of California, constitute an exemplar of intensive oceanographical investigation. By systematically and repeatedly tabulating and mapping standardized values of the temperature, salinity, density, currents, and gas content of the water of the Pacific Ocean, serially observed at ascertained intervals of depth from the surface to the bottom in fixed locations, the variations of these physical elements, with time and locality, in their distribution in the depths, have been revealed to an important extent within the confines of the oceanic tract in the region of the seat of the Institution, stretching from San Diego to Point Concepcion and embracing an area of more than 10,000 square miles.

It is the present purpose of the Section of Physical Oceanography to foster the labors of these agencies and the similar ones which are contributed by the Navy and the Coast Survey and to seek opportunities to supplement them and link their operations, as far as may be, into coördination with the operations of the oceanographers of Japan, of Australia and New Zealand, of the North Sea International Council of Exploration, and the Mediterranean Sea International Council of Exploration. And, through the formation of committees, to provide that consideration shall be given to the problems of evaporation and heat transference and the interrelations between oceanography and meteorology, to the problems of dynamic oceanography including the variations of mean sea-level and the tides and their manifestations in the depths as well as the surface, to the investigation of the chemical and physical properties of the waters including the penetration of light, to the investigation of the origin and distribution of bottom deposits, to the problem of ascertaining the conformation and topography of the basins, and to the ways and means of advancement in the domain of physical oceanography.

THE PROBLEMS OF VOLCANOLOGY

BY HENRY S. WASHINGTON

INTRODUCTION

Of the various sciences represented in the American Geophysical Union that of volcanology is perhaps the most complex and has probably most points of contact with the other geophysical sciences. This complexity and variety in the problems presented by the study of volcanoes arises, in part, from the fact that they are, as has been well said, "natural laboratories." Also the distribution and many of the activities of volcanoes are closely connected with some of the physical, as well as the chemical forces that are involved in the formation and in the present condition of the earth.

In presenting some of the main problems of volcanology, we may begin with those that are essentially and more purely volcanological, and then take up seriatim the consideration of certain problems in which the other sciences represented by sections of the Union may enter. Because of the limitation of space only a brief enumeration and presentation will be made, and no adequate discussion will be undertaken. I am much indebted to various members of the Union for some valuable suggestions, which will be mentioned in their proper places.

VOLCANOLOGY

A word may be said as to the name of the science. The spelling, *volcanology,* (rather than *vulcanology*), has been adopted officially by the Executive Committee of the Union, following the report of a sub-committee. The decision was arrived at chiefly in accordance with the dictum of the Century Dictionary (*s. v. vulcanism*): "The words *volcano* and *volcanic* are firmly fixed in English, and the former is in universal and exclusive use among those who speak that language. Hence all the derivatives should be spelled accordingly."

It is now well recognized that there are different types of volcanoes, distinguished by their form and structure, as well as (generally) by the differing kinds of volcanic activity, and that these differences are to a large degree dependent on, or at least coincident with, the differing chemical types of the volcanic material, such as, for instance, whether rhyolitic, andesitic, or basaltic. It follows that the activity or form of any one volcano, such as Vesuvius, Kilauea, or Stromboli, cannot be taken as typical of all volcanoes generally. This important principle does not seem to be generally recognized.

One of the first and most fundamental needs for the proper study of volcanoes is the compilation of a complete and fairly detailed catalogue of volcanoes (suggested by Wood and the writer). Such a catalogue should list all known active, dormant, or recently extinct volcanoes. It should give briefly, so far as known or ascertainable, the geographical position; the hypsometrical and areal data, including those of the crater; the general petrographical characters of the lavas, with the general order of succession of the different types; whether active, dormant, or extinct, with the geological period of commencement if possible; the general types of volcanic activity; a chronological list of the known eruptions, with some indication of the degrees of intensity; and a bibliography of the chief sources of information as to each volcano; with possibly such other data as may present themselves.

The older lists, as those of Daubeny (1848), Landgrebe (1855), Scrope (1862), and Fuchs (1865), are far from being complete; while even the more recent ones, such as that of Mercalli (1907), though they list many volcanoes not known to the earlier volcanologists, are yet themselves not complete, nor do they give many of the varied data mentioned above as desirable. The compilation of such a catalogue might be entrusted to a special committee.

Another great desideratum is the keeping of a systematic record of all known volcanic events, eruptions, indications of renewed activity, and so on. This should be as complete as possible, and might be compiled by another, or the same, special committee, possibly with the assistance of some news-clipping bureau and correspondents at various volcanoes. In such a record, and in all other official volcanological literature, the sensational features should have a minimum of stress laid upon them.

If possible, some systematic investigation of the little known volcanoes and volcanic regions should be undertaken. This applies especially to those of the islands in the Pacific and Atlantic Oceans, and Daly, in an important paper, has called attention to the paucity of our knowledge as to the first of these. It is possible that such an investigation may be started by the coming Pan-Pacific Congress at Honolulu, at which the scheme will probably be proposed. For this purpose the assistance and coöperation of intelligent persons living in, or trading among, the various islands may be obtained, as well as, possibly, that of some private expeditions. Even the collection of chance specimens from the little-known islands would be of great value.

In this connection it may be suggested that the early history of our own western volcanoes should be investigated, as by search through the records of the early explorers and settlers, for possible mention of volcanic activity, and the verification or disproof of some such reported occurrences. The lavas of these volcanoes are well known, but the character of their volcanic activity has been much neglected.

Apart from the purely scientific question as to how and why a volcano "works," is the practical, and scientifically equally interesting, one of the prediction of eruptions. Unfortunately, with two or three exceptions, we know of volcanic activity almost entirely as displayed only during eruptions, and especially major ones. It is much like studying a complicated machine only when it is working at full speed; we can understand better the relations of the parts and their working if the machine is examined when the parts are moving slowly or are at rest.

For the prediction of eruptions, and for the solution of many other volcanological problems, prolonged, continuous, and systematic observations on volcanoes are absolutely necessary, not only during eruptions, but during the quiet intervals that precede and follow eruptions. Such observations have been carried on at Vesuvius, at first by Mercalli from 1892 to 1906, and by Malladra from about 1912 to the present time. Similar observations have also been carried on for nearly ten years at Kilauea by Jaggar, at times with the assistance of Perret, and Wood. It is hoped that the very detailed observations of Malladra will soon be published; they will form an invaluable contribution to volcanology. The records of the Kilauea observing, kept by Jaggar since 1911, are especially full and detailed and constitute what would be, if published, one of the most valuable contributions to volcanology yet made. It is of the greatest importance to our science that both these stations be maintained, and their observations published, so as to continue the important work so well begun. And it is also important that similar stations be established and maintained at other volcanoes of types different from these two. In its type of activity Kilauea is very unusual, while Vesuvius, though more normal in its form of activity, is very unusual in the character of its ejected material. Stations for continuous observations over a long series of years are needed at volcanoes of the rhyolitic, andesitic, and basaltic (besides Kilauea) types. These should be established at volcanoes which are more or less continuously active, and with a fair prospect of some eruptions from time to time. Several volcanoes in Japan and Java suggest themselves as favorable, and there might be mentioned also Apia in Samoa, Izalco in San Salvador, Stromboli and Santorini in the Mediterranean, and some volcanoes along the Andes and in Mexico. The establishment of such stations offers, of course, many difficulties, but it would be well for the Section to bear this in mind as one of the most important, even if one of the most difficultly realizable, objects of effort.

At any such station the continuous observations to be made would be many and various, including, for instance, daily notes on the state of the crater and fumaroles, the noises emitted, the microseismic vibrations, the weather and barometric data, etc. With all this, there would be opportunity for the collection of specimens from the various flows, fumarolic salts, gases from the lava; measurement of the earlier flows; observation of the temperature of the lavas; and many other matters. The collection of volcanic gases, and study of the best methods for this, are of special importance.

It is not probable that many of these stations will be maintained, at least in the near future, and, as the study of the phenomena of great eruptions is also of great importance, it would be very desirable if some arrangements could be made (possibly international as well as national), through which any usually dormant volcano that was reported to be showing signs of renewed activity or to be in a state of eruption might be visited immediately by competent observers. This has been done for several great eruptions, such as Santorini in 1866, Mont Pelée in 1902, Vesuvius in 1906, and Sakurajima in 1914; but always in a haphazard way, thus diminishing materially the value and scope of the observations in some cases. The immense value of such visits, however, is shown by such monumental works as those of Fouqué on Santorini, the British and Dutch at Krakatoa, and of Lacroix at Pelée, of Perret, Omori, and Kato at Sakurajima, with others of scarcely less importance. It may be mentioned here that we may hope soon to have a similarly complete and monumental report by Perret on the Vesuvius eruption of 1906.

Among other problems with which volcanology has primarily to deal the following may be mentioned:

Study of the rôle played by earth strains is suggested by Wood, who points out that, although such factors as accumulated gas tension and possibly others, may enter, yet "a general cause of volcanic extrusion [may be] due to the so-called mountain building forces as builders of strain, and to certain variable stresses acting as trigger forces." He suggests that study of this phase of volcanology would be of interest also "to the geological seismologist, the physical geologist, and the student of isostasy." The importance of arriving at some estimate, however crude, of the magnitude of volcanic forces, possibly as a measure of crustal deformation forces, is pointed out by Wright.

A systematic and properly conducted study of thermal gradients in the crust is suggested by several (Daly, Van Orstrand, and the writer). Such a study should be carried out at carefully selected points, the stations being chosen with due regard for both the proximity and the absence of volcanoes, differences in the underlying rocks and their geological structure, the absence of secondary sources of heat (such as the proximity of ore bodies), and with proper and well-controlled means of measuring the depths and temperatures. It is reasonable to suppose that such a systematic project might be carried out with no very great difficulty or prohibitive expense. It is needless to say that the results obtained by such properly controlled means would be of the greatest value for our study of the interior of the earth, and would supersede many of the, for the most part, haphazard and not mutually comparable data that are now available.

Connected with this matter is that of the investigation of the thermal gradient and the sub-surface conditions in the mass of an active volcano, both on its flanks and within the crater. Such investigations might throw light on the rôle of gas inter-reactions as causal in the production or maintenance of volcanic heat, as has been suggested by Day, and they might also be of great practical importance in the study of the possible utilization of volcanic heat as a source of energy, a matter to which my attention was directed in Italy, both before the war and during the past year. The study of the possibilities of regions of geysers and hot springs, as the Yellowstone, and in the Hawaiian Islands, along this line, is also suggested. In this connection the present successful utilization of the soffioni at Larderello in Tuscany by Ginori Conti may be recalled.

The problem of radioactivity as a source of heat, and the possible formation of a special committee for this purpose, is suggested by Daly, who also suggests the study of the "meaning of the earth's rigidity."

As minor matters may be mentioned the study of geysers and their mode of action, and also the formation or unification of a terminology for lava structures, since "aa" and "pahoehoe," the two terms most commonly used, by no means cover all the types that are met with.

VOLCANOLOGY AND GEODESY

The apparently intimate correlation between the average chemical composition of the igneous rocks of the continents, oceanic floors, and of smaller petrographical provinces (as a means of arriving at comparable densities of their masses), and their elevations, together with the bearing of this study on the theory of isostasy, has been pointed out recently by the writer. W. Bowie suggests the continuation of such investigations "as a contribution to the study of isostasy." He also suggests the advisability of establishing gravity stations in the immediate vicinity of volcanoes, the selection of appropriate localities to be made with the coöperation of volcanologists. He thinks that there is reason to believe that "areas where volcanoes are active are probably in a high state of isostatic equilibrium," and the determination of this and analogous points would be of great service to both sciences.

VOLCANOLOGY AND SEISMOLOGY

At the outset it must be emphasized that, contrary to a wide-spread belief, there is little connection between volcanoes and most earthquakes, though their frequently contiguous localization may be due to one and the same cause, such as a fracturing of the earth's crust. By far the great majority of recorded earthquakes (it has been estimated at about 95%), and these the most important, are due to crustal movements and, so far as we know, have no direct connection with volcanoes or their activity. The small remainder of earthquakes of volcanic origin are mostly very local and of comparatively small magnitude. Notwithstanding this, the two sciences are in contact at several points.

The study of the small number of truly volcanic earthquakes is, of course, intimately connected with the study of the volcanoes that produce them; while, conversely, the question of the influence of earthquakes as possibly initiating volcanic eruptions or other activity is an interesting field for study.

The study of volcanic tremors of small amplitude and energy, during periods both of quiet and of eruption, is of great importance, and would naturally form part of the systematic, continuous study carried on at a volcano station, as has been done both at Kilauea and Vesuvius. This may be expected to be of very material aid in the future prediction of eruptions. For such observations some of the forms of seismographs and other seismological instruments, duly modified to suit the different conditions, are necessary, and seismological principles or data would also enter into the study.

VOLCANOLOGY AND METEOROLOGY

As has been already noted, the systematic observation of certain meteorological data, especially barometric pressures and rainfall, would form an important item in the routine observations at a volcano station; the former entering into the question of the "trigger forces" needed to start an eruption, and the latter as bearing on the question of the origin of the water present in volcano clouds and gases.

Humphreys called attention some years ago to the influence of the finest volcanic dust, blown into the upper regions of the atmosphere during first magnitude eruptions and suspended there for prolonged periods, in lowering the solar constant of radiation, and thus affecting the weather over wide areas for long periods. This has been invoked to account for periods of glaciation. A knowledge of the chronology of volcanic eruptions is necessary for their proper correlation with meteorological and radiation data, and the further study of this theory.

In this connection mention may be made of the possible utility of the study and identification of volcanic dust collected at great distances from a volcano in eruption, as bearing on the study of the currents of the upper atmosphere.

The possible influence of the supposed blanketing effect of carbon dioxide on past climates has long been a favorite hypothesis, and as it is known that this gas is given off by volcanoes, a possible line of research is indicated connecting climates with periods of great volcanic activity—a matter that has already received some attention.

A minor problem, and one that has been little studied, because of the rarity of its occurrence, is that of the blue or green color presented by the sun during some eruptions, as that of Krakatoa in 1883. Especial attention might be paid to this by the observers of future eruptions.

VOLCANOLOGY AND TERRESTRIAL MAGNETISM

Bauer calls attention to the "local changes in the distribution of the earth's magnetic forces in the neighborhood of volcanic eruptions." He also lays special stress on the investigation of such phenomena as the world-wide magnetic disturbance that took place coincident with the eruption of Pelée in May, 1902, and the fact that no such world-wide disturbances seem to have occurred in connection with that of Krakatoa in 1883. This is a problem in which the observations of local observers might be of great value, were their attention called to its importance and their observations properly directed. The lightning flashes in the volcanic cloud, and other such phenomena, during eruptions, are also of interest and are probably worthy of study.

Bauer also suggests the problem of electric currents in the earth's crust during volcanic eruptions, such as have been observed by Palmieri at Vesuvius. A minor point is the magnetization of lava flows, and that of clay beds covered by them; while there might also be mentioned here the study of fulgurites—the vitreous tubes and patches formed by lightning strokes fusing the rock of the summits of volcanoes, (as Ararat), and other places.

VOLCANOLOGY AND PHYSICAL OCEANOGRAPHY

The most important point of contact between these two sciences is presented by submarine eruptions. Far too little is known of these occurrences, either as to their characters or their distribution over the ocean floors. For their study a most important and but little gleaned field of information is furnished by ships' logs, and I would suggest here the advisability of examining the thousands of ships' logs for records of submarine eruptions. This might be done through a duly appointed committee, with the coöperation of the Section of Oceanography, and with the assistance of the naval and other maritime authorities and ship owners, in whose hands the logs may now be. The data revealed by such an investigation would be invaluable for the study of submarine eruptions, and also for that of other important geophysical problems, such as earth fracture lines and lineaments, the origin of "tidal waves," etc. The submarine cable companies might also furnish valuable data on this subject from their records of broken cables, as in the case of the Aeolian Islands. I recommend this project most strongly for the consideration of the two Sections most interested.

Another problem is that of the material of the deep sea deposits, the study of which was first taken up by the "Challenger" expedition. The "red clays," as is well known, are composed largely of the decomposition products of volcanic material, and their study should be carried out more systematically and extensively than is being done at present. Further study also of the included, and too little known, chondritic and manganese nodules would also be of interest; while the study of blocks of rock (many of them volcanic) dredged from the depths also presents many features of interest. Some provision or arrangement might be made for the preservation and study by some central body of any such material that may be collected in the future. In connection with this the importance is urged of making special effort to obtain rock specimens, or sea floor deposits, from the immediate vicinity of submarine eruptions, or from areas of the sea floor that are known to be specially subject to such disturbances. These would throw much light on the petrographical and other characters of such volcanoes, and the information thus yielded would be very useful in several ways.

VOLCANOLOGY AND GEOPHYSICAL-CHEMISTRY

It is needless to dwell on the close connection between these two sciences —closer indeed than that between any other pair of the geophysical sciences. Some phases have already been alluded to on a previous page of this report, and the matter is also touched on in the portion devoted to the Section of Geophysical-chemistry. It will suffice here merely to indicate briefly some of the main points of interest.

The study of the formation of volcanic rocks and of their component minerals is one of the utmost importance to some phases of the study of volcanoes. Of similar importance is the study of the gases contained in volcanic and other igneous rocks, as well as of the gases given off by volcanoes in activity, with experimental laboratory study of their equilibria and possible interreactions. As is well known, all these, and similar problems form objects of investigations carried out at the Carnegie Geophysical Laboratory.

The formation of volcanic salts and other fumarole products, as well as the action of the fumaroles themselves, their temperatures and other characters, also come under the domain of geophysical-chemistry. Among other subjects may be mentioned: the determination of the actual temperatures of lavas of different compositions, and the thermal and luminous radiations of molten lava; the study of volcanic flames with the spectroscope; the melting-points or intervals of solidified lavas, especially as compared with the temperatures at which they issue; the expansion of the included gases as a factor in producing the various types of lava texture, such as the scorias and pumices; the formation of jointing through cooling, whether on a large or a small scale; the specific heats, compressibilities, thermal expansion coefficients, densities, and other physical or physico-chemical data, of rocks and rock minerals; the viscosity of lavas and its relation to temperature, chemical composition, and gas content. Many others suggest themselves, but the possible list is too long for enumeration here.

VOLCANOLOGY AND MISCELLANEOUS SCIENCES

In a previous section we have already touched on the connection with engineering in the possible utilization of volcanic heat. There may also be mentioned the application of engineering to the prevention of destruction by lava flows or eruption-bred torrents of mud on the flanks of volcanoes.

In connection with botany and related sciences there may be mentioned the subject of the effect of volcanic gases on different kinds of vegetation, a study that is being made at Vesuvius. The problems of the reclamation for agriculture of areas covered with recent lava flows or thick deposits of volcanic ashes or dust is also one of great practical importance in many volcanic regions. It may be mentioned, in this connection, that the recent expedition to Katmai, under Dr. Griggs, was undertaken primarily for the study of the vegetation of the region devastated by the eruption. Though the conditions are almost diametrically opposed, the main object was like that of the study of the Salton Sea flora by the Carnegie Desert Laboratory. Study of methods for the commercial extraction of potash from certain types of lava, as those of the Italian volcanoes, is also a matter of possibly great importance for agriculture in the future.

Finally, to leave the earth, the suggestion is made that some knowledge of the character and chemical composition of the rocks of the moon, and thus possibly a decision of the question of the volcanic or non-volcanic origin of its "craters," might conceivably be arrived at by astronomers, through study of the maximum polarization angle of various portions of the moon's surface, such as the floors of the "seas" and the "walled plains." From the determination of this, calculation of the index of refraction of the material is a simple matter. The difference between the refractive index of a rhyolitic glass (*ca.* 1.490) and that of a basaltic glass (*ca.* 1.590) is so great that it would seem to be possible to obtain some general or at least roughly approximate knowledge of the general composition of the surface rocks of the moon, especially if they are glassy lavas. We should be able, in any case, to determine thus whether all parts of the moon's sur face are composed of the same material.

AN OUTLINE OF GEOPHYSICAL-CHEMICAL PROBLEMS

By ROBERT B. SOSMAN

The subject-matter of geophysical-chemistry may be defined as "the physical properties and chemical reactions of the substances and aggregates that make up the earth". It may therefore be roughly divided into two parts: A. Properties and reactions of materials accessible at the earth's surface. B. Properties and reactions of materials in the earth's interior.

Each of these may again be sub-divided as follows:

1. Properties and reactions of individual chemical substances; for example, the silicate minerals.

2.. Properties and reactions of aggregates; for example, oceanic water, silicate rocks.

3. Properties and reactions of larger units of matter; for example, glaciers, batholiths.

A. MATERIALS AT THE EARTH'S SURFACE

CHEMICAL SUBSTANCES

A relatively small number of "common" oxides serves to make up practically 98% by weight of the outer ten miles of the lithosphere. All the other elements and compounds known to chemistry are included in the remaining 2%. From the geochemical standpoint, therefore, we may divide chemical substances into two classes: "abundant" and "rare."

The "abundant" oxides are, in the order given by averages of a great many analyses of terrestrial rocks, as follows:

SiO_2	About 60 per cent by weight
Al_2O_3	About 15 per cent by weight
FeO, Fe_2O_3	About 6 per cent by weight