should be a system of them reaching to every part of the vessel; for the pumps may be needed the most when the vessel is careened on her beam, or at some unusual angle fore and aft.

If possible, a tender should accompany the exploring-vessel proper, especially if she be a steamer, whose stores of coal and other articles are to be transferred when the ice becomes dangerous for such a craft, presumably not strengthened to combat with that element.

FREDERICK SCHWATKA.

ON THE FUNDAMENTAL THEORY OF DYNAMIC GEOLOGY.

MANY lines of inductive research lead to the conclusion that the interior of the earth is in a fluid condition, and that the solid shell is comparatively very thin, but variable in its thickness from district to district, and in the same district from time to time geologically. A crust twenty-five miles in thickness at a maximum, and very much thinner at a minimum, best explains geologic phenomena. If we consider this crust to be made up of units defined at the upper surface by districts of some magnitude, it seems necessary to regard it as existing in a state of floating equilibrium; so that, if some portion of the rocky material is taken from any such district, it rises, and the district on which it is deposited subsides. In case material is transferred for a very short distance, appreciable displacement may not result, the local structural rigidity being sufficient to withstand, or largely withstand, the stress. But if the short transferrence is across the line of a fault, from the upraised to the thrown side, the facts seem to show that the upheaved side continues to rise by reason of unloading, and the thrown side to subside by reason of increased load.

The rigidity of the crust of the earth arising from the molecular cohesion of the solid state is greatly modified by mechanical structure. The crust is composed of geologic formations of diverse origin, diversely arranged. The formations are broken into great blocks by great fault and flexure planes, in many cases doubtless extending quite through the crust. It is also fractured in multitudinous ways, and the crevices filled with vein matter. Again: each block or segment of a faulted formation is divided into small fragments by stratum planes, joints, schist planes, and slaty cleavage. The rigidity of each minute fragment is due to the molecular cohesion of solidity, but the general rigidity of the crust is dependent on mechanical structure. The fragments of which the crust of the earth is composed are exceedingly minute when compared with geologic formations, and they appear relatively as but grains of sand when compared with the whole crust of the earth.

This fragmental character of the crust is exhibited at the surface, and to the greatest depths to which observation has extended; and, so far as it depends upon the great faults, it must extend quite through the crust. There may be and probably is a zone beneath, so nearly fluid by reason of temperature and pressure, that fractures are less easily generated and more easily repaired, but the rigidity of the crust is not increased thereby.

The solidity of the crust of the earth is limited by temperature and pressure under conditions of chemical constitution and hydration, and is further limited by the conditions of its mechanical structure.

If vertical stress be applied to a point on the surface of the earth, the strain is propagated laterally by the condition of rigidity, but not indefinitely, as this rigidity speedily vanishes in the presence of the enormous forces involved in the weight of the crust itself, and in the great bodies of matter that are unloaded and loaded at the surface. The distance to which the strain extends is greatly lessened by the fact that the crust is not a continuous solid by cohesion, but preserves continuous rigidity in a very imperfect way by mechanical structure alone.

If the crust of the earth were practically homogeneous in the specific gravity of its materials, its static equilibrium would not permit the existence of any great elevations at the surface; but to the conclusion of a general equilibrium, geologists and geodesists are alike converging; and, if true, it necessitates the further conclusion that the crust, and perhaps to some extent the underlying fluid matter, is of varying density from region to region. This conclusion follows from a consideration of the inequalities of altitude existing in the earth's surface: and, since they are ever changing from district to district, — as one subsides and another rises, — contraction and expansion must occur. The necessity for the hypothesis of contraction and expansion is not obviated by the hypothesis of a fluid interior, nor is the latter rendered unnecessary by the former.

There is a constant lateral transferrence of material at the surface by rains, rivers, and marine currents; there is a constant vertical transferrence of material by displacement; there is a constant transferrence of material from beneath to the surface by extravasation; and geologists postulate a constant transferrence of material beneath by subterranean flow, thus completing the cycle of transferrences.

But transferrence of material laterally and vertically does not serve completely to explain all the history of geologic movement. Another hypothesis is yet necessary; and this exists in the postulate of ever-changing density, arising from the following sources: first, changes in density due to chemical action, especially as exhibited in hydration; second, changes in density due to solidification from the melted state, and to liquefaction from the solid state; third, changes in density due to pressure and to relief from pressure. A consideration of many geologic facts has suggested to the writer that it may be possible, that, when the rigidity of the solid state is overcome by pressure, the rate of condensation due to added pressure is increased at that critical point; or, stated in another way, that the passage of rocks from the fluid state induced by pressure, to the solid state by relief from pressure, is marked by a sudden expansion. Should experiments hereafter give warrant to this conjecture, the chain of conditions necessary to the explanation of dynamic geology would seem to be complete.

Early in the history of geologic research, a contraction of the earth, due to the loss of heat, was postulated to explain the deformations of the crust. This loss of heat occurs in two ways, — by conduction, and by convection from the interior to the surface. The convection is accomplished by the heating of subterranean waters, and their escape as hot water and steam from the multitudinous hot-springs and geysers of the world, by the steam discharged in large quantities from volcanoes, and by the lavas which come to the surface to be cooled. By this method of convection, cooling progresses at a high rate; for the lavas even of quaternary times are of vast extent, and the lavas of all geologic history are correspondingly vast in amount. How cooling by convection is quantitatively related to cooling by conduction cannot be stated with our present knowledge; but, when all of this cooling is considered, the rate of condensation is insufficient to explain the known displacement — it is necessary to resort to other agencies.

For the fundamental theory of geologic dynamics we have as conditions, first, a fluid interior of great specific gravity, in part due to compression; second, a solid crust of irregular thickness, not continuous by molecular cohesion, but composed of small fragments mechanically arranged, and permeated by water from above; and, third, an aqueous fluid and an atmospheric gas in motion over the crust.

The agencies of change may be considered as primary and secondary. The primary agencies are, first, general secular cooling by conduction and convection; second, the heat of the sun setting in motion the air and water at the surface; third, the astronomic agencies that produce stresses. The secondary agencies are, first, local heating and local cooling; second, local loading and unloading, having an augmented effect at the critical point of solidity; third, chemical reactions arising from changes of temperature, pressure, and hydration; fourth, the expansion of water into steam by internal and local heating.

The changes wrought are, first, general secular contraction; second, transferrence of material horizontally at the surface by aqueous agencies, and in the interior of the earth by flow, and vertically by subsidence and upheaval, and from within to the surface by extravasation; third, change in the chemical and lithical constitution of rocks, as seen in various forms of metamorphism; fourth, local lateral compression of formations, exhibited in plication and implication, and local stretching, exhibited in certain parts of flexures.

Conjointly and severally, the conditions, agencies, and changes thus enumerated seem to furnish a fundamental geologic theory, in harmony with and explanatory of the multifarious facts discovered in geologic research. Geologists widely accept the several parts of the theory save one; namely, that which assumes that the solid state is a critical condition of volume. The general theory enunciated is modified by a multiplicity of minor conditions, agencies, and changes, to expound which a voluminous treatise on geology would be necessary.

The correlation and interdependence discovered to exist between volcanism, seismism, displacement, surface degradation, sedimentation, and metamorphism, furnish important evidence in favor of the general theory. So far as research has progressed, regions of great and frequent displacement are found to be regions of great degradation and sedimentation, of great extravasation and seismism, and of great metamorphism; while regions of small displacement are regions of small degradation and sedimentation, of small extravasation and seismism, and, so far as known, of small metamorphism. The evidences of correlation are exhibited in many and diverse ways.

The agencies of change enumerated in the above theory are interdependent, so that the increase or diminution of one results in the increase or diminution of all. If the agencies of the first order — i.e., secular cooling, heating of the sun, and astronomic stresses — be neglected, the other agencies are interdependent in such a manner that there is a tendency secularly to establish an equilibrium; and doubtless such an equilibrium would be established in a period not of great length considered geologically. But the agencies of the first order continuously destroy the static equilibrium, and, conjoined with the others, they produce the sequence of changes discovered in geologic history.

The rate of internal cooling is manifestly diminishing, and physicists incline to the opinion that the heating due to the sun is diminishing. From this stand-point, then, the rate of change in geologic history is secularly diminishing. On the other hand, the secondary agencies of change increase in efficiency by reason of increased heterogeneity in the structure of the crust. From the irregularities of the upper surface, and those probably existing at the lower, as suggested by many facts, the crust is heterogeneous in thickness, and doubtless is becoming more so. It also becomes more and more heterogeneous in constitution by the progressing differentiation of its parts, exhibited in the diversification of geologic formations, density, temperature, conductivity, hydration, and chemical and lithical constitution. This internal heterogeneity renders the crust more sensitive to external agencies of change, so that a smaller amount of primary change serves to unlock a given amount of secondary change. At the present stage of geologic research the facts are not sufficient to establish the quantitative relation between the diminished rate of change from the primary agencies and the increased rate of change from the secondary agencies. It is therefore impossible to predicate any variation in the rate of change from the close of archaean time to the present.

J. W. Powell.

EVOLUTION OF THE DECAPOD ZOEA.

Principles applicable to adults are often equally applicable to larvae. In the discussion of natural selection most writers have confined themselves to adult animals and their reaction upon environment. There is no reason, however, why the principle should not be extended to include larval forms; and, indeed, to a slight extent this has already been done. Weismann's 'Theory of descent' proceeds upon this line, and indicates some of the important results which may arise from such research. Crustacean larvae offer particularly good opportunity for work in this direction. They are abundant, are easily obtained, and readily studied. They present great varieties of form, which are frequently not in any degree related to the adult characteristics. Indeed, crustacean larvae seem almost like a distinct group of animals, and may be studied as such, with the extra advantage that they are highly variable, and undergo rapid metamorphosis. Some of the possibilities of such research may be seen by a short consideration of the different forms of decapod zoea.

To make the subject clear, it will be necessary to give a brief description of three types of decapod larvae, confining ourselves, however, only to such points as particularly concern us here. The first is the type, which is undoubtedly the oldest, known as the protozoea. It is a comparatively rare form, being found in a few macruran species (Peneus, Lucifer, Euphausia). Fig. 1 represents such a larva. As far as concerns us, the peculiarities are these: the long body consists of a large cephalothorax, a more or less complete thorax, and an abdomen. The important point is, that all of the regions of the body are represented. When viewed from above, the part of the body composed of thorax and abdomen is seen to be very slender and weak, and to extend for a long distance backwards. A second important point is the method of locomotion: unlike all other forms, the antennae, instead of being sensory organs, are used in locomotion. They are large, and covered with swimming-hairs, which convert them into paddles; and, by moving them to and fro, the protozoea slowly propels itself by a series of jerks through the water. The telson is a third important feature: it is small, being in our figure no broader than the abdomen; it is usually forked, and carries a number of long spines (typically seven, though the number varies); it is not a swimming-organ, — a point of particular interest. One other feature must be mentioned, — the usual though not universal absence of protective spines.

A second type is that of the ordinary macruran zoea; e.g., the larva of the common shrimp. Such a zoea is represented in fig. 2. Here we find a number of changes. First we see that only two regions of the body are present, the cephalothorax and the abdomen, the thorax being unrepresented. The cephalothorax is not very different from that of the protozoea. The abdomen is, however, very different: it is distinctly divided into segments, all of which are well developed; it is tolerably thick, and is a much more powerful structure than the corresponding part of the protozoea. The muscular and usually the nervous system is well developed. In short, the abdomen is much more perfect than that of fig. 1. The locomotion of this zoea is entirely different from that of the protozoea. It does not use its antennae for moving, but propels itself vigorously with powerful strokes of its abdomen, after the manner of the lobster: at least, this is its motion when trying to escape danger; and that is all that concerns us. In correlation with this changed locomotion, the antennae have altered their form, and are now true sense-organs. On the other hand, the telson has become broadened into a flat