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GROUNDWORK OF THE EARTH'S DIASTROPHISM¹

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INTRODUCTION

Recent studies have been fruitful in bringing to light new evidences of diastrophism. The older terranes have been found to be more and more intricately deformed, as inquiry proceeds. The later terranes have disclosed overthrusts of unexpected extent and frequency. Troughs of graben type have been found to form chains of almost continental length. The recognition of unconformities has been multiplying to an embarrassing degree. Moreover, as inquiry passes from local and regional fields to the greater features of the earth, the continents and the oceanic basins it discloses evidences of a profound order of diastrophism whose significance has been only meagerly recognized in the past. In the light of these revelations, it is important to workers in this difficult field to know whether

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sufficient resources of diastrophism support all the types of interpretation that are currently offered for acceptance. If the dynamic resources that form the groundwork of any type of interpretation are obviously insufficient to actuate the great diastrophisms implied by direct evidence, the deficiency should be recognized and this mode of interpretation placed on the shelf. It is the purpose of this paper to discuss the fundamental sources from which energy available for actuating diastrophism may arise. This necessarily leads back to the genesis of the earth, for in the mode of its formation there should be found the energies it later displayed.

TWO BASAL HYPOTHESES

From the dynamic point of view, two types of genetic hypotheses practically cover the whole field: the one, gaseous or quasi-gaseous; the other, orbital. The two rest on distinctly different systems of dynamics, and they inherited unequal measures of energy; their potential resources of diastrophism were thus diverse from the start. In addition to this, and even more important, their modes of evolution led at once to divergencies in the degrees of conservation or of dissipation of their inherited energies. Accepting the common view that the earth was once extensively deployed, it is quite clear that its material carried sufficient energy to actuate any diastrophism that has been disclosed or is likely to be discovered in the earth, whether its substance was distributed gaseously or orbitally. An orbital deployment must have carried much the greater potentialities, but both should have carried sufficient energy, if well conserved and brought into service. In this sense, either of the two hypotheses may be regarded as competent potentially. *The vital difference lies in the extent to which the two modes of descent conserved their original energies, or wasted them before the time for diastrophism came.*

THE COLLAPSING TYPE

Gaseous organization is an ideal type of a failing structure. If matter is removed from any point within a gaseous mass, the whole collapses on the vacancy, because the support of the mass depends on the repellancy of the molecules at all points within it. So, also, whensoever radiation of heat or any other influence is brought to bear on any part of a gaseous body, or on the whole, so that its energy is reduced, the body proportionately collapses and reorganizes itself to fit the new status of its energy. In so far, then, as there was opportunity for the radiation of heat or for other losses of energy, during the formative history of a gaseous earth, it promptly collapsed to a smaller spheroid of similar form, and thus

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much of its potential energy was dissipated without leaving any diastrophic record, in the accepted sense of the term.

THE NON-COLLAPSING TYPE

On the other hand, if the molecules that were to form the earth were moving in individual orbits about their controlling center, they were essentially independent of one another; they had moving forces of their own; they were self-supporting. If any molecule was cooled or removed, it made little difference to the rest. They kept on in their predetermined paths. And so an orbital nebula is not directly collapsible, in the sense that a gaseous nebula is. The individual molecules of an orbital nebula are likely to be gathered in ultimately, but the process is much more indirect. The time required is much longer; a larger measure of energy is likely to be conserved. A gaseous organization is so constituted as to *expedite* the loss of its energy and hasten the collapse of its mass; an orbital organization is singularly well suited to conserve its energy and to *delay* concentration.

THE WASTEFUL TYPE

Under the traditional concept of the gaseous origin of the earth, not only was its energy radiated rapidly away, with collapse closely following, but the energy that remained was largely engaged in maintaining fluidity, for the prime effect of the collapse was an accelerated conversion of potential energy into additional heat (Lane's law). The earth mass was thus all gathered in before the concentrating process could record itself as diastrophism because of the fluid state. (I use the term diastrophism to denote any distortion that keeps a record of itself in the solid state. Concentration, of course, takes place in a liquid body, but it retains no record of any distortion of its structure that may arise incidentally, for a new and symmetrical structure is at once formed in accordance with hydrostatic laws.) No one, I think, has ever assigned any diastrophism to the earth so long as it remained in a fluid state; obviously deformation was only assignable after the whole earth mass had been assembled and had cooled sufficiently to become crusted over. In the meantime the earth-matter was drawn toward its center of gravity as far as its molecular activity would permit, and a corresponding portion of its potential energy was converted into heat. A maximum temperature was thus preserved which greatly facilitated the loss of energy by radiation, especially as this follows the law of the fourth power. According to Lane's law, the temperature tended to rise and the rate of radiation to increase so

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long as the gaseous condition remained. While in this active fluid state the possibilities of chemical combination of the earth substances should have exhausted themselves so far as temperature permitted. So, also, should the physical adjustments of the matter. According to the old masters, whose logic was admirable, the heaviest substances should have gathered at the center, the less heavy next, and so on in order, the lightest forming the outer layer. Thus the earth should have taken on almost perfect symmetry, and at the close of the assembling process it should have been in perfect isostatic equilibrium, both vertically and horizontally.

Thus we see that, to a maximum degree, the potential energies represented in the original-deployed state should have been converted into fugitive forms of energy and have been dispersed *before any diastrophic record could be made*. There was little possibility of shrinkage left except the meager amount that could arise from further cooling.

THE CONSERVATIVE TYPE

On the other hand, if we neglect for the time being so much of the central part of the earth as is supposed to have been formed from the earth nucleus, as defined in the preceding article, and assume that the outer and much larger part was built up of planetesimals or planetesimal dust, in a relatively cool and solid state, an earth of very different potential resources of diastrophism would arise. To fully realize this, it should be noted that after the earth had reached the mass of Mars, it should have been able to hold a notable atmosphere. All the planetesimals that made up the later growth must have plunged through this atmosphere after the fashion of meteorites on their way to the earth. Their velocities were thereby checked and their substance more or less converted into dust.²

The outer mass of the earth, built up thus at random by the infall of mixed clastic material, should have been highly porous and should have retained almost a maximum of susceptibility of compression in a solid state. Moreover, the distribution of the infalling matter by the atmosphere and hydrosphere should have been irregular, so that compression must have worked on uneven textures as well as varying substances, and hence should have produced distortion. As this was the distortion of solid matter, it should have retained a record of the action.

The mass as first built up should have been heterogeneous in chemical composition and almost totally devoid of adjustment in respect to density

² For a discussion of the size, rate of infall, and physical condition of planetesimals, see Article xiii, Diastrophism and the formative processes, *Jour. of Geol.*, vol. xxviii, (1920), pp. 665-701.

and other physical properties, and so these important sources of reorganization involving more or less diastrophism should have been retained almost intact. More or less of air and water should have been entrapped in the growing clastic mass, and these should have helped to fit the mixture for eruptive action later, when the conditions of vulcanism arose.

THE LONG SERIES OF SUCCESSIVE DEFORMATIONS

The potential resources of diastrophism entrapped in the growing earth should have begun to take on the early phases of actual diastrophism as soon as appreciable pressure was brought to bear on the loose material by the weight of added layers, and this initial diastrophism should have been followed at intervals by a long series of like partial self-compressive actions brought successively into function as the mass grew. These would give rise to various forms of cumulative distortion, local and general. It is immaterial to the general purposes of this discussion just how the deformations took place, beyond the basal fact that it was the distortion of solid matter. Probably the whole series of distortional methods were involved. Probably even partial liquefaction, as it arose here and there, gradually and selectively, gave rise to new distributions of stresses and led on to diastrophism of the enveloping and interstitial solid matter. It is a vital part of the doctrine here urged that the growing globe was kneaded by the rhythmical action of imposed forces, and squeezed the interstitial fluent matter out into the colder zone or quite to the surface. This action would, in its own fashion, contribute to new differentiations and new distortions of the associated solid parts, and so be a cooperating factor in diastrophism.

THE EARLY AND PERSISTENT DEVELOPMENT OF SURFACE DIFFERENTIATION

One of the early effects of deformation thus instituted should have been the development of surface reliefs of the same general types as those that accident the surface today. These surface reliefs must have had their inevitable effects on the currents of the atmosphere and of the hydrosphere, as these grew up with the growing earth. These currents in their turn should have reacted on the surface features much as they do now. The whole complex of surficial agencies should thus have begun their intricate and mutually reactional work. The later incoming matter must, then, have been more and more differentiated by these growing surficial agencies. They thus continued to cooperate with the volcanic and diastrophic actions that spring from the deeper horizons, so long as growth continued to be effective. With little doubt, a maximum of differentia-

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tion was reached at a certain stage, after which there set in a long effort to reach a better balanced distribution, a movement still in progress. Thus, in the growing stages, each partial deformation led on to increased differentiation of the incoming matter, and so laid the foundation for still further diastrophism when these effects turned into causes. In a certain sense, the complex process was cumulative, even though the resulting diastrophism, taken by itself, tended toward the equation of stresses and a better balancing of inequalities.

THE PERSISTENT EFFECTS OF THE DEEPER DIASTROPHISM

The earlier deformations were, of course, buried deeper and deeper and made more and more inaccessible as growth went on. It is easy to jump to the conclusion that they thus became inconsequential, so far as the outer diastrophism was concerned; but a little consideration will show that deformation in the depths, however buried, continued to be a potent factor in the diastrophism above, and that of later dates as well. All the earlier distortions gave warped foundations for all later compressions. Thus, in a sense, they transmitted their deformities and weaknesses to the terranes built on them. Besides this, and more important, *the matter in the depths partook anew in every recurrent stage of self-compression*. This was logically inevitable unless the substance reached a state of incompressibility, and this notion has become untenable since the compressible nature of even the atoms has been disclosed. But we need not fall back on this, for a comparison of the density of the earth with its neighbors clearly implies that central compression continued to be effective so long as the planet grew.³ After a careful study of the case, it seems safe to say that the high densities of the interior were not original, nor were they attained at any single stage, but rather by renewed stages of self-compression which affected each inner layer in its due proportion. This is clearly implied by the law of increasing density, which is not only theoretically sound, but is supported by the convergent testimony of several lines of concrete evidence, in addition to the comparison already cited.

THE PENETRATION OF THIS BASAL DIASTROPHISM

The considerations just sketched may almost serve as a discussion of the depth of penetration of all such diastrophism as sprang from increase of mass—that is, the basal diastrophism that especially prevailed during the formative stages of the earth.

³ Diastrophism and the formative processes. X. The order of magnitude of the shrinkage of the earth deduced from Mars, Venus, and the Moon. Jour. of Geol., vol. xxviii (1920), pp. 1-17.

If the earth, as it grew up, had been perfectly homogeneous, layer by layer, as in the supposed fluidal earth, the whole effect of increased mass might have been merely a uniform self-compression; but since the texture and composition of the earth was very heterogeneous in a minute sense and became regionally diversified in a large sense, by reason of the external agencies that affected its growth, it was inevitable that distortion should arise not only whenever, but wherever, self-compression took place. It is thus a firm inference that diastrophism in some form permeated, in a general sense, the whole of the self-compressing body, certainly the whole of that part which was built of planetesimals. The concept of merely surficial diastrophism, in response to general stresses in a body having such a genesis, seems to be altogether untenable. Of course, there were local distortions of all sorts, surficial as well as otherwise.

THE TOTAL VALUE OF THE SELF-COMPRESSION

I have recently endeavored to determine the total amount of self-compression which the earth suffered in the course of its history by means of a comparison of its density, mass, and volume with the densities, masses, and volumes of the planetary bodies nearest to it and most like it in their conditions of genesis, namely, the next inner planet, Venus; the next outer planet, Mars, and the earth's own satellite.⁴ The method consisted of building up the moon with moon-stuff, at the moon's density, until its mass equaled that of the earth, when its dimensions and volume were computed, after which it was theoretically shrunk to the density of the earth and the amount of self-compression determined. Though not the actual process of formation, this is believed to fairly represent the degree of self-compression which would take place in a growing body under terrestrial conditions between a stage represented by the moon and a stage represented by the full-grown earth. So, in like manner, Mars was built up of Mars-stuff at Martian density and the self-compression between a Mars-stage and the mature earth-stage computed. So likewise of Venus. The results were concordant in a very suggestive and satisfactory way and were surprisingly large. Between the moon-stage and the earth-stage, the radial contraction was found to be 725 miles, the equivalent of 4,555 miles contraction of the circumference. The shrinkage between the Mars-stage and the earth-stage came out 618 miles radial shortening; that between the Venus-stage and the earth-stage, 177 miles. By a comparison of these results with one another, there came out the further very important conclusion that the self-compression became pro-

⁴ Diastrophism and the formative processes. X. The order of magnitude of the shrinkage of the earth deduced from Mars, Venus, and the Moon. *Jour. of Geol.*, vol. xxviii (1920), pp. 1-17.

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gressively *greater per unit mass of increase* during the later stages. This bears on the last two subjects discussed, in that it clearly implies *progressive compression of the inner parts*. This conclusion is supported by cogent theoretical considerations. A similar comparison with the great outer planets is not admissible, for their constitution, their intimate history, and their dynamics are distinctly different. They appear now to be largely gaseous and to have been gaseous from the outset. Hence they never underwent the sifting of solar material that was necessary to give the stony and metallic substances that make up the main mass of the solid terrestrial planets.⁵ The giant planets were thus evolved under the sole control of gaseous dynamics, and their material differs radically in proportions from that of the small solid planets.

An elaborate inquiry was made to see if any part of the great self-compression indicated by the comparison might be explained reasonably by supposing that the larger bodies had a higher content of inherently heavier matter, but the evidence was found to favor precisely the opposite view. Any consistent mode of genesis makes it almost certain that the larger bodies contain relatively more *light* material than the smaller bodies. It appears, then, that the self-compression of the earth was not only large relative to its neighbors, but that it became increasingly large as the earth-mass grew, and hence that the interior participated in the self-condensing process throughout all stages.

THE CAUSE OF THE BASAL DIASTROPHISM

The fundamental source of this great self-compression, and of the diastrophism that necessarily accompanied it because of the differentiated and solid state of the earth material, has been definitely implied in the statements already made and needs to be explicitly stated here merely for emphasis. The self-gravity of the assembling mass converted its own potential energy of position into the actuating energy of diastrophism. This potential energy became available for diastrophism simply because it had been conserved in a high degree by the slow orbital process by which the earth material had been assembled. Secondary causes of diastrophism, of course, cooperated with this basal cause at all stages. During the formative stages the basal cause of diastrophism was probably more dominant relatively than in the later stages. In these, various minor causes seem to have had a higher proportionate value, but in all stages, I think, they are to be regarded as incidental rather than fundamental, at least in the main.

⁵ Diastrophism and the formative processes. XII. The physical phases of the planetary nuclei during their formative stages. Jour. of Geol., vol. xxviii (1920), pp. 473-504.

It will help to clarify thought on the subject if we distinguish between the leading part played by heat as the chief *opponent* of shrinkage in a gaseo-molten earth and the secondary part it plays in a planetesimal earth as merely the *product* of compression. In a gaseo-molten earth heat is the main agent that stands in the way of further immediate collapse; it must be dissipated before shrinkage will go further. The old masters were, therefore, quite logical in regarding cooling as the chief prerequisite to shrinkage and deformation; hence cooling seemed to be the chief cause, whereas it was merely the removal of the hindering agency. But, in a body built up of heterogeneous clastic matter at relatively low temperatures, it was at first the solid form of the particles that stood in the way of their collapse; later it was the lack of the most dense chemical combination and physical organization that stood in the way. Heat was thus only one of a group of restraining agencies; it is not even the leading one in the order of action. The polarized forces of the solid state had to be overcome and heat *produced* by compression before it came into action to aid in restraining further compression. This, of course, applies to the heat mechanically produced rather than that which may arise from chemical action of radioactivity. When heat is thus produced mechanically it becomes a cooperating factor of notable importance; it may come to be a leading one, or even the chief one. But, normally, as the heat rises, some part of it is likely to be consumed in endothermal reactions, some in liquefaction, some in crystalline organization, and some in mineralogical and other forms of physical reorganization. In so far as any part of the substances engaged in these complex processes takes a mobile form, gravitative pressure, aided by tidal, nutational, rotational, and other forces which were more or less constantly or rhythmically working concurrently with it, tended to force the mobilized products into higher and cooler zones. They thus mechanically disposed of that part of the heat which produced weakness in the interior, and in that way helped to preserve its rigidity. There is evidence that this restrained the interior action to the limit of insipient liquefaction on the borders of the solid state. In so far as the heat arose from radioactivity, the source is likely to be carried out with its products. A combination of this sort should naturally work toward an equilibrium status between the processes that tended in opposite directions, and this equilibrium status should have for its boundary line the fusion-solution curve. This automatically separated the matter that was rigid enough to hold its place and do its part in maintaining the rigidity of the earth, and the weak yielding part that had to go practically as fast as it arose. In the nature of the case, the equilibrium status—and its determinant on the liquid side, the fusion-

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solution curve—was accommodated at all depths to the conditions imposed by pressure, by the constitution of the material, and by other properties. The critical temperature, the solution-fusion temperature, rose as depth increased, but the rate of rise was dependent on too many unknown factors to permit a trustworthy determination, either at present or in the past. The essential point here is that the part which heat played in the complex action was that of a *product* rather than a *primary determinant*. The high rigidity of the earth, now so well authenticated, seems to point definitely to some such automatic mechanism as this: So equally do the dribbles of liquefied matter that have been forced to the surface, or to the cool surficial zone, in all the geologic ages, past and present. The working out of this automatic adjustment by the cooperating processes is to be regarded as the attainment of the past billions of years rather than millions of years.

THE TIME OF THE MOST EFFECTIVE DIASTROPHIC ACTION

Among the strong contrasts between the two views of genesis under comparison are those that relate to the time when the chief diastrophic events took place. If the earth was at first a globe of gas, it collapsed as fast as the radiation of its excess of heat permitted. The time consumed in the process was relatively short, for radiation takes place in proportion to the fourth power of the temperature, and the temperature in this case was necessarily high, according to Lane's law. If, on the other hand, the earth was formed by the ingathering of planetesimals, the process followed the laws of orbital dynamics and the formative process was very much slower. It may have taken three or four billion years. In this long period of gradual upbuilding, the graded adjustments just described should have had time to work out their mutual adaptations.

In another respect, also, the contrast was striking. In the traditional gaseo-liquid earth, diastrophism did not start until after the formative process had ceased and encrusting had begun. In the planetesimal earth, the diastrophism began with the earliest accessions and *ran progressively through all the formative stages*, and through all later time. It apparently grew in effectiveness during the main assembling of material, but it appears to have declined when the accessions fell to a relatively ineffectual rate. The most effective diastrophism thus fell *within the formative eons*. The sum total of diastrophism in the whole earth body was thus greatest during the formative eons. It is probable that during any large fraction of the formative ages greater diastrophism took place, even in the surficial shell, than during any of the later periods of equal length, though this can not, perhaps, be affirmed with the same confidence, for it

involves the distribution of diastrophic effects which depends on other considerations than those under study here. The observational evidence respecting the Archean Era, whose terranes are closest of kin to those of the formative stages, seems to support the view that the surficial diastrophism was then greater than during any period of equal length in later time.

BEARINGS OF THE PLANETESIMAL VIEW ON VULCANISM

Under the planetesimal view, vulcanism, as recorded in the geologic ages, arose chiefly from the partial selective liquefaction of eutectic materials as they happened to be in contact here and there in the body of the earth. The squeezing of this mobilized material to or toward the surface by the differential pressures engendered within the earth-body, including the graded stresses, more intense below than above, imposed by outside bodies, was the main extrusive factor of the case. Vulcanism is thus in itself little short of a phase of diastrophism. The heterogeneity of the earth-substance, the inequalities of its distribution, and the prevalence of greater stresses below than above combined to promote both processes and make them helpful companions in action. The distortions of the deformative process are the natural counterparts of the partial mobilizations and displacements of the volcanic process.

In a gaseo-molten earth, all of whose material passed gradually from very high to much lower temperatures, while the mass was stirred by convection at all stages, there should have been developed and brought to the surface all the gaseous material in the earth-substance which high heat could set free. When these hot gases entered the hot atmosphere their molecular velocities should have been at a maximum, and the rate and the extent of their escape from the atmosphere should have exceeded that of any later time. When the long boiling process ceased and the encrusting of the liquid sphere began, there should have been left in the mass a minimum of gaseous material. Only that small measure which might be held there by the partial pressure of like gases in the atmosphere would be assignable under these conditions. The earth-body should then have been scantily supplied with explosive volcanic gases. It would seem, therefore, that an earth-body formed in this way should be unsuited to give rise to such a degree of gaseous vulcanism as is actually manifested. Just as a once molten earth must have exhausted its main resources of diastrophism before a record of diastrophism could be made, so it must have exhausted in its hot youth essentially all its resources of explosive vulcanism before a solid environment was provided to give effect to its explosive possibilities.

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In the case of the moon, the logic is even more cogent, for even in its present cold full-grown state its gravity is insufficient to hold an appreciable atmosphere. Certainly, then, in its earlier and hotter stages, if it were once molten, *all* its volcanic gases should have escaped as fast as they were set free, and it should have cooled into a solid, gasless mass. The highly explosive vulcanism of the moon implied by the special features of its present pitted surface and the long lines of debris that radiate from some of its craters, irrespective of the reliefs of the surface, find ready cause under the alternative view, because it supposes that gaseous and gas-forming materials were entrapped during the planetesimal growth. This entrapped material would become an ample source of explosive vulcanism at a later stage, when internal conditions, like those previously sketched in connection with the earth, brought into play their solvent and gas-freeing activities, while differential pressure forced the gases and other mobile matter to the surface. The fragmental state of the outer matter in the absence of the cementing effect of a hydrosphere should give peculiar effect to the explosive action.

BEARINGS OF THIS VIEW ON IGNEOUS PETROLOGY

The prevailing view of magmas, when regarded as inheritances from a once molten earth, usually makes them either residues of the original molten mass or else re-solutions, *en masse*, of rock previously solidified. In either case the solidifying process is usually interpreted as involving a differentiation into a series of derivatives which separate more or less successively from the original magma. Magmatic *differentiation* thus becomes the essence of igneous petrology. Its problems become essentially questions of *descent* from an assumed primitive, or quasi-primitive, magma. In the field, the critical issue is to find all the derivatives required to make up, quantitatively and qualitatively, a consistent primitive, or quasi-primitive, magma. The embarrassments are many and formidable.

On the other hand, if magmas consist merely of partial solutions of heterogeneous mixtures, such as would naturally be formed by a multitude of small bodies of different natures falling in at random, they would quite certainly become highly diversified in the making. The primary problem would then lie in the *generation* of the magmas; in the *ascent* of magmas rather than their *descent*. While differentiation in the process of solidification would still remain a factor, it would be a secondary matter, in the sense that it was necessarily conditioned by the previous generative process. The inquiry in the field, in this case, should start with the evidence as to what petrological species and varieties are actually present.

and thence seek the probable mode of genesis where the possibilities are large and the embarrassments few. Each particular case presents purely an *a posteriori* problem of its own. It is wholly unembarrassed by any requirement that its factors shall sum up into a speculative primitive magma.

BEARINGS ON THE PROBLEM OF ISOSTASY

A liquid earth should be an ideal example of perfect isostasy in the highest sense—that is, isostasy in perfect *horizontal* as well as vertical adjustment. The earth's crust, as it began to form, should have inherited this quality in full perfection. Such distortions as later arose in the crust from cooling and shrinking were the beginning of a long series of actions that were destructive of this perfect isostasy. Diastrophism is thus made to function at the outset as an antagonist of isostasy. But its normal function, as we find it in action today, is tributary to isostasy. The surface forces of erosion, solution, transportation, and deposition, that must have set in as soon as the deformation of the crust exposed it to subaerial agencies, tended to counteract the effects of the first deformations and thus to reduce the deviation from the originally perfect isostasy. The interplay of diastrophism and the surface agencies tends in general, but not in all particular cases, toward the equalization of weight among the earth columns—that is, toward isostasy. If diastrophism produces inequalities at variance with isostasy, the surficial agencies and creep tend to restore isostasy; if diastrophism produces inequalities in the interest of isostasy, the surface agencies tend to smooth out the inequalities in disregard of isostasy. The two sets of agencies tend to hold one another in check. Starting with perfect isostasy and with little more than the meager effects of cooling to actuate diastrophism, we should not expect these mutually checking processes to permit inequalities to get far from the original isostatic state. On the assumption of a once molten earth, the first and greatest problem of isostasy is then to find an adequate and consistent explanation of the profound differences of density that are revealed by present evidence. Many years ago, when I still accepted the molten theory, I worked industriously on this problem of the differentiation of what must once have been very homogeneous material theoretically, but I never reached a solution that met the full requirements. The first few steps seemed easy and promising, but very soon the counteracting processes rose in efficiency and tended to destroy the gain that had been made. The combination of processes seemed to confine the extent of their differentiating effects to limits much short of the effects actually in evidence. I am not aware that any one has had better success.

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On the other hand, the planetesimal view brings into play a group of effective processes which tended to cumulative differentiation of the material of the earth from the earliest stage of accretion throughout the whole period of growth, though these were also antagonized by some counteracting agencies; but the limit in this case was very much broader. As a result, the full-grown earth inherited profound differentiations of material. These had a broad regional distribution correlated with the currents of the atmosphere and hydrosphere as well as the main lines of early diastrophism. From these fundamental differentiating agencies there arose segments of lighter and heavier material of continental and oceanic dimensions. These diversities are held to be the specific ancestors of those that now manifest themselves in the great reliefs of the earth. It is the prodigious task of surface agencies and of diastrophism, working together, to bring about, in the course of coming ages, a closer equation between these segments of lighter and heavier matter. This will require a vast lapse of time; but we have no wish to hasten its completion. The perpetuation of land life hangs on the extent of the delay in its accomplishment.

Probably one of the greatest contributions of isostasy, when its values shall be fully realized, will be its testimony to the significance of those wide and deep inequalities of substance which make possible the great reliefs of the present earth's surface.

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Groundwork of the earth's diastrophism

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