SCIENCE

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MSS. intended or publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson N. Y.

*THE AGE OF THE EARTH AS AN ABODE FITTED FOR LIFE.**

§ 1. THE age of the earth as an abode fitted for life is certainly a subject which largely interests mankind in general. For geology it is of vital and fundamental importance—as important as the date of the battle of Hastings is for English history—yet it was very little thought of by geologists of thirty or forty years ago; how little is illustrated by a statement,† which I will now read, given originally from the presidential chair of the Geological Society by Professor Huxley in 1869, when for a second time, after a seven years' interval, he was President of the Society:

"I do not suppose that at the present day any geologist would be found * * * to deny that the rapidity of the rotation of the earth *may* be diminishing, that the sun *may* be waxing dim, or that the earth itself *may* be cooling. Most of us, I suspect, are Gallios, 'who care for none of these things,' being of opinion that, true or fictitious, they have made no practical difference to the earth, during the period of which a record is preserved in stratified deposits."

§ 2. I believe the explanation of how it was possible for Professor Huxley to say that he and other geologists did not care for things on which the age of life on the

* The annual address (1897) of the Victoria Institute, by Lord Kelvin, with additions written at different times from June, 1897, to May, 1898. Printed also in the *Philosophical Magazine.*

† In the printed quotations the italics are mine in every case, not so the capitals in the quotation from Page's Text-book.

earth essentially depends, is because he did not know that there was valid foundation for any estimates worth considering as to absolute magnitudes. If science did not allow us to give any estimate whatever as to whether 10,000,000 or 10,000,000,000 years is the age of this earth as an abode fitted for life, then I think Professor Huxley would have been perfectly right in saying that geologists should not trouble themselves about it, and biologists should go on in their own way, not inquiring into things utterly beyond the power of human understanding and scientific investigation. This would have left geology much in the same position as that in which English history would be if it were impossible to ascertain whether the battle of Hastings took place 800 years ago, or 800 thousand years ago, or 800 million years ago. If it were absolutely impossible to find out which of these periods is more probable than the other, then I agree we might be Gallios as to the date of the Norman Conquest. But a change took place just about the time to which I refer, and from then till now geologists have not considered the question of absolute dates in their science as outside the scope of their investigations.

§ 3. I may be allowed to read a few extracts to indicate how geological thought was expressed in respect to this subject, in various largely-used popular text-books, and in scientific writings which were new in 1868, or not so old as to be forgotten. I have several short extracts to read and I hope you will not find them tedious.

The first is three lines from Darwin's 'Origin of Species,' 1859 Edition, p. 287 :

"In all probability a far longer period than 300,000,000 years has elapsed since the latter part of the secondary period."

Here is another still more important sentence, which I read to you from the same book :

"He who can read Sir Charles Lyell's grand work on the Principles of Geology, which the future historian will recognize as having produced a revolution in natural science, yet does not admit how *incomprehensibly vast* have been the past periods of time, *may at once close this volume.*"

I shall next read a short statement from Page's 'Advanced Students' Text-Book of Geology,' published in 1859 :

"Again, where the FORCE seems unequal to the result the student should never lose sight of the element TIME, *an element to which we can set no bounds in the past*, any more than we know of its limit in the future.

"It will be seen from this hasty indication that there are two great schools of geological causation—the one ascribing every result to the ordinary operations of Nature, combined with the element of *unlimited time;* the other appealing to agents that operated during the earlier epochs of the world with greater intensity, and also for the most part over wider areas. *The former belief is certainly more in accordance with the spirit of right philosophy*, though it must be confessed that many problems in geology seem to find their solution only through the admission of the latter hypothesis."

§ 4. I have several other statements which I think you may hear with some interest. Dr. Samuel Haughton, of Trinity College, Dublin, in his 'Manual of Geology,' published in 1865, p. 82, says :

"The infinite time of the geologists is in the past; and *most of their speculations regarding this subject seem to imply the absolute infinity of time*, as if the human imagination was unable to grasp the period of time requisite for the formation of a few inches of sand or feet of mud, and its subsequent consolidation into rock." (This delicate satire is certainly not overstrained.)

"Professor Thomson has made an attempt to calculate the length of time during which the sun can have gone on burning at the present rate, and has come to the following conclusion : "It seems, on the whole, most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. As for the future, we may say with equal certainty, that the inhabitants of the earth cannot continue to enjoy the light and heat essential to their life for many million years longer, unless new sources, now

unknown to us, are prepared in the great storehouse of creation."

I said that in the sixties and I repeat it now, but with charming logic it is held to be inconsistent with a later statement that the sun has not been shining 60,000,000 years, and that both that and this are stultified by a still closer estimate which says that probably the sun has not been shining for 30,000,000 years! And so my efforts to find some limit or estimate for Geological Time have been referred to and put before the public, even in London daily and weekly papers, to show how exceedingly wild are the wanderings of physicists, and how mutually contradictory are their conclusions, as to the length of time which has actually passed since the early geographical epochs to the present date.

Dr. Haughton further goes on:

"*This result* (100 to 500 million years) of Professor Thomson's, *although very liberal in the allowance of time, has offended geologists, because, having been accustomed to deal with time as an infinite quantity at their disposal, they feel naturally embarrassment and alarm at any attempt of the science of physics to place a limit upon their speculations.* It is quite possible that even a hundred million of years may be greatly in excess of the actual time during which the sun's heat has remained constant."

§ 5. Dr. Haughton admitted so much with a candid open mind, but he went on to express his own belief (in 1865) thus:

"Although I have spoken somewhat disrespectfully of the geological calculus in my lecture, yet I believe that the time during which organic life has existed on the earth is practically infinite, because it can be shown to be so great as to be inconceivable by beings of our limited intelligence."

Where is inconceivableness in 10,000,000,000? There is nothing inconceivable in the number of persons in this room or in London. We get up to millions quickly. Is there anything inconceivable in 30,000,000 as the population of England, or in 38,000,000 as the population of Great Britain and Ireland, or in 352,704,863 as the population of the British Empire? Not at all. It is just as conceivable as half a million years or 500 millions.

§ 6. The following statement is from Professor Jukes's 'Students' Manual of Geology:'

"The time required for such a slow process to effect such enormous results must, of course, be taken to be inconceivably great. The word 'inconceivably' is not here used in a vague but in a literal sense, to indicate that the lapse of time required for the denudation that has produced the present surfaces of some of the older rocks is vast beyond any idea of time which the human mind is capable of conceiving.

"Mr. Darwin, in his admirably reasoned book on the origin of species, so full of information and suggestion on all geological subjects, estimates the time required for denudation of the rocks of the Weald of Kent, or the erosion of space between the ranges of chalk hills, known as the North and South Downs, at *three hundred millions of years.* The grounds for forming this estimate are, of course, of the vaguest description. It may be possible, perhaps, that the estimate is a hundred times too great, and that the real time elapsed did not exceed three million years, but, on the other hand, it is just as likely that the time which actually elapsed since the first commencement of the erosion till it was nearly as complete as it now is was really a hundred times greater than his estimate, or thirty thousand millions of years."

§ 7. Thus Jukes allowed estimates of anything from 3 millions to 30,000 millions as the time which actually passed during the denudation of the Weald. On the other hand, Professor Phillips, in his Rede lecture to the University of Cambridge (1860), decidedly prefers one inch per annum to Darwin's one inch per century as the rate of erosion, and says that most observers would consider even the one inch per annum too small for all but the most invincible coasts! He thus, on purely geological grounds, reduces Darwin's estimate of the time to less than one one-hundredth. And, reckoning the actual thicknesses of all the known geological strata of the earth, he finds 96 million years as a possible estimate for the antiquity of the base of the stratified rocks; but he gives reasons for supposing that this may be an overestimate, and he

finds that from stratigraphical evidence alone we may regard the antiquity of life on the earth as possibly between 38 millions and 96 millions of years. Quite lately a very careful estimate of the antiquity of strata containing remains of life on the earth has been given by Professor Sollas, of Oxford, calculated according to stratigraphical principles which had been pointed out by Mr. Alfred Wallace. Here it is*: "So far as I can at present see, the lapse of time since the beginning of the Cambrian system is probably less than 17,000,000 years, even when computed on an assumption of uniformity, which to me seems contradicted by the most salient facts of geology. Whatever additional time the calculations made on physical data can afford us may go to the account of pre-Cambrian deposits, of which at present we know too little to serve for an independent estimate."

§ 8. In one of the evening Conversaziones of the British Association during its meeting at Dundee in 1867 I had a conversation on geological time with the late Sir Andrew Ramsay, almost every word of which remains stamped on my mind to this day. We had been hearing a brilliant and suggestive lecture by Professor (now Sir Archibald) Geikie on the geological history of the actions by which the existing scenery of Scotland was produced. I asked Ramsay how long a time he allowed for that history. He answered that he could suggest no limit to it. I said, "You don't suppose things have been going on always as they are now? You don't suppose geological history has run through 1,000,000,000 years?" "Certainly I do." "10,000,000,000 years?" "Yes." "The sun is a finite body. You can tell how many tons it is. Do you think it has been shining on for a million million years?" "I am as incapable of estimating and understanding the reasons which you physicists have for limiting geological time as you are incapable of understanding the geological reasons for our unlimited estimates." I answered, "You can understand physicists' reasoning perfectly if you give your mind to it." I ventured also to say that physicists were not wholly incapable of appreciating geological difficulties; and so the matter ended, and we had a friendly agreement to temporarily differ.

§ 9. In fact, from about the beginning of the century till that time (1867), geologists had been nurtured in a philosophy originating with the Huttonian system: much of it substantially very good philosophy, but some of it essentially unsound and misleading; witness this, from Playfair, the eloquent and able expounder of Hutton:

"How often these vicissitudes of decay and renovation have been repeated is not for us to determine; they constitute a series of which as the author of this theory has remarked, we neither see the beginning nor the end; a circumstance that accords well with what is known concerning other parts of the economy of the world. In the continuation of the different species of animals and vegetables that inhabit the earth, we discern neither a beginning nor an end; in the planetary motions where geometry has carried the eye so far both into the future and the past we discover no mark either of the commencement or the termination of the present order."

§ 10. Led by Hutton and Playfair, Lyell taught the doctrine of eternity and uniformity in geology; and to explain plutonic action and underground heat, invented a thermo-electric 'perpetual' motion on which, in the year 1862, in my paper on the 'Secular Cooling of the Earth,'* published in the 'Transactions of the Royal Society of Edinburgh,' I commented as follows:

"To suppose, as Lyell, adopting the chemical hypothesis, has done,† that the substances, combining together, may be again separated electrolytically by thermo-electric currents, due to the heat generated by their combination, and thus the chemical action and

*'The Age of the Earth,' *Nature*, April 4, 1895.

* Reprinted in Thomson and Tait 'Treatise on Natural Philosophy,' 1st and 2d Editions, Appendix D (g).

† 'Principles of Geology,' Chap. XXXI., ed. 1853.

its heat continued in an endless cycle, violates the principles of natural philosophy in exactly the same manner, and to the same degree, as to believe that a clock constructed with a self-winding movement may fulfil the expectations of its ingenious inventor by going forever."

It was only by sheer force of reason that geologists have been compelled to think otherwise, and to see that there was a definite beginning, and to look forward to a definite end of this world as an abode fitted for life.

§ 11. It is curious that English philosophers and writers should not have noticed how Newton treated the astronomical problem. Playfair, in what I have read to you, speaks of the planetary system as being absolutely eternal, and unchangeable; having had no beginning and showing no signs of progress towards an end. He assumes also that the sun is to go on shining forever and that the earth is to go on revolving round it forever. He quite overlooked Laplace's nebular theory; and he overlooked Newton's counterblast to the planetary 'perpetual motion.' Newton, commenting on his own 'First Law of Motion,' says, in his terse Latin, which I will endeavor to translate, "But the greater bodies of planets and comets moving in spaces less resisting keep their motions longer." That is a strong counterblast against any idea of eternity in the planetary system.

§ 12. I shall now, without further preface, explain, and I hope briefly, so as not to wear out your patience, some of the arguments that I brought forward between 1862 and 1869, to show strict limitations to the possible age of the earth as an abode fitted for life.

Kant* pointed out in the middle of last century what had not previously been discovered by mathematicians or physical astronomers, that the frictional resistance against tidal currents on the earth's surface must cause a diminution of the earth's rotational speed. This really great discovery in natural philosophy seems to have attracted very little attention—indeed to have passed quite unnoticed—among mathematicians and astronomers and naturalists, until about 1840, when the doctrine of energy began to be taken to heart. In 1866, Delaunay suggested that tidal retardation of the earth's rotation was probably the cause of an outstanding acceleration of the moon's mean motion reckoned according to the earth's rotation as a timekeeper found by Adams in 1853 by correcting a calculation of Laplace which had seemed to prove the earth's rotational speed to be uniform.* Adopting Delaunay's suggestion as true, Adams, in conjunction with Professor Tait and myself, estimated the diminution of the earth's rotational speed to be such that the earth as a timekeeper, in the course of a century, would get 22 seconds behind a thoroughly perfect watch or clock rated to agree with it at the beginning of the century. According to this rate of retardation the earth, 7,200 million years ago, would have been rotating twice as fast as now; and the centrifugal force in the equatorial regions would have

* In an essay first published in the Königsberg *Nachrichten*, 1754, Nos. 23, 24; having been written with reference to the offer of a prize by the Berlin Academy of Sciences in 1754. Here is the title page in full as it appears in Vol. VI. of Kant's Collected Works, Leipzig, 1839: Untersuchung der Frage: Ob die Erde in ihrer Umdrehung um die Achse, wodurch sie die Abwechselung des Tages und der Nacht hervorbringt, einige Veränderung seit den ersten Zeiten ihres Ursprunges erlitten habe, welches die Ursache davon sei, und woraus man sich ihrer versichern könne? welche von der Königlichen Akademie der Wissenschaften zu Berlin zum Preise aufgegeben worden, 1754.

* 'Treatise on Natural Philosophy' (Thomson and Tait), § 830, ed. 1, 1867, and later editions; also 'Popular Lectures and Addresses,' Vol. II. (Kelvin), 'Geological Time,' being a reprint of an article communicated to the Glasgow Geological Society, February 27, 1868.

been four times as great as its present amount, which is $\frac{1}{289}$ of gravity. At present the radius of the equatorial sea-level exceeds the polar semi-diameter by $21\frac{1}{2}$ kilometers, which is, as nearly as the most careful calculations in the theory of the earth's figure can tell us, just what the excess of equatorial radius of the surface of the sea all round would be if the whole material of the earth were at present liquid and in equilibrium under the influence of gravity and centrifugal force with the present rotational speed, and $\frac{1}{4}$ of what it would be if the rotational speed were twice as great. Hence, if the rotational speed had been twice as great as its present amount when consolidation from approximately the figure of fluid equilibrium took place, and if the solid earth, remaining absolutely rigid, had been gradually slowed down in the course of millions of years to its present speed of rotation, the water would have settled into two circular oceans round the two poles; and the equator, dry all round, would be 64.5 kilometers above the level of the polar sea bottoms. This is on the supposition of absolute rigidity of the earth after primitive consolidation. There would, in reality, have been some degree of yielding to the gravitational tendency to level the great gentle slope up from each pole to equator. But if the earth, at the time of primitive consolidation, had been rotating twice as fast as at present, or even 20 per cent. faster than at present, traces of its present figure must have been left in a great preponderance of land, and probably no sea at all, in the equatorial regions. Taking into account all uncertainties, whether in respect to Adams' estimate of the rate of frictional retardation of the earth's rotatory speed, or to the conditions as to the rigidity of the earth once consolidated, we may safely conclude that the earth was certainly not solid 5,000 million years ago, and was probably not solid 1,000 million years ago.*

§ 13. A second argument for limitation of the earth's age, which was really my own first argument, is founded on the consideration of underground heat. To explain a first rough and ready estimate of it I shall read one short statement. It is from a very short paper that I communicated to the Royal Society of Edinburgh on the 18th December, 1865, entitled, 'The Doctrine of Uniformity in Geology Briefly Refuted:'

"The 'Doctrine of Uniformity' in Geology, as held by many of the most eminent of British Geologists, assumes that the earth's surface and upper crust have been nearly as they are at present in temperature, and other physical qualities, during millions of millions of years. But *the heat which we know, by observation, to be now conducted out of the earth yearly* is so great, that if this action had been going on with any approach to uniformity for 20,000 million years, the amount of heat lost out of the earth would have been about as much as would heat, by 100° C., a quantity of ordinary surface rock of 100 times the earth's bulk. This would be more than enough to melt a mass of surface rock equal in bulk to the whole earth. No hypothesis as to chemical action, internal fluidity, effects of pressure at great depth, or possible character of substances in the interior of the earth, possessing the smallest vestige of probability, can justify the supposition that the earth's upper crust has remained nearly as it is, while from the whole, or from any part, of the earth, so great a quantity of heat has been lost."

§ 14. The sixteen words which I have emphasized in reading this statement to you (italics in the reprint) indicate the matter-of-fact foundation for the conclusion asserted. This conclusion suffices to sweep away the whole system of geological and biological speculation demanding an 'in-

* The fact that the continents are arranged along meridians rather than in an equatorial belt affords some degree of proof that the consolidation of the earth took place at a time when the diurnal rotation differed but little from its present value. It is probable that the date of consolidation is considerably more recent than a thousand million years ago."—Thomson and Tait, 'Treatise on Natural Philosophy,' 2d ed., 1883, § 830.

conceivably' great vista of past time, or even a few thousand million years, for the history of life on the earth, and approximate uniformity of plutonic action throughout that time; which, as we have seen, was very generally prevalent thirty years ago, among British Geologists and Biologists; and which, I must say, some of our chiefs of the present day have not yet abandoned. Witness the Presidents of the Geological and Zoological Sections of the British Association at its meetings of 1893 (Nottingham), and of 1896 (Liverpool):

Mr. Teall: Presidential Address to the Geological Section, 1893, "The good old British ship 'Uniformity,' built by Hutton and refitted by Lyell, has won so many glorious victories in the past, and appears still to be in such excellent fighting trim, that I see no reason why she should haul down her colors either to 'Catastrophe' or 'Evolution.' Instead, therefore, of acceding to the request to 'hurry up' we make a demand for more time."

Professor Poulton: Presidential Address to the Zoological Section, 1896. "Our argument does not deal with the time required for the origin of life, or for the development of the lowest beings with which we are acquainted from the first formed beings, of which we know nothing. Both these processes may have required an immensity of time; but as we know nothing whatever about them and have as yet no prospect of acquiring any information, we are compelled to confine ourselves to as much of the process of evolution as we can infer from the structure of living and fossil forms—that is, as regards animals, to the development of the simplest into the most complex Protozoa, the evolution of the Metazoa from the Protozoa, and the branching of the former into its numerous Phyla, with all their Classes, Orders, Families, Genera, and Species. But we shall find that this is quite enough to necessitate *a very large increase in the time estimated by the geologist.*"

§ 15. In my own short paper from which I have read you a sentence, the rate at which heat is at the present time lost from the earth by conduction outwards through the upper crust, as proved by observations of underground temperature in different parts of the world, and by measurement of the thermal conductivity of surface rocks and strata, sufficed to utterly refute the Doctrine of Uniformity as taught by Hutton, Lyell, and their followers; which was the sole object of that paper.

§ 16. In an earlier communication to the Royal Society of Edinburgh,* I had considered the cooling of the earth due to this loss of heat; and by tracing backwards the process of cooling had formed a definite estimate of the greatest and least number of million years which can possibly have passed since the surface of the earth was everywhere red hot. I expressed my conclusion in the following statement: †

"We are very ignorant as to the effects of high temperatures in altering the conductivities and specific heats and melting temperatures of rocks, and as to their latent heat of fusion. We must, therefore, allow very wide limits in such an estimate as I have attempted to make; but I think we may with much probability say that the consolidation cannot have taken place less than 20 million years ago, or we should now have more underground heat than we actually have; nor more than 400 million years ago, or we should now have less underground heat than we actually have. That is to say, I conclude that Leibnitz's epoch of emergence of the *consistentior status* [the consolidation of the earth from red hot or white hot molten matter] was probably between those dates."

§ 17. During the 35 years which have passed since I gave this wide-ranged estimate, experimental investigation has supplied much of the knowledge then wanting regarding the thermal properties of rocks to form a closer estimate of the time which has passed since the consolidation of the earth, and we have now good reason for judging that it was more than 20 and less than 40 million years ago; and probably much nearer 20 than 40.

§ 18. Twelve years ago, in a laboratory established by Mr. Clarence King, in con-

* 'On the Secular Cooling of the Earth,' Trans. Roy. Soc. Edinburgh, Vol. XXIII., April 28, 1862, reprinted in Thomson and Tait, Vol. III., pp. 468–485, and Math. and Phys. Papers, art. XCIV., pp. 295–311.

† 'On the Secular Cooling of the Earth,' Math. and Phys. Papers, Vol. III., § 11 of art. XCIV.

nection with the United States Geological Survey, a very important series of experimental researches on the physical properties of rocks at high temperatures was commenced by Dr. Carl Barus, for the purpose of supplying trustworthy data for geological theory. Mr. Clarence King, in an article published in the *American Journal of Science*,* used data thus supplied, to estimate the age of the earth more definitely than was possible for me to do in 1862, with the very meagre information then available as to the specific heats, thermal conductivities, and temperatures of fusion of rocks. I had taken 7000° F. (3781° C.) as a high estimate of the temperature of melting rock. Even then I might have taken something between 1000° C. and 2000° C. as more probable, but I was most anxious not to *underestimate* the age of the earth, and so I founded my primary calculation on the 7000° F. for the temperature of melting rock. We know now from the experiments of Carl Barus† that diabase, a typical basalt of very primitive character, melts between 1100° C. and 1170°, and is thoroughly liquid at 1200°. The correction from 3871° C. to 1200° or 1/3.22 of that value, for the temperature of solidification, would, with no other change of assumptions, reduce my estimate of 100 millions to $1/(3.22)^2$ of its amount, or a little less than 10 million years; but the effect of pressure on the temperature of solidification must also be taken into account, and Mr. Clarence King, after a careful scrutiny of all the data given him for this purpose by Dr. Barus, concludes that without further experimental data 'we have no warrant for extending the earth's age beyond 24 millions of years.'

§ 19. By an elaborate piece of mathematical bookkeeping, I have worked out the problem of the conduction of heat outwards from the earth, with specific heat increasing up to the melting point as found by Rücker and Roberts-Austen and by Barus, but with the conductivity assumed constant; and, by taking into account the augmentation of melting temperature with pressure in a somewhat more complete manner than that adopted by Mr. Clarence King, I am not led to differ much from his estimate of 24 million years. But, until we know something more than we know at present as to the probable diminution of thermal conductivity with increasing temperature, which would shorten the time since consolidation, it would be quite inadvisable to publish any closer estimate.

§ 20. All these reckonings of the history of underground heat, the details of which I am sure you do not wish me to put before you at present, are founded on the very sure assumption that the material of our present solid earth all round its surface was at one time a white-hot liquid. The earth is at present losing heat from its surface all round from year to year and century to century. We may dismiss as utterly untenable any supposition such as that a few thousand or a few million years of the present régime in this respect was preceded by a few thousand or a few million years of heating from without. History, guided by science, is bound to find, if possible, an antecedent condition preceding every known state of affairs, whether of dead matter or of living creatures. Unless the earth was created solid and hot out of nothing, the régime of continued loss of heat must have been preceded by molten matter all round the surface.

§ 21. I have given strong reasons* for believing that *immediately* before solidification at the surface, the interior was solid

* 'On the Age of the Earth,' Vol. XLV., January, 1893.

† *Phil. Mag.* 1893, first half-year, pp. 186, 187, 301–305.

* On the Secular Cooling of the Earth, Vol. III. Math. and Phys. Papers, §§ 19–33.

close up to the surface; except comparatively small portions of lava or melted rock among the solid masses of denser solid rock which had sunk through the liquid, and possibly a somewhat larger space around the center occupied by platinum, gold, silver, lead, copper, iron and other dense metals, still remaining liquid under very high pressure.

§ 22. I wish now to speak to you of depths below the great surface of liquid lava bounding the earth before consolidation; and of mountain heights and ocean depths formed probably a few years after a first emergence of solid rock from the liquid surface (see § 24, below) which must have been quickly followed by a complete consolidation all around the globe. But I must first ask you to excuse my giving you all my depths, heights and distances, in terms of the kilometer, being about six-tenths of that very inconvenient measure the English statute mile, which, with all the other monstrosities of our British metrical system, will, let us hope, not long survive the legislation of our present Parliamentary session destined to honor the sixty years' Jubilee of Queen Victoria's reign by legalizing, the French metrical system for the United Kingdom.

§ 23. To prepare for considering consolidation at the surface let us go back to a time (probably not more than twenty years earlier as we shall presently see—§ 24) when the solid nucleus was covered with liquid lava to a depth of several kilometers; to fix our ideas let us say 40 kilometers (or 4 million centimeters). At this depth in lava, if of specific gravity 2.5, the hydrostatic pressure is 10 tons weight (10 million grammes) per square centimeter, or ten thousand atmospheres approximately. According to the laboratory experiments of Clarence King and Carl Barus* on Diabase, and the thermodynamic theory* of my brother, the late Professor James Thomson, the melting temperature of diabase is 1170° C. at ordinary atmospheric pressure, and would be 1420° under the pressure of ten thousand atmospheres, if the rise of temperature with pressure followed the law of simple proportion up to so high a pressure.

§ 24. The temperature of our 40 kilometers deep lava ocean of melted diabase may therefore be taken as but little less than 1420° from surface to bottom. Its surface would radiate heat out into space at some such rate as two (gramme-water) thermal units Centigrade per square centimeter per second.† Thus, in a year ($31\frac{1}{2}$ million seconds) 63 million thermal units would be lost per square centimeter from the surface. This is, according to Carl Barus, very nearly equal to the latent heat of fusion abandoned by a million cubic centimeters of melted diabase in solidfying into the glassy condition (pitch-stone) which is assumed when the freezing takes place in the course of a few minutes. But, as found by Sir James Hall in his Edinburgh experiments‡ of 100 years ago, when more than a few minutes is taken for the freezing, the solid formed is not a glass but a heterogeneous crystalline solid of rough fracture; and if a few hours or days, or any longer time, is taken, the solid formed has the well-known rough crystalline structure of basaltic rocks found in all parts of the world. Now Carl Barus finds that basaltic

* *Philosophical Magazine*, 1893, first half-year, p. 306.

* Trans. Roy. Soc., Edinburgh, Jan. 2, 1849; Cambridge and Dublin *Mathematical Journal*, Nov., 1850. Reprinted in Math. and Phys. Papers (Kelvin), Vol. I., p. 156.

† This is a very rough estimate which I have formed from consideration of J. T. Bottomley's accurate determinations in absolute measure of thermal radiation at temperatures up to 920° C. from platinum wire and from polished and blackened surfaces of various kinds in receivers of air-pumps exhausted down to one ten-millionth of the atmospheric pressure. Phil. Trans. Roy. Soc., 1887 and 1893.

‡ Trans. Roy. Soc. Edinburgh.

diabase is 14 per cent. denser than melted diabase, and 10 per cent. denser than the glass produced by quick freezing of the liquid. He gives no data, nor do Rücker and Roberts-Austen, who have also experimented on the thermodynamic properties of melted basalt, give any data, as to the latent heat evolved in the consolidation of liquid lava into rock of basaltic quality. Guessing it as three times the latent heat of fusion of the diabase pitch-stone, I estimate a million cubic centimeters of liquid frozen per square centimeter per centimeter per three years. This would diminish the depth of the liquid at the rate of a million centimeters per three years, or 40 kilometers in twelve years.

§ 25. Let us now consider in what manner this diminution of depth of the lava ocean must have proceeded, by the freezing of portions of it; all having been at temperatures very little below the assumed 1420° melting temperature of the bottom, when the depth was 40 kilometers. The loss of heat from the white-hot surface (temperatures from 1420° to perhaps 1380° in different parts) at our assumed rate of two (gramme-water Centigrade) thermal units per sq. cm. per sec. produces very rapid cooling of the liquid within a few centimeters of the surface (thermal capacity .36 per gramme, according to Barus) and in consequence great downward rushes of this cooled liquid, and upwards of hot liquid, spreading out horizontally in all directions when it reaches the surface. When the sinking liquid gets within perhaps 20 or 10 or 5 kilometers of the bottom, its temperature* becomes the freezing-point as raised by the increased pressure; or, perhaps more correctly stated, a temperature at which some of its ingredients crystallized out of it. Hence, beginning a few kilometers above the bottom, we have a snow shower of solidified lava or of crystalline flakes, or prisms, or granules of feldspar, mica, hornblende, quartz, and other ingredients: each little crystal gaining mass and falling somewhat faster than the descending liquid around it till it reaches the bottom. This process goes on until, by the heaping of granules and crystals on the bottom, our lava ocean becomes silted up to the surface.

(*To be concluded.*)

* The temperature of the sinking liquid rock rises in virtue of the increasing pressure: but much less then does the freezing point of the liquid or of some of its ingredients. (See Kelvin, Math. and Phys. Papers, Vol. III., pp. 69, 70.)

THE POSTHOM PHANTOM: A STUDY IN THE SPONTANEOUS ACTIVITY OF SHADOWS.*

At the April meeting of the Astral Camera Club of Alcalde the veteran sciosophist and former President of the Stanislaus Geological Society, Mr. Abner Dean of Angels, described his investigations of shadow-life, as exemplified in the strange case of Peter Schlemihl.

It seems that this gentleman, late a resident of Kunersdorf, in Germany, on one occasion was approached by a gray-haired stranger who offered to purchase his shadow. Schlemihl named a price, which was instantly accepted. Thereupon the stranger knelt upon the grass, rolled up the shadow, folded it neatly and thrust it into his knapsack, at once disappearing down the road between two hedges of roses, leaving Schlemihl himself absolutely shadowless.

At first the poor man took the deprivation lightly. But, as time went on, the singularity of his position wore upon him, the whispered words and doubtful glances of his friends began to distress him, and he fell into a condition of marked physical discomfort. He set out in search of

* 'Posthumous Humanity:' A study of Phantoms, by Adolph D'Assier, Member of the Bordeaux Academy of Sciences. Translated and Annotated by Henry S. Olcott; London, George Redway, York St., Covent Garden.