partly by tidal action, in the bottom of one of the old north and south longitudinal valleys, mentioned as occurring so frequently in Cheshire; on the emergence of the country it was re-excavated by the Mersey, which cut for itself a fresh channel in the Drift, in addition to excavating out the Wallasey Gorge, and cutting its present course between Egremont and Liverpool, which is daily becoming wider and wider, under the horizontal denuding power of tidal waters.

NOTICES OF MEMOIRS.

On the Nature of the Earth's Interior.[1]

By David Forbes, F.R.S., etc.

IN a previous discourse on Volcanos, Geological Magazine, 1870, Vol. VII., p. 314, attention was directed to the phenomena of volcanic action, specially considered in relation to the part which such igneous or internal forces have played in determining the grand features of the external configuration of the sphere upon which we live.

If, now, we follow up this subject still further, it will naturally lead to an inquiry into the nature of the internal substance of the globe itself, within which the foci of such agencies must be situated; but quite independent of this, there can be little doubt but that most intelligent persons have at some time or other already asked themselves the question as to what the central mass of the earth beneath them consisted of.

The answer which in the first instance would be most likely to suggest itself to the mind would be, that it consisted of solid stony matter, such as is seen forming the body of its mountains, the foundation of its continents, and the rock basins which contain its seas. The belief in such an hypothesis would, however, be rudely shaken by the first personal experience of the shock of an earthquake, the sight of a volcano in eruption, or the consideration of the immense faults which, in many places have disturbed and dislocated the solid land; whilst, so far from disposing us to regard the ground under us as entitled to the appellation of *terra firma* commonly employed by the ancients, the study of such phenomena could not but suggest grave doubts in our minds as to whether the earth, after all, could be anything like so solid and stable as at first sight we might have felt inclined to suppose it.

But very little inquiry into this subject is necessary, however, to convince any one of the great difficulties in the way of obtaining a satisfactory answer to this question, and to prove that in the present state of science we have not at our command sufficient data or evidence to enable us to arrive at any thoroughly conclusive solution of this most interesting problem.

As the rapid advances made by the natural sciences in all directions are, however, daily adding to our information bearing upon this subject, and thereby enabling previous deductions to be

[1] A lecture delivered in St. George's Hall, January 29, 1871.

modified or corrected, so as to lead to the formation of a more and more trustworthy opinion on the nature of those parts of our globe which, from their position, must always remain inaccessible to our powers of direct observation, it is imagined that a concise sketch of the present actual state of our knowledge concerning the probable constitution of the interior of the earth may prove interesting and instructive.

In treating this subject, we must first take into consideration what has already been done in the way of direct examination of the earth's substance in depth; yet, when it is remembered that the mean diameter of our planet is some 7912 miles, whilst the greatest depth hitherto attained by man's direct exploration has not even yet reached one mile from the surface downwards, the disproportion appears so enormous as to render it self-evident in the pursuit of this inquiry, especially as regards the more central portions of the earth, that we must in the main rely upon the less direct evidence furnished by calling in the assistance of the natural sciences.

The direct examination of the exterior of the earth, even when restricted to this depth, has, nevertheless, furnished us with many important data which can serve as a starting-point for this to a great degree speculative inquiry, and to some of these attention will now be directed.

It must in the first place be remembered that all the rocks which we encounter, and which compose so much of the solid exterior of our globe as is actually known to us, may be arranged under two principal heads, viz. the volcanic or endogenous, *i.e.*, those formed within the body of the earth itself, and the sedimentary or exogenous, *i.e.*, those rocks formed, or rather reconstructed, upon its surface out of the débris of previously existing rocks, arranged in beds or strata by the mechanical action of water.

It was until lately taken for granted by geologists, that the lowest sedimentary strata, in their normal, or in a more or less altered condition, rested directly upon granite, which was for a very long time regarded as the rock foundation upon which they, in the first instance, were deposited; this rock being then looked upon as the oldest of all, and even as representing the primeval or original surface covering of the earth. Later researches have, however, proved this hypothesis to be untenable, which is self-evident, since no instance of a granite has yet been met with in nature which, if followed up, does not at some point or other break through or disturb and alter, more or less, the stratified rocks in immediate contact with it, so that it naturally follows that such stratified rocks must have pre-existed on the spot, or in other words, that they must be older in geological chronology than the granite which came to disturb them.

In the present state of geological science, it is utterly impossible for us to point out any variety of rock whatever as the one which may have served as a foundation upon which the oldest sedimentary beds were originally deposited; in point of fact, the oldest rocks which we know at present are sedimentary rocks, mostly in an

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altered condition, belonging to the Laurentian series of Canada, and as yet geologists have not been able to discover what these sedimentary beds may in their turn rest upon, *i.e.*, what is actually beneath them.

Since we therefore have not as yet been able to reach down to examine directly any rocks lower in the geological series than those pertaining to the Laurentian formation, we will now turn to the Volcanos, in order to examine the mineral products which they bring up for our consideration, from depths vastly lower than those which we can ever hope to reach directly. What Volcanos teach us with regard to the nature of the Earth's interior at the depth from which they derive their supply of molten mineral matter, may be summarized as follows:—That at this depth, the earth's substance exists in a state of molten liquidity, forming as it were a sea of melted rock or lava, analogous in character to the eruptive rocks which have in former ages broken through the earth's crust; secondly, that the mineral products ejected by volcanos are very similar in chemical and mineral constitution, no matter from what part of the globe they may emanate; and lastly, that from the same volcanic orifice, and during the same eruption, lavas of two totally different classes may be emitted, viz. the light acid or trachytic lava, analogous to the granites, felsites, etc., of the oldest periods, and the heavy basic pyroxenic lava, all but identical with the dark basaltic or trappean rocks commonly met with, as dykes, etc., intersecting and disturbing most of the different sedimentary formations.

Besides these, another deduction from the study of volcanic phenomena, indicating that at a certain depth below the surface the volcanic vents must be in connexion with a continuous sea of molten lava, is based upon the influence which the moon appears to have on volcanic eruptions, an opinion which seems to have been confirmed by the observations by Professor Palmieri made during the last outburst of Vesuvius, on which occasion he reported that distinct tidal phenomena could be recognized, thereby indicating that the moon's attraction occasioned tides in the internal zone of molten lava similar to those it causes in the ocean. A further corroboration of this view is seen in the results of an examination of the records of some 7000 earthquake shocks which occurred in the first half of the present century, compiled by Perry, and which, according to him, demonstrate that earthquakes are more frequent in the conjunction and opposition of the moon than at other times; more so when the moon is near the earth than when it is distant, and also more frequent in the hour of its passage through the meridian.

Returning now to the more direct examination of the superficial parts of the earth, we find that the results of mining operations have also thrown considerable light, not only on the mineral nature of the rocks encountered in depth, but also upon some of their physical conditions. A numerous set of experiments made in deep mines in various parts of the world, far distant from one another, have most conclusively proved that the temperature of the earth, at least as deep down from the surface as has yet been explored by man, increases in direct ratio as we descend towards its centre. Other observations on the temperature of the water from deep-seated and hot springs, and from Artesian wells, fully confirm the experiments made in mines, and show that the temperature of the water furnished by them also becomes more elevated in proportion to the depth of the source from which it is derived.

As might naturally be expected, the interference of local circumstances renders it a matter of considerable difficulty to determine the true mean rate of such increase in temperature of the earth's substance downwards; still, in the main, observers all agree in placing it at somewhere between $1\frac{1}{2}°$ and $2\frac{1}{2}°$ Farenheit for every hundred feet in depth downwards, so that we shall not be far wrong if for our present object we estimate it at 2° Farenheit for every hundred feet, a rate which will be equivalent to 121° for each geographical mile nearer the earth's centre. Since no facts are at the present time known which can in any way invalidate the supposition that this or a somewhat similar rate of increase in temperature holds good at still greater depths, it appears to be perfectly correct and justifiable reasoning to assume that such is actually the case; whence it follows by a very simple calculation that, at a depth of about twenty-five geographical miles from the surface downwards, a temperature of about 3000° Farenheit should be attained, which would represent a heat at which iron melts, or one which is sufficient to keep lava in a state of perfect fusion at the surface of the earth. As it must be remembered, however, that at this depth the substance of the earth would be exposed to the pressure of the superincumbent mass, and as it has been demonstrated by experiment that many substances become more refractory, *i.e.*, require a greater heat to melt them or keep them in the molten state when exposed to pressure, the above calculation will have to be modified considerably in order to meet this condition of things. Unfortunately, we have not as yet sufficient data at command to enable us to settle the true ratio in which the melting points of rocks would become elevated by increased pressure; yet we may safely take it for granted, after allowing far more than the maximum rate of increase found in the experiments of Bunsen and Hopkins, that we should not require a distance as deep again in order to reach an internal temperature fully sufficient to keep such substances in a state of fusion, or in other words, to necessitate the inference that the solid rock crust of our earth cannot, at the utmost, be more than fifty miles in thickness.

If now we reason from the above data as our premises, it will follow as a natural consequence, that our globe must in reality be a sphere of molten matter surrounded by an external shell or crust of solid matter of very insignificant thickness when compared to the diameter of the entire globe itself, and that in point of fact this deduction represents exactly such a state of things as would be brought about in the event of a sphere of molten matter becoming consolidated on its exterior by the cooling action of the surrounding atmosphere; and the figure of the earth itself, which is an ellipsoid of revolution, *i.e.*, a sphere somewhat flattened at the poles, but

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bulging out at the equator, being that which a plastic mass revolving round its own axis would assume, is generally regarded by natural philosophers as all but conclusive evidence that the earth, at an early period of its history, must have been in a fluid condition.

Although the doctrine that the earth is a molten sphere surrounded by a thin crust of solid matter, was all but universally taught by geologists, there have of late years been brought forward several arguments to the contrary, which are apparently more in favour of its being a solid, or nearly solid mass throughout, and these arguments are fully entitled to our mature consideration. As our object is not to defend any particular theory, but to arrive as nearly as we can at the truth, we shall in the first place proceed to scrutinize all which has been brought forward in opposition to the older hypothesis of the earth's internal fluidity, and then to consider whether any other explanation as yet advanced may be more in accordance with the facts of the case.

First of all we have to answer the question as to whether it is possible for such a thin crust to remain solid, and not to become at once melted up and absorbed into the much greater mass of the molten matter beneath it. This would doubtless be the case if the central fluid mass had any means in itself of keeping up its high temperature independently of the amount of heat which it actually possessed when it originally assumed the form of an igneous globe. This question, however, in reality, answers itself in the negative, since it is self-evident that no crust could even commence to form upon the surface, unless the sphere itself was at the moment actually giving off more of its heat from its outer surface to the surrounding atmosphere than it could supply from its more central parts in order to keep the whole in a perfectly fluid condition, so that once such a crust, however thin, had formed upon the surface, it is self-evident that it could not again become melted up or re-absorbed into the fluid mass below.

The process of solidification due to external refrigeration would then continue going on, from the outside, inwards, until a thickness of crust had been attained sufficient to arrest or neutralize (owing to its bad conductibility of heat) both the cooling action of the surrounding air and the loss of more heat from the molten mass within, and thus a stage would soon be arrived at, where both these actions would so counterbalance one another, that the further cooling down of the earth would be all but arrested, a condition apparently ruling at the present time, since the surface of the earth at this moment, so far from receiving any or more than a minute amount of heat from the interior, appears to depend entirely, as regards its temperature, upon the heat which it receives from the sun's rays.

We have next to consider the argument, that if the earth's exterior was in reality only such a thin covering or crust like the shell of an egg, to which it has often been compared, that such a thickness would be altogether insufficient to give to it that stability which we know it to possess, and that it consequently could never sustain the enormous weight of its mountain ranges, such as, for example, the

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Himalayas of Asia, or the Andes of America, which are, as it were, masses of heavy matter piled up high above its mean surface-level. At first sight this style of reasoning not only appears plausible, but even seems threatening to upset the entire hypothesis altogether; it requires, however, but little serious consideration to prove it to be more, so to say, sensational than actually founded upon the facts of the case; since it is only requisite for us to be able to form in our mind some tangible idea as to the relative proportions which the size of even the highest mountain bears to that of the entire globe, to convince us thoroughly, that if such a crust could once form and support itself, that it could with ease support the weight of the mountains also. This will be at once seen by a glance at the diagram before you, which represents, upon a scale of 200 miles to the inch, an imaginary section through the centre of the earth, whose mean diameter is taken at 7912 miles. The thickness of the earth's crust, supposing it to be, as before estimated, about 50 miles, is on this scale denoted by the black outer line or zone, only a $\frac{1}{4}$ of an inch in width, whilst on the top of this again are placed (coloured bright red) some little markings, scarcely amounting to more than a slight roughness on the outline of the circle, and which is quite impossible for any one to see, except upon very close inspection, since they at the highest part do not project more than $\frac{1}{35}$ of an inch above the circle itself; these markings, however, do upon this scale represent the actual comparative size of the great Himalaya chain of mountains, which rise to a maximum altitude of 31,860 feet, or six miles above the mean level of the sea. From this it will be readily perceived that if the earth could be seen reduced in scale down to about the size of an orange, that to all practical intents and purposes it would resemble to the eye an almost smooth ball, since even the highest mountains and deepest valleys upon its surface would not present to the eye greater inequalities in outline than the little pimples and hollows on the outside of the skin of an ordinary orange. A mere glance at such a diagram will therefore, I think, fully convince us that if this thin crust can support itself, it is not at all likely to be crushed in by the comparatively speaking insignificant weight of even our very highest mountain chains; in fact it would be quite as unreasonable to maintain such a supposition as to declare that the shell of a hen's egg would be crushed in by simply laying a peice of a similar eggshell upon its outside.

That a very thin spheroidal crust or shell, inclosing a body of liquid matter, such as an ordinary fowl's egg, does possess in itself an enormous degree of stability, and power to sustain pressure from without, is easily demonstrated experimentally, by merely loading a small portion of its surface with weights, as long as it does not give way under them. Even when placed upon its side (or least strong position), it was found that a portion of the shell of a fowl's egg, only one quarter of an inch square, could sustain several pounds' weight, without showing any symptoms of either cracking or crushing, or, in other words, this simple experiment indicates that if the external crust of the earth was only but as thick and strong in pro-

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portion as an eggshell, that it would be fully capable of sustaining masses of rock equal in size and weight to many Himalayas, piled up one atop of another, without any danger whatever to its stability.

For the sake of comparison, another diagram was prepared, which shows the actual proportions of the cross section of a fowl's egg, enlarged to the same size as the ideal section of the earth's mass previously alluded to; now as in this instance the crust of the earth was assumed to be some 50 miles thick, which is in the ratio of $\frac{1}{158}$ part of its entire diameter, it naturally follows that the crust would comparatively be considerably stronger in proportion than the shell of the egg in question, since this was found only to possess a thickness of $\frac{1}{200}$ part of its mean diameter (two inches), or in other words, if the earth's crust were proportionately as thick as the eggshell, it would be only 40 miles in thickness, which is one-fifth less than previously assumed.

The next argument which has been advanced against the probability of the major part of the earth's substance being in a fluid condition, is one based altogether upon astronomical considerations. It having been demonstrated that when two clocks are set agoing, the pendulums of which are similar to one another in all respects, except that whilst the bob of the one is solid, that of the other is hollow and filled with mercury, that the latter will swing somewhat faster, and consequently this clock gain time upon the former.

The late Mr. Hopkins, of Cambridge, applied this observation to the consideration of the movements of the earth in space, and by a very elaborate course of mathematical reasoning and calculation, demonstrated that the earth, if not quite solid, must be nearly so, since, according to his results, if the earth was merely a comparatively thin shell, filled with liquid matter, the ratio of certain of its movements (precession and nutation) would differ considerably from what they are actually known to be, and these conclusions appeared to be confirmed by the subsequent calculations of Sir William Thomson and Archdeacon Pratt.

Although grave doubts suggested themselves as to the correctness of the values used in these calculations for two of their most important elements, viz. the condensing action of pressure, and the expanding action of the very high temperatures within the globe itself, neither of which have as yet been determined with any certainty;—and although it might also be surmised that the conditions of a pendulum bob of polished glass filled with heavy slippery mercury swinging at the end of a rod must be very different from those of a nearly spherical globe filled with viscid sticky lava revolving on its own axis;—still geologists felt themselves quite unable to answer the arguments of the astronomers and mathematicians, and since none of them appeared to be sufficiently versed in either astronomy or mathematics as to be able to submit either the mode of reasoning or the calculations themselves to any strict scrutiny, they felt themselves, reluctantly no doubt, compelled to bow to the decision of such eminent authorities.

So stood the matter until the summer of 1868, when, fortunately

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for the advance of this inquiry, M. Delaunay, now Director of the Observatory of Paris, an authority equally eminent as a mathematician and astronomer, was induced to undertake the reconsideration of this problem; a labour which has not only resulted in his having altogether reversed the above decision by demonstrating the complete fallacy of the premises upon which so much elaborate reasoning had been based, but which proved conclusively by experiment that a sphere filled with liquid matter would, under circumstances such as are present in the case of the earth, behave in precisely the same manner as an entirely solid one, and consequently that the fact of the earth being either solid or liquid in its interior could neither have any influence whatsoever upon the rates of precession and nutation, nor be of any use as a means of deciding as to the real or approximate thickness of the earth's crust.

It may be remarked, however, that the conclusions arrived at by Mr. Hopkins, even when supported by Sir William Thomson and Archdeacon Pratt, were not universally acquiesced in; the celebrated German physicist Helmholtz for example, amongst others, was not satisfied as to their correctness; and in direct opposition to the deduction of Sir William Thomson that the earth's crust must be some 1000 miles in thickness, we have the conclusions of Mr. Henessy, whose calculations show that it cannot be more than 600 miles or less than 18 miles in thickness. We may conclude, therefore, that all the objections as yet advanced from an astronomical point of view against the theory of the fluid condition of the interior of our planet have been invalidated or explained away.

The only other argument in favour of internal solidity is one which bases itself upon the law announced, from purely theoretical considerations, by Professor Thomson in 1849, that the fusing points of bodies become more elevated when subjected to pressure, or in other words, that under the influence of pressure, bodies will require more heat to melt them or keep them in the molten state.

Starting from this, Bunsen argued that the earth could not be other than solid to the core, since, according to him, the enormous pressure accumulated at its centre would render its internal substance so infusible that it could not possibly remain in a molten state. To a certain extent this law was corroborated by the experimental researches of Bunsen and Hopkins made upon some of the very easily fusible substances, such as wax, spermaceti, parrafine, and sulphur; but later experiments did not appear to confirm it in the case of metallic substances, nor did it appear to hold true in other than the more compressible bodies.

In the case of the earth, therefore, the conclusions of Bunsen cannot be warranted or accepted, since we have to deal with materials to which this law has not as yet been even proved to apply; still, assuming, as seems most probable, that the materials composing the earth's mass do become to a certain extent more and more infusible, according as they approach nearer to its centre, it must on the other hand be remembered that this effect would be at the same time more or less neutralized by the expansion which these substances would undergo from the action of the earth's internal heat, since incontro-

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vertible evidence has been produced to prove that the temperature of the earth increases in direct proportion to the depth; so that it seems most probable that the combined effects of expansion and heat would more than counteract any tendency to solidification due to the influence of pressure.

Having now taken into consideration the various objections which have at various times been urged against the theory of the earth's internal fluidity, as well as devoted some consideration to the opposing view of its solidity, it will be noticed, if we pass in review the more distinctive features of the two hypotheses, that the former theory is a legitimate deduction from the data afforded by the direct study of the earth itself, whereas the latter, on the contrary, instead of making the explanation of the earth's phenomena its starting-point, devotes itself all but exclusively to the task of proving that it could not be fluid. Thus, how is it possible, if the earth's mass be solid throughout, to account for the great upheavals and sinkings down of large portions of the rock formations which compose its external surface; do not these phenomena lead to the direct inference that the external crust cannot by any possibility rest in depth upon any unyielding mass of matter in a solid condition, but that it must necessarily be superposed upon some more or less fluid substance, which by its mobility can, when some one portion of the crust above it sinks down, become displaced, and so make room for it by elevating or as it were floating up some other part of the same?

In like manner the hypothesis that the earth is essentially solid necessitated that the phenomena of Volcanos should be explained upon the supposition that they had their sources in numerous small isolated basins of molten lava scattered over the surface of the globe, a view which is totally inconsistent with the results of chemical and mineralogical investigation, which proves that the ejected products are identical in constitution, even if taken from volcanic vents the most distant from one another; nor does such a theory attempt in any way to explain the tidal phenomena of volcanic outbursts and earthquakes previously referred to.

So far, therefore, as we have gone into this subject, we may regard the balance of evidence as indicating that at a depth of about fifty miles, or less, from the surface, there exists a continuous zone of molten rock or lava, such as is brought up to the surface in volcanic eruptions. Let us now consider how deep this zone or stratum of molten matter is likely to extend, and also what forms the more central mass of the earth below it.

In order to answer these questions, we must look for information to other than direct evidence, and first of all may inquire as to whether the consideration of the mean density, *i.e.*, expressed in other words, the actual weight of the entire earth itself, can throw any light upon these abstruse points. The consideration of the attraction which bodies exert upon one another in the ratio of their respective magnitudes has enabled the physicist to effect the at first thought apparently impracticable task of weighing the entire earth itself; it is, however, out of our province on the present occasion to describe the mode of doing so, and therefore we must content ourselves with accepting as facts the results of such investigations, which prove that the total weight of our planet is approximately five and a half times the weight of a similar globe of pure water.

Knowing thus that the mean density (or specific gravity, as it is also called) of the earth is 5½, and also from direct experiment that the mean density of the entire solid matter or rocks forming its external crust, cannot be higher than about 2½, or less than half that of the entire sphere, it naturally follows that the central parts must be infinitely more heavy than the surface, in order to account for so high a mean figure as 5½; indeed, it has been calculated that if we suppose the earth is composed of three concentric portions, of equal thickness, and respectively increasing in density towards the centre in arithmetical progression, that we should have an outer crust of specific gravity of 2½, like our ordinary rocks; an intermediate zone of specific gravity 12, or as heavy as quicksilver, and a central nucleus of about twenty times the density of water, or as heavy as gold.

This admitted increase in density has sometimes been erroneously represented as entirely due to the effects of the enormous pressure of the superincumbent mass, a supposition which is, however, quite untenable, since the tendency of all the numerous experiments made in this direction has been to prove that no substances exist which can be compressed or condensed to an indefinite extent, since what may be termed their approximative maximum density is soon obtained, beyond which point the effects of pressure become so much smaller in proportion to the extra force applied, that at last the further condensation effected by still greater pressure becomes all but inappreciable. Besides this, it must not be forgotten that the crust of the earth is a species of dome, like the shell of an egg, which can support itself without resting or floating upon its fluid contents, and further that the earth's high internal heat, by causing the materials which compose it to expand, must also counteract the effects of the superincumbent pressure; so that when all these facts are taken into due consideration, it appears evident that the materials which actually form the mass of the interior must be infinitely denser than any of the rock matter met with at the surface, and that they must also be of a metallic nature, since no other bodies are known which could at all fulfil these conditions of high density.

If, now, we imagine that the earth's interior be composed of a series of concentric zones or layers, made up of substances which are of more and more dense nature in proportion as they are situated nearer the centre, and also take for granted that the external one is rock of a density of 2½, a calculation will show that the centre or nucleus will then be about specific gravity 10, or about as heavy as silver. Supposing now that the zone of molten lava, which we have already been led to conclude as existing at a depth of some 50 miles from the surface, has a density of 3, or say even 4, in order to make the fullest allowance for the condensing effects of superincumbent pressure, we should then find by calculation that this zone could not extend deeper than 400 miles, since below this depth the matter would be so heavy that its density can only be explained upon the supposition that it consists of metallic compounds, and as the density of the lower zones would still go on increasing up to the centre of the earth, the natural inference would be that the whole of the great central mass of our planet, situated at a distance of some 450 miles, or less, below the surface, is in reality formed of metals and their compounds.

Whether this great central metallic nucleus is solid or fluid may next be inquired into. According to Bunsen's theory previously alluded to, it ought to be solid, for, owing to the enormous pressure to which it would be exposed, the solidification of the molten sphere should first commence at the centre. This view would, no doubt, be quite correct if the earth were known to be composed of highly compressible non-metallic materials; but since this is not the case, and since, as before alluded to, the experimental data already obtained indicate that neither the metallic nor the less compressible substances become more refractory in proportion to the increase of pressure, we are at present, at least, more justified in assuming that this central nucleus must also be in a fluid condition, and the more so, not only because it is known that, as a rule, metallic compounds are much more fusible than rock silicates, but also as the well-known high temperature of the earth's interior would also, by its expanding action, tend to counteract the effects of the pressure.

In summing up the results of this inquiry, the balance of evidence appears to me to be decidedly in favour of the hypothesis that the interior of our earth is a mass of molten matter arranged in concentric zones according to their respective densities, and the whole inclosed within a comparatively thin external crust or shell, and that our globe consists of (1st) an external solid crust not exceeding fifty miles in thickness—the upper third or more of which consists chiefly of stratified sedimentary rocks which rest upon some, to us at present unknown, species of igneous rock, which at one period had formed the lower part of the primeval crust; (2ndly) below this again a zone or sheet of molten rock extending all round the sphere, and reaching to a depth not exceeding 400 miles below the solid crust; and (3rdly) a dense metallic nucleus, the outer part of which consists of the compounds of the metals with sulphur, arsenic, etc., whilst in the very centre we should expect metals in an uncombined condition, or alloyed with one another, to predominate.

Having now completed the task of giving a concise exposition of the present state of our knowledge respecting the nature of the interior of our planet, a few words may be added in conclusion by way of apology for introducing a scientific subject of so extremely speculative a nature. Although the first thing in science is to collect as many facts, *i.e. truths*, as possible, it is nevertheless absolutely necessary, in order to utilize these truths and not allow them to degenerate into a mere chaos of disconnected facts, to from

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time to time attempt their arrangement under some system or theory. If we could insure our possessing every single fact of the case, such a theory or system could not be other than the true one; for knowing all the facts, we should be able to correct it and test its accuracy. So long, however, as we have not arrived at such a desirable consummation, it must nevertheless be admitted that science may be benefitted by occasionally attempting—as in the present instance—to bring all the facts already obtained under some systematic hypothesis, even if this be regarded as but a temporary arrangement and subsequently found to require much modification in order to accommodate itself to the advances of our knowledge of the subject.

REVIEWS.

I.—Sun Pictures of Rocky Mountain Scenery; with a Description of the Geographical and Geological Features, and some account of the resources of the Great West; containing Thirty Photographic Views along the Line of the Pacific Railroad, from Omaha to Sacramento. By F. V. Hayden, M.D., U.S. Geologist, Professor of Mineralogy and Geology in the University of Pennsylvania. Quarto, pp. 158, with 30 full-page Photographs. (London: Trübner & Co., 8 and 60, Paternoster Row.)

THE construction of the Pacific Railroad led to the production of a series of fine photographic views by Mr. A. J. Russell, of New York, who spent more than two years along the line of road in the employ of the Union Pacific Railroad Company. From these photographs thirty have been chosen, mainly with a view to the illustration of some special feature of physical geography and geology, to which Dr. F. V. Hayden has contributed 158 pages of excellent descriptive text.

The district chosen for illustration in these sun pictures commences with the first range of mountains west of Cheyenne, and continues thence to Salt Lake City, thus serving as an illustrated guide to those who may desire to study those grand geological features which the Pacific Railroad opens to enterprising tourists.

Prior to the travels of Lewis and Clark in 1803 and 1804, it was supposed that the Rocky Mountains formed a single ridge, extending from north to south; or at least of one main range, with a few minor ranges. We now know that this name includes an almost limitless series of ranges of every variety of form. From the eastern slope westwards, we pass over range after range for a thousand miles or more, until we descend the western slope of the Coast Range to the Pacific Ocean.

Dr. Hayden shows us how the features of the country have been as it were developed. He points out that in proceeding westward from the Missouri or Mississippi rivers there is a gradual ascent. At first not more than one foot per mile, but steadily increasing until we reach the base of the mountains, where the ascent is fifty