WHAT WE KNOW ABOUT THE EARTH.—II.*

MANY PUZZLING QUESTIONS ANSWERED BY SCIENCE.

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THE awful phenomena of earthquakes, in which the firmest thing we know—the ground on which we walk—begins to shake, and in which often in a few moments all human work is reduced to ruins and thousands of human lives destroyed, have always powerfully attracted the attention of men. Fervid fancy was tireless in picturing ever new horrors. It was supposed that the tremors were due to the movements of fabulous monsters, or to the malign fury of demons, or to the anger of the deity. With the increase of civilization, natural science began to occupy itself with the phenomena of earthquakes. At the present day civilized nations have united in common systematic work. The Göttingen Geophysical Institute on the Hainberg represents one of the German seismologic stations. For some years the Göttingen Scientific Society has maintained a station for geophysical observations in the tropical belt of the Pacific, at Apia, on German Samoa, and one of its adjuncts is a seismologic station.

At the first the observation of earthquakes was naturally confined to the direct investigation of the traces left by them. Soon, however, special instruments were employed in order to gain a more accurate idea of the nature and magnitude of the earthquake movements. As these instruments were improved, the scope within which tremors could be observed at a distance from their focus grew wider. Finally it appeared that instruments of sufficient delicacy are able to record the tremors produced by every large earthquake originating anywhere on the globe. Since that time—from about 1890 onward—earthquake investigation gained a mighty impulse; for the observer was henceforward no longer confined to local investigations, but enabled to trace the earthquake processes of the whole earth from any station, no matter where situated.

Science asks, What is the significance of earthquakes in the history of the development of the earth? What is the nature of the shocks that are propagated to a distance? What paths do they follow? What do they tell us regarding the condition of the globe? Anxious humanity will also demand an answer to the further question, How can we know what localities are endangered, what antecedent symptoms may be used as warnings, and what sort of structures must be erected in order to afford protection?

You see the tasks are numerous and involve profound interests of science and of human life. Thus we can understand the extraordinary zeal with which earthquake investigations are conducted nowadays. I must resist the temptation to present to you a general picture of this activity and of its achievements, for my time is drawing to a close. For the purposes of our present theme, we are concerned only with one question, What do earthquake observations teach us concerning the condition of the globe?

Volcanic eruptions are accompanied by earthquakes; earthquakes also result from the collapse of subterranean caves, for example, those hollowed out by water. But both the "volcanic earthquakes" and the "collapse earthquakes" are only of subordinate importance for the globe. In the main, earthquakes occur when sudden displacements take place in the earth's crust, along fissures either of ancient origin or newly developed. The displacements thus formed on the surface, and the shocks by which they are accomplished, are the factors that produce the fatal effects. But all this I mention merely in passing. The essential point for our present purpose is that earth tremors starting from the focus of the quake pass through the body of the globe as elastic waves. To these earthquake waves we must now turn our attention.

The oscillations of the ground caused by these waves are recorded by the seismometers of the seismologic stations. It is found that the oscillations of great earthquakes are perceptible for hours. At the same time various kinds of oscillations may be distinctly observed, which pass through the globe at different rates of velocity. The swiftest are those waves in which, as in the case of sound waves in the air, the oscillations take place in the direction of the movement of propagation to and fro, the longitudinal waves, as they are called in science. Transverse waves, in which, as in the case of light, the oscillations take place at right angles to the direction of propagation, show

only half the velocity of the longitudinal waves. Considerably slower even than the transverse waves are the rocking waves, resembling sea waves, inasmuch as they pass along the surface and do not reach a great depth. It is precisely the last-arriving surface waves that as a rule cause the greatest oscillations of the ground, far from the focus, and which accordingly become most prominent in the records of the instruments; they are on that account called "principal waves." In contradistinction to them, the longitudinal waves first arriving are called "first precursors" and the next-following transverse waves are called "second precursors."

As the principal waves are limited to the surface, they can give us no information on the condition of the deeper parts of the earth, and hence we are not now concerned with them. The case is different with the "precursors." Their behavior shows that their paths lie through the body of the globe. From the observations made at the surface we are, in fact, enabled by the aid of calculation to trace their paths with accuracy through the depths of the earth. How is that possible? I must attempt to give you at least an approximate idea of it.

If the precursors remained at the surface of the earth, the velocity with which they are there propagated would have to remain the same at all distances from the focus. Now, this is not the case. On the contrary we note that the velocity of their propagation increases the farther we remove from the focus and the closer we approach to the opposite point. We are thus led to the conclusion that these waves must find paths of more rapid propagation in the depths of the earth. By studying the manner of their propagation along the surface it is possible, by means of mathematics, not only to calculate their paths in the interior of the earth, but also to ascertain the velocity of their propagation along those paths. It is a beautiful illustration of the power of mathematics that all this can be done without any appeal to unsafe hypothetical assumptions. We are merely concerned with reliable deductions from the observations themselves. The more accurately we are able, by the aid of the seismologic stations, to record the rate of propagation of the waves on the surface of the earth in point of time, the more accurately are we able to trace the paths and the velocity of the earthquake waves in the interior of the earth. At this moment there are probably one hundred seismologic stations in existence, with instruments which constantly record the earthquakes. Quite a number of these stations possess instruments so fine and so carefully watched that the arrival of earthquake waves can be recorded with precision to within one or two seconds. Thus even at this day, when we can look back over hardly more than ten years of more intense work, we possess a mass of records that we are able to use for reliable deductions. And what do we find? I hope that you will feel some astonishment when I announce the results, and to share with me to some degree the investigator's joy, when I address you as the representative of geophysics.

It is found that to a depth of about 1,500 kilometers the velocity both of the first and of the second precursors steadily increases, to become suddenly almost constant from that point onward. It is probable that there is a gradual increase in velocity even beyond that point; but this is so slight that existing observations do not as yet permit any definite conclusion regarding it. This statement is valid to a depth of about 3,000 kilometers, that is to say, about halfway between the surface and the center of the earth. Existing observations do not permit us to carry our inferences farther into the interior. But I think even this is a respectable achievement, and, moreover, we have every hope of farther advance and eventually reaching the center.

We will now turn to the point in which we are specially interested. While the behavior of the earth's strata changes at a uniform rate down to a depth of about 1,500 kilometers, a sudden jump occurs at that depth. What does this mean? Evidently we have to infer that at a depth of 1,500 kilometers there is a sudden change in the condition of the earth's strata. Recall now, if you please, what I said in the beginning of my address concerning the conclusions which we are authorized to draw concerning the masses in the interior. We found that in all probability the earth contains a metal core embedded in a rocky mantle some 1,300 to 1,600 kilometers thick. You will admit

that the evidence furnished by earthquake study agrees with this conclusion in a remarkable manner. We are justified in assuming that the place of the jump in the propagation of earthquake waves is precisely the passage from the rock mantle to the metal core. This vanishes the uncertainty which affected our conclusions concerning the composition of the earth out of core and mantle, so long as we were able merely to appeal to observations on gravitation and on the flattening of the earth. With greatly strengthened confidence we may now affirm that the earth consists of a metal core enveloped in a rock mantle. Previously we were only able to estimate the thickness of the rock mantle in a crude way as approximately 1,300 to 1,600 kilometers. The earthquake phenomena now tell us that the thickness amounts to about 1,500 kilometers. The residuum of uncertainty can hardly exceed 100 kilometers. Similarly, our previous inference regarding the density of the metal core now attains increased certainty, and the conclusion that the material of the metal core is mainly iron gains a new support.

I have not yet given you any indication of the velocity of propagation of earthquake waves. I will now state that the first precursors traverse near the surface about 7 kilometers in a second, and in the metal core about 13 kilometers in a second. In case of the second precursors the corresponding figures are about 4 kilometers at the surface and 7 kilometers in the metal core. The principal waves, which move along the surface of the earth, traverse about 3.4 kilometers in a second.

The mathematical theory of elasticity enables us to infer the elastic properties from the velocity of the elastic waves. Thus the earthquake observations of the present day also place it within our power to determine the elasticity of the earth's strata with accuracy down to half the distance from the center. We find that as we descend, the rigidity of steel, that is to say, its elastic resistance to changes of form, is exceeded after a few hundred kilometers. The metal core shows a rigidity four times as great as that of steel. All this agrees perfectly with what we learned concerning the rigidity of the earth as a whole, from the tides and from the oscillations of the poles. We are also enabled to calculate the compressibility of the earth's strata by pressure. As a definite inference therefrom, we learn that the increase in density toward the earth's interior can not be explained by the pressure of the overlying strata. What I was at first able to present to you merely as a conjecture, namely, that the differences in density in the earth indicate differences in material, thus becomes a definite and precise outcome of observations.

But how are we to explain why the rigidity increases so rapidly toward the interior, and in the core is even four times as great as the rigidity of steel, seeing that we are to suppose the mantle to be composed of the known rocks, and the core mainly of iron? The answer is very simple: Evidently we have here the effect of the pressure of the earth's strata, which forces the molecules closer and closer together the farther we penetrate into the interior of the earth. As proved by calculation, the pressure at the surface of the metal core amounts already to half a million atmospheres and increases toward the center of the earth to about 3,000,000 atmospheres. Under such circumstances, it may readily be conceived that there must be an increase in rigidity. The fact that earthquake phenomena furnish information concerning the behavior of matter under such high pressure is of the greatest importance for physics, for by our human appliances in laboratories we are enabled to produce a pressure of at most a few thousand atmospheres.

You will probably expect me to say something regarding the temperature in the interior of the earth. I can not say much. That the temperature is very high is proved by the rapid rise observed wherever men have penetrated into the interior—in mines, in railway tunnels, in drill holes. It is also proved by the hot springs and, above all, by the volcanoes. Near the earth's surface, where we are able to make direct observations, we find an increase of temperature of about 2 to 4 degrees centigrade for every 100 meters. Considerations based on these observations suggest that in the far interior of the earth the temperature must surely attain some thousands of degrees centigrade. That the material of the earth nevertheless does not become liquid or even gaseous at such high temperatures, but is proved to be very rigid, must be

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attributed to the extreme pressure, which packs the molecules together and robs them of their mobility. Keeping this in mind while trying to ascertain the physical behavior of bodies with increase of temperature, we may infer that the temperature in the interior of the earth must certainly remain below 9,000 degrees; in all probability it does not even reach 4,000 degrees.

Let us look back over everything that has been discussed to-day. As the verdict of science, we learn that the earth has become, as it were, transparent to our view. In particular the earthquake waves render to the geophysicist somewhat the same service that the Röntgen rays render to the physician who tries to examine the human body.

If we consider the feebleness of human means, natural science may well be proud of its achievements. But we should not forget also that the retrospect affords us no less motive for humility; for, as I tried to point out, success was only achieved by an immense expenditure of labor and pains. And yet I have reported to you only the advances, and have said nothing of the failures and mistakes, nothing of the labor that was spent in vain.

In fact, in this respect geophysics does not differ from the other branches of natural science—every forward step which man is able to make in the path of knowledge is dearly purchased. But this need not discourage us. So long as the joy of life fills the breast of man conquerors will be found ready, not as dreamers but with the will to do, placing their strength resolutely and joyously at the service of the investigation of nature.

I will add by way of supplement a few remarks additional to those made in the address.

(a) *The moon a drop of the earth's crust.*—To man, standing on the surface of the earth, the tide waves seem to run around the earth with the moon. But if we imagine an observer stationed in space he will have the impression that the earth revolves beneath the tide waves created and held in position by the attraction of the moon and sun. As the tidal currents involve friction of various kinds, it is evident that the earth must be checked in its revolution. The retardation is but slight; calculating from the present factors, we infer that it would merely add one second to the length of the day in about five hundred thousand years. However, looking back into the past, we find that many millions of years ago the earth revolved far more rapidly than it does now. The tidal friction has another consequence of importance for our inquiry: It causes the moon to move farther and farther away from the earth. To understand how this comes about we must note that the rotating earth drives the tide waves somewhat forward, in advance of the moon. As a consequence, the tide waves by reciprocal gravitation, impart to the moon a constant forward impulse, and this acceleration, which means an increased force of revolution, drives the moon away from the earth.

If, with our minds filled with the ideas thus gained, we go back to remote ages, we arrive by the aid of calculation on the basis of actual conditions, at a time when the earth performed one revolution in a few hours, while the moon revolved around it in immediate proximity, in the same space of time. This evidently leads us back to the time when the moon itself originated by detachment from the earth. The process must have been somewhat as follows: In the early ages the earth in its outer parts was liquid, or even gaseous. Contraction, due to cooling, caused its motion to become more and more accelerated, till finally it reached a point where gravitation was no longer sufficient to maintain the ellipsoidal shape. As inferred by calculation, the subsequent detachment of a drop began thereupon to be preindicated by the development of a pear-shaped appearance. This pear-shaped body was constricted more and more, until the original single planet was divided into a main body, the earth, and a satellite, the moon. As the moon was thus formed of the outer parts of the original body, we infer that it consists of the same material that in the earth was arranged in the form of a rock mantle. The friction of the tides thereupon carried the moon farther and farther away from the earth, and diminished the rate of rotation of the earth. Thus the moon, which to-day describes its orbit at a great distance from the earth, is simply a drop detached from mother earth by the centrifugal force.

A very interesting question is that regarding the time that has elapsed since the moon was severed from the earth. Keeping in view the magnitude of the forces at work in the tide phenomenon, we can form at least an approximate judgment concerning it. We infer that it took place about ten thousand million years ago. By an "approximation" we must understand in this case that the time can hardly have been more than one hundred thousand million years, but very probably more than one thousand million years. Life on the earth can only have begun a good while after the separation of the moon, and yet we are forced to admit that life has lasted several thousand million years.

Compared with human life, a period of ten thousand and million years appears enormous; and yet it is so small that even the moon can not have lost, during that period, any great fraction of the heat that it took away at its birth. Thus we have to infer that the moon, like the earth, is still intensely hot in its interior. As the pressure conditions in the interior of the moon's body must be similar to those existing in the rock mantle of the earth, we arrive at the conclusion that the physical conditions of matter in the rock mantle of the earth are not greatly different from those prevailing in the body of the moon. We saw that the material, too, must be the same. Thus we are presented with an opportunity to a certain degree to test the correctness of the views above developed; for if they are correct, the rock mantle of the earth and the body of the moon must have very nearly the same density. It was shown a while ago that, according to observations on earthquakes, the thickness of the rock mantle is to be estimated at 1,500 kilometers. If with this we combine the known data on the average density of the earth and the degree of its flattening, we may conclude that the material in the rock mantle is on an average 3.4 times denser than water. The average density of the moon, on the other hand, may be inferred from astronomic observations. And what is it? Referred to water, 3.4. A better agreement than this could not be wished, and through it we gain a further and very important support for the whole series of our conclusions regarding the condition of the globe.

(b) *The earth's crust.*—Vast differences in elevation are found to exist on the surface of the earth. Some plateaus are situated 2,000 meters and more above sea level; the highest mountain tops rise to nearly 9,000 meters. The floor of the ocean lies on an average about 3,500 meters below sea level; the greatest depths of the sea attain about 9,000 meters. On an average, the land rises about 4,200 meters above the floor of the sea. In view of these facts it seems natural to infer that the elevations indicate accumulations of mass and the depressions deficiencies of mass, and in fact this was formerly supposed to be the case. But if this were really so, gravitation on the earth would have to be greater the higher the surface; but this is by no means the case. On the contrary, the measurements of gravitation have shown that while variations occur, indicating an excess or a deficiency of mass at various points, on the whole the mass of the earth is uniformly distributed over its surface. Thus the elevations and depressions of the earth's crust in a general way mean simply that in the former the crust is less dense, in the latter denser, and that for this reason it rises higher at the former points, less high at the latter.

These conclusions assume a special significance for the reason that, as shown by geologic investigation, rock strata many thousand meters thick have in the course of past ages, mainly through water circulation, been carried away from certain parts of the earth and deposited at other points. How is it possible that nevertheless the mass is to-day distributed with practical uniformity all over the earth? To explain this there is no other way than by assuming that the superficial accumulations of mass are compensated for by subterranean removal. Therefore the solid crust must have a soft sub-stratum, on which it floats, as it were. Geologists have for this reason often been led to infer that the interior of the earth is liquid. We have seen that the earth as a whole, in the presence of tidal forces, in the case of pole oscillations and of earthquake waves, behaves as a solid and that it is even remarkably unyielding in the matter of elasticity. Hence we can not conceive the interior of the earth as being liquid throughout, in the current meaning of the word. It is possible, however, that beneath the outer solid crust there exists at no very great depth a molten layer, so thin in proportion to the earth's body as not to cause any perceptible diminution of its rigidity. Volcanoes might then be regarded as vents connecting that layer with the surface. It might also be imagined that the liquid layer at the present day no longer extends beneath the entire crust, but that it is interrupted by solidified portions and thus divided into provinces. Various phenomena of vulcanism would seem to agree better with that assumption. I will readily grant that such inferences may correspond to the reality; but yet it seems to me very remarkable that the observations on earthquakes furnish no indication of a liquid layer. While I must admit that the mass of existing observational material is as yet small, and that this fact may explain the circumstance just mentioned, yet while awaiting further developments, I am inclined to subscribe to the view that really liquid areas are found only in isolated parts of the earth's crust, and that on the whole the substratum of the crust is not "liquid," but merely "plastic." It is well known that many apparently solid bodies gradually yield even to very slight deforming forces, if these act long enough. A stick of sealing wax supported at both ends will bend, according to the temperature, in a few minutes, days, or years; pitch flows

readily and quickly. Glass acts like sealing wax even under a slight rise of temperature, and the same has been proved to be the case with many minerals. There is reason to believe that by far the greater part of the substances surrounding us, perhaps all, are plastic, provided sufficient time is available for them to show it. Thus it seems possible that the earth's crust in the deeper, hot parts may indeed act as a solid toward the quickly passing earthquake waves, but as a plastic body toward the geologic forces acting through millions of years.

One more point has to be considered, which is of great importance, in many respects of decisive importance, for the shaping of the earth's crust and of the visible surface of the earth. A notable part of the rocks forming the earth's surface possesses the property, when subjected to high temperature and high pressure, of absorbing water and forming with it more liquid and less dense compounds. Thus we may well assume beneath the earth's surface a hot rock layer formed of these water-impregnated compounds; it is usually called the "magma layer." It probably represents the plastic factor which, by yielding to increased pressure, effects the equalization of mass in the earth's crust. During the gradual cooling of the earth the water is liberated from the magma. It has often been suggested, and I must confess that I am disposed to welcome the suggestion, that in this way the origin of the entire ocean may be explained, and that the hot springs show us at least some of the paths by which the water liberated from the depths of the earth by cooling and forced out by the pressure of the earth, is conveyed to the ocean.

One more remark. The plasticity of the earth's crust gives rise to a peculiar instability of the surface. If, in the case of differences of level, material is washed away from one part of the surface by water and deposited on another part, the earth's crust at the points of denudation must rise in consequence of diminished pressure, while at the points of deposition it must sag by reason of the increased pressure. Hence, at the points of denudation hot, water-charged, and therefore less dense rock masses will rise from beneath, while at the points of deposition water-free, cold, and therefore denser strata will descend. Consequently, as a final result, the former higher parts of the earth become less dense, so that their surface, despite denudation, must be raised still higher, while the former deeper parts of the earth become denser and their surface therefore descends still lower than it was before. Thus denudation and deposition, instead of equalizing, accentuate differences of level. Mountains rise still higher, the sea bottom sinks still lower, and this continues until other factors make themselves felt. We have thus arrived at the exceedingly complex geologic processes which determine the formation and transformation of continents and seas, plains and mountains, and this reminds me that it is time to close, for the discussion of that theme would require a treatise by itself. I am all the more compelled to conclude at this point because even the indications that I gave exceed the limits of what is generally admitted in geology, and I shall therefore have to prove the correctness of my assertions elsewhere before the tribunal of science.

FLOOD DRAINAGE IN PARIS.

ACCORDING to a report by M. Colmet Daaé, the engineer-in-chief to the commission appointed to consider the question of flood prevention in Paris, the main drainage is inadequate for safeguarding the city in the event of an unusually wet Summer. Owing to the numerous bends of the river within the metropolitan area the risk of flooding in Paris is even greater than that of London, as it was before the important extensions which have been made to the drainage system during recent years. Consequently it is desirable that steps should be taken without unnecessary delay. At the present time recent rainstorms have had the effect of raising the level of the river by several inches, a development which has probably influenced the Prefect of the Seine Department to ask the Municipal Council for a sum of 200,000 francs for the execution of flood prevention works.—The Builder.

MATANUSKA COAL FIELD.

A SYSTEMATIC investigation of the Alaska coal fields was begun in 1902. Reconnaissance surveys have now been carried over nearly all the coal-bearing areas that are of immediate economic importance and detailed investigations of some of these areas are now in progress. In accordance with the general plan the detailed survey of the Matanuska field will be undertaken this season. For this work the topographic base map completed in 1909 will be used. The survey will be made under the direction of G. C. Martin, assisted by F. J. Katz and Theodore Chapin. Mr. Martin has sailed from Seattle with five men and six horses and will spend the Summer in the Matanuska field. This party expects also to make a reconnaissance of the Willow Creek gold-bearing district.