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ORIGINAL ARTICLES.

I.—THE AGE OF THE WORLD AS VIEWED BY THE GEOLOGIST AND THE MATHEMATICIAN.

By T. MELLARD READE, C.E., F.G.S.

UNTIL Geology began to take the place of a science, few, if any, troubled themselves about the age of our planet. The habit of thought, created partially by the Mosaic Cosmogony, which led us to look at all the natural features around us as if but just freshly formed by the hands of the Creator was not favourable to any such inquiry.

To think that everything, as we see it now, is as it always was, is easy and natural, saves trouble, and is a habit of mind deeply engrained in human nature. It is only within the last few years that we have been able to dispossess ourselves of this notion with regard to animated nature. Special creation of everything as we see it answers best to our anthropomorphic ideas, derived from a contemplation of man's creative efforts. The conception of innate energy, continuity, and evolution, is a higher stage of thought, only arrived at by close observation of, and reasoning on, the relations of natural phenomena.

So far as my knowledge of history extends, the geologist was the first to raise the question of the Earth's age. Astronomy did not lead to its contemplation. No one that I am aware of, before geological inquiry, said the Earth must be so many millions of years old, because the rate at which the temperature increases downwards shows that it must at least have taken so long to cool from the time when it was an incandescent globe. Yet it is the astronomer who inferred long since that this Earth of ours, from its spheroidal form, must originally have been in a molten state, and the same elements existed at the time for the calculation of its age from a physical basis that do now. Why then was it not done? Simply because it did not strike any one that it must be extremely ancient, as the evidences of age did not come prominently forward.

When, however, the curiosity of the geologist, delving into the Earth's crust brought to light the fact that under thousands of feet of rock lay the evidences of the existence, at an earlier period, of a fauna and flora differing from those of the present day,—of rivers, seas and continents now buried below deposits to which those obscuring the remains of ancient Troy are as a film of dust,—it was impossible any longer to resist the conviction that the age of the

world was enormously greater than any one had before contemplated.

So averse, however, is the human mind to receive new impressions, that the first geologists had to shorten the life of the world by periodical convulsions and the assumption of more potent natural causes in the earlier periods of the Earth's history.

In this again they were assisted by another vice of the mind—that of generalizing from small data. Faults, foldings of the strata, and other evidences of former volcanic activity, that have been since proved to be only local phenomena, were assumed to have extended all over the Earth at the same time, and to have separated its history into "periods." This I call constructive geology, due to an unscientific use of the imagination. Yet those crude and hasty generalizations were not to be wondered at; for the peculiar scientific habit of thought engendered by sound geological reasoning had not then been acquired.

To Hutton is due the merit of placing geological investigation on a sound basis, and to Lyell philosophical geology almost owes its existence.

The conception of the possibility of explaining all the phenomena of the Earth's crust by agencies at present at work, lies at the foundation of all geological reasoning. It is one, however, that does not necessarily commend itself to the judgment at first sight, because there are no *a-priori* improbabilities in conceiving that agencies may have been at work at former periods of which we now know nothing. If, however, we attentively study the Earth's crust, we become gradually convinced that the agencies we are acquainted with are competent to explain all the complicated phenomena with which it abounds, and not only so, but that no other agencies can satisfactorily explain them.

Therefore, instead of a playful exercise of fancy, we begin our investigations on a sure foundation—so sure indeed that no geologist, so far as I am aware, has been compelled to adopt any other hypothesis, though of course different opinions are held with regard to the relative activity of these forces at various stages of the history of the Earth.

Geology, then, is a pre-eminently practical common-sense science, because it is always testing its conclusions by reference to the Earth itself. The reasoning is essentially of an inductive cast. It is necessarily a safe science, for it cannot get far on the wrong road without being set right. Astronomy is a more exact science; the relations it sets itself to investigate are simple ones—mechanical conceptions capable of mathematical demonstration and verification by exact measurement. When I say the relations it investigates are simple, I say it with the profoundest respect; for the solutions of some of these problems are among the greatest triumphs of the human mind. The method of procedure is, however, essentially different, and the attempt to displace the geological by the mechanical method in developing the geological history of the Earth is, I trust to be able to show, one not likely to succeed.

To Sir Wm. Thomson is due the merit of first attempting to apply the physical, or what I prefer to call the mechanical method, to the determination of the age of the Earth. Three ways have been suggested by him for doing this; but it is only to the one on which he most relies—founded on the increase of temperature proved by experiment to take place from the surface downwards—that I propose to refer. The calculation is based upon the assumption that the whole mass of the Earth was at one moment at an incandescent heat estimated at 7000° Fahr. warmer than our present surface temperature; that it was at an initial moment at this uniform temperature throughout, from which time it has since been uniformly cooling through being exposed to the present surface temperature. By a mathematical process, the experimental elements of which depend upon the average thermal conductivity of the materials of the Earth, and the average augmentation of heat downwards, he arrives at the conclusion that it is improbable more than 100 millions of years have elapsed since the surface of our globe became habitable.

Now the geologist neither denies nor affirms that the Earth was once an incandescent mass. By analogy it is probable at the present time the heat goes on increasing downwards until incandescent matter is reached: but it cannot be experimentally proved; though volcanic action now existing in various parts of its surface points to the same conclusion. It is also not an improbable further deduction that at one time the globe was incandescent from the centre to the surface. Arguing from an hypothesis of this nature, and reconstructing the globe upon it, is what the cosmogonists used to do; but it is a method alien to geology, which aims at interpreting the history of the Earth by an examination of its rocks.

Now, for a calculation such as this one suggested by Sir Wm. Thomson to command assent, it must be based upon very accurate experiment and observation, that the material points on which it hinges may be first proved beyond doubt. He says,¹ "Whatever the amount of such effects is at any one time, it would go on diminishing according to the inverse proportion of the square roots of the times from the initial epoch. Thus, if at 10,000 years we have 2° per foot of increment below ground,

at	40,000 years	we should have	1°	per foot
	160,000	"	$\frac{1}{2}$ °	"
	4,000,000	"	$\frac{1}{10}$ °	"
	100,000,000	"	$\frac{1}{50}$ °	"

If, therefore, through any error in the calculation, arising from incorrect inference from experiment, the increment of temperature should be not 2° but 4° per foot at the end of the first 10,000 years,² the times would be multiplied fourfold, and would stand thus:

¹ Treatise on Natural Philosophy, Thomson and Tait, p. 721.

² Prof. Helmholtz has calculated, from the rate of cooling of lavas, that the earth in passing from 2000° to 200° C. must have taken *three hundred and fifty millions of years!* Dana, commenting upon this, says: "But the temperature when the Archaean Time (Laurentian and Huronian periods) ended was probably not over 18° C. (100° Fahr.)." Dana's Manual of Geology, second edition, p. 147.

At	40,000	years	2°	per foot
	160,000	"	1°	"
	4,000,000	"	$\frac{1}{2}^{\circ}$	"
	100,000,000	"	$\frac{1}{25}^{\circ}$	"
	400,000,000	"	$\frac{1}{100}^{\circ}$	"
	1,600,000,000	"	$\frac{1}{1000}^{\circ}$	"

So, if we assume the increment at 1° in 100 feet, and there are to my mind as good reasons to do so as to assume 1° in 50 feet, the observations being, as I shall show, so contradictory and inconclusive, it would in this case bring up the age of the world to 1600 millions of years. These values may hold good with regard to a homogeneous mass of uniform conductivity, but not in the case of a globe built up of strata of varying conductivities. Let us, for example, consider how the effect would be varied in a very simple case.

First, we may assume a globe, the mass of which below a certain depth is of unknown materials and unknown conductivity,—as is really the case with the Earth, but that it is a reservoir of heat which it transmits to a surface layer of rock 3500 feet deep,—having a conductivity of .006,¹ and that in 100 million years it has cooled down so that this surface stratum possesses an increment of $\frac{1}{25}$ of a degree of heat per foot.

Secondly, let us assume a similarly unknown globe having a surface layer of rocks also 3500 feet deep, but composed of two equal layers, the external one having a conductivity of .003, and the inner layer .009, the average conductivity of the two strata would be .006, the same as before; but as the increment of heat varies inversely as the conductivity, with the same flow of heat, the outer layer would increase in temperature at the rate of $\frac{1}{25}$ of a degree per foot, and the inner one $\frac{1}{75}$ of a degree per foot. Thus the average rate of increase of temperature with the same loss of heat taking place would be $\frac{1}{375}$ of a degree per foot.² The conductivity averaging the same as in the first example, and the increment of heat being greater, the inferred age of the globe would be less than 100 million years.

But, as we have already assumed, only the same loss of heat taking place, the actual age of the globe, if its constitution in other respects were the same, in both cases would appear to be more correctly estimated at the same figure. Should, however, the calculation be based upon the rate of increase of the *outer* layer and the average conductivity of the two layers, a practical error that might readily occur in estimating the increment of heat in borings, and the average conductivity of the materials of the Earth within our reach, the age of the Earth would be inferred as only 25 million years.³ It is, however, quite evident that all these conclusions

¹ I adopt in all cases the British Association Unit of Conductivity, viz. centimetre—gramme—second.

² This is arrived at by calculating the total increase of heat downwards in both cases and dividing by 3500 feet the total thickness of the strata.

³ In these illustrations, and my reasoning throughout, for the sake of simplicity I omit all consideration of specific heats, as they do not affect the line of argument adopted, except that in nature they further complicate the thermal effects.

cannot be right, and, further, that any estimate of age from the thermal condition of the crust may be further vitiated by our ignorance of the nature, constitution and materials of the globe underlying the outer strata.

These, I think, are the nature and character of the errors incidental to any calculation of the actual age of the Earth from the outer crust of sedimentary rocks. Possessing as they do varying conductivities, and being of various thicknesses, the average conductivity of the whole has not improbably been overestimated, and the average increase of heat overstated, while the combined resistance of strata of varying conductivities may be greater to the passage of heat across them than what would be inferred, even from a correct average, as was shown to be the case in my second theoretical example.

If, in addition, we assume that our crust rests upon a basement of rocks analogous to granite possessing high conductivities, it is evident the more non-conducting envelope would be retained at a high increment of temperature for a longer period than if the whole mass of the Earth underneath possessed only the same conductivity as the crust. Nor should it be lost sight of in this inquiry, that the strata we are acquainted with are not cooling down from a state of fusion, but are deposits laid down upon the surface and gradually heated from below. This, again, obscures the results, and, indeed, the question becomes so exceedingly complicated, that it is beyond my powers to unravel; but it is not inconceivable that an initial increment of temperature might be retained in this way for a lengthened period.

The cumulative results of these possible errors might then at least quadruple the maximum age of the Earth as inferred from calculation. At all events, I trust that I have shown the extremely untrustworthy character of averages in such an investigation. But these are not by any means all the arguments that can be urged against the method—the data, as ascertained by experiment, being of a complicated and contradictory character.

Before dealing with the purely geological aspect of the question, it will be well shortly to examine the nature and extent of the data forming the vital elements of the mechanical problem.

Sir W. Thomson states the variation of the increase of temperature to be from $\frac{1}{100}$ of a degree Fahr. in some localities, to as much as $\frac{1}{10}$ in another per foot of descent, but $\frac{1}{100}$ is accepted as a rough mean.

The Reports on Underground Temperature by the British Association show most remarkable differences in localities not very far apart. Thus, according to experiments made by Mr. Fairbairn at Astley Pit, Duckinfield, Cheshire, the average rate of increase was 1° every 80 feet for a depth of 685 yards; while similar experiments at Rose Bridge Colliery, Ince, near Wigan, for a depth of 815 yards, gave an average increase of 1° in every 54.3 feet.¹ Again, the rate of increase in some of the wells in Paris is 1° for every 50 to 60 feet; while the great well of La Chappelle at Paris showed, at a depth

¹ British Association Report on Underground Temperature, 1870, pp. 31-2.

of 600 mètres, an average increase of 1° in 94.3 feet.¹ In experiments made at Przibram, in Bohemia, by Herr Johann Grimm,² Director of the School of Mines, in a depth of 1900 feet, there was an increase of 1° in every 141 feet. The experiments at the Mont Cenis Tunnel show an increase of 1° in 93 feet, without correction for the convexity of the ground.

If, however, there exist this variation in the average increase of temperature of each total depth of rock penetrated, there is still more variation in the rate of increase in different parts of the same bore, the variation in the Bohemian mine being from 1° in 45 feet to 1° in 1400 feet.

On the other hand, if we refer to the conductivity of certain rocks, we find, according to the revised scale in the experiments made by Herschel and Lebour,³ the thermal conductivities vary from .00882 for opaque white quartz to .00065 for cannel coal. I understand Sir W. Thomson's average was founded upon the conductivity of only two descriptions of rock, viz. Calton trap rock and Craigleith sandstone, estimated respectively by him, if reduced to British Association units, at .00266 and .00689.⁴

Without going further, I think sufficient has been said to show on what an insecure basis this tremendous superstructure of inference has been built. From experiments only made in a few places, and necessarily upon rocks, geologically speaking, subject from time to time to great fluctuations of temperature, and in mere scratches in the Earth's surface, through all manner of variations, the first average necessary to the calculation has been deduced, viz. a ratio of increase of heat of 1° per 50 feet.

The average conductivity is a still greater assumption, because, in the first place, the relative amount of each class of rock composing the crust of the Earth and its conductivity should be calculated, which is not done, and would prove very difficult to even approximately estimate. Neither are laboratory experiments on conductivity conclusive, as a mass of rock through its structure may behave in a different way to a small piece, while the impossibility of testing in any way the average conductivity of the materials of the interior of the Earth, subject to such enormous pressure and heat, is apparent. It is also not at all improbable that frequent variations of strata, possessing different conductivities, may create interference in the transmission of heat; for it is proved that laminations increase the non-conducting property of rock across the planes of lamination.

If we turn from this most complex and difficult problem, to study the history of the Earth, and form our views by induction from observation, we find that from the earliest periods to the present time the known crust of the Earth has been in continual process of construction, or reconstruction, by sedimentary and volcanic deposits,

¹ *Ibid.* 1873, p. 253.

² *Ibid.* 1875, p. 15.

³ British Association Report on Thermal Conductivities of certain Rocks, 1875, p. 57.

⁴ The estimate is really made in terms of the thermal capacity of the unit of bulk, which is averaged at 400; the unit in length being a British foot, and unit of time a year.

the result of atmospheric waste and volcanic emissions and intrusions; that this composite body, called the crust, has, from time to time, throughout all geologic ages, been not only broken up, but heated matter has been injected into it¹ or thrown over it; and that this has occurred at one time or another over the whole of the known globe.

Not only has this been the course of events, but the great mountain chains—the Andes, the Alps, the Pyrenees, and the Himalayas²—have been thrown up at a comparatively recent time, geologically speaking, so that the more we restrict the age of the world, the hotter should the strata be under those great continents on which these mountain chains rest.

To get out of this dilemma is impossible; for we cannot consider these volcanic outbursts as mere local effects, the volcanos at present active being in lines thousands of miles long, the effect of deep-seated forces probably connected with central heat, but, even if not, fed by lakes of molten rock sufficient to set all calculations of secular cooling at defiance.³

A study of existing volcanos also shows that molten rock at the surface does not act now in the way Sir W. Thomson assumes it did in his hypothetical incandescent globe. Why it should not I cannot conceive. In the volcano of Kilauea, Hawaii, in the Sandwich Islands, the molten rock boils up in the crater, while waves of red-hot matter dash against the surrounding cliffs, and break in incandescent spray.⁴ If molten rock does this now, why should it in the first formation of the globe set suddenly solid from the circumference to the centre, as required by Sir W. Thomson's theory, and ever afterwards be gradually cooling as an iron shot might cool from a white heat?

¹ Prof. Judd points out, in his admirable "Contributions to the Study of Volcanos," *Geol. Mag.* 1876, p. 211, that in the Southern Tyrol, during the Permian period, "enormous masses of volcanic rock were erupted, leading to the formation of volcanic mountains at least 8,000 feet to 9,000 feet high." The great "Whin Sill" has also been proved by Topley and Lebour to be a vast intrusive sheet. Innumerable similar examples may be quoted; and as it is usually only by denudation we get a glimpse of those volcanic rocks occupying the interior of the crust, we may be sure there are many others unknown because undisclosed.

² Ramsay, *Geological History of some of the Mountain Chains and Groups of Europe*, *Mining Journal*, 1875. Judd, *Contributions to the Study of Volcanos*, pp. 133-41.

³ As a proof of the failure at present to establish any law of increase of temperature, the remarkable temperature results in the boring at Sprenenberg, near Berlin, 4172 feet deep, may be quoted. In this case the first 283 feet were in gypsum, with some anhydrate, and the remainder entirely in rock-salt. Although rock-salt possesses a considerably higher conducting power than even quartz, being .01154, and more than twice that of Aberdeen granite, the rate of increase of temperature averaged 1° per 51.5 feet. (*British Association Report on Underground Temperature*, 1876, p. 206.) If the rates of increase should be inversely as their conductivity, on the supposition of an uniformly cooling globe, the increase of temperature should, compared with Mont Cenis, not be more than 1° per 200 feet. Does it not suggest that the source of the heat must be nearer the surface, or that there exists beneath, some mass of rock abnormally heated?—a supposition consistent with the geological fact already stated of the intrusion of heated matter into the crust of the globe and at various epochs of its history.

⁴ *Log Letters of the Challenger.*

Reasoning from observation, as a geologist is bound to do, the greater probability is that the surface would become crusted over in a way that the lava in a volcano becomes crusted over, and that the surface rock would be of a vesicular character of less specific gravity than the molten matter. Nasmyth's theory of the volcanos of the Moon¹ is founded on the supposition that the molten matter expands in cooling, giving examples in support of his idea, such as the fact that a lump of cold cast-iron will float in molten iron. Sir W. Thomson assumes the rock will cool, contract and sink in the molten mass. Which is right? Nasmyth certainly has had the most practical experience of molten metals! That a cooling globe solidifies from the surface, I think the Moon is a striking proof.²

The crust would most probably solidify and break up again and again, and hot materials be injected into, through, and on to the surface.

A glance at a map of the volcanos of the Moon should satisfy any one on this point, for there are the evidences of almost countless myriads of volcanic rings or craters, covering the whole surface and superimposed or breaking through one another in a most remarkable way. Observation, then, tells us that a crust will most likely form on a globe of molten rock. Now, in the case of the Earth, comes in the question of denudation; for no sooner is a sufficient crust formed than the aqueous vapours and atmospheric agencies begin to eat it down, and thus we have a composite crust of sedimentary and volcanic materials, such as the geologist is acquainted with as existing in Nature. There is also this fact in favour of a retention of heat by the globe, that pumice rock, and any rock of a loose or vesicular nature, possesses small conducting power,—the proportion of absolute resistance to the passage of heat being as 1818 in dry pumice to 87 in rock-salt.

The laminations and alternations of beds is also, I strongly believe, favourable to the retention of heat,³ so that we see a coating must be gradually formed round our incandescent globe like the felt round a steam boiler.

This speculation, though interesting, is rather outside of true geological inquiry; it is beginning at the wrong end. No one yet has ever had a glimpse of this primitive globe; for though we have a knowledge of a thickness of rock estimated at from 14 to 17 miles, the base is practically the same as the topmost story of the superstructure. These original crusts have most likely been broken up, melted and destroyed long since, as sediments have been also melted and destroyed.

Much more may be said on the subject, but I trust enough has been shown to prove that the hypothetical way of treating such

¹ The Moon as a Planet, as a World, and a Satellite, Nasmyth and Carpenter.

² Mr. Mallet has controverted Nasmyth's conclusions, *Proc. Roy. Soc.* 1874, p. 366. Nevertheless, he admits the fact of certain pieces of cold cast-iron floating upon molten iron.

³ In my Presidential Address to the Liverpool Geol. Soc. Session 1875-6, "On the Moon and the Earth," it is suggested, p. 89, that "the sediments accumulating on the Earth from age to age must act as a non-conducting envelope."

problems, however clever, ingenious and interesting, is unreliable. Geology demands that a thing should be tested as you go along; for so little is really known of the physics of the Earth that we continually find facts in discordance with preconceived notions, though, when once known, it is easy to see that such and such a thing *might* have been predicted by theory.

It is proverbially easy to prophesy after a thing has happened, and it is just as easy to see that any proved fact is in accordance with the laws of physics. Nevertheless, the observer is continually discovering new things that no one predicts. If there is any one thing that physicists ought to have predicted, it is that the bottom of the ocean is uniformly occupied by water of a very low temperature. Now I think there are few physicists who would not have supposed that the secular cooling of the Earth would, to some degree, have influenced the bottom water of the ocean that must have travelled thousands of miles in contact with it, yet the *Challenger* temperature soundings prove that it has no appreciable effect.¹

It is impossible in this space to explain the way the geologist approximates to the immense age of the Earth, and as I have already elsewhere² attempted the calculation on a geological basis, it is thus less necessary for me to do so now. A calm investigation of all the multitudinous facts which necessarily enter into the problem satisfies me, at all events, that no case has been made out for restricting the age of the Earth below that demanded by Geology, even on the assumption of a globe of molten materials to commence with. According to Sir W. Thomson's expressed opinion, "The general climate cannot be sensibly affected by conducted heat at any time more than 10,000 years after the commencement of superficial solidification." So that as the rate of deposition of sedimentary rocks cannot by this hypothesis have been affected by the interior heat of the Earth, it tends to show it is a reasonable assumption on the part of the geologist that the rate of formation of these rocks, dependent on atmospheric degradation, was in former ages very much what it is at present.³

I am also of opinion that the rate of increase of underground temperature has, probably, been for long ages past very much what it is now; for if I have shown that the interior heat of the Earth is introduced into the crust by intrusion, as well as by conduction, there is even now, according to Sir W. Thomson's showing, a vast reservoir of unexhausted heat; nor must we forget that the present crust of the Earth is not an originally formed product, but one built upon

¹ Mr. Croll (*Climate and Time*) attempts to explain why the secular cooling of the Earth does not affect the bottom water of the Ocean, but the explanation comes after the knowledge of the fact.

² "On Geological Time," Presidential Address, Liverpool Geol. Soc. Session 1876-7.

³ Sir W. Thomson, however, infers, that as the Sun must have been hotter in former ages, the atmospheric agencies were then more potent; but this is all pure hypothesis, no proofs that they were being adduced. Mr. Croll again has his own hypothesis on the subject, but the fact is we know absolutely nothing of the Sun's heat, and cannot safely reason on conjectures.

the pre-existing materials: so that if we assume a freer circulation of underground heat below this crust than through it, as I think volcanic action indicates, and a successive building up of crust upon crust as it is destroyed from below, together with an intrusion of melted materials which from time to time, as we know, has taken, and is taking place, the conditions of varying increments of heat actually met with in equal spaces downwards will be pretty well fulfilled. That this circulation of heat takes place at great depths is rendered probable by the alteration of the positions of volcanos from time to time in the Earth's history, by the tremendous evidences of volcanic effects in Tertiary times, and by existing volcanos.¹

Facts are safer than theories, and as at 100 miles deep, even according to Sir W. Thomson's theory, the rocks now must be at 7000° Fahr., if this circulation of internal heat takes place as I suggest, there is sufficient store of heat in the Earth now to carry us on comfortably for another 1000 million of years, without those reconstructive agencies on which our existence depends becoming impotent.

II.—GEOLOGICAL TIME.

By C. LLOYD MORGAN, F.G.S., A.R.S.M.

(PART I.)

ONE of the most important questions which modern geologists have to answer is that which refers to the duration of Geological time. How long is it since the Glacial epoch? What was the date of man's appearance on the earth? How many ages have rolled by since the earth first became the habitation of organized beings? Such are the questions, daily repeated, to which we must make some answer, or, if need be, honestly confess our ignorance.

It is interesting to notice the change which has taken place, within the last century or so, in the opinions of educated men on these fundamental questions. At the beginning of the present century it was the almost universal belief, that the earth had been in existence some 5800 years, and the human race some six days less. Now there are few men of ordinary education who do not admit the great antiquity of man, and the vast age of the globe which he inhabits; while theologians vainly endeavour to persuade us that the Mosaic six days meant six long geological periods, forgetful that Moses (if indeed he was the author of Genesis) was writing a history of the Jewish race and their beliefs, so far as he could gather it from tradition, not a treatise on Geological Cosmogony.

But just as a young man who has been subject to too great and unwise restraint, when he has once broken the fetters, rushes into

¹ A study of Mr. Darwin's "Geological Observations," published first as early as 1844, will, I think, convince the most sceptical of the continued activity of the volcanic forces in South America on a tremendous scale, which must leave some impression on underground temperature there in future ages, though I agree with Prof. Judd that there has not necessarily been the same actual display of energy at every period of the Earth's history. This is dependent on many causes, which I hope to be able to further explain at a future time.