ORIGIN AND DEVELOPMENT OF GRANITIC, ETC., ROCKS. 199

VI.—*Notes on the Origin and Development of Granitic and other allied Varieties of Crystalline Rocks.* By JOHN REID, F.R.S.S.A., C.E.

(Read 15th January 1885.)

ALTHOUGH in no sense a geologist beyond that of a mere amateur tolerably familiar with the literature of the science as embodied in Lyell's "*Principles of Geology*," from which I have derived most of what I know of the theories of the science, and the nature and mode of action of those forces beneath and above the earth's surface, which have developed the phenomena which form the subject of geological study, these topics have always possessed a deep interest for my occasional study, and more especially on account of the very attractive manner in which the author presents his theories and arguments for solving the difficult problems presented by the earth's crust, which can hardly fail in carrying the conviction of a careful reader as to the general accuracy of the author's views. This has been my own general experience as an occasional student of Lyell's great work, with the single exception of one important branch of his subject wherein he treats of the large class of rocks which are commonly called Plutonic, as having their origin in the action of igneous forces residing within and under the solid crust of the earth;—the theory being that they existed originally in a melted state, and, in the process of cooling down, have probably passed through an intermediate pasty condition, and finally solidified into a crystalline state, as we now find them. The nature of these difficulties, and some considerations which occurred to me as likely to furnish a key to help in their solution, were formulated for private reference alone, until, when recently mentioning the subject to a scientific friend, he persuaded me—a good deal against my inclination—to prepare an abstract of these notes, as likely to prove a suitable subject for a short Paper to this Society, which is herewith respectfully submitted.

It is unnecessary for the purpose of this Paper to go into the questions of the shrinking nucleus of the earth, the fracturing and falling in of the solid shell, and certain forces which may have been at work in the past in forming the mountain and valley and all the diversified architecture by which the shell of the earth has been moulded and built up. I confine myself entirely to the difficulty I refer to, which raises a question probably belonging more to physicists than to geologists to solve. This question will be best understood by examining what Lyell

says about the changes which take place in the gradual passage of molten rocky matter from a fluid to a crystalline state.

In Lyell's work (edition 1853, page 562), treating of the *expansion* by heat of solid rocks, he proceeds to consider the *contraction* in bulk to which molten rocky matter is subject when cooling down into the concrete state. His statement is:—
“If we suppose that lava cooling slowly at great depths may be converted into various granitic rocks, we obtain another source of depression, for, according to the experiments of Deville and the calculations of Bischoff, the contraction of granite, when passing from a melted or plastic to a solid and crystalline state, must be more than *ten* per cent.”

It is many years since these statements regarding expansion and contraction of rocky materials in the process of heating up or cooling down gave rise in my mind to difficulties in satisfactorily reconciling the theory of continued contraction, accompanying the cooling down of molten rock to the final stage of cold crystalline solids, such as granites and other varieties of that class of rocks are said to do, with the phenomena presented to our observation.

I am not aware that the question has ever arisen in the minds of others, or received any consideration as a question for geologists, and bearing upon one of the most important of geological theories; but, on the assumption by Bischoff that granite loses ten per cent. of its bulk while cooling down into a concrete solid, and of course becoming increased in density, it has always seemed to me irreconcilable with the well-known fact that these dense masses of crystallized rocks form the nuclei of most of the mountain ranges, whose elevated summits protrude to the highest elevations above the mean level of the earth's crust. These rocks may reasonably be supposed to rest upon the molten masses within the earth, and are borne up above its surface, as icebergs are in the arctic seas.

It ought to be noted that the eminent geologist makes use, not of his own authority in this matter, but adopts the dicta of the physicist above named. We do not know the nature or manner of Bischoff's experiments by which he arrived at his conclusions. In any case, they seem to me to be open to doubt, and might with much advantage undergo verification in the interests of geological science, by being made the subject of careful experiment, to show whether or not molten granite rock, while passing from the molten into the crystalline state, loses ten per cent. of its bulk, and acquires a corresponding increase in its density. Considering the position occupied by these rocks in the earth's crust already referred to, it would seem that the matter is at least open to doubt, if not misleading, and might be set at rest by careful experiment with a molten mass

ORIGIN AND DEVELOPMENT OF GRANITIC, ETC., ROCKS. 201

of granite, watching its changes as it cools down. We may be warranted in believing that the molten mass will contract in bulk as it cools; but the point to which special attention is directed is this, that contraction while cooling will probably cease altogether when the temperature reaches or is approaching to *change of form* from the liquid to the solid condition, when the process of crystallization begins. This process may be preceded by the molten materials passing through an intermediate or plastic state of short duration; it would then enter upon its concrete and finally crystalline condition; and as this change takes place while the mass is at the highest temperature it can sustain, *as a solid*, it will have reached the maximum bulk and the minimum density of which such rocky matter is capable. Thereafter, as it cools, contraction in bulk will set in, while the remaining heat is given off until it reaches the temperature at which it settles down, as we now find it.

I have long held the idea that crystalline rocks do not progressively decrease in bulk as they cool down from a molten to a concrete state, but at certain stages the change of *state* is accompanied by expansion instead of contraction, and undergoes the same order of change which water passes through in its transformation from a fluid to a solid state.

A vulgar error prevailed during my parish school-days, which was found in the school books, and impressed by the teacher upon his pupils, that the well-known fact of water expanding as it passes into ice was a specially exceptional law designed to prevent our seas and lakes becoming permanently solid, and leading to the death of all organic life on the earth.

I could never get over the difficulties attending such a supposition, and have for long held the opinion that the law which enlarges the bulk of water when crystallized into ice must hold good with other substances that pass from the molten or fluid state into a crystallized condition when cooled down into the latter state, and should apply to the Plutonic series of rocks, which must also have enlarged in bulk and diminished in density in the same manner as water on becoming solid under refrigeration, and for the same reasons, viz.: that in crystallization certain molecular changes take place in the solidified structure that determine an enlargement in bulk and diminution of specific gravity.

Having this idea, I have frequently watched the behaviour of the residual slag as it was drawn out of an iron-smelting furnace, after the pig iron reduced from the ore had been run out. This very hot semi-fluid residue when drawn into rectangular boxes being sufficiently mobile, and very readily levelling itself into the receptacle, quickly gathered a black hardening scum or crust over its surface, which after a time became disturbed

by cracks and fissures, through which the plastic mass beneath discharged itself by flowing upwards and over the surface, and heaving up ridges along the sides and over the surface, and, when sufficiently cooled down, the surface became corrugated into ridge and hollow, suggesting a reasonable analogy with the igneous forces which have moulded the surface of the globe.

This analogy is favoured by the fact that the furnace slag consists mainly of calcerous, silicious, sandy, and earthy matter, which, when cooled down, assume a marked crystalline structure.

Perhaps the most striking illustration of these views may be obtained by any one desirous of satisfying himself on this point, if he will visit any ordinary iron foundry at the time the furnace gives out its molten iron into the pot for receiving it. Alongside he will find broken lumps of the self-same *cold* metal with that glowing in its fused condition, in the pot; by taking one such piece of metal, and plunging it into the melted mass, he will find that, instead of sinking to the bottom of the melted metal, it will float upon its surface, precisely as in the case of ice upon water—because the solid is of greater bulk and less density than the fluid. Other examples of the same thing will be familiar to those giving attention to the subject.

Like cast iron, some other metals, such as antimony and bismuth, seem also to expand at the moment of entering into the concrete state. Roll sulphur, which is crystalline as a solid, and probably some other terrestrial minerals, have the same properties of expanding when becoming solid, as may be verified in the same manner as with cold iron floating on the melted metal. These substances are crystalline solids, and correspond in this respect with the granitic class of rocks which analogy would indicate as being influenced by expansion instead of contraction of bulk at the moment of assuming the crystalline state. It is important to state that the writer has experimented with several of the more easily fused metals, and has found that those of an amorphous character, such as *Lead*, do not possess the property of floating in the same metal in a state of fusion as crystalline metals, such as cast iron certainly does.

Take a solid bar of cast iron, say 100 inches in length, and at the temperature, say, of 32° Fahrenheit. Supposing this bar to be exposed to heat, expansion in bulk will proceed with accessions of heat until it is on the border of the fusing point, when its length will be found increased by about one inch—or $\frac{1}{16}$ th of its length when cold; at this point the metal will have attained its greatest bulk and least density. Proceeding a few degrees further in temperature, it will suddenly collapse and fall down into the molten state, wherein it will attain its greatest possible density and least bulk. If accessions of heat could be added to

ORIGIN AND DEVELOPMENT OF GRANITIC, ETC., ROCKS. 203

raise the temperature to what is believed exists in the sun, the metal would be transformed from the state of a fluid to the exalted condition of vapour. The process of cooling down would no doubt bring back the metal, through its fluid state, to the solid form in which the process began.

What is noticeable in these transformations is, that heat expands cast iron throughout the stage of passing from a solid to a fluid, and suddenly contracts to its least dimensions on reaching fusion. On cooling down from fusion it may undergo little contraction while passing through a viscous condition to that of a solid ; but if my theory is right, the continued reduction of temperature to the point of crystallisation will be accompanied by a great expansion in bulk as it crystallises ; after which, contraction in bulk as a solid will slowly bring it to the density of the iron bar with which the experiment began.

Should these observations be looked upon as fanciful, or at the best of a merely speculative character, it will be observed that they are meant to apply to the principles of a science the least exact, and certainly not the least speculative, of any science of modern times ; and must be so, from the vast field of its observation, and the subtle nature of the problems it sets itself to deal with. Geology as a science is still in its infancy, and most of its theories are, from their very nature, of a purely hypothetical character. There can be no doubt that, as time goes on and observation is extended, more or fewer of the existing theories will undergo revision and improvement.

The question suggested by this paper hangs on a single point, and according to its solution it must stand or fall. The question is, "Are granitic and allied varieties of Plutonic rocks larger in bulk and of less specific gravity in their cold concrete state than they are while in a molten condition ?" The question is easier asked than answered, and that only by experiments.

With bodies whose melting and solidifying temperatures are not widely apart, as in the case of water, the thing can be easily handled ; but not so with granite or other crystalline rocks, whose fusion can only be accomplished with something like the heat required for fusing cast iron. We do not require for the object aimed at to follow the *cooling-down* process of melted granites into their crystalline state, having it at hand as crystallised by nature. Melt a mass of the rock to be tested into perfect fluidity. All that is then required is to plunge a piece of the cold rock into the fluid mass, and if it floats, as I conjecture it will, on the surface of the liquid, as cast iron does—then an affirmative new fact will thereby be established of great importance to the modern science of geology. If it *does not* float, there is an end to it.

The temperature required for reducing cast iron to a con-

dition of absolute fluidity has been estimated at about 1200° centigrade or 2100° Fahrenheit; and there is no doubt that a much higher heat is needed to attain the same result with granitic rocks, under which such an experiment could be made with any reliable result.

Obviously it has not been practicable for the writer to test the accuracy of his views on this point, and it can only be satisfactorily done under the auspices of qualified experts at one or other of the manufactories where Siemens' regenerative furnaces are employed, as in the steel manufacture, by which an adequate temperature might be got for the thorough fusion of the most refractory crystalline rocks, and their relative densities, as solid and as fluid, be determined in the way mentioned as applicable to solid and fluid cast iron.

To show that such a crucial test is desirable in the interests of geological science, has been the purpose for which these Notes have been drawn up.

In conclusion, it will readily appear that, if the result of such a test should be in favour of the views herein set forth, it would bring in a hitherto unrecognised natural force that may have largely contributed to produce some of the most important geological phenomena in the earth's crust, such as the heaving up of the rocky mountain masses, and throw some new light upon the hitherto obscure explanations that have been given regarding the slow, quiet, but constantly-acting terrestrial forces which are known to be in activity in raising large areas of the earth's surface at the rate of so many feet or inches in a century, as in Scandinavia and elsewhere.