLUGH). Scale, 1 : 7,040 or 9 inches = 1 mile.

A = Marly clays with *B. minimus* etc. (slipped); B = Clays of zone of *B. brunsvicensis*; C = Clays of zone of *B. jaculum*, PHIL.; D = Clays of zone of *B. lateralis*, PHIL.; E = Coprolite-bed . . . . . .; F = Bituminous shale with *B. oweni* and its varieties; oooo = Compound Nodular Band (D[1]).

(The lines show the strike; where continuous, the beds have been actually observed; where broken, they are suppositious.)

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Above the jaculum-zone come 30 m. (100 ft.) of clays, 15 m. (50 ft.) of "Cement-beds" and perhaps 15 m. (50 ft.) of black clay, in all of which *Bel. brunsvicensis* STROMB., and allied boreal species occur. *Hoplites deshayesi* LEYM., *Exogyra sinuata* SOW., *Syncyclonema orbicularis* SOW. are also recorded from this zone. A slightly higher horizon seems to be indicated by a bed of marly clay with *Bel. fusiformis* VOLTZ, which is followed by marls with *Bel. minimus* LISTER, which in turn pass up into the Red Chalk, to be described later.

The probable correlation of these several divisions of the Speeton Clay is shown in the table given on pp. 240—243.

B. Neocomian of Lincolnshire.

Resting conformably on the Spilsby Sandstone is the highly fossiliferous Claxby Ironstone, formerly worked as an iron-ore. Although its lower part is closely linked to the underlying beds by having belemnites of the *lateralis*-group, the upper part contains *Belemnites jaculum* PHILIPPS, and ammonites such as *Polyptychites blakei* PAVLOV, and *P. beani* PAVLOV occur throughout, while *Neocomites regalis* PAVLOV occurs at least in the upper portion. It is therefore necessary to draw the line between Jurassic and Cretaceous either within the thickness of this formation or at the base of it. The most abundant fossils are Lamellibranchs, e. g. *Arca raulini* LEYM., *Exogyra sinuata* SOW., *Pecten cinctus* SOW. and *Trigonia ingens* LYCETT. Other species are *Pleurotomaria neocomiensis*, *Rhynchonella walkeri* DAV., *Terebratula praelonga* SOW., *Waldheimia tamarindus* SOW., *W. faba* D'ORB.

Above the Claxby Ironstone lies the Tealby Clay, a sandy clay with pyritic fossils, which include *Belemnites jaculum* PHILL., *Simbirskites umbonatus* LAHUSEN, *Exogyra sinuata* SOW., and *Perna mulleti* DESH. Not much is known of this clay, owing to the infrequency of exposures.

Above it lies the Tealby Limestone (replaced to the south by Clay and ironstone). This yields *Belemnites brunsvicensis* STROMBECK, and allied species, *Ammonites* cf. *carteroni* D'ORB., *Pecten (Camptonectes) cinctus* SOW., *Ostrea (Alectryonia) frons* PARK., and *Exogyra sinuata* SOW.

C. Wealden Beds.

In the South of England, the lithic change from the limestones and marls of the Purbeck to the sandstones of the Wealden beds is very striking, and makes a very convenient level for the division-line between Jurassic and Cretaceous. There is, however no palæontological justification for the separation, the freshwater fauna and land-flora of the two series being very closely related and having many species in common; while there are no marine intercalations in the Wealden by which it can be correlated with the typical marine Lower Cretaceous.

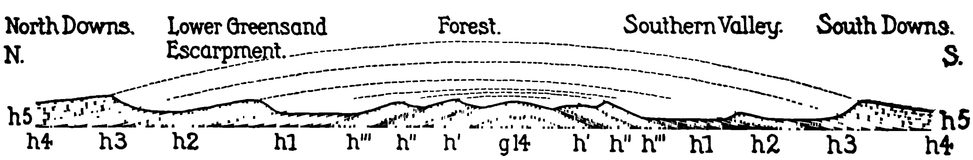

Fig. 48. Diagrammatic Section of the Weald.

h5 = Chalk	h2 = Lower Greensand	h'' = Wadhurst Clay
h4 = Upper Greensand	h1 = Weald clay	h' = Ashdown Sands
h3 = Gault	h''' = Tunbridge Wells Sands	g14 = Purbeck Beds

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The Wealden beds (Fig. 48) are thickest in the western part of the Weald or the concealed area farther west, and thin away in all directions. The lower division is mainly sandy, the upper mainly argillaceous. In the typical area, the lower or Hastings Sands series is divided into three divisions. The lowest consists of soft sandstones or sands (Ashdown sands) with plant remains, including *Endogenites erosa* MANTELL.

The middle division of the Lower Wealden is the Wadhurst Clay, in which are beds of fossiliferous calcareous sandstone (Tilgate Stone), with *Iguanodon mantelli* MEYER, *Hylaeosaurus oweni* MANTELL, *Goniopholis crassidens* OWEN, *Lepidotus mantelli* AG., and freshwater shells, particularly *Cyrena media* Sow., and *Vivipara fluviorum* Sow.

Towards the base of the Wadhurst Clay occur nodules and seams of clay ironstone, which were for many centuries worked as iron-ore — the Weald of Sussex having long been the chief iron-producing district in England, until the utilization of coal in iron-smelting led to the migration of that industry to the coal-fields.

The upper division consists of sands in part consolidated into sandstones, which often weather into very remarkable shapes (Tunbridge Wells sands).

The Upper Wealden or Weald Clay, consists of clays and shales with beds of limestone very similar to the *Paludina* limestones of the Purbeck beds but with other species of *Vivipara* — *V. sussexiensis* Sow. and *V. fluviorum* Sow. The more shaley beds are full of Ostracods. Other freshwater fossils are *Vicarya lujana* and *Unio valdensis* MANTELL.

In the Isle of Wight, only the upper portion of the Wealden beds is exposed, the lowest visible horizon being full of drifted trunks of conifers — the "Pine-raft". On the Dorset coast, sandstones are the principal rock-type, and they contain much lignite. The sandstones become thinner westwards and at the same time coarser and more conglomeratic.

Inland, Wealden beds are exposed in the Vale of Wardour (Fig. 49) and again on Shotover and Brill Hills near Oxford, where they consist of variable sands and clays with rare fossils.

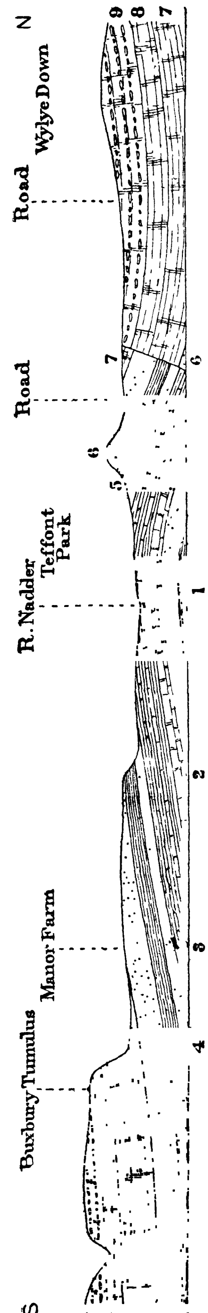

Fig. 49. Section across the Vale of Wardour. Horizontal Scale one mile to an inch or 1: 63,360 Vertical Scale, 1,200 feet to an inch or 1: 14,400.

9 = Upper Chalk; 8 = Middle Chalk, 100 feet; 7 = Lower Chalk, 200 feet; 6 = Upper Greensand, 160 feet; 5 = Gault, 90 feet; 4 = Lower Greensand and Wealden, 60 feet; 3 = Purbeck; 2 = Portland Beds; 1 = Kimmeridge Clay.

Reproduced from the Memoirs of the Geological Survey — Cretaceous Rocks of Britain, vol. II., p. 146, f. 37, 1903; with the permission of the Director and of H. M. Stationery Office.

D. Lower Greensand.

The beds which intervene between the Wealden and the Gault are still almost universally known in England by the unfortunate name of "Lower Greensand", relic of a time when the importance of the Gault was not recognized and it was only looked upon as an intercalation in a "Greensand formation". Although sandy facies predominates in these Aptian strata, glauconite (the presence of which is implied in the prefix "green") is absent from the greater portion. With the beginning of this series marine conditions are again found over a large area of south-east England, and at scattered points in the Midlands.

In the typical locality, near Folkestone, these strata are usually divided into four divisions. At the base is the Atherfield Clay, constant over the whole region south of the London basin. It yields *Perna mulleti* DESHAYES, as well as many fossils common to the next overlying beds.

The Hythe beds are glauconitic limestones and sandstones with *Hoplites deshayesii* LEYM., *Trigonia alaeformis* FORBES, *Exogyra sinuata* SOW., and *Terebratula sella* SOW., as their most distinctive fossils. The Sandgate beds are glauconitic clays, not separable palæontologically from the Hythe beds. The top division, or Folkestone beds consist of light greenish sands with beds of calcareous sandstone and chert full of sponge-spicules. The fossils include *Avicula pectinata* SOW., and *Waldheimia pseudojurensis* LEYMERIE.

Traced inland, the Atherfield Clay alone remains constant in lithic character. The Hythe beds take the form, now of massive glauconitic limestone (Kentish rag), now of thick beds of sponge-spicule-chert, now of unfossiliferous ferruginous sands. The Sandgate beds only maintain their distinctness from the Hythe beds here and there, particularly near Nutfield, where they include valuable deposits of Fuller's earth. The Folkestone beds most frequently take the form of red or white, non-glauconitic, unfossiliferous sands, with bands and irregular masses of hard ferruginous sandstone (carstone).

In the Isle of Wight, the Atherfield Clay is again found with a very fossiliferous Perna-bed *(P. mulleti* DESH.*)* at the base. Above the clay is another highly fossiliferous bed, the "Crackers", yielding *Gervillia sublanceolata* D'ORB., *Panopaea plicata* SOW., *Trigonia daedalea* FORBES, and *Hoplites deshayesii* LEYM.

The overlying beds are nearly all sandy, and different fossil-beds are found in them characterised respectively by *Exogyra sinuata* SOW., *Macroscaphites gigas* SOW., *Crioceras bowerbanki* SOW., and the macrurous decapod *Meyeria vectensis* BELL. In Dorset, the Atherfield Clay is succeeded by white and ferruginous sands, not divisible.

Inland, beds of Aptian age have a very discontinuous outcrop, being over wide areas overlapped by the Gault. Thus at Seend, in Wiltshire, ferruginous sands occur which have been worked for iron-ore, and contain casts of fossils among which *Toucasia lonsdalei* SOW. is most notable. At Faringdon, in Berkshire, there are deposits famous for calcareous sponges, *Raphidonema faringdonense* SHARPE, *Peronidella ramosa* ROEMER, *Barroisia anastomans* MANTELL, Brachiopods, *Terebratella menardi* LAM., *Waldheimia tamarindus* SOW., *Terebratula tornacensis* D'ARCHIAC, *Rhynchonella latissima* SOW., and Echinids *Peltastes wrighti* DESOR, with *Belemnites speetonensis* PAVLOW, and many derived Jurassic fossils. In Bedfordshire, the Aptian sands suddenly attain a great thickness and include valuable fuller's earth deposits; and near the base the Faringdon fauna is found with phosphatised Jurassic fossils. The greater part of the overlying sands is quite unfossiliferous, but at one place near Leighton Buzzard there occurs a bed of limestone with a much later Brachiopod fauna having Cenomanian affinities.

These sands, frequently passing into ferruginous sandstone (carstone) and having often at the base a bed of phosphatic nodules with derived Jurassic fossils, have an almost continuous outcrop from Bedfordshire to Lincolnshire, where there underlie them the Neocomian beds already described. As a transition to these, in Norfolk, the Snettisham Clay which comes below the Carstone, contains an association of marine fossils and plant-remains that indicates the nearness of a land-surface.

E. Gault.

The typical locality for the Gault is Folkestone on the Coast of Kent, where its whole thickness is clearly exposed in cliff-sections, and minute zoning is possible, as follows

		metres	feet
Upper Gault (24 m.)	zone of *Mortoniceras rostratum* Sow.	19	63
	„ „ *Kingena lima* DEFR.	1·75	5
	„ „ *Inoceramus sulcatus* PARK.	3	10
Junction-bed—(clay with nodules)		0·25	0·75
Lower Gault (8 m.)	zone of *Hoplites auritus* Sow. (Dark bed)	2	6
	„ „ *H. denarius* Sow. (Mottled Bed)	0·3	1
	„ „ *H. lautus* Sow. (Coral bed-*Smilotrochus*)	0·5	1·5
	„ „ *Dipoloceras delaruei* D'ORB.	0·1	0·3
	Crab bed *Palaeocorystes stokesi* MANT.	1·4	4·5
	zone of *H. auritus* Sow., var.	1·3	4·25
	„ „ *H. interruptus* BRUG.	3	10
zone of *Douvilléiceras mammillatum* SCHLOTH.		2	6

In most of the zones of the Lower Gault, the index-species is not confined to its zone but only very abundant in it, and for general zonal purposes only the zones given in the table are of value. The *mammillatum*-zone, consisting of a grit with phosphatic nodules, is usually considered as part of the Lower Greensand.

Fossils, beautifully preserved and often iridescent, are very abundant. From the interruptus zone may be mentioned *Desmoceras beudanti* BRONGN., *Hamites rotundus* Sow., and *Nautilus bouchardianus* D'ORB.; from the lautus zone (in the broad sense) various *Hoplites*, *Hamites intermedius* Sow., *Turrilites hugardianus* D'ORB., and *Nucula gaultina* GARD.; from the Upper Gault, *Inoceramus sulcatus* PARK., *Turrilites bergeri* D'ORB.; while *Nucula pectinata* Sow., and *Belemnites minimus* LISTER occur all through.

Traced inland from Folkestone the Gault varies little in character for a great distance, but increases in thickness. With the opening of the Albian epoch, uniform marine conditions were re-established over a wide area as they had not been since the Kimmeridgian. In all the deep borings under the London district, while the beds below the Gault are very inconstant, the Gault maintains itself, only showing a tendency to thin away towards the east. Nevertheless when traced far enough, either northwards or westwards, it undergoes at last marked lithic changes.

Northwards, in Norfolk it passes into a very remarkable thin bed, the Red Chalk, which separates the white Chalk from the Carstone. This is a foraminiferal limestone, with much of the structure of white chalk, but with coarse quartz-grains and a brick-red colour. This persists without very great modification as far as Speeton.

Westwards, the Gault overlaps the Lower Greensand in Dorset and rests unconformably on Jurassic strata (Fig. 50). At the same time, the "Upper Greensand" facies of the strata above the Gault passes downwards through that formation itself, so that in Wiltshire, the rostratum zone is a fine sandy, micaceous and glauconitic limestone; while in Somerset and Devon, the Blackdown Beds with their chert may represent perhaps the whole of the Gault. If not, the Upper Gault has here overlapped the Lower.

F. Lower Cretaceous of Scotland.

No strata comparable to the Speeton Clay are known *in situ* anywhere farther north than Yorkshire; but in the glacial drift of Moreseat, on the east coast of Aberdeenshire, there are abundant remains of a fine glauconitic sandstone with sponge-spicules and many other fossils, which indicate the speetonensis zone and possibly higher zones also. Among the fossils are *Simbirskites* aff. *speetonensis* YOUNG and BIRD, *Crioceras duvalii* LEV., *Cardium raulinianum* D'ORB., *Plicatula placunea* LAM., *Rhynchonella sulcata* PARK., and *Galerites castanea* BRONG. The last-named fossil, though in the same matrix as the rest appears to indicate an Upper Cretaceous horizon. It is possible that the Upper Jurassic strata of Sutherland may, in their submarine extension, be followed by Lower Cretaceous. Upper Cretaceous erratics have also been found in the glacial drift of Caithness.

G. Underground Extension of Lower Cretaceous Rocks.

Many borings in search of water or coal have been made in the London Basin and the Weald, and much is now known of the underground extension of these strata.

Gault. This has been proved to be everywhere present under the London basin, but to thin rapidly eastwards in the Harwich district. In the absence of zonal observations it is not possible to say whether this thinning is due to overlap of the higher zones, or to thinning of all the zones. Over a large area north of the Thames, the Gault rests directly on the Palæozoic rocks which formed the land surface in Portlandian and Neocomian times.

Aptian. In view of the continuity of outcrop from Leighton Buzzard to the Wash, and all round the Weald, it was at one time anticipated that it would be found to be continuous under London and was looked to for a supplementary water-supply to that from the Chalk. This expectation was disappointed, and the occurrence of Aptian beds under the London basin is as sporadic and variable in thickness as in the area to the west.

Wealden. These beds thin out and disappear with startling rapidity to the north of their outcrop. They have not been met with in any one boring in the London basin. They also become thin under the Chalk of north-east Kent, being only 11 m. (36 ft.) thick at Fredville and only 5 m (16 ft.) at Ropersole (see Fig. 46, p. 232.)

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12. Upper Cretaceous.

a. Great Britain.

By H. J. OSBORNE WHITE.

By British geologists the Upper Cretaceous strata of the United Kingdom are usually taken to comprise those beds of Cretaceous age which lie above the base of the zone of *Douvilleiceras mammillatum*, that is to say, the Selbornian (Gault and Upper Greensand) and Chalk formations. In the following article however, we adopt the Continental usage, and place the lower limit of the Upper Cretaceous at the base of the Cenomanian stage, including in that stage the ill-defined and impersistent zone of *Pecten asper*. The several divisions and sub-divisions of the Upper Cretaceous, as thus limited, and their salient lithological features in divers parts of Great Britain, are shown in the accompanying comparative table (pp. 262—263).

The Upper Cretaceous series has its chief development in the south of England, where, by surface outcrop and underground extension, it occupies the greater part of the country that lies to the south-east of a line drawn from West Dorsetshire to the inlet of the Wash. A second tract, separated from the first by the Wash, occupies the area of the Lincolnshire and Yorkshire Wolds; and other tracts, of smaller dimensions, are found in Argyllshire, in the West of Scotland.

A. England.

In this country the prevailing dip of the Cretaceous rocks is to the east, at low angles, but the general inclination is interrupted by a series of late Tertiary folds, whose axes have a roughly westward trend. These disturbances are most pronounced to the south of the River Thames, and there the Upper Cretaceous beds in many places have been removed from the anticlines, exposing the Lower Cretaceous and older strata as inliers, or as embayments of the Upper Cretaceous boundary line. The largest of these denuded areas is that of the Weald of Kent and Sussex, while the principal embayments occur in the Vales of Wardour, Warminster, and Pewsey.

Cenomanian. The zone of *Pecten asper* and *Cardiaster fossarius* (3 to 18 m., 10 to 60 ft. thick) comprises a group of sandy beds, sometimes termed the "Warminster Beds", from their markedly fossiliferous character in the Vale of Warminster, in Wiltshire. In that locality they are about 5.5 m (18 ft.) thick, and consist of glauconitic sands with chert and siliceous rock (cherty sandstone) composed largely of sponge spicules.

The Pecten asper Beds are confined to the south-western and south-central counties, from the Isle of Wight to Buckinghamshire. They are doubtfully represented at the south-western angle of the Weald, but are absent in Kent and eastern Sussex. In Wiltshire and the Isle of Wight they pass up into the glauconitic marl ("Chloritic Marl") of the *Schloenbachia varians* zone, but in Devonshire and Dorsetshire their upper limit is an erosion-surface, by which they are clearly marked off from the overlying Chalk.

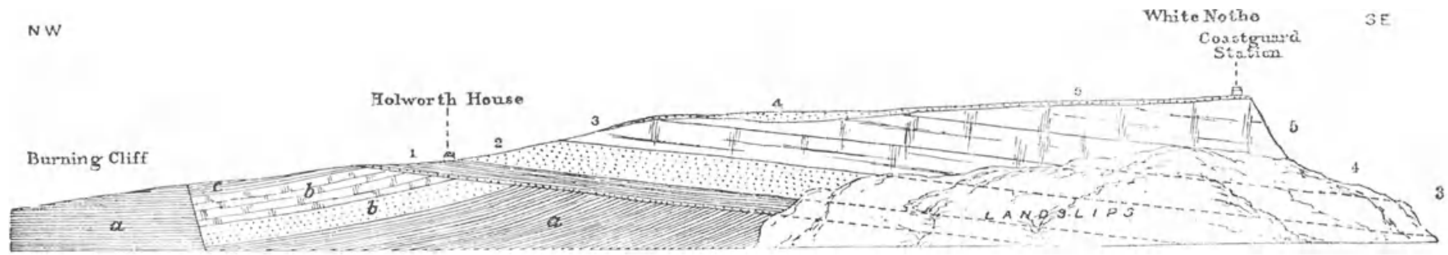

Fig. 50. Section through Holworth House and White Nothe, Dorset. Scale, horizontal and vertical, 8 inches to a mile, or 1: 7,920.

5 = Upper Chalk; 4 = Middle Chalk; 3 = Lower Chalk; 2 = Upper Greensand; 1 = Gault; c = Purbeck Beds; b = Portland Beds; a = Kimmeridge Clay.

The Lower Chalk should have been drawn less thick (21 m., 70 feet) and the Middle Chalk thicker (40 m., 134 feet). Reproduced from the Memoirs of the Geological Survey — Isle of Purbeck and Weymouth, pl. IX, 1898; also, Cretaceous Rocks of Britain, vol. 2, p. 421, 1903; with the permission of the Director and of H. M. Stationery Office.

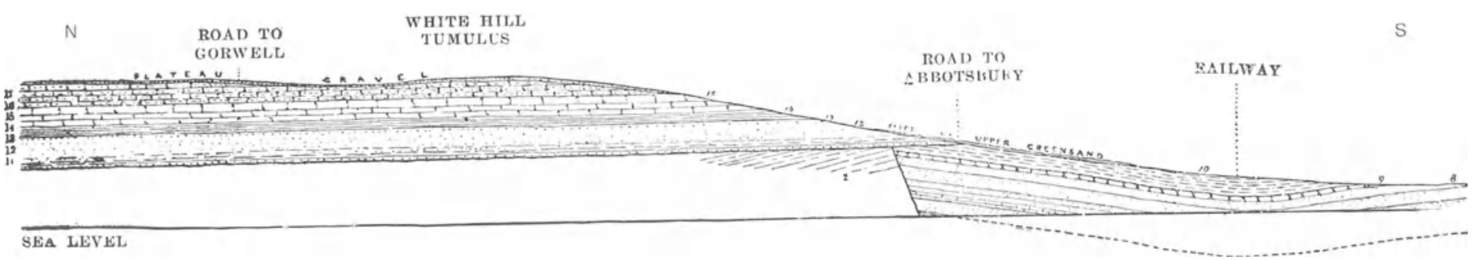

Fig. 51. Section through the southern slopes of the Chalk Downs near Abbotsbury (Dorset) (A. Strahan), forming a continuation to the north of Fig. 44, see p. 228. Scale horizontal and vertical: 5¾ inches = 1 mile, or 1: 11,000.

17 = Upper Chalk.
16 = Chalk Rock.
15 = Middle Chalk.
14 = Lower Chalk.

13 = Grit and Chert. } Upper Greensand
12 = Sands.
11 = Gault.

10 = Kimmeridge Clay
9 = Abbot'sbury Iron-ore. } Corallian.
8 = Sandsfoot Beds.

Reproduced from the Memoirs of the Geological Survey of the United Kingdom, Jurassic Rocks of Britain, vol. 5, p. 93, 1895, with the permission of the Director and of H. M. Stationery Office.

Among the common or characteristic fossils are *Doryderma benetti* HINDE, *Hallirhoa costata* LAM., *Pachypoterion robustum* HINDE, *Cardiaster fossarius* BENETT, *Epiaster lorioli* WRIGHT, *Discoidea subucula* KLEIN, *Rhynchonella dimidiata* Sow., *Pecten asper* LAM., *P. galliennei* D'ORB., *Exogyra columba* LAM. *E. digitata* J. Sow.

The zone of *Schloenbachia varians* (1 to 50 m., 3 to 160 ft.) varies in lithological character but consists generally of grey, fissile marls, alternating with layers of hard grey chalk. In the northern counties (Yorks. and Lincolnshire) the marls occur only in thin seams. Beds of compact siliceous chalk with nodules of impure flint occur in Wiltshire and Berkshire, and similar nodules, with nuclei of pure black flint, are present in light-grey homogeneous chalk on this horizon in Dorsetshire.

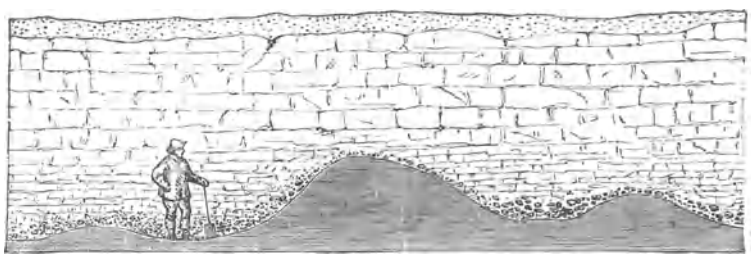

Fig. 52. View of a coprolite pit near Horningsea (now closed)
a = Gault; b = Cambridge Greensand; c = Chalk Marl.
Reproduced from the Memoirs of the Geological Survey of the United Kingdom. Cretaceous Rocks of Britain, vol. 2, p. 194, 1903; with the permission of the Director and of H. M. Stationery Office.

At the base of this zone, and included in the range of *S. varians* J. Sow., is the sub-zone of *Stauronema carteri*, an arenaceous, glauconitic chalk, ranging up to 5 m. (17 ft.) in thickness, and commonly termed "Chloritic Marl". The distinctive siliceous sponge is of sporadic occurrence in the southern counties and has not been recorded north of the River Thames. The well-known "Cambridge Greensand", on this horizon, contains many derived fossils (Albian) in a phosphatized condition and pebbles of older rocks, and rests on an eroded surface of the Gault. The derived fossils here comprise upwards of 200 species of Invertebrata, about one-third of which have not been recognized elsewhere in England. Among the commoner Albian forms are *Terebratula biplicata* J. Sow., *Plicatula gurgitis* PICT. and ROUX, *Hoplites auritus* G. Sow., *Mortoniceras rostratum*, J. Sow. Bones and teeth of many reptiles (Ornithosauria, Dinosauria, Ichthyopterygia, Crocodilia, Chelonia), and of a few birds also occur, the great majority being derivative. (RASTALL 1909, JUKES-BROWNE, 1900—04 and Mem. Surv. 1880.) In Devonshire the zones of *S. varians* and *Holaster sub-globosus* are represented by a quartziferous limestone (1 to 12 m., 3 to 40 ft.) which has been termed the zone of *Mantelliceras mantelli* J. Sow. The fossils of the S. varians zone include: *Plocoscyphia labrosa* T. SMITH, *Stauronema carteri* SOLLAS, *Rhynchonella grasiana* D'ORB, *R. mantelliana* J. DE C. Sow., *R. martini* MANT., *Pecten elongatus* LAM., *Aucellina gryphaeoides* J. DE C. Sow., *Metacanthoplites rotomogensis* BRONG., *Schloenbachia coupei* BRONG., *S. varians* J. Sow., *Baculites baculoides* MANT., *Scaphites aequalis* J. Sow., *Turrilites costatus* LAM., *Nautilus deslongchampsianus* D'ORB.

The zone of *Holaster subglobosus* (12 to 36 m., 40 to 120 ft.) is of a more constant lithological type than the zone below. From Yorkshire southward to the valley of the Thames its base is marked by a bed of hard gritty chalk known as Totternhoe Stone.

Farther south, where this stone is absent, the lower limit of the zone is rather indefinite, the marly beds with *S. varians* passing up into a firmer and more massive grey chalk in which *S. varians* becomes rare. The grey chalk is succeeded by firm chalk of a lighter tint, often almost white; and this arrangement holds good over most of south-eastern England, though with much variation in the thickness of the grey and white beds. In the Isle of Wight and Dorsetshire, however, the grey beds are wanting, and the zone consists of massive white chalk; while in Lincolnshire and Yorkshire the lower parts consist of rough greyish chalk, in regular beds separated by seams of grey marl.

Throughout the English Chalk-country the highest beds of the zone are laminated grey marls (1 to 5 m., 3 to 16 ft.), which, from the frequent presence of *Actinocamax plenus* DE BLAIN., have been termed the *Act. plenus* or "Belemnite" Marls. Intercalated in the marls there is often a definite bed of hard white chalk. Characteristic fossils of the *Hol. subglobosus* zone are: *Cidaris bowerbanki* FORBES., *Discoidea cylindrica* LAM., *Holaster subglobosus* LESKE, H. *trecensis* LEYM., *Offaster sphaericus* SCHLÜT., *Haploceras austeni* SHARPE, *Actinocamax plenus* DE BLAINV. *Holaster trecensis* LEHM. is especially characteristic of the upper beds (BOWER and FARMERY 1910).

Turonian. By most British geologists this stage in England is considered to comprise the zones of *Rhynchonella cuvieri* and *Terebratulina gracilis* var. *lata* only. In the present article we follow the Continental geologists and include in this stage the zone of *Holaster planus*.

Zone of *Rhynchonella cuvieri* and *Inoceramus labiatus* (3 to 25 m., 10 to 80 ft.). This is typically a hard white or cream-coloured chalk, largely nodular. Thin partings of grey marl are a common feature. The nodular character is most marked at the base of the zone, and the lowest beds, over the greater part of the Chalk country, form a band of hard nodular limestone (1,5 to 9 m., 5 to 30 ft.) known as Melbourn Rock. This rock is thickest in Kent and Sussex and has there been described as the "Grit Bed". In north-western Norfolk, Lincolnshire, and Yorkshire it is indistinguishable from the rest of the zone. Scattered flints occur in the higher beds of this zone, but are seldom abundant. The thickness of the Rh. cuvieri beds is usually about 18 to 25 m. (60 to 80 ft.), but decreases northward to about 3 m. (10 ft.) in Yorkshire. A noteworthy instance of local thinning is seen at Hooken Cliff, near Beer, in Devonshire, where the zone dwindles from 8 m. (25 ft.) to nothing in a distance of about 100 m. (330 ft.). Fossils: *Serpula avita* J. DE C. Sow., (habitually attached to shell of *Inoceramus labiatus*). *Cardiaster pygmaeus* FORBES, *Discoidea dixoni* FORBES (= *D. minima* AG.), *Rhynch. cuvieri* D'ORB., *Inoceramus labiatus* SCHLOTH., *Acanthoceras cunningtoni* SHARPE, *Pachydiscus peramplus* MANT.

The zone of *Terebratulina lata* (9 to 65 m., 30 to 210 ft.) possesses a fairly uniform character in the southern counties. It consists of rather soft, white to greyish-white, massive chalk, with occasional thin layers of grey marl. Flints occur in the upper beds but are thinly disseminated, except in Devonshire where they are abundant. From Cambridgeshire northward they are of common occurrence, and in Lincolnshire and Yorkshire, where the chalk is very hard, they are found in well-marked beds. The upper limit of the Terebratulina lata zone is marked by no persistent feature, though in parts of Southern England it coincides with, or closely approaches, the base of the Chalk Rock (described below). Fossils: — *Conulus subrotundus* MANT., *Discoidea dixoni* FORBES, *Hemiaster minimus* AGAS., *Micraster cor-bovis* FORBES, *Terebratulina lata* ETHER., *Inoceramus brongniarti* J. DE C. SOW., *Ostrea vesicularis* LAM., *Prionotropis woolgari* MANT.

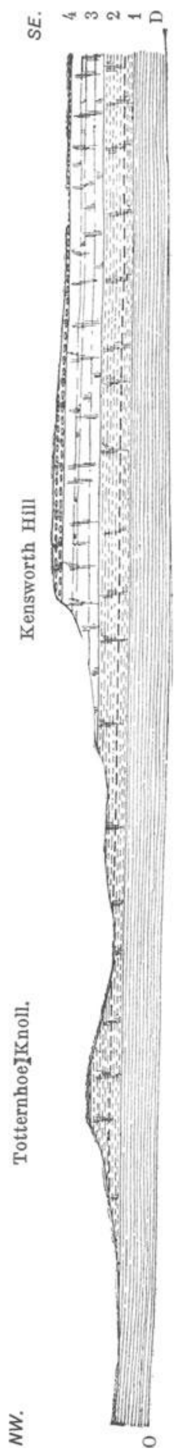

Fig. 53. Section through Totternhoe Knoll and Dunstable Downs. Showing the escarpment of Middle Chalk capped by the zone of *Holaster planus*. Horizontal scale $1^1/_3$ inches to a mile or 1 : 47,520. Vertical scale, 800 feet to 1 inch or 1 : 9,600.
4 = Upper Chalk; 3 = Middle Chalk; 2 = Lower Chalk; 1 = Gault (Upper and Lower); O D = Level of Ordnance datum.
Reproduced from the Memoirs of the Geological Survey of the United Kingdom, Cretaceous Rocks of Britain, vol. 3, p. 225, 1904; with the permission of the Director and of H. M. Stationery Office.

Zone of *Holaster planus.* In recent memoirs of the Geological Survey of England and Wales this zone, as lately defined by A. W. ROWE (1900), is described as the lowest member of the "Upper Chalk" — a division which includes the Upper and Lower Senonian stages. Its thickness ranges from 5 to 37 m. (16 to 120 ft.). Save in the counties of Norfolk, Lincoln, and York (where it is usually a homogeneous, hard, white chalk) it is markedly nodular or lumpy. Flints are everywhere present, in the upper half, at least, and in Lincs. and Yorks. these chalcedonic concretions occur in tabular masses, some exceeding 0,3 m. (1 ft.) in thickness. Along the main outcrop between North Dorsetshire and Cambridgeshire the zone contains, at or near its base, a hard cream-coloured limestone (0,3 to 3,5 m., 1 to $11^1/_2$ ft.) with green phosphatic nodules and grains of glauconite. This hard bed — the Chalk Rock — is best developed in the counties of Berks and Oxford. Where the Chalk Rock is present the peculiar faunule of the Heteroceras reussianum subzone is confined to it. Where the rock is absent this faunule has a greater vertical range, but is usually limited to the lower half of the Hol. planus zone

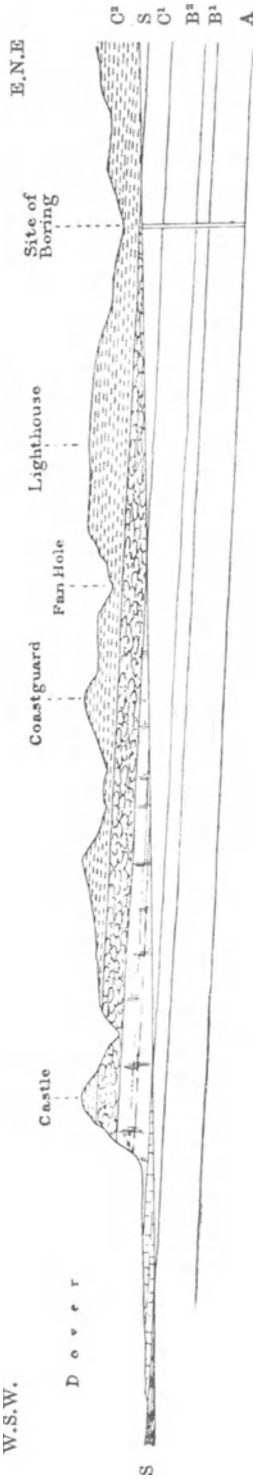

Fig. 54. Section along the coast, east of Dover. Horizontal scale, $1^1/_2$ inch to a mile or 1 : 42,240. Vertical scale, 900 feet to an inch or 1 : 10,800.
C^2 = zone of *Micraster coranguinum*; C^1 = zones of *M. cortestudinarium* and *H. planus*;
B^2 = zone of *Terebratulina lata*; B^1 = zone of *Rhynch. Cuvieri*; A = Lower Chalk; SS = Sea level.
Reproduced from the Memoirs of the Geological Survey of the United Kingdom.—Cretaceous Rocks of Britain, vol. 3, p. 137, 1904; with the permission of the Director and of H. M. Stationery Office.

(e. g. Hampshire, Kent). In most of the southern counties, however, and in Lincolnshire and Yorkshire, the Reussianum fauna is either absent or very poorly represented. The upper limit of the *Hol. planus* zone is occasionally marked by a thin layer of hard yellowish chalk, with or without green nodules. At Southerham, near Lewes (Sussex), the lower beds of the zone are strongly phosphatic (STRAHAN 1896).

Characteristic fossils of the Hol. planus zone are *Ventriculites mammillaris* T. SMITH, *Pentacrinus agassizi* v. HAG., *Cyphosoma radiatum* SORIG., *Echinocorys (Ananchytes) scutatus* LESKE, (gibbous form), *Holaster placenta* AG., *H. planus* MANT., *Micraster cor-bovis* FORBES, *M. leskei* DESM., *M. praecursor* ROWE (a group-form including *M. beonensis*, *normannia*, *cayeusi*, ROWE 1899), *Terebratula carnea* J. SOW., *T. semiglobosa* J. SOW., *Spondylus spinosus* J. SOW., *Ostrea proboscidea* D'ARCH. (in Yorkshire), *Pleurotomaria perspectiva* MANT., *Solariella (Turbo) gemmata* J. SOW.

The subzone of *Heteroceras reussianum* contains the above-named fossils with the following additional forms; — *Arctica quadrata* D'ORB., *Trapezium trapezoidale* F. A. ROEMER, *Cuspidaria caudata* NILSS., *Emarginulina sanctae-catharinae* PASSY, *Avellana* cf. *humboldti* MÜLLER, *Natica vulgaris* v. REUSS., *Turbo geinitzi* WOODS, *Baculites bohemicus* FRITSCH., *Crioceras ellipticum* MANT., *Heteroceras reussianum* D'ORB., *Scaphites geinitzi* D'ORB., etc. (WOODS 1896—7).

Lower Senonian. The zone of *Micraster cor-testudinarium* (12 to 36 m., 40 to 115 ft.) is a white to yellowish chalk, with nodular layers which are frequently conspicuous in the south of England but are wanting in the north-eastern counties. Bands of flint-nodules and continuous layers or veins of flint are abundant.

Fossils: — *Serpula cincta* GOLDF., *S. ilium* GOLDF., *Echinocorys scutatus* LESKE (gibbous forms), *Holaster placenta* AG., *Micraster cor-testudinarium* GOLDF., *M. praecursor* ROWE (of a characteristic form), *Cidaris serrifera* FORBES, *Cardiaster cotteauanus* D'ORB., *Rhynchonella reedensis* ETH., *Inoceramus lamarcki* PARK.

The zone of *Micraster cor-anguinum* (50 to 95 m., 165 to 320 ft.) is typically a white, soft chalk with regular bands of nodular flint. In Yorkshire, however, the lower third of the zone alone contains flints. Fossils: *Cidaris clavigera* KOENIG, *C. sceptrifera* MANT., *C. perornata* FORBES, *Conulus albogalerus* LESKE, *Echinocorys scutatus* LESKE (ovate forms), *Epiaster gibbus* LAM., *Hagenowia rostrata* FORBES, (usually rare, but abundant in Yorkshire), *Micraster cor-anguinum* LESKE, *Thecideum wetherelli* MORRIS, *Crania ignabergensis* RETZ, *Inoceramus cuvieri* J. DE C. SOW., *I. digitatus* J. DE C. SOW., *I. involutus* J. DE C. SOW (in lower part of zone), *Exogyra sigmoidea* v. REUSS (rare), *Lima (Plagiostoma) hoperi* MANT., *Ostrea normaniana* D'ORB., *Actinocamax westphalicus* SCHLÜT.

Zone of *Marsupites testudinarius* (12 to 64 m., 40 to 210 ft.). In the pure white chalk of this zone flints are relatively scarce in the South of England, and are absent in Yorkshire. *Marsupites testudinarius* v. SCHLOTH. (= *M. ornatus*, etc.) is confined to the upper half (approximately) of the zone, the lower half being characterized by remains of *Uintacrinus sp.* Phosphatic chalk occurs on these horizons at Taplow (Buckinghamshire) and Winterbourne (Berkshire), the abnormal lithological condition accompanying a decrease in the thickness of the zone and certain modifications in its fauna (WHITE and TREACHER 1905, 1906). Fossils: *Porosphaera globularis* PHILL. (large), *Caryophyllia cylindracea* v. REUSS, *Echinocorys scutatus* LESKE, special forms (BRYDONE 1911/12), *Bourgueticrinus ellipticus* MILLER (nipple-shaped calyx), *Marsupites testudinarius* v. SCHLOTH., *Uintacrinus sp.*, *Terebratulina rowei* KITCHEN, *Ostrea semiplana* MANT., *O. wegmanniana* D'ORB., *Actinocamax granulatus* DE BLAINV. (upper beds), *A. verus* MILLER (lower beds).

The zone of *Actinocamax quadratus* and *Offaster pilula* (60 to 122 m., 200 to 400 ft.) is usually a soft white chalk in which flints are more numerous than in the zone below, save in Yorkshire where, like the Marsupites zone, it is flintless. The base of the A. quadratus zone is phosphatic at Winterbourne (Berkshire). It is probable that the highest part of the phosphatic chalk of Taplow belongs to this division.

Fossils: *Coeloptychium agaricoides* GOLDF. and many other sponges in Yorkshire, *Coelosmilia laxa* EDW., *Echinocorys scutatus* LESKE, (gibbous and other forms, BRYDONE 1911/12), *Offaster pilula* LAM., *Inoceramus lingua* GOLDF. (in Yorkshire), *Ostrea lateralis* NILSS. (striate form), *Actinocamax granulatus* DE BLAINV., *A. quadratus* DEFR., *Pachydiscus leptophyllus* SHARPE, *Scaphites binodosus* ROEM. (upper beds in Yorkshire).

Upper Senonian. Zone of *Belemnitella mucronata* (144 m., 480 ft., Isle of Wight.) This zone appears to be confined to the southern parts of Dorsetshire, Wiltshire, Hampshire, and the south-western end of Sussex (?), in the south of England, and to Norfolk and Suffolk in the east. It is normally a soft white chalk with numerous flints which often attain great dimensions. Vertical columns and vase-shaped concretions of flint, termed "pot-stones" and "paramoudras", are a notable feature of this zone in Norfolk. Fossils: *Terebratula carnea* J. Sow., *Rhynchonella limbata* SCHLOT., *R. plicatilis* var. *octoplicata* J. Sow., *Crania costata* G. B. Sow., *Magas pumilus* J. Sow., *Cidaris pleracantha* AG., *C. serrata* DESOR., *Cardiaster ananchytis* LESKE, *Echinocorys scutatus* LESKE var. *pyramidatus* (and other characteristic forms), *Belemnitella lanceolata* SCHLOT., *B. mucronata* SCHLOT.

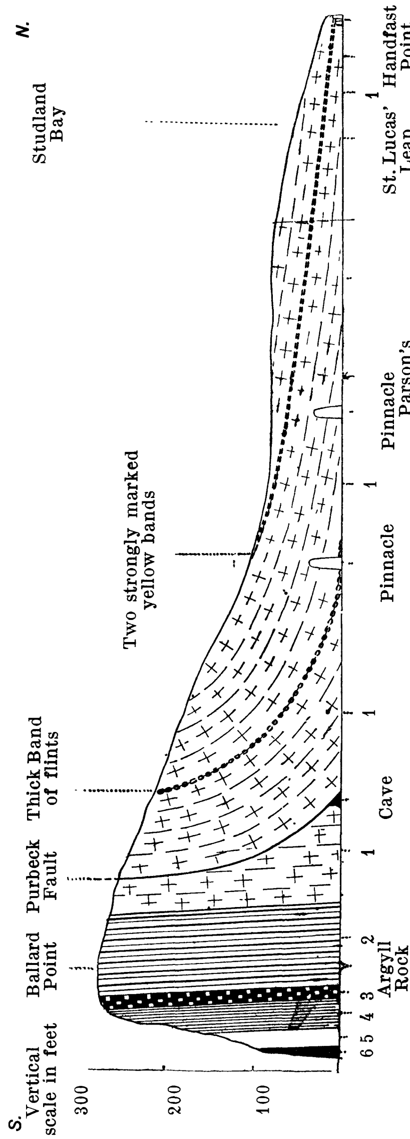

Fig. 55. Cliff-section from Ballard Point to Studland Bay, South-east Dorset (C. DAVIES SHERBORN, illustrating a paper by ARTHUR W. ROWE). Length of Section = 1 mile. Scale about 1:1,150.

1 = Zone of *Belemnitella mucronata* | 4 = Zone of *Micraster cor-anguinum*
2 = Zone of *Actinocamax quadratus* | 5 = Zone of *Micraster cor-testudinarium*
3 = Zone of *Marsupites* { *Marsupites-band*, *Uintacrinus-band* | 6 = Zone of *Holaster planus*

Reproduced from the Proceedings of the Geologists' Association, vol. 17, p. 32, 1901 with the consent of the Council and of C. DAVIES SHERBORN and of ARTHUR ROWE.

The zone of *Ostrea lunata* (33 m., 110 ft. ?) is found only at Trimingham near Cromer, on the coast of Norfolk. On the shore at Trimingham R. M. BRYDONE (1908)

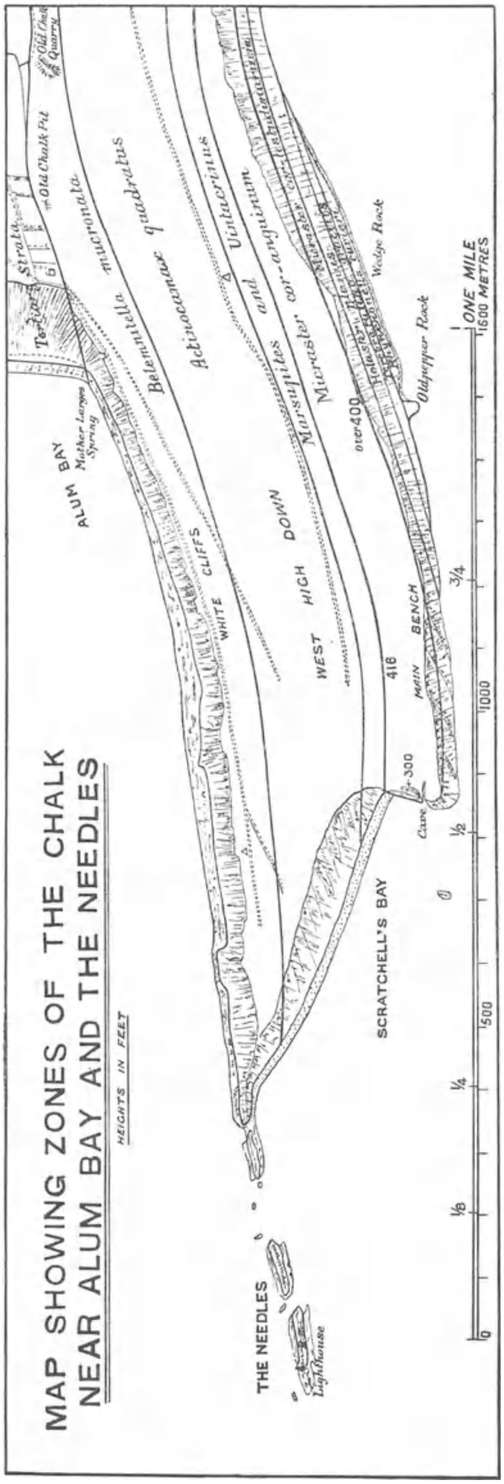

Fig. 56. Map showing zones of the Chalk near Alum Bay and the Needles, Isle of Wight (Sherborn and Rowe). Redrawn from the Proceedings of the Geologists' Association, vol. 20, p. 352, pl. A, 1908; with the permission of the Council and the authors.

recognises five distinct beds, which are, in ascending order, —(a) Lower grey chalk, 3.5 m. (12 ft.); (b) Lower white chalk, with *O. lunata* Nilss., 6 m. (20 ft.); (c) White chalk without *O. lunata*, 2.5 m. (8 ft.); (d) Upper white chalk with *O. lunata*, 3 m. (10 ft.); (e) Upper grey chalk, 7.5 m. (25 ft.). There is a discordance between beds (d) and (e) which may be due to faulting. The exposures are small and the beds are much disturbed, largely, if not entirely, by glacial agencies in post-Pliocene times. Characteristic fossils are: *Pentacrinus bronni* Hag., *Serpula canteriata* Hag. (quadrangular form), *Thecideum vermiculare* Schloth., *Terebratulina gisei* Hag.. *T. gracilis* Schoth. (type), *Ostrea lunata* Nilss., *Nautilus bellerophon?* Lindgr.

B. Scotland.

Small relics of Upper Cretaceous strata, of the Irish type, are preserved under Tertiary lavas in the Morvern District of Argyllshire and the adjacent island of Mull. On the shores of the inlet called Loch Aline, and on the lower slopes of the hills Beinn-y-Hun and Beinn-y-Hattan, J. W. Judd (1878) made out the succession shown in the last column of the table p. 261. The glauconitic sands at the base of the section contain *Pecten asper* Lam., *P. orbicularis* J. Sow., *Exogyra conica* J. de C. Sow., *Nautilus deslongchampsianus* d'Orb., etc. They probably represent the zones of *Pecten asper* and *Schl. varians*. The succeeding White Sandstones with coal are unfossiliferous. A. J. JUKES-BROWNE (1902) suggests that they are homotaxial with the zone of *Ostrea (Exogyra) columba* in Ireland. The Turonian and Lower Senonian seem to be unrepresented. In the White Chalk above are *Belemnitella mucronata* and *Inoceramus sp.* The highest sandstones, etc., may be of either Cretaceous or Eocene age.

Detached masses of hard chalk occur in an agglomerate occupying a Tertiary volcanic neck in the Island of Arran. They contain *Porosphaera globularis*, *Inoceramus*, *Bryozoa*, and other remains, and are most probably of post-Turonian age (PEACH, GUNN, and NEWTON, 1901). Pebbles of chalk, and flints containing Senonian fossils, occur in the Pleistocene deposits of Aberdeenshire, and have been dredged from the Moray Firth.

C. Physiographical Conditions.

Little is known concerning the geography of the British area in Upper Cretaceous times. The wide-spread transgression which commenced in Albian or earlier ages was continued, without important interruption, in the Cenomanian, and by the close of that age the greater part of England, north-eastern Ireland, and Western Scotland were submerged. Cornwall and western Devonshire, and part of the Welsh upland, probably were promontories of a western land which included the south of Ireland; while the Pennine uplands, together with much of Scotland, may have been a peninsula connected with a westward extension of the Scandinavian massif. The Irish and Scotch sediments of the time were laid down in shallower water than the English, but they contain no truly littoral deposits.

The Turonian chalks mark an increase in the depth of the sea, so far at least as the English area is concerned, though both the lithology and fauna of the Heteroc. reussianum beds suggest a temporary shallowing of the water towards the close of this stage.

The submergence reached its maximum in Lower Senonian times, when it is probable that almost all the British area was under water. Except in Scotland, where the highest beds are sandstones, there are few indications of the great regression with which the Cretaceous period came to an end. The record is everywhere abrupty broken off with the Senonian, the thoroughly marine Cretaceous beds being covered unconformably by the fluvio-marine sediments of the Eocene in England, and by the lava-flows of that period in Scotland and Ireland.

D. Economic Products.

The building material most extensively employed is flint. The nodules of this substance are much used in construction of churches, small dwellings, and garden walls, and are usually only roughly faced or left untrimmed. Architectural flint-work is seen at its best in Norfolk, where the art of "flint-knapping" has been practised from time immemorial. The hard grey chalk known as Totternhoe Stone is worked in Bedfordshire, Hertfordshire, and Cambridgeshire. Beer Stone, from the Rhyn. cuvieri zone of Beer and Sutton in Devonshire, has been much used in the west of England. In Berkshire and Buckinghamshire the soft, regularly-jointed beds of the Tereb. lata zone have been employed, to a small extent.

The lime made from the Turonian and superior chalks is usually of the common or "light" kind; stronger, "hydraulic" limes are got from the more argillaceous Cenomanian beds. "Portland" cement is manufactured from the latter beds in Hertfordshire, Bedfordshire, and Cambridgeshire, and from mixtures of Turonian and younger chalks with alluvial clays in Kent and Sussex. Whiting or whitening is made by levigating the soft Senonian chalks.

COMPARATIVE TABLE OF THE

Stages	Zones	Sub-zones	England		
			Kent	Isle of Wight	South Dorset
Upper Senonian	*Ostrea lunata*				
	Belemnitella mucronata			White chalk with flints, 144 m. (480 ft.)	White chalk with flints, 76 m. (250 ft.)
Lower Senonian	*Actinocamax quadratus* and *Offaster pilula*			White chalk with flints and veins of marl, 122 m. (400 ft.)	White chalk with flints and veins of marl, 117 m. (385 ft.)
	Marsupites testudinarius	*Marsupites*	White chalk with few flints, 15 m. (50 ft.)	White chalk with flints, 14 m. (46 ft.)	White chalk with flints, 9 m. (30 ft.)
		Uintacrinus	ditto, 9-25 m. (30 to 82 ft.)	ditto, 11 m. (36 ft.)	ditto, 24 m. (80 ft.)
	Micraster cor-anguinum		White chalk with flints, 85 m. (278 ft.)	White chalk, nodular at base, with flints, 94 m. (308 ft.)	White chalk, nodular at base, with flints, 51-73 m. (170-240 ft.)
	Micraster cor-testudinarium		White and yellowish chalk with flints, 17 m. (56 ft.)	White and light red nodular chalk with flints, 16 m. (52½ ft.)	White nodular chalk with flints, 15-33 m. (50-110 ft.)
Turonian	*Holaster planus*		Nodular chalk with flints	Grey-white nodular chalk with flints, 18 m. (60 ft.)	Grey-white nodular chalk with flints, 6-17 m. (20-56 ft.)
		Heteroceras reussianum	ditto (with *reussianum* fauna)		
			Nodular chalk, flints, total 10.5 m. (35 ft.)		
	Terebratulina lata (*T. g.* var. *lata*) and *Inoceramus brongniarti*		White chalk, partly nodular, with marl seams and few flints, 50 m. (164 ft.)	White nodular chalk with marl veins. (Green nodules and few flints near top), 19 m. (62 ft.)	White chalk with marl seams and few flints, 9-17 m. (30-56 ft.)
	Rhynchonella cuvieri and *Inoceramus labiatus*		White chalk with nodular beds: "Grit-bed" (10 m) at base, 21 m. (70 ft.)	White nodular chalk, 27 m. (90 ft.)	White nodular chalk, with few flints at top, 13-22 m. (42-72 ft.)
Cenomanian	*Holaster sub-globosus* and *H. trecensis*	*Actinocamax plenus*	Yellow-grey marl, 1.8 m. (6 ft.)	Grey marl, 2 m. (6½ ft.)	Grey marl, 2 m. (6 ft.)
			White and grey chalk, 36 m. (120 ft.)	White and grey marly chalk, 30 m. (100 ft.)	Grey marly chalk, 15-30 m. (50-100 ft.)
	Schloenbachia varians		Grey marl and marly chalk, 20 m. (65 ft.)	Grey marly chalk, 24-36 m. (80-120 ft.)	Grey chalk and marl with few flints, 8-12 m. (26-40 ft.)
		Stauronema carteri	Glauconitic ("Chloritic") marl, to 5 m. (16 ft.)	Glauconitic marl, 3 m. (10 ft.)	Glauconitic marl, 1 m. (3 ft.)
	Pecten asper and *Cardiaster fossarius*		(wanting)	Glauconitic marly sand with chert, 7 m. (23 ft.)	Glauconitic sand and calcareous sandstone, 8 m. (26 ft.)
	Underlying strata		Gault clay (Albian)	Sandstone (Albian)	Green sands (Albian)

BRITISH UPPER CRETACEOUS STRATA.

England					Scotland
Devonshire	Wiltshire	Berksh.&Oxfordsh.	Norfolk	Yorkshire	Argyllsh.
			White and grey chalk with flints (of Trimingham), 33 m? (110 ft.)		Sandstones and white marls (? Cretaceous), 6 m.
	White chalk with flints, 30 m? (100 ft.)		White chalk with big flints ("paramoudras"), 76 m? (250 ft.)		White indurated chalk, glauconitic at base, 3 m. (10 ft.)
	White chalk with flints, 90 m? (300 ft.)	White chalk with few flints (Berkshire), 15 m. (50 ft.)	White chalk with flints, 125 m? (410 ft.)	White chalk with seams of marl ("Zone of *Inoceramus lingua*"), 100 m? (330 ft.)	
	White chalk with flints, 15 m? (50 ft.)	White chalk with few flints (Berkshire), 10 m. (33 ft.)		White chalk with marl seams, 36 m. (120 ft.)	
	ditto, 15 m? (50 ft.)	ditto, 10 m. (33 ft.)		ditto, 26 m. (85 ft.)	
	White chalk with flints, 60 m? (200 ft.)	White chalk with flints, 60 m. (200 ft.)	White chalk with flints, 105 m? (350 ft.)	"Zone of *Hagenovia rostrata*", comprising white chalk with flints 49 m. (160 ft.) overlying white flintless chalk, 30 m. (100 ft.)	
White chalk with nodular beds, marl seams, and flints, 15 m. (50 ft.)	White chalk, nodular in lower part, with flints, 15 m. (50 ft.)	White chalk, nodular at base, with flints, 15 m. (50 ft.)		White chalk with marl seams and flints, 36 m. (120 ft.)	?
Grey-white nodular chalk with flints, 12-18 m. (40-60 ft.)	Greyish nodular chalk with flints. Chalk Rock (with reussianum-fauna) near base, total 9 m. (30 ft.)	Nodular chalk. Chalk Rock (with reussianum-fauna) at base, total 5-6 m. (16-20 ft.)	White chalk with flints, 15 m? (50 ft.)	White chalk with flints, 37 m. (120 ft.)	
White and greyish chalk with marl seams, 6-46 m. (20-150 ft.)	White and greyish chalk (nodular at top) with marl seams and few flints, 15-30 m? (50-100 ft.)	White and greyish chalk, with marl seams and few flints near top, 30 m. (100 ft.)	White chalk with marl seams and few flints near top, passing down into nodular chalk with Melbourn Rock at base, 30 m? (100 ft.)	White chalk with flints, 64 m. (210 ft.)	
White chalk, partly nodular, with flints in places, 0-24 m. (0-80 ft.)	White nodular chalk, Melbourn Rock at base, 15-20 m. (50-65 ft.)	White nodular chalk. Melbourn Rock at base, 18 m. (60 ft.)		Yellowish chalk with marl seams, 3.5 m. ($11^1/_2$ ft.)	
Grey marl (local), 1 m. (3 ft.)	Grey marl, 30 cm. (1 ft.)	Grey marl and white chalk, 1.5 m. (5 ft.)	Grey marl, thin.	Grey marl ("Black-band"), 0.5 m. (1 ft. 6 in.)	White sandst. with seam of coal, 9-30 m. (30 to 100 ft.)
Glauconitic sand and calcareous sandstone ("Zone of *Acanthoceras mantelli*), 1-12 m. (3-40 ft.)	White and grey chalk, 24 m. (80 ft.)	White and grey chalk, Totternhoe Stone at base, 24 m. (80 ft.)	Grey and white chalk, Totternhoe Stone at base, 10-15 m. (30-50 ft.)	White marly nodular chalk, Totternhoe Stone at base, 12 m. (40 ft.)	
	Grey marly and siliceous chalk, 48 m. (160 ft.)	Grey marly chalk, 42 m. (140 ft.)	Grey marly chalk, glauconitic at base, 6-23 m. (20-75 ft.)	Grey nodular chalk with white or yellow limestone at base, 7-20 m. (23-65 ft.)	Glauconitic sands and calcareous sandstone, 6-18 m. (20 to 60 ft.)
	Glauconitic marl, 2 m. (6 ft.)	Glauconitic marl, 1 m. (3 ft.)			
Calcareous sandstone and sand with chert, 21 m. (70 ft.)	Green sand and sandstone with chert, 6 m. (20 ft.)	Glauconitic marl and sand, 5-8 m. (16-26 ft.)	(wanting)	(wanting)	
Sand or clay (Albian)	Green sands (Albian)	Gault clay (Albian)	Gault or "Red Chalk" (Albian)	"Red Chalk" (Albian)	Jurassic

For manuring or "dressing" soils deficient in calcium carbonate, all the softer kinds of chalk, the Chloritic Marl, and the calcareous sands of the *Pecten asper* zone, are freely used, though not to so large an extent as in former times. Phosphatic nodules have been dug for agricultural purposes from the Chloritic Marl in Cambridgeshire and Surrey, but the few local phosphatic beds of Turonian and Lower Senonian age have as yet been put to no economic use.

For road-making, flints from the Chalk and cherts from the *P. asper* zone are commonly used: also the limestones known as Melbourn Rock and Chalk Rock, and other hard chalks of more local occurrence.

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See also Jukes-Browne, A. J., Penning, W. H.

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b. Ireland.

By G. A. J. Cole.

The Cretaceous rocks of Ireland possibly include at their base some representative of the Albian stage; but they are practically all of Upper Cretaceous age. It is impossible to say how far they once spread over the Irish area. A high outlier remains on Slieve Gallion in Co. Londonderry, and the eastern escarpment of the beds is traceable, under basalt, southward into the north of Co. Down. But the Cretaceous strata clearly owe their preservation to the capping of Kainozoic lavas, and at one time must have covered a far wider stretch of country (Jukes-Browne, 1911 p. 333). The abundant flints in the superficial deposits of south-eastern Ireland (Mem. Geol. Surv. 1879), and those on the west coast, as on Inishbofin, probably represent the waste of Senonian strata. Dredgings have shown, moreover, the presence of chalk, as well as flint, in depths of about 1000 m. (500 fathoms) off the coast of Kerry (Cole and Crook 1908—9).

A large part of the flints that occur so freely in the gravels of Co. Wexford were probably derived from the western extension of the strata which once lay over Devon and Cornwall.

In the north-east, the beds rest on an eroded land-surface of Middle Cretaceous times, so that Lower Jurassic, Triassic, Carboniferous, and Dalradian rocks are found in various places immediately underlying the deposits of the Cretaceous sea. The general succession in Co. Antrim is as follows (Tate 1865; Barrois 1876; Hume 1897; Jukes-Browne and Hill 1900):

Senonian	5. White Limestones (hard chalk) with flints; sometimes conglomeratic at base, with quartzite pebbles ("Mulatto stone"). 30 m. (100 ft.), where thickest. *Belemnitella mucronata* abundant. 4. Glauconitic white or pinkish limestone, with numerous sponge-remains (= "Chloritic Chalk"). About 3 m. (10 ft.) *Actinocamax verus*, *Echinocorys gibbus*.
Possibly Upper Turonian in upper part. Mainly Cenomanian.	3. Yellow glauconitic sands (= "Chloritic Sandstones"). About 3 m. (10 ft.) *Exogyra columba*.
Cenomanian.	2. Yellow Sandstones, often cherty. About 8 m. (26 ft.) *Alectryonia carinata*.
Cenomanian. Possibly Albian in lower part.	1. Glauconitic Sands, of a deep green colour. About 3 m. (10 ft.) *Exogyra conica*.

The Glauconitic Sands at the base are often very largely composed of glauconite. They contain *Pecten asper*, *Pecten orbicularis*, *Janira quinquecostata*, *Exogyra conica*, *Thetis sowerbyi*, *Belemnites ultimus*.

The Yellow Sandstones above are somewhat barren in fossils; *Alectryonia carinata*, *Janira quadricostata* and *Acanthoceras rothomagense* are recorded. The overlying sands, which contain more glauconite (formerly regarded as chlorite), are characterized by *Rhynchonella schloenbachi*, *Exogyra columba*, *Pecten asper*, *Janira quinquecostata*, and the crustacean *Callianassa*. The upper beds of these

"Glauconitic Sands" are often more calcareous, and contain numerous fragments of *Inoceramus*. They seem to be of Upper Turonian or Lower Senonian age, and to have been laid down on the underlying beds after an elevation of the district.

The Glauconitic Chalk is clearly Lower Senonian (Emscherian), containing numerous sponges, *Terebratula carnea*, *Spondylus spinosus*, *Actinocamax verus*, *Actinocamax quadratus*, *Echinocorys gibbus*, and *Micraster coranguinum*. The White Limestone above, with its numerous bands of flint, is the most conspicuous Cretaceous rock in Ireland, being largely quarried for the production of lime. Rivers seem to have often brought down pebbles of vein-quartz and quartzite from the exposed Dalradian promontories into the Senonian sea, while it was still shallow in this area. The resulting Senonian conglomerate or "Mulatto Stone" is about 30 cm. (1 ft.) thick at Murlough Bay east of Fair Head, where it rests directly on Triassic sandstone. This pebbly zone indicates that the western limit of the great chalk sea of Europe was not very far away. The White Limestone is especially characterised by *Belemnitella mucronata*. *Terebratula carnea*, *Rhynchonella octoplicata*, and *Ostrea vesicularis* occur.

Though the complete Upper Cretaceous Series is nowhere present, and rarely more than 30 m. (100 ft.) can be seen at any one point, there is evidence of a prevalence of Cenomanian beach-deposits in the country near Belfast (Geol. Surv. Mem. 1904), while north-east of this the sea was generally deeper. After a brief epoch of elevation, by which an unconformity occurred at the top of the Cenomanian deposits, the sea in Senonian times spread northward, southward, and westward, over a wide area, until Senonian conglomerates and white limestone were deposited from Moira to Lough Foyle. By far the larger part of these deposits is now concealed by the Kainozoic basalts of the plateaus.

The Cenomanian overflow was marked by deposits very rich in glauconite. The frequent occurrence of pebbles of fair size in beds of glauconitic chalk of early Senonian age shows that a deposit of the white limestone type could be formed in shallow water. The true white limestone, with its residue of fine grains of quartz, and only minute quantities of heavy minerals, certainly suggests (Hume 1897) conditions of greater depth, but it is difficult to believe that the absence of coarse detrital material in the upper zones of the chalk of Co. Londonderry is entirely due to the remoteness of the shore. If a large part of the uplifted Irish area were at this epoch covered by Carboniferous Limestone, karst-conditions may have arisen, and any rivers that flowed into the sea in this region may have been almost devoid of material in suspension.

Economic Products.

The white limestone (compact chalk) of the north-east of Ireland is extensively used for lime-burning.

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See also Cole, G. A. J. and Jukes-Browne and Hill, W.

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13. Tertiary.

a. Great Britain.

By H. J. OSBORNE WHITE.

I. Sedimentary Rocks.

A. Palaeogene.

1. Eocene.

As in the case of the Upper Cretaceous beds, the principal masses of Eocene strata in Great Britain are situated in the south-east of England, where they occupy the broad tectonic depressions known as the London and Hampshire Basins. In the northern part of Britain, thin sediments of this age are intercalated in the lavas of the islands of the Inner Hebrides (Mull, Skye), off the west coast of Scotland.

The British Eocene beds consist mainly of sands and clays of marine, estuarine, and fresh-water origin, and they rest on Upper Cretaceous and older rocks with a more or less marked unconformity. Their principal divisions are shown in the subjoined table.

Comparative Table of British Eocene Strata.

		England		Scotland
	Stages	London Basin	Hampshire Basin	Isle of Mull
Upper Eocene	Marinésian		Headon Beds	
			Barton or Headon Hill Sands	
			Barton Clay	
	Auversian	Upper Bagshot Beds	Upper Bracklesham Beds	
Middle Eocene	Lutetian	Middle Bagshot Beds	Lower Bracklesham Beds	
Lower Eocene	Cuisian	Lower Bagshot Beds	Alum Bay Sands	
		London Clay	Bognor Beds or London Clay	
		Oldhaven and Blackheath Beds	(wanting)	
	Sparnacian	Woolwich and Reading Beds	Reading Beds	
	Thanetian	Thanet Beds	(wanting)	?
	Montian	(wanting)	(wanting)	Leaf beds

α. England.

Although the formation of the Eocene basins of the South of England is due to earth-movements which took place in post-Eocene times, and there is no good reason to doubt that the contemporaneous beds in each were once continuous across the intervening country, it will be convenient to consider the stratigraphical succession in each basin separately.

1. The London Basin.

This basin has the form of a triangle, with the town of Marlborough (Wilts) at the apex, on the west, and the base on the east coast between Deal (Kent) and Southwold (Suffolk). Its length is about 200 km. (125 miles), and its width at the coast is about 120 km. (75 miles). The region is bounded on the north by the Chalk uplands of the Berkshire Downs and Chiltern Hills, and on the south by the Sydmonton Hills and the North Downs.

The Thanet Beds (24 to 27 m., 80 to 90 ft.), which are the oldest of the English Eocene strata, consist of white and yellow sands, clayey and glauconitic in the lower part and having at the base a thin, persistent layer of unworn, green-stained flints. In East Kent

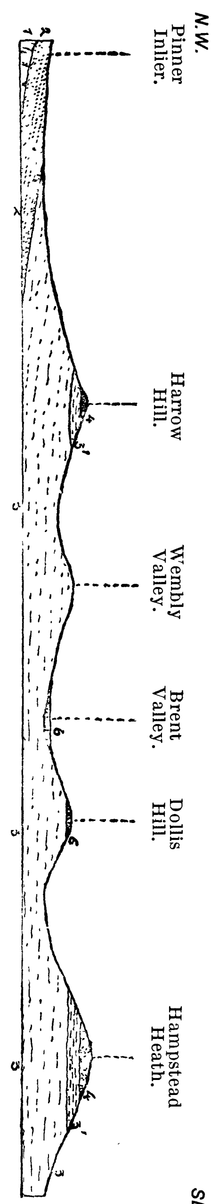

Fig. 57. Section from Pinner to Hampstead (J. Logan Lobley). Horizontal scale 1 inch to 2 miles or 1:126,720. Vertical scale exaggerated.

1 = Chalk; 2 = Reading Beds; 3 = London Clay; 3′ = Upper Sandy London Clay; 4 = Bagshot Sands; 5 = Hill Gravel (? Glacial); 6 = Brent Gravels (Post-Pliocene Alluvium). The Thanet Sands are absent.

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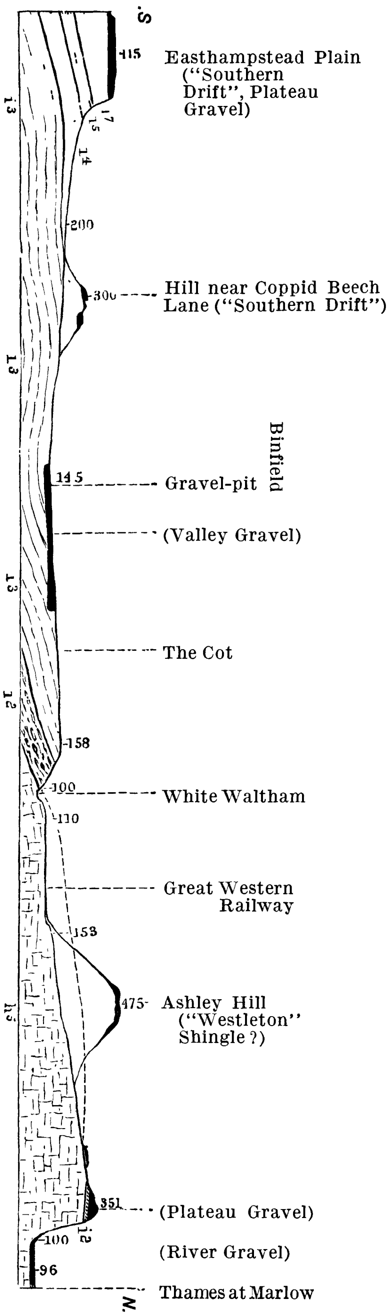

Fig. 58. Section from Easthampstead Plain to the Thames at Marlow (H. W. Monckton). Horizontal scale 1:126,720 or 1 inch = 2 miles. Vertical scale 1:10,800 or 1 inch = 900 feet, which is about 11,7 times the horizontal scale.

i^7 = Upper Bagshot Sand; i^5 = Middle Bagshot or Bracklesham Beds; i^4 = Lower Bagshot Sand; i^3 = London Clay; i^2 Woolwich and Reading Beds; h^5 = Chalk. The Thanet Sands i^1 are absent.

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the beds are made up of green sandy marl (15 to 18 m., 50 to 60 ft.) overlain by grey and green sand (9 to 12 m., 30 to 40 ft.), both being fossiliferous. The best exposure is in the cliffs of Pegwell Bay, south of Ramsgate. The sandy marl passes westward into fine green and buff sand, the upper beds thinning out, so that at Woolwich and Charlton, in west Kent, the whole formation is not more then 15 m. (50 ft.) thick. It dies out westward in Surrey and northward in Essex. The Thanetian fauna comprises about 70 known species, all marine, including *Astarte tenera* Mor., *Corbula regulbiensis* Mor., *Cyprina scutellaria* Lam., *Cucullea crassatina* LAM., *Ostrea bellovacina* LAM., *Sanguinolaria edwardsi* MOR., *Pholadomya cuneata* SOW., *P. konincki* NYST, *Aporrhais sowerbyi* MOR., *Natica subdepressa* MOR., *Scalaria bowerbanki* MOR., and fish-remains.

Woolwich and Reading Beds (15 to 25 m., 50 to 80 ft.). These are a variable series and present three distinct facies as they are followed from east to west. In East Kent, and confined to that district, is a marine facies consisting of grey sands with marine mollusca. The second or Woolwich type, composed of laminated clays and sands full of estuarine shells, is best developed in West Kent and East Surrey, but has thin, local representatives as far westward as Guildford and Reading. The third, and more widespread, Reading facies, found in the western and northern parts of the London Basin, includes unfossiliferous or sparingly-fossiliferous, varicoloured (mottled), plastic clays and brightly tinted sands, with local beds of flint-pebbles and (on the north-west) occasional inclusions of flint and quartz gravel. The Reading Beds proper appear to be mainly of freshwater origin; they contain impersistent seams of clay with impressions of leaves ("leaf-beds"), which occur in the Estuarine (Woolwich) beds also, but their basal layers, whether in contact with the Chalk or the Thanet Beds, consist of glauconitic sand and loam with green-stained flints and remains of oysters (*Ostrea bellovacina* LAM., *O. tenera* J. SOW., and sharks-teeth (*Odontaspis*, etc.).

The flora of the leaf-beds has a temperate aspect: it includes *Acacia*, *Anemia subcretacea* SAP., *Aralia*, *Corylus*, *Ficus*, *Grevillea*, *Laurus jovis* DE LA HARPE, *Liriodendron*, *Platanus*, *Populus*, etc. Among the molluscan forms present in the Woolwich Beds are *Corbicula cordata* MOR., *C. cuneiformis* J. SOW., *C. tellinella* FER., *Cyprina morrisi* J. DE C. SOW., *Unio sub-parallela* S. WOOD, *Melania* (*Melanatria*) *inquinata* DEFR., *Melanopsis buccinoides* FER., *Natica labellata* LAM., *Neritina globulus* DEFR., *Pitharella rickmani* EDW. Vertebrates are represented by *Odontaspis*, *Gastornis*, *Coryphodon*, etc.

The Oldhaven and Blackheath Beds (3 to 15 m., 10 to 50 ft.) are of limited stratigraphical extent, and though in places very fossiliferous they are hardly of sufficient importance to rank as a primary division. They consist partly of sands, partly of well worn flint-pebbles in a matrix of light-coloured sand. Cross-bedding is usually a very marked feature. In places the pebbles are cemented by calcareous matter derived from the associated shells. Near Reculvers in east Kent, where the beds consist mainly of sand (Oldhaven type), they appear to be conformable with the Woolwich Beds: south of London, where they are very pebbly (Blackheath facies), they rest on an eroded surface of the same and older Eocene strata, and even come in contact with the Chalk. Their small flora (including *Cinnamomum* and *Ficus*) suggests a warmer climate than that of the Woolwich epoch. The fauna is partly estuarine, but mainly marine (gastropoda being especially abundant), and includes *Calyptraea trochiformis* LAM., *Potamides funatus* J. SOW., *Melanatria inquinata* DEFR., *Natica labellata* LAM., *Protocardia plumstediense* J. DE C. SOW., *Pectunculus terebratularis* LAM.

London Clay (to 150 m., 500 ft.). This is a deposit of more uniform character than the beds below. It consists of stiff, blue-grey clay (weathering brown) with layers of septarian nodules of argillaceous limestone. Its lowest or "Basement" bed (2 to 4 m., $6^1/_2$ to 13 ft.) is a glauconitic sandy clay with seams of impure limestone and flint-pebbles. The formation as a whole attains its greatest thickness (150 m., 500 ft.) in Essex, and thins westward to about 90 m. (300 ft.) near Windsor, 15 m. (50 ft.) near Newbury, and 0,3 (1 ft.) or less near Bedwyn in Wilts. Most of the clay is poorly fossiliferous or barren, but at certain horizons it has yielded a rich fauna. J. PRESTWICH 1854, recognized four ill-defined zones, the lowest (including the basement bed) indicating, in the eastern part of the area of deposition, a maximum depth of water; while a progressive shallowing is indicated by the higher zones, the uppermost of which contains (at Sheppey in Kent) abundant remains of terrestrial vegetation, and of fish and reptiles. The plants are of subtropical character and include the genera *Amygdalus*, *Cupania*, *Diospyros*, *Gingko*, *Laurus*, *Musa*, *Nipa*, *Pinus*, *Quercus*, *Victoria*, *Magnolia*, *Liquidambar*, etc. Of the fauna, mention may be made of *Hemiaster forbesi* GREG., *Ditrupa plana* J. SOW., *Vermicularia bognoriensis* J. SOW., *Lingula tenuis* J. SOW., *Terebratulina striatula* MANT., *Axinaea brevirostris* J. DE C. SOW., *Cyprina scutellaria* LAM., *Modiola elegans* J. SOW., *Nucula bowerbanki* J. DE C. SOW., *Pholadomya margaritacea* J. SOW., *Pinna affinis* J. SOW., *Panopaea intermedia* J. SOW., *Aporrhais sowerbyi* MANT., *Cassis striata* J. SOW., *C. ambigua* SOL., *Pyrula smithi* J. SOW., *Nautilus imperialis* J. SOW.

The fish, of which nearly 100 species have been recorded, include *Carcharodon*, *Lamna*, *Myliobatis*, *Odontaspis*, etc.; the reptiles *Chelone*, *Crocodilus*, and *Polaeophis*; the birds *Dasornis*, *Lithornis*, *Odontopteryx*, and the mammals *Coryphodon*, *Didelphys*, *Hyracotherium*, *Lophiodon*.

Lower Bagshot Beds (15 to 45 m., 50 to 150 ft.). The London Clay passes up, gradually or abruptly, into light-coloured, cross-bedded sands, with subordinate beds of grey and white clay, and lenses of flint-pebbles. Save for lignite and occasional impressions of leaves the Lower Bagshot Beds are usually unfossiliferous, but have yielded a few casts of marine mollusca in Surrey and Essex.

The Middle Bagshot Beds (12 to 18 m., 40 to 60 ft.) are usually regarded as the equivalent of the Bracklesham Beds (of the Hampshire Basin), and are now generally known by the latter name, but this correlation is open to question. J. S. GARDNER 1879—1888 and G. F. DOLLFUS 1909 regard them as equivalent to the lower part only of the true marine Bracklesham Beds of Hampshire. They consist of laminated sandy clays, in two groups, between which lies a dark-green, glauconitic, clayey sand (3 to 6 m., 10 to 20 ft.) in which fossils are plentiful locally. Some of the forms present are *Nummulites laevigatus* BRUG., *Cardita planicosta* LAM., *Corbula gallica* LAM., *Ostrea flabellula* LAM., *Pecten corneus* Sow., *Fusus* (*Clavalithes*) *longaevus* LAM., *Turritella imbricataria* LAM., and many fish-teeth — *Aetobatis*, *Galeocerdo minor* AGAS., *Myliobatis*, *Lamna*, *Odontaspis macrota* AGAS., etc.

Upper Bagshot Beds (70 m., 230 ft.). These are the youngest Eocene strata in the London Basin. They are composed of yellow and white sands, argillaceous near the base, which is marked by a thin pebble-bed. Their precise age is uncertain, some authors correlating them with the Barton Clay (Marinésian) of Southern Hampshire, others with the upper part of the Bracklesham Beds (Auversian) of that district. Organic remains are rare, and take the form of casts in ironstone. About 50 species have been recorded from Pirbright in Surrey. The Upper Bagshot fossils include — *Nummulites variolarius* LAM., *Cardita sulcata* BRAND., *Corbula pisum* J. Sow., *Ostrea flabellula* LAM., *Pecten reconditus* BRAND., *Tellina scalaroides* LAM., *Natica patula* DESH., *Turritella imbricataria* LAM.

2. Hampshire Basin.

This area is limited on the north by the anticlines of Wardour, Winchester, and the Weald, and on the south by those of Purbeck and the Isle of Wight; the Tertiary tract having a maximum width of 45 km. (28 miles), and a length, from Dorchester to Worthing, of about 135 km. (84 miles), with small outlying tracts near Newhaven 40 km. (25 miles) farther east.

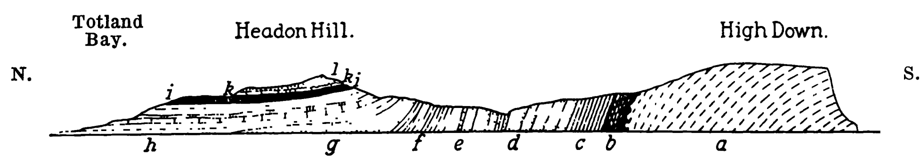

Fig. 59. Section across the west side of the Isle of Wight (after H. W. BRISTOW).
a = Chalk; b = Reading Beds; c = London Clay (Bognor Beds), d = Alum Bay Sands (Lower Bagshot Beds); e = Bracklesham Beds; f = Barton Clay; g = Barton Sands; h = Headon Beds; i = Osborne Beds; k = Bembridge Beds; l = Gravel and Sand (Pleistocene).
Horizontal and vertical scale about 1:14,500 or abont 4,3 inches to one mile.

In this basin the Thanet Beds are unrepresented, the oldest of the Eocene rocks being the Reading Beds (18 to 49 m., 60 to 160 ft.). As in the London Basin, these Sparnacian strata are mainly mottled clays and sands, with a glauconitic bed at the bottom. Near Dorchester they contain gravel of fluviatile aspect. They have yielded few fossils, except in Sussex, where thin estuarine shell-beds of the Woolwich type occur on the coast between Worthing and Seaford. The average thickness of the Reading Beds in the Hampshire Basin is probably between 20 and 25 m. (65 and 82 ft.). The maximum (49 m., 160 ft.) is reached at the eastern end of the Isle of Wight.

Unfossiliferous pebble-beds occur in the upper part of this formation near Romsey (Hampshire), and in other places.

Bognor Beds or London Clay (91 to 122 m., 300 to 400 ft.). Excepting a thin outlier at Newhaven in Sussex the easternmost sections of Cuisian beds are at Bognor (in the same county), where beds of clay and richly-fossiliferous calcareous sandstone, forming part of a series of sands and clays with occasional pebble-beds, are exposed on the shore. The formation contains sands with *Lingula* near Chichester, and at Portsmouth it is divisible into three lithological series, the highest of which consists chiefly of clays containing *Cyprina scutellaria* J. Sow., *Pholadomya margaritacea* J. Sow., *Rostellaria lucida* J. Sow., etc. (MEYER 1871).

In the Isle of Wight the junction with the Reading Beds is sharply marked by a layer of flint-pebbles. About 11 m. (36 ft.) above this layer, at Whitecliff Bay, there is a fossiliferous zone with *Panopaea intermedia* J. Sow. and *Pholadomya margaritacea* J. Sow.; at 15 m. (50 ft.), a band of *Ditrupa plana* J. Sow.; at 36 m. (120 ft.) an oyster-bed, above which come brown clays with *Panopaea intermedia* J. Sow., *Cyprina scutellaria* J. Sow., *Cytherea tenuistriata* J. Sow., *Pinna affinis* J. Sow., succeeded by laminated sandy clays.

In Dorsetshire the London Clay is mainly sandy clay or loam, with seams of ironstone and the usual pebble-bed at the base. Near Wareham it is 20 to 24 m. (65 to 80 ft.), but it thins westward, and is overlapped by the succeeding Alum Bay Sands.

Alum Bay Sands ("Bagshot" or "Lower Bagshot Beds"), 10 to 30 m. (33 to 100 ft.) These are red, yellow, and white sands with intercalations of grey laminated clay and, near the middle, layers of white pipe-clay, containing plant-remains in places. This is their character in the Isle of Wight and in East Dorset, but near Dorchester they pass into coarse pebbly sands with irregular beds of pipe-clay and of gravel, and overlap both the London Clay and the Reading Beds. The gravel, though mainly flint-stones, contains fragments of pre-Cretaceous Mesozoic and of Palæozoic rocks of the types found farther west, and are most probably of fluviatile origin. Some of the hill-gravels and masses of pudding-stone found in West Dorsetshire and East Devonshire have been referred to these Upper Cuisian beds. Most of the plant-remains recorded from Alum Bay in the Isle of Wight were found in a lenticular thickening of a seam of pipe-clay near the middle of the series. The most typical and conspicuous forms are referred by J. S. GARDNER 1879—1888 to *Aralia primigenia* HEER., *Cassia ungeri* HEER., *Comptonia acutilobata* STERNB., *Caesalpina*, *Dryandra bunburyi* DE LA HARPE, *Ficus bowerbanki* DE LA HARPE. Leaves of palm, and pods of *Acacia* and *Cassia*, have been found near Corfe on the mainland.

Bracklesham Beds (Lutetian and Auversian). These comprise a set of estuarine and marine sands and clays (to 179 m., 587 ft.) which vary so markedly in their character from place to place that the correlation of their parts in the several sections in Sussex, Hampshire, and the Isle of Wight is a task presenting considerable difficulty. At Bracklesham Bay (Sussex) and in Whitecliff Bay (I. of W.) they are wholly or largely marine. The descending succession shown in the cliff at the latter spot is as follows —

		m.	ft.
Zone of *Numm. variolarius* (Auversian)	Green and blue clays, with a little sand *Nummulites variolarius* LAM., *Corbula pisum* Sow., *Pecten corneus* J. Sow., *Pleurotoma plicata* LAM.	55	180
	Yellow sands and sandy clays	8,5	28
Zone of *Numm. laevigatus* (Lutetian)	Sandy clays and green sands, with lignite	37,5	123
	Nummulites laevigatus BRUG., *Sanguinolaria hollowaysi* J. Sow., *Volutilithes spinosus* LINN., *V. cithara* LAM. Laminated clays and calcareous sands and sandy clays with pebble-bed at base *Nummulites laevigatus* BRUG., *Ostrea flabellula* LAM., *Calyptraea trochiformis* LAM., in upper part	76	250
The lower 30 m. (100 ft.) of these beds is unfossiliferous		177	581

At Alum Bay, at the western end of the Isle of Wight, the series is represented mainly by sandy clays and lignites, marine fossils being restricted to the highest beds (*Numm. variolarius* zone). Farther west, between Poole Harbour and Highcliff on the mainland, the descending succession made out on the coast by J. S. GARDNER (1882) is:

	m.	ft.
6. Dark sandy clays with pebbles at base	4,2	14
5. Highcliff sands, unfossiliferous	9,2	30
4. Hengistbury clays with septaria	17,3	57
3. Boscombe sands	42,1	138
2. Bournemouth marine beds with plants and mollusca	15,2	50
1. Bournemouth freshwater beds with plants	?122,0	400

The thickness of the series is here about 179 m. (587 ft.)

The freshwater beds (**1**) consist of sand with beds of clay in which plant remains are numerous — notably *Acrostichum*, *Osmunda*, *Polypodium*, *Araucaria*, *Eucalyptus*, *Priartea*, *Salix*, *Sequoia*. The Bournemouth marine beds (**2**) are referred to the *N. laevigatus* zone, and the succeeding beds (**3** to **6**) to the zone of *N. variolarius*.

Barton Clay (28 to 48 m., 90 to 160 ft.). This formation is well exposed on the Hampshire coast at Barton and Hordle, and in the Isle of Wight. It is composed of grey clays and light coloured sand, and is celebrated for the abundance and good preservation of its fossils, especially marine mollusca, of which some 500 species have been collected. The lower beds ("Lower Barton" of GARDNER, KEEPING, and MONCKTON 1888, (15 to 16.5 m., 49 to 55 ft.), consist of green sandy clay — in which *Nummulites wemmelensis* DE LA HARPE (= *N. elegans* var. *prestwichianus* T. R. JONES) is of common occurrence — with a thin pebble-bed at the base, and of grey clays and sands containing *Schizaster d'urbani* FORBES, *Cassis ambigua* BRAND., *Volutilithes athleta* BRAND., *V. nodosa* J. Sow.

The higher beds or Barton Clay proper ("Middle Barton" of the above-named writers) are composed of grey and brown clays (16 to 28 m., 53 to 92 ft.) with layers of septarian concretions, and *Crassatella sulcata* J. Sow., *Clavalites longaevus* Lam., *Murex minax* Brand., *Rostellaria ampla* Brand., *Volutilithes ambiguus* Brand., *V. luctatrix* Brand.

Barton Sands (otherwise "Upper Barton", "Headon Hill Sands") 27 to 67 m. (90 to 220 ft.) These are white, grey, and yellow, argillaceous at the base, and characterised in the lower part ('*Chama*-bed') by *Chama squamosa* Brand., *Terebratula bisinuata* Lam., *Conus scabriculus* Sol., *Voluta costata* Sol., *V. humerosa* Edw., *V. solandri* Edw., and in the upper part by *Cerithium* (*Potamides*) *concavum* J. Sow., *C. pleurotomoides* Lam., *Oliva branderi* J. Sow. These are the "Becton Bunny" and "Long Mead End Beds" of the Hampshire mainland section. and are well shown in the cliffs north of the pier at Alum Bay in the Isle of Wight.

Headon Beds (44 to 45 m., 144 to 148 ft.). By most British geologists this series is regarded as the lowest division of the Oligocene system. A recent comparison of the English Palaeogene rocks with those of the Paris Basin and Belgium, however, has led G. F. Dollfus (1909) to the conclusion that this series belongs rather to the Marinésian stage of the Upper Eocene, and is approximately on the horizon of the Calcaire de St. Ouen. The Headon Beds underlie the northern part of the Isle of Wight and are shown in the cliffs between Headon Hill and Cliff End, and at Whitecliff Bay. On the Hampshire mainland they occupy part of the New Forest area, and their lower beds are exposed on the coast at Hordle. Three divisions are recognized — an upper and a lower freshwater group, and a middle group containing marine and estuarine mollusca. In the typical section at Headon Hill the descending succession is:

		m.	ft.
Upper Headon Beds (15 m., 50 ft.)	Variegated clays with *Erodona gregaria* J. Sow.	6.15	20
	Limestone with *Limnaea longiscata* J. Sow. and *Planorbis euomphalus* J. Sow.	2.4	8
	Blue clays with similar fossils	1.5	5
	Limestone, with similar fossils	3.0	10
	Sand	0.6	2
Middle Headon Beds (10 m., 33 ft.)	Clays with *Potamides concavus* J. Sow., *Cyrena obovata* J. Sow., etc.	2.1	7
	Limestone with *Limnaea* and *Planorbis*	0.3	1
	Sandy clay with marine fossils	4.5	15
	Sand and clay with *Neritina*, *Cyrena*, *Cerithium*, etc.	3.0	10
Lower Headon Beds (20 m., 65 ft.)	Limestone with *Limnaea* and *Planorbis*	0.9	3
	Sand and clay with lignite	6.1	20
	Clay sand sands with two beds of limestone containing *Viviparus angulosus* J. Sow., *Nematura parvula* Desh., *Limnaea*, *Planorbis*, etc.	7.6	25
	Sands and clays with *Erodona plana* J. Sow., etc.	6.0	20

In Whitecliff Bay, at the opposite (eastern) and of the Isle, the Lower Headon Beds are only 8,5 m. (28 ft.) thick. At Hordle on the mainland they are 26 m. (85 ft.), and have yielded many reptilian and mammalian remains. The middle beds, which are exposed to 37 m. (120 ft.) at Whitecliff Bay, and are well represented about Brockenhurst and Lyndhurst on the mainland, contain about 150 known species, including the anthozoa *Solenastraea granulata* Dunc., and other spp., *Axopora michelini* Dunc., *Lobopsammia cariosa* Dunc., *Litharea* cf. *deshayesi* Michelin, *Madrepora solanderi* Dunc.; the mollusca *Meretrix* (*Cytherea*) *incrassata* Desh., *Ostrea flabellula* Lam., *O. velata* Wood, *Potamides concavus* J. Sow., *Melanopsis fusiformis* J. Sow., *Pisania*, *Melania muricata* Wood, *Ancilla buccinoides* Lam., *Neritina aperta* J. Sow., and the cirripede *Balanus unguiformis* Sow.

Evidence of the presence of Eocene strata off the coast of Cornwall has been brought forward by C. Reid (1904).

β. Scotland.

Mull Leaf-Beds. Thin sedimentary beds are intercalated in the Tertiary lava-flows of the islands of Mull, Skye, and Eigg, off the west coast of Scotland.

In the promontory of Ardtun Head, Mull, many plant-remains have been obtained from bands of gravel, sand, and shale. The descending sequence seen in one of the quarries on the coast here is:

	m.	ft.	in.
Columnar basalt	3.0	10	
Stratified sandstone	2.4	8	
Indurated gravel of flints and lava-fragments	2.1	7	
Indurated dark mud with ferns	0.3	1	
Soft black shale full of leaves	0.7	2	6
Hard gravelly sand	0.6	2	
Basalt		—	

Among the plants are *Equisetum*, *Onoclea hebridica* FORBES, *Gingko*, *Podocarpus*, *Taxus*, *Sequoia*, *Populus arcticus* HEER, *Cornus*, *Boehmeria antiqua* GARD., *Corylus*?, *Laurus*?, *Rhamnus*?

These beds were first examined by the late Duke of ARGYLL (1851) and were long thought to be of Miocene age. J. S. GARDNER (1887), who has studied them more recently, points out the late Cretaceous character of their flora, but is inclined to regard the deposits as of earliest Eocene age, and not younger than the Thanetian.

2. Oligocene.

The British Oligocene rocks — so far as known — are confined to three small areas, situated in tectonic troughs, and disposed along a line running approximately westward through the Isle of Wight, and the southern part of Dorset, to Bovey Tracey in Devonshire.

1. Isle of Wight. The largest of the three areas just mentioned occupies the northern part of this island, where the following stratigraphical divisions are recognized:

Upper Oligocene, Stampian	Hamstead Beds (marine).
Lower Oligocene, Sannoisian	Hamstead Beds (freshwater and brackish). Bembridge Beds. Osborne Beds.

The Osborne Beds (24 to 33 m., 80 to 110 ft.). At Headon Hill and Colwell Bay these consist of white and coloured marls, and concretionary limestones with siliceous nodules. They contain *Limnaea longiscata* BRAND. var., *Planorbis discus* EDW., *Viviparus lentus* BRAND., and other freshwater shells. At Whitecliff Bay they are green clays and sands, but between Osborne and Nettlestone they consist of marls with beds of sandy and shelly limestone full of *Viviparus lentus* BRAND., and *Melania acuta*, var. *excavata* MORRIS (Nettlestone Beds), overlain by coloured sands, marls, and clays (St. Helens Beds) with *Limnaea longiscata* BRAND., *Planorbis obtusus* J. SOW., and *Cypridae*. At King's Quay near Osborne, and other places, the lower beds contain the fish *Clupea vectensis* E. T. NEWT., in remarkably good preservation, and remains of *Lepidosteus*, *Diplocynodon*, *Emys*, *Trionyx*, *Chelone*, *Palaeotherium*, *Theryodomys*. Nucules of *Chara* are plentiful. Other plants have been found at Cliff End and near Ryde, but have not been much studied.

The Bembridge Beds (27 to 39 m., 90 to 130 ft.) comprise the Bembridge Limestone and overlying Bembridge Marls. The Limestone (4,5 to 8 m., 15 to 26 ft.) is the most constant of the fluvio-marine strata in the Isle of Wight, and is everywhere readily recognizable. It is a cream-coloured stone, partly homogenous, partly tufaceous and concretionary, and contains bands of marl. The base is sharply marked, and the upper surface frequently shows signs of having been eroded before the deposition of the succeeding Bembridge marls. The highest limestone of the Headon Hill and Sconce sections, and the limestone of Hamstead and Gurnard Ledges, of Cowes, and of Newbridge are on this horizon. Its fauna is terrestrial and freshwater, the mollusca including *Amphidromus ellipticus* J. SOW., *Glandina costellata* J. SOW., *Helix d'urbani* EDW. and other species, *Limnaea elongata* M. DE SERRES, *Planorbis oligyratus* EDW.; the mammalia *Palaeotherium magnum* CUV., *P. medium* CUV., *P. crassum* CUV., *Plagiolophus minax* CUV., *Pterodon dasyuroides* DE BLAINV., *Chamaeropotamus gypsorum* DESM., *Anoplotherium commune* CUV., *A. secundarium* CUV., *Hyopotamus porcinus* GERV., *Dichobune leporina* CUV., all found also in the Sannoisian of the Paris Basin.

At Hamstead, the Bembridge Marls (21 to 36 m., 70 to 120 ft.) consist entirely of freshwater marls and clays, of grey or greenish tints, and contain the plants *Chara lyelli* FORBES, *Chrysodium*, *Carpolithes*, *Cinnamomum*, *Ficus*, *Pinus*, *Sabal*, *Zizyphus*, and the mollusca *Cerithium plicatum* BRUG., *Cyrena convexa* BRONG. (= *semistriata* DESH.), *Melania* (*Striatella*) *muricata* S. WOOD, *Melanopsis carinata* J. SOW., *Nystia duchasteli* NYST, *Viviparus lentus* BRAND. At Whitecliff Bay there is, near the base of these marls, a thin, sandy marine bed with *Cytherea incrassata* DESH., *Mytilus affinis* J. SOW., *Nucula similis* J. SOW., *Ostrea vectensis* FORBES. This is succeeded by clays with *Cyrena convexa* BRONG., and *Viviparus lentus* BRAND., in which clays there is a bed of sandy limestone containing *Amphidromus ellipticus* SOW., *Glandina costellata* SOW., *Limnaea longiscata* BRAND., var. The highest beds contain abundant *Potamides turritissima* FORBES. In places, as at Cowes, the marls contain, about 3 m. (10 ft.) above their base, a thin seam of bluish limestone, like lithographic stone, in which are occasional leaves and insects. About 20 genera of insects have been identified, belonging to 8 orders.

The Hamstead (Freshwater and Estuarine) Beds (60 to 70 m., 200 to 225 ft.), which G. F. DOLLFUS (1909) refers to the same (Sannoisian) stage as the Osborne and Bembridge Beds, are black and green clays. They occur at the surface over a large area of the northern part of the Isle of Wight, between Hamstead (or Hempstead) on the west and Brading on the east. Near Hamstead they show the following descending succession:

		m.	ft.	in.
Cerithium Beds	Clay with *Cerithium plicatum* LAM., *Cyrena semistriata* DESH., *Nystia duchasteli* NYST	10,5	35	
Leaf and Seed Beds	Green and red clays with lignitic layers containing remains of *Andromeda*, *Sequoia*, *Carpolithes*, *Chara*, *Nelumbium*	46,0	150	
White Band	Green clay with white shell-marls	2,0	6	8
Nematura Beds	Green and black clays with *Nematura pupa* DESH., *Melania fasciata* J. SOW., *Mya minor* FORBES, *Nystia duchasteli* NYST, *Melanopsis carinata* J. SOW.	19,5	64	
Black Band	Black clay with *Viviparus lentus* BRAND.	0,5	1	8

The vertebrate remains include *Pterornis*, *Anthracotherium*, *Coryphodon*, *Entelodon* (= *Elotherium*), *Hyopotamus*.

The Hamstead (Marine) Beds (6 m., 20 ft. ?). At Hamstead these consist of blue and bluish-green clays, abounding in *Corbula pisum* J. SOW., *Cyrena semistriata* DESH., *Ostrea callifera* LAM., *Natica labellata?* LAM., *Voluta rathieri* HERB., *Strebloceras* sp., *Balanus*. According to DOLLFUS 1909, they belong to the Lower and Middle parts of the Stampian stage.

2. **Dorset.** A little outlier of Lower Oligocene beds, including a representative of the Bembridge Limestone of the Isle of Wight, has recently been identified in the so-called 'Isle' of Purbeck (H. KEEPING, 1910). It forms the upper part of the isolated, conical hill of Creechbarrow, between the villages of Corfe and Lulworth. Among the few Bembridge Limestone fossils so far recorded are *Amphidromus ellipticus* SOW., *Helix occlusa* EDW. *Clausilia striatula* EDW., *Glandina costellata* SOW. A tooth of *Palaeotherium* was found at a lower horizon.

3. **Devon.** At Bovey Tracey, near Newton Abbot, an interesting series of freshwater clays, sands, and lignites occupies a small basin, about 14.5 km. (9 miles) in longest diameter and surrounded by hills of Carboniferous and Devonian rocks.

In 1863 this series was referred, on the evidence of the flora of the lignites, to the Miocene period, by OSWALD HEER (1863), who correlated it with the Aquitanian of France, and with the Hamstead Beds of the Isle of Wight. J. S. GARDNER, writing in 1879, considered that the plant-remains collected by HEER and PENGELLY were the same as those yielded by the Bournemouth leaf-beds (Lower Bracklesham, Lutetian), and on the strength of this opinion the Bovey Beds have since then been generally classed as Eocene. Recently, however, C. and E. M. REID (1910) have shown that the flora, so far from having an Eocene facies, is almost identical with that of the lignites of the Wetterau (Rhine valley), which are referred to the close of the Oligocene, or beginning of the Miocene. HEER's correlation would seem, therefore, to be approximately correct.

The following is a generalized description of the strata found in a pit and boring at Heathfield (JUKES-BROWNE 1909) near the middle of the Bovey basin:

	m.	ft.
Superficial deposits, about	6	20
Beds of clay and sand with occasional beds of lignite	76	250
Beds of lignite and clay, with one of sand	16	50
Beds of lignite, with thin layers of clay	67	220
	165	540

The base of the series was not reached in the boring, but the beds traversed all appear to belong to a single formation.

The plants in the lignitic beds include — *Magnolia attenuata* WEBER, *Nyssa europaea* UNGER, *N. obovata* O. WEBER, *N. ornithobroma* UNGER, *N. vertumni* UNGER, *Sequoia couttsiae* HEER, *Palmacites daemonorops* UNGER, *Carpolithes boveyana* HEER.

"The Bovey flora, so far as examined, seems to be essentially the flora of the granite-ravines, with the admixture of a very few aquatic forms — —". The mingling in it of "the outgoing warm-temperate with incoming northern forms is probably due to the proximity of Dartmoor, which rises sharply above the Bovey basin, but is also a characteristic of the close of the Oligocene period. The absence, or great scarcity of sedges, grasses and mosses make it difficult to call the Bovey Beds Miocene, in the modern sense of the term" (C. and E. M. REID, 1909).

It may be noted that there is a smaller basin, containing lignites and clays of uncertain age, near Marland, in the northern part of Devonshire.

3. Physiographical Conditions.

At the close of the Cretaceous period the British area emerged from the sea and the Cretaceous rocks underwent considerable erosion. So far as the English area is concerned this marine regression appears to have been caused, in part at least, by a geocratic movement of a differential character, the elevation being greater on the north-west than on the south-east; for the Lower Eocene beds overstep the Upper Cretaceous in a northward direction in Dorsetshire, Hampshire, and Berkshire, and in a north-westward to westward direction in Essex and Suffolk.

The Thanet Beds of the London Basin mark the beginning of the Eocene transgression which, approaching from the east, probably extended, in early Sparnacian times, over the whole area now occupied by Cretaceous and Oolitic rocks in England. Relics of the glauconitic pebble-bed with *Ostrea* and teeth of *Odontaspis*, forming the base of the Woolwich and Reading Series, are found all over the Chalk country, up to the edge of the escarpments which mark the present inland limits of the Turonian and Senonian strata. Though wide spread, the early Sparnacian submergence was of small depth, and marine conditions soon gave place to the fluvio-marine and fluviatile conditions under which the greater part of the Woolwich and Reading series was accumulated. The London Clay, however, registers a more decided encroachment of the sea upon the southern English area, an encroachment followed, in late Cuisian and early Lutetian times, by a notable shallowing of the water over the country between Berkshire and Essex (Lower Bagshot Beds), and by a return of fluviatile conditions in the region of Dorsetshire and Hampshire (Alum Bay Sands, Bournemouth Beds). The succeeding Bracklesham Beds of Bracklesham and Whitecliff Bay, and the Barton Clay and Sands, together with the Middle and Upper Bagshot Beds of the London district, indicate a renewed submergence, probably not less widespread, though less deep, than that of the Cuisian age; but towards the close of the Eocene period there came another pronounced regression, and the small remnants of Oligocene strata preserved in the Isle of Wight and Dorset record alternations of marine or brackish and freshwater conditions, such as usually obtain in the deltas of large rivers.

With the lignitic freshwater beds of Bovey Tracey the Palæogene record comes to an end, and the oldest of the succeeding fossiliferous deposits in the British area are of Pliocene age.

4. Economic Products.

Of the building materials obtained from the Palæogene rocks the most important are the brick and tile clays, which occur in many of the constituent formations — notably the Reading Beds, London Clay (sandy beds), Lower and Middle Bagshot Beds, and Barton Clay. The scattered blocks of hard sandstone and flint-conglomerate (known as Sarsens and Greywethers), which occur in the superficial deposits of Surrey, Bucks., Wilts., etc., and are believed to have been derived from beds of Eocene age (e. g. Reading Beds, Upper Bagshot Beds), are used for building, as in Windsor Castle. These stones were much favoured by the builders of prehistoric stone circles, e. g. Stonehenge and Avebury, Wilts.) and dolmens (e. g. Kit's Cotty, Kent). In the Isle of Wight the Bembridge Limestone has been largely quarried for local dwellings. Septarian concretions from the London Clay and Bognor Beds were formerly burned for cement; fire-bricks for furnaces are occasionally made from a silty clay in the Reading Beds; glass sand and foundry sand are got from the Thanet, Reading, and Barton Beds.

Classification of the Pliocene Deposits of England.

Stage	Sub-Stages.	Zones.		English Localities.	Belgian and Dutch Equivalents.
	NEWER PLIOCENE.				
Arnian.	Cromerian.	Cromer Beds (so-called Forest-bed Series) Zone of *Elephas meridionalis*. Freshwater and estuarine.		Kessingland, Corton, Norfolk coast from Happisburgh to Weybourn, Dewlish, (Dorset) and Doveholes (Derby) fissures.	
Arnian.	Weybournian.	Zone of *Tellina baltica*. (Marine.)		Crostwick, Rackheath, Wroxham, Belaugh, Weybourn, and the Cromer coast.	
Arnian.	Chillesfordian.	Chillesford Clay and Sand. Zone of *Leda oblongoides*. (Estuarine).		Chillesford. Various localities in Norfolk and Suffolk.	
Arnian.	Icenian.	Norwich Crag. (Marine.)	Upper Division. Zone of *Astarte borealis*.	Easton Bavent, Yarn Hill, Aldeby, Bramerton, Thorpe near Norwich, Postwick, Brundall, Horstead, Coltishall, Burgh, Wroxham.	
Arnian.	Icenian.	Norwich Crag. (Marine.)	Lower Division. Zone of *Mactra subtruncata*.	Aldeburgh, Thorpe (Suffolk), Dunwich, Bulchamp, Southwold, Beccles, Ditchingham.	
Astian.	Butleyan.	Red Crag. (Marine.)	Zone of *Cardium groenlandicum*.	Sudbourn, Chillesford, Iken, Butley, Boyton, Bawdsey, Alderton Hollesley.	Amstelian. Upper part.
Astian.	Newbournian.	Red Crag. (Marine.)	Zone of *Mactra constricta*.	Suffolk, between the Rivers Orwell and Deben, and Ramsholt, Sutton, Shottisham.	Amstelian. Lower part.
Astian.	?	Red Crag. (Marine.)	?	Bentley, Tattingstone, and the district between the Rivers Stour and Orwell.	Amstelian. Lower part.
Astian.	Waltonian.	Red Crag. (Marine.)	Oakley Horizon. Zone of *Mactra obtruncata*.	Beaumont, Oakley, Dovercourt, Harwich.	Poederlian.
Astian.	Waltonian.	Red Crag. (Marine.)	Walton Horizon. Zone of *Neptunea contraria*.	Beaumont, Walton-on-the-Naze, ? St. Erth Beds, Cornwall.	Scaldisian—Zone à *Trophon antiquum (Chrysodomus contraria)*.
Astian.	Gedgravian.	Coralline Crag.	Zone of *Mactra triangula*.	Tattingstone, Sutton, Ramsholt, Boyton, Gedgrave, Sudbourn, Orford, Iken, Aldeburgh.	Casterlian—Zone à *Isocardia cor*.
	OLDER PLIOCENE.				
Messinian.	Lenhamian.	Lenham Beds.	Zone of *Arca diluvii*.	Lenham, Harrietsham, Charing, Paddlesworth, Folkestone.	Diestian—Zone à *Terebrat. grandis*. Waenrode Beds ?
Messinian.	Lenhamian.	Boxstone Fauna (derivative).		Base of Red Crag. Base of Coralline Crag at Sutton.	

For fuel, the lignites or "brown coal" of Bovey Tracey and Alum Bay have been worked on a small scale and to little profit. The principal minerals are pipe-clay and alum. The latter has been made from Eocene clays at Alum Bay, and pipe-clay is extensively dug at Corfe (Alum Bay Beds or 'Lower Bagshot') in Dorsetshire, and at Bovey Tracey. The Lower Headon marls are used as manure in the Isle of Wight. For road-mending the Eocene pebble-beds and gravels are dug wherever they occur in quantity.

B. Neogene.

a) Pliocene.

The British rocks known to be of Pliocene age comprise certain more or less ferruginous and shelly sands with frequent pebble-beds and occasional beds of sandy clay. They are, for the most part, of marine origin, and are confined to three small areas in southern and south-eastern parts of England, viz.—1, the low country of the coastward parts of East Anglia, including Essex, Suffolk, and Norfolk; 2, the North Downs in Kent (and, probably, in Surrey), and 3, the vicinity of St. Erth, near Hayle, in Cornwall. Considerable diversity of opinion exists among British authorities in regard to the proper grouping of these deposits. The classification here adopted is, in the main, that of F. W. HARMER, (1898, 1900).

1. East Anglia and the North Downs.

Older Pliocene.

The Boxstones. — The oldest of the Pliocene deposits occurs only in a remanié or derivative form, in a thin conglomeratic nodule-bed at the base of the Coralline and Red Crag divisions of the Newer Pliocene group, in East Anglia. The nodule-bed in question contains (besides flints, septarian concretions, pebbles of quartz, granite etc., phosphatic nodules, Jurassic fossils, bones of terrestrial and marine mammals, and other material) some rounded lumps of hard brown sandstone ("box-stones"), containing casts of marine shells, and evidently derived from a definite bed which has not been found *in situ*. The included shells comprise some 16 species, most of which are common British Pliocene forms, except *Conus dujardini* DESH., *Voluta auris-leporis* GRAT., and one or two besides, which occur in the Older Pliocene and Miocene of the Continent.

Lenham Beds (to 15 m., 50 ft. ?). These are thin and irregular patches of ferruginous, slightly glauconitic sand and iron-stone which occur at intervals along the higher parts of the chalk downs of East Kent, between Folkestone and Maidstone. They rise to about 190 m. (623 ft.) above sea-level near Lenham, and everywhere rest on a north-eastward sloping surface, which truncates the Chalk (Turonian to Lower Senonian), and has become deeply indented by differential solution since Lenhamian times. Generally unfossiliferous, these iron sands here and there contain casts of marine mollusca sufficiently preserved to admit of identification, and examinations of these remains, undertaken by J. PRESTWICH, C. REID (1890) and others, have shown that the sands themselves are of the same (Diestian) age as the similar deposits which cap the hills of Belgian Flanders, and form continuous strata in Holland.

Near Lenham and Hàrrietsham about 67 species have been obtained from ironstone contained in "pipes" (solution-hollows) in the Chalk. Most of these forms are found in the Coralline Crag of Suffolk, but the following are characteristic Lenhamian species: *Arca diluvii* LAM., *Cardium papillosum* POLI, *Gastrana fragilis* LINN., *Terebra acuminata* BORS., *Pleurotoma consobrina* BELLARDI, *P. jouanneti* DESM. The presence of *Pyrula*, *Xenophora*, *Lotorium*, and *Avicula* gives the fauna a meridional aspect.

Sands which may be of Lenham age occur on the North Downs in Surrey, farther west. They have yielded a few casts of marine shells at Netley Heath, near Guildford, but none that can be definitely referred to the Pliocene.

Newer Pliocene.

The Coralline Crag (otherwise White or Suffolk Crag), 10 to 20 m. (33 to 66 ft.) consists mainly of calcareous sands composed of broken shells and bryozoa. It is restricted to the county of Suffolk, where it occurs in a small tract around Gedgrave near Aldeburgh,

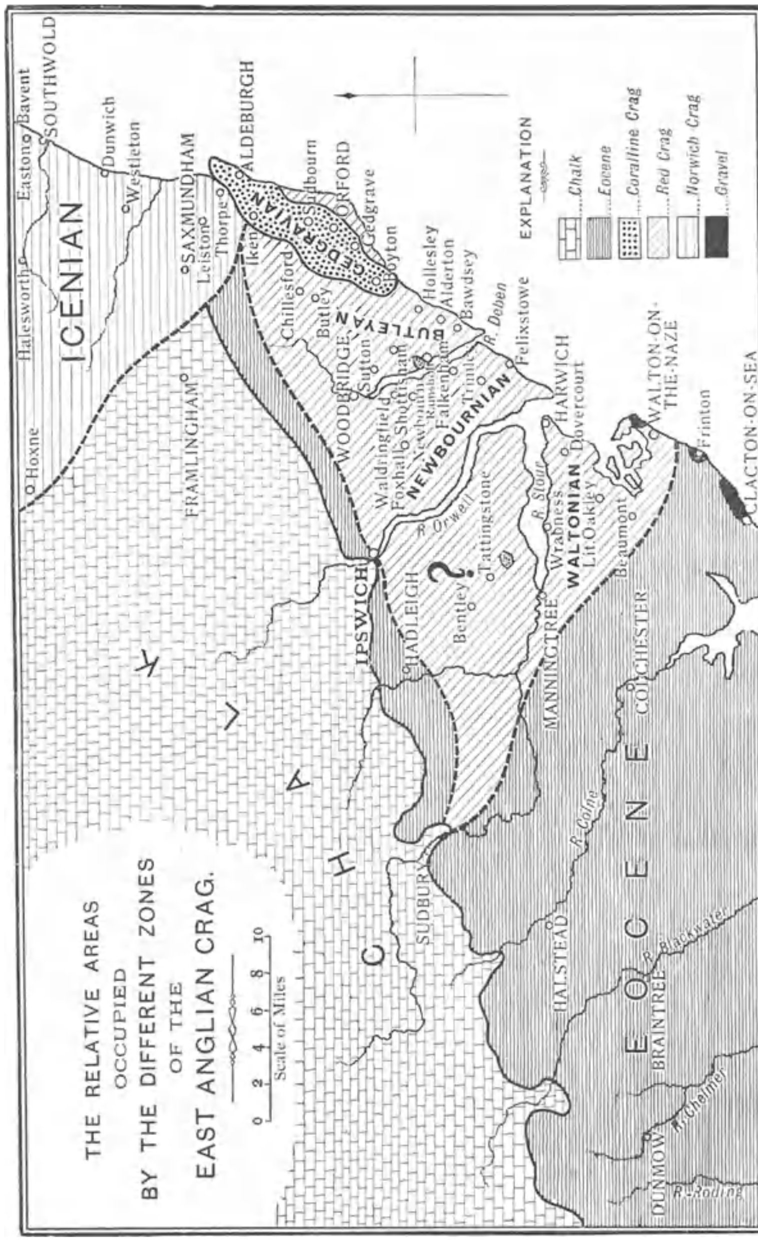

Fig. 60. Map of the Pliocene deposits of Essex and Suffolk by F. W. Harmer. The scale is about 1:667,000. South of the River Stour the Red Crag has been much denuded.

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and in other smaller areas at Tattingstone, Ramsholt, and Sutton. It rests on an eroded surface of London Clay, and contains, at its base, the interesting nodule-bed with box-stones, already noticed. Above the nodule bed are yellow marly sands (10 to 12 m., 33 to 40 ft.), with seams of broken shells, succeeded by about 10 m. (33 ft.) of soft brown, calcareous rock, made up of fragmentary bryozan and molluscan shells, and displaying a very irregular bedding. The mollusca (over 400 species) include many southern genera, such as *Voluta*, *Cassidaria*, *Chama*, *Mitra*, *Ovula*, *Pyrula*, *Ringicula*. Characteristic species are *Lingula dumortieri* Nyst, *Terebratula grandis* Blum., *Astarte omalii* Laj., *Cardita corbis* Phil., *C. senilis* Lam., *Pecten opercularis* Linn., *Pholadomya histerna* J. Sow., *Pyrula reticulata* Lam., *Ringicula buccinea* Broc., *Voluta lamberti* J. Sow. Of the abundant

Bryozoa or "corallines" about 120 have been named, of which 76 appear to be extinct. The large forms *Cellepora* and *Theonoa* (*Fascicularia*) are particularly characteristic. Fish-teeth and drifted land-shells also occur. In his memoir on Pliocene Mollusca (**1914**), F. W. HARMER divides the Coralline Crag into a lower or Gedgravian stage and an upper or Boytonian stage (of Boyton and Ramsholt). The latter is distinguished by the presence of certain Red Crag species, e. g., ***Nassa reticosa*** J. Sow., and appears to be intermediate between the Gedgravian (of Gedgrave and Sutton) and the Waltonian.

Red Crag (8 to 12 m., 25 to 40 ft.). The beds long grouped under this title consist mostly of ferruginous shelly sands, which are separated by a considerable break from the Coralline Beds. They lie on an eroded surface of the Gedgravian, and overlap it, so as to rest upon London Clay, Reading Beds, and the Chalk. The Red Crag covers a larger area than the Coralline, but, owing to the covering of glacial deposits, is seldom exposed except on the sides of the river valleys which cut through the Pleistocene beds.

From the variation in its fossils from place to place, it is inferred that the Red Crag includes sediments of diverse ages and having an imbricate arrangement, the younger deposits overlapping the older towards the north. F. W. HARMER (1898, 1900) recognizes four distinct stages, the oldest of which contains the largest percentage of extinct and southern forms, the newest the largest proportion of recent and northern species.

The oldest or Walton Crag, of Essex, is especially distinguished by the prevalence of *Neptunea* (*Jussus*) *contraria* LINN. Other characteristic mollusca are *Cardita corbis* PHIL., *Astarte obliquata* J. Sow., *Cypraea avellana* J. Sow., *Nassa labiosa* J. Sow., *Natica hemiclausa* J. Sow., *Pleurotoma mitrula* J. Sow., *Trochus cineroides* S. WOOD, *Turritella incrassata* J. Sow. The recent species common in the succeeding substages or zones are rare at Walton-on-the-Naze.

The Oakley Crag, or zone of *Mactra* (*Spisula*) *obtruncata*, exposed to the north-west of Walton, contains a fauna of more than 350 species, including a group of northern shells, such as *Astarte compressa* MONT., *Tellina obliqua* J. Sow., *Scalaria groenlandica* CHEM., *Trophon islandicus* GMEL., *T. scalariformis* GOULD. The Crag of Bentley and Tattingstone is thought to be rather younger than the Waltonian. In a section formerly visible near Bentley it was seen abutting against a reef of Coralline Crag.

The Newbourn Crag, or zone of *Mactra* (*Spisula*) *constricta*, is developed in Suffolk on the north side of the river Stour, and is distinguished by a scarcity of southern mollusca and by the presence of *Cardium angustatum* J. Sow., *Mactra ovalis* J. Sow., *Tellina obliqua* J. Sow., *T. praetenuis* LEATH., *Nucula cobboldiae* J. Sow., *Purpura lapillus* LINN., etc. At Sutton this division of the Red Crag surrounds an island of Coralline Crag, on whose sides two strand-lines of Newbournian age, 3 m. (10 ft.) apart, have been traced.

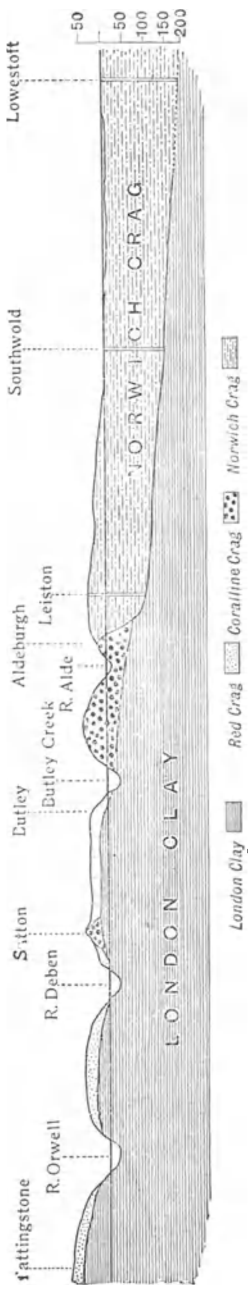

Fig. 61. Section from Tattingstone to Lowestoft (F. HARMER) showing the comparative thickness of the Red Crag and of the Norwich Crag of East Suffolk and also the rapid thickening of the latter northward. Glacial deposits are omitted. Horizontal scale about 1:460,000, or 1 inch = about 7,3 miles. The vertical distance above or below sea-level is given in feet on the right of the section.

Reproduced from the Quarterly Journal of the Geological Society, vol. 56, p. 734, 1900, with the permission of the Council and of the author.

The Butley Crag (zone of *Cardium groenlandicum*) occurs yet farther north, and is marked by a further diminution of southern, and increase of northern, types. The species *Tellina* (*Macoma*) *obliqua* J. Sow., *T. praetenuis* LEATH. *Mactra constricta* S. WOOD, and *Cardium angustatum* J. Sow., together form a great part of the deposit; while the northern forms *Cardium groenlandicum* CHEMN., *Buccinum groenlandicum* CHEM., *Natica* *groenlandica* BECK, and *Tritonofusus altus* S. WOOD, are more conspicuous than in the older crags.

The Norwich Crag (Icenian of F. W. HARMER), to 55 m. (180 ft.) or more, occupies a larger area than any of the preceding deposits. It extends through East Suffolk from Aldeburg northwards, by Beccles, to the Bure Valley in Norfolk, a distance of about 64 km. (40 miles). It cuts off the Coralline Crag abruptly near Aldeburgh, and thickens rapidly northward, to 41 m. (135 ft.) at Leiston, and 55 m. (180 ft.) at Lowestoft. It is only 5 to 9 m. (16 to 30 ft.) thick in the Yare Valley, however, and 2.5 m. (8 ft.) at Aylsham, beyond which place it has not been traced. The Norwich Crag forms a variable group of sands, laminated clays, and pebbly gravels with occasional seams of shells; the whole group being more evenly stratified than the beds of the Red Crag, and containing a fauna of more recent character than they. The extinct and southern molluscan species are few in number and of rare occurrence, while northern forms not found in the Red Crag make their appearance, notably *Astarte borealis* CHEM., *A. elliptica* BROWN, *Mactra subtruncata* DA COSTA, *Eumargarita groenlandica* CHEM., *Velutina undata* PEN. The marine fauna is relatively small (about 150 species) and most of the more abundant species are common living British forms. Of the 30 species of drifted non-marine mollusca, only three are extinct. In a conglomeratic bed ("Stone-bed") at the base of the Norwich Crag mammalian remains are locally abundant, whence the old name "Mammaliferous Crag" applied to this group. These remains are of *Lutra reevei* NEWTON, *Gazella anglica* NEWTON, *Cervus carnutorum* LANG, *Equus stenonis* COCCHI, *Mastodon arvernensis* CR. and JOUB., *Elephas antiquus* FALC., *Microtus intermedius* NEWT., *Trogontherium cuvieri* OWEN, and the marine mammals *Delphinus delphis* LINN. and *Trichechus huxleyi* LANK.

The Chillesford Beds (5 to 6 m., 16 to 20 ft.) are a series of micaceous sands with an overlying estuarine clay. They rest indifferently on the older crags, and are traceable along a sinuous belt of country from Walton-on-the-Naze to Mundesley in Norfolk. Characteristic fossils are *Cardium edule* LINN., *Tellina (Macoma) calcarea* CHEM., *T. obliqua* J. SOW., *Mya truncata* LINN., *Mactra ovalis* J. SOW., *Leda oblongoides* S. WOOD, *Nucula cobboldiae* J. SOW.

Weybourn Crag (to 4 m., 13 ft.). At Chillesford in Suffolk the Chillesford Beds pass upward into fine micaceous sand and sandy clay with *Buccinum undatum* LINN., *Purpura lapillus* LINN. etc. Farther north they appear to pass laterally into green and blue clay with loamy sand, well seen on the Norfolk coast, west of Cromer. These have yielded over 50 species of marine shells, of which five are extinct and nine are Arctic forms. Among the species present are, *Astarte borealis* CHEM., *Cyprina islandica* LINN., *Mya arenaria* LINN., *Saxicava arctica* LINN., *Tellina (Macoma) baltica* LINN., *Littorina littorea* LINN., *Buccinum undatum* LINN., *Neptunea antiqua* LINN.

The Cromer Beds (to 10 m., 33 ft.), which outcrop from beneath boulder clay on the Norfolk coast, form the highest recognized member of the East Anglian Pliocene deposits. They comprise:

		m.	ft.
3. Upper Freshwater Bed:	Sand and blue clay containing plants and non-marine mollusca — *Succinea putris* LINN., *Sphaerium corneum* LINN., *Valvata piscinalis* MÜLL., *Pisidium amnicum* MÜLL., etc. . . .	0.6 to 2,1	2 to 7
2. Forest Bed:	Laminated estuarine clays and lignite alternating with gravels and sands with masses of peat, stools and branches of trees, mammalian bones and teeth	to 7,0	to 23
1. Lower Freshwater Bed:	Carbonaceous, green, silty clays with seeds, lignite, etc.	to 1,5	to 5

The plants contained in the above group include about 60 species of flowering forms, nearly all still living in Norfolk. The land and freshwater mollusca belong to about 60 species, of which *Limax modioliformis* SANDB., *Nematura runtoniana* SANDB., *Viviparus glacialis* S. WOOD, *V. media* WOODW., *Pisidium astartoides* SANDB., appear to be extinct, and five others, including *Corbicula fluminalis* MÜLL., are no longer living in Britain. The marine species are all Weybournian forms, and probably in part derived.

Of the fish, *Platax woodwardi* AG., and *Gadus morhua* LINN., may be named, and there are 12 other kinds, marine and freshwater. There are also a few reptiles (e. g. *Vipera berus* LINN), amphibians (e. g. *Rana temporaria* LINN., *Triton cristatus* LAUR.), and birds (e. g. *Anser*, *Mergulus*, *Bubo ignavus* FORSTER). Mammals are well represented — nearly 60 species, mostly terrestrial and riparian. They include *Canis lupus* LINN., *C. vulpes*

LINN., *Machaerodus*, *Hyaena crocuta* ERXL., *Ursus spelaeus* BLUM., *Mustela martes* LINN., *Lutra vulgaris* ERXL., *Ovibos moschatus* ZIMM., *Cervus* (9 spp.), *Hippopotamus*, *Sus scrofa* LINN., *Equus stenonis* COCCHI, *Rhinoceros etruscus* FALC., *Elephas antiquus* FALC., *E. meridionalis* NESTI., *Microtus arvalis* PAL., *Castor fiber* LINN., *Trogontherium cuvieri* OWEN, *Talpa*, *Sorex*, *Myogales moschata* LINN.

The sandy clay with *Yoldia* (*Leda*) *myalis* COUTH., and succeeding "Arctic Freshwater Bed" with *Betula nana* LINN., which overlie the Cromer Beds, are now regarded as Pleistocene deposits.

2. Cornwall.

St. Erth Beds (6 m., 20 ft.?). These occur at St. Erth in western Cornwall, on the neck of land between St. Ives and Mounts Bays. They form small patches of sands and clays, 30 to 45 m. (100 to 150 ft.) above sea-level, occupying hollows in Palæozoic slates. The clays have yielded between 80 and 90 species of marine mollusca, most of the forms being such as occur in the lower part of the Red Crag beds of East Anglia. Some southern species, however, such as *Cardium papillosum* POLI, *Cardita aculeata* POLI, *Fusus corneus* LINN., *Nassa mutabilis* LINN., *N. reticostata* BELLARDI, are not known in the Pliocene of East Anglia, while the northern and arctic forms, so abundant in the higher part of the Red Crag, are absent.

A raised beach or strand-line, probably of about the same age as the St. Erth Beds, contours the hill of St. Agnes Beacon, at a height of 113 m. (370 ft.) above sea-level. Two older erosion-platforms, at about 228 m. (750 ft.) and 300 m. (1000 ft.), occur in the neighbourhood of Camelford and Bodmin (BARROW 1908).

3. Other Localities.

Remains of Pliocene mammals have been found in limestone fissures in Dorset and Derbyshire. At Dewlish, in the former county, bones and teeth of *Elephas meridionalis* NESTI and *E. antiquus* FALC. occur in fine sand with some polished pebbles, filling a trench-like hollow, of artificial aspect, on the top of a Chalk ridge (REID 1899, FISHER 1905).

The reddish ossiferous deposit, containing relics of *E. meridionalis* NESTI, *Mastodon arvernensis* CROIZ. and JOUB., *Rhinoceros etruscus* FALC., observed in the Victory quarry near Doveholes, Derbyshire, occupied a fissure of more normal type; and there were indications, in this case, that the bones (some of them gnawed by carnivora) had been washed in from above. (DAWKINS 1903.)

Indications of the existence of Pliocene deposits on the sea-bed off the British coasts are afforded by the Pleistocene drifts of the Isle of Man and the north-east of Scotland.

Deposits of Uncer tain Age.

Besides the foregoing there are, in the sou of England, many unfossiliferous accumulations, possibly or probably of Pliocene ag

Such are the apparently-marine pebble-b (Westleton Beds) which underlie the Pleistocene boulder clay and other glacial depo in Suffolk and Norfolk; also parts of the probably-fluviatile, inland, high-level grave ("Clay with flints", "Pebble gravel", "Plateau gravel", "Southern Drift") which range from 30 to 150 m. (100 to 500 ft.) about the level of the principal rivers in their neighbourhood.

b) Physiographical Conditions.

Concerning the condition of the British region in the Miocene period, nothing is positively known. From the entire absence of recognizable deposits of this epoch; from the small areal range and character of the Oligocene beds in the South of England; and from the nature and geographical position of the Miocene strata in north-western Europe, it is inferred that Britain was then dry land.

The east-and-west folds of the Weald, of Kingsclere, Wardour, the Isle of Wight, South Dorset, &c., which have played so important a part in determining the existing physiography of the south of England, are believed to be mainly of Miocene age. Certain it is, that the principal movements affecting the rocks of the Isle of Wight are of more recent date than the local Oligocene strata. These 'posthumus Armorican' folds are disposed en échelon, and have a markedly asymmetrical form, their northern limbs being, as a rule, more strongly inclined than their southern. In most cases the flexing is of a gentle order, but locally, e. g. in the Isle of Wight, South Dorset, and Surrey (west of Guildford), the disturbances have been more violent, and — in the second and third of these localities — the stresses have found relief in over-thrust faulting. The broad tectonic depressions of the London and Hampshire basins appear to be in part of more recent development than the better-defined folds just mentioned.

The Boxstones and Lenham Beds record the encroachment of the Messinian sea upon English territory. The extent of this transgression can only be surmised, but it probably was considerable, for the fauna of the Lenham iron-sands is not of a littoral type: it indicates, according to C. Reid 1890, a depth of not less than 73 m. (240 ft.) — and the sands themselves, as well as their (Diestian) equivalents in Belgium and Holland, rest on a peneplain of erosion for which it is hard to assign any probable western limit. It seems that much of the topographical relief arising from the development of the Miocene folds had already been obliterated when the early Pliocene transgression took place. At or about the close of the Messinian epoch the sea retired from the south-eastern angle of England, apparently as a result of the earth-movements which elevated the *crête de l'Artois* and its continuation north-west of Dover Straits; and the Coralline Crag (Gedgravian) of Suffolk, though lying at a lower level than the Lenhamian of Kent by some 150 m. (500 ft.), seems to have accumulated, as a current-built shell-bank, in a depth of water no greater than that indicated by the Lenham fauna.

The Red and Norwich Crags are clearly shore deposits, comparable, in a large measure, to the beaches and shell-banks formed on the coast of Holland at the present day, and pointing to the prevalence of easterly winds over the eastern part of the English area in Newer Pliocene times. The northward to north-eastward overlap of the younger zones of the Red Crag upon the older, and the overlap or overstep of the Norwich Crag upon the Red Crag, are taken to imply the continued northward retreat of the shore-line, proceeding *pari passu* with an elevation of the land to the south and south-west, and a depression of the sea floor over parts of the North Sea area and of Holland, to the north and north-east.

In the Chillesford Beds F. W. Harmer sees the sediment of a western distributary of the Rhine, and other indications of a large river flowing from the south-east are presented in the constituents of the estuarine gravels of the Cromer Beds.

c) Economic Products.

The shelly sands, or "crags", of East Anglia have been extensively dug for agricultural purposes, chiefly as manure for the heavy soils on the Eocene and Glacial clays. They are used also for paths, e. g. in the London parks. The pebble-beds are dug for road-mending, and the sands for general purposes. Phosphatic nodules and phosphatised bones, from the conglomeratic beds (Bone-bed, Stone-bed) at the base of the Coralline and newer Crags of East Anglia, were formerly much used in the manufacture of chemical manure.

II. Igneous Rocks.

By A. Harker.

Igneous action during early Tertiary time affected in greater or less degree a large part of the British area, but was most developed in the West of Scotland, including the Inner Hebrides, and the North-East of Ireland. In these tracts, where the record is most complete, we can distinguish three successive phases of activity: 1. *Volcanic*, 2. *Plutonic*, and 3. *Minor Intrusions*; and each phase includes distinct episodes, which followed one another in a definite sequence, and are marked by district groups of igneous rocks. In the outlying tracts only the last phase has left its evidence.

In the succession thus indicated we have further to recognize two different categories of events, Regional and Local. The regional groups of rocks have a wide distribution, in some cases perhaps almost coextensive with the whole region affected. Their intrusion and extrusion were related to crust-movements of a broad type, involving faulting and differential subsidence over considerable areas. In this way, in particular, the tract including the Inner Hebrides has been let down between the Outer Hebrides on one side and the mainland of Scotland on the other. The local groups of rocks occur within more restricted districts, each surrounding a certain centre which was marked out from an early stage as a special focus of activity. About these centres there were crust-movements of a more localized and accentuated kind, involving a certain degree of lateral thrust and in some cases strong anticlinal folding. Excluding Ireland, the chief centres of special activity were: a. St. Kilda, a small island group about 80 km. (50 miles) west of the Outer Hebrides; b. Central Skye; c. Southern Rum; d. the peninsula of Ardnamurchan; e. South-eastern Mull; f. Northern and Central Arran. It is possible that we ought to add Carrock Fell, on the north-eastern border of the English Lake District, but the Tertiary age of the igneous intrusions at this centre cannot be proved. The situations of the several centres are shown on the sketch-map (fig. 62).

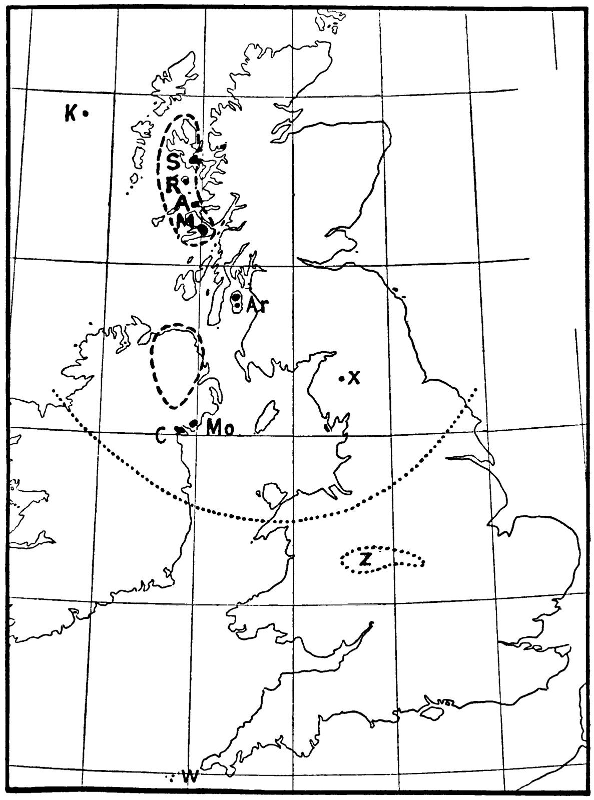

Fig. 62. Sketch-map to show the distribution of the British Tertiary igneous rocks (A. HARKER). Scala 1 inch to 150 miles, or 1 : 10 000 000.

The broken curves enclose the two areas in which basalt lavas are preserved, viz. the Inner Hebrides and the plateau of Antrim. The situations of the principal plutonic centres are indicated by letters: K = St. Kilda; S = Skye; R = Rum; A = Ardnamurchan; M = Mull; Ar = Arran; Mo and C = Mourne Mts. and Carlingford district; X = Carrock Fell.

A dotted curve marks the southern limit of known Tertiary dykes of basalt and augite-andesite. Z is the area of distribution of dolerites, diorites, etc., of possibly Tertiary age, in the Midlands of England. W is the situation of the Wolf Rock phonolite. Rockal, lies about 300 km. (190 miles) west of St. Kilda.

Redrawn with modifications from the Memoirs of the Geological Survey of the United Kingdom. The Tertiary Igneous Rocks of Skye, p. 3, 1904, with the permission of the Director and of H. M. Stationery Office.

Owing to the absence of the Tertiary sedimentary formations in the northern parts of Britain, the age of the igneous outbreaks cannot be fixed with precision. The volcanic series contains in some intercalated deposits a flora referred to the Eocene, but it is possible that the later phases of igneous activity were prolonged into subsequent divisions of Tertiary time. On the other hand, the igneous rocks of the Inner Hebrides have been affected by profound erosion, which has left the plutonic masses standing out as mountains, and almost the whole of this erosion was accomplished before the Glacial epoch.

Petrographically the regional and the local groups of rocks present a marked contrast. The regional rocks are, with relatively few exceptions, of basic nature, and they appear to have alkaline affinities (HARKER, 1912), though not very pronounced. The local groups show a much wider range, from ultrabasic to thoroughly acid, and belong in general to types of the calcic branch. The North British Tertiary igneous area forms part of the 'Brito-Icelandic' petrographical province of JUDD, and its relations are with the Arctic regions. Only in certain localities remote from the principal theatre of activity are found some rocks of highly alkaline nature, which suggest a relation with the Mid-Atlantic region. On Rockall, about 380 km. (240 miles) west of the Outer Hebrides, is a rock composed of ægirine, albite, and quartz; and the Wolf Rock, situated 30 km. (20 miles) south-west of the Land's End of Cornwall, consists of phonolite (ALLPORT 1871, 1874, TEALL 1888). The nepheline-basanite dyke of Butterton has already been mentioned (p. 170).

1. Volcanic Phase.

Basaltic lavas. — The principal event of the volcanic phase was the outpouring of basaltic lavas on a regional scale. These basalts make the greater part of the islands of Skye, Canna, Eigg, Muck, and Mull, with parts of Morven and Ardnamurchan on the Scottish mainland. These areas are merely relics left by erosion, and may be fragments of a continuous lava-field which once extended from Ireland to the Arctic regions, a distance of more than 3000 km. (2000 miles) There is no accumulation about particular centres, and, as Sir A. GEIKIE has shown, the lavas were not poured out from great volcanoes, but from innumerable small fissures distributed over the region. The thickness left by erosion amounts in places to over 1000 m. (3000 ft.), built up by many overlapping flows. The lavas were erupted subaerially, and the land stood relatively higher than at the present day. The courses of rivers of the volcanic epoch are indicated by fluviatile conglomerates, which at the eastern end of Canna reach a thickness of nearly 100 m. (300 ft.) and are also found, intercalated among the basalts, in Skye, Rum, Eigg, and Mull. The material of these conglomerates is of basalt together with pebbles of the underlying pre-Tertiary strata, derived from volcanic agglomerates. At many horizons in the basalt succession old land-surfaces are indicated by the weathered crusts of lava-flows, and there are occasionally small lacustrine deposits with the remains of land-plants. Beds of tuff and agglomerate are exceptional and of small importance, apart from the local accumulations to be mentioned below.

The lavas are mostly olivine-basalts, and are very commonly amygdaloidal, the chief contents of the cavities being minerals of the zeolite group. These minerals must be regarded as essential constituents of the rocks, and the frequent abundance of analcime and natrolite thus implies a noteworthy richness in soda. In certain of the lavas analcime occurs as a primary constituent of the ground-mass. Among the less frequent types are basalts very rich in olivine, while olivine-free lavas are also found. Where the basalts have been metamorphosed by subsequent plutonic intrusions, the zeolites are converted to felspars, the augite usually to hornblende and biotite.

The basaltic districts are broken by faults and divided into separate plateaux, the general arrangement being monoclinal, with gentle inclination. This faulting occurred during the phase of minor intrusions.

The important local episodes of the volcanic phase are two, and we will notice these in turn.

Volcanic agglomerates and tuffs of basaltic nature. — Among the basalts generally there is little evidence of explosive action; but at certain places vulcanicity took this form episodically and at an early stage. This is proved by accumulations of volcanic agglomerate and tuff in the lower part of the basalt series. They are of lenticular form, reaching a thickness sometimes of 300 or 400 m. (1000 to 1250 ft.) but rapidly thinning out in a lateral direction. There is more direct evidence of the existence at this early epoch of large volcanoes, for the actual vents are sometimes marked by cylindrical 'necks' of coarse agglomerate. The two largest and most remarkable of these old vents are at Kilchrist in Skye and in the centre of Arran: each has a diameter of over $3^1/_2$ km. (2 miles). The blocks in these agglomerates are often of large size, and are partly of basalt, partly of non-volcanic rocks. There are also large masses which have been engulfed in the vent from neighbouring stratified formations; and in this way the Arran vent has preserved evidence of the former existence in this district of Rhætic, Liassic and Cretaceous strata (PEACH and GUNN).

In the island of Mull, which at present has been only partly surveyed, the succession of events is more complex than elsewhere, and there occurs a very peculiar breccia. It was formed after the basalt lavas had been sharply folded, invaded by plutonic intrusions, and deeply eroded. It thus rests unconformably upon the older igneous rocks and upon the Moine gneisses, which here lie at the base of all. Subsequently the breccia has been itself folded and penetrated by newer plutonic intrusions (BAILEY 1912).

Trachytic and rhyolitic rocks.—Among the great spread of basalts there occur locally a few volcanic rocks of more felspathic and acid nature. In Mull certain volcanic 'necks' composed of trachytic agglomerate break through the basalts, and are pierced by plugs of trachyte. These may belong to a late epoch of the volcanic succession, but no corresponding lava-flows have been detected. There is however, a rhyolite associated with the peculiar breccia already mentioned. In Skye, on the northern border of the Cuillin Hills, a trachytic and rhyolitic group is intercalated in the midst of the basalts. It has a total thickness of about 700 m. (2000 ft.), but each member of the group thins away rapidly. The lower part consists chiefly of trachyte lavas, and these are succeeded by rhyolitic tuffs and lavas. Trachytes occur again near Bracadale, about 20 km. (12 miles) north-west of the Cuillin Hills.

2. Plutonic Phase.

Igneous action in the plutonic phase was localized wholly at the special centres already enumerated (Fig. 62). At each of these centres there were successive intrusions of different magmas, constituting distinct episodes; and the order of succession of these is always the same, although they are not all represented at any one centre. A partial exception is found in Mull, where two plutonic phases may be recognized, divided by a period of erosion with some revival of volcanic action.

The geological relations of the plutonic masses are not always the same. Most of the larger masses have something of the sheet-like or laccolitic habit, though with much irregularity in detail (Fig. 63). Such a mass has been built up, not by a single act of intrusion, but by repeated injections, not always identical in petrographical characters. Often there is a general parallel disposition of the parts, and this is very pronounced in the most basic rocks. On the other hand, there are boss-like masses and these are usually of more uniform composition.

The order of succession of the several groups of plutonic rocks was that of decreasing basicity: peridotites and other ultrabasic types, eucrites, gabbros, and finally granites, normal rocks of mean acidity being unrepresented. In some cases there was a marked interval between one group and that following; in other cases the interval was very brief. We shall notice the several groups in chronological order.

Peridotites and allied rocks. — This ultrabasic group is seen in Skye, on the south-west side of the main plutonic tract, but it attains a much greater development in Rum. The characteristic types are on the one hand dunite and other very olivine-rich varieties and on the other hand allivalites, consisting of olivine and anorthite in various relative proportions. Enstatite and augite are less abundant constituents. The intrusions usually show a stratiform appearance, due to alternating layers of olivine-rich and felspar-rich rocks, and a parallel arrangement of the crystals is also a common feature.

Eucrites. — These rocks are well developed in Rum, where they have been intruded partly beneath and partly into the ultrabasic group, and there is another large intrusion forming the headland of Ardnamurchan. The eucrites consist of a basic felspar (anorthite or bytownite) and pyroxene (often both monoclinic and rhombic), with or without olivine. Some varieties rich in olivine and poor in pyroxene graduate into the allivalite type.

Gabbros and norites. — Basic intrusions occur at most of the plutonic centres, and they are usually of gabbro, consisting of labradorite, augite, usually olivine, and some titaniferous iron-ore. Rhombic pyroxene is uncommon, norite and hyperite being almost restricted to Central Arran. The intrusive masses are often variable and heterogeneous in petrographical characters, but a pronounced banding is much less common here than in the ultrabasic rocks and eucrites.

Fig. 63. Section through Gars-bheinn, Skye, to illustrate alternations of basaltic lavas and gabbro, due to the successive intrusions of the latter rock having followed different bedding-planes in the lavas.
Scale: 2 inches to 1 mile or 1:126,720.
Reproduced from the Memoirs of the Geological Survey, The Tertiary Igneous Rocks of Skye, p. 89, 1904; with the permission of the Director and of H. M. Stationery Office.

Olivine-gabbro occurs as a composite stratiform mass on St. Kilda. In Skye a like rock makes a complex laccolitic body, 13 km. (8 miles) in diameter and probably 1000 m. (3000 ft.) thick, from which the Cuillin Hills are carved out. This intrusion is in the lower part of the volcanic series, and it has invaded and enveloped the earlier-intruded peridotite (Fig. 64). Farther east an olivine-free gabbro breaks vertically through the Cambrian dolomites N. W. of Broadford. There are small intrusions of gabbro in Rum, and a dyke-like mass occurs on Muck. In Mull the earlier gabbro, which is not extensively exposed, is of a felspar-rich variety. The later gabbro, of a more normal type, makes a number of intrusions of no great size, the largest constituting Beinn Buidhe in the south-east of the island. In Central Arran a broken ring of plutonic intrusions round the great volcanic vent comprises gabbros (with and without olivine) and norites, these basic rocks being often metamorphosed and injected by subsequent acid intrusions. Finally we may mention Carrock Fell, in Cumberland, where occur laccolitic intrusions of olivine-free gabbro (HARKER, 1894) possibly but not demonstrably of this age.

Granites, with granophyres.—The acid plutonic rocks have sometimes the granitoid, sometimes the granophyric structure, and these may be found in different parts of the same mass. In other respects these rocks are much less variable than the basic rocks, and banded structures are rarely seen. In some places the margin of a mass becomes porphyritic, felsitic, or spherulitic. In other places there is no indication of rapid chilling, and it is sometimes evident that the acid .rock has been intruded only a little later than a basic rock with which it is in contact. In this latter case there have been mutual reactions between the two, with the production of hybrid or mixed rocks. The admixture has been effected both by impregnation and partial fusion of the basic rock-masses and by inclusion and partial dissolution of basic material in the acid magma (HARKER, 1904).

Petrographically the acid rocks may be divided into three sub-groups: a. less acid, silica-percentage 70—72, with hornblende or augite, seldom biotite; b. more acid, silica-percentage 75—77, with less of the ferro-magnesian element, often biotite; c. relatively alkaline, with riebeckite.

a. To the less acid sub-group belongs the large tract of the Red Hills in Skye (Fig. 65). It has something of the habit of a very irregular sheet, but is often transgressive in its behaviour, and to the east there is a distinct boss forming Beinn na Caillich and the adjacent Hills. To the west the granite is intruded beneath and into the gabbro of the Cuillin Hills (Fig. 64), and on Marsco occur some interesting hybrid rocks, where strips of gabbro have been enveloped by the acid magma. A remarkable granophyre enclosing half-digested gabbro material is intruded along the border of the volcanic vent of Kilchrist. There is a considerable mass of granite, usually granophyric, in the West of Rum, and peculiar hybrid rocks have been produced by the admixture of granite and

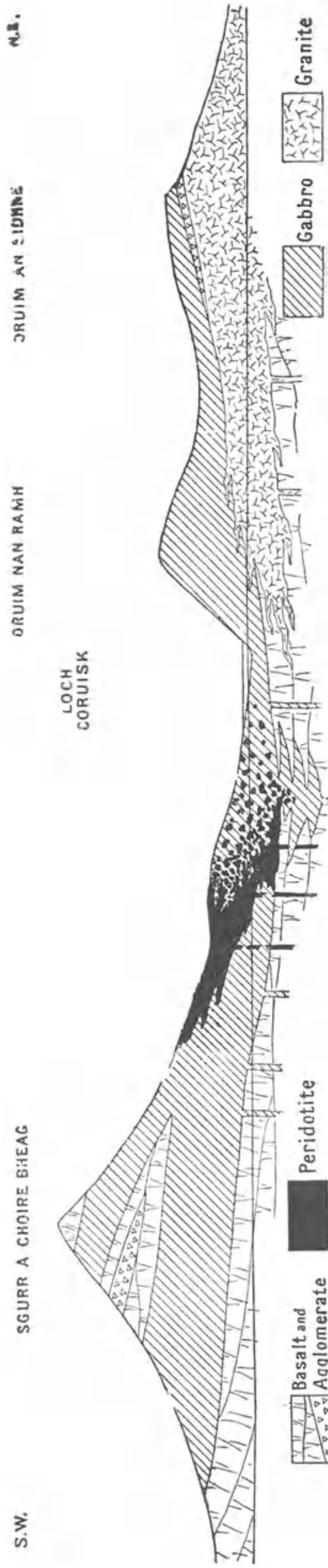

Fig. 64. Section across the gabbro tract, through Sgùrr a'Choire Bheag, Loch Coruisk, Druim nan Ramh, and Druim an Eidhne, scale: 2 inches to 1 mile or 1:126,720.

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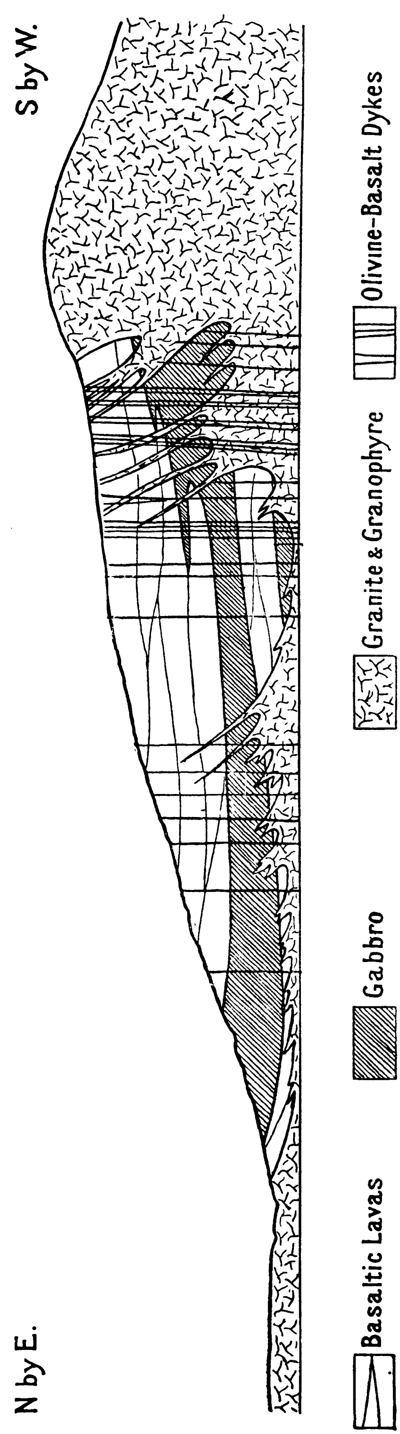

Fig. 65. Section along Beinn na Cro. Here a patch of the basaltic lavas, already invaded by sheets of gabbro, has been enveloped in the granite of the Red Hills, which sends numerous offshoots in the form of tongues and dykes through the enclosed mass. The whole is intersected by later dykes of olivine-basalt. Scale, 4 inches to a mile or 1:15,840.

Reproduced from the Memoirs of the Geological Survey of the United Kingdom.—The Tertiary Igneous Rocks of Skye, p. 138, 1904; with the permission of the Director and of H. M. Stationery Office.

eucrite. In the valley of Fiadh-innis and elsewhere such admixture, in conjunction with contemporaneous movement, has given rise to well-banded gneisses. At Glendrian and elsewhere in Ardnamurchan a hornblende-biotite-granite breaks through the eucrite, and again various hybrid products have been formed. Granites and granophyres, mostly augitic, occur in Mull. There is a large mass about Loch Ba, while another crosses Glen More and invades the gabbro of Beinn Buie. These belong to the later epoch; the earlier granophyre, seen on Sgurr Dearg, is not essentially different. Hornblende-granite, sometimes with biotite, makes part of the complex surrounding the volcanic vent of Central Arran, and has there invaded the gabbros and norites. The so-called 'diorites' are gabbros uralitized by metamorphism, and the 'quartz-diorite' of Zirkel is really a hybrid product. The augite-granophyre of Carrock Fell has also entered into reactions at its junction with the neighbouring gabbro. (Harker, 1895).

b. The granite of St. Kilda belongs probably to the second sub-group. The hornblende-biotite-granite of Beinn an Dubhaich in Skye is also one of the more acid kind. It makes an elongated boss, $2^1/_2$ km. ($1^1/_2$ mile) long, in a curved anticline of the Cambrian dolomites, which are highly metamorphosed. Finally there is the large mass of biotite-granite which occupies most of the northern half of Arran, making a nearly circular area with a diameter of 11—13 km. (7—8 miles). The manner in which the surrounding strata dip away from the mass seems to indicate a laccolitic habit. The prevalent coarse granite is pierced by a more fine-textured rock, otherwise similar.

c. Although the acid plutonic rocks are in general distinctively of calcic affinities, alkaline types are not wholly wanting. In the southern part of Raasay, near Skye, occur thick sheets of microperthitic granite and granophyre containing riebeckite, and there is a limited occurrence also at Meall

Dearg in the Red Hills of Skye. At the southern end of the principal belt of igneous action alkaline rocks are again found, the islet of Ailsa Craig, south of Arran, being composed of a riebeckite-microgranite (paisanite).

More remarkable is an isolated occurrence of syenite, which forms a small island opposite Carsaig, on the south coast of Mull. It has $10^{1}/_{2}$ per cent. of alkalies, and contains ægirine and arfvedsonite.

3. Phase of Minor Intrusions.

In this final phase regional igneous activity was resumed with great energy and over an extensive area. The intruded magmas took the habit first of regular sills and later of innumerable dykes. This change of behaviour was related to changes in the mechanical conditions affecting the region, and especially to the plateau-faulting. Sheet-formed intrusions posterior to the faulting are mostly of small size and of irregular habit. The rocks of this regional suite are, as a rule, of consistently basic composition, often with indications of alkaline affinities, but exceptions are found in certain subsidiary groups, which seem to belong to a late epoch. It appears that progressive differentiation of the parent-magmas attained an advanced stage before the cessation of activity, and probably subsidiary centres of differentiation were established, distinct from the special centres which had been operative from the beginning.

In addition to these regional groups of minor intrusions, there are others connected with the special centres at which activity had been localized during the plutonic phase. Where the record is most complete, as in Skye, these local groups fall under three heads:—acid, basic, ultrabasic; the order being the reverse of that found in the plutonic rocks.

a) Regional minor intrusions.

Basic sills. — Regular sill-intrusions are very numerous both in the basalt lava group and in the underlying Jurassic strata of Skye, Eigg, Mull, and other parts of the region. Where the volcanic rocks have been removed by erosion, the sills are still numerous in well-bedded strata, such as the Trias of Southern Arran, but not in massive formations such as the older rocks of South-eastern Skye and the Torridon Sandstone of Rum. The thickness of the individual sills ranges usually from 1 to 30 m. (3 to 100 ft.).

The prevalent petrographical type in most districts is an ophitic olivine-dolerite, and sills of this kind are widely distributed in Skye, Eigg, Muck, Mull, etc. A variety with conspicuous porphyritic crystals of labradorite is more common on Canna and Sanday. The rarer mugearite type is represented by a few sills in Skye, Eigg and Muck, and allied rocks occur in Rum and Canna. At certain localities in Skye there are double sills, consisting of an upper member of porphyritic olivine-dolerite and a lower member of mugearite. Some of the olivine-dolerite sills of Raasay, Northern Skye, and the Shiant Isles, 20 km. (12 miles) north of Skye approximate to picrite, being rich in olivine and containing a purplish pleochroic augite. A great sill, 160 m. (500 ft.) thick, in the Shiant Isles is of coarse texture and variable nature, becoming ultrabasic in its lower part. In Southern Arran there are some sills of analcime-dolerite, and others of a type very rich in magnetite. On the other hand quartz-dolerite sills are found exceptionally in Arran and Ardnamurchan.

Basic dykes. — One of the most striking features of Tertiary igneous action in Britain is the immense number of basic dykes, usually running in a N.W. or N.N.W. direction. They are most abundant in the Inner Hebrides and on the west coast of Scotland, but extend southward to the Isle of Man and Anglesey

(Greenly, 1900) and south-eastward across southern Scotland to the counties of Northumberland and Durham (Teall, 1884) (Fig. 62). In this last area the direction of the dykes is W. N. W. The width of the dykes probably averages 1—$1^1/_2$ m. (3-4 ft.), but some are 30—40 m. (100-120 ft.) wide. Where they are most numerous, it is common to find a number of distinct dykes intruded side by side in the same fissure.

Basic dykes have been intruded at various times during the Tertiary igneous history. Some belong to the volcanic phase, and represent the feeders of fissure-eruptions of basalt; others doubtless fed the sill-intrusions; but the majority are posterior to the sill epoch. They belong certainly to various subsequent epochs, but the chronological sequence of the different groups is not easily made out.

The larger dykes consist of dolerites of various kinds, with or without olivine and with or without porphyritic crystals of felspar and less often of augite. The smaller dykes have commonly a finer texture, and may be termed basalts. The dykes very generally become finer-textured towards the edges, and some of them have a thin skin of tachylyte. On certain less common varieties, which approach mugearite in composition, there is a thicker glassy crust. In the more outlying districts the dolerite dykes contain a purplish pleochroic augite and sometimes interstitial analcime. More decidedly alkaline types are found in Argyllshire (including its islands), such as camptonite and monchiquite; but these dykes, though they have been claimed as Tertiary, may be referred more probably to a late Palæozoic age (p. 189).

Subsidiary groups. — In all cases in which evidence of relative age can be obtained, these belong to the later episodes of the phase of minor intrusions, and some of them indicate considerable petrographical divergence. They assume the form sometimes of dykes, sometimes of sheets, but the latter have not the regularity or extent of the sills noticed above.

Here belong certain sheets of small thickness and irregular behaviour, which are often noticeable as presenting tachylytic surfaces. These occur at numerous localities in south-eastern Skye, Eigg, Mull, and elsewhere. Some of the rocks are basalts, while others are rather to be regarded as basic augite-andesites.

Another well characterized group is that of the augite-andesite dykes (with some sheets). They are found in Skye and other parts of the Inner Hebrides, though much inferior in number to the basalt dykes. They are more abundant in the more southern districts, viz. Arran, Bute, the Cumbrae Isles, and parts of Argyllshire, and similar rocks become the predominant type among the Tertiary dykes in Anglesey, Northumberland, and Durham. The rocks vary in character from basic augite-andesites to dacites, the more acid varieties containing much interstitial glass.

Related to the preceding group are the dykes and sheets of pitchstone. These are rare in most parts of the Inner Hebrides; but in Eigg, besides some dykes, there is a great sheet, 130 m. (400 ft.) thick, forming the prominent Sgurr. A similar rock makes the little island of Oigh-sgeir or Hyskeir, about 29 km. (18 miles) farther west. In Arran alone dykes and sheets of pitchstone are numerous. These rocks vary in composition, subacid types being more common than acid. Augite-andesites and pitchstones are often associated, and at certain places in Arran the two occur together in the form of composite dykes. It is possible that some of the more acid pitchstones should be separated from the rest and attached to the local series of intrusions.

Dykes of trachyte and allied rocks have a limited distribution. A group of such dykes, with pronounced fissile weathering, occurs about Drynoch, on the west side of Skye. Another group is found in the south-eastern part of Skye, and here the margins often show a quasi-spherulitic structure along lines following the direction of flow. Trachyte dykes are also represented in the Lorne and Cowal districts of Argyllshire and elsewhere.

On the other hand, the regional series includes some sheets and dykes of ultrabasic composition, or verging on ultrabasic. These likewise have only a limited distribution: they are known in the south-eastern part of Skye and a few other localities.

b) Local minor intrusions.

Acid group. — This, the earliest group of minor intrusions connected with the special centres, belongs to an epoch anterior to the regional faulting but in general posterior to the regional group of basic sills. Some of the acid intrusions, however, were closely connected with intrusions of basic magma, and form with them composite sills and dykes. In these the acid magma has been intruded, after only a short interval, along the middle of a basic sill or dyke, and there have been mutual reactions between the two.

In general the minor acid intrusions occur within distinct areas, each surrounding a granitic centre. In Skye the area has a greatest diameter of 36 km. ($22^1/_2$ miles), in a N.W.—S.E. direction, with the granite of the Red Hills in the centre. Composite sills and dykes occur along a curved belt within the boundary of this area, on the northern and eastern sides of the granite. In most districts the acid intrusions are quite inferior in numbers to the (regional) basic ones, but in the southern half of Arran they are very numerous, and some of the sills attain a great thickness. Some of these are composite sills, and another is found in the southern part of Bute. Two sheets of acid rock occur in Eigg, where there is possibly a plutonic centre concealed below; while there are also acid dykes in the Lorne district of Argyllshire, remote from any plutonic centre of Tertiary age.

Most of the rocks of this group belong to simple petrographical types. The larger masses are usually of granophyre and the smaller of quartz-porphyry, often spherulitic. Exceptionally there are more felspathic rocks, orthophyres and bostonites. In Skye these occur sparingly on the border of the area, and others are found in the Arran district.

Basic group. — Basic dykes belonging to local centres are not always easily separable from those of the regional series. It is found, however, that such dykes become extremely numerous about some of the plutonic centres, and may occur in great number intersecting the plutonic rock itself: the gabbro area of the Cuillin Hills in Skye is the most striking example. In some cases the dykes have a radiate disposition about the centres. This is only partially realised in Skye, but is well displayed in Rum.

More remarkable are the inclined sheets, which are found in great numbers about some of the plutonic centres, dipping always towards the special centre to which they belong. The main gabbro mass of Skye is intersected by a vast number of sheets of dolerite with this arrangement. In Rum they are less developed. They are very numerous round the eucrite mass of Ardnamurchan, and in this case they do not occur in the plutonic mass itself but outside its border. In south-eastern Mull intrusions of this kind attain an enormous development and complexity. They belong to more than one epoch of injection, and are not all of basic nature.

Ultrabasic group. — Minor intrusions of ultrabasic nature are only sparingly found. They intersect all other rocks which they encounter, and must represent the youngest intrusions connected with the local centres. They resemble in composition the plutonic ultrabasic rocks, but often show porphyritic and other structures indicative of their hypabyssal habit.

There is a group of ultrabasic dykes in the Cuillin Hills of Skye and the neighbouring district of Strathaird. They have a regular radiate arrangement, but represent only the south-western half of the complete circle. Some larger and less regular intrusive masses occur in the same area, and in the neighbouring island of Soay there are irregular sills or sheets intruded in the Torridonian strata. Elsewhere ultrabasic dykes are known only in the south of Rum.

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b. Ireland.

By G. A. J. Cole.

Owing to the perpetuation of the uplift that took place in the Irish area at the close of Cretaceous times, the Kainozoic deposits have none of the interest that they possess in the south-east of England. Milioline limestone, like that of the Paris Basin, has been dredged up from two localities off the coast of Kerry (G. A. J. Cole, 1908); but there is no evidence of Eocene marine deposits in Ireland. On the other hand, the north of Ireland formed part of the great volcanic region which became flooded by basaltic lavas during early Kainozoic times. An immense number of dykes, running north-west and south-east, mark the fissures up which the lava rose. The flint-gravels that had already formed on the denuded surface of the chalk are still seen as a reddened band, sometimes associated with lignite, buried beneath the earliest igneous flows. These first lavas were somewhat thin individually; but the long-continued activity obliterated the former features of the surface and converted the country into a region of high volcanic plateaus. A pause then occurred, and the accumulation of stems and leaves in a few places in pools on the surface of decomposing lava gives us the only evidence by which the geological horizon of the eruptions in the Kainozoic era can be ascertained. For a long time they were assigned to the Miocene period; but a revision of the evidence in Ireland and in Mull by J. Starkie Gardner (1885) has led to their being regarded as early Eocene. The vegetation is held to by Starkie Gardner correspond with that of the Lower Eocene (Heersian) beds of Gelinden in Belgium, and to be earlier than that of the plant beds of Mull. Even now, we know too little about Kainozoic floras to base very wide conclusions on such fragmentary material (Baily 1869, 1879—83), and the main part of the eruptive series may prove to be of Oligocene age. The early Kainozoic climate was a fairly warm one; and interesting support is given to this by the presence of a conspicuous zone of laterite on the surface of the Lower Basaltic series. The interbasaltic red iron ores of the counties of Antrim and Londonderry have a considerable literature of their own, and Tate and Holden (1870), with some earlier authors, maintained that they were formed at the expense of the basalt immediately underlying them. Other writers, however, have described the red zone, with its residual cores of unaltered basalt, as a band of tuffs, and have suggested that the materials were accumulated in lakes. The rich pisolitic ore that occurs, notably in eastern Antrim, at the summit of the zone, may have been formed in temporary pools; but Maufe has recently shown how such ores may develop in Uganda on a land-surface under the drip of rain from tropical forests. The lower basalts of northern Ireland remained, in fact exposed sufficiently long and sufficiently generally for lateritic decomposition to penetrate them for a considerable depth, often for 7 to 10 m. Purple lithomarge, red bole, and crumbling red and yellow masses retaining traces of the spheroidal structure of the basalt, were produced from the lava-flows in place; silica was lost during the process, as now happens in the tropics, and the residual clays approach in composition ferruginous bauxites (Tate and Holden 1870, Cole 1908—1912).

A true pale-grey bauxite occurs in places as a thin seam above the pisolitic iron-ore, and contains detrital bipyramidal crystals of quartz. Pebbles of rhyolite occur on this horizon at Glenarm, and there is little doubt that the tropical type of decomposition that produced the red zone in the Lower Basalts led to the formation of pale bauxite wherever rhyolites had been erupted. Rhyolites, in fact appeared sporadically during the interval between the basaltic outpourings. They are now best seen, in a variety of glassy and stony types, round about the volcanic neck of Tardree mountain, some 12 km. ($7^1/_2$ miles) north of Antrim town. McHenry has well pointed out that the granitic mass of the Mourne Mountains cuts a typical north-west and south-east series of basaltic dykes and is itself cut by a later series. Hence the epoch of its intrusion is very probably the same as that of the extrusion of the Antrim rhyolites, which correspond with it in composition. (McHenry 1895; Cole 1896.)

The plant-beds form, after all, the most interesting feature of the interbasaltic zone. They occur at Ballintoy, Glenarm (Libbert mine), and Ballypalady east of Antrim town. The last-named locality is the only one at present exposed for study; the leaves are here found in a brown volcanic tuff, with fragments of basalt and rhyolite. Silicified lignite (with *Cupressus*) has been found on the eastern shore of Longh Neagh, and no doubt comes from the interbasaltic beds. W. Swanston (1879) and J. S. Gardner have sought to include the Lough Neagh clays, covering a large area at the south-west end of the lake, in the Eocene series. These pale pipe-clays rest on an eroded surface of Lower Basalt and Trias, and are at least 100 m. (330 ft.) thick. They contain plant-remains; but these appear to be merely derived from the destruction of interbasaltic plant-zones a little to the north. The chief difficulty in accepting for them an Eocene age is the evidence of considerable erosion of the Lower Basalts in the neighbourhood, before they were laid down. If, however, no Upper Basalt was poured out in this area, they may be contemporary with the higher volcanic series of the country to the north. Following the suggestions of Hull and Hardman (1876), the Lough Neagh clays have generally been referred to the Pliocene Period, as products of the subsidence in the basalt plateaus which ultimately resulted in the formation of Lough Neagh (Swanston 1879; Mem. Geol. Survey Ireland, Interbasaltic Rocks, pp. 100 and 121).

Basaltic eruptions were resumed after the interval above described, and the Upper Basalts were poured out. The dolerite necks of Slemish, Tiveragh and Carnmoney (fig. 66), and the explosive vent of Carrick-a-rede in the extreme north, belong

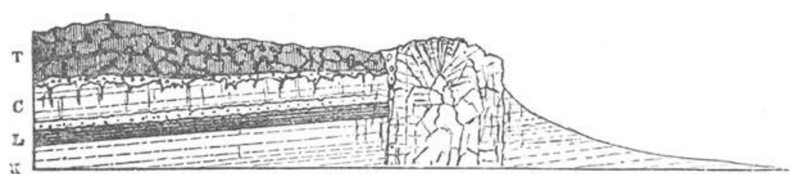

Fig. 66. Kainozoic volcanic neck of basalt: Carnmoney, Co. Antrim.
T = Basaltic lavas; C = Cretaceous; L = Lower Lias; K = Keuper Marls.
Reproduced from the Memoirs of the Geological Survey of Ireland, Country round Belfast, p. 43, 1904; with the permission of the Director and of H. M. Stationery Office.

to this stage. The lavas were mostly more massive and columnar than the Lower Basalts, and a fine example forms the Giants Causeway where it has been brought down by earth-movements to sea-level, and there denuded of its upper and more rubbly layer by the waves. The dolerite of Fair Head, forming a sea-front of columns 100 m. (330 ft.) high, above a huge block-talus, is a laccolitic mass intruded into Carboniferous sandstone, but clearly connected with the later upwellings of basic rock. The volcanic history of the whole area, which attracted J. H. Berger, Conybeare, and other writers early in the nineteenth century, has been fully dealt with by Sir A. Geikie (1897). The flora associated with the basalts may prove to be of later date than the Lower Eocene; but the Upper Basalts are hardly likely to be of younger age than Oligocene.

A considerable mass of olivine-gabbro, which was first correctly appreciated by A. von Lasaulx (1878), is intrusive in Silurian and Carboniferous strata on the south side of Carlingford Lough. Granite of the Mourne type has risen through its centre, producing in its basal portions an intricate network of veins (Sollas 1894). As has been already stated, there is every reason to believe that the Mourne granite (granophyre of Rosenbusch) is of Eocene or Oligocene age. This granite, moreover, is of the same type as those which invade the basic series of Skye, Mull, and St. Kilda, and which are undoubtedly connected as parts of the Kainozoic magma-basin. Hence the rugged crest of Carlingford Mountain, and the bold granite domes of Mourne, must be regarded as the latest additions to the mountain-scenery of Ireland.

Except for the problematic Lough Neagh clays, which are possibly Miocene or Pliocene, and one or two areas of quartzose clay near Cahir in Tipperary, left as residues from the solution of the Carboniferous Limestone, Ireland can produce no Kainozoic deposits between the Upper Basalts and the Glacial drift. The Wexford Gravels, which will be discussed under Pleistocene deposits, cannot be put back into the Pliocene period. It is, however, very probable that subsidence admitted the Pliocene sea into many parts of southern Ireland.

The history of the volcanic area may be thus summarized. The general uplift of the area of the British Isles that took place while the Danian sea still covered part of western Europe brought Ireland as a whole above sea-level. Her Eocene deposits were formed on a land-surface, and there are no indubitable traces of any subsequent submergence. Considerable denudation had taken place on the surface of the raised plateau of chalk before it became broken by the vents and fissures from which the first Kainozoic lavas poured. Flint-gravels had gathered in the hollows of the round-backed hills, and here and there taluses of blocks of chalk had formed against the steeper slopes. Then the ground over the whole northern half of Ireland cracked open in that remarkable series of parallel fissures which characterise the region from eastern Yorkshire to western Donegal. The surface-rocks over which the subaerial products of volcanic action spread must have been widely different from those in which we can trace the dykes to-day. The olivine-gabbro of Carlingford Mountain, followed by the granite of the Mourne Mountains, must have collected in subterranean cauldrons beneath considerable thicknesses of Older Palæozoic slate and probably of basaltic lava-flows. It is difficult, moreover, to believe that basaltic plateaus were not formed across the country which is marked by Kainozoic dykes in the county of Donegal and several of the adjacent counties. The denudation that removed the basalts must have also removed considerable thicknesses of the underlying rocks. It is only where the basaltic lavas remain that we can realise the true nature of the surface over which they flowed. In a very large part of the area we find that the eruptions took place before the Cretaceous limestone, which is only 30 m. (100 ft.) in thickness, had been cut through by denudation.

Here and there , the surface of a lava-flow remained exposed sufficiently long for a red earth to accumulate upon it; and a succeding flow has preserved this layer. But a fortunate pause in the eruptions of basalt occurred, and the decay of the lavas gave rise to thick lateritic soils and subsoils. Vegetation flourished, the types being suggestive of warm conditions, and the plants were washed down here and there into pools, and were preserved by the detrital material that accompanied them. The mode of decomposition of the basaltic surfaces, and the deep rotting of the rock, points to tropical conditions, such as now occur in India and in central Africa. During this comparatively quiet interval, a few small cones erupted rhyolitic lavas and tuffs, and these products were also seized on by agents of decay acting under tropical influences. Pale bauxitic clays and true bauxites, including crystals of quartz from the rhyolites, were thus spread locally over the red zone of the basaltic series. All these features were buried under a second series of basalts, which rose along fissures broken through the older lavas, and the country again assumed the monotonous character of a lava-covered plain.

It is difficult to reconcile the comparative tranquillity of Antrim in the epoch of the rhyolitic cones with the intrusion of a great mass of granite beneath the surface in the country immediately to the south. The Mourne granite occupies a cauldron excavated, as it were, in the Older Palæozoic rocks. Even if the strata on the crest of Thomas Mountain suggest a laccolitic mode of intrusion, there is no general evidence of arching of the strata, and the granite magma seems to have moved upwards in virtue of its own energy, perhaps aided by pressures originating somewhere else, rather than in response to orogenic movements in the Irish area. In this respect it presents a marked contrast to the core of Lower Devonian granite that lies so near to it on the north-west.

Since no organic remains are known among the basalts later than those in the red zone of iron-ores, it is impossible to say how long the volcanic outpourings continued. The upstanding dolerite neck of Slemish, and the exposure of the laccolitic mass at Fair Head, show how large an amount of superincumbent material must have been removed in later times by denudation. We may fairly presume that the later eruptions extended into the Oligocene period, but ceased before the well known outbreak of Miocene volcanoes in Auvergne. The activity in the Hebridean and Irish area may thus be regarded as the herald of the Alpine epoch of disturbance.

The crust-movements that gave us our modern mountain-system in Europe, though they are manifested by folding in the south-east of England, were probably accompanied by the falling in of the basaltic plateaus of the north Atlantic basin. Numerous faults, probably of late Miocene and Pliocene age, broke up the region, and admitted the ocean over an important area between Greenland, Iceland, and the British Isles (A. Geikie 1896 and Hardman 1875—76). The great extrusion of volcanic material was no doubt responsible for the general subsidence of this area. When the River Bann began to flow through a depression formed by the lowering of the basalt-surface, it denuded away the lavas along its course, and still further prepared a hollow, into which the sea penetrated in Glacial times. The post-Glacial uplift, marked by the raised beaches along the coast, probably drove out the sea again, but left the ground warped southward so as to allow of the accumulation of the waters now known as Lough Neagh.

Economie Products.

The Kainozoic **granite** and **dolerite** of Carlingford and the Mourne area afford materials for setts and road-metal. The cavities of the Mourne granite often contain colourless topaz, and sometimes aquamarine.

Basalt. The jointed columnar basalt of the Portrush area in Co. Antrim is now used, like that from the Rhine district, for the construction of sea walls and dykes.

Iron-ores. The most profitable iron-ores of Ireland are the bedded lateritic ores in the Kainozoic basaltic series of Co. Antrim. These red masses have arisen from the weathering of the Lower Basalts in Eocene times under tropical conditions. The upper part of the bed is often pisolitic; but a similar structure occurs in the decomposing basalt itself, where it has passed into the condition of bole. As is now recognised in India and elsewhere, these lateritic ores are rich in aluminium hydrate, and in parts are ferruginous bauxites. They are used as a flux for the haematite ores of Cumberland, and form the only iron-ores regularly mined at present in Ireland.

Bauxite. Pale bauxites occur as beds above the pisolitic iron-ore in several parts of Co. Antrim, and have been protected by the flows of later basalt. They often contain grains of quartz, and are probably derived from the disintegration of rhyolites, which are known to have been poured out locally in the interval between the two basaltic series. At present they are only used for the production of alum, and French bauxite is imported for the aluminium works established at Larne.

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14. Quaternary Period.

a. Great Britain.

By Percy Fry Kendall.

The Quaternary deposits and phenomena of Great Britain present a very complete record of geological time from the close of the Pliocene period up to the present. The conditions indicated are also singularly varied:—ground moraine, and terminal and lateral moraines of great ice-sheets, deposits of glacier-lakes, sea-beaches, and other marine deposits, estuarine clays, river-gravels, flood-loams, peats, æolian sands, and rain-wash furnish valuable details of the state both of the glaciated and the unglaciated areas during the Pleistocene stages. Relics of contemporary man and the Pleistocene mammalia are preserved in river gravels and cave deposits.

The post-Glacial conditions are, in consequence of fluctuations of sea level, chronicled with equal fullness and clearness. Raised beaches and submerged forests tell of these changes, while lake-deposits, peat-mosses and river-terraces, as well as the upper layers of the cave deposits yield data for the completion of the parallel history of the land surface.

The literature of the subject is of such enormous volume that no general reader can attempt to master it, but there are certain contributions of paramount interest and importance that should on no account be neglected. Among these may be cited Sir ARCHIBALD GEIKIE's paper on the Glacial phenomena of Scotland (1863) and his Scenery of Scotland (1901); Prof. J. GEIKIE's invaluable Great Ice Age 1894) and his Prehistoric Europe (1880); CROLL, Climate and Time (1875). Nothing comparable to these has been written from the point of view of English geology, but two classical papers by TIDDEMANN (1872) and GOODCHILD (1875) deal in the finest spirit with adjacent areas of the Northwest of England. SEARLES WOOD JUNIOR's summary of Newer Pliocene Geology (1880) and HARMER's many valuable contributions should be read. The posthumous work "Glacial Geology of Gt. Britain and Ireland" of CARVILL LEWIS (1894) contains much that is valuable especially in bibliography and a short summary of the knowledge of glacial geology then current can be obtained from G. F. WRIGHT's "Man and the Glacial Period" (1892).[1]

A. Pre-Glacial land-level.

It has long been known that a raised beach of Pleistocene age extends along the shores of the English Channel from Brighton westward but it is very fragmentary and its exact geological date is not easily or definitely ascertainable. Near Flamborough Head in Yorkshire however a beach and old cliff-line were found to be buried beneath the oldest glacial tills or boulder-clays of the district.

It yielded moreover to LAMPLUGH (1889) an assemblage of mammalia including *Elephas antiquus* and *Hippopotamus* that declared it to be of early Pleistocene age. The next important clue was obtained by TIDDEMAN (1900) in the Gower Peninsula, where a raised beach and cliff-line perforated by caves with an early Pleistocene fauna was found to be in places overlain by glacial deposits. Later, MAUFE and WRIGHT (1904), traced along the South Coast of Ireland and up to near Dublin a rock-shelf at times supporting beach materials and backed by a cliff. This they, no doubt correctly, inferred to be a raised beach though it has yielded no marine organisms. It is in some localities overlain by glacial deposits, and the sea-worn platform is sometimes re-dressed by glacial striae.

The height of this beach is remarkably uniform, at the maximum about 3.7 m. (12 ft.) above sea-level. Traces of it have been recognised in Carnarvonshire (FEARNSIDES 1910) and in the Isle of Man (LAMPLUGH 1903). Until recently no evidence of a similar phase was known from Scotland but WRIGHT (1911) found a strongly marked beach-platform of characteristic form covered by glacial deposits and at times partly obliterated by glacial erosion. It stands at about 30 to 37 m. (100—120 ft.) above existing high water mark and has been traced in Colonsay and other islands of the Inner Hebrides. No corresponding feature on the East Coast of Scotland has been recorded but the present writer has observed a rock platform of composite geological structure, upon which the greater part of the town of Dunbar stands, at 15 to 18 m. (50 to 60 ft.) above sea-level. It appears to be pre-glacial. WRIGHT (1914) considers that the discrepancy between the respective levels of the Scottish and the Anglo-Irish beaches may be due to block-faulting.

The Flamborough Head beach is separated from the boulder clay by blown sand and land wash, showing that the sea must have withdrawn before the advent of the ice, and as these deposits extend to at least 7 m. (23 ft.) below high water mark it is inferred that an actual rise of the land took place in the

[1] W. B. WRIGHT's "Quaternary Ice Age" has appeared since this contribution was written. It is particularly valuable for the chapters relating to the pre- and post-Glacial and levels.

interval. The cliff backing the beach extends behind and beneath the glacial deposits, and the present writer has, by the study of borings, traced it round by Nafferton and Beverley to Hessle on the Humber, where the beach and cliff were exposed in a railway cutting. The same features are traceable along the edge of the Chalk Wolds of Lincolnshire.

This cliff is confronted by the broad Drift-covered belt of Holderness under which the present writer has traced a Chalk-floor falling with a gradient of about 1 : 480 (11 ft. per mile) to the existing coast.

A marine deposit with *Pholas crispata* of exceptional size occurs at Selsey Bill on the Sussex coast and above it are large erratics of crystalline rocks probably from Brittany or the Channel Islands. Reid (1897) appears to regard this succession as marking an interglacial and glacial sequence.

At Goodwood, some 16 km, (10 miles) to the north at about 40 m. (130 ft.) above sea-level there is an upraised marine deposit described by Reid (1903). It contains a limited molluscan fauna and the allocation of a unique example such as this to a place in the Pleistocene sequence presents a problem of great difficulty of which no satisfactory solution has been offered.

In apparent conflict with the evidence of pre-Glacial raised beaches is that of a deep-sunken series of river-valleys found in many parts of the glaciated regions, of which a few examples must suffice. The most detailed description of any such system is that of the country about Glasgow (Geol. Surv. Mem., 1911). The study of many bores in this district has enabled the surveyors to contour the rock-floor beneath the Drift and it is seen that valleys exist beneath the Clyde and its tributaries, the White and the Black Cart, extending to 30 to 45 m. (100 to 150 ft.) below sea-level. These are shown to fall abruptly into the valley of the Kelvin with a descent of more than 15 in 180 m. (50 ft. in 200 yards), or perhaps even twice as much. Now the Clyde has a catchment roughly 10 times the area of that of the Kelvin and it is inexplicable why a main stream should "hang" to one of its minor tributaries.

Hollows of comparable depth exist below the Drift at Grangemouth in the Forth basin but on the same line as the Kelvin. The rivers Tyne, Wear, Tees, Ouse, Humber and Lower Trent, on the east coast, show similar relations, as does the Mersey on the west. A feature common to many of these is the fact that, so far as can be ascertained, the concealed valleys are shallower at the seaward end than further inland. It is in some instances possible that the borings have failed to hit the deepest part of the trough, but, in the case of the Mersey, all uncertainty was removed by the construction of a tunnel from Liverpool to Birkenhead the floor of which is entirely in rock, while a groove filled with boulder-clay just touches the roof at about 30 m. (100 ft.) below sea-level. There are large areas of country within the Mersey basin wherein the rock-floor is below sea-level even as far inland as Nantwich (1 m., 3 ft.) and Crewe. The deepest hollows are at Widnes (45 m., 147 ft.) and near Crewe in Cheshire, about (60 m., 200 ft.) (Annual Report Geol. Survey 1894, p. 274, 1895).

Three explanations of this common phenomenon may be offered — 1. That there was another outlet for the pre-Glacial drainage — this is highly improbable in the case of the Mersey and impossible in those of the Tyne and the Humber. 2. That there has been a depression of the interior of the country in consequence of the imposition of the ice-load, from which the recovery is not yet complete — this is highly improbable, for in the cases of the Tyne, Humber, and Mersey the greater load was at the seaward end and therefore the depression should have been greater there. 3. The last is that the interior regions have suffered great glacial erosion. This view, to which the writer has been brought with some reluctance,

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A few of the deepest drift-filled hollows may be cited. At N…port … east of Essex, the rock-floor is more than 43 m. (140 ft.) below sea-level; at Bost…, Lincolnshire, near the Wash, 49 m. (160 ft.); Barnby on Don, Yorkshire, north-east of Doncaster, 52 m. (170 ft.); Gateshead, Durham, on the Tyne, 43 m. (141 ft.). At the northern point of the Isle of Man drift occurs to a depth of 137 m. (448 ft.), starting from very near sea-level, and at Crewe, Cheshire, 60 m. (200 ft.). The maximum thickness reached is probably at Glemsford in the valley of the Stour in south-west Suffolk, where the thickness is 145 m. (477 ft.).

B. Marine Shells in Glacial deposits.

It may be convenient at this stage to consider the occurrence of fragmentary and, in a few instances, complete shells in the glacial deposits.

It is the nearly unanimous opinion of British geologists that where other indications, such as the transport of erratics, and striations upon rock surfaces, indicate a movement of ice onto the land after traversing some part of the sea-floor, shells have been brought in from the sea-bed as erratics. Thus, wherever ice out of the Irish Sea invaded the land, as in the neighbourhood of Dublin, the Isle of Man, the coastal regions of North Wales, South Lancashire and Cheshire, fragmentary and, very rarely, entire shells occur in the Drift even up to great altitudes, e. g. 366 m. (1200 ft.) on Three Rock Mountain, Dublin, 412 m. (1350 ft.) on Moel Tryfaen near Snowdon, 427 m. (1400 ft.) at Frondeg near Ruabon and 390 m. (1280 ft.) near Macclesfield.

From the North Sea they were carried into Caithness, Aberdeenshire, Northumberland, Durham, Yorkshire, and probably East Anglia.

It is of interest to observe that in the Irish sea-basin this fauna shows Arctic, British, and Southern, deep- and shallow-water types, all confusedly intermingled, and the same species are found at the highest levels as at the lowest, and the same in boulder-clays as in sands or gravels. In the Isle of Man, and in Wexford they are accompanied by many extinct species of Mollusca of Pliocene provenance; such as *Nassa monensis*, *Nassa reticosa* and *Columbella sulcata*. *Fusus contrarius* is of frequent occurrence, not only at these two localities but all through South Lancashire and Cheshire. Occasionally a pure fauna generally of high arctic type is found, e. g. in the Isle of Man (KENDALL 1894) and at Bridlington (LAMPLUGH 1881), in both instances probably in masses of sea-bottom transported bodily.

This evidence enables us to say that the Irish Sea and the North Sea, as well as some of the larger inflections of their margins, were already in existence at the beginning of the Ice Age.

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land, Caithness, showing that ice that came down Loch Ness
the Moray Firth was turned northward onto the land and brought with it Jurassic and Cretaceous rocks from the coast and sea-bottom, together with fragmentary marine shells, and deposited them, along with other matter, in the boulder-clays of the invaded country. CROLL definitely attributed this deflection to the influence of the Scandinavian ice-sheet bearing down upon Britain. Since the promulgation of this daring hypothesis his explanation has been found to apply to the whole tract from the Shetlands, which were completely overridden from the south-east (PEACH and HORNE), to Norfolk, Suffolk and Essex.

There must have been a place where a cleavage or divergence of the conflicting ice-flows took place, some going to the north and the rest to the south. CROLL shows this point as lying opposite the Yorkshire Coast. The present writer has suggested that it must have oscillated between very wide limits dependent upon the variations of alimentation of the components of the ice-sheets. The transport of erratics throws some light on the question. Rocks from the central Highlands of Scotland are rare in the Drift of the East of England, but examples have been recognised, especially one might cite a quartz-porphyry from Buchan Ness (57° 28′ N.) which in a not very characteristic form is relatively common on the Yorkshire Coast and has been recognised in Cambridgeshire (RASTALL and ROMANES 1909).

All authorities however agree that there was at one stage a movement from south to north along the coast of Aberdeenshire beginning at least 32 kilometres (20 miles) to the south of Buchan Ness, and some would extend it as far as the mouth of the Tay (BELL 1895 and Ann. Rep. Geol. Surv. 1895, p. 32 and Summary of Progress 1902, p. 103) and Professor J. GEIKIE places the point of cleavage at the Firth of Forth, following in this PEACH and HORNE (1879).

The late ANGUS PEACH (1909) found that the trail of boulders from an outcrop of essexite near Lennoxtown was so narrow and definite as to imply great constancy of direction of the ice-movement, and hence to oppose the views here set forth.

The Scandinavian ice-sheet affected the British ice in another way. By obstructing a free escape to the east, it caused a shifting of the line of ice-shedding to the east of the natural water-parting in the North of Scotland; thus, as in Scandinavia, rocks of the eastern slope were carried as boulders over to the West Coast.

The glaciation of Scotland at its maximum stage covered all except the highest mountains with a moving sheet of ice. The Hebrides were almost completely overridden and the ice must have terminated out in the Atlantic in a free, and perhaps floating, edge comparable to that of Ross's Barrier in the Antarctic. The mountains up to altitudes of over 1100 m. (3600 ft.) show signs of severe glaciation. The southern slopes of the Grampians poured a flood of ice into the great Midland Valley of Scotland that, encountering the hills of the Southern Uplands which at first were independent centres of glaciation, in part overflowed them, and the lower portions of the ice deviated to the right (west) into the Clyde and to the left (east) along the Forth basin and so into the North sea. The western element gradually surmounted the high grounds of Ayrshire and swept across the hills of Galloway into the Irish Sea carrying with it many characteristic rocks, such as the granites of the Cairnsmores and the riebeckite-eurite (see p. 304) of Ailsa Craig, a lofty islet 335 m. (1114 ft.) high in the Firth of Clyde (55⁰ 15′ N.).

We may leave the later stages of the glaciation of Scotland for subsequent description, and now consider the country further south.

The Lake District, a dissected mountainous dome, no doubt passed through the same early phases as we have suggested for Scotland. The northern Pennines and the mountains of both North and South Wales, nourished valley glaciers whose continued growth produced very complex interactions especially upon the west.

The Irish Sea, never of any great depth, formed a pool into which Scottish ice poured from the north, Irish ice from the west. Radial flow from the Lake District centre contributed on the north-east, and from North Wales glaciers radiated in a similar manner, as well as from South Wales.

From this congested area only three outlets were available, namely St. George's Channel, the plain of Lancashire and Cheshire, and the Solway. By each of these a vast ice-lobe was discharged.

The ice of the Lake District was cleft by the great pressure from the north and north-west, the line of cleavage being about the position of Skiddaw; the western moiety swept round into the Irish Sea while the eastern swung round and accompanied the Scottish ice up the Solway, into the Vale of Eden: here a new cleavage took place. A northern branch passed straight on into the valley of the Tyne while another, perhaps larger portion, went up the Vale of Eden receiving reinforcements from the Lake District but it was hemmed in on the east by the great faulted escarpment of the Cross Fell Range. At the southern end of the Vale of Eden this glacier came in front-to-front contact with the ice flowing off the Howgill Fells and the two elements fused and took a course, the resultant of their motions, to the east over Stainmoor. Across this pass a broad stream swept, charged with boulders gathered from Scotland, the Lake District (especially the Carrock Fell gabbro, and the Shap granite) and from the Vale of Eden itself. One noteworthy rock from the last source, the Permian conglomerate called 'Brockram' is of peculiar interest; its outcrop nowhere rises 214 m. (700 ft.) above sea-level, yet innumerable fragments were carried over the pass at altitudes ranging from 433 m. (1435 ft.) to about 550 m. (1800 ft.) and were borne by the ice down the Vale of York as well as along the Yorkshire Coast.

The second outlet from the Irish Sea by way of the plain of South Lancashire offered an easy gradient, for the distance between the Pennine Hills about Macclesfield and the corresponding heights near Ruabon is 64 kilometres (40 miles), and the watershed between the Mersey and Severn drainages scarcely exceeds 120 m. (400 ft.), while the lowest point is less than 90 m. (300 ft.) above the sea. Through this gap poured a great ice lobe, augmented on its left flank by ice from the western half of the Lake District as well as from the Ingleboro group of hills. This ice advanced across the plain and abutted against the Pennine Hills from Rochdale (53⁰ 37′ N.) to below Macclesfield and Stoke. On the west the ice of the Irish Sea had met the north-flowing ice from North Wales and repeated the evolutions performed in the Solway. The northward march of the

Welsh ice was arrested and the northern stream parted to east and to west, the dividing line being about Llandudno or Colwyn Bay. The eastern half was swept round into the Vale of Clwyd, which most singularly repeats the glacial history, as it does the tectonic development of the Vale of Eden. The ice passed up the Vale and finding, near the head, the Pass of Bodfari, corresponding to that of Stainmoor, it swept over into the estuary of the Dee. There was no 'Brockram' to be carried over, as in the Vale of Eden, but there was Triassic sandstone which was carried up on to the pass and re-deposited in a crushed condition in such vast quantities that on the first official maps of the region the Geological Survey represented it as Trias *in situ*.

The early extension of the Welsh ice into the Irish Sea is shown by a basal lead-coloured boulder-clay, without shells, and containing exclusively Welsh erratics, underlying 'Northern Drift' of a reddish colour, with Scottish and Lake District erratics and abundant shell-fragments. At the early stages of glaciation Welsh ice streamed out by the valleys of the Dee and Severn far into the plain, and boulder-clay with Welsh rocks is found in the Lickey Hills and isolated boulders are met with on the lofty ridges of Moel Fammau (53° 9′ N.) at 598 m. (1900 ft.), and near Clun in Shropshire.

The ice-lobe from the Irish Sea overrode the Dee-Severn watershed and left near Wolverhampton a great load of northern rocks, the 'terminal concentration' of MACKINTOSH (1879), which may represent a terminal moraine. The melt-water was discharged into the Severn drainage where the gravels contain traces of this phase in numerous foreign stones. Upon the shrinkage and withdrawal of the ice a lake probably formed between the front of the ice and the watershed, across which the overflow rapidly cut a channel of such magnitude as permanently to deflect the drainage, whereby the Upper Severn, a former feeder of the Dee, was carried southward at Ironbridge (LAPWORTH 1898).

To complete our review of the western ice it remains to mention the third outlet from the Irish Sea — the St.George's Channel between Wales and Ireland. A great ice-lobe some 112—128 km. (70—80 miles) in breadth poured through this gap and, though hemmed in on the flanks by Irish and Welsh ice respectively, it more than held its own and was able to encroach for a few miles upon the land where its inroads are recorded in deposits of boulder clay, sand and gravel containing erratics from the north as well as fragmentary marine shells. The gravels on the hill-sides south of Dublin and the Manure Gravels of Wexford will be alluded to in the section upon Ireland and demand no further mention here than to point out that they are closely paralleled in North Wales, at Moel Tryfaen, where a day's diligent search in gravelly beds at 412 m. (1350 ft.) will yield many crumbs of shells and perhaps half a dozen fairly perfect examples. The associated boulders here are of interest — they include many Scottish rocks from Galloway as well as the riebeckite-eurite of Ailsa Craig[1]. The first systematic petrological descriptions of this remarkable rock were furnished simultaneously by TEALL from specimens obtained at Ailsa Craig and by COLE (1892) from a pebble found[2] at Moel Tryfaen. The northern ice overrode the Lleyn Peninsula but did not come in contact with the Welsh Coast down the length of Cardigan Bay. Further south, however, it seems to have overridden the St.David's Peninsula (JEHU 1904). To the east of this place the ice-flow seems to have been directly off the Old Red Sandstone range of the Vans of Brecon and into the sea.

The termination of this great glacier has never been defined, but no doubt it was situated in the sea to the south of St.George's Channel. BARROW (1906) found

[1] It is described by HARKER as a riebeckite-microgranite or paisanite, see p. 289.
[2] By KENDALL (J. W. E.)

beach-materials containing erratics on the north coasts of the Isles of Scilly. They had evidently been transported by floating ice.

It is necessary now to revert to the East Coast region and consider the ice movements in the country south of Aberdeenshire.

The ice streaming off the Highland Mountains passed across the site of Glasgow and crossing the low watershed filled the basin of the Forth. Under the influence of the Scandinavian ice-sheet it took a course to the south-east partly over the Lammermuir hills and partly by way of the North Sea. At the same time a broad stream of ice flowing down the Valley of the Tweed was "shouldered" on to and across the Cheviots into Northumberland, where, upon its right flank, it came in contact with the Solway ice that crossed into the Tyne drainage and was augmented by a separate glacier flowing down the South Tyne from the hill country about Cross Fell (DWERRYHOUSE 1902). This new element in its turn suffered deflection across the hills of Durham and received tributaries from the Wear Valley before joining the Stainmoor Glacier with its tributary from Upper Teesdale. The interactions of all these elements have not yet been full elucidated, but it is clear that there was at one stage a free escape seaward of the Stainmoor—Teesdale ice, and the erratics belonging to this dispersion, notably the Shap granite and the Brockram, were distributed right down the Yorkshire Coast and even into Lincolnshire. At another stage, whether earlier or later, this ice was prevented from reaching the coast and was deflected down the Vale of York as a stream 29 to 32 kilometres (18—20 miles) wide. It received tributaries from the valleys of the Swale, Ure, Nidd, Wharfe, and perhaps the Aire, but none from the Cleveland area. It is doubtful also whether any of the valleys south of the Aire contributed contingents. The full extension of this glacier cannot be determined with certainty, though at some phase it must have reached far below Doncaster, but this question must be reserved for general discussion of the evidence of successive glaciations and only a specific stage can conveniently be discussed at the moment. The stage in question is that when the ice-front was oscillating in the neighbourhood of the city of York. Two magnificent terminal moraines, one at York itself and the other at Escrick 7 km. ($4^1/_2$ miles) to the south, completely span the valley. They are bold ridges rising from 8 to 30 m. (25 to nearly 100 ft.) above the plain and consist mainly of tough boulder clay with many erratics. Entangled however in the mass are irregular wisps of sand and gravel showing no definite order, position or arrangement. The writer suggested some years ago (KENDALL 1895) that, as it was improbable that boulder clay could be deposited as a subaerial terminal moraine, the glacier might have overridden its moraine and enveloped it in the material of its ground moraine. This view was not favourably received and the writer does not press it here, but remarks that the glacier probably terminated in the waters of a lake in which its moraine material may have been rucked up after the manner of that of the Sefström glacier of Spitsbergen.

The Coast region of Yorkshire was invaded for only a few miles by the ice-sheet thrusting in from the North Sea. This ice was apparently of diverse origin and constitution. At one time the Teesdale ice was pressed in against the coast-line; at another, probably, the main agent was of Scottish origin; while there may perhaps have been a time when the Scandinavian ice bore directly against the coast. Erratics from many sources are found in the boulder clay, including rhomb-porphyries (Rhomben-Porphyre), larvikites, and elaeolite-syenites from the south of Norway, the granites or syenites of Ångermanland, and many Scottish rocks, as well as stones brought over Stainmoor Pass. A certain vertical distribution has been noticed, thus Shap granite has been seen in situ on a few occasions, and, so far as can be ascertained, it is never in either the lowest boulder clay nor in the highest. On the other hand, rocks from the valley of the Tweed, and the Cheviot Hills are extremely plentiful in the highest boulder-clay, the Hessle Clay.

There are apparently at least three, more or less distinct, beds of boulder clay in the coast region of Yorkshire. 1. A leaden-coloured Basement Clay, 2. The Purple Clay, and 3. Reddish clay known as the Hessle Clay, from its development at Hessle near Hull.

Sands and gravels often occur either as intercalations between these beds or even dividing up the boulder clays themselves. This is particularly noticeable at the embouchure of valleys or in proximity to steep hills. In the Cleveland Hills gravels often extend to much higher altitudes than the boulder clays and they have been regarded as representative of the "Middle Sands" but the profusion of stones from the Tweed valley and the Cheviots establishes their correspondence with the Hessle clay.

In Lincolnshire the succession is much the same as in Yorkshire, but the ice-sheet seems at about the latitude of Louth, if not north of that place, to have over-ridden the Wolds, and the equivalent of the Purple Clay appears on the western side so charged with chalk gathered up in the passage of the ice over the Chalk outcrop as to become the typical Chalky Boulder Clay.

East-Anglia furnishes a series of Drift phenomena that connect Yorkshire and Lincolnshire with the Midlands and, as will be seen later, provide an important link in the chain of evidence fixing Man's relation to the Ice Age in Britain.

The Cromer Cliffs show a limited succession of Basement Boulder Clay (Cromer Till auctorum) and Contorted Drift, a heterogeneous mass of sands, gravels, muddy silts and marls. This division contains great lenticles of shattered chalky débris, sometimes so large as to give occupation to successive generations of lime burners. Of greater interest than these however, are the great slabs of chalk sometimes more than 250 m. (820 ft.) in length, but seldom amounting to a twentieth as much in thickness. The mode of origin of these great inclusions of chalk has been admirably discussed by Clement Reid (1882), with whose conclusions the writer is in entire agreement. According to this author the thrust and drag of an invading ice-sheet rucked up the higher layers of the Chalk, just as one may raise ridges upon a table-cloth by a sliding pressure, and further movement sheared off the ridge and carried it on to be included in the deposits. Ridges in various stages of development can now be observed upon the foreshore. Round the town of Cromer a fine amphitheatre of Drift hills has been identified as the terminal moraine of an ice-lobe (Harmer 1909).

The next regular member of the East Anglian Glacial sequence is the Chalky Boulder Clay. The distribution and origin of this great deposit present problems of extraordinary interest. Commencing at the Wash its margin may be traced by Fakenham, and Norwich, across to the sea near Yarmouth. It occupies all the country from this line down to Upminster in Southern Essex and the northern heights of London about Finchley, where it dies out abruptly without either moraine or outwash plain. Thence it extends with a sinuous margin till in the neighbourhood of Buckingham it runs into a tract of gravelly mounds regarded as a moraine. A map by Searles Wood Jr. (1880) exhibits its distribution in a north-westerly direction even into the Severn drainage. Deeley (1886) describes its occurrence at Abbotts Bromley and Hanbury in east Staffordshire, west of Burton on Trent. The margin runs eastward through Leicestershire, where, near Melton Mowbray, it forms a sort of spurious escarpment, overlooking the Valley of the Trent into which in this region the boulder-clay does not descend. Lamplugh attributes this, not to subsequent erosion, but to non-deposition. The further course of this boulder-clay is in the form of an elongated triangle between the

Lincoln Ridge (Inferior Oolite) and the Chalk Wolds. The total area may be roughly computed at 25 000 qkm. (10 000 square miles). Throughout the whole of its expanse this great sheet is characterized by the inclusion of large quantities of chalk of a type that is restricted to the country north of the Wash, a very hard chalk associated with grey flints, readily distinguishable from the soft chalk with black flints, of the country to the south. The Spilsby Sandstone (Lower Cretaceous) and Red Chalk are other Lincolnshire types that are more sparingly distributed, the latter, as far west as the Vale of Evesham and Chipping Norton. While everywhere characterized by the presence of these Cretaceous rocks, the matrix of the Chalky Boulder Clay is derived from the subjacent rocks or from the soft deposits, generally clays, over which it has passed. This is shown for East Anglia in HARMER's map (1909 p. 108) where a belt, intensely charged with Kimmeridge clay, extends from the Fens across almost to the coast between Lowestoft and Ipswich; again, in Huntingdon and Bedford the matrix is of Oxford clay. In the intervening tract the soft local Chalk and Gault clay seem to have contributed the bulk of the deposit.

RASTALL and ROMANES (1909) have made a careful study of the erratics in this deposit and they find that besides a very limited number of individual specimens traceable to the Lake District, the foreign stones include many from the south east of Scotland and from Scandinavia and some significant rocks from the East Coast of England. Rhomb-porphyries are recorded even from Highgate in the north of London. They note that to the "east and south of Cambridge the Red Chalk of Lincolnshire and examples of *Gryphaea dilatata* bored by *Pholas*" [more probably by *Saxicava* P.F.K.] are very abundant, but much less so to the west and north, where their place seems to be taken by fragments of Great and Inferior Oolite limestone. In the north western part of the area DEELEY (1886) has shown that the Chalky Boulder-clay succeeds a Drift series called by him the Pennine Boulder-clay and he argues (1914) that the latter was the product of the great ice-lobe from the Irish Sea, which turned across the Trent Valley, near Burton, and was augmented by a contingent that overflowed the Pennine watershed and passed down the Valleys of the Wye and Derwent. The sketch map which illustrated his paper unfortunately does much less than justice to his argument as it leaves large areas ice-free that were certainly severely glaciated.

This author considers that the Pennine ice spread eastward at least as far as Grantham and that its retreat preceded the advance of ice out of the North Sea which laid down the Chalky Boulder-clay, producing an intermingling of erratics by incorporating some of the previously deposited boulder-clay with its own ground moraine.

HARMER (1908, 1909) seeks to explain the Chalky Boulder Clay as the product of a great glacier originating in Teesdale (HARMER 1910) passing down the Vale of York, moving thence, in one direction up the Valley of the Trent, and in another towards the Fenland, having been reinforced by lateral glaciers descending from other Pennine valleys, and especially by ice which crossed the Chalk Wolds of Lincolnshire, or entered through the Humber gap from the North Sea." He considered that "the Wash gap was closed by the glacier which carried the Cretaceous Neocomian and Kimmeridgian material into Mid-Suffolk."

RASTALL and ROMANES consider that, first, a great ice-sheet advanced from the North Sea, and distributed Scandinavian boulders over the whole district: "this formed the Cromer Till and Contorted Drift of Norfolk." "At a later stage, ice of British origin moving parallel to the Coast" [which coast is by no means clear] "became relatively more powerful and tended to displace the Scandinavian ice towards the east."

In favour of DEELEY's views the fact should be noted that in several districts west of the Fens erratics of Mesozoic rocks are found to the east of the parent outcrops, particularly blocks of marlstone (Middle Lias) south of Grantham. HARMER's explanation, so far as relates to a movement from west to east across Norfolk and Suffolk, may be accepted without reservation, but that the Chalky Boulder-clay was the product of ice having its source in Teesdale, and flowing down the Vale of York is opposed by many facts of great significance. Allusion has already been made to the marked change in the distribution of the Drift below the Escrick moraine. The contrast between this region with only small isolated patches and shreds of glacial deposits and the broad expanses of the Chalky Boulder Clay seems decisively opposed to the idea that they had a common origin, and that the Chalky Clay, as being further from the source, was the older. A yet stronger argument is derivable from the distribution of the erratics. If the Chalky clay in East Anglia was laid down on the eastern (left) flank of a glacier, how is the occurrence, across the Midlands of large quantities of chalk, flint, and other rocks from Lincolnshire to be explained?

The explanation, a partial one, it is true, that seems preferable is that the advance of DEELEY's "Pennine" ice synchronized, broadly, with the great extension of the glacier of the Vale of York. This may have corresponded with the stage of the Cromer Till and Contorted Drift. Then at a later stage the two native ice-lobes shrank back and, after a longer or shorter interval, a new movement from the North Sea brought a great lobe in over a broad front extending from either the Humber or some more southerly point in Lincolnshire to the Wash. The great strength of the stream may be supposed to have been towards its median axis. As the ice crossed the Chalk Wolds of Lincolnshire it gathered up enormous quantities of chalk, flint, and some Red Chalk and Spilsby Sandstone, so that, while on the east of the Wolds its ground moraine was the relatively chalk-less Purple Boulder Clay, on the west it became intensely charged with Chalk and whereever the ice extended it carried the characteristic Cretaceous rocks.

The radial flow from the Fen depression is shown by the transportation of local rocks, as, for example, the Cambridge Greensand, a very distinctive material with a restricted outcrop, has been thrust or dragged up to the top of the Chalk escarpment 150 metres (500 feet) above sea-level near Royston. BOSWELL (1914) has shown that disturbances of the chalk, such as those at Trowse near Norwich and at Royston, which have long been recognised as effects of ice pressures, are of common occurrence in the Valley of the Stour and other valleys of Suffolk. They indicate a movement of ice down the valleys. Probably a further accentuation of the same action is to be seen in the giant erratics that appear to characterise in a quite exceptional way the Chalky Boulder Clay. The greatest of these, so far as identified, is a stupendous mass, or congeries of blocks, of flinty Chalk at Catworth, Huntingdon. CAMERON (1894) traced an outcrop for more than 800 m. (half a mile) and he regards it as only a small part of the Chalk actually present which he considers to occupy an area of about 50 qkm. (20 sq. miles) in all. It is surrounded by Chalky Boulder Clay and rests more or less directly upon Oxford Clay. No information is given as to the character of the Chalk or of the flints such as would decide whether it was of the Lincolnshire type. If actually an erratic, it must have travelled at least 40 km. (25 miles) and in Rutland smaller masses noted by earlier observers must have come at least 80 km. (50 miles). In these cases no evidence is adduced that they are actually underlain by Boulder-clay, but the famous composite erratic of Roslyn near Ely satisfies every requirement of proof. It consists of Chalk, Cambridge Greensand, and Gault in proper stratigraphical sequence and once occupied an area of several acres. It was not until extensive quarrying operations were carried out, that have now almost completely removed the mass, that it was found to be surrounded by boulder-clay which also separates it from the underlying Kimmeridge Clay. Though undoubtedly an erratic, it is not likely that it has travelled far; indeed it may be perhaps compared with an outlier that has been pushed off its base. Several outliers of Gault exist in the neighbourhood. Many other large erratics have been recorded in the track of the Chalky Boulder Clay; some of Lias, and of Great Oolite and one a mass of Ampthill Clay (or, possibly, Lower Kimmeridge) encountered in a well near Biggleswade. The clay proved to be 20 m. (67 ft.) thick and it was completely surrounded by Chalky Boulder Clay.

The latest glacial deposit of this region is the Cannon Shot Gravel of WOOD and HARMER (1877). The latter observer considers that it was deposited by glaciers occupying the shallow river-valleys of Norfolk and Suffolk — a view which seems to the present writer improbable. In the district West of Great Yarmouth, known as the Flegg Hundred, are sands and gravels attributed by the authors just quoted to a Middle Glacial Series and supposed to be of marine origin. They contain a suite of a hundred species of marine shells, commonly well preserved, of a modern British type, though containing a few extinct species.

We return now to the valleys trenching the eastern slopes of the Pennines. The particular phases of glaciation represented by the moraines in the vicinity of York can be traced with great clearness in the valleys of the Swale, Ure, Nidd, Wharfe and Aire, all of which were occupied by glaciers. Those of the Swale and Ure, fed by ice from the Howgill Fells, contributed enormous streams of ice to augment the glacier of the Vale of York, but those of the three valleys to the south had already shrunk back a few miles from the confluence, and the lateral moraine of the main glacier swept across the opening of Nidderdale and Wharfedale, both of which valleys were occupied as to their lower ends by glacier-lakes.

Lake phenomena have in recent years proved of great service in tracing, not only the position, but also the oscillations of the ice-margins. The first full recognition of such features in Britain is to be credited to T. F. JAMIESON, who explained the long-debated phenomena of the Parallel Roads of Glen Roy by demonstrating them to be beaches of a series of glacier-lakes held up in the recesses of the hills to the north-east of Ben Nevis (56° 48′ N) by glaciers whose moraines he defined and described. DUGALD BELL and JAMES GEIKIE had already inferred the existence of a lake near Glasgow from the anomalous character of the valley of the Black Cart and from lacustrine deposits. The present writer (KENDALL 1902) described a complete system of lakes in the Cleveland Hills and defined the criteria for the recognition of such lakes. In the district dealt with all the signs that might be expected to remain are found, viz: 1. Beaches, 2. Floor deposits, 3. Deltas, and 4. Overflow Channels. The first are but rarely found, as the overflows, being in comparatively soft rocks, were quickly lowered; but the other evidences are very constant in their occurrence. The overflow channels are by far the most easily recognised and the most valuable for the precision they give to the determination of the position of the ice-margin and the relative duration of the stages. Many conclusions, derivable from no other class of evidence, have been reached. The methods employed have been applied to a vast number of cases in other parts of the United Kingdom and very important rectifications of widely prevalent opinions have been made. For instance, a recent writer has stated that "the Cheviot Hills may have had their own ice-cap throughout", whereas the lake-overflows trenching the spurs, even of Cheviot itself, show that the local ice disappeared long before the glacier of the Tweed valley ceased to be driven athwart the grain of the country by the pressure of the Scandinavian ice-sheet.

The lake-phenomena of large areas of the glaciated country have been studied and the writer has traced systematic groups and sequences through almost the whole line of country from Edinburgh to Norfolk, where a lake-channel, now holding the two opposite-flowing rivers, the Little Ouse and the Waveney, freed the waters from the last constraints, and perhaps, though the evidence is very imperfect, the Straits of Dover may themselves mark the site of a great overflow, by which, not only the whole eastern drainage of England, but much of that of the continent, escaped, as was suggested long ago by BELT (1876).

No attempt has yet been made to correlate in a comprehensive manner the oscillations, and ultimate shrinkage and disappearance of the British glaciers but a few points may be noted.

The Welsh ice certainly moved out to north and east without interference until the Irish Sea glacier turned it from its direct course and usurped its place both in the sea itself and upon the plain of Cheshire, Shropshire and the Severn Valley. The Irish Sea Glacier, if responsible for DEELEY's "Pennine" boulder-clay, preceeded the ice of the Chalky Boulder Clay, and withdrew before its advance. The maximum extension of the glacier of Stainmoor Pass, and the Vale of York, long preceeded the age of the Chalky Boulder-Clay. The glaciers of the Pennine valleys south of the valley of the Ure had shrunk back prior to the withdrawal of ice from the Vale of York. The eastern coastal tract was liberated in regular order from south to north, but the evidence is singularly clear that the Scandinavian ice-sheet continued to exercise an influence upon the British ice-streams till a very late period. After the withdrawal of the ice-lobe that produced the Purple and Chalky Boulder Clays, Scottish ice, charged with rocks from the Tweed Valley and the Cheviots, was pressed strongly in against the coasts of Lincolnshire and Yorkshire, producing the Hessle Boulder Clay and giving rise to most of the lake-phenomena in Cleveland described by the present writer. The last phase in this area shows this with great clearness. A lobe of ice crossed the North Cleveland watershed by a saddle 206 m. (675 ft.) high while the mouth of the Esk at Whitby was free from obstruction. Lakes in the coastal tract of Northumberland described by SMYTHE similarly show obstruction by ice at the seaward side. KENDALL and MAUFE showed that the glacier of the Tweed valley was still bent to the south at its seaward end, when the eastern valleys of the Cheviots were, as regards their lower ends, ice-free. Beyond this latitude the evidence is not clear, but JAMIESON and DUGALD BELL's work seems to prove that there were glacier-lakes on the seaward slope of Aberdeenshire, upheld by ice in the North Sea. The last phases are recorded in the Raised Beaches of Scotland described later.

D. Evidences of Interglacial conditions.

The British evidence of Interglacial conditions is indecisive. While Prof. JAMES GEIKIE (1894) argues for an extensive series of Glacial and Interglacial periods, CLEMENT REID recognises no more than one interruption of the continuity of the Ice Age. LAMPLUGH (1914) speaking from an intimate knowledge of many large areas of glacial deposits in Ireland, the Isle of Man, Derbyshire, and the East Coast of England declares himself unable to recognise any break in the succession of more than local value. The present writer has for 25 years held the same opinion but long reflection upon a series of facts, quite other than those heretofore considered, have convinced him of the existence of a very early glaciation in Yorkshire that is separated by an immense interval of time from the stage represented by the

York moraines. At the same time he is not prepared to say, or to suggest, that during that interval there was a disappearance of the ice from the regions to the north or that there was anything more than a wide oscillation of the ice-margin. The evidence adduced in the preceding section seems indeed to show that once the Scandinavian ice began to exercise an influence upon the British shores, it never wholly withdrew until the final liberation of the coast of Aberdeenshire.

The evidence hitherto relied upon has been 1. Biological, 2. Stratigraphical. The biological evidence is almost purely botanical and has been stated with customary clearness and impartiality by CLEMENT REID (1899, 1911). He has investigated the plant remains in deposits found beneath boulder clay, and in other cases where no cover of boulder clay exists, but where superposed floras are interpretable as indicative of alternating mild and rigorous conditions.

This careful and most scrupulous observer enumerates, in the work cited, all the evidence available up to that date. Confining attention for the time to plant remains found beneath actual glacial materials, we find that, apart from a body of plants of wide range that are common to two of the groups, the burden of proof of the Glacial or Interglacial aspect has to be borne by a very small number of plants. Those indicating Glacial conditions are *Salix polaris*, *S. herbacea*, *S. reticulata*, and *Betula nana*, all except the first still surviving in Britain, though for the most part restricted to the mountains of Scotland. The Interglacial types are, particularly, *Prunus avium*, *P. padus*, and *Crataegus oxyacantha*, but the groups are not always definitely separated, thus at Airdrie, in peat "classed as Interglacial, on account of its occurrence between two beds of Boulder-clay," *Prunus padus* occurs in association with *Betula nana* and *Potentilla comarum*. Similar difficulties and incompatibilities have been encountered where no help is forthcoming from stratigraphy. At the Admiralty Offices, London, *Betula nana* is associated with *Hippopotamus*, and at Bovey Tracey, with *Pinus*. The difficulties of classification are much enhanced by intrinsic causes of confusion; for example, in a deposit at Gayfield, Edinburgh, *Crataegus oxyacantha* and *Prunus avium* were found along with three plants of the "Glacial" group, whence REID inferred that two beds were represented, one of which was of Neolithic age. At Hailes Quarry, near Edinburgh, two distinct layers occur, in vertical succession between two beds of boulder clay. The lower yields three willows of the "Arctic" group, along with many plants of no significance, and one obviously modern seed of a common cornfield weed; while the upper bed is rich, not only in plants of a temperate aspect, but in common weeds of cultivation such as *Chrysanthemum segetum* and *Matricaria inodora*, besides flax. J. GEIKIE (1880) gives a very full account of the geology with a section showing thick boulder-clay both above and below the plant-beds. This and other cases cited below illustrate the peculiar difficulties attending the study of these phenomena even when attested by observers of approved competence.

At Redhall near Edinburgh, "between two masses of till", is a deposit containing over 70 species of plants, the whole of which still live in the Scottish Lowlands. REID after rejecting three species as probably based on recent specimens says. "The many weeds of cultivation, capsules of flax and pieces of charcoal that it contains can scarcely belong to any earlier period than Neolithic. The flora closely corresponds with that of the upper bed at Hailes."

Other examples of similar confusion occur at Cowden Glen, and Overtown near Beith. In all these cases experienced observers vouch for the geological details, and one is driven to conclude that either complex land-slipping has taken place or that other causes have brought about a mixture of relatively modern and more ancient material. For this last cause numerous cases could be cited from REID's work, as, e. g. at Hoxne in Suffolk, where *Ranunculus repens*, *Rhamnus frangula*, *Sambucus nigra*, *Alnus glutinosa*, *Carpinus betulus* and *Taxus baccata* in an "Arctic" bed with *Betula nana*, *Salix polaris*, and *S. herbacea* are considered to have been accidentally introduced from an underlying lignite with temperate plants. With reservation of the foregoing to cover the eventualities here referred to, we may, nevertheless, following REID, admit the following as possibly genuine Interglacial plant-beds in Scotland: Airdrie (55° 52′ N), Faskine (55° 51′ N) (but containing *Salix herbacea* may be of late Glacial age), Kilmaurs (55° 38′ N) (associated with mammoth and reindeer), and Clava (57° 28′ N).

The only English plant-beds for which an Interglacial date can be claimed upon stratigraphical evidence is a bed containing plants upon which REID reported "The list is a small one, but it indicates estuarine conditions, and suggests a subarctic climate". In association with a silty loam with *Cardium edule* and *Scrobicularia piperata*, it lies between the Purple and the Hessle Clays at Kirmington in North Lincolnshire (53° 35′ N.).

So far the evidence only of plant-remains has been considered. Some geologists assign the same importance to the occurrence of marine shells. If we take however the middle course and reject those cases where the shells occur in boulder-clay, in a mainly fragmentary condition in gravels, or in manifestly disturbed deposits-the following may be noted. In Scotland there is a shell-bearing clay at Clava near Inverness, at about 153 m. (503 ft.) above sea-level between two beds of boulder-clay. The deposit was traced for a distance of 174 m. (190 yards) but this was not its full extent. It contained a large suite of marine animals of a cold water, but not Arctic, aspect. The shells were commonly well-preserved, some retaining the epidermis.

One other occurrence in Scotland is of a shelly clay found in three of the glens opening on the West Coast of Kintyre. It rests upon rock or is separated from it only by sands or gravels, and is overlain by boulder-clay. The points of observation extend over a north and south range of about 5 kilometres (3 miles) but there is no evidence to show that the bed is continuous. The top of the shelly deposit varies from 41 m. (135 ft.) above sea-level at the south end to 61 m. (199 ft.) at the middle station and 55 m. (179 ft.) at the northern. The fauna appears to be of a rather more Arctic character than that at Clava and it includes *Fusus contrarius*. The glaciation of the Kintyre peninsula was from the east. Assuming that this deposit was undisturbed, its age may well be pre-Glacial, and it may represent the pre-Glacial raised beach already described. The occurrence of *Fusus contrarius* is in some measure corroborative of this view. It has not been found elsewhere in Scottish deposits, though common among the obviously remanié shells of the Irish Sea basin.

The Clava deposit was investigated by a Committee, including HORNE, ROBERTSON and JAMIESON (BELL 1894—1895), who reported in favour of the opinion that it was an Interglacial seabottom in situ. A minority of two demurred, and pointed to the improbability of a single patch being the sole representative of this condition on the East of Scotland, and urged that, if this were in place, the Upper Boulder Clay in many areas ought to be charged with shelly detritus. JAMES GEIKIE replied that a depression of 183 m. (600 ft.) would submerge but a small area of Scotland, that the marine conditions may have been of brief duration, and that subsequent glaciation long continued would gradually work off the shelly deposits. The minority suggested that the shelly deposit was a mass transported from the bed of Loch Ness which they supposed might have been an arm of the sea in pre-Glacial times. DUGALD BELL (1895) supported this view by many arguments, laying especial stress upon the fact that in the gravel beneath the shelly clay and in the boulder-clay above it 53 to 82 per cent of the stones were from the Old Red Sandstone (the local rock) and only 14 to 26 % gneiss, whereas, in the shelly clay, the Old Red Sandstone contributed only 10 per cent and the gneiss 59 per cent of the stones. It was acknowledged by JAMIESON, that there was neither lamination nor distinct stratification in the clay. LAMPLUGH gave his adhesion to the views of the minority.

The English glacial series exhibits only three examples that demand consideration of beds with marine shells intercalated between two boulder-clays.

The district of Holderness is traversed by a range of hills, partly composed of gravel, and in part consisting of a boulder-clay with a gravelly core. The gravels in general present no features of special interest but at two adjacent localities, Kelsey Hill and Burstwick, they have long been known to contain many shells and mammalian bones. The general succession is apparently the same at both places, Purple Boulder Clay forming the base, succeeded by gravels in tumultuous heaps, with inclusions ("intrusions" according to JAMES GEIKIE) of boulder clay, and the whole swathed in Hessle Boulder Clay. The gravels have yielded a large suite of mammalian remains including walrus and a seal, but the "lion" recorded in the Geol. Surv. Mem. on Holderness was introduced on the evidence of a mislabelled specimen from another locality. The molluscan remains which are very plentiful present no special features, they are mainly species still living in the British seas with only a few Boreal and not British. At Kelsey Hill, but not at Burstwick, *Cyrena fluminalis* occurs in great profusion. REID regards these gravels as marine accumulations laid down on the spot during the one interglacial period that he recognises. He remarks upon the abundance of the *Cyrena* just opposite the Humber.

At Kirmington in Lincolnshire (53° 35′ N.) a very interesting and perplexing section is to be seen.

Gravel
Hessle Boulder-clay
Gravel
Laminated silt with estuarine shells, and a patch of peat with marsh plants and some freshwater shells
Sand
Purple Boulder Clay
Sand
Lead-coloured clay (probably "Basement" Boulder Clay).
Chalk

The deposit has been closely investigated (Brit. Assoc. Rept. 1904 and 1905) and the lower beds proved by borings. The altitude of the top of the estuarine bed is about 25 m. (82 ft.) above sea-level. REID connects this bed with the Burstwick and Kelsey Hill gravels, regarding one as the estuarine equivalent of the other. The difficulty here is to account for the fact that no corresponding marine or estuarine beds or their glacially distributed remnants are found in the Vale of York or the Trent valley, though these are at a much lower level and apparently unaffected by the Hessle stage of glaciation.

At Speeton (54° 7′ N.) on the Yorkshire Coast there are two beds containing estuarine shells. One deposit, still maintaining its horizontality, lies at an altitude of about 24 m. (80 ft.) above the sea upon the Kimmeridge Clay and beneath boulder-clay. It contains *Cardium edule* with valves in apposition, besides *Scrobicularia* and other shells. The other occurrence of apparently the same bed, is near sea-level, about a quarter of a mile further north. There are two interesting questions awaiting an answer. 1. Which, if either, is in its natural position, the low-level or the high-level? 2. If in situ how came an estuarine deposit out on the open coastline?

To neither of these questions can a decisive answer be returned. The condition of the shells at the higher level raises a presumption that they are in an undisturbed position, but the contrary view gains support from the analogy of great transported masses of Mesozoic clays that occur abundantly in the glacial deposits of this coast. One such, of Lower Lias, nearly 32 km. (20 miles) from the nearest outcrop of the parent formation, was by a very natural error, mistaken for Speeton Clay (Lower Cretaceous). A sheet of Speeton Clay itself rests upon the top of the Chalk cliff at Flamborough Head and is a prolific collecting ground for the fossils of the formation.

The physical evidence of great fluctuations of the ice-margins in England is clear and convincing, but the present writer is not prepared to assent to the proposition that these fluctuations were more than local, or that between the successive retreats and readvances of the ice, there was a complete withdrawal of the ice-sheets back to their very sources.

At one time it was considered sufficient to point to a bed of sand or gravel interpolated between two sheets of boulder-clay to demonstrate an interglacial period; now, however, only very large sheets of water-deposited material are accepted as proof, yet they do but prove oscillations relatively larger, and not complete withdrawal. Much more of the nature of the proof demanded is however available in Yorkshire. While the Drift phenomena are preserved in wonderful freshness and completeness in the Cleveland area and the Vale of York — little lake-channels, small but sharp moraines, kettle-holes and like evidences of recent glaciation retaining their features almost unimpaired —, outside (i. e. south of) the great moraine at Escrick the Drift deposits are reduced to a series of small and disconnected patches. One of the most remarkable for its situation is that at Crosspool, Sheffield 223 m. (730 ft.) above sea-level, but as evidence of severe and prolonged glaciation perhaps the patch of boulder-clay at Balby near Doncaster (53° 42′ N.) is the most remarkable. It is about 800 m. ($^1/_2$ mile) in length and 12 m. (40 ft.) thick and presents the finest inland section of boulder-clay in the county, hard and very tough and closely packed with well scratched stones, mostly local, but with a fair number of rocks from the Lake District, such as Shap granite and the micro-granite of Threlkeld. It is evident that these are relics of a great and extensive glaciation separated from the stage represented by the York and Escrick moraines by an interval many times greater than that separating the later glacial phase from the present day, even though a generous allowance must be made for the greater activity of subaerial denudation during the Ice Age.

E. The condition of the unglaciated parts of Britain.

The records of the Pleistocene age outside the sphere of ice-action are chiefly preserved in River- and Cave-deposits. There are, however, great sheets of heterogeneous rock-rubbish that are generally regarded as the products of soil-cap motion such as would result from seasonal freezing and thawing of a soil resting on a frozen sub-soil. This deposit called "Head" is typically developed in Devon and Cornwall where it forms a fairly tough argillaceous mass charged with fragments of the local Clay-slate. It rests upon the Early Pleistocene raised beaches there, as well as in Ireland and South Wales. In the latter region the cliffs behind the beaches are perforated by caves yielding remains of the Pleistocene mammalia and traces of Palæolithic Man.

Another interesting product of the cold conditions prevailing outside the glaciated area, and occasionally also within it, is the Coombe rock (Reid 1887).

This is a mass of chalky and sometimes flinty gravel occurring on the floors and more particularly at the mouths of valleys in the Chalk country. At present the Chalk outcrops are characterised by a notable paucity of streams yet there is an abundance of valleys often of great depth and presenting very steep sides. These valleys, which are known in the South of England as "Coombes", must obviously have been produced at a time when, in consequence of the frozen condition of the Chalk, it was as impervious as any other material. When the spring floods, due to the melting of the snows, ensued, the Chalk coombes developed a system of actively eroding streams. In Yorkshire at the present day a sudden thaw will sometimes bring streams down the normally streamless Chalk valleys, and they carry with them great lumps of the green-sward that have been torn up.

That the dry valleys in the Chalk are not relics of a river system that had been beheaded by the recession of an escarpment, is shown by the fact that they rarely, if ever, pass through the watersheds.

These phenomena are best seen in Sussex and upon the eastern flanks of the Yorkshire Wolds, but along the western foot of the Wolds and for a mile or two into the plain of the Vale of York there are gravels largely composed of quite angular flint-flakes with a variable amount of Chalk. They occur at various horizons and at Bielsbeck (see p. 318) they cover marls enclosing an early Pleistocene fauna with remains of lion. The occurrence of foreign stones in a driftless area on the Cotteswold Hills has provoked a copious literature of which a careful summary with some discussion of the complex conditions prevailing in the lower part of the Severn Valley is given by GRAY (1911, 1912) in papers communicated to the Cotteswold Field Club.

The River-gravels and Brickearths are best displayed in the Valley of the Thames, a river whose basin was but little invaded by the ice-sheets or the melt-waters flowing from their edges. In other river systems, also, traces are often to be met with of deposits that, by the character of the mammalian remains that they entomb, can be referred to an early stage of the Pleistocene and may belong to a time when ice-sheets were already occupying much of the North of England. There are in addition other river-deposits, which are referable to a late stage in the Pleistocene and these may rest upon boulder-clay. The evidence can be most conveniently dealt with in conjunction with that of the distribution of the Pleistocene mammalia and of man.

The Pleistocene mammalian fauna is referable to two groups[1] that, though not mutually exclusive, are broadly characterized, so that little difficulty is, as a rule, experienced in relegating an assemblage to its proper position. The older fauna is distinguished by the presence of *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus amphibius*, *Bison priscus*, *Bos primigenius*, *Felis leo*, *Hyaena crocuta*, and *Ursus spelaeus*.

The later fauna lacks all these forms, in general, but instead has the mammoth *Elephas primigenius*, and *Rhinoceros tichorhinus*. The mammoth occurs also in the older fauna and *Rh. tichorhinus* has been recorded as an associate of the straight tusked elephant *E. antiquus*, but a fauna containing mammoth and *Rh. tichorhinus* and lacking the notable members of the first group might generally be pronounced to be of late Pleistocene date. Conversely almost any member of the first group would carry the implication of early Pleistocene age.

The distribution of these faunas bears out this inference. The former group is found in caves, or, if in a glaciated region, in such a situation as to indicate an age either anterior to the advent of the ice, or one belonging to its earliest development;

[1] I find it convenient, and consider it preferable, to follow REID in regarding the Cromer Series as Pliocene.

thus, they may be found in alluvial deposits beyond the reach of the ice-sheets, or in deposits below, but never above, the glacial accumulations. On the other hand, the later fauna is commonly found in deposits resting upon or between boulder-clay, or in the terraces of river valleys excavated in glacial materials.

Occasionally a tooth or tusk of Mammoth may be found in a true glacial deposit, e.g. in boulder clay. It is in such cases generally to be regarded as a veritable erratic, but it seems probable that in some instances the remains of Mammoth indicate that the creature lived in the near neighbourhood even during the prevalence of the ice. LAMPLUGH has remarked, in this connexion, that large numbers of deer, bears etc. cross the Malaspina glacier.

Relics of mammoth and bones of reindeer have been found as far north as Kilmaurs (53° 58′ N.) near Glasgow beneath boulder-clay. In the Isle of Man tusks and teeth have been found in the glacial beds.

Yorkshire furnishes the most decisive evidence of the relation of the two faunas to the glaciation. Two notable caves containing an early Pleistocene fauna have been explored. One was the classic Kirkdale cave, described by BUCKLAND in his Reliquiae Diluvianae and commented upon by LYDEKKER (1906), OWEN (1846) and DAWKINS (1869). This cave, now entirely quarried away, was in the side of a valley, tributary to the Vale of Pickering which was a glacier lake at the climax of the Ice Age, and no glaciers reached to Kirkdale. The lists are somewhat contradictory but it is certain that the early fauna was richly represented by numerous specimens of *Hyaena* besides lion, *Hippopotamus*, *Elephas antiquus*, *E. primigenius*, *Rhinoceros tichorhinus*, *Rh. leptorhinus*, and *Rangifer tarandus*, to mention the most significant. Here there is probably a mélange of the two faunas due to the fact that cave-exploration was in its infancy at this time (1823), in fact, this was only the second work of the kind attempted in Britain.

The second example is the Victoria Cave, Settle, explored in an amateur fashion for many years after its discovery in 1837, but later, systematically and scientifically emptied of its contents by a committee of the British Association (TIDDEMAN 1877). TIDDEMAN's description is not complete but still is the best available. The cave is in a lofty limestone scarp 442 m. (1450ft.) above the sea and 275 m. (900 ft.) above the river Ribble near Settle. The mouth of the cave was at first hidden beneath talus 60 cm. (two feet) thick that covered a Romano-British layer. In descending order there was next a cemented talus 1.5 to 1.8 m. (5 to 6 ft.) and then a Neolithic layer. Within the Cave the Neolithic layer was underlain by

Upper Cave Earth
Laminated Clay
Lower Cave Earth

The Upper Cave Earth contained bones of a type later than the Pleistocene, but the grisly-bear (*Ursus ferox*) and reindeer are indications of an early post-Pleistocene fauna. The laminated clay is interpreted by TIDDEMAN as a glacier-mud deposit and the present writer endorses this opinion.

The Lower Cave Earth yielded bones and teeth of *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus*, *Bos primigenius* and *Hyaena crocuta* — a typical Early Pleistocene assemblage. The pre-Glacial age of the Lower Cave Earth is made certain not only by its being beneath the laminated clay, but, when the front of the Cave was explored, it was found that an enormous talus underlay the Neolithic stratum and this rested upon Boulder Clay with large erratics, which covered the truncated ends of the deposits of Lower Cave Earth and Laminated Clay. No relics of man were found in the Lower Cave Earth, a bone that was at first supposed to be a human fibula proving to belong to a bear.

Caves in Devon and in Derbyshire entomb the Early fauna along with relics of man, but the evidence connecting them with the Ice Age is not decisive. In North Wales, on the other hand, decisive proof seems to be provided of the occupance of the country by man and the Early Pleistocene fauna before the glaciation of the district. At Cae Gwyn and Tremeirchion (53° 15′ N.), in the Vale of Clwyd, caves have been found, either sealed beneath glacial deposits, or with their floor deposits under such a seal. They have yielded a limited series of Pleistocene forms including *Hyaena*, *Rhinoceros tichorhinus* etc. along with flint flakes.

Though giving no decisive, or indeed any, evidence of the relation of man to the Glacial Period, the famous Kent's Cavern and other caves in the vicinity of Torquay, are of great interest. Their exploration was begun by MACENERY and continued by PENGELLY, DAWKINS and others. In Kent's Cavern a succession of floor deposits are found ranging from Early Pleistocene, with *Machairodus*, lion, and *Hyaena*, through Neolithic and Bronze Stages, to the Roman and Mediaeval Periods. The following order from above downward was observed: —

A. Layer of dark Cave Earth with mediæval relics, Roman pottery, Bronze and Neolithic implements and bones of domestic animals.
B. Stalagmite floor 1—3 feet thick.
C. Red Cave Earth with fragments of stalagmite and breccia. Many bones and teeth of Pleistocene mammals were found, such as *Hyaena*, mammoth and, most noteworthy, *Machairodus latidens*. Many implements of flint and bone were found.
D. Compact dark red breccia with flint implements and bones of bears.

The occurrence of *Machairodus* was the first record of that genus in Britain: it has since been reported from two other caves — one, the much disputed case of Cresswell Cave, Derbyshire, whence a canine was obtained by DAWKINS, the second by the same observer from the débris of a quarry in Derbyshire. In this last instance it was associated with *Mastodon arvernensis* and other Pliocene forms and therefore belongs to another section of this Handbook.

The bed D. yielded a few teeth and bones, exclusively of bears, and it is interesting to observe that DAWKINS found, in the overlying Cave Earth, fragments of teeth resembling these, fashioned by chipping, apparently for use. This cave is the only one in Britain in which implements referable to a number of the Palæolithic stages have been found, but their vertical distribution, and the association with mammalian remains, present a perplexing problem of which the present writer offers a tentative solution.

In the Red Breccia were found implements "apparently of the age of St. Acheul or Chelles" (EVANS 1897), but SOLLAS is no doubt right in assigning the figured example definitely to the Chellean; characteristic Acheulean types were found in the Cave Earth at a depth of 1.2 m. (4 ft.), Mousterian were encountered at 6 m. (20 ft.) down and one, perhaps at 1.2 m. (4 ft.); Aurignacian flakes were found at 1.2 m. (4 ft.); Solutrian, of very characteristic form, at 0.6 m. (2 ft.) and Magdalenian flakes as well as harpoons at the same distance from the top of the Cave Earth. Magdalenian implements were also obtained from a black layer, presumed to represent a hearth. immediately beneath the stalagmite-floor. It may be here remarked that the animals associated in this layer included the hyaena and tichorhine rhinoceros — species which are found also in the overlying stalagmite.

The sequence of the sotne implements may be regarded as fairly normal having in mind that they were not obtained in the same part of the cavern and that the Cave Earth varied greatly in thickness, but the association of post-Chellean objects of almost every recognised stage with remains of *Hyaena* and of some of them with lion, and *Machairodus* (in the uppermost portion of the cave earth) is so opposed to experience in river deposits, and in most caves, that some explanation seems demanded. It may be pointed out, however, that relics of an immense stalagmitic crust are, in parts of the cave, found interposed between the Chellean breccia and the Cave Earth, and that another fragmentary crust is attached to the walls so high up as to show that the cave must have been practically filled with deposits. Dawkins infers from this that the Cave has been scoured out by a rush of water that left only the oldest deposit behind, together with the débris of the stalagmite floor that is found at all levels in the Cave Earth. The present writer is of opinion that the Cave Earth is mainly a disturbed mass let down by subsidences of the floor.

Another cause of confusion and intermingling certainly exists at Kent's Cavern. The explorers make frequent mention of the existence of fox-earths, rabbit-burrows and rat-runs, all through the Cave Earth, even to a depth of 1.2 m. (4 ft.). There is no ground for supposing that burrowings were less frequent in earlier times, and their effect must have been to produce a great mixture of horizons.

Other notable explorations have been carried on in caves in the Mendips, in Derbyshire and in South Wales. In the last case evidence has been adduced by Tiddeman (1900) to show that certain bone-caves in Gower with an early Pleistocene fauna of *Hyaena*, *Elephas antiquus*, and *Rhinoceros hemitoechus*, are shore caverns of a pre-Glacial age, as they are partly covered by "head" consisting of local materials, which is in turn overlain by glacial deposits with scratched stones. The succession is strikingly parallel to that of the raised beach at Flamborough Head. Clement Reid (1904) has described what may be hearths of Pleistocene date beneath the "head", but resting upon the raised beach at Prah in Cornwall.

We return now to the evidence of River deposits. These are gravels and flood loams with perhaps some true loess. They are very imperfectly developed within the glaciated area, and north of the Ouse Valley in Yorkshire no evidence of such deposits of Pleistocene age exists. The classification of these deposits in terms of Palæolithic stages or of Pleistocene mammalia is not easy, especially as, from the nature of the case, systematic exploration cannot be carried on in the same way as has been done with the cave deposits. In the glaciated regions however, it is sometimes possible to identify the two faunas. Thus at Leeds, which was apparently never under the influence of an ice-sheet, but was at most invaded by the end of a valley glacier, a deposit was found that yielded a splendid suite of remains of *Hippopotamus* — the finest yet discovered — in association with mammoth and *Bos primigenius* (Denny 1853). At Bielsbeck near Market Weighton (53° 40′ N.) a bed of marl resting on Keuper and covered by flinty chalky gravel, yielded a large fauna including lion, *Rhinoceros leptorhinus*, and mammoth (Vernon 1829, Phillips 1875, Blake 1873, Dawkins 1869). At Brough on the Humber a deposit containing *Elephas antiquus* and *E. primigenius*, is associated with gravels containing Scandinavian and other erratics and is covered by chalky flinty gravel. It occurs on the top of a hill 30 m. (100 ft.) above sea-level and is isolated from the Chalk Wolds whence the Chalky wash must have descended, by a deep valley, attesting the great erosion that has since taken place.

In contrast to these are the gravels at Fulford near York, lying between the two moraines at York and Escrick. These yield a fauna from which the older forms are absent. They may correspond with the gravels of Kelsey Hill.

Only two Palæolithic implements have been recorded from Yorkshire, and Lincolnshire, where the conditions of glaciation were very similar; namely one found "near Lincoln" and therefore beyond the limit reached by the Hessle glaciation; and a single ovoid implement, said to have been found "on the surface at Huntow near Bridlington (54° 5′ N), though it must be admitted that, so far as at present known, it was not lying in association with any remains of the Pleistocene fauna" (EVANS 1897 pp. 572, 581). It is a well marked Acheulean type. This unique discovery is not authenticated by the name of the finder.

Nearer the southern margin of the glaciated area, the Bedford gravels may be selected for notice. See EVANS (1897), and WYATT (1864). They clothe the slopes and floor of a valley excavated in Jurassic rocks, the adjacent hills being capped with Chalky Boulder Clay from which it is presumed the gravels were derived. The mammalian remains are found at the base of the section. They include, inter alia, *Hippopotamus*, two species of *Elephas*, and *Hyaena*. Implements were found of, apparently, both Chellean and Acheulean types. SOLLAS ascribes them to the Acheulean, but EVANS compares one with an implement from Kent's Cavern figured by SOLLAS as Chellean. At Hoxne in Suffolk (see pp. 311—312) a very important series occurs establishing very decisively the relation of one Palæolithic stage (Acheulean) to the Chalky Boulder Clay (Brit. Assoc. Rep. for 1895 pp. 679—680, and for 1896 pp. 400 — 415). The implement-bearing layer is separated from underlying Chalky Boulder Clay by deposits yielding a temperate, succeeded by an "arctic", flora. Remains of mammoth, horse, *Cervus* and *Bos* accompany the implements, which include the most beautiful of British palæoliths.

Near Cambridge, at Barrington, and Barnwell, rich mammaliferous deposits occur characterized especially by the abundance of *Hippopotamus*. They rest upon Cretaceous rocks and contain pebbles of distant derivation such as "syenite, jasper" (FISHER 1879). The fauna is clearly the Early Pleistocene with lion and hyaena. No implements are recorded.

The Thames Valley furnishes examples of river-deposits laid down outside the edge of the ice. The gravels and Brick earths present some anomalous relations, suggesting that in Pleistocene times the land stood for a time at a higher level than at present. It should also be borne in mind, however, that under more severe climatic conditions spring floods would rise much higher than they do at present. Moreover, with an ice-sheet extending with a wide front down from the northern watershed there would be discharged in this direction immense volumes of water alien to the actual basin of the river.

Palæolithic implements are found in deposits high above the river as well as down to or even beneath it (DAWKINS 1880). The mammalian remains include the Early, as well as the Late, Pleistocene types. Remains of lion occur at several places, e.g. Summertown and Ilford; on the other hand the Musk Ox (*Ovibos*) has been found at Crayford.

It has not however been practicable up to the present to define in a given section the points at which one fauna succeeds the other; reference should however be made to the important work of SMITH and DEWEY (1913).

Palæolithic implements have been found in localities too numerous to be specified. Chellean types are, in the judgement of the writer, identifiable at Summertown near Oxford, in association with lion. At Crayford SPURRELL found an actual manufactory on what must have been the river-strand, and obtained therefrom flakes that could be replaced so as to restore the flint nodule. In one instance the hâche had been broken as the finishing touches were applied, and SPURRELL could rebuild the flint about it.

Space does not permit further illustration of the subject, but mention must be made of the famous Piltdown skull, *Eoanthropus dawsoni* (SMITH WOODWARD) and the conditions of its occurrence.

The site of this most important discovery is in the valley of the Sussex Ouse between Fletching and Uckfield about 37 m. (120 ft.) above sea-level (50° 58′ N and 0° 2′ E). The succession of deposits was the following:

(e)	Surface soil	30 cm. (1 foot)
(d)	Sandy loam with patches of ironstone-gravel and iron-stained subangular flints. One Palæolithic worked flint.	60 cm. (2 ft.)
(c)	Dark brown gravel with subangular flints and tabular ironstone, Pliocene rolled fossils and *Eoanthropus*, *Castor* etc. Eoliths and one worked flint.	45 cm. (1.5 ft.)
(b)	Pale yellow clay and sand, reconstructed from (a). Large subangular flints.	20 cm. (8 inches)
(a)	Undisturbed Tunbridge Wells Sands (part of Hastings Beds).	

The skull is in many respects the most simian in character that has been found. In the same stratum were found rolled fragments of a tooth of *Elephas (Stegodon)*, and one cusp of a *Mastodon* of the *arvernensis* type, two teeth of *Hippopotamus*, a piece of an antler of *Cervus elaphus*, and a tooth of *Castor fiber*. The *Mastodon* and *Stegodon* are regarded as of Pliocene age, the *Hippopotamus* may be Upper Pliocene or Pleistocene, the beaver is probably Pleistocene, while the *Cervus elaphus* is of a typical form unknown from beds older than Pleistocene. Waterworn "eoliths" were abundant and there were several indubitable implements of a very primitive Chellean or pre-Chellean type. Dawson and Smith Woodward (1913 and 1914) regard the Pliocene species, which differ in condition from the others, as derived from a Pliocene deposit, while the remainder including the human remains they consider to be of Pleistocene age. The present writer is indisposed to admit this difference of age without stronger evidence than the restricted known range of *Cervus elaphus*, and the Chellean implements.

Announcements have recently been made of discovery of a human skeleton embedded in the Chalky Boulder-clay of Needham Market, Suffolk. The weight of geological testimony favours the view that the covering of boulder-clay is fortuitous and that the skeleton is comparatively modern. The enthusiastic opponents of this opinion fail to explain how a complete skeleton could become enclosed in a boulder-clay.

F. Raised Beaches.

Raised beaches referable to a period subsequent to the Pleistocene are of doubtful occurrence on the Coasts of England and Wales, the clearest being represented by the Shirdley Hill Sands of South-west Lancashire. At Cat Nab near Saltburn a deposit with marine shells is regarded by Barrow (1888) as an undoubted raised beach, but Hey demurs, pointing to the fact that the shells are all of edible species and do not form a normal shore-assemblage. Lamplugh also comments upon the unlikeliness of a beach being preserved in such a position. Woolacott (1907) describes shingle with marine shells at 46 m. (150 ft.) above sea-level in Durham but Lamplugh attributes them to glacial transportation.

In the Isle of Man an unmistakable beach occurs at 3 m. (10 ft.) above sea-level. It is clearly post-Pleistocene.

In Scotland evidences of secular uplift are of very wide extent, occurring on all the coasts. It is not yet clear how many successive stages of uplift are distinguishable. It was formerly considered that five could be identified, respectively at 7.5, 12, 15, 23, and 30 m. (25, 40, 50, 75 and 100 ft.) above present sea-level, but it can hardly be doubted that warping has taken place and that the same beach may appear at different levels, e. g. on the southern shores of the Forth a marine deposit exists at Portobello near Edinburgh rising to above 30 m. (100 ft.) and at Bo'ness to 38 m. (124 ft.), whereas, near Dunbar, the drainage-channels of old glacier-lakes debouche below 23 m. (75 ft.). This last shows that no uplift of that amount can have affected the area since the Highland ice was occupying the bed of the Forth. At St. Abbs Head the contours produced by glacial conditions extend without modification to even lower levels, perhaps to 7.5 m. (25 ft.) above tide-mark. In the Inner Hebrides as W. B. WRIGHT (1914) has shown, there was a culmination of the elevatory movement which attained a maximum of about 60 m. (200 ft.) in the Island of Jura (see also VETCH 1824) and many successive beaches descend by steps almost to present sea-level. The lower of these are in a very "raw" condition.

A few stations may be noted where a succession of beaches is clear. At Bo'ness at 7.5 m. (25 ft.), 38 m. (125 ft.) and an intermediate level; Black Isle, a peninsula south of Cromarty Firth, at 7.5, 15 and 30 m. (25, 50 and 100 ft.) with small fragmentary beaches between the two former; Applecross district at 15 and 30 m. (50 and 100 ft.); the Clyde basin at 7.5, 14, 23, and 30 m. (25, 50, 75 and 100 ft.). In the last-named area the 75 m. beach forms a broad smooth rock platform, backed in many places by a line of cliffs, which may be pierced by caves, as at Ballantrae (55° 6′ N).

The relation of the beaches to the glaciation is interesting and significant. The 30 m. (100 ft.) beach is, as a rule, confined to the principal inlets and merges into moraines and fluvio-glacial fans; though sometimes a moraine may rest upon the beach as in Strathconan (57° 33′ N.).

The 15 m. (50 ft.) beach runs up the principal inlets and into the tributary valleys as well. In some cases as in Loch Torridon (57° 35′ N) and Loch Erribol (58° 30′ N) moraines rest upon this beach, and, as it can be shown that in the Clyde area it encloses relics of Neolithic man, proof is afforded of a recrudescence of glacial condition at a very late period. The palæontological features of the raised beaches, which are of great interest, have been made the subject of careful study by Scottish and other naturalists (see particularly CROSSKEY and ROBERTSON).

The highest beach, which marks a very brief period of halting, rarely yields a satisfactory record, but at Portobello and Inch Lonaig (Loch Lomond), to cite a couple of examples, a fauna of pronounced cold aspect is found. The contents of the 15 m. (50 ft.) beach, a much stronger feature, cut in rock as well as into Drift, similarly show that the Scottish seas were colder than at present, the 7.5 m. (25 ft). beach on the other hand has yielded a large suite of shells presenting very much the aspect of the existing fauna. Near Paisley, from deposits of this stage, a number of "dug-out" canoes have been exhumed. Some were of very crude design, but others were quite shapely boats. One contained a Neolithic axe and the whole series is referred to that stage, to which, also, the 30 m. (50 ft.) beach belongs (J. GEIKIE 1895).

G. Submerged forests.

So far as can be judged from the evidence available, England and Wales, unlike Scotland, stood higher at the close of the Ice Age than at present and have suffered from a movement of depression of which Scotland shows only equivocal, if any, signs. At intervals round the whole coastline of England and Wales submerged forests or peat-beds are found, and not only this, but in many places similar beds are found below sea-level beneath deposits of silt in the estuaries and the lateral valleys that open into them. Nor does the evidence cease here. It has recently been shown by WHITEHEAD and GOODCHILD (1909) and by STATHER (1912) that a peat-bed exists on the floor of the North Sea over large areas. The subject is reviewed by REID (1913), whose little book summarizes the whole evidence. According to this writer the peat-beds and sunken river channels round the Anglo-Welsh coasts never extend to a greater depth than 24 m. (60 ft.) below sea-level, and the corresponding deposits on the Dogger Bank probably indicate a depression only slightly exceeding this amount.

The plant remains from the landward portions are of common British plants, the trees most commonly met with are *Betula alba* and *Alnus glutinosa*, less commonly, *Quercus robur*, but samples from the Dogger Bank have yielded *Betula nana* and may indicate a climate rather cooler than the present.

Sections commonly show two peat-beds separated by silts containing fresh- or brackish-water shells. Such sequences occur in the Thames, Humber, Mersey and South Wales. The finest exposure of these peats is to be seen at low water on the foreshore between the Mersey and the Dee where innumerable stools of trees stand embedded in the upper peat, and prostrate trunks strew its surface.

The evidence of the Dogger Bank is interpreted to show that the peat ("moor-log" of the fishermen, see also BUCKLAND) rests upon dark coloured clay crowded with shallow water marine shells such as *Littorina rudis*, *Cardium edule*, and *Paludestrina stagnalis*. There is no information available regarding any lower beds. REID thinks it possible that, as the moor-log is trawled from slopes at depths of about 40 m. (22 or 23 fathoms), as well as on the top of the Bank, there may possibly be more than one forest-bed; but that it is likely that the deeper lying blocks have slipped down the slope. These may also have been thrown over by trawlers into the deeper water, as we know to be the custom. Remains of vertebrates used to be obtained in considerable numbers from the North Sea floor in the early days of the fishery, and fine collections were amassed, but only in few cases were they localized. A tusk of mammoth for instance was obtained 13—16 km. (8—10 miles) from Texel. The remains include, inter alia, hyaena, musk ox, reindeer, mammoth, and woolly rhinoceros, but of these few, if any, belong to the age of the moorlog.

The plants include few trees *(Betula alba, Salix aurita, Corylus avellana)*, but of the lesser forms, all of Northern range, *Betula nana* is significant as perhaps indicating a climate cooler than now prevails on the adjacent coasts.

The date of the movement of which the sunken forests are the record can be ascertained with some precision. Neolithic implements have been found at several places in the upper peat, while the exploration of the lake dwellings of the 1st century B.C. or A.D. at Glastonbury (51° 8′ N.) (BULLEID and GRAY) demonstrated that the movement was completed before they were constructed.

It may be concluded that prior to a late stage of the Neolithic period South Britain and the southern part of the North Sea stood at a higher level, probably about 18·24 m. (60-80 ft.), than to day, and that the area underwent a spasmodic depression culminating in a descent of perhaps 9-10 m. (30-35 ft.) that brought tidal waters up many rivers and over marshes that were previously land. One consequence of this is interestingly illustrated by the country adjacent to the Humber. This estuary is probably the muddiest in Britain, and each tide would carry the turbid water into lateral creeks and valleys where the mud would be precipitated, gradually levelling them up to form marshes. These are the natural "warp-lands" of the River Hull and some other members of the Humber system. Other warps are deposits of glacier-mud in the ice-dammed lakes that covered a large area in this system. Modern artificial warping also has been carried on upon a large scale, whereby great areas of worthless land have been converted into arable land, the most valuable in the district. A concomitant of the natural warping was the production of what are called "blow wells", which are strong springs rising in the warp-lands, evidently from a considerable depth. They probably existed before the Neolithic depression as ordinary springs on the sides or floors of valleys excavated through boulder-clay. When the valleys were drowned the escape of the springs continued under water, just as they do in the bed of the Humber to day, and kept an orifice clear through the accumulating tidal muds.

Before leaving the subject of the submerged forests it should be remarked that no trace of them is found in Scotland except at Aberdeen (J. GEIKIE 1894).

A question of the deepest interest concerns the rôle of the Dover Straits, and the course of the drainage at the time of the formation of the moorlog. REID gives a map showing the North Sea floor, from the northern edge of the Dogger Bank southward to the Straits of Dover, as an alluvial plain traversed by the Rhine and its tributaries (including the Thames, Ouse and Humber) and the Weser. The Straits of Dover are also represented as land with a coastline about on the meridian of Dungeness. This reconstruction seems to the present writer highly improbable so far as concerns the southern portion, for down to a very late stage of the Glacial Period the whole drainage of the Eastern slopes of England and an enormous volume of water from the country drained by the rivers that now enter the North Sea and Baltic, as well as much of the melt-water from the great ice-sheet itself, must have found an outlet at Dover and only a very rapid differential movement could reverse this drainage. It should however not be forgotten that besides the raised beach at Sangatte near Calais, there is a submerged forest with an underlying fresh water bed on the foreshore at Wissant. This shows clearly that a tract of low swampy land contracted the Channel at this point but it by no means proves the union of Britain to the continent on this line.

H. Peat Deposits.

After the Submerged Forests there remain for consideration the inland peats. These have been specially studied by REID and by LEWIS who find evidence of a succession of plants-assemblages of great interest. The first intimation of boreal elements in these beds was given by NATHORST who found in deposits occupying a depression in the glacial accumulations of the Holderness Coast a scanty flora with plants of high northern range such as *Betula nana* and *Salix polaris*. REID (1899) has investigated many similar deposits, e.g. that at Hoxne (of Pleistocene age however, see pp. 311, 319) finding there, as at some other localities mentioned in an earlier section, a sequence of "Arctic" and Temperate floras.

F. J. LEWIS has been engaged for several years in the systematic examination of the floras in British post-glacial deposits. The appended table shows the broad general results of this investigations.

Recent Peat Forest Bed Peat-bog with some Arctic plants Forest Bed	Upper Forestian
Peat Bog plants	Upper Peat Bog
Arctic plant Bed	Second Arctic Bed
Peat Bog plants	Lower Peat Bog
Forest Bed	Lower Forestian
Arctic plant Bed	First Arctic Bed.

This succession appears to display a marked general constancy from the mountains of Galloway in the South of Scotland to the Shetland Islands in the far north, and this whether the peats are at or near sea-level or on the mountains.

The First Arctic bed with the Arctic *Salices* etc. brings the flora at present confined to mountain altitudes of 610 m. (2000 ft.) in Scotland down to within 46 m. (150 ft.) of sea-level. The Lower Forestian on the other hand carries the limit of forest trees from 488 m. (1600 ft.), the present limit, up to 610 m. (2000 ft.). The second Arctic Bed again marks the descent of the Arctic flora to within 46 m. (150 ft.) of sea-level, while, at the stage of the Upper Forestian, the forest growths ascended the mountains to an altitude of 1037 m. (3400 ft.) or 427 m. (1400 ft.) above their present range. The fluctuations, if the interpretations are correct, may be summarised by saying that the mountain flora descended 564 m. (1850 ft.) during the arctic phases and the trees ascended 427 m. (1400 ft.) during the Upper Forestian, a total change expressed in terms of altitude, of 991 m. (3250 ft.). If the customary allowance of 1° C. per 165 m. (1° F. for 300 ft.) of elevation be made, then the extreme Arctic phase might have been 3.4° C. (6° F.) colder than the present, and the extréme genial phase of the Upper Forestian may have been nearly 2.6° C. (5° F.) warmer than now.

Lewis recognises that temperature is not the sole determining factor. High winds, deficient or excessive humidity, competitive plants, animal enemies and probably many more will have to be brought into account before a thermograph curve can be drawn. The Outer Hebrides illustrate very strikingly the effect of the wind in limiting tree-growth. In spite of an extremely mild climate the island of Tiree is totally devoid of tree-growth. Saghalien, to go further afield, illustrates the same fact. In the deep valleys a rich and luxuriant flora flourishes, while on adjacent unsheltered uplands of small elevation the flora is of the steppe type.

That there was a succession of plant assemblages, having, at the present day, differences of distribution going in general pari passu with differences of temperature, cannot be disputed.

The most pronounced "Arctic" flora in Britain is that recorded by Reid from deposits filling a hollow in the surface of the Drift at Corstorphine near Edinburgh. It comprised the following:

Dryas octopetala	*Salix polaris*
Loiseleuria procumbens	,, *herbacea*
Betula nana	,, *reticulata.*

More convincing than the plants, perhaps, is the evidence of animals. *Apus (Lepidurus) glacialis*, a true Arctic species of crustacean, has been found at several localities, notably in lacustrine beds resting on boulder-clay at Auchterpool in Fife in association with *Betula nana* and *Salix herbacea*, and in the Isle of Man in a deposit of Silt with *Salix herbacea* overlying Marls containing *Chara* and remains of *Megaceros.*

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b. Ireland.

By G. A. J. Cole.

The deposits of the Pleistocene system in the Irish area, like those of northern Europe in general, are mostly of glacial origin. They have been treated as due to floods, to floating ice, or to ice-sheets moving over a land-surface, in accordance with the successive phases of thought in regard to the European "diluvium". The most modern study of them, including references to earlier views, is to be found in the Memoirs of the Geological Survey on the country around Dublin, Belfast, Cork, Limerick, and Londonderry, in which the drift deposits are specially considered.

Two terms of Irish origin have been introduced into general glacial literature, "eskers" and "drumlins", or hog-backed hills of boulder-clay (Close 1867). The most comprehensive view that we possess of glacial phenomena in Ireland is due to the labours of Maxwell H. Close (see bibliography). He was ahead of his time in recognising the effects of land-ice, and he particularly traced out the course of the ice-sheets and confluent glaciers in Ireland by means of the direction of the drumlin ridges and the ice-furrows on the solid rocks. As the result of his researches, it is now generally recognized that the principal deposition of snow occured along an axis extending from near Galway to Lough Neagh. The highlands of Connemara were sufficiently important to form a local centre from which glaciers streamed outwards into the lowlands; during the epoch of maximum glaciation, a great snow-dome was built up over the Twelve Bens, which are striated even on their crests, thus indicating the presence of ice at least 700 m. (2300 ft.) thick. Glaciers of the continental or ice-sheet type moved out eastward, southward, and westward, leaving traces on land which is now represented by islets in the Atlantic (Close and Kinahan 1872; Mem. Geol. Surv. 1913).

While the central peneplain of Ireland allowed of the formation of a sluggish ice-sheet, under which streams built up esker-ridges, there was a general movement south-eastward towards the Dublin area (Close 1865). Here matters were complicated by the presence of ice from Scotland, which occupied the hollow of the present Irish Sea. The boulder-clays and drift-gravels that are banked against the north end of the Leinster Chain rise to heights of 450 m. (1500 ft.), and contain abundant fragments of marine shells. These beds are rich in striated pebbles of Carboniferous Limestone, together with others of local origin; but hard chalk, perhaps from the Cretaceous beds of Co. Antrim, rhyolites and dolerites from Co. Down, and the singular riebeckite-eurite of Ailsa Craig in the Firth of Clyde (see p. 304), show how the materials, and even a large part of the limestone, have been brought from northern sources. The marine shells, as Lamplugh (1903) has urged, and as is now generally accepted, were transferred in the body of the Scottish ice from the floor of the Irish Sea. From north to south along the east coast of Ireland, similar shell-bearing gravels and boulder clays occur. Shell-bearing gravels are found as far inland as Antrim town. E. Hull justly included with these deposits the richly fossiliferous 'Manure-gravels' of Wexford, for which a late Pliocene age has been also claimed. These are shelly sands and gravels, resting on shelly boulder clay deposited by the Irish Channel ice, and covered by a second and more local boulder clay; they are spread over a wide area of the lowland country in Co. Wexford (Cole and Hallissy 1914). Their name is derived from their former use, with the shelly clay beneath them, as a fertiliser for the land. Kinahan 1879 regarded them as later than the boulder clay; A. Bell 1873—1890, from the resemblance of their fauna to that of the Chillesford Beds of Suffolk, held that they were distinctly older than the shell-bearing gravels of Killiney and the Dublin coast in general. The occurrence here and there of Pliocene species in the gravels suggests that some of the material is due to an epoch of submergence preceding the arrival of the Scottish ice. Kinahan, with much probability, similarly refers the abundant and large Cretaceous flints found in the shelly gravels of Wexford to drift from an area of Chalk now lost beneath the Irish Channel (Mem. Geol. Surv. 1879, Cole and Hallissy 1914).

The striations on the rocks along the eastern coast of Ireland are sometimes due to the invading Scottish ice, but more often to subsequent outflowing from Irish centres. A general trend and distribution of boulders from east to west is noticeable in the north, and is doubtless connected with the epoch of maximum glaciation, when ice crossed over from Scotland (Kilroe 1888).

The great eskers in the drift-covered upland of Tyrone indicate a distribution of material from south to north, as do the numerous drumlins in Sligo and northern Mayo. The eskers which form such conspicuous walls in the central plain, as in Roscommon and Kings County, have been grouped into a general system by W. J. Sollas (1896).

There seems little doubt that E. Hull was right in maintaining that the sands and gravels represent an epoch when the ice dwindled under the return of more genial conditions. After this interglacial episode, features due to local glaciation became manifest, and a second boulder-clay was often laid down over the gravels. The corries or cooms of the Irish mountains are true glacial cirques, often with lakelets remaining in them, and closed by terminal moraines. The hollow of Coumshingaun in the east of the Comeragh Mountains in Co. Waterford, with its cliff 330 m. (1100 ft.) in height, is one of the grandest glacial cirques in the British Isles. While the local ice was melting, huge erratics were deposited on the striated rock-surfaces. The ice of the first glaciation may have still lain stagnating in the plain; but finally its contents, in the form of drumlins and eskers, came to light. Great modifications of the original drainage were produced by the presence of this glacial detritus. Many cases can be pointed out where the overflow-streams of temporary lakes, the waters of which were held up by the ice, have cut recent gorges across rocky ridges, such as the well known Scalp in Co. Dublin (Mem. Geol. Survey 1903).

It has been suggested that the original course of the Shannon above Limerick became diverted by capture into the low ground west of Scarriff, and that glacial erosion enabled it to return into its course by Killaloe, owing to the overdeepening of its original channel through the hills (Kilroe 1907).

It is obvious that the Irish Channel was in existence before the invasion of ice from Scotland, as may be concluded from the evidence of the shell-bearing gravels. The discovery of a pre-Glacial shore-line, but little above the present one, throughout southern Ireland (Maufe and Wright 1904), indicates that the river-valleys had already become flooded by the sea before Glacial times. Elevation, initiated before the advent of the ice, may have brought the floors of these rias and fiords above sea-level; but they finally sank again, and the sea returned into them as the ice melted away. Oscillations of the coast in post-Glacial times are traceable in raised beaches and flats of Pleistocene marine clay, which are especially noticeable on the coast from northern Donegal to Wexford. In many cases it is clear, from the occurrence of peat, with timber and hazel-nuts, beneath the post-Glacial marine clay, and generally in submerged positions round the coast (Hallissy 1913), that a considerable margin of land has been lost since glacial times. A temperate, if moist, climate followed soon after the melting of the ice. Such a climate no doubt favoured the spread of the later peat, which still covers parts of the highlands, as well as parts of the central plain. The present epoch, however, appears to be one of greater dryness, and the wind is stripping off the old peat from many of the mountains, and exposing, at heights of even 500 m. (1700 ft.), the roots and stems of former forest trees.

The fauna of Pleistocene times, as revealed by remains discovered in caves and peat-bogs, has been extensively studied, and has shown the former presence of the mammoth *(Elephas primigenius)*, the remains of which have been brought into the caves by bears or other carnivores. Cave-exploration has also proved, despite common tradition, that the frog is an ancient inhabitant of Ireland (Adams 1867—1883, Kinahan and Ussher 1881, Scharff 1903—1906). The abundant remains of *Cervus giganteus* found in the boglands of Ireland have caused this animal to be popularly styled the Irish Elk and several complete skeletons are preserved in museums in Dublin. Large numbers of individuals may sometimes be traced in a limited area (Moss 1875—77). *Cervus giganteus* has been connected with the human period (USSHER and ADAMS), and other wild animals have died out within historic times in consequence of man's activity as a hunter (SCOULER). An admirable bibliography of the Post-Pliocene geology of Ireland has been published by R. LLOYD PRAEGER in the Proceedings of the Belfast Naturalists Field Club for 1895—96.

The geographical conditions of the Irish area during the Glacial epoch have been the subject of much discussion. The present fauna is held by SCHARFF (1897 to 1907) and others to have survived the invasion of the country by ice, and to have taken shelter in western and southern extensions of the land. This view receives considerable support from the evidences of recent depression, and consequent loss of land, along the western and southern coast. The pebbly beach of Larne contains flint instruments worked by man, in beds with marine shells now raised some 6 m. (20 ft.) above the sea (COFFEY and PRAEGER 1904). Worked flints are found in all levels of this beach, and indicate that the uplift occurred since man was in the country.

Tradition has always pointed to islands off the west coast lost to sight since man inhabited the country. There is nothing inherently opposed to this, and W. FRAZER (1879) has brought forward evidence of a much later date as to the existence of an alleged island, Brazil (or Brasil), near the present Porcupine Bank.

Economic products.

No good kaolin deposit is known in Ireland, though the altered granite on Lower Lough Erne was formerly used in the porcelain-works of Belleek; but ordinary **brick-clays** abound, especially among the glacial deposits. **Bog iron-ore** is raised here and there from peaty deposits, and is used for the purification of gas.

Peat occurs widely spread in the central plain and on many of the uplands, and forms a convenient fuel for the country population. Near Portadown it is used for the production of gas, and thus of electric power.

Kieselguhr. An extensive deposit of diatomaceous earth occurs in the flat land where the River Bann runs northward from Lough Neagh at Toome in Co. Antrim, and the material is worked commercially on a large scale for the making of bricks for non-conducting walls etc.

Mineral Waters. Ireland is not rich in mineral springs, though from time to time ferruginous or sulphurous waters have led to the establishment of small 'spas'. The sulphurous waters rising through Carboniferous Limestone at Lucan, west of Dublin, were discovered about 1750, and are still drunk for their medicinal value.

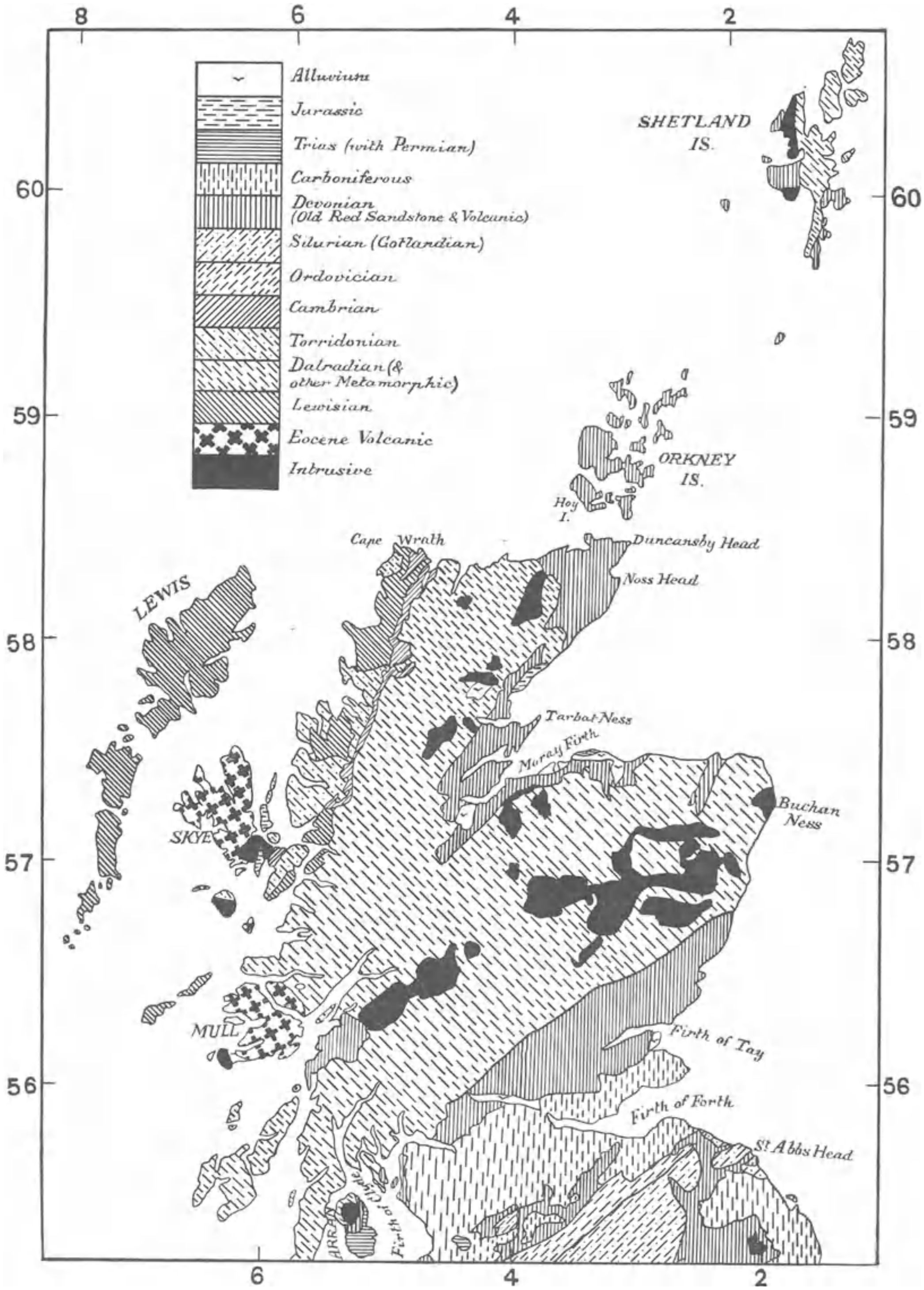

Fig. 67. Geological Map of the British Isles. Part I, A.-M. D.
The Scale of these maps is about 1: 3,360,000 or 53 miles to an inch.

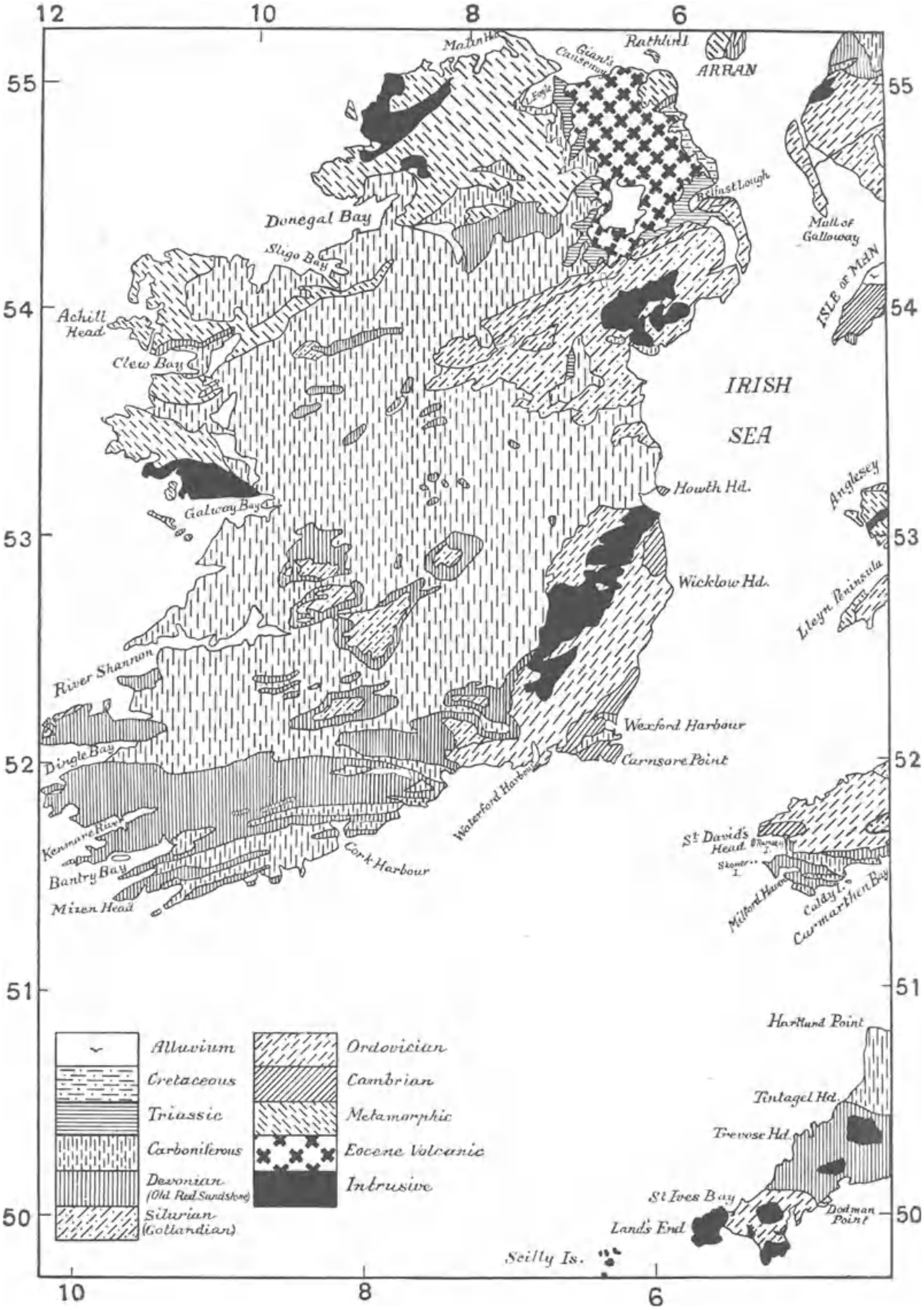

Fig. 68. Geological Map of the British Isles. Part II, A. M. D.

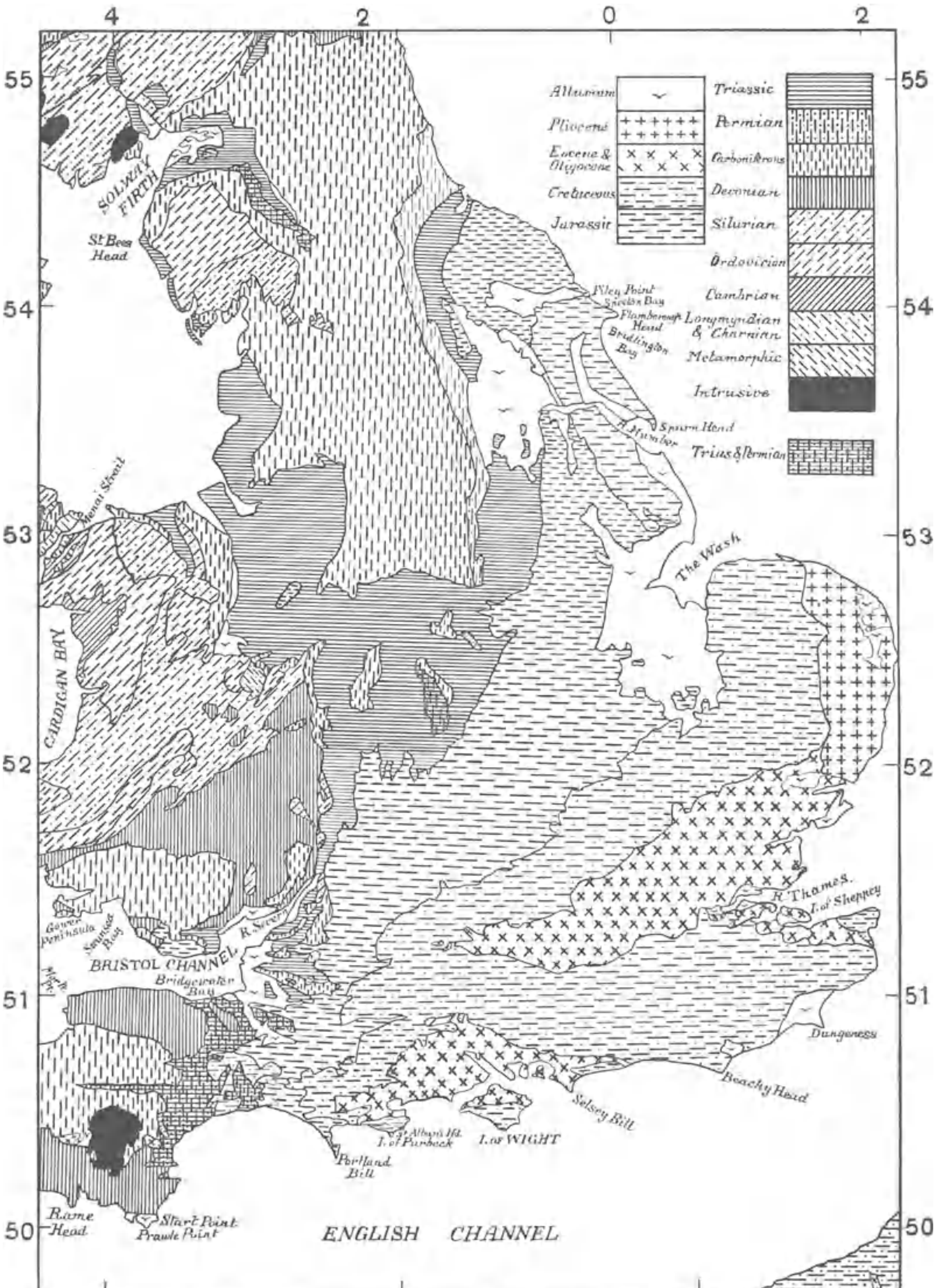

Fig. 69. Geological Map of the British Isles. Part III, A. M. D.

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See also Cole, G. A. J. and Crook, T.

IV. Appendix.

The Channel Islands.

By John Parkinson.

Introduction.

The Channel Islands constitute an archipelago, geographically French, situated a few miles to the west of the northern part of the Cotentin.

They agree with one another geologically:

a) in containing a great preponderance of crystalline rocks, and

b) in the absence of any sediments (except a few recent gravels) of later age than Upper Cambrian or basal Arenig (Lower Ordovician).

The rocks resemble in many respects those of the Lizard peninsula in Cornwall.

Of this archipelago, four islands, Guernsey, Jersey, Alderney and Sark are usually alone considered, but in addition there are smaller inhabited islands and very numerous rocky islets, a large proportion of them uncovered only at low-water.

1. Jersey.

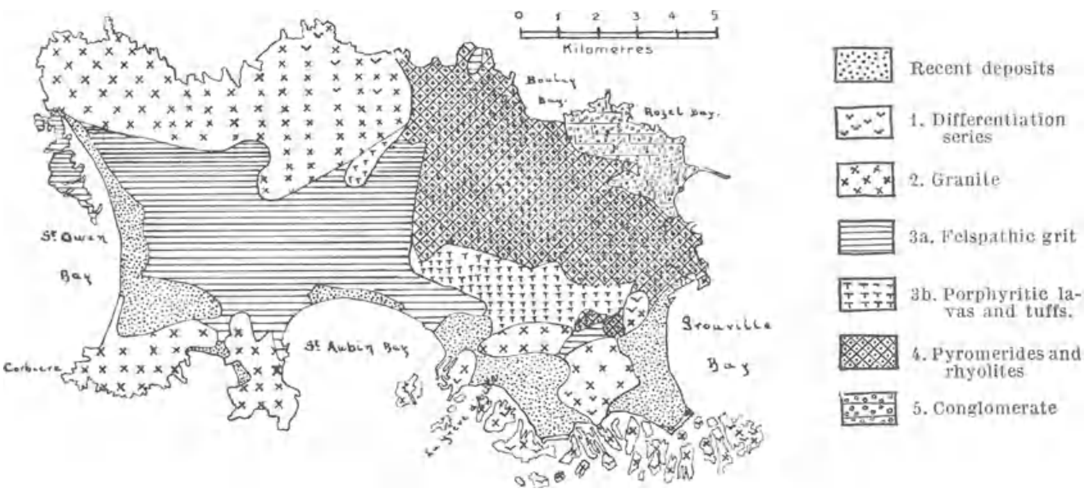

Fig. 70. Geological map of Jersey, founded on that of NOURY. Scale about 1:190,000 or 3 miles to the inch.

The island of Jersey, distant some 26 km. (16 miles) from the nearest point of France, and about 28 km. ($17^1/_2$ miles) from Guernsey, is nearly 18 km. (11 miles) in length from east to west.

The rocks, which are more diversified than in the other islands, comprise:

1. A very variable group of igneous rocks, forming a differentiation series. These occur on the south-east and at intervals along the northern coasts.

2. A number of granite masses, which may or may not be connected with the first group:— Les Corbières, Mont Mado, etc.

3. A felspathic grit (grès felspathique of NOURY), mapped as occurring between the south-west and north-west masses of granite and associated rocks, thus occupying about one-quarter of the island. NOURY divides these beds into a fine-grained rock (lydite or argillite), breaking with a conchoidal fracture, and, secondly, a felspathic grit in which the component grains are easily visible. The general dip is south-easterly, locally almost vertical. LAPPARENT (1892) correlates these rocks with the Phyllades de St. Lô (Brioverian, Pre-Cambrian). The presence of so-called spilites near St.Helier shows contemporaneous volcanic action (BONNEY and RAISIN).

4. A group of pyromerides and rhyolites of Pre-Cambrian age, showing typical spherulitic, devitrification and fluxional structures, Boulay Bay and Anne Port.

5. A conglomerate forming the north-eastern extremity of the Island. It contains pebbles of the argillite, and is of basal Cambrian age (Conglomerat pourpré of Normandy).

The oldest of the related igneous rocks in the south-east, referred to under heading 1. is a diabase, an ophitic plagioclase-augite rock, in which the latter mineral is largely converted into hornblende. With this is associated a hornblende-plagioclase rock. These were brecciated by an orthoclase-plagioclase rock, with resultant admixture. Intrusions of two more magmas followed successively, which formed granitic rocks of different habit. In both cases new rocks were produced by a process of absorption.

This sequence so closely resembles that obtaining in northern Guernsey, as to suggest that, the accompanying phenomena of admixture and peculiarity of petrographical types being taken into consideration, a consanguinity in origin exists between the rocks of the two islands.

Dykes of later date occur in this and the other islands and will be referred to below.

For much assistance concerning the ages of the Jersey rocks the author is indebted to T. G. Bonney.

The presence of raised beaches at South Hill, 43 m. (140 ft.) above mean sea-level, St. Clement's Road, 22 m. (72 ft.), Verclut, Anne Port, Creux Gabourel, Le Pinacle, &c. prove a considerable submergence. The yellow clay or brick-earth present in these beaches, e. g. at St. Clement's Road, is a fluvio-glacial deposit laid down in late Pleistocene times (Dunlop). Subsequent to the formation of the beaches the land rose until it stood at a greater height above the sea-level than now, as shewn by the submerged forest of St. Owen's Bay (Forêt de la Brequette), and traces of a second in La Grève d'Azette.

Communication with the Cotentin is said to have been cut off in historic times (Noury).

A palæolithic cave-dwelling in St. Brelade's Bay, providing evidence of former hearths, and furnishing many flint implements of Mousterian form, has been described (Nicolle and Sinel 1910). Of especial interest are nine human teeth 'indicating one of the most primitive examples of the Neanderthal type' (Keith 1911).

2. Guernsey.

Guernsey, an island some 15 km. (9½ miles) long and some 8 km. (5 miles) wide, is composed entirely of crystalline rocks with the exception of (a) an ancient grit near Pleinmont and (b) some clays with flints which occur here and there round the island, and thin gravels on its summit.

The southern and larger half of Guernsey consists of a plateau of gneiss; the northern half, almost triangular in shape is much lower in elevation and is formed of many varieties of diorites and granites. The highest point of the island is 110.7 m. (343 ft.) above sea-level, and situated about 1.6 km. (1 mile) from the southern shore, with which the principal watershed of the island is closely parallel. On the gneiss plateau the larger streams flow to the north-west.

In regard to the gneiss, apparently the oldest rock in the island, much more remains to be done before the details of its composition can be said properly to be demonstrated.

The common type is a granitic ortho-gneiss, a porphyritic granite, modified by pressure, and containing orthoclase, microcline, acid plagioclases and brown mica. It exhibits a fair amount of foliation, and varies locally to a dioritic gneiss.

At Jerbourg the rocks are very fine-grained and banded, while on the south-west coast there are darker bands which have an almost slaty appearance and indicate zones of crush. An example occurs near Rocquaine Castle. No doubt can exist that these rocks are igneous, and that the foliation is the result of pressure.

The Pleinmont Grit has been compared with the Brioverian of Brittany (BONNEY and HILL 1912).

The geology of the northern half of the Island has, on the whole, been the more closely studied, largely owing to the very numerous quarries which have been opened there.

With the possible exception of certain granites, which occur on the north-western coast, it would appear that the rocks form a series, related to each other as the products of a single magma, varying from a hornblende-gabbro, containing some 46 % of silica to one of granitic composition, locally containing fully one-third quartz.

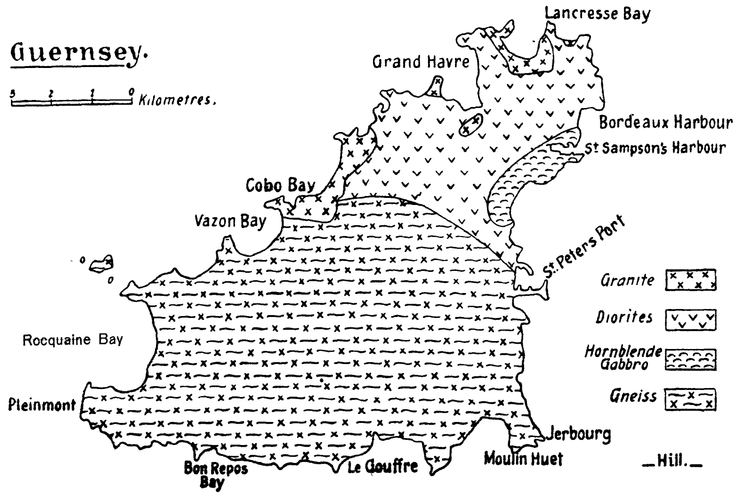

Fig. 71. Geological map of Guernsey, after EDWIN HILL. Scale about 1:190,000 or 3 miles to the inch.
Redrawn by J. PARKINSON from plate 20, p. 430, vol. 40 (1884) of the Quarterly Journal of the Geological Society and published with the consent of the Council of the Society and of the original author.

The sequence is as follows, beginning with the oldest form. (1) hornblende-gabbro; (2) a diorite, rich in hornblende; (3) a felspathic rock, containing little or no quartz, hornblende or mica, the felspar being probably labradorite, (4) diorites containing quartz and biotite, and (5) granites.

The second and third of these are found as dykes in the first, but show no sign of chilled edges, and the intrusion of the felspathic magma was accompanied by the local formation of a new rock by a process of incorporation of older material. Rock types indistinguishable from these dykes may frequently be seen to pass into the gabbro, of which they clearly form an integral part.

A local variant of the hornblende-gabbro (known to the quarry-men as 'bird's eye') forms one of the many types of the diorite of the northern shore. It is intrusive in the gneiss of the southern part of the island, at Bon Repos Bay, and also, presumably, at the Gouffre.

This association is not needed to demonstrate the greater age of the gneiss, for, apart from the foliation and the very distinct signs of crushing which it exhibits, HILL has found fragments of it caught up by the Cobo granite.

The rocks of the northern half of the island do not, in the experience of the writer, show signs of pressure, but throughout indications of fluxional movement and imperfect admixture are common.

3. Alderney (Aurigny).

Alderney, the most northerly of the Channel Islands, is separated from Cap la Hague by a channel, 13.5 km. (8½ miles) broad, called the Race (Ras) of Alderney. It is about 5.6 km. (3½ miles) long and 1.6 km. (1 mile) wide. The greater part is a flat-topped table-land rising to a height of some 91 m. (300 ft.). At a distance of 2.5 km. (1½ miles) to the west-north-west, across the passage known as 'the Swinge', is the island of Burhou, and some 10.5 km. (6½ miles) west of Alderney lie the Casquets, a group of rocks about 2.5 km. (1½ miles) in length from east to west.

Alderney is divided into two parts by a line, possibly of fault, running from Corblets Bay on the north to L'Etac de la Quoire on the south; to the east of this line are grits and sandstones, to the west hornblende-granites and quartz diorites, which are obviously a very variable series of rocks, probably the slightly differentiated products of a single magma. Typical specimens contain much black mica, hornblende in variable amounts and some quartz.

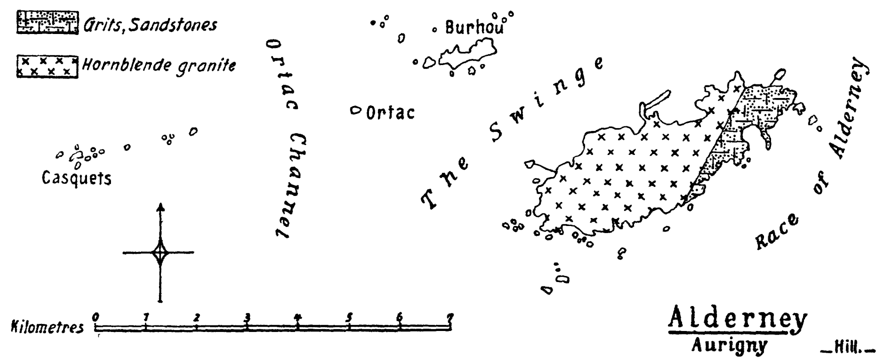

Fig. 72. Geological map of Alderney, after E. Hill. Scale about 1:147,000 or 2⅓ miles to the inch.
Redrawn by J. Parkinson from the map on p. 381 of vol. 45 (1889) of the Quarterly Journal of the Geological Society and published with the consent of the Council of the Society and the original author.

The grits form the islands of Ortac, Burhou and the Casquets, as well as the Eastern part of Alderney itself.

In these rocks felspathic material is present in variable amounts and occasionally beds of micaceous sandstone are found. The colour varies from white to pinkish, and, locally, is rusty-red. Current-bedding is frequently observable. Occasionally the rocks are typical arkoses. In some of the coarser grits the grains are 6 mm. (¼ inch.) across, and pebbles are common locally (Casquets, outlier north of Coque Lihou, Mannez Quarries, etc.). An average dip may be taken as 45° in a south-easterly direction. Edwin Hill, to whom we are indebted for an account of the geology of Alderney, identified these grits with the closely similar Grès Felspathiques of Omonville (Cotentin), which are now regarded as basal Arenig (Lower Ordovician).

4. Sark.

Sark (or Sercq), a small island, or group of islands, 13.7 km. (8½ miles) east of St. Peter's Port in Guernsey may be divided into:

(a) Great Sark, of roughly diamond shape, rather more than 3.2 km. (2 miles) in length, connected with

(b) Little Sark by a lofty natural causeway, and

(c) the island of Brecqhou on the west, rising to some 45 m. (150 ft.) above sea-level and separated from the main island by a channel 76 m. (250 ft.) wide.

The highest point of Sark is 110 m. (360 ft.) above mean tide level. Sark is separated from Herm by the Great Russel passage, about 50 m. (164 ft.) deep.

The geology of the Island has been worked out by HILL and BONNEY, and mapped by the former author. The rocks fall into two main divisions; (a) gneisses and hornblende-schists, and (b) later intrusive rocks. Of the former, important subdivisions occur.

Subdivision 1. This consists of masses and streaks of hornblendite, in banded aplitic and micaceous gneiss. It is well seen about Port du Moulin, and between Creux Harbour and Derrible Bay, where it is shown as gneiss on the map. South of Dixcart Bay it forms a gigantic breccia with a pale flesh-red granite, the lenticles of hornblendite being sometimes several cubic metres in size.

The hornblendite of the north-west coast occurs as fragments, producing with an acid magma a form of fluxion gneiss, as at Derrible Bay.

Subdivision 2. Hornblendeschists and banded gneisses, the latter characterized by more or less micaceous bands, alternating with others consisting mainly of quartz and felspar.

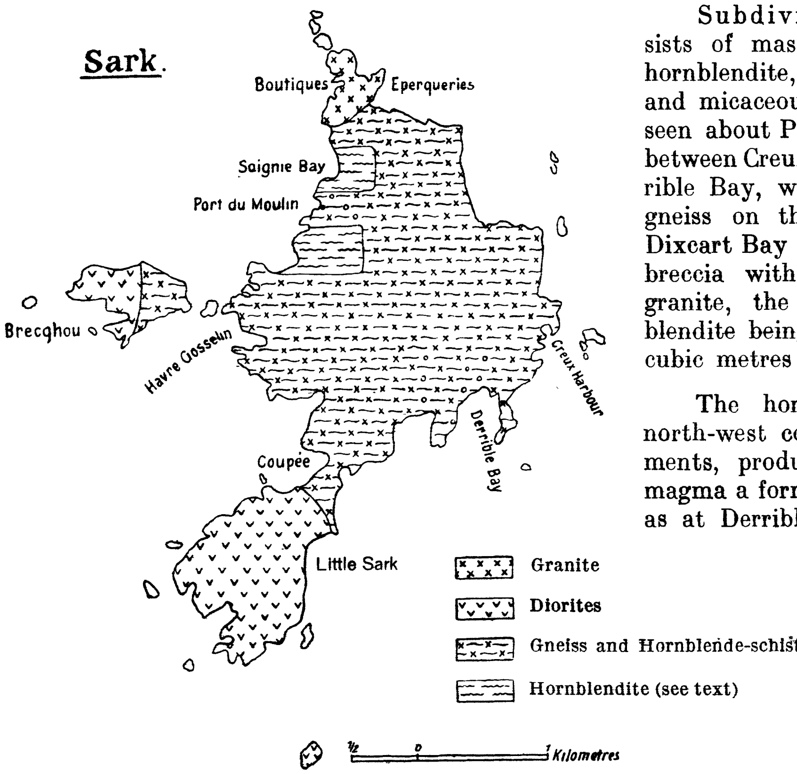

Fig. 73. Geological map of Sark and Brecqhou. Scale about 1:57,000 approximately nine tenths of an inch to one mile.
The map is essentially that of E. HILL, fig. 1, p. 323, vol. 43 (1887) of the Quarterly Journal of the Geological Society, and is published with the consent of the Council of the Society and of the original author.

As an explanation of the phenomena exhibited by subdivisions 1 and 2, it is suggested that a magma having the composition of an aplite, brecciated and locally melted a rock with that of a hornblendite, and that the two flowed on together; either magma dominating here and there, to produce the banded and fluxional structures observed.

On this hypothesis the biotite of the banded gneisses was formed, in part at least, at the expense of the hornblendite.

Subdivision 3. The Basement Gneiss. This rock is mapped as occurring at Creux Harbour on the east coast, and as forming the outlying islands of the Burons and the Grande and Petite Moie. It is a biotite ortho-gneiss (gneissose granite), containing microcline and probably orthoclase, and is considered as being older than the other foliated rocks (HILL and BONNEY 1892).

Later Intrusive Rocks, division (b).

A diorite, with a moderate proportion of biotite and only accessory quartz, forms the greater part of Little Sark.

The western half of Brecqhou consists of a quartziferous diorite; the northern end of Great Sark (Boutiques and the Eperqueries) of a hornblende-granite or quartz diorite.

5. Herm and Jethou.

For information on the geology of Herm and Jethou, two small islands situated between Guernsey and Sark, we are indebted almost entirely to the work of E. Hill. Herm, the larger, about 2.5 km. ($1\frac{1}{2}$ miles) in length, is separated by a passage some 600 m. (2000 ft.) in width from Jethou. The surrounding sea is studded with rocks. Herm is formed of granite, containing both hornblende and quartz; Jethou of a similar rock. In both islands the granite is slightly foliated locally.

Dyke Rocks.

Mica-traps are recorded from all the islands. In Guernsey, a kersantite porphyrite occurs at Moulin Huet and a kersantite at from the Bec du Nez. In Alderney Hill obtained a kersantite from the Mannez Quarries. In Sark there is a kersantite containing colourless augite at Port du Moulin, another in Saignie Bay, and a third with a well-marked pisolitic structure accompanied by secondary devitrification at Havre Gosselin. Many rocks of the mica-trap group are noted by Noury from Jersey (Creux de Vis, etc.). Hill records a large mica-trap dyke from the eastern side of Jethou. These mica-traps are probably pre-Mesozoic in age, but not pre-Ordovician, as in Alderney they cut the Grès Felspathiques.

In Jersey, Guernsey and Alderney there are dykes of aplitic rocks; and in the same islands, as well as in Sark, greenstone (mostly diabase) dykes also occur.

Other dyke rocks worthy of mention are a picrite from the western side of Fort Albert in Alderney, and a variety of the same rock type (scyelite) from Port du Moulin in Sark.

In the northern part of the latter island (the Eperqueries) occurs a dyke of mica-porphyrite.

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By J. W. EVANS.

Maps.

Geological surveys: (1) 6 in. = 1 mile (1 : 10,560) of certain areas; (2) 1 in. = 1 mile (1: 63,360); (3) 1 in. = 4 miles; (1 : 253.440); (4) 1 in. = 25 miles (1 : 1,584,000), British Isles in one sheet.

For some portions of England and Wales there are two series of maps on the scale of 1 in. = 1 mile, with different numbering. The older are usually divided into quarter sheets (N.E., S.E., S.W., N.W.), which in the north of England are the same as the whole sheets of the new series. There are also two series on the scale 1 in. = 4 miles. Some of the new series maps on both scales have two separate forms, one showing only the "Solid Geology", that is to say the formation exclusive of most Quaternary deposits and the other, the "Drift" map showing the areas covered with the different deposits of this age.

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England and Wales by Sir A. GEIKIE 1 in. = 10 miles (1:633,600) 1897.

Scotland by Sir A. GEIKIE, 1 in. = 10 miles (1 : 633,600), 1910.

Ireland by E. HULL, 1 in. = 7.7 miles (1 :488,000), 1890; and, with Drift deposits, by J. R. KILROE and others (under the direction of Sir A. GEIKIE), 1 in. = 10 miles (1:633,600), 1907.

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Annual Progress Reports, Monographs of Fossils (1849—1878), General Memoirs, District Memoirs and Sheet Memoirs of the Geological Surveys; the Transactions of the Geological Society of London (to 1844), and the Quarterly Journal (1844 onwards); the Proceedings of the Geologists' Association; publications of the British Museum (Natural History), the Royal Geological Society of Cornwall and the Geological Societies of Edinburgh, Dublin (10 vols. 1838—1864, continued as the Royal Geological Society of Ireland, 8 vols. 1867—1889 also published in the Scientific Proceedings of Royal Dublin Society), Glasgow, Liverpool, Manchester and Yorkshire; Monographs of the Palæontographical Society; Journal of the Mineralogical Society; the Geologist 1842-43 and 1858-64; the Geological Magazine from 1864. Papers of Geological interest also appear in the publications of the Royal Societies of London and Edinburgh; the Royal Irish Academy, the British Association and other societies and field clubs, as well as in the Annals of Natural History, the Irish Naturalist, and in Nature.

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Index to first 20 volumes of the Proceeding of the Geologists' Association, including the years 1895 to 1908, forming part of volume 21 (1909).

Index of the first 40 volumes of Geological Magazine, including the years 1864 to 1903 (1904).

The Geological Record 1874 to 1884.

[1] These are published at the meetings, the Reports in the following year; but abstracts of papers usually appear, at the time in the Geological Magazine, Nature and the leading newspapers, and from 1913 they have been published at the meetings.

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Stratigraphical Index to the British Isles.

VI. Table of Contents.