agents (such as bulbocapnine or mescaline), and thus avoids the contamination of the experimental situation from both the performance and the physiologic point of view. The opossum is also characterized by a primitive, "olfactory," nervous system with rudimentary neopallial structures, thus lending itself to experimentation directed towards the elucidation of the functional effect of phylogenetically old structures in the mammalian brain.


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# The Principal Characteristics of the Formation of the Earth's Crust


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AS THE QUESTION of the shape of the earth was a much disputed one several hundred years ago, so is today the question of its surface pattern. But while celestial mechanics has provided ample explanation for the gross appearance of our planet, the majority of contemporary geologists and geophysicists are still in want of a mechanism that would account for the principal characteristics of its crust. Many attempts have been made to explain different formations by assuming processes peculiar to a given case, but there has been little success in the efforts to harmonize this multiplicity of proposed mechanisms and to give a unified physical picture of the history of the outer shell of the earth. Yet a careful look at a physical map will reveal certain regularities in the structure and distribution of the continents, oceans, and mountain chains, and will lead one to believe that, although the existence of a multiplicity of particular mechanisms is unquestionable, there must have existed a dominant process exerting a determining influence on the formation of the principal features of the terrestrial surface.

Various processes have been ascribed such a dominant role. Of the more important ones, the shrinking of the planet, the separation of the moon, and the migration of continents (*1, 2*) should be mentioned. The first two processes seem far from furnishing a satisfactory explanation for many prominent features of the earth's surface pattern. As to the third one, a large amount of material in the field of geology and related sciences has been gathered by Wegener (*2*) to substantiate the hypothesis. However, despite the fact that a large part of the data appears to be in perfect agreement with this hypothesis, it has failed to gain general acceptance, largely because it does not provide for the mechanism that would satisfactorily explain the relative displacement of continents. If we are to decide on a process as playing a dominant part in the formation of the earth's crust, we ought to choose one that would best agree with the principal characteristics of this formation and for which a plausible mechanism could be established.

As a first step, then, an attempt has to be made to collect those characteristics of the formation of the earth's crust that could be regarded as the principal ones. Failure in the past to differentiate between the chief and the secondary features, as well as limiting the considerations to the findings of but one discipline, has led to the formulation of theories that can often be applied only to a very restricted number of data, although they appear plausible when taken by themselves. Later we shall consider a mechanical concept that suggests itself from our findings as a suitable explanation for all of the enumerated characteristics.

*Astronomy* has shown that the nearly spherical shape of the earth is not an exceptional phenomenon. This shape differs but little from one of several well-known figures of equilibrium for a fluid mass that is isolated in space. Thus, the assumption that the earth once was in a fluid state became a highly probable one. As with every liquid celestial body, it should have been covered by a crust in the process of cooling. This crust would take the form of a spherical shell if there were no rotation. In case a slow rotation should take place, the crust would become an ellipsoidal shell of small ellipticity. The earth, however, being a member of the solar system, was never an isolated mass. Its path in space during the three billion years of its history was a very complicated one, owing to the existence of external forces such as the attractions exerted by other members of the solar system. This fact makes impossible any situation that would correspond to the exact conditions of equilibrium. Even now, when a larger part of the body of the earth seems to be solidified, tidal deformations in the crust produced by the moon and sun are considerable.

However, external gravitational forces are not the only factor disturbing the mechanical equilibrium of the earth. In fact, there is no trace of mechanical equilibrium in any known fluid celestial body. Such a state is sometimes assumed, but only in order to simplify a theory. In the process of cooling, a temperature gradient is set up between the surface of a celestial body and its interior. Thermal equilibrium becomes

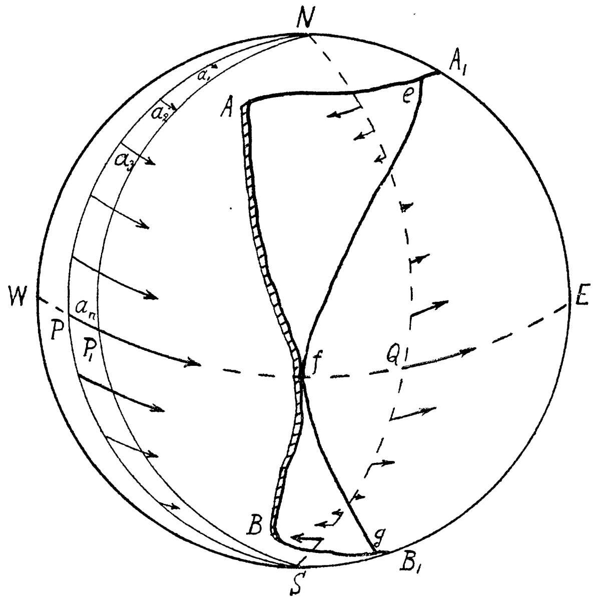


FIG. 1. A zonal distribution of velocities in a liquid substratum is shown by the arrows $a_1$, $a_2$, . . . $a_n$, which represent the components along the parallels, increasing toward the equator. The meridional components should have directions *NP* and *SP*. The arrows along *NQS* correspond to tangential stresses at the inner surface of the block $AB_1$; this block can burst along the line *efg*.

impossible even in gravitationally stable layers (*3*), and convection currents thus become a highly probable phenomenon in a fluid celestial body (*4*). It was pointed out that these currents could maintain a rotation-pattern different from that of a rigid body against the increasing viscosity (*5, 6*). Such a nonuniform rotation of celestial bodies is a well-known fact. At least three fluid members of the solar system (sun, Jupiter, and Saturn) manifest at the present time an unequal distribution of angular velocities characterized by an acceleration of the equatorial belt with respect to other parts of the mass. This situation is represented in Fig. 1 by the set of arrows, $a_1$, $a_2$, . . . $a_n$, displacements being proportional to the lengths of the arrow. The difference from the case of a rigid planet can be easily appreciated when one considers that in the latter, the particles undergo the same displacements as do the points of the meridian *NPS* (Fig. 1).

Thus, the principal characteristics of the formation of the earth's crust suggested by known astronomical facts could be the following: (a) lack of any kind of equilibrium in the outer layer of the earth when it was in a liquid state; (b) deformations of this layer in the liquid and solid states by tidal forces; (c) the existence of internal movements in the planet that influence the formation of the shell by stresses acting on the inner surface of the latter; and (d) a special distribution of convective currents which conceivably could be symmetrical in the two hemispheres, producing a zonal rotation of the planet.

To this group of astronomical characteristics must be added those facts that have been established in the sciences of the earth. *Geodesy* confirms once more that the figure of the earth differs but little from a slightly compressed ellipsoid. Thus, the progressing consolidation of our planet did not change its shape essentially, the irregularities of its surface being very small in comparison with its size. *Geography* yields the well-known descriptive material, and it should be borne in mind that every theory of the formation of the earth's crust has to explain this actual distribution of principal features, that is, the shape and position of *existing* continents, oceans, and mountain ranges. As simple and natural as this statement is, one finds it only too often neglected. One of the most important characteristics is the existence of the so-called geographic similitudes, which cannot be disregarded, as it frequently has been. The congruence of the opposite coasts of South America and Africa, which for a long time has attracted the attention of investigators, and the existence of the Mid-Atlantic ridge, which is stretched out on the midway between the New and Old World, are perhaps the most striking examples. Thus, we have to keep in mind these geodesic and geographic features: (a) the nearly spherical shape of the shell; (b) the actual distribution of continents and oceans; and (c) the distribution of mountain ranges existing at present as well as those that existed in the past geologic periods.

Further characteristics of the structure of the earth's crust are to be found in *geology*. There does not seem to be any doubt that the following conclusions reached in geology must be considered in the first place: (a) the earth has been changing its face, that is, the crust has been subjected to many major or minor deformations; (b) the composition of continents differs from that of ocean basins; (c) the continents themselves are not uniform in composition; there is a smaller part of each continent, the shield, that constitutes a nucleus, around which material has been accumulating until the continent has reached its actual shape and size; (d) certain parts of continents came to form sea bottoms at different geologic periods and were covered by layers of sediments; (e) by epeirogenic and orogenic processes, some parts of continents were raised and some folded; (f) the major folding processes, giving rise to the principal mountain ranges, were followed by intensive intrusions; the distribution of batholiths indicates that these could have been masses of molten magma which raised the overlying solid layers and probably melted part of the solid matter with which they came into contact; (g) the formation of mountain chains has been shown to have had a cyclic character; more precisely, there were geologic revolutions each comprised of several phases and separated from the preceding and following revolutions by time intervals of variable duration, during which no folding occurred on a larger scale.

Insight into the structure and properties of the deeper parts of the continents or of the ocean basins has been gained largely by students of *geophysics*.

Among many characteristics established with a good degree of certainty in this science are these: (a) the continental and suboceanic parts of the crust differ in composition; (b) the core of the earth displays, even at the present time, certain properties of a liquid; (c) the distribution of densities in the crust corresponds more or less exactly to the state of isostasy, which shows that there is a continuous adjustment of masses to the conditions of equilibrium for floating bodies; and (d) the existence of such deformations in the earth's crust suggests a certain plasticity of the material forming it, even at present.

These various statements, mentioned here as principal characteristics, are either facts established directly by observation or assumptions based on well-known facts. The question arises whether these are all the characteristics that should be taken into account in the first place. We always have to be aware that such a list can never be considered as definitely completed. The history of science abounds with examples of changes in the estimation of importance of certain facts. Nevertheless, it seems to the author that even the list so far presented makes it possible to start a systematic summary of that part of the history of the earth which refers to the formation of the crust. The list of assumptions will take a more precise and complete form as more of an agreement is reached about this process.

Such a systematic summary is attempted in the following with the hope that it will be of help in reaching an understanding of the principal mechanism or mechanisms involved. In an effort to find forces that would be large enough to account for displacements of such gigantic proportions as those of continents or those involved in the formation of mountain ranges, the author has suggested the forces due to a zonal rotation of the planet and has been able to show both theoretically and experimentally that this hypothesis will provide a plausible explanation (*6–9*).

The sequence of events as suggested by this hypothesis is as follows. Two or more billion years ago the earth was a fluid body of nearly spherical shape. Despite the fact that, taken as a whole, the earth had a shape differing but little from a figure of equilibrium, there was no real equilibrium. Tides and internal movements were superimposed on its rotation in a way similar to the ones observed now on fluid members of the solar system. Heated in the interior and cooled at the surface, the earth would have been subjected to two processes: (a) *the convection currents maintaining a nonuniform rotation and producing different zonal components of displacements or velocities* (Fig. 1); and (b) *the decrease in the average temperature of the outer layer after it became liquid, thus favoring the formation of solid blocks.* Because of the differentiation of material produced by the action of gravity, the density should increase with the depth. Thus, the solidified masses formed at the surface would be composed of the lighter material (sial) and would float in the outer layer. Both types of forces, namely, the tidal forces and the frictional stresses, acting on the submerged parts of the floating blocks could hinder a "fast" formation of the crust. It can easily be seen that each of these forces favored a horizontal segregation of the sial (*7, 10*). Thus for a certain time interval, the formation of a large single floating block was highly probable; whenever there are many floating masses on a liquid planet moving with different velocities along the parallels, the faster ones will capture those that are moving more slowly, after several revolutions. This probably relatively short period of the history of the earth was followed by another during which the whole surface was covered by a thin shell. Such a crust could be broken into parts several times and welded again. This could provide an explanation for certain deviations from homogeneity in the uppermost layer, for example, for the existence of shields which represent the largest homogeneous parts of continents (*7*).

Until this point there is no definite reason for making a choice among three hypotheses, namely, among the assumptions that the formation of the present features of the earth's crust is due either (a) to the action of tidal forces, or (b) to a zonal rotation opposite to that represented by Fig. 1 (i.e., corresponding to an angular velocity increasing toward the poles), or (c) to the effect accepted by the author, which is characterized by the existence of an equatorial acceleration. Nobody has yet succeeded in providing a satisfactory explanation for the real topography on the basis of tidal forces or on the assumption of a zonal rotation characterized by polar acceleration. On the contrary, if one assumes (*6*), for the duration of several geologic periods, a zonal rotation of the earth following a law similar to that of Carrington-Faye, which holds for the sun, $\omega = a + b \sin^2 \theta$, where $\omega$ is the angular velocity, $\theta$ the latitude, $a$ a positive constant, and $b$ a negative constant, one can demonstrate that the field of forces resulting from this rotation will be able to produce deformations in the crust of the same nature as those outlined above (*7*). To show this, we shall briefly consider the field of forces due to the stresses at the interface crust-substratum, leaving out of consideration, for the present, the secondary effect of gravitational forces.

After solidification, the earth's crust should rotate with an angular velocity having a certain average value if compared with angular velocities in different zones of the liquid part. The equatorial belt and the polar caps of the underlying liquid layer would have the extreme values of velocity and, therefore, liquid particles would be displaced with respect to the solid block $ABB_1A_1$ (Fig. 1) in a manner shown for one meridian, $NQS$. This block could represent a floating body or cover the liquid completely, that is, be a solid crust. The relative displacements of the underlying liquid (magma) must produce horizontal stresses at the inner surface of the block. Their distribution has, of course, the same zonal character; and the author has been able to show that if a solid block subjected to stresses of this kind will burst, it will do so along a line represented by the curve $efg$ in Fig. 1 (*7*).

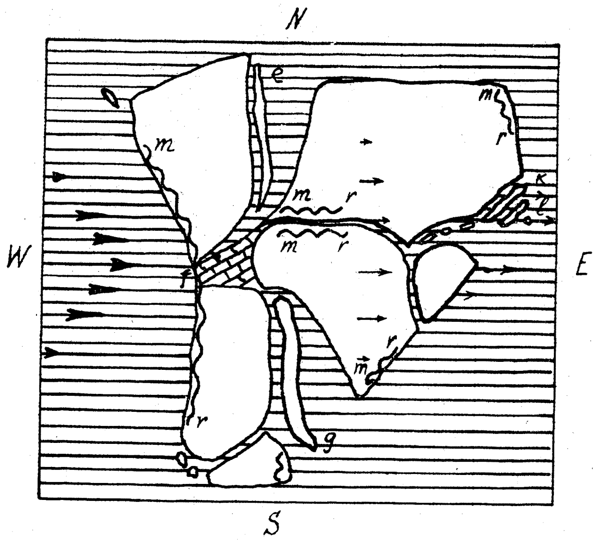


FIG. 2. The initial form of the plate broken into parts shown on this figure was similar to that of Pangea as determined by A. Wegener.

Rupture of the block may occur at several places in a similar manner. Moreover, the suboceanic parts of the crust, being subjected to similar stresses, could also be broken. If we compare the western parts of a block broken off in this way with the geographic map, we will see that these parts, *Aef* and *Bgf,* are similar to North and South America.

The author's experiments (*8*) concerning the rupture of thin plates subjected to superficial stresses have shown that it is possible to obtain a model of the formation of continents in this way. Stresses acting on fragile plates were produced by a substratum in which the distribution of velocities followed the law of zonal rotation. The parts resulting from the rupture of a plate turn out to be very similar in appearance to the actual continents, particularly if one also takes account of the heterogeneity of the plate. One of these broken plates, which was reinforced at places corresponding to the actual positions of shields, is shown on Fig. 2. The exact number of continents, their relative position, their shape, and even certain secondary features—such as a strip *efg* corresponding to the Mid-Atlantic ridge and many islands *kl* of "East Indies"—were obtained in this and similar experiments (*7*).

Thus, the author's assumption that a zonal rotation took place in the interior of the earth after the crust solidified provides a simple mechanism for the formation of continents and ocean basins that corresponds to their actual distribution. Moreover, it serves to explain certain mountain ranges and several other details of the structure of the crust. In many experiments, the whole Tertiary mountain belt, except the Himalayas, was formed at the right places, as it is shown by the several lines *mr* in Fig. 2. A little consideration shows that this folding must occur when the forces due to the assumed zonal rotation produce a pressure, for example, like that at the west side of the New World, or drag the other continents to the east and, because of equatorial acceleration, force the northern continents to turn counterclockwise and the southern ones to turn clockwise. As to the Himalayas, one has to take into account the fact that the peninsula of India was located on the faster moving equatorial belt and, therefore, could be pressed into the continent of Asia. The last idea was suggested by Wegener and should be confirmed by a special experiment.

A part of the mountain ranges older than the Tertiary belt can be explained in the same way, but the formation of the remaining mountain ranges will become clearer when the changes in the field of internal forces are more extensively investigated. One reason for such changes can immediately be seen. The distribution of masses in the earth's crust covering a liquid core was always an asymmetric one (*11*). Therefore, larger displacements of the crust with respect to the "axis of rotation" of the earth were highly probable (*11*) and there is no doubt that such displacements would produce essential changes in the field of forces.

Even the simplified form of the hypothesis of a zonal rotation of the earth, as given above, seems to be in very good agreement with all principal characteristics of the formation of its crust. No essential additions have to be made in order to draw the conclusion that there are no contradictions with the characteristics taken from geology. As to the accumulation of the matter around a shield by folding, this process can be easily included in the general plan. Let us explain this by an example. Suppose the Old World, as required by the hypothesis of zonal rotation, was separated from the western continents and dragged by the underflowing magma[1] to the east (Fig. 2). The bottom of the newly created Atlantic Ocean could be partly formed by magma rising into the fissure, but the bottom of the Pacific was solid and also dragged to the east. On the other hand, the two western continents having a smaller area over the equatorial belt should be subjected to a smaller displacement to the east, or to none. Thus, the equatorial part of the bottom of the Pacific should exert a pressure along the western coast of America, and the folding of a continental strip parallel to the coast as well as of a strip of the ocean bottom becomes a well-explained phenomenon. It is evident that in the last case new folds could increase the land area. It seems to the author that in a similar way many changes in the size or shape of the continents can be clarified.

As to the cyclic character of the mountain building, it has been pointed out several times that the "flow" or creep in the solid crust could occur only in phases (*12*). The increasing viscosity of the underlying liquid magma was the factor that produced stresses large enough to overcome at a certain moment the resistance of the crust existing at that time. With the advanced cooling and a larger thickness of the crust, larger stresses were needed to produce the same effect, but

[1] To avoid a misunderstanding, the words "floating" or "underflowing" have a descriptive character only for later geologic periods. In the last case, for example, we mean extremely slow displacement of the plastic magma.

in the meantime, the magma became more viscous and the horizontal stresses could again reach a value required for a new folding. Such a process could be repeated until the crust became too thick for further changes on a larger scale.

Having in mind only to find a plausible mechanism of the formation of principal features in the earth's crust, the author was not concerned with the determination of the geologic periods during which the outlined events could occur. This remains to be done. Also, one can only say that if this mechanism worked throughout geologic history, there ought to be an internal source of energy producing the convection currents which themselves, as mentioned, would maintain the zonal rotation against the increasing viscosity. There is no indication that such a rotation has ceased to exist in the past. The existence of an energy source in the interior of the earth has been asserted at various times, but its exact nature is still open to speculation.

As mentioned, these few considerations show a good agreement between the author's hypothesis of zonal rotation of the earth and the most important conclusions of geology and related sciences. And although much remains to be done, the way seems to be open to the understanding of many other characteristics of the formation of the earth's crust that were not discussed in this paper.

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# Samuel Clark Harvey: 1886-1953


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SAMUEL CLARK HARVEY died on August 22, 1953. His death came suddenly, in the midst of work, and terminated a career of courageous thought and action.

Doctor Harvey was born in Washington, Connecticut, February 12, 1886. He received his bachelor's degree from Yale College in 1907 and his degree in medicine from the Yale Medical School in 1911. He trained in pathology with MacCallum at the College of Physicians and Surgeons and in surgery with Cushing at the Peter Bent Brigham Hospital in Boston. After an interval with the U.S. Army Base Hospital No. 5 overseas, he returned to Yale as a member of the faculty and was appointed professor and chairman of the Department of Surgery in 1924. In 1947 he relinquished this chair to become professor of oncology, and held this post until his retirement in 1950.

His position in American surgery derived from preeminence in the classroom and laboratory, as well as in the operating theatre. To him, surgery represented a compendium of medical knowledge, encompassing all divisions and recognizing no artificial boundaries. He was not a specialist in any one field but a master in all. His operative procedures were characterized by superior technical ability, combined with infinite patience but, in essence, they were classic demonstrations of applied physiology and pathology. Not only was he the surgeon's surgeon but also he was the physician's physician. Above all, he was the patient's doctor, and his calm considerateness at the bedside evoked a degree of trust and confidence that gave dignity to pain. Such healing left few scars.

His teaching, based on the unorthodox assumption that the student of medicine was an intelligent individual, went beyond instruction to stimulate a lasting inquisitive interest. Learning, to him, was not a passive acquisition of established knowledge but a fresh dynamic experience of the mind. To him the function of the teacher was to inspire with enthusiasm rather than to supplant critical judgment. His ability to arouse speculative interest reflected a deep personal sense of the necessity for constant inquiry, and the rich flavor of his teaching stemmed from participation in many fields of intellectual endeavor.

His research interests were concerned with the phenomena of growth and development as applied to both tissues and ideas. Early experiments on the genesis of the pia-arachnoid and later investigations of wound healing revealed a keen insight into biological processes and led to lasting scientific contributions. His historical and philosophical essays reflect a wealth of knowledge and thought and will be relished, as well, for their style and concept.

He was active in medical and scientific affairs on a national as well as a local scale and was honored by election to the presidency of a number of distinguished societies. He served on a wide variety of governing boards and his wisdom and understanding of men and events rendered his counsel invaluable. In the medical school, he was instrumental in the introduction of broad new concepts and programs and his progressive outlook and sound critical judgment were dominant factors in the determination of institutional policy. A remarkable ability to clarify a confounded situation