Climatic variations in historic and prehistoric time

BY

O. PETTERSSON

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Introduction.

In the last centuries of the middle ages a series of political and economic catastrophes occurred all over the then-known world. They synchronise with occurrences of a startling and unusual kind in the kingdom of Nature. The coasts of Iceland and Greenland became blocked by Polar ice. Frequent volcanic eruptions occurred in Iceland and the surrounding seas. Violent storm-floods devastated the coast of the North Sea and Baltic. In certain cold winters Öresund and the Baltic were frozen over and the lucrative Hanseatic herring fishery of the early middle ages which had been carried on in the Baltic and Öresund ceased altogether. All these events are recorded in ancient chronicles which also depict the social and economic state of the communities, which were greatly influenced by these violent climatic variations and their consequences: famine and disease.

The ancient Sagas and convent chronicles give no hint of any supposed connection between the catastrophes in nature and the human world. The Icelandic chronicles from the 14th and 15teenth centuries abound in descriptions of catastrophes, such as

»hallæri micit vm allt land • hafis vmhærfis Island • landskialfte mikill vm allt land • elldz uppkoma j Heklu fialli • elldeyar — myrkr mikit sva at fal sol — bolnasot — mandaudi a. e. o.

Simultaneously there occurred violent floods and inundations of the European continent and winters of unexampled severity. Such was that of the year 1322—1333 thus described in the history of Olaus Magnus.

»ait Albertus Crantsius diligentissimus omnium regionum scriptor: anno MCCCXXIII gelidissimo frigore constringebatur mare ut pedestri itinere per glacie de littore Lubicensi in Daniam in Prussiam mare transiretur, dispositis per loca opportuna in glacie hospicii — —» etc.

We are told in the Cronica Guthilandorum that in that winter it was possible to drive over the ice between Sweden and Gothland.

The climatic variations recorded in mediæval chronicles have given rise to much speculation lately, especially in Sweden. I here give the names of three wellknown Swedish papers on the subject: Ehrenheims speach on his resignation of the presidency of the Royal Academy of Science in 1824 »Om Climaternas Rörlighet»; the chapter on climatic variations pag. 562—572 in »Lehrbuch der kosmischen Fysik» by S. Arrhenius and N. Ekholm's paper »On the variations of climate» etc. The historic material at hand is much more extensive than generally supposed. Only part of it is published, f. inst. the 10 Icelandic annal-series, by G. Storm and Hennig's »Katalog bemerkenswerther Witterungserscheinungen von den ältesten Zeiten bis zum Jahre 1800».

The unpublished Danish and Norwegian records are being prepared for publication, the former by Captain C. J. Speerschneider of the Danish Met. Inst., the latter by Dr. E. Bull of Christiania.

Till quite recently the opinion has prevailed among meteorologists and geographers that the old records are unreliable and exaggerated and that no real variation in the climate has occurred in historic time. This opinion is concisely expressed in Nansen's book »Paa ski over Grönland»: »The physical conditions of Greenland remained all through the middle ages approximately the same as they are to day» The same view characterises Nansen's latest publication »Nord i Taakeheimen».

Of late, however, dissenting opinions have been advanced in various countries, in Sweden by Ekholm and Sernander, in Germany by Brückner and in America by E. Huntington.

In Ekholms opinion the climate of Scandinavia has changed since mediæval time and this change he attributes to a gradual transition from a continental to a more maritime climate. Such a change would manifest itself by variations in the mean temperature and precipitation at Stockholm, Lund, Copenhagen, Petersburg a. o. places when compared with earlier observations made in the 18th and 19th centuries and with the oldest observations we possess, i. e. those made by Tycho Brahe on the island of Hven in Öresund at the end of the sixteenth century. Such a comparison made by Ekholm will be referred to later.

E. Huntington approaches the question from an archæological point of view. In his extensive travels in Central Asia and the interior of North America he studied the former extension and gradual exsiccation of steppe-lakes as shown by ancient shorelines and remnants of cities abandoned in periods of drought. The climatic variations which caused floods, inundations and ice-blockades in Greenland, Iceland and Europe manifested themselves in the interior of the continents by devastating periods of drought, forcing the population to emigrate. Huntington holds the invasion of the Tartars into China and Europe in the 14th century, as well as that of the Aztecs into Mexico, to be caused by such variations in the climate.

We possess no actual observations of climatic variations in the countries on the western and northern shores of the Atlantic. Here we have only the ancient Sagas to go by, and what they have to say on the subject I will recapitulate later. It is neccessary, however, that I should say a few words now as to my own standpoint in this matter.

In my opinion the ancient records of variations in the climate indicate that a change in the oceanic circulation and in the conditions of the Atlantic has occurred. No geologic alteration that could influence the climate has occurred for the past six or seven centuries. The changes due to cultivation of land, clearing of forests, draining of marshes and regulation of river-beds are too insignificant to explain these phenomena. Their very nature, i. e. floods, inundations, ice-blockades, suggests a dislocation in the oceanic circulation, the ultimate cause of which must be ascribed to cosmic agents.

The third part of this paper will contain the proofs in support of the theory here propounded as regards the countries west and north of the Atlantic. The fourth part will contain those pertaining to the European seas and coasts. In the first part I will endeavour to point out the cause of these climatic variations.

My own researches and those made during the past thirteen years by the International Cooperation for the investigation of the sea, have enabled me to study the variations in the seas surrounding Sweden since 1891. The material collected by myself and by Dr. G. Ekman, who in 1876 with A. W. Cronander and in 1877 with F. L. Ekman investigated the Baltic and Cattegat, and later by himself carried out the first fundamental investigation of the conditions off the Bohuslän- coast in the first years of the present herring-period, have enabled me to study the causes of these variations. They appear to be of a periodic nature and ultimately ruled by cosmic agents, i. e. variations in the tide-generating force exercised by the sun and moon upon the waters of the ocean. I have also ascertained that the tide-generating force exhibits secular variations and that an absolute maximum occured 500 years ago accompanied by a series of secondary maxima and minima in the centuries immediately before and after.

The seas surrounding Sweden are particularly well adapted for the study of periodicities in the oceanic circulation and its dependance on the tide-generating force. The tidal movement, almost imperceptible at the surface, reappears on a vastly enlarged scale as great submarine waves in the borderlayer between the surface and the deepwater. The Swedish expedition in august 1907 to the Belts and Öresund, first discovered the submarine semidiurnal waves which for the last 4 years have been registered daily at the Marine Station on Bornö.

As director of the work of Svenska Hydrografisk-Biologiska Kommissionen, I have been able to concentrate my attention on these problems and to obtain expert help in such questions of astronomy and mathematics, as are beyond my own reach. Reports by the experts J. W. Sandström, N. Zeilon, H. Pettersson, G. Strömberg a. o. are published separately in Sv. Hydr.-Biol. Kom:s Skrifter. The material compiled from selfregistering instruments and from the analytic work of our assistant V. Söderberg is too large to be published in extenso. All observations, however, are recorded in the archives of the Station of Bornö and are available to experts.

In publishing this paper I have to acknowledge the aid of numerous contributors. The historic dates I have obtained partly by studying original authors, partly from personal communications both verbal and by letter from historians, archeologists, and philologists in this and other countries. It is impossible to enumerate all those from whom I have obtained information. I shall, however, always give the name of my informant when making use of a statement and I wish here to express my grateful acknowledgement of the information so courteously and readily given.

I.

Cosmic Causes of Climatic Variations of Short Periods.

As mentioned in the introduction, the floods on the North-Sea coast are among the events on which the mediaeval chronicles put the greatest stress. In the last centuries these seem to have been of an unprecedented violence and much more frequent than now. The devastating force of the flood is governed by two agents, i. e. high water-level and force of wind. It is impossible to ascertain now whether the wind-force was greater in those ages, but it is beyond doubt that the water-level on some occasions and especially in winter was abnormally high and at other times much below the average, or in other words, that the range of the tide attained an absolute maximum in those centuries. This assertion is borne out by the following facts.

The tide-generating force of the sun and moon, which governs the range of the tide, increases in our latitudes with their declination and proximity to the earth and is greatest when each of the heavenly bodies attains its maximum of declination and proximity to the earth simultaneously.

This happened as to the sun about 1328 (Bohlins calculation) when the perihelion of the earth and the wintersolstice occurred on the same day. At the time of the winter-solstice 600 years ago the tide-generating force of the sun must have had an absolute maximum.

The node and apside line of the moon's orbit coincide (on an average) on a certain day every third year. At present that day is approximately the 26th of September. In 1796 it was the 19th of October and at the end of the 14th century it must have coincided with the winter-solstice. The figure 1 represents schematically the position of the moon's orbit at wintersolstice during a 9 years period at the end of the 14th or beginning of the 15th century. It is evident that in all probability the moon (at newmoon), at least every ninth year, attained a position nearer to the sun at winter-solstice than it has since attained or will attain for thousands of years to come. At fullmoon both sun and moon approached nearer to the earth than usual thereby increasing their disturbing influence on its gravitation.

The position of the moon's orbit with the apside-axis pointing to the sun is indicated by the ellipse. Three years later the apside-axis has revolved 3 ×40°645 = 121°935 (40°645 annually) in the one direction and the node-axis 3 ×19°355 = 58°065 (19°355 annually) in the other direction. Thus they again coincide forming a node-apside in the position α_{III}. Six years later the node-apside will assume the position α_{VI}, and after nine years the position α_{IX}. In this position, however, the node-apside no longer points straight to the sun at perihelion. It now forms an angle of 5°7 with its original position at perihelion nine years ago, 18 years later the angle will be 11°4, after 36 years 22°8 a. s. o.

Evidently a constellation like that represented by position α_{I} offers the greatest chance that the moon revolving in its orbit will approach nearest to the earth and exercise its greatest influence simultaneously with the sun (at the earth's perihelion). In this constellation the maximum of the tide-generating force will occur at *full-moon*. The disturbing influence on the sun's photosphere and corona, exercised by the moon and earth together, will attain its maximum at *newmoon*. Both maxima are absolute and will not regain their full force till 2 thousand years have passed, though in the mean time secondary maxima will appear. The situation may be described as *perihelion-node-apside*.

According to a rough calculation I made, the last occurrence of perihelion-node-apside ought to have taken place 1369. The interval does not quite amount to 2 000 years. In order to get the time and period more accurately determined I requested Mr. Strömberg, assistant to the Observatory of Stockholm, to revise my calculation using the latest values of the lunar constants. I also requested Dr. Hans Pettersson to calculate quantitatively the variation of the disturbance in the gravitation.

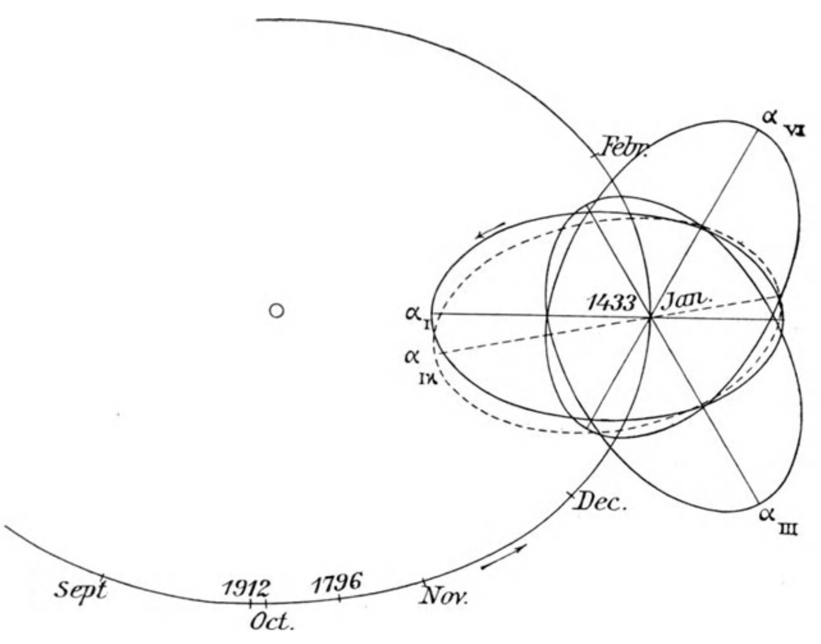


Fig. 1.

The calculation of Mr. Strömberg gave the year 1433 a C. as the year of perihelion-node-apside.

The report on the variation by Mr. Pettersson is published in the »Publications de Circonstance» of the International Council for the Study of the Sea and is called »Longperiodic Variations of the Tide-generating Force». According to the researches by Strömberg and Pettersson the absolute maximum of the tide-generating force must occur about 3 500 b. C., 1 900 b. C., 250 b. C. 1 433 a. C., 3 300 a. C. o. s. o. or with an interval of about 18 centuries (the intervals are not quite equal).

The secondary maxima which occur in the intervals between absolute maxima are more or less developed in proportion to their distance from an absolute maximum. Their appearance is regulated by the occurrence of the constellations node-perihelion and apside-perihelion. These coincidences occur at intervals varying between 84 and 93 years (= secondary maxima). The coincidence will be less perfect every ninth year (= tertiary maxima). Finally the proximity of the apside-line to the line earth-sun at perihelion will cause the tidegenerating force to attain still weaker maxima in the interval between two tertiary maxima, viz. between the 4th and 5th year before or after a tertiary maximum.

The amplitudes of these different periods are approximately calculated

for secondary (84—93 years period) 2,0 $^{0}/_{00}$

For tertiary (9 years period) 2.1 $^{0}/_{00}$

when taking as unit the value of the force at the absolute maxima.

In calculating these values, the exentricity of the lunar orbit is assumed to be constant. The exentricity, however, is affected by the sun and is greatest when the apside-line coincides with the direction towards the sun and greatest of all when the apside-line at the earth's perihelion coincides with the direction of the major-axis of the earth's orbit. The absolute maxima therefore are noted by a high exentricity of the lunar orbit and are strengthened by the growth of exentricity. In perigee the moon approaches the earth and in apogee it withdraws from the earth and approaches the sun. It is impossible on account of the complicated nature of the lunar disturbances to get any approximate estimate of the influence of the excentricity on the value of the maximum of the tidegenerating force 500—600 years ago.

In contrast to the maximum-years mentioned: 3 500, 1 900, 250 b. C and 1 433, 3 300 a. C. we get the years 2 800 and 1 200, b. C. and 550 and 2 400 a. C. when the constellation perihelion-node-apside is changed into its opposite: aphelion-node-apside.

If we represent the variation in the tide-generating force graphically by a continuous curve it would appear like a succession of big oceanic waves with intervals of some thousand years, their crests rippled by numerous lesser wave-systems each with their proper crests and hollows.

The amplitudes of all wavesystems increase as they approach years of absolute maximum and decrease near the minimum years 1 260 b. C. 530 a. C. a. s. o. The difference in springtide and eap-tide, as well as of the sea-level in general at ebb and flood, in winter and in summer must also be greatest at the time of maxima and smallest at the time of minima. This variation in the tide-water at the surface need not neccessarily be great to work destruction on a lowlying coast-line guarded by sand-dunes. Formed by the action of the waves on the beach in centuries of weak ebb and flood these sand-dunes may in succeeding centuries of a growing tide become gradually undermined till at last easily broken through by a slight increase in the destructive forces.

Fig. 2.

If we find that the absolute maxima are followed by catastrophes such as floods, outbursts of polar ice, and climatically by sharp contrasts of temperature, excessive drought and excessive precipitation, we should expect the minimum-years to be noted for the reverse conditions. In such an investigation the sea neccessarily comes first, for it is far more susceptible to the influence of the tide-generating force than is the atmosphere or the solid earth's crust. What we should expect from the tidegenerating force at the time of absolute maxima is this:

1) In the surface: Greater tidal phenomena with bigger flood-waves and a greater difference between spring-tide and neap-tide capable of breaking through dikes and flooding lowlying coasts.

2) In the border-layer (when a less heavy waterlayer superposes salter and heavier water, as is always the case in arctic seas and in the Skagerak, Cattegat and Baltic): strong pulsations in the undercurrent appearing as submarine waves, which enter into fjords and inlets like the s. c. »moon-waves» we have observed in the Belt, the Cattegat and the Gullmarfjord.

This diagram, shows how submarine waves, 2 5—30 m. in height enter the fjord in the border-layer between the »Baltic» water of the surface and the salt deepwater which rises and falls causing the surfacelayer to retract or expand in thickness.

The instrument which records these movements of the deeplayer consists of a float of sheet-copper of 500 l. capacity filled with water

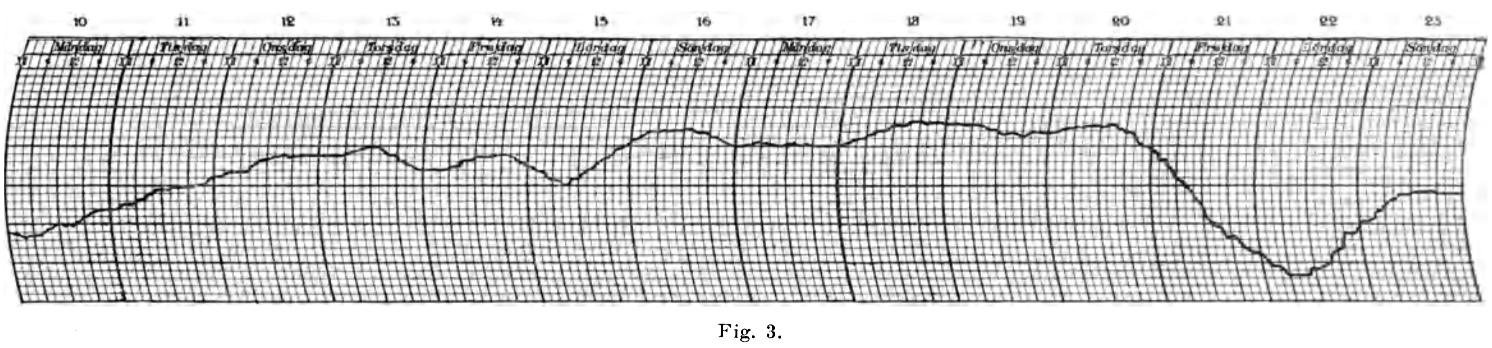


Fig. 3.

and so constructed as to float in the border-layer and partake in its movements.

The undulations of the border-layer are evidently of tidal nature and have hitherto been overlooked. This is not the time to settle whether they should be classed as »wave-movements» or »seiches». In any case they are not local oscillations originating within the fjord, for their period is 13—14 days (or 7 days) and follows the lunar periods, while the longest independant oscillation of the fjord is 1 hour 49 min. for the surface seiche and 2—3 days for the uninodal seiche of the deepwater. In all probability these submarine waves are formed by the impact of the oceanic tidal wave on the submarine ridges in the North Atlantic, f. inst. the Faroe-Shetland ridge or the North-sea bank in lat. 60°, rising out of the depth of the Norwegian Sea. The phenomenon is akin to that reproduced in Dr. Zeilon's experiment[1]. The advancing wave is stopped and broken by the wall in the experiment (the suboceanic ridge) and pours over the lip of the wall in little cascades of water then to travel along the bottom on the other side as a succession of submarine »solitary-waves». According to Zeilon these submarine waves preserve their original period of undulation, though otherwise modified as to length, face and amplitude. If the original undulation contains several periods as in tidal phenomena some of these may be suppressed while others develop and become dominant. The total of the energy in the wave-motion will remain constant, of course, but it may be unequally divided among the induced wave-systems. This seems to be the case in the Cattegat where the diurnal tidal waves are blotted out by the longperiodic waves (»the moon-waves»), the amplitude of which is so great that they measure up to 30 m. between crest and hollow in the Gullmarfjord and even more at the Skagen light ship.

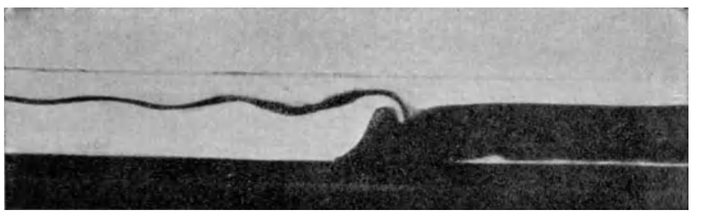


Fig. 4.

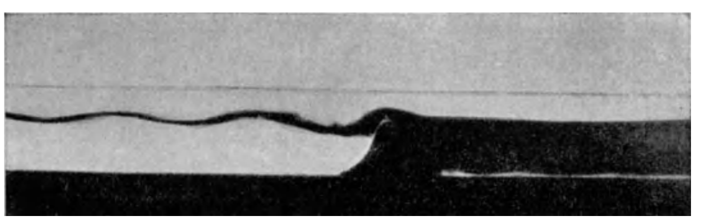


Fig. 5.

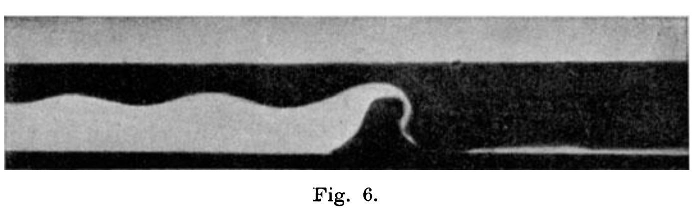


Fig. 6.

When these giant-waves enter the fjord they appear as an influx of water at 33 m. depth while there is an outflow of surface-water. The strengh of both currents is registered in cm/sec. by two propeller-wheels at Bornö Station. The velocity of the undercurrent may on occasions (as shown in the diagram fig. 7) amount to 8—17 cm./sec. When the submarine wave subsides the currents are reversed.

The strongest currents observed were those of the 16th and 17th Nov. 1910.

The submarine wave, which had entered in the 3 previous days then sank more than 25 m. in 24 hours. The astronomic constellation which caused this was the total lunar eclipse the night between the 16th and 17th Nov. or in other words the combination of fullmoon with perigee and nodeapside of the lunar orbit, which constellation for the past 4½ years observations in the Gullmarfjord has been found to bring strong ebb in the »moon-waves».

[1] N. Zeilon, on the Seiches of the Gullmarfjord Sv. Hydrogr. Biol. Komm:s Skrifter.

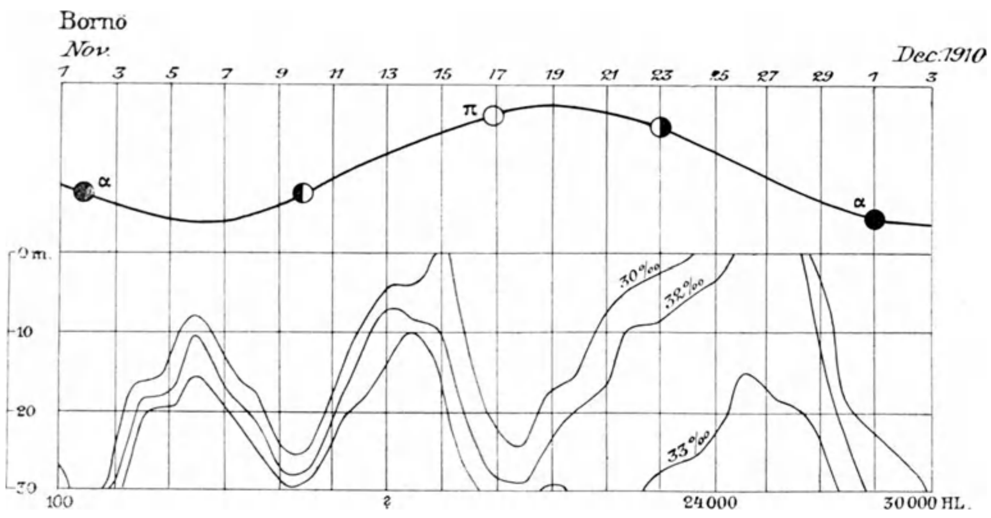


Fig. 7.

The diagram shows the upheaval of the undermost water-layers represented by the isohalines of 33, 32 and 30 $^0/_{00}$ (which occurred 3 times in November 1910) and the sudden subsidence of the waterlayers the 16—17 Nov. (eclipse day) and the 29 Nov.—1 Dec. (new moon).

This instance alone shows that the submarine waves are not incidental movements of the water caused by meteorologic agents such as changes in the atmospheric pressure, winds o. s. a.

The real proof of their tidal nature, however, is that they reappear on the same date in a succession of years. Thus the moon-waves of 1909 reappear and can be identified in the wave-series of 1910, and 1911. Not so, however, that the wave of, say 7th Febr. 1909, will return on the 7th Febr. of 1910 and 1911. Next year's wave appears 10—11 days *earlier* than the wave of the previous year. In the diagram representing the moon-waves of the Gullmar-fjord in 1909, 1910 and 1911 the dates are so arranged that the

Corresponding Moon-waves

observed in the Gullmar-fjord during the winter-months 1909, 1910 and 1911.

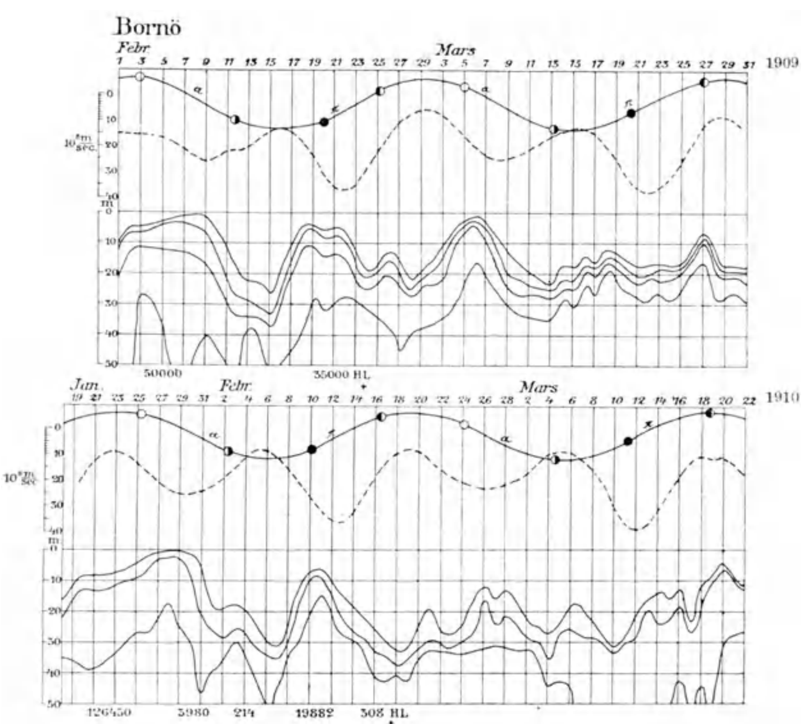
The fulldrawn line represents the declination of the moon.

The dotted line represents the daily variation of the tide-generating force of the sun and the moon at the Lat. of the Station Bornö.

a, b, c, d etc. denote the corresponding boundary waves in the years 1909, 1910 & 1911.

50,000 H L; 35,000 H L etc. the weekly catch of herrings in the Cattegat.

The isohalines of $34^0/_{00}$, $33^0/_{00}$, $32^0/_{00}$ and $30^0/_{00}$ are represented by fulldrawn lines.



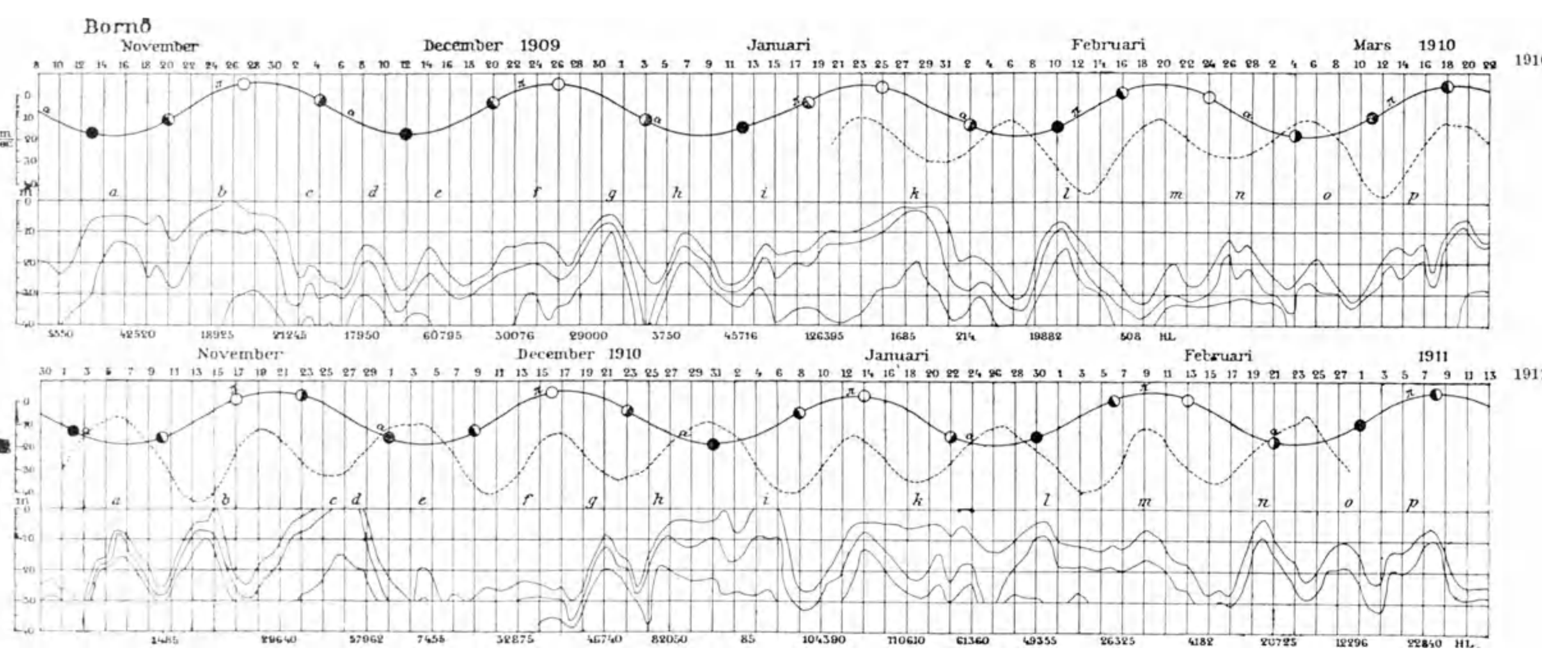


Fig. 8 & 9.

wave of Febr. 7 1909 is placed above the wave of 29 Jan. 1910. In the second diagram we see this wave placed above that of 19 Jan. 1911. Arranged in this manner the analogy is quite obvious. The difference in the dates at first puzzled me till I found the simple solution.

The lunar year is 10 days shorter than the solar. It comprises 12 synodic lunar revolutions, each of 29,531 days, and 13 tropic periods of declination of 27,399 days each. Thus the same lunar phase will recur after nearly 355 days and the moon will attain almost the same declination north or south.

12 ×29,531 (synodic revolutions) = 354,57 days
13 ×27,399 (periods of declination) = 355,18 days.

This means:

1) That the phase and declination of the moon influences the movements in the oceanic border-layer.

2) That if the moon's synodic period of revolution and period of declination at a certain season unite in raising a submarine wave somewhere in the sea, it is not to be expected that new waves will appear regularly every 14th (or 7th) day except for a limited space of time on either side of the epoch. One month or two before

or after the epoch the two lunar periods will counteract each other (viz. tend to raise to separate waves instead of one in common) because a periodically acting agent which comprises 12 periods in a lunar year can not continue to coincide with an agent that comprises 13 periods in the same space of time. A regular formation of waves all the year round cannot be expected.

3) It may, however, be expected to recur the same season next lunar year, though with some discrepancy, seeing that the two lunar periods are not quite synchronous after 355 days, but differ some 0.61 days. In reality the discrepancy is much greater because we have omitted to count the influence of the third or anomalistic lunar period. This period is 27,55 days and tends to cause a displacement of 7 instead of 10 days from year to year in the wave-series. This period is also more irregular than the others.

It is only under favourable circumstances when two lunar periods combine that we may expect welldefined moon-waves at intervals of 7 or 14 days to arise in a certain part of the year. These wave-series may be expected to reappear at the same season next lunar year and even in the following, though the discrepancy with the solar year will have increased. After that, however, the analogy will very likely cease as was the case in the year 1912.

This brings us to a fact that hitherto has been overlooked, and yet characterises every phenomenon of cosmic origin in which the lunar periods and the tide-generating force play a part, viz.

That every periodic phenomenon of this kind has a limited term of existence. The period is »worn out» in consequence of the inner want of harmony between the different lunar periods. Another consequence is:

That no periodic phenomenon which depends on the tide-generating force will reappear in a perfectly analogous manner within finite time. The period repeats itself approximately a given number of times till it disappears and a new combination of periods prevails.

These corollaries may surprise those who look upon cosmic phenomena as possessing a continuous unchanging periodicity. It is commonly supposed that the periodic nature of a phenomenon is only proved by its regular repetition through endless time. In studying its periodicity by harmonic analysis it is usual to found the analysis on as long a series of observations as possible, so f. inst. on observations of the frequency of sunspots, of the waterlevel, precipitation, the mean-temperature in different places etc. As a fact, however, a phenomenon in Nature may be of perfectly periodic type and yet have a limited term of existence.

Every lunar period still exercises its influence, but no longer in conjunction with the others. The big moon-waves break up into minor waves which succeed one another with apparent irregularity, not always at intervals of 14 days, but sometimes less. Thus they become impossible to distinguish from the short tidal waves and from local submarine seiches in the border-layer of the fjord. If the level of this layer remained constant and the specific gravity of the surface and bottomlayer was uniform, and if the bottomformation at the mouth of the fjord could affect the short waves like the long waves, then the wave-series could be reconstructed by the aid of harmonic analysis and with the lunar period as base for the calculation. The longer the time of observations, the better would be the result gained. An attempt to do this has been made and failed, as was to be expected.[1]

The reason why the harmonic analysis, as usual in these cases, gave an obscure result will be explained later on. The moon-waves are undulations in the border-layer of the sea and subject to all circumstances that affect boundary-waves. The phenomenon would disappear if the seawater became homogenous. On encountering submarine ridges the waves change into cascades or breakers. If the ridge rises to or above the level of the border-layer as in the middle and south part of the Cattegat, then the oceanic tidal wave is broken by innumerable phase-ruptures just as the flood-wave of the surface breaks when encountering an obstacle. In other words: the character of the medium precludes the use of the analytic method.

I found the insufficiency of the analytic method when trying to reconstruct the sunspot curve for 150 years by the aid of the harmonic analysis. I found that the sunspot curve could not be reconstructed on the basis of *any* given period for more than 34 years. Then a new periodicity set in. In reading up the subject I found that Schuster before me had had the same experience with the same problem. He found *that no single period dominated the sunspot frequency permanently; one period would prevail for a time and then be supplanted by another.* He discerned a number of such periods, 4.7 years, 8.34, 13.5 and finally the most important of them all, 11.125 years. He says: »The existence of a number of definite periods can not be doubted whatever we may think of their numerical relationship. The recurrence of the maximum activity of each period seems to take place with an accuracy which may be equal to that of orbital revolution, but the characteristic property of these periods is the great variability of the activity». In other words, the periods succeed one another. The one will attain its full activity when the influence of the other abates or ceases (becomes latent). The recurrence of the sunspots give an instance of periodic phenomena with short terms of existence.

The recurrence in the Saros period of occultations (the eclipse-cycle) is the best defined and most lasting of the phenomena which depend on the lunar periods. The coincidence of the lunar periods in Saros is as follows:

223 synodic lunar periods	= 6.585,32 days	=	Saros: 18 years $11\frac{1}{2}$ days
242 draconitic » »	= 6.585,34 »		
239 anomalistic »	= 6.585,55 »		

The tropic lunar period does not fit so well into Saros as the others. Because of the otherwise high conformity the period »Saros» of the eclipse-phenomenon, however, obtains a long term of existence. The lunar eclipse repeats itself 48—49 times in regular succession with a very small displacement in time and place $865\frac{1}{2}$ years once in 223 months or 19 eclipse years (of 346.62 days); a solar eclipse repeats itself 68—75 times till the end of its term of existence in 1 260 years.

Probably the »long'evity» of the eclipse-series, known of old in China and Caldea, caused the belief that all phenomena originating in celestial causes possess unlimited periodicity and that every such phenomenon in Nature could by the aid of the harmonic analysis be theoretically reconstructed with a higher accuracy the longer the chain of observations.[2] By demanding too much of permanency many phenomena investigated by meteorologists and oceanographers have been classed as irregular and incidental, though in reality they are bound by laws and periodic although their periodicity has but a brief existence. Often the apparent periodicity of a phenomenon gets obscure and as if blotted out by other periods somewhat in the manner as a seawave when watched for a time appears to dissolve and merge into other wavesystems. Yet no one doubts that every particle of water will perform its orbital revolution with perfect though very complex periodicity.

An analysis of the variation of the tide-generating force shows its period to be very complex. No less complex will its effect on the sea and the atmosphere be. The ordinary way of reconstructing complex periods by adding a number of sinus- functions into a Fourier's series with constant coefficients, requires that all periodically acting agents shall act continuously and uniformly through the ages. This is not the case with the constellations of the sun, moon and earth in their action on the photosphere and the corona of the sun and on the hydrosphere and atmosphere of the earth.

Phenomena which cannot by harmonic analysis be recognised as periodic are otherwise disposed of. They are treated as incidental and eliminated from the calculation by the ordinary meteorologic way of elimination by averages using the method of least squares, which method presupposes the phenomena to be independant of one another. In this way the relation between many hydrographic and meteorologic phenomena is blotted out and to Chance is accorded far too important a part. The individuality of a phenomenon and its relation to similar phenomena are both underrated by allowing it to be represented by an average which is the exact expressive of a situation unknown to Nature.

Both the harmonic analysis and the calculation by averages are used quite indiscriminately in Hydrography. I do not mean that they should be left out in any case where they are of real advantage but I wish to point out that they are not infallible. The harmonic analysis was incapable of showing the relationship between the undulations in the border-layer of the sea and the lunar periods when analysing the $4\frac{1}{2}$ years series of daily observations on the basis of the same lunar period. Yet the relationship is quite evident in the diagrams which depict the real situation from the daily observations put together.

In the Swedish oceanographic work, of which G. Ekman and I are the leaders, we have sought to collect such »snapshots» of the situation in the sea at different seasons in a succession of years in order to study the periodicity of the oceanic circulation and its causes. This too was the object of the joint investigation of the Swedish and Danish Commissions in 1891—1899 carried out by seasonal cruises 4 times annually which gave a general view of the

[1] A similar instance is mentioned in my paper: The connection between hydrographical and meteorological phenomena. Quart. Journ, R. Meteorol. Soc. July 1912.

[2] On the other side it is obvious that the harmonic analysis must comprise a number of periods — the more the better. For a shortlived or cyclic periodic phenomenon — as the moonwaves, the sunspots a. O. — it consequently must give vague and indistinct results if indiscriminately employed. It seems possible that a number of meteorologic phenomena (as f. inst. the variations of high and low pressure, of dry and wet periods etc.) are in reality periodic and of cosmic origin although their real nature is obscured because the medium (the ocean & the atmosphere) is subject to alterations (of stratification and otherwise, etc.)

North Sea, the Cattegat and the Skagerack. In 1893 and 1894 other countries partook in this investigation and at the Stockholm Conference 1899 these seasonal cruises were put as chief article on the hydrographic program of research.

A general view of the Atlantic surface-water, its salinity, temperature and plankton-life was obtained in 1897—1898 by monthly observations[1].

The synoptic method is valuable and necessary because through it we trace and locate the relationship of different groups of phenomena, such as f. inst. the relationship of plankton- and fishlife to the salinity, temperature and movement of the sea. This fact is accentuated by the recommendation for the future reconnoitering of the Atlantic of the three Geographical Congresses: of London, Berlin and of Rome, and also by being taken up by the Austrian—Italian investigation of the Adriatic whose program is based on the pattern of the Stockholm Conference. It is all the more deplorable that the seasonal cruises of the international Investigation have been discontinued and that we have fallen back on a pedantic computation of averages from observation-series far too defective to serve this purpose. Fortunately the fish-biologic investigation which is carried on in a less abstract manner has given so brilliant results that they make up for the want of general interest in certain other fields of research.

From the beginning the oceanic periodicity and its causes has been the problem of greatest interest to Swedish investigators. As has been shown the cause of our present periodic phenomenen, the moonwaves, is cosmic and must be ascribed to the changes in the lunar constellations. Recent observations made by the Danish Commission with the »Tor» and by the Michael Sars Expedition to the Strait of Gibraltar in 1910 show that waves similar to those we found in the Belt and Skagerak, though far greater, appear on the suboceanic ridges: the Wyville Thomson ridge, the Faroe-Shetland a. o.

They may be regarded as breakers of the oceanic tidal wave impinging on submarine ridges. Their amplitude is very great and they make the interchange of water between the Atlantic basins pulsate in accord with the periods of the tidal wave. The submarine breakers which enter into the Cattegat are forced to dissolve into irregular eddies when the deep-channel shoals out, as at Anholt, or changes into narrow grooves as in lat. 57°10′, Here the border-layer in which they travel thins out when meeting the solid seabottom. When General Carp denies the existence of the moon-waves, because they were not found in South Cattegat *(and the Baltic!)* he expects too much from the transmitting power of the tidal phenomenon. The localities where they can be observed are probably restricted to Skagen, the Gullmarfjord and possibly the Christiania-fjord though as yet we know nothing of the latter. They are only to be found where the water is *deep* and *stratified*. In front of the great submarine ridges they dissolve into breakers in the manner of surface-waves. The herring-shoals travelling with these cascades generally stop at the point in the Cattegat where the wave-motion breaks up. Sometimes, if the undercurrent is very intense, the herring may pass across the south plateau of the Cattegat and will then collect in the sounds where the different current-branches unite. Later it will be shown that this must have happened in the centuries 1,100—1,600 a. C. when the great Hanseatic herringfishery flourished and the maximum of the tidegenerating force occurred. Of this lucrative fishery only faint traces now remain in the years of good fishery on the coast of Scania and in the Belt.

II.

Outbursts of polar ice from Arctic and Antarctic Seas.

Submarine waves also enter the polar basin. They were first traced by Nansen, who at a depth of some hundred meters found irregular variations in the temperature of the Gulfstream branch which enters the Polar Sea. In periods of maxima this influx will be stronger and able to break up the ice, the effects of which will be seen in an increase of the ice transported by the polar current. In periods of minima the ice, no longer subject to the melting influence of the undercurrent will increase in thickness by the cooling from the atmosphere which very slowly penetrates the icecover. It is a wellknown fact that »outbursts» of drift-ice fom the polar seas occur *periodically* and it is significant that the last great outburst from the Antarctic which culminated in 1894—1895 occurred under the constellation I have described as »perihelion-apside» (fig. 10).

The following charts illustrate this great outburst of antarctic icebergs. In 1888 no icebergs were reported by the Australian liners. In the following years icebergs were sighted more and more frequently

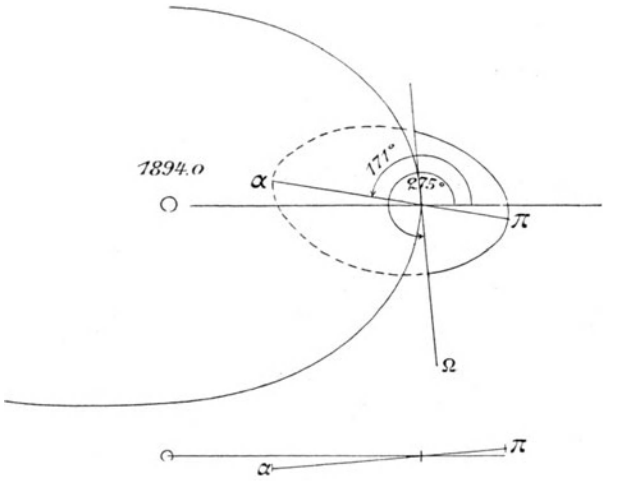


Fig. 10.

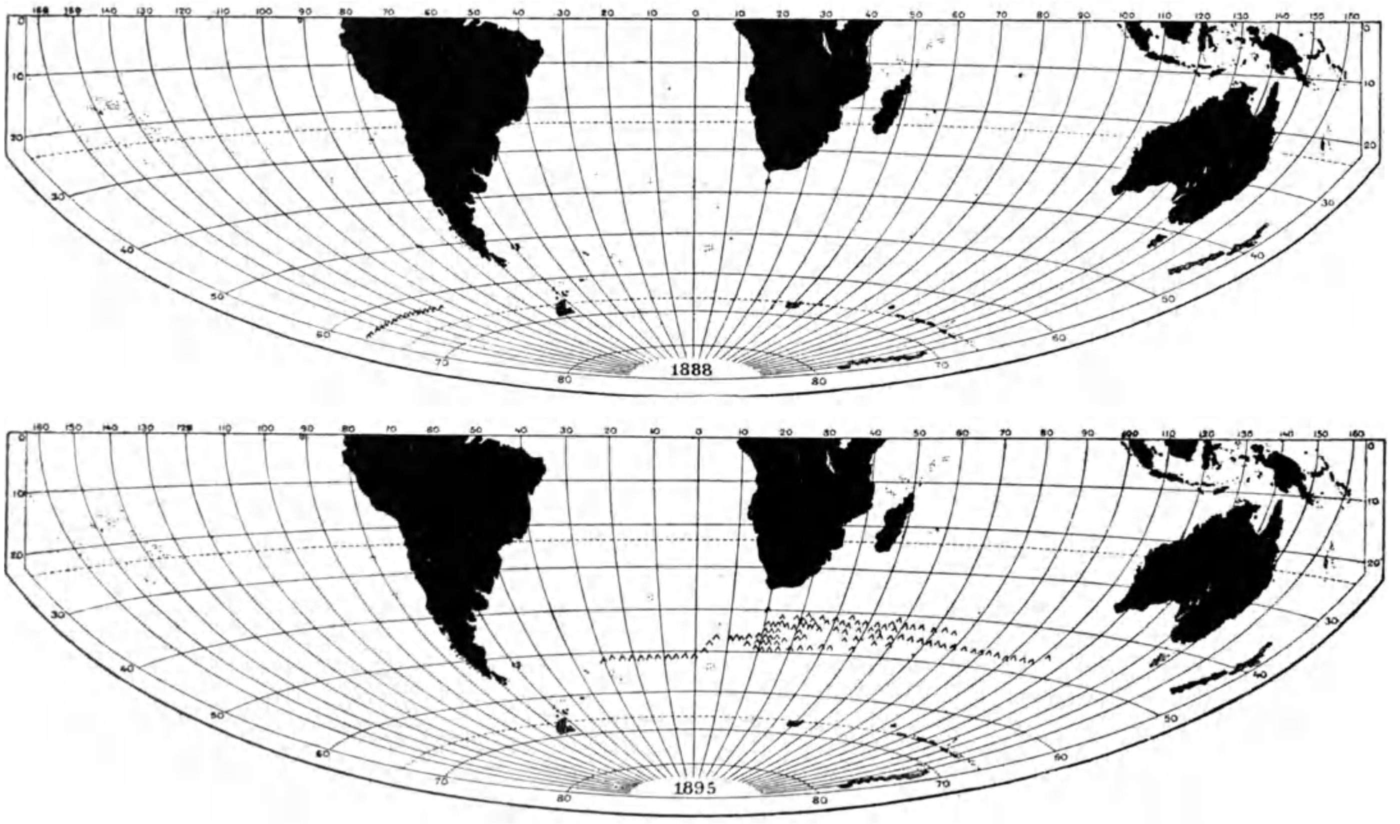


Fig. 11. Icebergs in the antarctic ocean.

The charts are compiled from H. C. Russels paper (Proc. R. Soc. Nw S. Wales 1896. The Signs ∧ ∧ denote groups of icebergs sighted.

[1] O. T. Cleve, G. Ekman and O. Pettersson: Les variations annuelles de l'eau de l'ocean Atlantique. Göteborg 1901.

and in the years 1892—1897 they became a serious danger to navigation.

Nine years afterwards there occurred a remarkable outburst of drift ice from the Arctic Sea which will be in fresh memory in the Scandinavian countries because it was followed by a general failure of the fisheries of cod, herring etc. along our coasts from Finmarken and Lofoten to the Skagerak and Cattegat. The greater part of the Barentz Sea was covered with pack ice up to May, the ice-border approaching to the Murman- and the Finmark-coasts nearer than ever before. Herds of arctic seals visited these coasts and some specimens of the arctic »white-fish» extended their wanderings to the Christiania fjord and even entered into the Baltic. The position of the moons orbit was as shown in the following diagram.

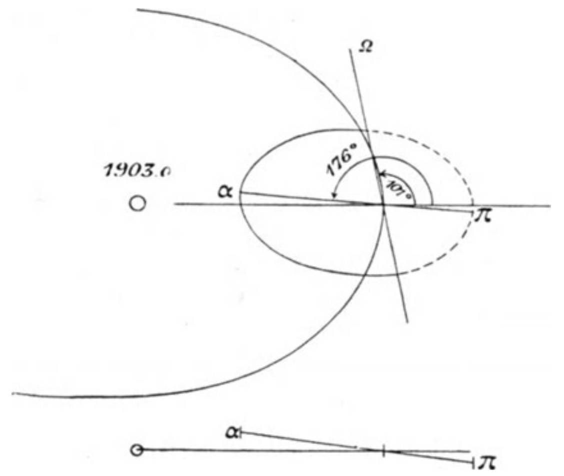


Fig. 12.

Nine years afterwards, in 1912, the last great ice-year of the Labrador current, the situation was as figured in the following diagram (fig. 13).

All these constellation are of the type which I have denoted as perihelion-apside which brings a secondary maximum of the tidegenerating force and — if we may judge from late experience —

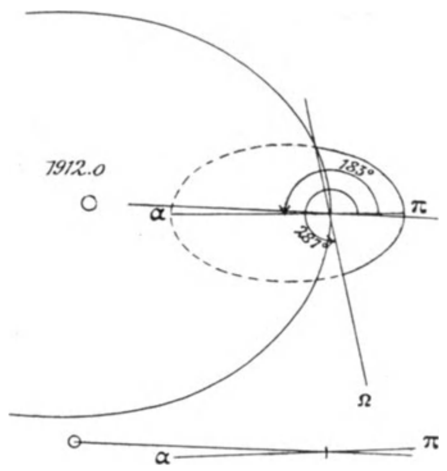


Fig. 13.

outbursts of ice from the polar seas. If this is so it seems worth while to discuss the question: what happens at the epochs of maxima of the tidegenerating force ruled by the constellation *perihelion node-apside* akin to that which occurred at the beginning of the 15th century (fig. 12)?

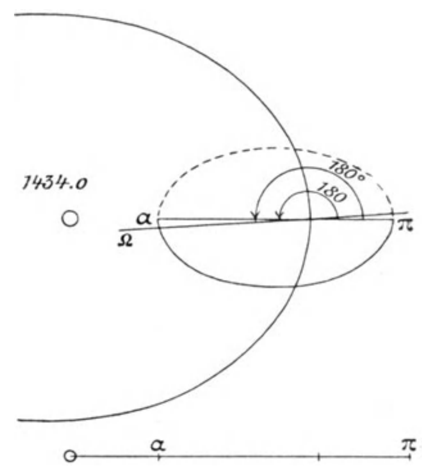


Fig. 14.

III.

Iceland and Greenland in Mediæval time.

A. Iceland.

The earliest information we possess regarding the climate of Iceland is derived from the record of the monk Dicuil of Ireland in 825. He describes a visit some 30 years earlier by some Irish ecclesiastics to the Island of »Thyle» (Iceland). At that time, about a century before its colonisation by the Norsemen, Iceland was visited and inhabited by the Irish. The Sagas call them »Papar» which indicates that they were monks or hermits and that before the time of the »Landnama» or Viking-age intercourse was kept up between these anachorets and the monastries of their mothercountry. Dicuil narrates the description of the island given by his fellow-monks, who had been there from February to August, and adds: »....because of this I believe that those authors (Plinius, Solinus a. o.) who have written that there is a frozen sea (mare concretum) about Thyle have erred in as much as those who sailed thither have been on that island in the natural season of severe cold.... But after a days journey to the north of the island they found a frozen sea (congelatum mare)»

Like Nansen most geographers of our time take it for granted that the climate of Iceland has not altered in historic time. In order to reconcile Dicuil's description with this view, Nansen makes the totally unwarranted supposition that Dicuil's »Thyle» was in reality part of the Norwegian coast about the lat:s of Iceland, perhaps the coast outside Romsdale. Nansen writes: »All the information preserved regarding »Thyle» fits in on the Norwegian coast, but on no other country.» For my part, I own, I cannot see why Dicuils description should pass for something else than what it claims to be, i e. an account of a visit by some Irish monks to their fellowmonks in Iceland, who, as is actually known, at that time lived on the island as hermits or as missionaires among the Celtic settlers there. As far as we know, no Irish hermits or anachorets settled in Norway in the seventh or eight century. There was no inducement then for the monks to sail to Norway and if we assume that they were stormdriven thither it remains to be explained how, in sailing a days journey from the coast off Romsdale, they could come upon a frozen sea, a problem that may offer difficulties to those who with Nansen hold that the climate has not varied in historic time.

According to most of the Sagas, the island was discovered in 874 by Ingolf (Are Frode, Isléndingbók 1120—1130):

»Ingolf built (his house) in Reykiavik. Upon that time Iceland was covered with woods from mountain to shore. Then there were christian men which the Norsemen call Papar....»

According to another version the island was first visited by Gardar Svavarson, a man born in Sweden after whom the island was called »Gardarsholm» (Tjodrik Munk:s Historia de antiquitate regum Norwegiensium, about 1180, and Sturla's Landnámabók about 1250) The text runs: »Gardar sailed round the land and proved it to be an island. He spent a winter at Husavik in Skialfande and built a house there (in 864 according to Arngrim Jonsson) In the spring when he was ready to sail a boat drifted from him.... Gardar sailed to Norway and said much in praise of the land. After him the land was called Gardarsholm and there was wood then from mountain to shore.» There was snow on the mountains and because of that Iceland was also called »Snölandet» (snowland). The name Iceland was given to it by a third viking, Floki Vilgerdarson. He sailed south of the island and landed at Vatsfjord on the northwestern shore. »The spring was rather cold. Then Floki went north on the mountain and saw a fjord which was full of sea-ice. Therefore they called the land Iceland.»

This is the only statement I can find from the Landnama-time which speaks of the ice of the polar current having reached Iceland. It is nowhere mentioned that the driftice hindered the norsemen in their journeys to and from the island. Nowadays the drift-ice is the cause of the bad years in Iceland when, as frequently happens, the ice of the polar current blocks the coast. Its absence in old times must have favoured the cultivation and farming in Iceland even if the climate did not differ much from what it is now in iceless years.

A. Jonsson[1] (in 1593) shows that the early settlers in Iceland were successful in the tillage of the ground and that laws existed for the harvesting of the corn. Local names were often derived from agricultural terms, »hence from the fields there are proper names of certayne places.... all which are manifest takens of the tillage of the ground amongst the first Islanders which also even unto this day, I heare, is practised by some Inhabitants of South Island but with less increase, the ground and temper of the ayre degenerating from the first goodness there-of after so many ages....»

Arngrim Jonsson, the contemporary of Björn Jonsson, evidently did not share the modern view that the climate of Iceland had not changed since its first colonisation in the 8th century up to his own time, the end of the 16th century. In the Icelandic annals and in Thoroddsen's paper »Den Grönländska drifisen vid Island» (tidskr. Ymer) we can follow the gradual deterioration of the Icelandic climate.

Thoroddsen writes:

»The drift-ice causes the bad years in Iceland[2]. The north-coast is most exposed to the ice and here it is very seldom that we do not in some way or other and in some season or other, experience its unpleasant neighbourhood. In the older Icelandic annals the drift-ice is often mentioned, but only when it has proved specially disastrous to the country...

»Although weather conditions are often mentioned in the older annals and Sagas I cannot find that the annual ice-drift to the shores of Iceland is spoken of before the 13th century....»

In the 13th century Iceland began to get blocked by the drift-ice from Greenland. The blockade was much more severe then than now; although even now the northcoast is frequently blocked and sometimes, though not often, even the east-and southcoasts. Owing to the influence of the Irmingercurrent the westcoast in our time is nearly always free from ice. Thoroddsen enumerates the worst ice-years beginning with:

»1233 The drift-ice lay off the shore all summer.

1260 [3]Drift-ice all round Iceland so that every fjord was packed with it.

1279 [4]Very severe cold in the winter and so much ice that it was possible to drive for miles out from the coast. The ice continued far into the summer and from many fishing harbours it was impossible to get out to sea and fish.

1290—91. Ice north of the country all summer measuring 15 ells in thickness.

1306 Drift-ice almost all summer by the north country.

1320 The spring was called »the ice-spring». Drift-ice on the east coast down to Sjoa. The ice went away at Easter.

1347—48 Much ice. The sea was frozen all round the land so that one could ride from one headland to the next.

1360 The drift-ice lay off the shore till 24th of August.

1375 The drift-ice lay off the shore to the 17th of June.»

Ice-blockades of this kind which were unknown in the Viking-age have since occurred several times in every century and have naturally put back the cultivation of the land. To show what an »ice-year» in Iceland means I will quote the description by Thoroddsen of the year 1695.

»The ice encompassed the whole country except Ingolfsnæs, which is unexampled in history. There were such quantities of ice in most places that the open sea was invisible even from the loftiest mountainpeaks and the merchantships could not land. The ice drifted from the north-country to the eastcoast and thence to the south-coast. As early as in Aprilit had reached Thorlakshavn whence it continued to Hitaros. On the northwest side the ice drifted past Latrabjerg into the Bredebugten. In the beginning of May it was possible to ride or drive outside every fjord in the north-country.»

It is interesting to compare the series of ice-years in Iceland with the description in Swedish records (f. inst. in Scriptores rerum Suecicarum), of the severe winters in Scandinavia in the 12th and 13th centuries, when the Baltic was frozen over several times between Sweden, Denmark and Germany. Later on I shall collocate the ice-years in Iceland and the alteration in the old direction for navigation between Iceland and Greenland as described by Ivar Bårdsson, stewart to the bishop of Österbygden in Greenland 1341. This description is recorded by Björn Jonsson (1574—1656) in his »Grönlands Annaler».

The ice-conditions in Greenland are intimately connected with those of Iceland. The advance of the ice out of Nordbotn in the 12—13th centuries of which Bårdsson speaks proved fatal to the old Norse colonies in Greenland, because it cut off the communication with their mother-country. Thus the Vestbygd settlement was destroyed about 1342 and the Österbygd about 1418[5]. In discussing these catastrophes so often described I will begin by stating my own opinion as to the cause of it and later discuss the facts on which my theory is founded.

B.

The ice-conditions and climatic variations in Greenland.

Even in the age of the Sagas and the Vikings there existed an ice-bearing current on the east and northeast coasts of Greenland. But the current in those days cannot be compared to the present one, neither in extent nor in its importance to navigation. This fact I attribute to a more vivid circulation in the Irminger Sea in former days. According to the researches of the Danish Ingolf-expedition, the bulk of the Gulfstream branch known as the Irmingercurrent turns westward at the entrance to the Denmark Strait and runs along the eastcoast of Greenland forming the underlayer of the ice-bearing polar current. According to A. Hambergs investigation in 1883 this varm underlayer has a temperature of 3°—4°. The heating from the underlayer melts the ice of the polar current and the amount of driftice on the eastcoast off Cape Dan in lat. 65½° will vary with the strength of the Irmingercurrent. South of Cape Farewell the ice turns west and northwest collecting outside the southwestern coast of Greenland (Julianehaabs Distrikt). Here 8—9 centuries ago the Icelandic colonists found an open sea. Now it is blocked by ice all summer because the Irmingercurrent is too weak to melt the ice before it reaches Cape Farewell.

A small increase in the temperature of the underlayer, or a stronger influx of Gulfstreamwater, or a stronger oscillation in the borderstratum causing a more vivid contact of the waters of the two currents would scatter the drift-ice so that the neighbourhood of Cape Farewell would be free from ice and the deep sounds between that island and the main land open to navigation. Later we shall see the importance of these sounds for the journeys of the Viking-settlers.

The formation of the coast in the lat. of Cape Dan causes the drift-ice to scatter after the passage of the Denmark Sound. The scattering of the ice and the action of the Irmingercurrent which still in its full force crosses over from Iceland to Greenland makes the neighbourhood of Angmangsalik (Cape Dan) more accessible from the east than the southermost point of Greenland.

Nordenskiöld was the first in modern time to profit by this when in 1883 he broke through the thin ice-layer outside Cape Dan and anchored his ship »the Sophia» in King Oscar's Harbour (lat. 65°35[6]).

The stronger development of the Irmingercurrent a thousand years ago brought two important consequences:

1) The climate of Österbygden (the eastern settlement) was more temperate because the sea coast was free from ice, whereas now the district of Julianehaab has an ice-bound sea in front and the inland-ice behind.

2) As the ice did not go round Cape Farewell and enter Davis Strait, Baffins Bay and the Labrador-current were also relatively free from ice. This again influenced the climate of New-foundland and North America. It is also probable that the warm undercurrent which runs through Davis Strait, like the Irmingercurrent and the rest of the western Gulfstream-branches, was otherwise developed in those days. In other words: *that the polar-ice then melted at a higher latitude than now.*

At the end of the Middle-ages a change came in these conditions, which can only be explained by an alteration in the oceanic circulation. Such changes in the oceanic circulation will of course be more

[1] *Purchas, his Pilgrimes,* published 1670.

[2] From 800 to 1250 Iceland seems to have had a prosperous time without calamities caused by volcanic eruptions, earthquakes, frost & ice blockades. Between 1291 and 1348 however a catastrophic period set in. At least 29 of these 58 years an noted for terrible catastrophes according to G. Storms »Icelandic Annals unto 1578» (»hallæri micit om allt land, etc..») The volcanic eruption in 1300 and following years was preceded by a series of earthquakes and upheavel of volcanic islands (»elldeyar») on the Reykianæs submarine ridge.

[3] refers probably to the following year. In Annal. Regii we read »mcclxI Hafiss umhvarfiss Island».

[4] Also the year 1275 was an ice-year:» »Kringdi hafis nær vm allt Island» (Gottschalks Ann).

[5] The exact time cannot be determined with security.

[6] Nordenskiölds intention (see p. 403 of Den andra Dicksonska expeditionen till Grönland 1883) was, according to his own words, to follow the sailing directions of Ivar Bårdsson: »Steer straight westward from Iceland: *there is Gunnbjörnskär»!* Thus Nordenskiöld found the Gunnbjörnskär of the Sagas which had been lost 500 years ago.

perceptible in the border-areas where the waning Gulfstreambranch contents with currents of northern origin as in Cattegat, the Baltic, Baffins Bay and at the south-point of Greenland. It is inconceivable that a state of equilibrium lasting through thousands of years should exist in those parts. Even now the conditions, especially the ice-conditions, vary greatly from year to year in these seas. In Greenland there are good ice-years and bad ones. Now I will show the conditions in South Greenland in a good year like 1883 when Nordenskiöld on the Sophia landed at Fredriksdal and penetrated into the sounds north of Cape Farewell which have not been navigated by European ships since the days of the Vikings. Then I will give an instance of the conditions and the route of navigation in a bad year like 1902 as described by the Danish archeologist, Captain Bruun.

Finally I will draw a comparation between these conditions and those which prevailed a thousand years ago when Iceland and Greenland were colonised and the Norsemen discovered America.

In our time the eastcoast of Greenland from 65° lat. to Cape Farewell is almost inaccessible.

In good years the pack-ice may form a narrow belt along the coast. But the pressure of this ice-girdle, which is packed close to the coast whenever the wind blows in that direction, is almost more formidable to navigators than in bad years when the ice spreads for miles over the sea but generally leaves an open channel along the shore. This channel was used by the Danish expeditions under Graah, Holm and Garde o. a. Nansen too used this channel to get to the point from whence he started on his ice-wandering after he had landed on the drift-ice and carried his boats across it, *just as they did in cases of emergency in ancient time,* as is told in Kungaspegeln (the Kings Mirror) from the 13th century. Doubtless 600—700 years ago it was at times dangerous and even impossible to penetrate to the eastcoast of Greenland if it happened to be a bad ice-year. But it must be remembered that in the Viking-age such years were *exceptions* and not the rule as is now the case. In spite of the strong tidal currents the sounds between Cape Farewell and the mainland are now always blocked by drift-ice which is crammed into their eastern inlets by the polar current outside. West of Cape Farewell there is the great fjord-district with the settlements of the ancient »Eystribyggd». All summer the Bay is blocked by drift-ice, and navigation is generally impossible till authumn and then only by circuitous routes as shown by the dotted lines in the map on Plate II.

Circumstances being exceptionally favourable, Nordenskiöld was able to get to Julianehaab as early as the 17 of June 1883. It is generally neccessary to wait till late in summer and, working through the ice-girdle, make the coast by the northliest route through Nunarsiut Sound, then go south-wards on an inner route along the coast to Julianehaab and Fredriksdal which is the farthest accessible settlement. From here the expeditions of Wallö, Giesecke, Graah, Holm and Garde in eskimo-boats penetrated through the sounds north of Cape Farewell: the Ikerasak, the Ikek, the Tunua, the Kipisak a. o. which, though never sounded, were found to be navigable up to their eastern inlets, where the ice of the polar current was encountered. In spite of the favourable conditions in 1883 Nordenskiöld had no better luck. He was turned back by the ice when trying to penetrate through the sounds and was unable to reach the eastcoast. Such are the conditions in a good ice-year. The ice-charts of 1903 and Captain Bruun's description of his journey to Greenland in the summer 1903 show how the navigation must be performed in a bad year.

»Cape Farewell as usual lay shrouded by heavy mist from our sight (in May 1903). We put into Davis Sound and very soon encountered the great ice. Having made Cape Farewell you follow the ice-border till south of Nunarsiut, at the earliest, you may break through the ice. South of that headland your change your course making the coast in a curved line.» Commander Norman says: »East of Cape Farewell the ice presses continuously on to the coast so that it must be regarded as impossible to reach it from the south. West of Cape Farewell the ice also presses on to the coast, part of the year, and makes navigation difficult, but as a rule this only concerns the harbours in Julianehaab Bay, for as soon as Nunarsuit (Cape Desolation) is passed the current leaves the coast and the ice begins to scatter, so that only in bad years and after continous sea-wind the sailor will be troubled by it.»

Great indeed is the difference between the experiences of these modern travellers and those of the Vikings as told in the Sagas. Eric Röde's discovery of Greenland is described in this manner:

»Erik came from the sea to land at the middle-glacier and the place called »Blåserk» (Black Sark). From thence he went south along the coast to see if the land was habitable. The first year he wintered on Erik's Island. In the following spring he went to Erik's fjord and settled there. That summer he journeyed to the western Wilderness.... The second winter he spent on Eriks-holme att Hvarfsgnipa. But the third summer he went north as far as Snefjeld and into the Rafnsfjord; he then thought that the inmost creek of the Eriksfjord lay just opposite to the place he had reached. He then turned back and spent the third, winter on Eriks Island in the mouth of the Erik's fjord.»

It is inconceivable that Eric should have carried out this program without the greatest hindrance from the ice in the Julianehaab bay if the ice-conditions had been the same then as now. But if drift-ice existed in these parts in Eric's time, the Sagas do not mention it. Nor is it mentioned by any Sagas from the Viking-age.

As my knowledge of the Icelandic Sagas is not sufficient to authorise such a statement, I asked for information from Professor Finnur Jonsson of Copenhagen on this matter. By Prof. Jonssons leave I here give an extract of the lettre containing his answer to my question:

»*With regard to your question I can tell you that there is no mention of ice in the original records of the journeys to Wineland. They go from Greenland to Wineland as if there was no question of difficulties from the ice. Indeed there is no hint at all of such hindrances on the coast of the ancient Österbygd. This has always struck me when thinking of the present conditions. The spread of colonisation from Ikigait (Herjolfsnes) up to Erik'sfjord has always appeared more natural to me, provided they could get into the inner fjords directly from the sea. I think it much less likely that the colonisation should have spread southwards from Erik'sfjord to Ikegait, by land. Judging from present conditions, however, we must surmise this to have been the case.*»

G. Brynjulfsson in a lecture to Nordisk Oldskrifts Forening 1871, pointed out that the colonists in Greenland experienced little difficulty from the ice in their hunting expeditions to Baffins Bay. In Nordr-setudrapa (the 11th century) there is no mention of ice in these northern parts though dangers arising from wind and waves are dwelt upon. The Norsemen possessed two fishing- and hunting-places: Greipar and Furðuðustrandir on Baffins Bay. South of these was Helluland. He mentions the rune-stone that was found on an island 25 miles north of Upernivik. This stone was put up by Erling Sivatsson »Löverdag for Gangdag» (25th of Apr. 1135), viz. at a time of year when this place is inaccessible nowadays. (The deciphering of this rune-stone is however disputed). Björn Jonsson's version of the Hauks-book (but not the Hauksbook as it now exists) describes an adventurous journey in 1266 or 1271 to Smith's Sound and further on to an open sea. Eskimoes were first encountered at Smith's Sound (Krogsfjordsheden?) Their invasion into Greenland appears to have commenced in the 14th or at the end of the 13th century.

Reading the ancient records in chronologic order we find:

1) That the Sagas proper from the 9th to the close of the 12th century never mention that the Norsemen were hindered by ice in their journeys to Österbygden while still adhering to the old navigation-route »*the Erikstefna*». Eric himself spent 3 successive winters on the islands in the Julianehaab bay and starting from thence every summer explored the country. This cannot be explained otherwise than by assuming that the polar ice did not reach Cape Farewell and the westcoast of Greenland in those days.

2) In the »Kungaspegel» from the 13th century we are told that those who sail for Greenland encounter much ice in the sea. Navigators are warned not to make the east-coast too soon on account of the ice; still there is no new route recommended *then.*

The only mention of *ice-bergs* I can find in the older writings is from the Kungaspegel and runs thus:

»There is yet another kind of ice in that sea (the Greenland Sea) which is of a different shape and called »falljaccla» (falling glacier) by the Greenlanders. It has the appearance of a mountain rising out of the sea and it never mixes with other ice but keeps to itself.»

Considering the part ice-bergs play in the accounts of all modern travellers, we must conclude that in the Viking-age they were very rarely seen on the south-coast of Greenland.

On the east-coast matters were different. Even in the 10th century the east-coast of Greenland was a wilderness, the refuge of a few outlaws who settled there. The landing was dangerous on account of the ice, partly drifting down from the Denmark Sound and partly formed by the calving of the glaciers on the coast. In the »Floamanna Saga» we are told of Thorgils, an Icelander who in 998 went to Greenland to visit Eric Röde but was wrecked on the east-coast where he was hospitally received by his countryman Rolf, an outlaw, who had settled there. After many adventures Thorgils and Rolf at last reached a sound which led to the »Österbygd». In the words of the Saga:

»þeir fara sudr fyrir land ok koma i fjord og lögdu i laegi.» according to the commentor of Gr. Hist. Mindesm. the translation

[1] It is not quite clear if Eric spent two or three winters in this district (see Finnur Jonssons Grönlands gamle Topografi in Meddelelser om Grönland 7 p. 270.)

is that they sailed *»round the headland»*, meaning Cape Farewell. This translation is quite unwarranted. The sound may as well have been the neighbouring Ikek or Allumlengri as any of the more distant ones west of Cape Farewell. The Saga tells further how, having anchored, they saw a ship putting into the fjord from the sea which kept the same course. It was Thorsten Hvide, the foster-father and stepfather of Thorgils, who had sailed from Norway and Iceland in search of Thorgils. Together they then went to Eric Röde.

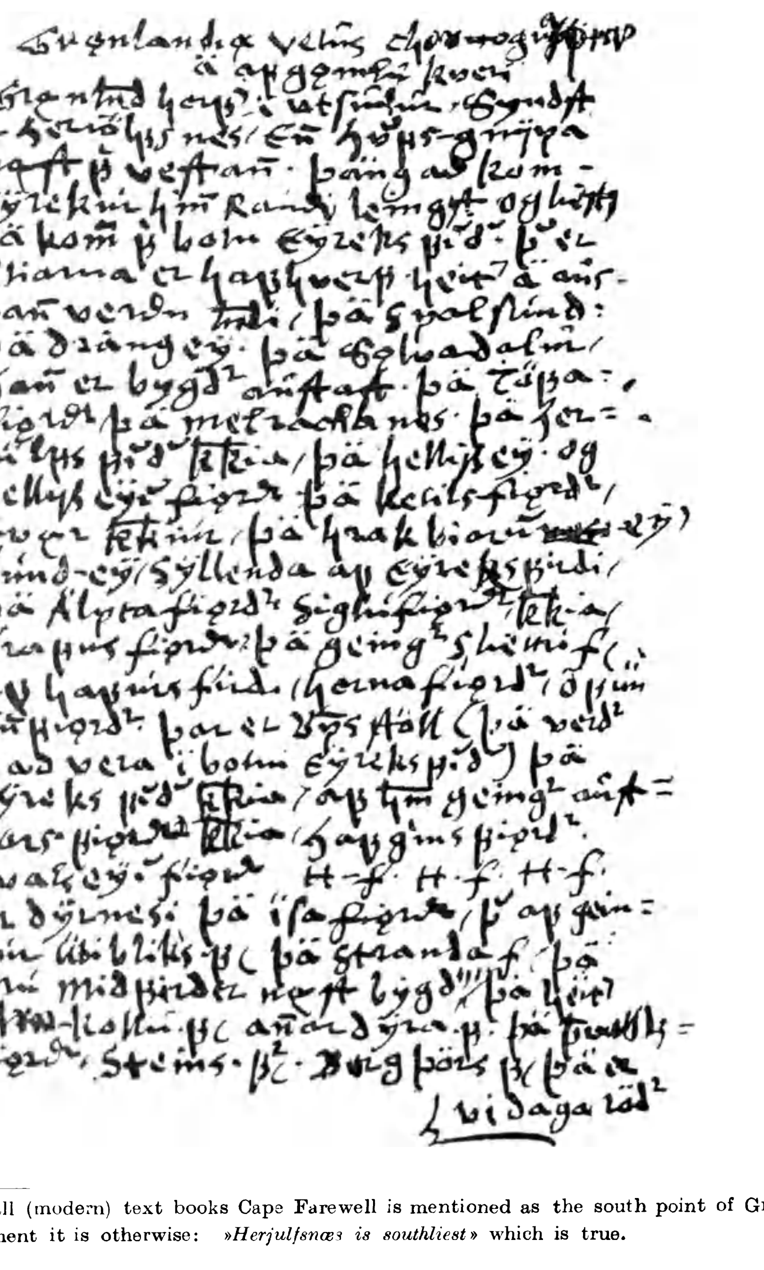
3) That 150 years later in the time of Ivar Bårdsson, or at the end of the 14th century, the old sailing-route was abandoned and the ships took a southwestern course to avoid the ice.

These authentic statements from various times show the gradual deterioration in the ice-conditions of Greenland which went on for centuries till at last in 1300 and 1400 the Polar current had surrounded Iceland and Greenland with its ice and even blocked up the westcoast of the latter in summer.

Since then the east-coast of Greenland has remained inaccessible and all expeditions sent to rediscover the »Österbygd» have failed.

With regard to Eric Röde's journey after »he came to land at the middle-jökul and the place called Blåserk» and took up his winterquarters on Eric's Island, the manuscript before cited only says that he went south along the coast. It is not mentioned whether he went round Cape Farewell or by any of the sounds north of Eggerts Island. If we assume these sounds to have been navigable then, it is probable that he went by them for it is said that »Eric went to see if the land was habitable there».

There are many versions of Eric Röde's Saga. The interpretation here followed is from Gr. Hist. Mindesm. II. pag. 686. which omits the addendum contained in later versions: »han siglde vestr um Hvarf». The oldest manuscripts do not say that Eric sailed round Hvarf. The significance of this omission becomes evident when studying the »Eriksstefna» (Eric's sailing-route) in Björn Jonsson's annals taken from an ancient manuscript, the »Groenlandiae vetus chorographia à afgömlu kveri», Gr. Hist. Mindesm. III pag. 226. This is probably the oldest sailing-direction in existence for the course to Greenland. From an addendum by Björn Jonsson *»there unto came Erik the Red when farthest»* it is evident that this old sailing direction concerns the Erikstefna. This manuscript also has several interpretations contained in the glossary to this chapter in Gr. Hist. Mindesm. They are so important to the rest of this paper that I have obtained permission from the Librarian, Dr. Kaalund, to print a facsimile-photogram of the original, i. e. of Björn Jonssons copy of the ancient record.



The critical passage in this manuscript are the words:

»þar er stjarna, er Hafhverf heitir».

There are three ways of reading these words.

1) The canonic version in Gr. Hist. Mindesm. is founded on the assumption that the word »stjarna» is wrongly copied and that the original had »straumr» (stream) instead. This current should have borne the name Hafhverf. That name undoubtedly fits the neighbourhood of Cape Farewell. The south part of Greenland consists of an archipelago of big islands, Eggerts Island, with Cape Farewell, being the outermost[1]. This island is surrounded by strong currents and vortices on its south and still more on its north side facing the Ikek and Tunua sounds. In these straits the tidal currents are so violent that the ice-blocks are whirled along in such a way that the Danish explorer, Captain Holm, characterises these currents as maelstreams.

Holm started from Ilua by boat the 1 st. of July 1881 and passed through the sound Ikerasak 2 (danish) miles in length. The ice whirled through the sound with great velocity. The manner of advancing was to keep to the leeward of a foreland waiting for a rift to open in the ice; »for as quickly as it opened it closed again». »At high water the current set southwest, at low water northwards. There was never for a moment still water». Holm then rowed through the broad Ikek and through Tunua of which he writes »big maelstroms in Tunnua». Going back he passed outside of Eggerts Island in calm weather and west of Cape Farewell outside the fjord Kangia again met with strong »maelstroms» in the sea.

2) The second version contained in the Glossary to Chorographia vetus etc. in Gr. Hist. Mindesm. is also based on the assumption that the word »stjarna» is wrong and ought to be »Stjórn à» (= steering on). The passage then reads.

»Greenland faces southwest. Farthest south is Herjulfsnäs.... etc. *You shall steer on (the place) which is called Hafhverf on the eastside of the country. Then Spalsund, then Drangö, then (comes) Sölvadal which is the settlement farthest east....» a. s. o.*

3) The third version is to take the passage literally without improvements. Then it would read:

»Greenland faces southwest. Farthest south is Herjulfsnäs, but Hvarfsgnipa next west to it. (Thereunto came Eric Röde farthest and then said that he had come outside of the innermost of the Eric's fjord). There is a star (beacon) in the place which is called Hafhverf on the east side of the country, then Spalsund, then Drangö, then (comes) Sölvadal, which is the settlement farther east, then Tofafjord, then Melrakkanäs, then Herjolfsnäs abbey a. s. o.

Should Björn Jonssons copy of the ancient manuscript be incorrect (which I do not believe), conjecture n:o 2, stjórn à, instead of stjarna would be the simplest and most plausible.

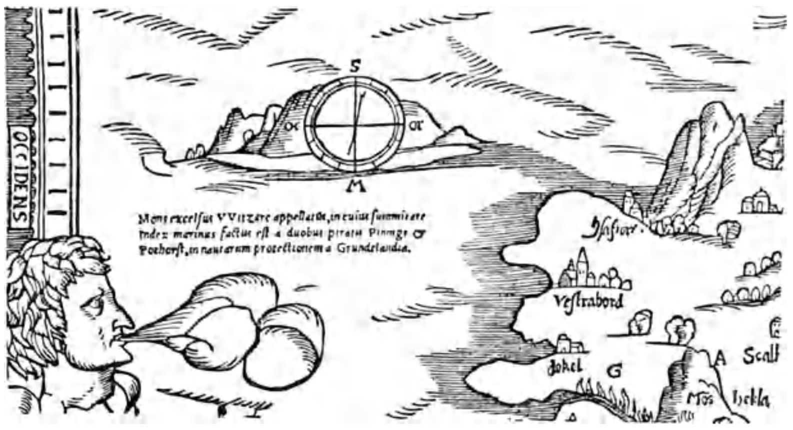
If accepted it evidently contains the key to the mystery of the Eriksstefna. The course most likely to be taken by Eric who came from the north and went south to see if the country was habitable, was just to stear on Hafhverf on the east side of the country (»er Hafhverf heitir a austanverdu landi»), then take the first sound that opened up to the interior, Spalsund, past Drangö to Sölvadal a. s. o. This last excursion into the Iluafjord, where later the large settlements of Skage and Sölvadal arose, is certainly no shortcut to Herjulfsnäs, the shortest road to which would be by the sound at Pamiagdluk (the road taken by Nordenskjöld in 1883). But to Eric who was exploring the country, it was only natural to penetrate through a sound which opened upon the big Iluafjord. This conjecture »stjórn à» would perhaps be most in favour of the hypotesis I wish to indicate. But in the two years I have spent in reading up the old literature of Iceland, Greenland and America I have been so much impressed by the authenticity of the Sagas that I have decided to take their text literally. We should attempt to understand their meaning not to alter their text.

What kind of beacon is meant by »stjarna» must of course be a matter for conjecture. The simplest would be to assume that in the prime of the colonies when busy intercourse was kept up with other countries, Norway, Iceland, Ireland, some kind of sea-mark with the contours of a star was put up on an island at the entrance to the Ikek sound to guide sailors into this sound, *the biggest inlet from the east to the Eystrabyggd.* According to my hypothesis the sounds north of Eggerts Island (Cape Farewell) were free from ice and open to navigation in the 10th century. It is safe to assume that Ikek is the Spalsund of old to which you came having made the sea-mark (stjarna) at Hafhverf. It is probable that there was a kind of sea-mark in the time of the colonies, for as a fact another was put up after their downfall on the high mountain Hvidserk by the governor of Iceland, Didrik Pining (in 1478). This was to warn sailors of the Greenland coast because of the piracy of the escimoes. The historic re-

[1] In all (modern) text books Cape Farewell is mentioned as the south point of Greenland because the sounds north of the islands are now closed. In the text of the old parchment it is otherwise: *»Herjulfsnæs is southliest»* which is true.

cord of this was discovered by Björnbo and L. Bobé in Copenhagen 1909. The accompanying maps are reproduced from Nansen's Taakeheimen, pag. 380 and 381.

In Gourmont's map we see Iceland with Hekla and Snefellsnäs, the usual starting point for Greenland and right opposite the mountain Hvitserk carrying a compas-star and the inscription »Mons excelsus Withzerc appellatus in cujus summitate index Marinus factus est a duobus piratis Pininge & Porthorst in nautarum protectionem a Grundtlandia.»



De Gourmonts chart.

Pining and Porthorst are called pirates because later they too were suspected of piracy and condemned.

Geographers and historians have never been able to agree as to the exact situation of the mountain Hvitserk. This mountain is always given as the first landmark on the way to Greenland. Finnur Jonsson who has been most active in localising the ancient colonies holds Mount Hvitserk to be identic with Cape Farewell. I do not share his view because Hvitserk, which may be the »Blåserk» mentioned by the oldest Sagas, is expressly described as a *high mountain* and in later records as a »jökel» i. e. an ice-clad mountain. In my opinion the name should apply to one of the lofty nunatakes that rise out of the ice north of Cape Farewell. I will go more fully into this matter when discussing the ancient records containing the directions for navigation between Iceland, Norway and Greenland. It seems important, however, that Finnur Jonsson too thinks to locate Hvitserk in the vicinity of the old straits that led to the »Österbygd».

There is a tendency now to underrate the intercourse and means of communication in bygone ages. Professor O. Montelius has caused this view to be modified by bringing facts to light which show *that even a thousand years before the Viking-age an eager intercourse was kept up between England, Sweden and Denmark across the North Sea* Eric Röde's Saga shows the national character to have been the same then as now at least as regards the tendency to emigrate. In the tenth and eleventh centuries a strong emigration took place to Iceland and Greenland. It was to the interest of Eric Röde to encourage this tendency. The year after his return a Viking-fleet numbering some 25 ships with colonists on board sailed for Greenland. They carried cattle, building material and householdgoods. Probably each ship carried 30—40 human beings. By and by the settlement of Österbygden numbered 190 farms, 12 churches, 2 monastries and one bishop-see. The less important settlement of Vesterbygden numbered 90 farms. At the end of the 13th and the beginning of the 14th century the European civilisation in Greenland was wiped out by an invasion of the aboriginal population. The colonists in the Vesterbygd were driven from their homes and probably migrated to America lieving behind their cattle in the fields. So they were found by Ivar Bårdsson steward to the bishop of Gardar on his official journey thither in 1342. The colonists of the Österbygd succumbed after a hard struggle some time after the year 1418. Their houses and churches were destroyed by fire as the ruins still testify. (Finnur Jonsson). According to Escimoe traditions the last of the colonists fled to the east-coast and there succumbed. After the destruction of the colonies the Escimoes appear to have taken up piracy attacking and sinking the English, Portuguese and Dutch whalers that visited the south-coast.

The Escimoe-invasion must not be regarded as a common raid. It was the transmigration of a people and like other big movements of this kind impelled by altered conditions of nature, in this case the alterations of climate caused by the advance of the ice. For their hunting and fishing the Escimoes require an at least partially open arctic sea. The seal, their principal prey, cannot live where the surface of the sea is entirely frosen over. The cause of the favourable climatic and ice-conditions in the Viking-age was, according to my hypothesis, that the ice then melted at a higher lat, in the arctic seas.

The Escimoes then lived further north in Greenland and North-America. When the climate deteriorated and the sea which gave them their living was closed by ice the Escimoes had to find a more suitable neighbourhood. This they found in the land colonised by the Norsemen whom they attacked and finally annihilated. The description in the old records of the cruelties of the Escimoes Nansen simply rejects because the disposition of this people for the two centuries past since the time of Hans Egede has been noted for its mildness and gentleness. A glance at the Olai Magni map, however, shows that they were regarded in quite another light in the 15th and 16th centuries. La Peyrère in his Relation de Groenland (1647) charac-

De Pygmæis Gruntlandiæ, & rupe Huitfark.

Olai Magni chart.

terises them as being treacherous and wild. Their conquest in the 14th century appears to have brought out quite different qualities in them. The survivors of Hudson's third expedition 1610—1612 were treacherously assaulted and murdered on an island by the Escimoes. In the reign of Christian I they were regarded as pirates who in their canoes stod up to foreign fishingvessels and sunk them.

Certain passages by Björn Jonsson indicate that the colonists looked with apprehension and suspicion on the advance of the Escimoes in North Greenland.

The governor of Iceland attempted to warn sailors of their piracy by erecting a star-shaped beacon on mount Hvitserk. The Escimoes appear to have made use of the old water-ways on the east-coast for their piracy. Thus these sounds became doubly dangerous both on account of the ice and of the pirates. The Escimoes in their kayaks even went as far as Europe. Now and again it happened that an Escimoe with his kayak and fishing-gear was captured off the Norwegian or Scottish coast. Reliques of these strange visitors are still to be seen in museums.

Such is the testimony of the chronicles when taken literally with no alterations of their text. The only explanation of such a situation would be to admit that the ice-conditions have changed signally in historic time.

Reading the old passage literally or substituting »stjórn a for »stjarna», the result will be the same in both cases, viz: that the passage describes the *route taken by Eric Röde on his voyage of discovery, the same course being taken afterwards by all vessels in the first centuries after the colonisation of Greenland.*

The »Eriksstefna» guided the sailor to make the land at the big glacier Blåsärk (later Hvitserk), to put into the archipelago at the extreme south-end, where the great Maelstroms, »the Hafhverf», were met with and guided by the star-shaped beacon find his way to the eastern settlements Skage and Sölvadal on the Iluafjord, by Spalsund (Ikek) past Drangö, then by Tofafjord to the chief port and trading-place of Greenland, Sand by Herjulfsnäs; then onwards past the towering headland of Hvarfsgnipa on the island Semersok where the route branched off to the big fjords of the interior, the Ericsfjord a. o. into the very heart of the colony.

I will now show how the local names mentioned in the ancient records can be identified with those of the present from »Hafhverf a austanverdu landi» up to »Hvarfsgnipa» which Finnur Jonsson has proved to be the Cape Egede or Kangek of the present day. In order to do this I must refer you to the map by Finnur Jonsson of the Eystribygd in Greenland contained in part 20 of Medd. from Greenland.

In the Viking-age there were two navigable sounds used by vessels coming from the east or northeast. One is the present Allumlengri, 9 danish miles in length, which owing to its name is easily identified as the present Ikerasarsuak. The second to which the vessel comes having made Hafhverf must correspond to the broad Ikek sound which thus is identical with the Spalsund of the Eriksstefna. Then came Drangö. This Finnur Jonsson thinks should be easy to identify because of its name, Drangey = high peaked island, which is hardly possible to mistake when studying the topographic curves of the islands in these sounds from the Danish admiralty charts. I will also quote Nordenskiölds description of these sounds in his »Den andra Dicksonska Expeditionen till Grönland 1883» pag 404.

»The scenery was here very grand. The narrow straits were surrounded by lofty mountainpeaks now almost snowless sculptured into the most phantastic shapes, some resembling old ruins, some fortifications. Now and again we caught a glimpse beyond them of the bluish white crest of some glacier in the interior».

Judging from the topographic curves of the map it seems probable that the Drangö of the Eriksstefna is identic with the island that forms the western shore of the sound between the Ikek and the Iluafjord where the mountainpeak Umiagsiut, 2790 feet in height, rises steeply from the shore.

In Jonssons map Sölvadal is found on the Iluafjord. There too is the Tofafjord while Herjolfsnäs with the abbey is found where the present Igikait and Fredriksdal are situated.

The fjords of the Österbygd north of Cape Farewell are also enumerated, though in reversed order (from west to east), in the record by Ivar Bårdsson. I here quote his own words as they are rendered by F. Jonsson.

Having mentioned Herjolfsnäs and the trading-center Sand the description proceeds:

»Item the Easter Dorpe of Groneland lyeth East from Hernoldsnæs hooke, but near it and is called Skagen ford and is a great Village.

Item, from Skagen ford East, lyeth A Haven called Beare ford: it is not dwelt in. In the mouth thereof lyeth a Riffe, so that great ships cannot harbour in it. Item there is a great abundance of whales: and there is a great fishing for the killing of them there: but not without the Bishops consent, which keep the same for the benefit of the Cathedral Church. In the haven is a great Swalth: and when the Tide doth runne out, all the Whales do runne into the sayd Swalth.

Item, East of Beare ford, lyeth another haven called Allabong Sound and it is at the mouth narrow, but further in, very wide: The length whereof is such, that the end thereof is not yet known. There runneth no Streame. It lyeth full of little Iles. Fowle and Oxen are there common: and it is playne Land on both sides, growne over with green Grass.

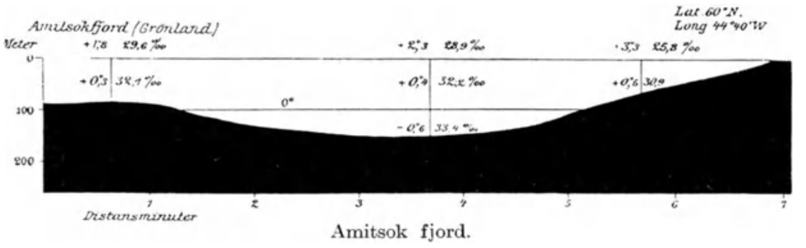
Item East from the Icie Mountagne, lyeth an Haven called Fenderbothen; so named, because in Saint Olafes time there was Ship cast away, as the speach hath beene in Groneland; in which ship was drowned one of Saint Olafes men, with others: and those that were saved did burie those that were drowned, and on their Graves did set great stone Crosses, which we see at this day.

Item, somewhat more East toward the Icie Mountagne, lyeth a high Land called Corse Hought, upon which they hunt white bears, but not without the Bishops leave, for it belonged to the Cathedral church, and from thence more Easterly, men see nothing but Ice and Snow, both by Land and Water».

The Fenderbothen haven on the Eastcoast has not yet been identified. The place appears to have been much frequented in the 10th century but only as a haven of refuge where shipwrecked crews were brought ashore and the bodies of those who lost their lifes on the dangerous east coast were recovered and buried in consecrated ground. In the Saga of Lik-Lodin it is told »how Lik-Lodin (Corpse-Lodin) got his by-name because he often in summer ransacked the northern wilderness and brought to church the dead men he there found in caves and mountain-clefts» to which they had come from the ice or from shipwreckes, but with them were usually carved runes telling of their adventures and sufferings». In another Saga about Lik-Lodin it is told that he brought the bodies of Finn Fegin and his crew from »Finnbbuðir east of the glaciers in Greenland». In Nansen's version pag. 217 from which this note is taken, this is said to have occured some time before the downfall of Harald Hårdråde in 1066. Similar accounts are told from the 12th century of ship-wrecks on the east-coast near Hvitserk (Einar Sokkason 1129, Ingimund 1189). Probably Fenderbothen (Finnbudir) was what we should call an out-post lying north of the eastern inlets of Allumlengri and Spalsund near mount Hvitserk. From the Saga about Asmund Kastanrazi who visited Finnbudir in 1189 on his voyage to Iceland, we see that the haven was used by merchant-men as late as the end of the 12th century. It is difficult to understand how, with this testimony from bygone days, anyone who by experience knows the present inaccessibility of the entire east-coast, can declare that »The climate and iceconditions in Greenland are the same now as of old.»

The local description by Ivar Bårdsson completes the ancient sailing direction and gives a clear though somewhat incomplete notion as to the extension eastwards of the Österbygd and of some of its inlets, f. inst. the Allumlengri and the Bearefjord. The results of Holm's expedition in 1881 have settled beyond doubt that the latter is identic with the sound Itivdliak. Holm says: »On the eastcoast of the big island east of Ilua there is a dwellingplace called Igdlorsuatsikit. There is a sound to the north from this place very narrow and bordered by precipitous mountain-sides of phantastic shapes. The northern inlet to this sound is cut off by a barrier of bluntedged stones, the Itivdliak, and falls dry at low-tide». This then is the Bearefjord of Ivar Bårdsson with the reef that prevented big vessels to enter excepted at spring-tide. Since this reef according to Holm still falls dry at low-tide, we may conclude that the elevation of the south-coast of Greenland has not altered perceptibly in the last 5 centuries. Geographically the sounds have not altered since the time of the Vikings, but in their hydrographic state there is a change as the fishery conditions indicate.

According to A. Jensen the Hellefisk[1], the Havkal[2].
and a special kind of cod, the fjord-cod, are found in nearly every fjord in South-Greenland. The migratory salmon, the halibut and sea-cod (Gadus Calliaris) again are only occasional visitors to certain shoales off the Greenland coast and to those fjords into which the warm water of the deeper layers in Davis Sound can penetrate[3]. In the other fjords the cold water of the polar current prevails in the deep layer.



Amitsok fjord.

In 1883 A. Hamberg investigated the hydrographic state of the Amitsok fjord, in August, the result of which is seen in this section. Our boreal fishes cannot exist in fjords of this hydrographic type. Knowing that in old times a great cod-fishing was carried on in the Österbygd and even at Gunbjörnskär, we must conclude that the ice-conditions were more favourable then.

I shall now consider the effect of the ice conditions on the climate of Greenland. Since the advance of the drift-ice round Cape Farewell to the west coast of Greenland the former colonies Vesterbygden and Österbygden are wedged in between two ice-areas, the see-ice and the inland-ice. This fact alone is sufficient to account for the deterioration of the climate of Greenland. Those who with Nanen hold, that no change has occurred since the age of the Vikings will iscredit the description in the ancient records of the fertility and ultivation of the land. Thus Ivar Bårdssons statement that.

»Item in Groneland runneth great Streams; and there is much Snow and Ice: But it is not so cold as it is in Iceland or Norway.

Item, there grow on the high Hills Nuts and Acornes, fruit of trees, which are as apples and good to eate. There groweth also the best wheate, that can growe in the whole Land.» (is regarded by Nansen as sheer nonsense concocted from old legends about Winland.)

We must remember that the Österbygd of Greenland is in the same lat., as the Hardanger and the Sognefjord of Norway and that in the interior of these fjords there are farms situated immediately below the greatest glacier in Europe, the Jostedalsbræ. Yet they ripen excellent fruit, apples, cherries etc. Even now the fertility of the Österbygd surprises those who visit Greenland as Nordenskiöld among others affirms. Before the ice blocked the coast the climate of these fjords must have resembled that of the Norwegian fjords. We must, however, not conclude that the similarity of climate would extend to the vegetal and animal life, for this is a question of migration and importation from other parts of the earth and in this respect Greenland has been at a disadvantage, because of its isolated position. A thousand years ago all our common forest-trees except the pine had reached the west-coast of Norway but only the birch had become naturalised in Greenland (and Iceland). There is no ground for supposing the norsemen to have cultivated forest but there is every reason to expect the monks to have imported fruit-trees and cultivated gardens as they did everywhere they went. There is no incredibility in the statement by Ivar Bårdsson, that under the high mountains trees grew, which bore big apples good to eat. When we are told of the early inhabitants of Iceland, that they lived in winter of the fruit of trees they had cultivated in summer, we must remember that these early inhabitants were monks and anachorets who from their homes in Ireland were well aquainted with gardening. Also the climate of Iceland in the 7th century may have been much more temperate when the frequent blocking of the coast by drift-ice had not yet commenced. Still fruit-growing in Iceland must always have been more difficult than in Greenland because of the more exposed position of the former island.

As to the cultivation of grain, regard must be taken to local conditions such as night-frost, etc. Probably Greenland was never well adapted for corn-growing though in certain places, as stated by

[1] Platysimatichtys hippoglossoides.

[2] Somniosus microcephalus.

[3] A. S. Jensen Fiskeriundersögelser i Grönland 1908 & 1909 (Atlanten N:o 82).

Ivar Bårdsson, excellent wheat might very well have been grown. Already in Eric Röde's Saga the want of corn to make malt is mentioned and the Kongaspegel, though admitting that grain was grown in Greenland, adds that its cultivation was not general and that the majority of colonists depend on import to supply them with grain and building material.

With regard to pasture, however, Greenland seems to have been quite as well off as any of the northern countries. Cattle-raising and fishing appear to have procured a good living for the colonists until the ice made the fishinggrounds barren and shortened the period of vegetation so that the cattle had to be fed indoors most of the year. At present the whole stock of cattle in Greenland probably does not amount to a hundred animals although wealth is increasing and the population is at least as numerous as in the time of the Colonies. In 1780 there was (according to Crantz) probably no single representative of the genus Bos taurus.

Commander Holm who spent several years in Julianehaab's District and visited more than a hundred ruins of old Norse dwellings says:

»*In the neigbourhood of all larger groups of ruins there has been ample fodder during summer to feed large flocks of sheep and cattle. How these herds were fed in winter is difficult to say unless we assume the climate in those ages to have been milder, so that the cattle could graze in the open field a greater part of the year than now. The ancient records state that the icedrift along the coast has increased in historic time and this assumption seems indeed necessary in order to explain how the ancients could navigate the inlets and fjords of the District, nor can it be denied that the ice which now encloses this part of the country greatly enhances the severity of the climate.* »

Another effect of the climatic deterioration is that the inland-ice appears to have advanced for a considerable time, so that certain groups of ruins have been buried underneath it. Ruins of ancient dwellings were discovered by Captain Bruun, curiously wedged in between glaciers and rivers so as to be very difficult of access. That ruins of farmhouses are found in such places nowadays may be explained so that the glacier has advanced after they were built. In the interior of Ilua Captain Holm found 4 groups of ruins just below the glacier. The Eskimos told him that beneath that glacier was buried a village and a churchyard. As many of the villages and churches enumerated in the ancient Chorography have not been retrieved it may be that part of the old Österbygd has been covered by the advancing inland-ice in the course of the last 5 centuries. Perhaps this may also explain the curious confusion of names respecting the ancient landmarks on the east-coast. Blåserk and Hvitserk. Nansen says: (pag. 223)

»It is more difficult to explain the two names Blåserk and Hvitserk which were the most frequently mentioned especially later on. They have often been confused with one another, and while Blåserk is mentioned by the oldest records, Hvitserk gradually supplants it in later writings. Later authors often mention the names in an opposite sense, Blåserk representing a dark glacier or mountain peak, Hvitserk representing a white one. It is a curious fact, that, while Blåserk is mentioned only in the elder writings, such as the Landnama and Erik Raude's Saga in Hauksbook, this name almost disappears from later writings and is supplanted by that of Hvitserk which name is first mentioned in manuscripts from the 14 th century and later on. In the manuscript (A. M. 557 qv.) from the 15:th century of Erik Raude's Saga (as also in other later extracts of this Saga) Hvitserk is written in lieu of Blåserk. In no Icelandic manuscript I have found both names used simultaneously, it is always the one or the other, nor are they ever mentioned as representing different localities on the Greenland coast. It then appears too rash to conclude, as hitherto, that the names indicate two mountains, one somewhere to the north on the east-coast, the other near Cape Farewell. That the names indicate mountains is a very old conception».

Ivar Bårdsson speaks of Hvitserk as »a lofty mountain near Hvarf».

The solution of the problem appears to me to be this:

All opinions agree that Hvitserk, the lofty landmark of Greenland on which later was put up a beacon to warn sailors off the dangerous neighbourhood, was situated in the proximity of Cape Farewell. According to Finnur Jonsson it was identic with Cape Farewell which is not covered by ice. North of the sound Allumlengri however lies a towering alpine country with some of the loftiest mountainpeeks found on the eastcoast. These are now mostly covered by snow and are probably surrounded by glaciers. Here in my opinion, is the site of the acient »Blåserk» which was so called in the time of Eric Röde, because it then was free from snow and ice, which a few centuries later covered it and changed the name Blåserk »blå=blue- black) into Hvitserk (Hvit=white).

Blåserk or Hvitserk played an important part in the old directions for the navigation, because it was the landmark of Greenland.

Eric Röde went in search of Gunbjörnskär. He came from the sea to land at the Middle jökel (or glacier) and the place called Blåserk. In Björn Jonsson's version of the ancient record it is said;

Item from Sneffelznes on Iceland which is nearest to Greenland 2 days and 2 nights sailing straight towards west, and there lies Gunbjörnskiær right midways between Greenland and Iceland.

Keeping to our rule not to alter the text of the manuscripts we may consider Gunbjörnskär to denote the islands surrounding Cape Dan in lat 65°36 'almost straight west of Snefelsnæs on Iceland in lat. 64°50. According to Ivar Bårdsson it took 2 days and 2 nights sailing and rowing for the Viking-ships to cover this distance. It took about the same time to reach the eastern settlements in Greenland from Gunbjörnskär. One would then reach the east-coast at lat. 61° where commenced the ancient Österbygd. On the road one would pass by the big glacier Puisortok in lat. 62° and the lofty mount Blåserk (which then was free from ice) somewhat more to the south. Then the goal of the voyage would be reached, Spalsund (Ikek), the eastern inlet to the Österbygd.

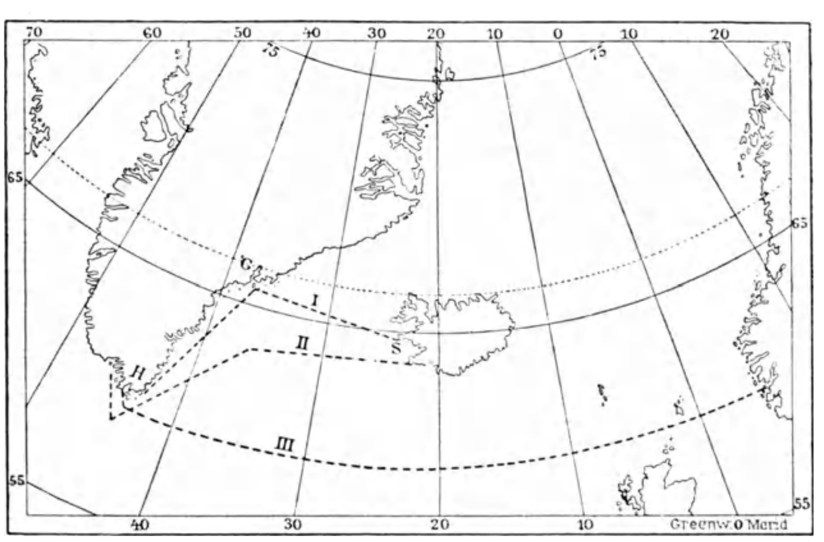
»**This was old sailing**» (I. Bårdsson).

In this way I think that the much-discussed problem of the Eriksstefna can be solved. We must now look to how the new route which Bårdsson recommends agrees with the old bearings.

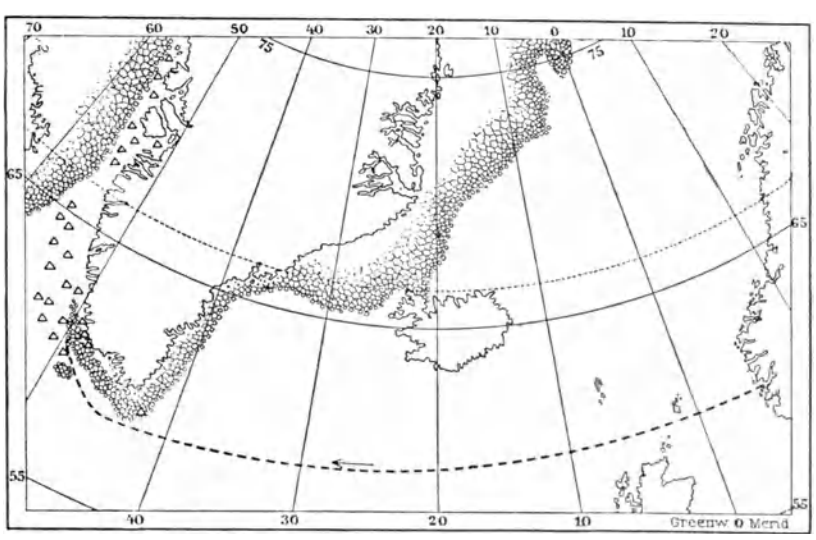
— — — »**But as they report there is Ice upon the same Riffe, come out of the long north Botherne, so that we cannot use the same old passage as they think. Item, if you go from Bergen in Norway, the course is right West, till you be South of Rokenesse in Iceland and distant from it thirteen miles or leagues. And with this course you shall come under that high Land that lyeth in the East part of Groneland, and is called Swafster. A day before you come there you shall have a sight of a high Mount called Hvitserke and between Hvitserke and Groneland, lyeth a Headland called Hernoldus Hocke, and thereby lyeth an Haven, where the Norway Merchants ships were want to come, and it is called Sound Haven.**»

There is a later addition to Ivar Bårdsson's description of the new route to Greenland (see Gr. Hist. Mind. III, p. 491):

»**If men bee South from the Haven of Bred ford in Iceland they shall sayle West, till they see Whitesarke upon Groneland, and then sayle somewhat Southwest till Whitesarke bee North off you, and so you need not feare Ice, but may boldly sayle to Whitesarke, and from thence to Ericks Haven.**»



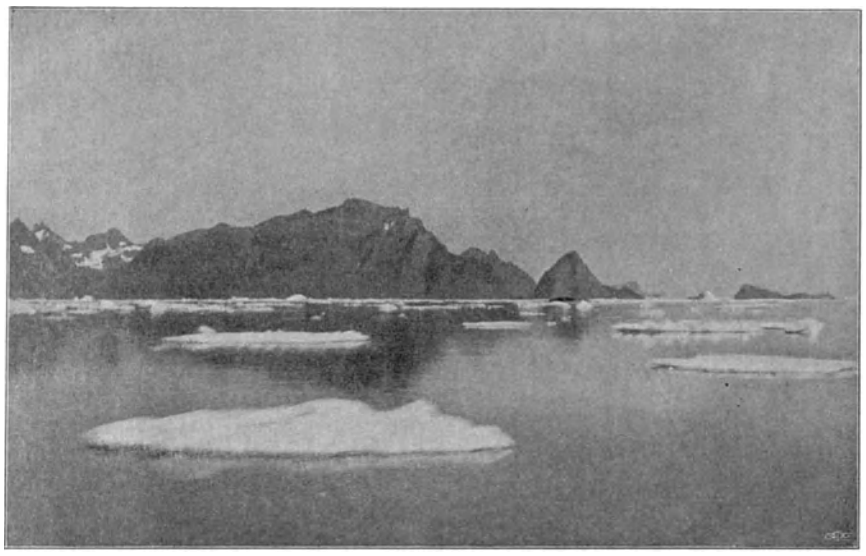
Old Sailing routes to Greenland (S = Snefjelsnæs, G = Gunbjörnskær; H = Hafhverf.) I Erikssteſna 1000—1200. II & III. Sailingsroutes from 1200—1400 [Ivar Bårdsson].



Sailing-route to Greenland (present time).

Here again we have Hvitserk as a landmark. The meaning of the passage is that if you start from Norway you must go south of Iceland right west till Mount Hvitserk is sighted. Then put that mountain to the north of you, then head for northwest to the high mountain Hvarf on Semersok which is one day's journey from Hvitserk. Between these two towering landmarks (Hvitserk and Hvarf) lies Herjolfsnæs and Sand. Sailing from Iceland you must head for the west one day and night, then turn to southwest to avoid the ice lying about Gunbjörnskär till you sight Hvitserk, then it is one day's journey to Hvarf in the Northwest a. s. v.

The problem is: how the same mountain, Hvitserk, could serve as landmark to both routes, the old and the new. Bårdsson's statement, that Herjolfnæs lies between the two mountains Hvitserk and Hvarf, has made Finnur Jonsson assume Hvitserk to be identic with Cape Farewell. This conjecture can scarcely be considered correct if you take the elevation into account. Cape Farewell is certainly a good-sized rock (some 900 feet high) and would be a good landmark in itself if seen against a less elevated background, or if you sail close to it. But the topographic curves on the map show that Cape Farewell is quite insignificant if compared to the towering mountainpeaks on Christian the IVth's island and the continent of Greenland. The distance of these peaks from Cape Farewell is 30 miles but on account of their height, 5—6,000 feet, they must be visible at a distance of 150 kilometer when Cape Farewell still is below the horizon. We must also conclude that the directions for the new sailing route which was taken up to avoid the ice, did forbid any closer approach to Cape Farewell which, surrounded as it is by maelstroms, had become still more dangerous because of the driftice. It is evident that the addendum to Ivar Bårdsson's sailing direction, viz. to get Mount Hvitserk north before sailing along the west-coast to Hvarf and the Ericsfjord is founded on experience.



Cape Farewell.

The numerous sailing directions recorded in Gr. Hist. Mindesm. agree pretty well with this, but are fragmentary and obscure on account of the curious terms by which distance in time and place is measured. Ivar Bårdsson's and Björn Jonsson's directions however are so definite and clear that they might be used even now if the ice conditions had remained unchanged. In our time however the sounds in the archipelago of South Greenland are shut up by ice and the ancient Eriksstefna is closed. Cape Farewell is surrounded by storm-clouds and mists so as to be seldom visible. Still rarer will the alpine peaks beyond it be visible, least ways not on so close approach to it as the rise of land suggests. Nor is it possible to stear on Hvarfsgnipa (Cape Egede) and to put into Herjolfsnäs sound (Fredriksdal) which nowadays is so inaccessible that Nordenskiöld's ship, the Sophia, was said to be the first European ship to anchor in that harbour since the time of the colonies. The way to take now is by Cape Desolation, passing through Torsukatak sound at Nunarsuit and others of the inner straits between the coast and the surrounding ice-girdle until you reach the fjords of the ancient Österbygd.

One more statement has to be examined, viz. Björn Jonsson's description (in the Gripla) of the three glaciers on the east-coast».

»to the one glacier no one has penetrated (naturally the one farthest north) **to the second is one months journey, to the third is one weeks journey. It is nearest to the settlement, it is called Hvitserk, there the land bends northwards.»**

According to Gisle Brynjulfsson, Björn Jonssons statements does not allude to a journey from Iceland with the swift sailing-ships of the Vikings. What is really meant is a journey in rowing-boats starting from the southermost places of the Österbygd and going east and northeast. Brynjulfsson estimates that 30 eng. miles a day would be covered in this manner. Thus the Puisortok-glacier would be reached in a week. This glacier Brynjulfsson concludes to be Hvitserk. Even if we admit that it is possible to cover 30 miles a day in a calm sea with a rowing boat, the experience of Gieseke, Holm, Graah a. O. show that it requires 6 weeks rather than 6 days under the present conditions to go from Ilua or Fredriksdal by way of the sounds to the east-coast in 60° lat. and thence to Puisortok in lat. 62°10. Even if we assume with Brynjulfsson, that the ice-conditions 600 years ago were so favourable as to allow the distance to Puisortok to be covered in only 6 days, still Gripla's description of Hvitserk does not fit in with Puisortok because of the words:

»it is nearest the settlement, there the land bends northwards.»

This description instead fits in on the highland between Allumlengri and the fjord Kangerdluksuatsiak, where the highest mountain-peaks in south Greenland are situated. With open water it would be quite possible to reach this place on the eastcoast in lat. 60°—60° 15′ in a weeks journey by rowing-boat passing through the Allumlengri-sound or the Ikek. *There, at the eastern inlet to these sounds, the coast really bends north-wards.* It is significant too that all expeditions sent out in the 15th and 16th century to rediscover the lost colonies had orders to approach Greenland (and attempted to do so) *from the eastside.* In the maps from the 15th and 16 centuries, e. g. in that of Thorlacius, the two sounds play a prominent part. These maps are of no use however for the problem we here try to solve and since the two sounds were confounded with the two inlets on Americas coast discovered by Frobisher they have become a subject of endless idle discourses among geographers. The fact however *that in these maps two sounds are shown through the South of Greenland* shows, that the tradition of the Eriksstefna of the eastern inlets to the Österbygd had survived the closing of these passages by the driftice.

I reproduce here the contourlines of such a map discovered by H. Pettersson in the archive of British Museum.

Evidently the ice-conditions of Davids Sound and Baffins Bay were also different in the Viking-age. A large contingent of the driftice in Davis Sound is supplied by the Greenland ice current. Failing this supply, the quantity of ice in Davis Sound and the Labrador current will be reduced. Besides a decrease in the ice would mean an increase in the heat supplied by the Gulfstream-branches. We may therefore a p r i o r i conclude that the Labrador current in Mediæval time did not carry ice, or at least not in the same degree as at present. This conclusion is born out by the fact *that no mention is made in the Sagas and the existant documents from year 1000 to the end of the Middle-ages of ice as impeding the traffic between Greenland and Wineland.* It is impossible that the Greenland colonists should have landed on the Labrador coast or Newfoundland without having been in contact with the driftice and icebergs of the Labrador current. The complete silence on this point is remarkable and becomes still more so when we remember that the records of Cabot, who discovered Newfoundland in 1497, do not mention ice or ice-hinderances. In the records of the journey of the younger Sebastian Cabot in 1508—1509 to the coast of America (which however is considered unreliable) it is said that he went as far as lat. 60° and saw quantities of ice in the sea at a depth of more than 100 fathoms (which means that he was in the Labrador current). But in a later journey, 1516 or 1517, he is said to have gone as far as lat. 67 ½ ° and there found open sea and no hinderance from ice. This is one reason why Nansen, who finds it surprising that ice is not mentioned in connection with the elder Cabot's journey to Newfoundland, doubts the veracity of Sebastian Cabot's journey to these parts in 1516—1517.

A map of the regions and countries round the North Pole by John Seller Hydrographer to the King (van Loos Atlas 1666).

This however is immaterial. Fact is, that reports of ice outside the American coast are not forthcoming till the 15 th century although communication with that continent was established as early as the 10th century as recorded in the ancient literature. The utter silence on this subject in the records would be inexplicable if the Labrador current had had the same character then as now.

The first mention of ice im American waters we find in Corte Reales journeys to Newfoundland in 1501, further in the journey to St. Lorent's Bay in 1534, and in Frobishers (1576—1578) and Davis (1585—1587). Records of ice at that time however are very rare and the 15th century explorers of the coast of America do not appear to have been much troubled by ice, whereas the eastcoast of Greenland was then already blocked by ice and quite inaccessible. In the 16th century the conditions were changed and the account of Hudson's 3rd and last journey mentions ice and ice-hindrances which shows that at least along the Labrador coast conditions were approaching the present state. It is however noteworthy that Hudson, when pushing along the Newfoundland bank in lat. 44 °—45 ° where he sounded and fished, found no ice on that bank. In continuing his journey to New Brunnswick, Nova Scotia and the American coast he everywhere reports the weather to be very warm and the country exceedingly fertile with »goodly grapes», rosetrees etc. He sometimes fought and sometimes bartered with the Indians obtaining »greene tobacco, Indian Wheate and Maize whereof they make good bread», a. s. f. in exchange for his goods. If the Wineland expeditions of the ancient Greenlanders extended past Newfoundland (Markland?) to the southwest, as G. Storm has shown, then no objection can be raised on account of the climate to their really having found wine and wheat, as described in the Saga.

The problem of Wineland is getting more complicated from the theory propounded by Professor Fernald, an American, who transfers the Wineland of the Sagas to Labrador, changing the grapes into cran berries, the wheat into lyme-grass, a. s. v. In the 14th Chapter of the Taakeheimen Nansen also adds to the confusion by indiscriminately mixing the Icelandic Sagas with the fantastic folk-lore of Moltke Moes collection,

IV.

Climatic Variations on the East-coast of the Atlantic at the end of the Middle ages.

In Northern Europe the variations in the oceanic circulation chiefly manifested themselves in:

A: Stormfloods in the North Sea and the Baltic.

B: The freezing of the Baltic and the Cattegat in certain winters.

C: The removal of the herringfishery from the Baltic and Öresund to the northern parts of the Cattegat, Skagerak and the North Sea.

These variations naturally exerted an influence upon the climate. According to the hypothesis enounced in the foregoing chapters these phenomena were caused by variations in the tidegenerating force which will repeat themselves in future as certainly as they have occurred in the past.

A.

Stormfloods.

In the last centuries of the Middle-age Holland passed through a stage of transformation caused partly by the fact that its coast is slowly subsiding. In addition to this, inundations from the rivers carried away the soil of its peat-moors. Then came the attack on the seacoast by stormfloods. Several such floods are on record from the early middle-age but the greatest devastations set in from the latter part of the 12th century, followed in rapid succession by the great floods of the 13th and 14th century which is denoted as »the catastrophic age» of Holland. It culminated with the destruction of South Holland, »the Waard», beginning of the 15th century, i. e. the time of the perihelion-node-apside and the absolute maximum of the tidal force.

Both before and after that time calamities of this kind have occurred more rarely[1]. From the 15th century to our time only three great stormfloods are on record, viz. in 1570, 1717, 1825[2]. The principal diasters of the catastrophic age were.

1219 (the »Marcellus»-flood)[3]
1246 (the »Lucas»-flood)
1287 (the »Lucia»-flood)
1421 (the Elisabeth-flood).[4]

which seems to have surpassed all others in its disastrous effect. The catastrophe occurred on the 18 Nov. 1421 and devastated the towns of Dordrecht and Geertruidenberg. The stormfloods between 1374 and 1421 mark the culmen of the catastrophic period for South-Holland[5]. Also from England we have records of heavy stormfloods in 1404 and 1412. The latter occurred the 12th Otcober and is described in the following curious manner: »Sea flooded thrice without ebbing», which brings back to our memory the remarkable description in the Kings Mirror of the great »havgerdingar» which were said to have occured in the Greenland seas in the 13th century but never have been observed or heard of since[6].

In these centuries also was achieved the last stage of the transformation of the old Friesian lake-district into the present Zuidersee. It is impossible to fix with surety the exact time of the catastrophes which mark the different stages of the incessant encroaching action of the sea upon the Ijssel, the ancient mouth of the Rhine, and the whole subject is very much debated. According to a number of old chronicles it happened so. In the time of the Romans the interior part of the present Zuidersee formed a shallow lake, Lacus Flevo, the shores of which were widened by the erosion of the rivers. Then came the attack on the seashore by stormfloods. The Marsdiep by Helder was formed finally in the 15th century. In 1170 the isthmus between North Holland and Friesland was broken through. In 1250 the sea reached Enkhuizen, engulfing the intervening land where now lies the island of Wieringen. On the 14th of December 1287 the great catastrophe occurred which Hennig thus describes: »extraordinary heavy stormflood in the North Sea causing the loss of more than 80,000 human lifes. The sea broke into the s. c. Lacus Flevo forming the present Zuidersee. Simultaneous stormfloods occurred in Norfolk and Suffolk»[7].

In support of this version is adduced the fact that there existed in the 10th century (960—985) the flourishing towns Stavoren, on the shore of the »Flie», and Medemblik. It is also noticeable that the name Zuidersee first appears in documents from the year 1340. Before that time the name »Aelmere» had substituted the ancient denomination »Lacus Flevo». According to a private communication from professor van Everdingen in Bilt it seems certain that the part of the Zuidersee south of Enkhuizen was open to navigation from 1395. The final stage of the formation of the Zuidersee probably fell in the latter time of the catastrophic age[8], viz. the 14th century. On account of the innumerable sequences of stormflooods which then devastated the Hollandish coast it seems difficult to judge with certainty the much debated question of the veracity[9] of the old chronicles.

In the 14ht century the coasts of Friesland and Schleswig were exposed to destruction. On this subject much has been written lately and I here give a quotation from the last publication on the subject.

[1] As I cannot enter upon the litterature concerning these catastrophes, which is extremely vast, I prefer to follow the latest treatise published in Sweden on this subject by Dr. A. Norlind: »Die geographische Entwicklung des Rheindeltas», (Lund and Amsterdam 1912).

[2] A Norlind l. c. p. 235, 236.

[3] This was followed by other floods in 1248, 1249, 1257 (the »Gereonflood») and 1267 (A. Norlind l. c. p. 249).

[4] A. Norlinds description of this stormflood fills the pages 196 to 204 in his paper: Die geographische Entwicklung des Rheindeltas.

[5] »Die letzte Hälfte des 15ten Jahrhunderts war von unheilverkündenden Vorzeichen für den südholländischen Waard sehr reich gewesen. Es wurde in den Jahren 1374 (zweimal) 1376, 1377, 1393, 1396 und 1397 überschwemmt. Diese Ueberschwemmungen waren teils vom Flusse teils vom Meere gekommen. Das schwerste Gefahr drohte aber von Seiten des Meeres. Und sie kam in deutlicher und eindringlicher Gestalt was allen die nicht blind waren offenbar werden musste». A. Norlind l. c. p. 194.

[6] »Est adhuc in mari Groenlandicæ mirandum quod cingulorum maris nomine venit... oriuntur tres decumani fluctus qui totum mare cingunt nullibi pervii, montibus altiores præuptisque montium jugis admodum similes: raraque prestant exempla eorum qui salvi hæc pericula evaserint» (Speculum Regale).

[7] In Walfords essay — on the Famines of the world (Statistical Journal sept. 1878 London) we read the following passages:
Holland: 1283—87, a dreadful storm laid the whole country on both sides of the Zuidersee under water. To such a height did the water rise that Count Florence took advantage of the circumstance to subdue the inland towns by armed vessels called »cogs» (Davis' Holland)
England: 1287. Winter ecessively rainy, great floods 1 Juni. Sea broke in from the Humber to Yarmouth forced by the winds. In December on Suffolk and Norfolks coasts. Plague all the year.

[8] A. Norlind l. c Dr Norlind who has kindly superseded the preceding description of stormfloods is of the opinion that the climax of the catastrophic epoch fell in the 13—14 th century.

[9] On the other hand we ought to be on guard against the predisposition common to geographers and meteorologists of the present time to belittle and minimize all historic accounts of phenomena of catastrophic character which seem to them to be incompatible with every day experience,

»Wahrscheinlich bildeten die Friesischen Inseln in alten Zeiten eine zusammenhängende Dünenkette nur durchflossen von den grösseren Flüssen. Der ganzen Bodengestaltung bei den friesischen Inseln und im ausgedehnten Wassergebiet ist nach Krümmel erst durch die Gezeitenströmung der charakteristische Typ aufgedrückt worden. (Peterm. Mitt. 1889 s. 129 ff). Die säkulare Senkung von der die Dargschikten unter der Marsch und die submarinen Wälder und Moore Zeugniss ablegen, so wie der, nach Browne an der Schwelle der historischen Zeit, nach Walther vor 6,000 bis 8000 Jahren, erfolgte Durchbruch des anglo-französischen Isthmus, ferner der stärkere Flutwechsel der ja erst nach diesem Ereigniss besonders in die Erscheinung tritt, machten ihre verheerenden Einwirkungen auf die Dünenkette geltend» — — — —

V.

The freezing in certain winters of the Baltic and Cattegat and the growth of the Hanseatic herringsfishery during the Middle-ages.

Both these phenomena are important when studying the cause of climatic variations in historic time. In the first place it is neccessary to prove their reality by carefully sifting and comparing available data which are numerous but often contradicting as to the time and extent of freezing a. s. f. We have come to look upon climatic variations as quite irregular and incomprehensible and because of this there is now a tendency to discredit the statements of the chronicles regarding the severe winters and occasional abnormally hot summers of the 13th and 14th centuries, the shifting in the climatic seasons, the variation between drought and extreme precipitation, a. s. f. The old writers are supposed to have exaggerated, because in their time humanity was less able to protect itself against the influences of such variations and it is assumed that, as navigation was generally suspended during winter, the ice-conditions of the sea were judged from what could be seen from the shore. As to the abundant herringfishery of the Öresund, it is argued that in certain years even now a tolerably abundant fishery is carried on off the coast of Scania and that the astounding records of the old Hanseatic fishery are due to an enormous exaggeration of the ancient returns of the yield.

In my opinion the state of the Baltic during the Middle-ages, when known, will furnish the key to the mystery of the climatic variations. The statements relating to this subject are so numerous and distributed over so many ancient chronicles and later summaries of chronicles that the collection and sifting of this material will require a special study.

In France the interest for historic climatology was awakened by Arago, in Sweden by Ehrenheim in his celebrated presidential address to the Academy of Sciences of Stockholm in 1824. The scientific scrutiny of the Swedish material was begun by R. Rubenson and continued by N. Ekholm, [1]) who in the 5th chapter of his paper »Om klimatets ändringar och dess orsaker» gives the most complete summary of the subject known hitherto. The name of the chapter is: »Klimatväxlingar under historisk tid, särskildt i nordvästra Europa.»

Ekholm commences his discourse thus;

»It remains to consider the climate-variations in historic time. The observation-material is certainly very comprehensive but there is such a want of order and regularity in it that it seems almost impossible at present to get a clear view of the different kinds of phenomena and the connection between them».

The material from which such deductions can be drawn consists, according to Ekholm, partly of historic records, numerous but unreliable and irregular, and partly in actual observations of the weather which however do not date further back than 150 years. Our knowledge of climatic variations during the Middle-ages must thus be based chiefly on historic records. As their authenticity has been questioned, because in some cases the writers have taken down their accounts from hearsay or copied one another, I have tried to collect new documents and concentrate my research upon one problem, viz., the state of the Baltic. For, if it is possible to show that the records regarding the freezing of this sea and the herringfishery therein are based on actual facts, it is absolutely certain that hydrographic changes have occurred in the circulation of the waters of our seas and we have obtained a basis for our endeavour to discover their causes. In the Icelandic, the Swedish and particulary in the Danish historic literature I have found material wherewith to compare and criticise these records. This chapter contains a collection of such statements which I have obtained partly directly, partly from information given by Swedish authorities on Mediæval historic literature. Captain C. J. Speerschneider of the Danish Met. Inst. has collected a great deal of information regarding the ice-years of the Baltic. I have been able to compare my historic data with those of Captain S. and I have found that several of the old records have been wrongly copied and suffer from confusion of geographical names. Captain S. has particulary pointed out that the statements regarding the freezing of the Skagerak in reality concern the Cattegat, as in old times no proper distinction was made between the two seas. Thus when the Icelandic records state that in one winter packs of wolves went across the ice from Norway to Denmark, or when the Diarium Minoritorum Wisbyensium relates of the year 1296: »congelatum est mare tanto rigore ut eqvitari poterat de Opslo ad Jutiam», it probably does not mean that communication was kept upon the ice directly between Christiania (Oslo) and Skagen, but probably between some place on the coast of Bohuslän and Jutland. But even if the freezing of the North Sea or the Skagerak should not be taken literally, that of the Baltic, which occurred so frequently in Mediaeval time, is a fact that cannot be doubted or explained otherwise. As the large material collected by Captain Speerschneider is soon to be published I will here only consider a few years, which may be regarded as typical for a mediaeval ice-winter.

1306. The freezing of the Baltic during the winter 1306—1307 is a wellknown historic fact which cannot be doubted. So severe a winter had not occurred for many years. The entire Baltic was frozen over from Livonia and the Gulf of Finland to the Sound. There the ice is said to have measured 15 ells in thickness and for 14 weeks to have formed a solid bridge between Sweden and the Danish Islands. The war between Sven Estridsson and the Dukes was stopped by the cold.

In Diarium Minoritorum Visbyensium we find: »fuit hiemps maximus ita quod mare inter Olandiam et Estoniam exstitit congelatum».

In the Icelandic records (Annales regii) and in the Skalholt Annals a. v. I have found the following description of the icewinter 1306—1307, which was felt in Icelandic seas as well as in the Baltic.

»1306. Haffis fyrir Nordanland um allt sumar 15 alna harr. Frost sva mikit i þyversku landi ok i Franz sem pa er stera lagi eru i Noregi ok gengv af Ravdstock til Danmerkr yfir Eyrassvnnd».

1323.

From 1322—1323 we have the greatest number of notes regarding a mediæval ice-winter in the Baltic. Captain Speerschneider has permitted me to quote from his collection of historic meteorological data, drawn from Danish and German records, everything that concerns this particular winter.

»We are told in the history of Olaus Magnus, that the frost was so hard that it became possible to cross the ice from the coast of Lybeck to Denmark, and that hostelries were put up on the ice.

Both Hennig (Katalog bemerkenswerther Witterungsereignisse, Berlin 1904) and Mansa (Folkesygdomme og Sundhetspleiens Historie i Danmark, Köpenhamn 1873) relate that the winter began on the 30 of Nov. 1322 and lasted to the half of Lent 1323 had passed. Peter Olsen says that the cold culminated in March. Hvidfeldt (Scriptores rer. Dan. II: 528) tells us that there was general traffic across the frozen Belt from Candlemass 2/2 for 6 weeks and that the Drost, Herr Lauritz rode across from Taarborg with the troops. Pfaff (Über den strengen Wintern etc. Kiel 1809) speaks of the severe winter and that it was possible to ride and drive from Germany to Denmark and from Lübeck to Dantzic over the Baltic, so late as 28/2 Arago (Æuvres completes) repeats after him that one could ride from Denmark to Dantzic.

Mansa says that the entire Baltic was frozen between Denmark, Venden and Fehmern. Strelow (Cronica Guthilandorum Köbhvn. 1633) says that one could drive across the ice between Sweden and Gulland.

Quotations:

A. De frigoribus autem illius Germaniæ seu Gothicis maris plura meminit Albertus Crantzius, diligentissimus omnium regionum scriptor. Ait enim: anno 1323 gelidissimo frigore constringebatur mare ut pedestri itinere per glaciem de littore Lubicensi in Daniam & in Prussiam mare transiretur dispositis per loca opportuna in glacie hospiciis (Olaus Magnus' historie 1555).

B. Erat autem 1323 qvum gelidissimo frigore mare constringeretur ut pedestri per glaciem itinere de littore nostro in Daniam inqve Prussiam mare transiretur dispositis per opportuna loca in glacie hospitiis, si quid commentibus intervenisset (Albertus Krantzius Francof, 1580).

C. Via communis erat ambulantibus et eqvitantibus in multitudine super glaciem per passagium maris Baltici eundo et redeundo qvasi per continuum sex septimanarum spatium circa purificationis Mariæ virginis similiter per passagia inter Seelandiam et proximos partes Slaviæ (Appendix ad incerti annales Danarum).

D. Between Norway, England and the Flanders (from the harbour Leven in the latter country) the ships were frozen in on the open sea so that the merchants went visiting one another over the ice. When the ice broke up most of the ships frozen in the south were saved but few remained of those frozen in the north. (Suhm a St. 11.61).

Captain Speerschneider summarizes his impressions of the icewinter 1322—1323 in this manner:

1) Quarterly Journ. of the R. Meteorol. Soc. 1901 January.

The winter was severe and began early. From the 1:st of Febr. to the middle of March the ice lay in the Cattegat, the Belts and the western Baltic. The ice was used for communication across the great Belt and the Fehmerbelt, probably also the Sound. There must at least have been ice along the whole of the Baltic coast of Germany extending far out into the sea and also between Sweden and Gulland.»

Also in the southern countries the winter must have been severe. Hennig says, that the Gulf of Venice was frozen over; Arago says, that the winter was severe in France and Italy».

This shows that the cold culminated between 1 Febr. and 15 March »as it does now».

1394.

»It was possible to walk across from the coast of Venden to Denmark and Sweden.» (Captain Speerschneiders notes.)

1407.

»one of the coldest winters on record. The sea between Sweden and Denmark was frozen over. (Captain Speerschneiders notes.)

Hennig's Katalog has the following note on the winter 1407—1408:

Der grosse winter von 11 Nov. bis 27 Jan; in England v. 11 Dezember bis 2 Jan. Alle Flüsse tragen die schwersten Lastwagen, über den gefrorenen Skagerak (Kattegat?) laufen die Wölfe von Norwegen nach Jütland. Seit 3 Jan. veranlasst plötslich starkes Tauwetter in England grosse Überschwemmungen. 28 Jan. plötzliches Tauwetter in ganz Mittel-Europa wodurch sehr grosse Überschwemmungen hervorgerufen wurden.

1418.

According to Stavenow, Chronologia vetusta 1298—1473 contains this statement: Anno MCCCCXVIII. Hiemps erat nimis aspera et mare salsum fuit congelatum ita qvod homines transierunt intra Alemanniam et Daniam videlicet Gezör et Rotstock.»

1423.

According to Stavenow the following statement is contained in an anonymous record called »Remarkable occurrences in Sweden 1220—1552». »In 1423 the winter was so severe that the Baltic was covered with ice so that it was possible to travel in sleighs along the route of the vessels from Dantzic to Lübeck and from Pomerania to Denmark.»

1460.

From Hennig's Katalog; »Ausserordentlich strenger winter bis 20 Märtz. Die Ostsee friert vollständig zu so dass man zu Fuss über das Eis von Lübeck und Stralsund nach Norwegen (Dänemark?), von Reval nach Schweden gehen kann. Die Donau und andere Flüsse von 13 Jan. bis 11 Märtz derart zugefroren dass sie die schwersten Wagen tragen.»

From the 16th century also there are records of the Baltic being frozen in such a degree that the ice could be used for communication between Germany and Denmark. But this happened more and more seldom and the winter of 1636 is considered to be the last in which the Baltic was frozen between Scania and Bornholm. In the above quotations I have only made use of such notices which, as far as I can find, have never before been published or compared before. Hennig's Katalog contains several notices to the same effect, f. inst. regarding the ice-winter 1318—1319, like this: »Strenger winter, alle grosse Flüsse auch der Po zugefroren 20 Tage lang derart dass sie Wagen trugen» etc. I do not however intend to enumerate and examine all notices on ice-winters which occurred at that time. The subject is of great interest and deserves a special study, which will be undertaken sooner or later. I only wish to prove the reality of the phenomenon and to obtain a general view of the of time in which it occurred most frequently. To sum up, I find that the freezing of the Baltic occurred most frequently during the last centuries of the Middle ages. The period of cold winters appears to have commenced about 1200 and to have culminated in the 14th century. The year 1322—1323 may be taken as typical. After heavy floods of the Rhine, the Rhone a. o. rivers in June and later months 1322 the cold set in at the end of November. In the beginning of 1323 the Baltic and part of the North Sea were frozen and the cold made itself felt over the greater part of Europe. As a rule these cold winters were followed in spring by devastating inundations of the great rivers. No less than 55 such occurrences are mentioned by the chronicles of the 13th century. Some other years, like 1304 and 1328, however, had exceedingly mild winters and hot and dry summers. Such were the years 1387, 1393 a. o. On the whole this century was noted for its extreme climatic variations on the eastern shore of the Atlantic. As I have already shown in this paper, corresponding phenomena occurred in Iceland and on the coast of Greenland. Later on I will show the influence which these variations exercised on the harvest yield and the economic conditions of Scandinavia.

The freezing of the Baltic in severe winters appears to have been most frequent in the last centuries of the Middle-ages. Then gradually it occurred more rarely. In the last 3 centuries the Baltic has never been frozen to. The intervals between the ice-winters gradually lengthened till at last they ceased alltogether. Yet the recurrence of the old severe winters have been felt up to our time, although mitigated, in the freezing of the water along the shores of the Baltic, the crowding of ice in Öresund, driftice appearing in the Cattegat etc. which has happened now and again in the last decades. The phenomenon appears to be of a periodic nature with a complex periodicity and to have culminated 6-7 centuries ago. Whether the freezing of the Baltic occurred before, f. inst. during the Viking-age or the time of 800—900 a. C. is not possible to tell, but it seems improbable that so could be the case as the Sagas never mention it. Nor do the Icelandic records speak of ice having hindered navigation in the western Atlantic.

It should be observed that the culmination of the Baltic ice-winters occurred simultaneously with the period of great storm-floods and the absolute maximum in the tide-generating force of the sun and moon at the beginning of the 14th century. Besides this there is another phenomenon, viz. the annual immigration of herrings into the Baltic and Öresund, the s. c. Hanseatic herring-fishery, which culminated 1100—1500 and afterwards declined.

Summing up all that the chronicles tell us of the ice-winters of that time we find:

That there was a period 6-7 centuries ago when the Baltic, the Sounds and the Cattegat were frozen over and covered by a solid sheet of ice which could be frequented by pedestrians and carriages in certain winters. This happened most frequently in the 13th, 14th, 15th centuries but ceased in the 16th century. For the last 250 years the Baltic has not been frozen over.

It must not be concluded, however, that the average *winter climate* for the last centuries has been less severe than during the Middle-ages. It is possible and even probable that it is so; but this »climatic improvement» which would mean a transition from a continental to a more maritime climate for the countries on the Baltic must be proved in other ways to become a recognised meteorological fact. *For the freezing of the Baltic depends not, as will be shown, on meteorologic but on hydrographic causes, though the phenomenon may very well have influenced the climate.*

The waters of the Baltic as well as of the Cattegat and Skagerak are stratified. The surface layer in the Middle and South Baltic has a comparatively even and uniform salinity varying from 7 ‰ to 9 ‰. The freezing point is about — 0°.35 and the maximum of density more than 1° above 0. Every particle of water, which is cooled by contact with the atmosphere in winter, sinks down to the lower border of the water-layer while other particles, warmer and less heavy take its place at the surface and are cooled in their turn. In this manner the whole bulk of water is cooled by convection down to 1° or 2° above 0 during authumn and winter. Because of the thickness of the layer (40-50 m. in the Baltic proper) and the rapid interchange of water in the horizontal direction in the western Baltic and the Belts the surface layer has not time to cool to its freezingpoint in winter. In Febr. and March the cooling reaches its maximum a little above +1° in severe and a little above +2° in mild winters.

Because of the thickness of the surfacelayer it is impossible at present that the Belts or the southern Baltic should be covered by a continuous ice-sheet. For this to happen (except of course near the shore and in shallow bights) it is neccessary that the surface-layer gets thinner and the bottomlayer is swelled by a stronger influx through the Belts and Sound, thus raising its level. Under such conditions the Baltic would freeze as easily as would a shallow lake or one of the fjords of the Cattegat, where a thin layer of fresh water is superposed over a deep layer of salt and warm oceanic water. Whereas these fjords, f. inst. the Gullmar and the inner Christiania fjord, freeze every winter the Baltic has kept open now for 3 centuries even in very cold winters.

Knowing, as we do, that 600 years ago the Baltic froze frequently so that the ice could be used for communication between Denmark and Germany and even for so vast a distance as that between Sweden, Gothland and Esthland, we are forced to conclude that the oceanic current of salt water entering through the Belts and the Sund must have been more powerful at that time and able to raise the level of the salt water which filled the depths of the Baltic basins to a greater height than now. Under such conditions the surface of the Baltic would freeze in cold winters. A deepening by some meters of the channels in Öresund would do the same and the explanation nearest at hand would be, that Öresund and the Baltic were deeper during mediæval time and gave wider access to the undercurrent.

I have carefully examined this alternative by taking the opinion of the geologists who have made a special study of the level of the Baltic, (Munthe, Sernander and de Geer) and by examining carefully the oldest sea charts existant of Öresund which are in keeping of the Pilot-Office of the Royal Danish Marine. There are none of these older than the 17th century and the soundings show on the whole the same depths as our modern charts between Scania and Sjælland.

The changes in the Baltic from mediaeval to modern time cannot be attributed to geologic causes. They must be caused by the altered hydrographic conditions and the only possible explanation is that the salt undercurrent was more intense during the Middle-ages than now, so that the bottom-layer of the Baltic then attained a higher level and the surface-layer was thinner, which caused the latter to freeze in cold winters. There is no other explanation possible.

What then was the state of the Baltic at that time when it happened in cold winters that its surface became frozen over? The Swedish researches have furnished an answer to this question.

Fig. 15 gives the position of the the isohalines in the western Baltic as found by F. L. Ekman in August 1877. We see that the mixed salt water, which is found in the Cattegat and the Belts, imme-

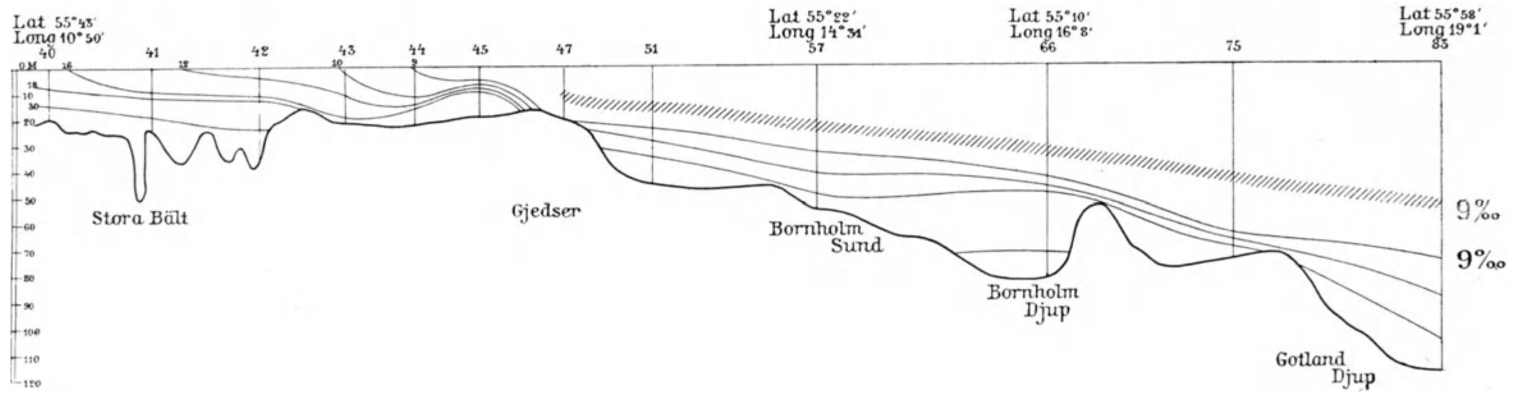


Fig. 15.

diately upon entering the Baltic flows along its bottom to the big basin east of Bornholm. Nowadays the undercurrent cannot fill this basin to a higher level than some 40—50 meters from the surface north and east of Bornholm and 60—70 meters below the surface in the big basin east of Gothland.

If the undercurrent increased so as to raise the level of the bottomlayer some 9—10 meters in the neighbourhood of Bornholm, the Baltic would freeze as it did in the 13th or 14th century. The following tables contain the results of 3 soundings at the station S6 east of Bornholm where the water is 95 meter deep and the surface layer of uniform salinity is 50 meter in thickness.

	15 august 1904.		5 november 1904.		15 march 1905.	
	55° 21′ Lat. N. 15° 39′ Long E.		55° 20′ Lat. N. 15° 30′ Long. E.		55° 21′ Lat. N. 15° 30′ Long. E.	
Depth	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
0 m.	15°.09 C.	7.29 ‰	10°.3 C.	7.29 ‰	2°.2 C.	7.39 ‰
10 »	14°.61 »	7.25 »	10°.23 »	7.27 »	2°.12 »	7.39 »
20 »	14°.60 »	7.25 »	10°.23 »	7.28 »	2°.08 »	7.43 »
30 »	13°.40 »	7.25 »	10°.23 »	7.29 »	2°.15 »	7.56 »
40 »	4°.70 »	7.32 »	10°.23 »	7.29 »	2°.20 »	7.67 »
50 »	3°.52 »	10.21 »	7°.02 »	9.42 »	3°.40 »	9.15 »
—	—	—	—	—	—	—
75 »	3°.64 »	16.04 »	4°.25 »	16.06 »	5°.33 »	15.61 »
95 »	3°.52 »	17.02 »	3°.70 »	16.58 »	4°.59 »	16.03 »

It is easy to calculate from the tables that the surface-layer has given off some 30.000 calories to the atmosphere from August to November. From November to the middle of March the surface of the sea had lost 367500 calories pro squaremeter. The temperature of the surface-layer had in the meantime sunk from an average of 9.°71 C. to 2.°36 C. or with 7.°35 degrees. Had the surface-layer been some 35.7 meter thick instead of 50 meter and given off the same amount of heat to the atmosphere, then its temperature would have sunk to the freezing point = —0.°5 C. and the open Baltic east of Bornholm would have been covered by ice in March 1905, The same calculation can be made for the Baltic north of Bornholm wherefrom we possess soundings from Nov. 1914 and March 1905. The Swedish station S5 is situated in the strait between Scania and Bornholm.

	6 november 1904.		15 march 1905.	
	55° 26′ Lat. N. 14° 46′ Long. E.		55° 26′ Lat. N. 14° 46′ Long. E.	
Depth	Temperature	Salinity	Temperature	Salinity
0 m.	10°.6 C.	7.54 ‰	2°.3 C.	7.50 ‰
10 »	10°.59 »	7.54 »	2°.31 »	7.56 »
20 »	10°.59 »	7.52 »	2°.26 »	7.65 »
30 »	10°.63 »	7.67 »	2°.5 »	7.80 »
40 »	11°.81 »	11.56 »	1°.91 »	8.04 »
—	—	—	—	—
60 »	11°.25 »	14.52 »	1°.75 »	13.14 »
—	—	—	—	—
68 »	8°.87 »	15.61 »	1°.71 »	13.87 »

Here the surface layer, which measures 40 m., had emitted some 340000 calories pro square-meter from Nov. 6th 1904 to March 15th 1905. The temperature had sunk from 10°.6 to 2°.16 C. If the surface- layer had been 10—12 meter less thick the temperature would have sunk somewhat under 0° by the same heat emanation. The surface layer, however, is cooled farther in some winters. In 1896 its temperature sank to 1°.3 C. If in such a winter the bottom water had risen 8—9 meters nearer to the surface a continuous sheet of ice would have covered the middle part of the Baltic proper. If the influx of salt water into the Baltic were so strong that its level reached up to 30 instead of 40—45 meters from the surface in the strait of Bornholm, then the ice would have been safe for communication between Scania and Bornholm in the winter 1896—1897. But in the mild winter 1904—1905 the sea would have been open and free from ice.

In this way we may form an opinion as to how much the Baltic has altered in the course of the last 5 to 6 centuries. Fig. 15 is the outcome of such a calculation and shows a section of the western and southern Baltic reconstructed after this method. A larger supply of salt water would make the Baltic physically resemble the fjords of the Cattegat which as we know freeze to in cold winters; and the herring shoals from the North Sea would then follow with the salt current to the gates of the Baltic as they did every authumn in the Middle-ages.

It would thus require no very considerable change in the hydrographic conditions to bring about the freezing of the Baltic in severe winters or to make the herring return to its ancient haunts in the Sound at the coast of Scania. Such conditions recur approximately even in our days in certain years and at certain intervals. It all depends upon the intensity of the watersupply from the ocean through the undercurrent. In other papers I have shown that this undercurrent varies under the influence of the tides. It possesses semidiurnal, diurnal, monthly, annual, multiannual and secular periods according to the variation in the tide-generating force. The daily pulsation we discovered in 1907 and succeeding years in the Great Belt, the monthly in the Gullmarfjord. The annual period has been traced in many ways by its effects; higher water-level in authumn, maximum of the influx through the Great Belt and Öresund in December, the seasonal migrations of the herring which now generally stops at the point where the Cattegat channel shoals out S. of Gothenburg, but in certain authumns sends contingents down to Öresund and the Belt in such a number as to suggest to certain authors the idea that the great Hanseatic fishery of the Middle-ages was no other than the herring fishery which is carried on nowadays in Öresund.

Finally there is the wellknown fact, that in certain winters the driftice appears in the Sund, the Baltic and the Cattegat in such quantities as to block the Sund and the Cattegat harbours for a couple of months. Such winters appear to occur periodically. In 1809—1814 there occurred such winters, the drift-ice getting crammed into the strait between Scania and Bornholm.

The exchange of water between the N. Sea and the Baltic through Cattegat and the Great Belt.

Regarding this subject I must refer to former publications.[1]) The circulation of waters through the Great Belt, which is the chief channel by which the ocean-water finds its way into the Baltic, can be represented by the following diagram.

This figure represents a longitudinal section through the Great Belt, with 3 stations; one at Revsnaes in the northern entrance of the Belt, another at Langeland at its southern egress, and the third at Korsör, in the middle. The salt under-current enters the Baltic nearest to the bottom of the sound and introduces water with a salinity of 30 $^0/_{00}$ and 32 $^0/_{00}$, the limits of which are shown

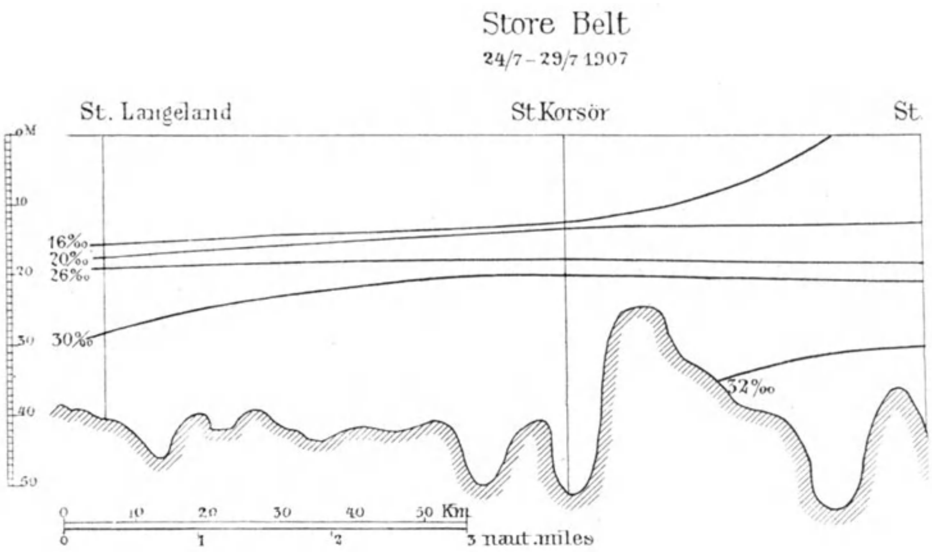


Fig. 16.

by the isohalines. The fresher surface stratum is the Baltic water which streams out from the Baltic, its lower limit being represented by the isohaline for 16 and 20 $^0/_{00}$ salt. Between the surface current and the under-current there exists a limiting-stratum, in which the two other water-strata are mixed. We see that the in-going and out-coming kinds of water rest on each other like two wedges, turned with their sharp ends towards each other.

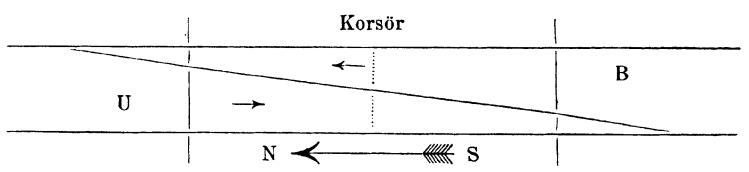


Fig. 17.

The pressure of the salt water-masses from the Ocean drives in the lower wedge, and the pressure of all the river-water that is collected in the Baltic presses out the upper water-wedge. The result is an outward flowing surface-current (the Baltic stream) and an in-going under-current. It was first believed that these currents were continuous and that the one was dependent on the other, so that a greater out-current at the surface necessitated a more rapid inflow of salt water below, in order to preserve the balance in the exchange of water between the Baltic and the Ocean. A. W. Cronander, however, made some observations at the light-ships in the Cattegat, which showed that both currents were not always active at the same time. Then the opinion was adopted that it would be the result of the wind and the barometrical pressure over the North Sea if the lower wedge was pressed inwards more powerfully than the upper wedge was pressed outwards: for occasions are imaginable when the under wedge is pressed inwards with such force that its salt-water masses dam up the surface-current, so that the latter absolutely cannot make its way out. The reverse would be the case if the water-pressure, or the wind- and barometrical pressure, were strongest over the Baltic; the out-going water-wedge in the Great Belt then being able to fill the whole of the Belt all the way to the bottom and prevent the entrance of the under-current. In a word, the exchange of water would, it was thought, depend on temporary atmospherical causes, such as wind, rainfall, atmospheric pressure etc. This is the opinion generally adopted at present.

But in July, 1907, the Swedish Hydrographical Commission made observations at the named stations in the Great Belt and, with the help of modern apparatus, studied the movements of the limiting-stratum lying between the surface-current and the under-current. It was found that its movement was not always the same, *but that it was pulsatory* or *periodic* and it was also discovered that the movement proceeded from the lower wedge, which was pressed inward more powerfully every 12th hour of the day and regressed once in between, i. e., also at intervals of 12 hours. The limiting-surface between the currents, consequently did not lie exactly straight, or, more correctly speaking, at a level slope from north to south, but went in waves as shown by the following schematic illustration.

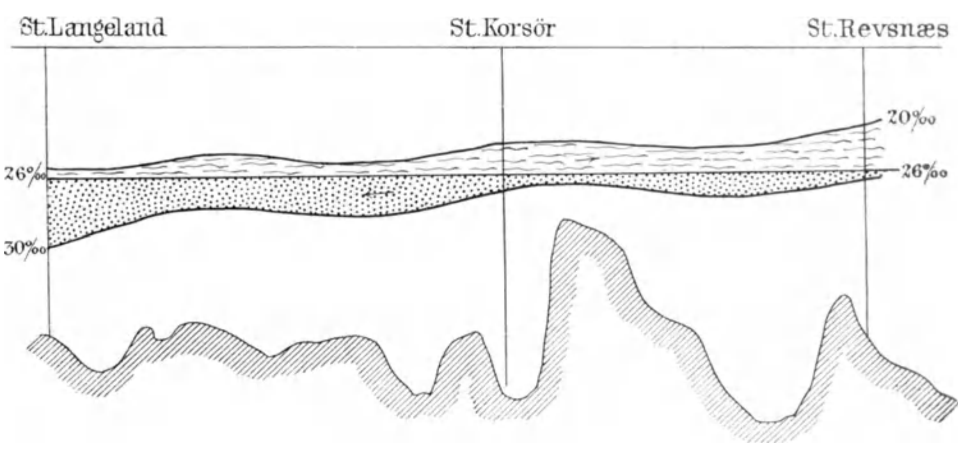


Fig. 18.

This was, of course, clearly a tidal-phenomenon and a very unexpected one for, as is well known, the tide ceases to be felt at the embouchure of the Skagerak, no ebb and flood being noticeable at Lindesnäs. Inside Lindesnäs the tide is slightly noticeable, amounting on the Bohuslän coast to about 3—4 decimetres while in the Belt itself, at Korsör, it is about 1½ Danish foot at the surface. We found, however that the tide-waves in the limiting-stratum at Korsör, 18—20 metres below the surface, were about 10 times as high or about 3 metres. This showed that the ebb and flood of the North Sea, which seems almost to disappear in the Skagerak and Cattegat, still exist in the lower limiting-stratum, although it is lessened towards the surface by the upper stratum of light Baltic water, which acts as a moderator on the waves.

If this moderating surface-stratum did not exist, i. e. if the Baltic were a lake (as during the Ancylus period) and the Great Belt formed the innermost bay of the North Sea and the Cattegat, with homogenous water of oceanic origin from bottom to surface, the alternations of the tidewater along the shores of the Belt would probably be considerable. The low shores of the Danish Islands would then, perhaps, have the appearance of a marshland defended from the waves by enormous dams, as at Walcheren and on the Friesian coast of the North Sea, or else of a »drowned-land», such as exists off the west coast of Schleswig. It was, therefore, surprising to feel the pulse of the sea beat so strongly in the depths of the Great Belt. But the tidal wave which rushes in through the Belt at a depth of 18—20 metres, does not cross the exceedingly uneven bottom of the strait undisturbed and so enter the Baltic. Each tide-wave drives like a cascade of salt water over the threshholds of the Belts and sinks down into the deep channel of the Baltic south

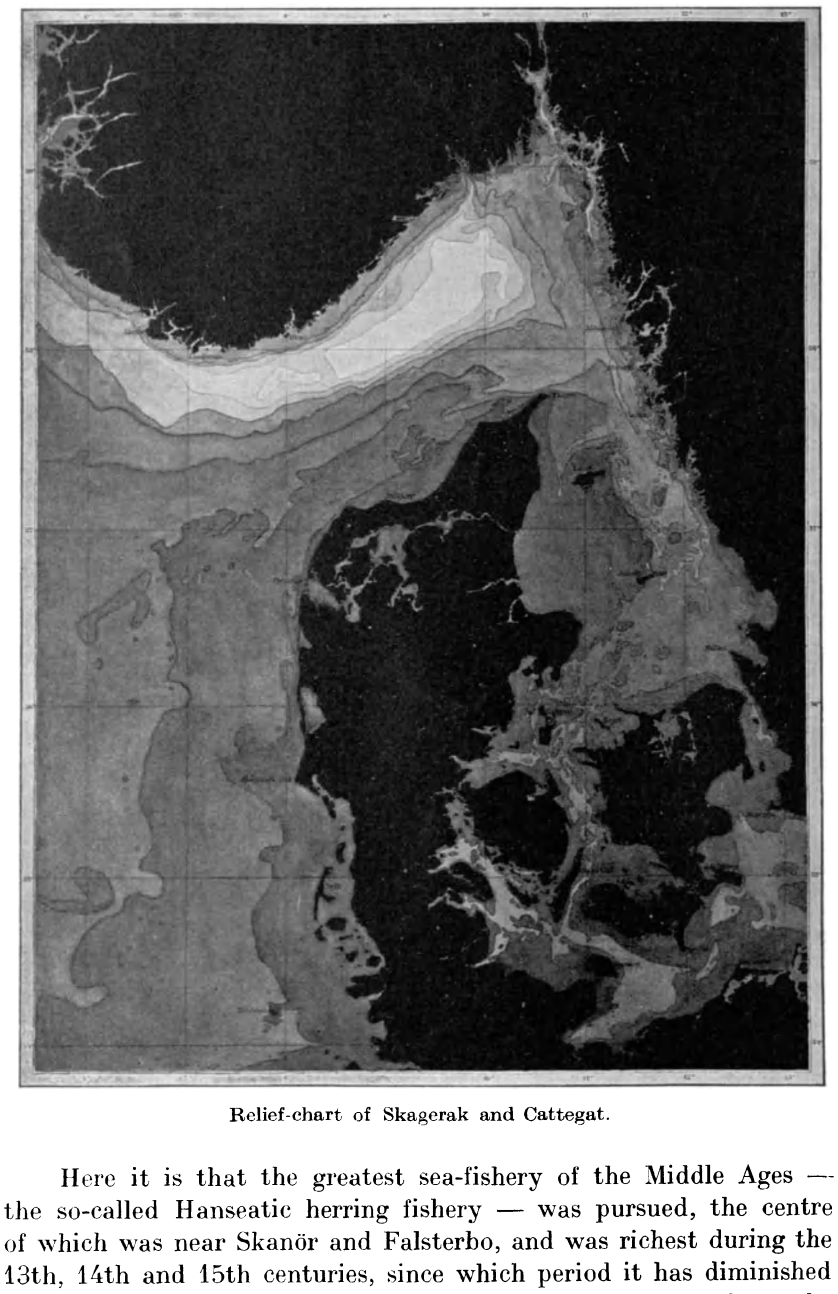
[1] O. Pettersson. Strömstudier vid Östersjöns portar. Häfte III af Svenska Hydrografisk Biologiska Kommissionens Skrifter.

of the strait, and then continues its inward course along the bottom of this sea, in the form of a so-called »solitary wave».

The exchange of water between the Ocean and the North Sea thus obtains a pulsating character, in consequence of the influence exerted by the tide-water on the under-current. In consequence of these cascades of salt water, the deep depressions of the Baltic are filled one after the other, and when one basin is filled it pours its superfluous water in another cascade into the next, so that, in proportion as the salt water enters the Baltic, the surface water is driven out.

Such is the influence of the daily and semi-daily tide-water on the circulation in the Baltic sounds.

Beside these tidal waves in the boundary between the upper current and the bottom current we have the great waves of longer period described in the foregoing which come in from the North Sea moving slowly through the whole of the Skagerak and the Cattegat like great cascades of water which carry with them the shoals of herring from the eastern regions of the North Sea into the Cattegat, which acts like a funnel or a fish-trap in the narrow innermost end of which the immigrating herrings are crowded together. There are several such tracts where the shoals of herring are crowded into close masses — »herring-mountains», as they are called by Swedish fishermen — in consequence of the small breadth of the channel, or the irregular contour of the bottom, which acts like a filter that admits the water-current but stops the progress of the herring. In such places the herring-fishery is carried on with seines (»snörpvadar»). In places where the channel is wider, such as around Anholt and off Varberg, fishing is best carried on with driftnets as the shoals of herring are more widely spread there. The last and the narrowest passage that the water-current has to pass before it enters the Baltic is formed by the Sund and the Belts.



Relief-chart of Skagerak and Cattegat.

Here it is that the greatest sea-fishery of the Middle Ages — the so-called Hanseatic herring fishery — was pursued, the centre of which was near Skanör and Falsterbo, and was richest during the 13th, 14th and 15th centuries, since which period it has diminished to the humble proportions it now has. What could have been the cause of this decline in one of the principal fisheries of Scandinavia within historic times? It cannot have been any geological alteration diminishing the exchange of water with the Baltic as was the case after the close of the Littorina period, for during the last 2,000 years the bottom of the Sund has not risen more than ¼ meter at most.

The reason does not lie in a geological, but in a hydrographical alteration in the intensity of the circulation of the water, which has been caused by cosmic influences. It can be shown that the tide-producing powers of the moon (and the sun) were considerably greater during the centuries mentioned above than they are now, in consequence of the relative position of the orbit of the moon in respect to the earth and the sun at the period of the winter solstice. At certain occasions during that time of the year the sun, earth and moon approached each other more nearly than usual. Such constellations return at intervals of about 1,800 years and are distinguished by an increased intensity in the circulation of the sea, and of ebb and flood, by great variations in the climate and in solar activity. The increased intensity in the circulation of the water drove the waters of the North Sea into the Cattegat, the Sund and the Baltic. During the Middle Ages, as now, this did not occur in one even continuous stream but cascade-like, by means of great under-water waves that pressed the salt water into the Baltic much more powerfully than now. These pressings-in were strongest in the autumn, just as now, and with the watermasses or »water-mountains» that the tide-producing power of the moon drove into the Baltic went the great herring shoals, »the mountains of herring» of which Saxo and other chroniclers from the 13th and 14th centuries have astonishing tales to tell. This hydrographical circumstance gave Skanör and Falsterbo a period of extraordinary prosperity during the last centuries of the Middle Ages.

The powerful in-current during these centuries filled also the deep channels and basins of the Baltic with salt water to a greater height than now occurs. In consequence, the fresh surface-stratum was shallower and during cold winters could be cooled down below the freezingpoint so that, during certain winters, as for example in 1306, 1321, etc. the Baltic became one great sheet of ice, making it possible to cross the ice from Skåne and Denmark to Germany and from Gothland to Estland in Russia. I have shown that it is possible to calculate what the proportion must be between the surface-water and the bottom-stratum for the Baltic to freeze again as during the Middle Ages. In the fig. 15 the limits of such a proportion are shown by dotted lines. If, in consequence of an increased intensity of the undercurrent, the limit of the salinity, 9 $^0/_{00}$, should be altered so as to lie on a level with that shown by the dotted line, i. e. about 8—10 met. higher at Bornholm and 15—20 met. higher at Gothland, the southern Baltic would freeze as now takes place in the Gulf of Bothnia when there is a cold winter. The same thing would result if the Sund were made a couple of metres deeper; for example, by dredging the submarine-channel called the »Flintrännan» to a greater depth. We should then once more have the rich herring-fisheries of the Middle Ages at their old places but we should also suffer from the cold winters of that era, with the Baltic Sea completely frozen over, and Skåne, in the south of Sweden, would have the cold continental winter-climate it had in the days of Tycho Brahe (middle of 16th century).

The great immigration of herring that nowadays takes place in the autumn and winter does not, as a rule, extend farther than the tract south of Gothenburg, between Nidingen and Tistlarne, where the submarine channel of the Cattegat becomes narrower. The advance-guard of the herring-shoals, which makes its appearance as early as in August and September, swims higher up into the upper water-strata and spreads over the broad expanse of the southern Cattegat where the fish are caught by means of drift-nets; the herrings are finally once more squeezed into crowded shoals at the northern mouthpiece of the Sund and the Belts. In certain years, when the sea-impulses are stronger, there is a fairly rich herring fishery here which can be experienced even for some distance into the Baltic. On these occasions there is repeated in our days, although on a diminished scale, the great herring fishery of Öresund that existed in the Middle Ages, see the relief-chart

The great period of the greatest possible tide-power and water-circulation in the sea and the most intense solar activity will not return before the lapse of more than 1,000 years. The last time it occurred was at the close of the Middle Ages, and the time before that, at the close of the Bronze Age, about 600—400 B. C. But within these 2,000-year periods there are shorter lunar-periods of the second, third and fourth rank with a length of 80—90 years, 18 years, 9 years, 4 years and 2 years, all of which influence the water-circulation and the fish-life of the Baltic, Cattegat and Skagerak. In the annual migrations of the herrings we have a very sensitive indicator of the influence exerted by these lunar periods on the movements in the sea. When the tide-producing power of the moon increases the movements in the boundary stratum af the sea become stronger and the current and the under-water waves carry the herring-shoals farther into the Cattegat and gather them in more crowded multitudes at the now-existing principal fishery-places, viz., the coast-bank south of Gothenburg between Tistlarne and Nidingen. If the lunar power is weaker the herring-shoals remain farther out, on the western and eastern sides of the submarine channel of the Cattegat, all of which acts on the results of the herring fishery. An example of this is given by the following diagram. The undulating line represents the declination of the moon, and the years when this has been greatest are marked at the upper curve, and the years when it has been least are shown at the lower arc of the curve. Between every maximum of declination there lies a period of 18.6 years. When the moon attains its highest declination, i. e. when it comes highest and lowest in the skye it exercises its greatest tide-producing power on our seas. I have examined all the information that exists respecting the Swedish herring fishery for 150 years, during the herring-periods of the 18th and 19th—20th centuries, and have marked the favourable fishing-years with *max.*, and the unfavourable with *min.* We find that, without exception, the good fishery-years coincide with the greatest lunar-declination and tideraising power, and the bad fishing-years with the lowest declination [1]).

When the tideraising power of the moon last was greatest it was able to carry the herring-shoals through the whole of the narrows of the submarine channel of the Skagerak and the Cattegat all the way into the Sund and the Baltic. That was 600—900 years ago.

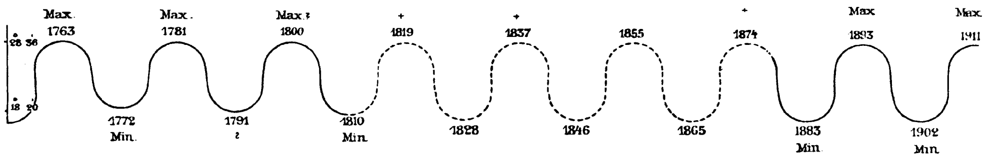


Fig. 19.

When the tide-producing power diminishes most, the herring-migration stops at the first narrows of the submarine channel of the Cattegat, south of Gothenburg, or even farther to the north, so that, at last, the herring has to be sought for off the Skaw (Skagen) in Denmark, as was the case this winter (1913—14). When the tide-generating power is not sufficient to carry the North Sea herring farther in, an advance-guard of the herring-shoals is usually found during December and January in the German North Sea bays and at the mouths of the Elbe and Weser. That which is lost by the Cattegat is gained by the North Sea fishery, just as happened this winter. It is remarkable that the first growth of the herring fishery in the North Sea known in history began in the 16th century, the period when the great fishery in the Sund came to an end.

This may seem to present but cheerless prospects for Swedish fishermen and, it is true of course, that the herring fishery is a difficult and dangerous pursuit. But of late years fishing-vessels and fishery-methods have developed so that it is now possible to look for the herring-shoals at other places and to catch them by other means than a century ago, when the Swedish fishermen were contented with fishing in the fjords and sounds with standing-nets (»sättgarn») and land-seines (»land-vadar»). It is to be hoped too that in the same degree that we are able to discover and study the causes of the visits of the herring to the Swedish coast and its occasional absences from our waters, it will be possible to calculate in advance the prospects of the autumn and the winter fishing-seasons.

VII.

The Climate of Northern Europe at the close of the Middle-age.

The state of our surrounding seas varies on a lesser scale than in the Middle-ages owing to the fact that the periodically acting agent is less variable now than formerly, and is not powerful enough to cause the great climatic variations at the close of the Middle-ages to be repeated. This cannot be expected to happen till after the lapse of 1000 years. But the sea is so sensitive to variations in the tide-generating force that the smaller variations now observed serve as an index to estimate the great changes which have occurred in the fishlife and the ice-conditions of the Baltic.

The changes must have reacted on the summer- and winter-climate of the Baltic countries. In summer the thin surface-layer was heated to a higher temperature and in winter the icecold or ice-covered surface must have cooled the atmosphere above it. The climate must have been more continental with warmer summers and colder winters than now. The observations made on Hven by Tycho Brahe about 1590 compared with H. E. Hamberg's review of the time 1750—1800 bear out this conjecture. It is not likely that the spring and authumn climate would differ much from the present.

Tycho Brahe's observations have enabled Ekholm[2] to attempt a reconstruction of the climate at Öresund in the 15th century. Like myself Ekholm assumes it to be true that the Baltic was frozen over in severe winters.

»Although even now there is considerable formation of ice in the Scandinavian seas, it is evident that the freezing of the Baltic, the Sund, the Belts, Cattegat and Skagerak occurred on a much larger scale in Mediæval time, especially from about 1000 to 1400. What the conditions were before the year 1000 is not known, because the Sagas mention nothing about iceconditions. It is difficult to imagine what the weather could be like in a winter that covered the entire southern Baltic, Cattegat and Skagerak with ice strong enough to be used for communication.»

Ekholm points out that our cold winters now are always characterised by numerous cyclones, which pass south of Sweden. They generally come from the west and probably originate in or are fed by the Gulfstream.

»The most plausible explanation would be that the Gulfstream was weaker in Mediaeval time or took a more westerly course then and that consequently the climate was more continental. *In the latter case the climate of Iceland and Greenland must also have been milder*».

Ekholm also points out that P. La Cour has found a considerable divergence in the wind-direction during the wintermonths of Tycho Brahe's time from the present one.

»Nowadays the ruling wind-direction for the year is averagely Southwest, during all months except April and May when the South-east is more frequent. In Tycho Brahe's time South-east was the average direction for the year; Southeast or East ruling the 7 months January—May and October and December. In the remaining months too the Southeast obtained a secondary maximum of which now scarcely a trace remains. This shows that the distribution of pressure must have been very different then, the low-pressure belt which now as at rule lies between Norway and Greenland and in the Arctic sea must have been very little developed in those days.

In consequence of this low-pressure belt the cyclones now generally pass across the south or middle part of the Scandinavian penninsula, bringing southwesterly winds in Öresund. But the eastern or southeastern winds of the winters in Tycho Brahe's time show that the cyclones then took a course more to the south passing as a rule south of Hven, f. inst. from the North Sea, through southern Denmark to Germany. This course is almost never taken by cyclones now except in the early spring months and in exceedingly severe winters».

The opinions I have expressed in my paper on climatic variations in historic time coincide with Ekholm's representation in the chapter bearing the same title in his papers of 1899 & 1901.

The impression to be got from our joint descriptions of the chief features in the climatic variations of the Middleages is the following:

At the beginning of the Viking-age 500—600 a. C. the minimum period of the tide-generating force occurred. From that time till about 1100, or in the Viking-age proper, the climate of Iceland and Greenland was comparatively mild, as there was no ice-blockade of the north coast of Iceland and the eastcoast of Greenland. Notes about ice hindering navigation in these seas are very rare. The sailing-route to Greenland from Iceland ran straight west over the Gunbjörnsskär group of islands off Cape Dan, thence along the eastcoast to the straits north of Cape Farewell, which were then navigable and free from ice. Nor was navigation hampered by the ice in Davis Sound or in the sea between Greenland and North-America. Ice was first met with in the far north at the fishing places of Baffins Bay. The powerful Labrador-current carried no ice in those centuries, or in any case, nothing comparable to the present quantity. This again reacted on the Gulfstream.

[1] In N:o 7, 8, 9 of the fishery journal »Der Fischerbote». (Hamburg. 1911). I have published a detailed description of the vicissitudes of the Swedish herring-fishery during the last 150 years.

[2] Ekholm. Quarterly Journ. R. Meteor. Soc. 1901 January.

It is the driftice of the Labrador-current which attacks the Gulfstream south of Newfoundland and compels its warm water to spread eastwards towards the submarine base of the Acores and the coastal bank of Europe. There it is joined by the warm outflow from the Mediterranian, which the Danish expedition on Thor in 1910 found extended as far as the weastcoast of Ireland, and forms the vast area of warm water over which the great low-pressure belt south of Iceland forms in winter. When no ice was carried by the Labrador current and this current consequently played a less conspicous part in the oceanic circulation the Gulfstream »could take a more westerly course», as Ekholm says. Then the icemelting took place in higher lat:s; in Baffins Bay, in the arctic sea and even in the Polarbasin.

Western and northwestern Europe then possessed a more continental climate with colder and calmer winter weather.

At the end of the 13 century the first signs of an iceblockade of Iceland appeared and at the close of the 14th century the drift-ice outside East-Greenland had developed so far, that the sailing-route had to be altered. At the close of the 13th century the invasion of Greenland by the Eskimos appears to have begun and in the 14th century came the destruction of the west Greenland settlement followed by that of the eastern settlement and the loss of communications over sea. In 1200—1300 Iceland was again and again subjected to ice-blockades. The icedrift from the polar sea steadily increased towards the time of the maximum of the tidegenerating force.

In the Baltic the effect was to increase the influx of salt water which carried the herring shoals into Öresund and gave rise to an abundant fishery which attained its maximum from 1100 to 1500 and then declined or removed to northern Cattegat and the North Sea. The swelling of the bottomlayer compelled the surfacewater to escape and to spread as a thin coating over Skagerak and Cattegat which there, as well as in the Baltic proper, became excessively heated in summer and cooled in winter, when there was a tendency for anticyclonic development over the snowcovered Scandinavian penninsula surrounded as it was by a broad brim of ice-cold or frozen Baltic water. Cyclones originating in the lowpressure-belt south of Iceland could as a rule not pursue their present course over Skagerak and south Sweden, which then was the centre of an anticyclone. They bent their course to the South, south of Hven, passing over the coast of north Germany where, in conjunction with the high-water at spring-tide, they caused the destructive stormfloods of the winters and the torrential rains and inundations of the summers described in the chronicles. This is proved by yet another circumstance. The Volga is the only considerable tributary to the Caspian Sea. Brückner and Huntington have shown (see later) that the Caspian Sea had an exceedingly low waterlevel in the 11th century. This must mean that the conflux from the Volga decreased in consequence of the continental meteorologic conditions in Europe at this time. This conditions must have altered entirely at the end of the 12th century for then the level of the Caspian Sea again rose according to Huntington:

»In 1106, if the pilgrim Daniel has not erred in his distances, the Dead Sea stood higher than to day. *Next comes a dry period.* The caravanserai in the waters of the Caspian Sea off Baku appears to date from the twelfth or thirteenth century, to judge from its architecture. The aridity of this time was not permanent, however, *for in 1306 a. D. the Caspian sea again rose to a height of thirty seven feet above the present surface.*»

It was the Volga, which had increased its watersupply, its sources feeding on the rain brought by the Atlantic cyclones which, as Ekholm says, passed over Europe south of the island of Hven. From the Atlantic cyclones were sent out, partly to the Norwegian Sea and the coast of Norway, partly over the North Sea and the coast of middle Europe. Sweden, Denmark and the Baltic countries generally appear to have suffered less from cyclones, according to Tycho Brahe's observations, owing to the fact that the Baltic in winter formed part of the anticyclonic area which probably at that time was joined to the great Siberian-Russian anticyclonic belt.

These climatic conditions had a bad effect on the harvest and economic conditions of Iceland, Greenland and north Europe. As regards Greenland and Iceland I refer to a previous chapter of this paper.

As to south Europe I here reproduce the following description from the 14th century contained in Jessop's Historic Essays p. 175:

»It seems established that during the year 1347 there was an atmospheric disturbance extending over a large area of Southern Europe resulting in extensive failure of the harvest and consequent famine and distress. In January 1348 one of the most violent earthquakes in history wrought immense havoc in Italy the shocks being felt in the islands of the Mediterranian and even north of the Alps.»

All through the 14th century earthquakes occurred continually over all Europe (which was the case in Iceland also). The earthquake in Jan. 1348 became famous because it occurred in Avignon simultaneously with the outbreak of the plague (in January according to Guido de Chauliac).

It does not seem strange that the maximum of the tidegenerating force which so greatly influenced the ocean's movements should be accompanied by earth-quakes. The Committee for earth-quakestatistics appointed by the B. A. has found a periodicity of 18 years in this phenomenon, which seems to hint at a connection with moon periods. Also in the Scandinavian countries the climatic variations appear to have brought bad years.

Of corresponding events in Iceland during the 14th century Professor P. A. Munch relates[1]).

»So many tales are still told of the many scourges and violent catastrophes in Nature which visited Iceland in this year that one feels tempted to conclude that this must have been one of the sometimes recurring periods in which the volcanic forces in the interior of the earth are extraordinarily active and the elements are in extraordinary commotion».

On examining the historic dates from the last centuries of the Middle-ages, Dr. Bull of Christiania has come to the conclusion that the decay of the Norwegian kingdom was not so much a consequence of the political conditions at that time, as of the frequent failures of the harvest so that corn for bread had to be imported from Lübeck, Rostock, Wismar a. s. o. The Hansa-union undertook the importation and obtained political power by its economic influence. The Norwegian landowners were forced to lower their rents. The population decreased and became impoverished. The revenue sank 60-70 %. Even the income from Church-property decreased. In 1367 corn was imported from Lübeck to a value of ½ million kronor. The trade-balance inclined to the disadvantage of Norway whose sole article for export at that time was dried fish. Dr. Bull draws a comparition with the conditions described in the Sagas when Nordland produced enough corn to feed the inhabitants of the country. At the time of Asbjörn Selsbane the chieftains in Trondenäs grew so much corn that they did not need to go southover to buy corn unless three successive years of dearth had occurred. The province of Throndhiem exported wheat to Iceland a. s. o. Probably the turbulent political state of Scandinavia at the end of the Middle-ages was in a great measure due to unfavourable climatic conditions, which lowered the standard of life, and not entirely to misgovernment and political strife as has hitherto been taken for granted.

I have already pointed out that these conditions must be due to cosmic causes. But the influence of cosmic agents is not purely local, it is felt all over the earth. If the absolute maximum of the tidegenerating force in the beginning of the 15th century really affected the climate of the earth, then its effects should be traced also outside the area whose climate is dominated by the Atlantic.

VIII.

Climatic Variations outside Europe at the end of the Middle-age.

The areas that can come under consideration are North America and Central Asia. In these parts of the world an intense research work is carried on which I can only slightly touch upon here. Professor E. Huntington[2] has studied the climatic variation both in Asia and Amerika from an archeological point of view. In America he has obtained results of considerable interest by measuring the annual growth of the big Californian firtrees Sequoia gigantea some of which are 2000—3000 years old. I reproduce here Huntington's diagram of the growth pro decade of their annual rings (i. e. the width of 10 annual rings in mm. corrected for the

[1] P. A Munch: Det Norske Folks Historie III.

[2] E. Huntington, The fluctuating climate of N-America. Geogr. Journ. Oct. 1912. The Pulse of Asia; Palestine and its Transformations.

difference in growth in the different ages of the tree). Fig. 20. The growth of course depends on the climate. Huntington writes:

»The Sequoia grew in a region whose climate resembles that of New Mexico except that it is colder and has no rain-period in summer. Long winters with much snow and rains that last till the beginning of the hot and dry summer are conditions which promote a rapid growth.»

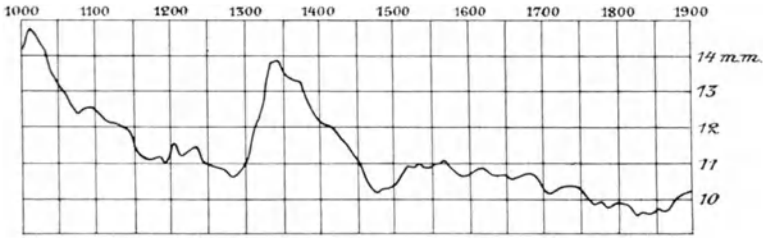


Fig. 20. Uncorrected growth of the Sequoia Gigantea in California.

Judging from the diagram such climatic conditions have prevailed during the 13th and 14th centuries.

To me it seems probable that the abundant precipitation which favoured the rapid growth of the Californian pinetrees was due to the influence of the tide-generating force on the circulation in the Pacific. In any case it is interesting to find evidence of exceptional climatic conditions at the end of the Middle-ages on the Pacific coast as well as on the Atlantic. In the interior of Asia these variations were still more fateful. The Asiatic steppe-lakes alternately expanded and dried up causing destruction to the districts and cities on their shores which compelled the population to migrate. Huntington's investigation of ancient ruins and shore-lines brings him to the following conclusion: »*all the lakes appear to have experienced a period of contraction in the early part of the Christian era followed by expansion in the Middle-ages and by renewed but less marked contraction in modern time*».

The expansion of the steppe-lakes in Asia, which indicates a wet period occurred, according to Huntington, simultaneously with the moist period in California or about 1400 a. C. It was preceded by a dry and warm period which turned the kingdoms of central Asia into deserts and caused the invasion of Europe by the steppe-peoples under Genghis Khan a. o. According to Huntington several such periods of drought have occurred since the beginning of the Christian aera both in America and in Central Asia. Huntington's opinion has recently been confirmed by Brückner who is a great authority on this matter; Brückner writes: »ebenso ist der Mongolinvasion eine Klimaverschlechterung in Asien vorausgegangen. Für diese liegt ein sicheres Symptom vor: das Kaspisehe Meer hatte, nach Bauwerken an seiner Uferzone deren Alter sich bestimmen liess, im XII Jahrhundert einen Tiefstand wie niemals nachher und wie lange Zeit nicht vorher. Ein solcher Tiefstand kann nur durch grosse Trockenheit hervorgerufen worden sein. Diese Trockenheit kann aber nicht lokal gewesen sein sondern muss, wie das ganze Gebiet der Wolga, so auch weite Gebiete Zentral-Asiens mitbetroffen haben. In ihr möchte ich die Veranlassung zum Einbruch der Mongolenscharen nach Europa wie nach Indien und China sehen. So spricht denn gar manches dafür dass auch die Völkerwanderungen der Vergangenheit durch grosse Klimaschwankungen verursacht worden sind. Huntington hat geradezu von einem Pulsschlag Asiens gesprochen. Rhytmisch, wie der Puls schlägt, so wirft Asien entsprechend den Schwankungen des Klimas von Zeit zu Zeit Völkerwellen in die peripheren Gebiete der alten Welt.»

Brückner also points out how the effects of these wet or dry periods differ according to the geographical position of the countries. A period of draught which turns vast areas in Asia and North America into desertland may bring fertility and opulence to the countries on the Atlantic shores:

»in Europa verhalten sich die feuchten dem Atlantischen Ozean naheliegenden Länder, so vor allem Norwegen, Dänemark, Irland und Grossbrittanien, aber auch Schweden und Mitteleuropa, gerade umgekehrt wie das trockne Innere des Kontinents».

Brückner's investigations concerning the 35—36 years variation of the climate, the rise and fall in the amount of precipitation, the prices of corn, and the emigration within the last century indicate that the problem started by Ehrenheim in his paper »Om climaternas rörlighet» has once more become actual.

The very extent of these variations which encompass both America and Central-Asia indicates that they are of cosmic origin. I have suggested that one of their causes may be the variations in the tide-generating force, which in the first place depends on the changing of the moon periods. To be valid this explanation must be shown to apply to the great periodic variations encompassing 1800 years as well as to the smaller changes which are accomplished within a month. It is possible that by using the harmonic analysis in a less summary manner than hitherto we may be able to distinguish between the effects of heat and gravity upon the meteorological variation of short periods. Mr. Strömberg who assisted me in the calculations of astronomic values has brought forward a new hypothesis which is the subject of a special paper and which shows the influence of the variation in the tidegenerating force on the changes of the meantemperature in the course of a month. It is a common belief that the moon influences the weather. This belief is founded on the actual experience of mankind through countless ages.

Before starting weather-forecasts of long range, however, it would be well to see how far the experience of the past bears out the theory here advanced as to the connection between *climatic* changes and the variation in the tide-generating force. The greatest of the periods I have indicated, the period for the occurrence of the absolute maxima, attained its latest epoch in 1434 and has a periodicity of about 1800 years. The maximum previous to that of 1434 must have occurred about 366 b. C. In the interval there must have been an absolute minimum of the period, somewhere about 500—600 a. C. What happened then?

IX

Climatic Variations in Prehistoric Time.

As already mentioned an absolute maximum of the tide-generating force occurred 3 or 4 centuries before the Christian aera. We must now see if this maximum also had effects resembling those in the 14th century a. C, e. g: the devastating stormfloods on the North Sea and the Baltic coats, the inundations and cold periods in the northern countries with their consequences, famine and migration of the population. We possess a few historic notes from which we may infer something relating to the climate. The best proofs however the study of archeology and quartenary geology will furnish. The 3rd and 4th ce tury b. C. denote the earliest epoch of the Iron age or rather the transition from the Bronze-age to the Iron age. During the later Stone-age and the first stage of the Bronze-age, which, according to Montelius, may be put at about 1600 b. C., the Littorina epoch still lasted. The oceanic water had then freer access to the Cattegat and the Baltic, partly because the headland of Skagen was not yet formed, partly because the great depression with which the Littorina-epoch commenced had made Öresund deeper than it is now by some 5 or 6 meter. The salt water then entered the Baltic in larger quantities and the North Sea fishes found the same conditions of life in the middle of the Baltic as nowadays in southern Cattegat (see Munthe's map p. 24).

To the geologist of the quaternary period the tresholds of the Baltic in the Belts and the Sund constitute a point of vantage in estimating the influence of post-glacial changes. The numerous careful measurements of the fossil deposits on the coast of Scania and Sjælland have given the following results.

During the epoch of the Littorina sea Öresund was 5 or 6 meter deeper than it is now. The salt occeanic water could then enter the Baltic more easily than now, and this influenced the hydrographic state and the animal life of the Baltic, which then differed greatly from that of the present. From the former and present spread of the mollusc fauna Munthe has mapped out the salinity limit (the isohalines) of the surfacelayer of the Baltic at the Littorina period. A comparison between Munthe's surface map and that of the present time which I have compiled from F. L. Ekman's observations in 1877 shows the influence on Baltic hydrography caused by a livelier interchange with the waters of the ocean due to the lowering of these thresholds of the Baltic. The state of the Baltic in the neighbourhood of Gothland during the Littorinaperiod corresponds to that of southern Cattegat at the present time.

The salt water had, consequently, a far freer access to the interior of the Baltic, and with the salt water came the sea-fish whose migrations at that time ex-tended far into the Central and Northern Baltic. Munthe has been able to reconstruct the hydrographical conditions existing during the Littorina-period, in a surface-map of the salt-percentage existing at that time. If we compare Munthe's chart of the salt-proportion in the Baltic during the Littorina period, i. e., for about 5,000—6,000 years ago, with a similar map for the present day we shall find that the limit for 10 $^0/_{00}$ salt, which now lies at the Sund and Gedser, during the Littorina period lay in the gulf of Bothnia, north of Åland The annual herring migration from the North Sea, which now extends to the neighbourhood of the Sund, extended during the Littorina period through the whole of the Baltic and into the Gulf of Finland and the Gulf of Bothnia. The same state of things must have existed as regards the other sea-fish: plaice, flounder, cod and sprat, etc. Southern forms of molluscs, too, such as Tapes, Littorina, Ostrea, came with the Atlantic waters into the Baltic. Oyster-banks existed everywhere in Isefjord, and around the Danish Islands. This was the period of the »kitchen-middens»; the great fish-migration period, when the gates of the Baltic stood wide open to the fish from the Atlantic. *All the species of fish found in the Baltic, except the eel, sea-pike, and mackerel, are to be considered as relicts from the Littorina period,* at the close of which *began the rise of the land* which restored the depth-conditions of the Sund and the Belt to about their present position. This geological alteration, which was completed about 3,000 years ago, had a far-reaching influence on the fish-races of the Baltic, which are now in a greater or less degree separated from their relations in the ocean and live und other hydrographical conditions,

Surface-map (present time).

Surface-map (Littorina-epoch).

which have gradually altered their physiological life-conditions and have even commenced to set their stamp on the bodily and exterior form of the fish.

The expression »relict» must, however, be understood relatively, The ancient relicts from the days of the Polar Sea consist, at present, of some lower animal forms, mostly inhabiting the great depths and including too the arctic gray-seal, which still lives in the Baltic and in lake Ladoga in Russia. These are relicts in the original sense of the word, from a period dating 50,000—100,000 years back. Amongst them there is only one certain arctic species of fish, the Cottus quadricornis.

Among the relicts of the Littorina period we reckon, in the first place, the strömling or small herring, the indigenous herring race of the central and northern Baltic, which now lives isolated from the North Sea-herring, whose migrations nowadays do not extend past the portals of the Baltic Sea. From the first, the strömling was a local race — a relict of the great herring migrations of a couple of thousand years ago, which has survived and gradually differentiated physiologically and even morphologically into a new species.

After the maximum of the Littorina epoch, which occurred before the beginning of the Bronze-age, in the time of the »Kjökkenmöddinger» (ancient refuse-deposits) 4000—5000 years ago, an upheaval of the landsurface occurred which lessened the depth of the Öresund to something like the present. This elevation of the land was almost complete at the close of the Bronze-age 600—500 b. C. From then, for the last 2500 years the bottom of the Öresund has remained nearly constant, its elevation increasing only some 0.25 meter since that time. The atmospheric conditions also changed into the cold climate of the early Iron-age. The transition from the warm climate of the Bronze-age was according to Sernander accomplished in a few centuries, 650—400 b. C the last stage of the Bronze-age. The temperature of this epoch (»the »Fimbul-winter» of the Sagas) must have been considerably lower, for in the peat-layers from that time we find deposits of subarctic forms. From the end of the Bronze-age a gradual elevation of the land has been and is still in progress. Sernander estimates the elevation for the last 2,000 years to:

In the environments of Upsala	10 meter
On the West-coast of Sweden	5 »
In Öresund	0.24 »

On the Bohuslän-shore are found sub-fossil remains of Ostrea edulis, Tapes decussatus a. d. which formed the ancient oyster-beds of the Littorina epoch, but which now are either extinct or survive only as relicts in a few protected localities. They bear testimony both to the climatic deterioration and to the upheavel of land during and after the Bronze-age.

In Greenland, Spitzbergen, Frans Josefs land and on the coast of North America subfossil deposits are found of molluscs which must once have lived in warmer waters. This proves that the land-elevation and the deterioration of climate have passed over the entire North Atlantic coast. I will give some examples in proof of this:

The Swedish expeditions found in numerous places on Spitsbergen sub-fossil deposits of Mytilus edulis[1])Among such subfossil relicts from a more temperate sea found on Spitzbergen there are, beside Mytilus, also Cyprina Islandica, Littorina littorea and Anomia squamula, all of which can not live in the fjords of Spitzbergen under the present conditions.

On the shores of the southeast coast of the Disco-bight on Greenland A. S. Jensen[2] has found fossil shells of Anomia squamula and Zirphea crispata. The present limit of these molluscs is the south coast of Labrador and the St. Lawrence bight, which shows that during some part of the post-glacial time a warmer climate must have prevailed than now.

The chief representative of this warmer postglacial period in the mollusc-fauna of East-Grönland and of Franz Josefs Land is Mytilus edulis[3]. On Iceland it is represented by Purpura lapillus[4] a. o.

It is probable that all these southern species of molluscs lived simultaneously in the North Atlantic ocean and its ramifications during this warm postglacial period. For the more distant parts of the ocean this view still must be regarded as a hypothesis but in Sweden and Denmark we have archæologic finds excavated from the shore-deposits which enable us to discern between the warmer and the colder period and to fix the time-limit with some approach to certitude. The southern mollusc-species are found together with remains from the Bronze-age. As to the next period, the rarity of archæologic finds in the graves from the early Iron-age about 400 b. C. to 100—200 a. C. shows that the high stage of civilisation in the Bronze-age had for some reason or other declined and that the population had decreased and

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[1] G. Andersson found Mytilus also on King Charles island about 40 M. above the sea-level; the Norwegian geologist Staxrud found the same mollusc at 60 M. on Spitzbergen. V. Nordmann: Anomia squamula som Kvartær-fossil paa Spitzbergen. Meddel. Dansk Geol. Forening Bd 4 Köbenhavn 1912.

[2] Ad. S. Jensen: On the Mollusca of East Greenland I. With an introduction on Greenlands fossil Mollusc-fauna from the quaternary time. Medd. om Grönland, Bd 29. 1909 (Reprint 1905).

Ad. S. Jensen and Poul Harder: Post-glacial changes of climate in arctic regions as revealed by investigations on marine deposits. Postglaziale Klima veränderungen seit dem Maximum der letzten Eiszeit. Stockholm 1910.

[3] A. G. Nathorst. Bidrag till nordöstra Grönlands geologi. Geol. Föreningens Förh. Bd. 23. Stockholm 1901.

[4] G. Bardarson, Purpura lapillus i hævede Lag paa Nord Kysten af Island. Vidensk. Meddel. Naturhist. Fören. i Köpenhavn 1906—1907.

was less prosperous. This decline begins already in the last stage of the Bronze-age, which according to Montelius occurred 600—500 b. C. About this time another significant alteration took place. Montelius,[1] has proved *that the amber trade then took up a new route.* During the Bronze-age amber was chiefly brought from the North Sea coast and transported on the western trade-routes, the Elbe, the Weser a. s. o. to the Mediterranean countries. From 700 b. C. the western route for this trade was exchanged for the eastern trade-route along the Vistula a. s. o. which indicates *that the supply of amber was thenceforth derived from the Baltic instead of from the N. Sea.* The cause of this was, according to my opinion, the following:

The climatic deterioration which set in towards the end of the Bronze-age resembled that which occurred 1800 years later at the end of the Middle-ages in so far that violent storm-floods devastated the coasts of the North Sea whereby the districts in which amber was found: Friesland, the westcoast of Jutland and Schleswig, were destroyed. I here recall the fact that there are statements in literature which connect the invasion by the Teutons and Cimbrians into Gallia and later into Italy with a big inundation of the Sea which destroyed their homesteads in Jutland (the Cimbrian penninsula).

These catastrophies, which probably began as early as the 6th century b. C., struck directly the Scandinavian tribes who invaded the German and later the Gallic countries. Italy first felt the shock when the Gallic tribes began to raid the country. All the stages of this transmigration of the northern tribes, which was the first to shake the power of Rome, can now be traced thanks to the archæologic discoveries which were discussed by the archæologic and geologic Congresses at Stockholm 1908 and 1910. Kossinna of Berlin proved that a transmigration of the tribes from the neighbourhood of the Vistula began about 600 b. C. and Lienau of Lüneburg traced the same movement in the western provinces along the Weser. Next come the proofs to be gathered from ancient writers of History (the ancient Roman writers of History, Florus a. o.) who tell us of the Cimbrians invading Gallia and Italy threatening the Roman republic by their great victories at Noreia, where Papirius Carbo was defeated in 118 and at Arausio in 109, until Marius by his victory at Aquæ Sextiae averted the consequences of this first transmigration of the German tribes from the countries on the Mediterranean.

»*Cimbri Teutoni atque Figurini ab extremis Galliœ profugi cum terras eorum inundasset oceanus novas sedes toto orbe quærebant.*»[2] This was the primary cause of the great transmigrations in the first millenium b. C. which commenced with the decline of the Bronze-age-civilisation through catastrophies in Nature which forced the inhabitants of the North Sea countries to emigrate.

If we inquire into the physical causes of the alterations which compelled the tribes of northern Europe to emigrate we find that a maximum in the tidegenerating force of the sun and the moon must have occurred about the 3rd and 4th century b. C. This caused disturbances in the oceanic circulation such as storm-floods and inundations of the coast and a deterioration of the climate of the borderland of the N. Sea and the Baltic. Its effect on the Atlantic coast of Spitsbergen, Iceland and Greenland is traceable by the lowering of the sea-temperature which caused the extermination of the delicate southern species of molluscs, the Tapes, Anomia, Zirphæa a. o. Very likely outbursts of polar ice also occurred as happened 18 centuries later about 1300—1400 a. C.

In the Littorina epoch there were oyster-beds along the coast of Sjælland and the Scandinavian coast offered great opportunities for the maintenance of a population both with regard to agriculture and to fishery. The people of that time traded with the British Isles as well as with the Mediterranean countries[1]. Besides fur and slaves, amber was the chief article for barter. The supply of amber came then chiefly from the North-Sea coast. The principal trade-route was along the Elbe up to the Danube and then over the Brenner pass into Italy.

The climate at the culmination of the Littorina-epoch was Atlantic, insular, but with the beginning of the great landelevation it passed over into a warm and dry »sub-boreal» stage which lasted the greater part of the Bronze-age up to 600—400 b. C. when the climate deteriorated greatly and the civilisation of the Bronze-age perished with the postglacial warm period.

The land-elevation during the Littorina epoch was greatest on the Bothnian coast. North of Hernösand it attained its maximum of 288 meter. At Öresund and the Belts it was at its lowest, about 5—6 meter, which however was sufficient to change the conditions of the fish life in the Baltic in the manner already described.

In the Bronze-age, 1600—650 b. C., the Scandinavian climate was warm: all boundaries of vegetation in Sweden were then on the average 3° further north than now. In proof of this B. Sernander[3] relates the following facts.

In Sjælland millet was grown. Trapa natans, now extinct in Sweden, grew in the lakes of northern Sweden.

The hazel-tree grew in higher lat:s, and at greater height over the sea in the Swedish Nordland.

The boundary of the pine-forests lay in higher altitudes on the mountain-slopes[4]. Stipa, now extinct safe in the neighbourhood of Falköping in Vestergothland, was then quite common.

According to Sernander[5] the climate during the Bronze-age was warm and dry. The landelevation brought large areas, of the present Baltic coast of Sweden, f. inst. part of Upland, above the sea-level and numerous lakes and marshes were formed, which evaporated in the dry climate. Sernander claims to have discovered a »drying zone» in the bottom deposits of these lakes contrasting sharply with the succeeding layers which consist of clay and sand brought thither by the rivers during the next period which was markedly colder.

We have of course no report as to the state of the Greenland sea at this remote period, but we know something about the sea north of Iceland from Pytheas journey in 330 b. C. He speaks of the sea as »mare pigrum» a sluggish and congelated sea. It is curious that ice and ice-hindrance are mentioned just *then* as being typical for the northern seas and that 18 centuries afterwards, at the next maximum epoch, the Icelandic annals also report new and powerful ice-blockades of the coasts of Iceland and Greenland, whereas in the intervening time in the 8th & 9th century a. C. the Vikings appear to have met with no hindrance at all from ice in their journeys to Iceland, Green land and America. Apparently a warm and ice-less period, which favoured agriculture and shipping and allowed the Scandinavian races to expand in the powerful manner which characterizes the Viking-age, must have occurred between the interval of the two maxima of 400 b. C. and 1400 a. C. This prosperous epoch then corresponds to the former post-glacial heat-period or the Kjökken-mödding- and earliest stage of the Bronze-age

The remembrance of the bygone civilisation two thousand years earlier lived in the myths of the German race and found its expression in the Edda. According to Victor Rydberg the myths of the Edda centre around a great catastroph in Nature, the *Fimbul-winter*, or »Götterdämmerung» when frost and snow ruled the world for generations.

One relict of the lost civilisation appears to have outlived the »Fimbul-winter». By the ancient temple of Upsala stood an enormous tree, perennially green, which is thus described by Adam von Bremen: »*Prope illud templum est arbor maxima late ramos extendens semper viridis in hieme et æstate, cujus illa generis sit nemo scit. Ibi etiam est fons ubi sacrificia paganorum solent exerceri et homo vivus immergi.*»

Sven Nilson expressed the opinion that the holy tree of Upsala was a yew-tree. Fritz Läffler in a recently published paper »Det evigt grönskande trädet vid Upsala Hednatempel» (i Fästskrift till H. F. Teilberg), has expressed the same opinion founded on a large collection of proofs. Adam von Bremens statement: »no one knows what kind of tree it is» has caused some difficulties because nowadays the yew-tree can be grown in Upland and is still found in western Norway although it requires a more temperate climate than ours. In the Swedish museums also prehistoric vessels made of yew are preserved. Conventz, who examined these finds, which belong to the period 800 b. C. to 900 a. C., reports however, that vessels made of this wood-material are very rare in the ancient provinces of Sweden. This Schübeler corroborates. Nathorst reports that no fossil or sub-fossil remains of the yew have been found within the precincts of ancient Sweden. The vessel in the museum of Stockholm was found in Bohuslän and the two vessels in the museum of Lund are probably from Danish territory. Läffler says: »ancient Sweden would thus be devoid of finds of antiquities made of the wood of the yew-tree. This would sufficiently explain why the holy tree of ancient Upsala was said to be of a kind unknown to the inhabitants of that place in 1100».

Läffler comes to the conclusion that during the Viking-age the yew was extinct in Sweden, because it had been exterminated. He believes, that the big tree at Upsala was a remnant left from a pre-

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[1] O. Montelius: Handeln i forna dagar. Nordisk Tidskrift 1908.

[2] Florus III 3, 1. Ammianus Marcellinus (Leb XV, 9) speaks of the tradition amongst the Druids that their ancestors had been expulsed from the islands on the other side of the Rhine by hostile tribes *and by a great invasion of the ocean.*

[3] R. Sernander Postglaziale Klimaschwankungen im Skandinavischen Norden (Gerlands Beiträge zur Geophysik).

[4] Th. C. E. Fries Swedish Climate in the late-quaternary period XI Geolog. congress Stockholm 1910.

[5] Sernander. Sv. Bot. Tidskrift 1910. Bd. 4.

vious period, »It cannot be denied, that such a tree may have grown from a seed brought from abroad, or that the population may have protected and guarded this relict of a past vegetation.»

In this conjecture Läffler is probably right. The yew-tree grows very slowly and may certainly attain an age of 1000—2000 years. We have every reason to believe that the holy tree of Upsala was more than 1000 years old and had survived from the Bronze-age.

Great transmigrations af people occurred also in the second millenium b. C. Then too the direction of the movement was towards the Mediterranean countries and it is not impossible that its cause may also have been unfavourable climatic conditions in northern Europe, which, according to our theory, should have culminated about 2000 b. C. It should also be remembered that at the time of the melting of the inland-ice in Sweden, cold and warm periods must have alternated.[1] The traces left in the stratified clays indicate that the melting process was not uniform the whole time through. It would be of great interest to ascertain whether some kind of periodicity can be traced in the ice-melting process.

Going back so far as to the melting of the ice-cover or about 9000 years ago we have to take into account one more fact, i. e. the change in the excentricity of the ecliptic and in the inclination of the earths axis against the ecliptic, which according to Ekholm and Charlier must have caused a warm period about 9000 years ago (and a cold period about 28000 years ago).

If we keep to the theory that climatic variations are caused by cosmic agents, then we must conclude that the greater variations which accompany the geological epochs (the glacial period, the tertiary period a. s. o.) are ruled by changes in the ecliptic and in the position of the earth's axis and the lesser variations, which are the subject of this investigation, are ruled by changes in the position of the orbit of the moon of which the longest periods encompass some 18 centuries with minor periods of 93, 18, 9, 4½ years a. s. o., the briefest, or those which influence the weather, measuring months or weeks.

Several maxima of the tide-generating force have fallen in the interval between the melting of the inland-ice and the end of the Littorina-epoch. These maxima have been accompanied by catastrophs in Nature such as storm-floods, inundations a. s. o. On the coast of Scania there are remnants of such catastrophs in the shape of shingle-banks, as e. g. the »Järabacken» which must have been formed in prehistoric time. It would be interesting to find out if its formation coincided wit the critical epochs of the Stone-age and the Bronze-age here described.

Sven Nilson held that Järabacken was formed by a violent uproar of the sea probably at the end of the Bronze-age, which event marked the time of the great emigration of the northern tribes 600—100 b. C. Recent geologic and archæologic investigations make it probable that Järabacken belongs to an earlier period. De Geer who has traced this formation all round the coast of Scania beleives that it marks the maximum limit of the sea during the Stone-age.

It is a recognized fact that after the glacial period great variations of climate have occurred. My effort has been to show in this paper that these climatic variations are connected with variations of the tide-generating force. At the epochs when maxima in the tide-generating force occur, changes in the climate have occurred which in some cases have assumed a catastrophic character whereas at the time of minima the climatic conditions appear to have been more stable and uniform. I have shown that there is an interval of about 18 centuries between the absolute maxima, the last one occurred at the end of the Middle-ages and the last minimum at the beginning of the Viking-age. The diagrams on page 7 show the position of the lunar orbit in 1434, 1894, 1903 and in 1912. The diagrams show clearly the difference between our time and the time of absolute maximum 500 years ago. It is also evident that a secondary maximum of the type we call perihelion-apside has approximately occurred within the last 18 years at the time of the wintersolstice and the earths perihelion.

These constellations have shown their effects in certain changes of short period in the climate, but chiefly in disturbances of the ice-conditions in the arctic and antarctic seas and the polar currents.

[1] At least three such alternations can with surety be traced in the clay deposits examined by de Geer and his disciples and there are probably still more to discover.

Wald. Zachrissons Boktryckeri A.-B., Göteborg 1914

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