The Machinery of the Earth.*

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A DEFINITION of the word "machine" given in "The New English Dictionary" is "a combination of parts moving mechanically, as contrasted with a being having life, consciousness and will". According to that definition, the whole earth may be regarded as a machine, as it consists of various parts with differential movements, and it is moving in mechanical obedience to the forces of the universe and without any impulse or free will of its own. The study of the primary machinery of the earth involves consideration of its construction and of those movements of its parts which control its main function—the preparation and maintenance of its surface as the home of man.

THE STRUCTURE OF THE EARTH.

The geological method—the interpretation of the direct contemporary evidence of the rocks—has the drawback that it can only be applied directly to a thin layer, which is about one five-hundredth of the radius of the earth; and this restriction is the more regrettable as the material of the interior is different from that of the surface crust. The extent of this difference was revealed by Sir Isaac Newton, who calculated that the specific gravity of the earth is between 5 and 6. The figure generally accepted is 5·53.

Ordinary rocks vary in specific gravity between the 1·8 of clay, and 2·2 of sandstone, and 3·0 of basalt. The average cannot be more than about 2·5. For the whole rocky crust or lithosphere, which includes a great thickness of the deeper basic igneous rocks, the average specific gravity is taken by Tyrrell as 2·7. Hence the earth as a whole is composed of material more than twice as heavy as that of the crust. The internal mass is therefore appropriately named the barysphere, and a large amount of it must have a specific gravity four times as high as that of the rocks of the upper crust. It has been suggested that the matter in the interior owes its density to compression; but that view has been abandoned, and the high specific gravity of the interior is attributed to the segregation there of a large proportion of metals.

The high specific gravity of the earth can be accounted for by a metallic core with the specific gravity of about 8 to 10, or, perhaps in part, as much as 12. The material is probably mainly metallic iron alloyed with nickel, and containing smaller proportions of other metals and various silicates.

The composition of the barysphere is revealed by several lines of evidence. We may expect the earth to consist of the same materials as other heavenly bodies; and the most positive information as to the extra-terrestrial material is given by samples which fall upon the earth from outer space. They are known as meteorites and are most familiar to us as shooting stars. Their numbers are enormous. Any quick-sighted observer on a dark cloudless night can see about seven in the hour. Hence from 10 to 20 millions enter the earth's atmosphere every day. The meteorites are shattered into fragments, which fall in lumps or dust upon the surface. They are divided into two main classes. The iron meteorites or siderites consist of metallic iron with from 3 to 41 per cent and usually from 7 to 15 per cent of nickel and small proportions of other metals and some silicates. The second class are the aerolites or stony meteorites, which consist mainly of silicates and of mineral species, especially olivine and enstatite, common in the basic rocks of the earth's crust. A small intermediate group, the stony-iron meteorites or siderolites, consists of nickel-iron and silicates.

The proportion of the iron to the stony meteorites according to Sir Lazarus Fletcher's list of the meteorites in the British Museum in 1904 was 13·7 to 1. Dr. Prior's British Museum Catalogue of Meteorites (1923) includes all those known up to 1922 and has rendered practicable a more complete estimate. According to the records in that catalogue nickel-iron is twenty-one times more abundant in meteorites than stony material. Hence, if the earth represents a fair average of the material of the universe as revealed by meteorites, its metallic barysphere would have twenty-one times the bulk of the stony crust, which would be about 140 miles thick.

The relative thinness of the stony crust is confirmed by radioactivity. The earth's radioactive power is surprisingly weak. As determined by Lord Rayleigh, it can be accounted for if all the radioactive constituents are confined to a depth of about 45 miles. The material below that shell is practically non-radioactive. The iron meteorites are also non-radioactive. This evidence indicates that the earth's core is composed of nickel-iron.

This conclusion was originally advanced by J. Milne from the study of earthquakes. He found that earthquake waves which in their course go deeper than 30 miles undergo marked acceleration, owing to their entry into a highly elastic material which Milne called 'geïte', as it is the rock that forms the bulk of the earth; and he concluded that it consists mainly of nickel-iron. Subsequent research has confirmed this conclusion. The earth consists of an outer stony shell—the earth's crust or lithosphere—which is separated by a fairly sharp surface from the underlying barysphere. This inner mass, being denser, more elastic, and non-radioactive, is probably a mass of nickel-iron, like the iron meteorites. That the core of this mass is different in constitution from the rest was shown, also from earthquake evidence, by R. D. Oldham. He found that earthquake waves of distortion do not pass through the central region of the earth. Within the elastic barysphere is a centrosphere, which transmits waves of compression but not waves of distortion. It is therefore either a liquid or a gas.

An earthquake sends out waves of three kinds from its centre of origin. Two of the sets of waves are small vibrations or tremors that go through the

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earth; the third set are large waves that travel along the surface and may cause widespread devastation. All three kinds of wave are recorded on seismographs at a suitable distance.

The simple earthquake seismogram includes records of the three kinds of waves; it begins with small jerks made by the first tremors, which are waves of compression. They are known as the *P*-waves, *P* standing for primary, as they arrive first; but the late Prof. Turner suggested the name of push-waves as they are pressure waves. The second set are the *S*-waves or secondary waves, which are due to vibrations at right-angles to the path of the earthquake. They are waves of distortion. Prof. Turner called them the shake-waves. They are followed by the large waves or *L*-waves.

The first push- and shake-waves travel at the speed with which such waves travel through granite; hence they must have passed through a layer of the earth's crust composed of a rock like granite.

Farther from the centre the seismogram is more complex, as two sets of push-waves and two of shake-waves may arrive before the large waves. Still farther away there may be three sets of push-waves and three of shake-waves. The P_g or shallow push-waves have a velocity of $3\frac{1}{4}$ miles per second, which is that of such waves through granite. The second set of push-waves (*PP* or P_x waves) have a velocity of 4 miles per second, which is that of such waves in diorite; the third set of push-waves (P_n) have the velocity of $4\frac{3}{4}$ miles per second, which is that in such a highly basic rock as dunite.

Accordingly it appears that below the surface is a layer of rock like granite; beneath it occurs diorite, as suggested by Prof. Holmes; and lower still is a more basic rock, which transmits the push-waves at $4\frac{3}{4}$ miles per second.

Farther from the origin of the earthquake four out of these six sets of waves are not recognised and only the P_n and S_n waves and the main waves leave their record on the seismogram.

The P_n and S_n waves both traverse the geïte until they reach the depth of 1800 miles. A wave going to that depth, emerges at the surface at a distance of 103° from its origin; between that distance and 144°, the push- and shake-waves are not recorded. So an earthquake under the north pole would be felt by its push- and shake-waves so far as 13° S. of the equator, in say southern Peru; farther south there would be no record of them before reaching the latitude of Cape Horn; but farther south again the push-waves would disturb the surface so far as the south pole. The shake-waves, however, would not be felt anywhere south of Peru.

This suppression of the shake-waves around the antipodes to the place of origin of an earthquake was first recognised and explained by R. D. Oldham. He pointed out that as only the waves of compression reach the antipodes, the earth's central core must consist of material which transmits waves of compression but not waves of distortion. It must therefore be liquid or gaseous. That it is liquid is shown by the yielding of the earth to tidal strain, which indicates a less rigid earth than earthquake observations; and Dr. H. Jeffreys has shown that the contradiction between this evidence disappears if a liquid centrosphere occupies half the diameter of the earth.

According to Oldham and Knott, the liquid core is a fifth of the radius or $\frac{1}{125}$th of the mass of the earth; but according to Dr. H. Jeffreys' estimate it is half the radius, or an eighth of the mass of the earth. This huge centrosphere is doubtless a liquid mass of nickel-iron, which, owing to compression, has a specific gravity of 12.

Such, then, is the general structure of the earth-machine; it has a fluid centre, a thick metallic shell, the barysphere, and an outer rocky crust, the lithosphere.

As the earth is approximately spherical, we may regard it as a huge projectile, travelling at an enormous velocity through space, and consisting of an iron shell which, like those of modern artillery, is hardened with an alloy of nickel.

Origin and History of the Earth.

The separation of the barysphere and lithosphere is the natural result of their difference in specific gravity. The lithosphere consists of light silicates and earthy materials which floated to the surface out of the heavy metallic mass, as the earthy impurities in iron-ore float to the top as slag when the ore is smelted in a furnace. The rocky crust may therefore be regarded as a slag which has exuded from the metallic mass below.

Laplace's long accepted nebular theory of the origin of the solar system is now generally discredited; and the earth is regarded as either a mass torn out of the sun by the attraction of a passing star, or as due to the aggregation of a swarm of meteorites, and mainly of those which, having a planetary orbit, are regarded as infinitesimally small planets and are known as planetismals.

The meteoritic theory of Lockyer and the planetismal theory of Chamberlin and Moulton are both out of favour in Great Britain; but they have to the geologist the advantage that they do not start the earth as a fragment of a body with, according to C. E. St. John, the temperature of 29,000,000° C. For the oldest and most deep-seated of the known rocks in the earth's crust show no evidence of transcendent temperatures.

Either the earth never experienced the supreme temperatures of the sun or hotter stars, measured by millions of degrees, or it had cooled down to about 5000° F. before the formation of the oldest known part of the crust.

The earth clearly passed through a stage in which it was so hot that it was plastic and behaved as a fluid body. One relic of this early stage is the high temperature of the earth's interior, as known from the uncomfortable heat of deep mines and the boiling water of deep-seated springs. The standard rise of temperature underground in Europe is 1° F. for every 53 or 58 feet of descent.

If that rate continued, the temperature 5 miles deep would be above 500° F. and at the earth's centre, 3950 miles deep, would be nearly 400,000° F. There is no geological evidence for such a temperature within the earth. None of its minerals imply temperatures higher than the 2500° F. of sillimanite, or the 3100° F. of cristobalite, or the 3450° F. of some species of olivine. There is no geological evidence that the central hot mass or thermosphere has a temperature higher than a few thousand degrees. The internal heat was not too high to prevent the formation of a solid non-conducting crust, which soon became so thick as to prevent the thermosphere having any material influence on climate. The oldest interpretable fossils indicate that at the beginning of geological time the climate of the earth was about as warm as in modern times. Evidence of this surprising fact is given by the existence at about the time of the oldest fossiliferous rocks of glaciers in the Yangtze-kiang Valley, and of glaciers that nearly reached the tropics in South Australia. Those glaciers do not imply that all the earth had then a colder climate; but they do prove that the conditions were not tropical over the whole of the earth. Judging from the marine organisms nearest in date to these early glacial deposits, the mean climate of the earth was similar to that of to-day.

Climate has undergone marked local variations. Sometimes it was more uniform over the earth and at others the extremes were greater, after mountain uplifts had increased the local differences.

Even allowing for such changes and for those due to different distributions of land and sea, the meteorological agents have been remarkably uniform. In rocks of all ages the imprints of the rain-drops are of about the same size. The sand grains spread over the deserts or heaped in sand dunes, and the ripples on 'the sands of time' have been always approximately equal; and the particles of volcanic dust and tuff also show that the ejecta of ancient and modern volcanoes have been scattered by volcanic explosions and winds of similar power.

This climatic uniformity since the Cambrian period indicates that the earth's crust had by then acquired approximately its present thickness and strength. Before that date it must have been thinner and weaker, as is proved by the universally tilted condition of the primeval (Pampalozoic) rocks. The sedimentary rocks of the crust were deposited in horizontal layers; most of them have been tilted. The younger rocks generally have a slight dip except near fold-mountain chains, which are due to the crust having been squeezed into a smaller space, and having accommodated itself to this compression by folding. In modern rocks violent lateral compression is limited to relatively narrow belts along the younger fold-mountain chains.

As the older rocks of the crust are steeply tilted in all parts of the earth, the pressure that disturbed them was then universal. The crust was undergoing contraction to an extent which threw all that is known of it into folds, for as the crust sank over the diminishing internal mass the whole of it was packed into a narrower space and was thereby thickened and strengthened.

The change from the thin, universally crumpled crust of the older primeval time to the thicker, stronger crust which yields to compression by package along narrow bands has led to a fundamental difference in geographical conditions. Land and water were re-distributed and this change had a great effect on local climates.

When the crust was weak, its buckling would have produced many shallow basins and domes, so that water was distributed in land-locked seas, scattered widely over the surface. The total sea surface was apparently much less than at present, for the commonest rocks of the latter part of the primeval era are reddish sandstones and layers of red shale, with wind-rolled sand grains and pebbles polished and faceted by wind-blown dust.

The powerful effects of the wind and the prevalent desert conditions may have been due in part to the absence of turf, which binds the sand and prevents its grains being constantly rolled forward by the wind. The lack of land vegetation suggests that the environment was unfavourable for it. The extensive limestones in the primeval seas indicate that seaweeds were luxuriant. The failure of plants to grow well on land suggests that the conditions did not suit them. The absence of land vegetation until Silurian and Devonian times may have been due to climate. The prevalence of deserts in the upper Pampalozoic is evidence of a dry atmosphere, which would have been the natural result of a greater proportion of land to sea than in later geological epochs.

The growth of the seas involves an increase in the amount of water on the earth's surface. The possibility of this increase was discredited when the authoritative estimates of the age of the earth varied between ten million and a hundred million years. Annual additions to the surface water that would be negligible in a few million years become important when they accumulate for thousands of millions of years.

At one time it was held that all the water on the earth's surface is meteoric and has fallen as rain. But the evidence is convincing that much of the water of hot springs and deep mines and that given off by igneous rocks and volcanoes is of deep-seated origin. It is plutonic water which has worked its way to the surface. The amount discharged was probably greatest in early times when the crust was thinner and more often fractured. The transfer of deep-seated water from the interior to the surface during geological time must have added largely to the volume of the seas. According to Prof. Schuchert the earth's surface water may have increased by 25 per cent since the beginning of the Cambrian period. Though data for a quantitative determination are inadequate, the evidence is in favour of the seas of the earlier days having been shallower and less extensive.

Hence, although the earth's crust had early become sufficiently thick to cut off the surface from any material contribution from the internal heat, yet the shrinkage of the interior so frequently fractured the crust that plutonic water rising through the fissures has continually widened the seas and thus helped in the better nourishment of the land.

THE EARTH IN MOTION.

The earth is not only a complex structure built up of several distinct parts, but also it is in motion at a terrific speed. It is charging through space, with the rest of the solar system, at the rate of 750 miles a minute ; it travels along its orbit around the sun at more than 1000 miles a minute ; and its rotation around its axis gives any place on the equator an additional movement of more than 1000 miles an hour. The fact that the earth holds together in spite of such movements shows that it is strongly constructed ; but it is sufficiently plastic, owing to its hot interior, to be automatically moulded into a spheroid, or more correctly, into a geoid. It is approximately an oblate spheroid owing to the moulding force of its rotation.

The rotation has not been uniform. Owing to tidal friction it is slowly losing speed and the day lengthening. According to Sir George Darwin and Dr. H. Jeffreys, the earth's day was at one time only five hours long. Changes in the shape have also affected its rate. For example, the polar regions have been raised and lowered to an extent that would have affected the earth's ellipticity as shown by the widespread occurrence of raised beaches in both the polar regions. These beaches are so regular and horizontal that they have been attributed to the so-called 'eustatic' movements or world-wide variations of sea-level. But that view is improbable, as the raised beaches, which are conspicuous in Scotland, occur at a lower level or are absent from most of England.

A change in the earth's rate of rotation would produce circumpolar beaches, for its slackening would lower the sea in the tropics and raise it in the polar regions. The distribution of the raised beaches is, however, probably due to the alternate subsidence and upheaval of the polar areas ; and if both of them had sagged simultaneously the earth's ellipticity would have been increased and therefore also its rate of rotation.

The earth revolves like a badly made and badly mounted fly-wheel, and its wobbling causes some shifting in the position of the poles, as proved by the variation of latitude. The movement of the poles that has been actually observed is small, and has been attributed to meteorological factors, which Dr. Jeffreys has shown to be insufficient. The deformation of the earth by crustal changes is the more probable cause. Any extensive migration of the poles has been declared impossible, since a body with so heavy a load on its circumference as the earth's equatorial bulge could undergo but minor oscillation of its axis. That the wandering of the poles has been within narrow limits is consistent with the geological evidence ; for the distribution of animal life has been along zones that were in general parallel to the present climatic zones.

The changes in shape of the earth have, however, had an important influence in other respects. The earth cannot be deformed beyond a limited amount or it would become unstable and ultimately fly to pieces. But with the wonderful automatic adjustments of the earth, as soon as deformation renders the crust unstable, stability is restored by movements by which the approximately spheroidal form is recovered. The convulsions during this process lead to changes in the crust that are indispensable for its primary service as the home of man. The lot of man is dependent on the earth's movements in space and on its power of self-adjustment to changing conditions, both internal and external. The combined rotation and revolution determine the weather and weather-changes in all parts of the earth, and thus control the habitability of the earth. The movements within the crust, which depend on its adjustment to the shrinking interior, provide for our many and fastidious needs.

The earth's atmosphere is apparently fickle and liable to great changes in composition, but the limits of its variation must be narrow. Its maintenance at the special composition breathed by animals, and that protects the earth from undue changes of temperature, is one of the beneficent functions of the sea. The efficiency of the atmosphere depends on its content of carbon dioxide, which is affected by many agencies. The sea acts as the great regulator of the atmosphere, and counteracts the disturbing factors ; if too much carbon dioxide is taken from the air the bicarbonates in the water are dissociated and the sea breathes it forth until the standard proportion is restored. If volcanic activity or forest fires add an injurious amount to the air, the sea absorbs the excess and retains it as bicarbonates. The atmosphere is thus maintained at the special composition necessary for human respiration.

Man requires dry land that has been drained and left available for his occupation, and it would be of no use unless most of its surface were sloping. The land is constantly being lowered by wind and rain, and would in time be planed so level that the rain water would lie upon it and be removed only by the slow, chilling process of evaporation. But, thanks to the interaction of the crust and the shrinking interior, the surface is being lowered in some places and upheaved in others. The instability of the crust, which we deplore when an earthquake devastates a province or slays a hundred thousand people, renews the slopes on which the habitability of the earth ultimately depends.

The crustal movements by tilting the surface produce slopes which are essential for the flow of water and the formation of the grassy steppes where have evolved many of the animals most helpful to man, including those that supply wool and hair for clothing, meat and milk, and serve as beasts of burden.

Man also requires a soil that will produce the foods necessary for his nourishment ; and soil is a delicate instrument that is easily exhausted and rendered infertile. The flow of water, though indispensable, charges the soil heavily for its service. Water is the most active of general solvents and removes in solution enormous quantities of the constituents essential to plant growth.

This process would in time leave only insoluble materials, and the soils would be barren and useless.

The earth is saved from this fate by the re-fertilisation of the soils from the primary rocks of the interior, which are rich in lime, alkalis, and phosphorus. Movements within the earth upraise igneous rocks to form highlands and mountains, and their constituents are washed down the slopes and renew the fertility of the lowland plains.

The tilting of the rocks on the surface in consequence of the internal shrinkage makes another essential contribution to the economy of Nature. Many of the most useful minerals lie in the old rocks, and if they were still horizontal the minerals would be so deeply buried that their discovery and economic working would be impracticable. But as the rocks have been tilted and folded the mineral seams are exposed on the surface, where they are easily found and can be profitably mined.

Hence the interaction of the different parts of the earth machine has rendered possible the evolution of man and still controls his destiny; for it keeps the earth's surface drained and habitable, it distributes the seas so that the land is supplied with rain and fresh water; it maintains the constituents of the air at the balance required in the breath of life, and it raises from the interior the minerals that renew the fertility of the soil and provide the mechanical engineer with the materials that have rendered possible the development of modern civilisation.

The Adequacy of Human Dietaries.

The importance of the food supply in the preservation of normal health and well-being is generally recognised among scientific observers, but the necessity for a scientific selection of the food, in addition to that due to the dictates of appetite, is not always realised by many classes of the population. Dietary surveys, carefully performed, will indicate the adequacy, both quantitative and qualitative, of popular diets, in terms of accepted standards; when estimates of the cost of the diets are also made, data are available as to the minimum cost of an adequate food supply under different conditions. At the same time, encouragement may be given to education on the planning of adequate diets at minimum expense, especially if the surveys indicate that many dietaries are not only inadequate but also expensive.

J. B. Orr and M. L. Clark (*Lancet*, vol. 2, p. 594; 1930) have recently completed a survey of 607 families in seven cities and towns in Scotland. The information was collected from the housewives and is considered to be fairly reliable. For the calculation of the composition and energy value of the diets, Sherman's and Plimmer's tables were used. These tables allow for inedible material in the food purchased, but not for waste, for which 10 per cent should probably be deducted from the figures given for food consumption. Allowance must also be made for the fact that the food requirements of women and children differ from those of men; it is customary to express their requirements as a fraction of that of an adult man, taken as equal to 1, so that the 'man-value' of the diet of each family was calculated, using Cathcart's table. No account, however, was taken of the occupation of the adults. The mean man-value for each family was 4·86; the calorie consumption per man per day was 3609 cal., composed of 108 gm. protein, 574 gm. carbohydrate, and 86 gm. fat. The consumption in individual households varied widely from the mean, as shown by coefficients of variation of 20-30 per cent. Cases of insufficient calorie consumption were, however, relatively few; a larger number showed an intake of 4000 cal. per man per day or more, indicating either an unnecessarily high consumption or excessive waste. The average is slightly higher than that found in previous studies in Great Britain, but lower than in those carried out in other countries. Protein accounted for 12·3 per cent, carbohydrate for 65·5 per cent, and fat for 22·2 per cent of the calories.

A less satisfactory state of affairs was disclosed when the protein, calcium, phosphorus, and iron intakes were determined. The protein consumption was below the standard in about two-fifths of the families. The average figures found for the minerals were: calcium 0·86 gm., phosphorus 1·70 gm., and iron 0·0143 gm. per man per day. The figures for calcium and phosphorus are slightly above Sherman's estimates of an adequate intake, that for iron slightly below. About one-quarter of the families were receiving too little calcium and phosphorus, and nearly two-thirds too little iron.

Cathcart's figures for man-value are based on maintenance requirements; when a more stringent standard (Hawley's) was employed, which makes allowance for the fact that growing children require relatively more of certain constituents than adults, a larger number of families showed deficiencies in their intake of protein or minerals. In fact, most of the diets appeared incapable of supporting the optimum rate of growth.

The results of the survey probably explain, at any rate in part, the results obained by G. Leighton and M. L. Clark when extra milk was added to the diet of school children (*B.M.J.*, vol. 1, p. 23; 1929). It was found then that the addition of about a pint of extra milk daily to the diet was followed by an increase in the growth rate, indicated by increased weight and height as compared with the controls. Separated was as good as whole milk, but biscuits had no such effect; separated milk is a good source of protein and minerals, and to these a part at any rate of the good effect can be ascribed. Orr and Clark conclude that the dietaries of urban households can be considerably improved by the addition of milk to supply protein, calcium, and phosphorus, and of green vegetables to supply calcium and iron; both would also supply any vitamins deficient in a carbohydrate-rich diet.

F. M. Williams and J. E. Lockwood have carried out a similar survey among farm and village