and to sink them again, in order to explain a few rounded pebbles on the isolated flank of a hill, and make ice travel by some properties unknown to experience over hundreds of miles of level country, scraping the rock as it marches, and yet carrying under its gentle slipper several hundred feet thick of soft clay and sand, and sometimes delicate and fragile shells. I do not understand, and feel bound to protest against, the continual appeal of the modern school of geology to causes which have not been verified; and it seems to me like trying to turn the flank of the north wind by an appeal to the east wind, when a geologist, in order to save a mere scholastic formula, such as Uniformity, ignores the laws and conditions of science.

V.—SOME PHYSICAL QUESTIONS CONNECTED WITH THEORIES OF THE ORIGIN OF MOUNTAIN RANGES.

By T. MELLARD READE, C.E., F.G.S., F.R.I.B.A.

MR. A. VAUGHAN has honoured with a criticism¹ my exposition of the physical principles upon which my Theory of the Origin of Mountain Ranges is founded, which appeared in this MAGAZINE last May.²

Had it not been that much of what I have written seems to have been misapprehended, I should probably have refrained from comment and left the two papers to speak for themselves.

If Mr. Vaughan will refer to my "Origin of Mountain Ranges," which has been before the scientific public for eight years, he will see that chap. xi., while dealing with "the Hypothesis that Mountain Ranges are ridges thrown up by the Compression induced in the rigid Crust of the Globe by a Shrinkage of the heated Nucleus," was written to show that the ideas then prevailing on the effects of secular contraction were inaccurate, and in this chapter the conception of the existence of a level-of-no-strain was first developed. Further, to quote my own words, I say: "If the above reasoning be valid, it is plain that whatever compression may take place in the crust of the globe must be confined to a very slight depth below the surface; to such a *thin stratum*, in fact, that the ordinary denudation constantly going on would probably obliterate most of the resultant corrugations."³

In the contrast I have drawn from time to time between my expansion theory, and the older one of secular contraction, I have studiously given the latter theory the benefit of maximum figures in order to prove up to the hilt that the expansion theory gives the most effective explanation of geological facts as we find them. I join issue with Mr. Vaughan, however, in his calculation of the amount of material which the compression of the outer shell, according to my figures, would give for mountain-making. It would not exceed on the most favourable conditions one twenty-third of the amount he states (p. 316). Also as a practical result such surplus material could not possibly be all used for mountain-making, much

¹ GEOLOGICAL MAGAZINE, July, 1894, pp. 312-320.

² *Ibid.* pp. 203-214.

³ Origin of Mountain Ranges, p. 125.

less be concentrated in one spot; some of it would go to thicken the earth's crust.

Mr. Vaughan calls in question the principle adopted by me of ascertaining the radial contraction of the earth under the conditions assumed by me. The method, of course, is only a rough one, but when we are dealing with quantities which cannot be established with great accuracy the rough method is the safest. I take the direct linear radial contraction across the contracting shells, and multiply that by three. A little consideration will show why the linear contraction across the shells is not a true index of the earth's contraction as a whole. The shells are stretching themselves over a nucleus that remains of a nearly constant diameter, therefore they are thinning themselves by *stretching*, as well as by radial contraction. To put it in other words: A voluminal contraction is a contraction of a given volume along three axes at right angles to one another—this will be expressed roughly by a figure three times the linear contraction. When, however, a shell of rock contracts over an unshrinking sphere below, contraction along two of these axes being impossible, the whole effect is concentrated on the third and becomes a linear contraction—roughly, three times the linear contraction proper for the rock; of course being accompanied by tensile stresses and deformation of shape.

Having had considerable difficulty in following Mr. Vaughan's reasoning respecting his own theory, I may possibly have misapprehended it as he has mine in the cases just dealt with.

To put it shortly, his may be called a *tensile* theory. Before such a theory could be established it would be necessary to show that the tensile strengths of the materials of the earth are sufficient to stand the stresses this theory puts upon them. It appears to be part of Mr. Vaughan's theory that the outer crust has not been able to withstand the tensile stress put upon it by shrinkage through loss of heat, and is consequently full of fractures. How then could the underlayers by shrinking exert such a huge pressure on the interior as to actually compress the materials of the earth into a smaller volume? Is the tensile strength of any of these underlayers equal to that of steel? We know that 30 tons to the square inch is about the breaking strength of steel. It would be interesting if Mr. Vaughan or some other mathematician would work out the decrease of volume which would result from a given contraction of a shell of steel, say 30 miles thick, acting on a sphere of the size and composition of our earth.¹ A theory is of little use without a quantitative basis. When this is worked out it may be found unnecessary to calculate the amount of compression of the interior which a local shrinkage of a given segment of the sphere would be competent to produce, if, indeed, it would produce any, which I very much doubt.

¹ If we look upon this shell as a spherical boiler of steel 30 miles thick and of the diameter of the Earth, dependent only upon its tensile strength, a pressure of steam of half a ton to the square inch would burst it. It is questionable if such a shell of steel could by shrinkage exert an effective pressure of one quarter of a ton per square inch on the materials of the interior of the Globe.