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it to simple algebra. I was led to it by an examination of the effect of telephones bridged across a common circuit (the proper place for intermediate apparatus, removing their impedance) on waves transmitted along the circuit. The current is reflected positively, the charge negatively, at a bridge. This is the opposite of what occurs when a resistance is put in the main circuit, which causes positive reflexion of the charge, and negative of the current. Unite the two effects and the reflexion of the wave is destroyed, approximately when the resistance in the main circuit and the bridge resistance are finite, perfectly when they are infinitely small, as in a uniform non-distortional circuit.

XXV. *The Geological Consequences of the Discovery of a Level-of-no-Strain in a Cooling Globe.* By T. MELLARD READE, C.E., F.G.S., F.R.I.B.A.*

WHILE working out my theory of the Origin of Mountain-Ranges I became clearly convinced that there was a fallacy underlying the popular conception of the effect of secular cooling upon the crust of the earth. It is very extraordinary that the physicists who supported the hypothesis that mountain-chains had been ridged up through the outer uncontracting crust following by gravitation the shrinking nucleus, were content to leave the idea in this very vague form.

It is obvious, when once pointed out, that on this hypothesis it is only the actual surface of the earth that does not contract. As the isogeothermal lines sink deeper in the progress of secular refrigeration, each zone below the surface in the solid crust must contract horizontally proportionately to the lowering of the temperature. At a certain depth the rate of this horizontal, or in other words circumferential, contraction must equal the mean rate of the radial contraction of the sphere. At this particular zone—which varies in depth as the time—I showed† that there is no strain; while all of the crust above it is in compression, and below it all the cooling matter is contracting. After fully realizing this conception, a few calculations convinced me that on the hypothesis that our globe has cooled in this way during all geological time, the level-of-no-strain, as Mr. Fisher aptly names it, could not at the present time be many miles deep below the surface. All this seemed so very clear to me that I

* Communicated by the Author.

† Chap. xi. 'Origin of Mountain Ranges.'

confess I was surprised at this particular chapter escaping the notice of my reviewers, who, as a rule, dealt very fairly and openly with the ideas put forth, so that I was fully prepared for a long continuance of indifference towards this interesting problem.

The able papers of Mr. Davison and Prof. Darwin, and the exhaustive mathematical investigation of Mr. Osmond Fisher* have agreeably dispelled this fear.

It is very satisfactory that each of these mathematicians, though working on an independent basis, and all holding different views as to the geological consequences of the discovery, are in singularly close agreement in numerical results. Mr. Davison puts the level-of-no-strain after the lapse of 174 million years since consolidation at 5 miles; Prof. Darwin at 2 miles in 100 million years; and Mr. Fisher, taking the present temperature gradient as 1° F. in 51 feet, arrives at the conclusion that the level-of-no-strain is now at a depth of 2.1361 miles. I may add that my own numerical results, computed in an entirely different manner, approximate closely to those of Mr. Fisher and Prof. Darwin.

My present intention is not, however, to dwell upon the interesting nature of these mathematical investigations of the properties of a cooling globe, but from a geological standpoint to speculate upon the results that flow from the discovery of the existence of a level-of-no-strain situated not many miles beneath our feet.

Volcanic Energy.—Mr. Mallet has based a complete theory of the origin of volcanic energy upon the heat developed by the crushing and compression of the rocks of the outer crust of the earth while following the contracting nucleus. Many objections to this theory have been pointed out from time to time by practical geologists, and I have dealt with the question elsewhere†. The existence of a level-of-no-strain within a few miles of the surface, if admitted, is absolutely fatal to Mallet's hypothesis. Not only is the number of cubic miles of rock‡ crushed quite insufficient to account for the necessary heat, but the limitation of the crushing to what I have called

* "On the Distribution of Strain in the Earth's Crust," by C. Davison, Phil. Trans. of Royal Soc. 1887, p. 231. "Note on Mr. Davison's paper," by Prof. G. H. Darwin, Ibid. p. 242. "On the mean height of the Surface-elevations and other Quantitative Results of the Contraction of a Solid Globe through Cooling" (Phil. Mag., Jan. 1888), by Rev. O. Fisher.

† Pp. 3-5 and chap. xxi. 'Origin of Mountain-Ranges.'

‡ Mr. Fisher estimates the amount of rock displaced by compression during all geological time as equal to a spherical shell the diameter of the Earth and 19 feet thick.

the "shell-of-compression" entirely forbids the acceptance of this secondary theory of volcanic energy.

Taking the greatest estimate of the present depth of the level-of-no-strain, the seat of volcanic energy on Mallet's hypothesis would be limited to a depth of less than 5 miles. When we point out that lava rises up to and flows from orifices of volcanoes at a level in some cases of $2\frac{1}{2}$ miles above the sea, it is obvious to anyone who has the slightest knowledge of mechanics that the locus of its origin in the earth's crust must be greatly below the highest estimate of the thickness of the shell-of-compression.

Cores of Mountain-Ranges.—The distinguishing characteristics of great mountain-chains is, as I have fully pointed out elsewhere, the presence of a central core of gneissic or granitic rock, frequently, as in the case of the Alps, taking the form of a series of ellipsoidal bodies throwing off on the flanks—not seldom with reversed dips—the sedimentary rocks through which they have been protruded.

This is also true of the great ranges of the Caucasus, the Pyrenees, the Rocky Mountains, the Himalayas, the Andes; and I believe such gneissic cores will be found to distinguish every great range when sufficient observations have been made. The apparent exception of the Appalachian chain is, in my view, no exception at all; and I have already brought forward a considerable body of evidence to prove that the gneissic masses lying to the eastward of the great sedimentary folds is the original core of the range, much denuded and deprived of the flanking sedimentary masses formerly existing to the eastward*.

Whether this explanation be accepted or not, the gneissic and granitic rocks protruded through and often entangling in their folds the great sedimentary deposits which together admittedly constitute most mountain-chains, are a standing monument of the untruth (said in no offensive sense) of the contractional hypotheses of the origin of mountain-ranges.

These central cores could not have been forced up except accompanied by great lateral pressure, yet now we find, on accurately working out the contractional hypothesis, that the lateral pressure is, taking the highest estimate, zero at a depth of 5 miles, whereas, according to the estimates of accomplished geologists, the sedimentary strata through which the cores were protruded ranged from 5 to 10 miles thick. It is plain to demonstration that the lateral pressure that forced up the mountains could not reside in a shell-of-compression only 5 miles thick having a zero strain on the underside.

* Pp. 34 and 35, 'Origin of Mountain-Ranges.'

Colorado Plateaus.—The contractional hypothesis is equally incapable of accounting for the elevation of the great monoclinical plateaus lying to the west of the Rockies. Indeed this has been insisted upon by American geologists, notably by Dutton and Gilbert, before the discovery of the level-of-no-strain. It is, therefore, unnecessary for me to dwell upon these arguments here, except to say that by this discovery the difficulties are increased beyond all possibility of explanation.

Effects of Contraction on the Shell underlying the Shell-of-Compression.—The bulk of the contracting portion of the earth's crust, even if the whole crust be estimated at not more than 30 miles thick, is so much in excess of the shell-of-compression, in addition to the much larger underlying contracting envelope, that I fully expect some reverse theory of mountain-building may be based upon it. Mr. Davison has already suggested that the ocean-basins are due to the localization of this contraction. Let me examine the problem in a fair spirit, and as fully as the limits of this paper will allow. In discussing the effects of contraction on the rocks of the crust underlying the shell-of-compression, I have said, "Practically tension could not take place, as the superincumbent strata would by vertical compression elongate the rocks at the zone of greatest contraction to fill the vacuities that otherwise would be created."*

The depth of the zone at which compressive-extension commences will differ according to the nature and crushing strength of the rocks: but we may safely assume that all known rocks will be plastic under the superincumbent pressure at a depth of 10 miles†. It is, therefore, possible that somewhere in the solid crust between that depth and the surface, cavities might be formed by secular contraction, and shearing and faulting take place by the subsidence of overlying masses of crust into the plastic medium below. Irregularities of the surface of the sphere might arise in this way, as well as by inequalities in the amount and mode of shrinkage of the whole of the underlying contracting body or shell. It needs, however, but little consideration to see that such orographic changes of the surface would tend generally in the same direction; depressions once commenced would increase in depth by a continuation of the contraction which initiated them; while such elevations as might originate in the much smaller shell-of-compression would tend to increase in height and in number also. But while the agencies invoked in our

* 'Origin of Mountain-Ranges,' p. 125.

† Ibid. .91.

hypothesis are tending to corrugate the surface of the globe, subaerial denudation is, *pari passu*, levelling all the irregularities that appear above the waters of the ocean, and sedimentation in varying degrees at different localities is more or less effacing the irregularities below the waters.

It would be an interesting calculation to approximately work out the relative magnitudes of these opposite actions, but such is not my present intention. It will be more to the purpose to enquire whether such a process—deductively arrived at—is in correspondence with what takes place in nature. The geological standpoint is an entirely different one to that of the deductive reasoner. The geologist is prepared to question any physical dogma otherwise called a “law,” no matter how high the authority on which it may stand, if observation leads him in an opposite direction. It is, however, in this branch of enquiry by the application of the two methods, the inductive and the deductive and their correspondence, that the most important and far-reaching truths are eventually discovered.

I can quite understand a contractionist, in view of the discovery of the level-of-no-strain, giving up the position that mountain-ranges have originated in the shell-of-compression, yet contending that the other irregularities of the earth's surface have originated in the differential movements of the underlying contracting shell. He would probably point to such a persistence of movement of subsidence, though only deductively arrived at, as another proof of the permanence of oceans and continents.

When, however, as geologists we go to Mother Earth and ask her to yield up her secrets, what does she answer?

It seems pretty safe to assert anything of the abysmal depths of the ocean, for we know little of the ocean-bottom excepting what is yielded by a few scrapings of the dredge and the number of fathoms read off on the sounding-line. When, however, we investigate that which is more within our reach, we find that everywhere on the globe there has been in progress a constant flux and reflux of elevation and subsidence, and it would be difficult to say which has been, on the whole, of the greater magnitude. It is but lately that Dr. Guppy has shown us that there are on the Solomon Islands soft foraminiferous rocks which, according to Murray and Brady, represent deep-sea deposits laid down in water from 1800 to 2000 fathoms deep. These deposits in many cases lie upon old denuded volcanic rocks, and are overlain with a capping of hard coral rock.

These deep-sea rocks are, in the case of Ugi and Treasury

Islands, themselves folded ; a most remarkable fact, for which we are indebted to Dr. Guppy's intrepidity and love of science. Assuming the correctness of all the facts made known by Dr. Guppy, they appear to me inconsistent with the assumption that the deposits took place on submerged volcanic peaks, for it is difficult to see how folding could originate in such a position by any cause now known. But in any case it points to an elevation of the sea-bottom, estimated by Dr. Guppy at 12,000 feet*.

In reading the accounts of various observers scattered over the face of the globe, nothing has struck me more than the universality of the evidences—side by side—of recent depression and recent elevation in each and every country. It would be wearisome to recount them here. We know that the great continental masses are built up of sedimentary rock-systems, some of them reaching, in the locus of mountain-ranges, an estimated thickness of ten miles. Now let us see what this means. It indicates that the crust of the earth on these areas has been bent to a depth double that of the deepest of the deep-sea soundings.

Yet these very deposits now constitute the highest mountain-ranges! With these evidences of flux and reflux before our eyes, it seems really useless to invoke as an explanation the aid of a secular change tending to act more or less constantly in one direction. The investigation of the properties of a cooling globe and the discovery of the existence of a level-of-no-strain only a few miles beneath our feet, have greatly helped to clear the ground for the reception of a theory of mountain-formation which takes more fully into account the actualities of nature.

It may, however, be desirable, in the light of these recent discoveries, to try and trace by geological or other observations whether any features of the earth are directly attributable to secular cooling. Such would be a difficult inquiry, superimposed as I believe the effects will be found to be (if found at all), upon much more pronounced features due to other agencies.

Here for the present I must leave the subject, perhaps to return to it at a future time.

* 'Geology of the Solomon Islands' (1887). "Observations on the recent Calcareous Formations of the Solomon Group made during 1832-4 by H. B. Guppy, M.B., F.G.S.," Trans. Roy. Soc. of Edin. 1885, p. 545.