II.— On the Critical Point in the Consolidation of Granitic Rocks,

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IN carefully reviewing the various facts which I have been able to collect since the publication of my paper on the Microscopical Structure of Crystals,* I have been led to believe that many peculiarities in the structure of granitic rocks may be explained by a principle, which, as far as I am aware, has not hitherto attracted attention. It appears to me extremely probable that the critical point in the consolidation of granitic rocks is very closely connected with the critical temperature at which highly heated and compressed steam would condense into an equal volume of highly heated and expanded liquid water.

As I pointed out in the paper already mentioned, rocks melted under great pressure probably contain water either dissolved as a gas in a liquid, or in the state of a fused hydrate. On cooling down to a lower temperature, the crystallizing out of anhydrous minerals would almost necessarily set free this previously combined water. As long as the temperature was above the critical point it would necessarily remain more or less disseminated in the rock as highly compressed steam, but as soon as the temperature fell below the critical point, it would condense into highly expanded liquid water. Unfortunately, the temperature at which this occurs is only imperfectly known, and I fear it would be very difficult to determine it accurately, on account of the very intense action of such highly heated water on glass. The only determination of this temperature that I am acquainted with is that of Cagniard de La Tour†

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* Quart. Journ. Geol. Soc. 1858, Vol. XIV., pp. 453—500.
† Ann de Chimie, 1822, t. XXI., p. 127 and 178; t. XXII., p. 410.

who found that water expands to nearly four times its volume and passes into an equal volume of highly compressed steam at about the melting point of Zinc, which, according to Daniel, is 412° C.; that is to say, at what would be a dull red heat visible in the dark.

As long as the temperature was higher than this, the solvent action of water could not be brought into play, since earthy substances and alkaline salts could not be dissolved in steam; but as soon as it condensed into a liquid, the solvent power of the ater would be very great, as shown by its intense action on glass. Amongst other effects, it would at once dissolve any alkaline chlorides that might be present, so as to form a highly saturated solution. Now all these theoretical deductions agree most remarkably well with the microscopical structure of a very interesting granitic rock from Ponza, the exact history of which I do not know, but am strongly inclined to believe that it is a portion of an ejected block, consolidated at a great depth; and did not form part of a lava flow.

As I pointed out long ago, in the paper already cited, the minerals of ejected blocks and the quartz of granite contain many true gas cavities, as though, besides water, gas was present during the crystallization of the minerals, and was caught up in them as well as liquid water. Very often also, we can see that in those cases where the gas cavities occur, the vacuities in the fluid-cavities are frequently of variable relative size, as though a variable amount of gas was caught up along with the water. This fact, known to me and described long ago, has since been alluded to by Mr. Phillips and Mr. Allport, as though I had overlooked it. I showed that the fluid cavities often had the same character as those in artificial crystals formed at a heat of boiling water near the surface, which catch up variable amounts of water and air. It is a character of considerable importance, and serves to distinguish at once crystals formed under such circumstances from those deposited in the midst of a solution quite free from contact with any gas. Thus for example, in many granites we find true gas cavities, and fluid cavities with a variable abnormal amount of included gas, whilst the quartz in the extremely coarse-grained granite veins at Rubislaw, near Aberdeen, contains no gas cavities, and the vacuities in the fluid cavities are of almost absolutely uniform relative size, as is also the case in that of some simple quartz veins. I may, however, here say that the very great variation in the relative amount of water

and liquid carbonic acid in the cavities, clearly proves that very great changes in the surrounding circumstances sometimes took place, even during the growth of one single crystal; and there is good reason to suspect that there may often have been considerable variations in temperature and pressure, as well as in the relative amount of water and gas.

This difference is still more marked in the case of the different minerals in the curious granitic rock from Ponza already mentioned. The felspar contains many gas cavities, but also many with a small amount of water. It is very difficult to accurately determine the exact relative volume of this liquid, but in the most characteristic cases it appears to be not far from about ¼ or ⅓ of the volume of the entire cavity. If so, the explanation of the origin of such fluid cavities is very simple. According to Cagniard de La Tour's experiments, highly compressed steam heated to a temperature somewhat above the critical point, if caught up in growing crystals, would finally condense and contract so as to give rise to just such cavities as occur in the felspar. In support of this conclusion, it may be said that very few, if any, of the cavities in the felspar contain crystals of the alkaline chlorides, which occur in large amount in the cavities of the quartz, so that there is every reason to conclude that the felspar caught up *steam*, but the quartz *liquid water* saturated with soluble salts. In some parts of the quartz occur gas cavities, but in those parts of the crystals which are more or less free from them, the relative size of the vacuities is sufficiently uniform to enable us to form some idea of the true temperature. There may be, and probably is, some variation, perhaps from about ·5 to ·3, but this may be only apparent, and due to those irregularities in the form of the bubbles and the cavity which cannot be seen when we can only examine a cavity in one line of vision. Probably ·4 is as good an approximation as we can make to the relative size of the vacuity as compared to the liquid, and if so, in accordance with the method of calculation adopted in my paper on the structure of crystals, the temperature must have been about 425° C. Considering all the sources of uncertainty this agrees very well with the temperature of the critical point of water. At all events, the facts seem to show that the quartz was mainly, if not entirely, formed when the temperature of the rock had fallen *just below the critical point of water*, that is to say that it began to crystallize as soon as the partially melted mass could be exposed to the *solvent* action of *liquid* water. In support

of this conclusion, I would say that the cavities in the quartz contain a most unusually large relative quantity of the crystals of alkaline chlorides.   Perhaps their bulk is very nearly equal to that of the water, so that for solution the temperature must necessarily have been about as high as that indicated by the size of the vacuities, the one fact thus confirming the conclusion derived from the other.

It would extend this paper to a most undesirable length to enter into the discussion of a considerable number of physical questions connected with this subject, and I must, therefore, confine myself chiefly to general deductions.   At all events, in the case of this Ponza granite the facts seem to shew that the greater part of the felspar crystallized when the temperature was above the critical point of water, when it could not act as a solvent; but the greater part of the quartz crystallized when the temperature was below the critical point, so that the water could act as a solvent.   As soon as this occurred it would become rapidly saturated with the alkaline chlorides and any other easily soluble salts, and have a most important influence on subsequent changes in the rocks.   My own experiments at only moderate high temperatures, and those of Daubrée,[*] prove that the action of only a small quantity of water at such an elevated temperature as 400° C, is most energetic on artificial glasses, and amongst other things does actually give rise to crystals of quartz.   Now, though some of the trachytes of Iceland contain quartz with glass cavities, thus proving that in some cases quartz may crystallize out from a stony mixture in a state of true igneous fusion, yet this is an exceptional circumstance.   Taking everything into consideration, it seems more probable that by far the larger part of the quartz in granitic rocks was set free and crystallized through the action of the liquid water, when the temperature had fallen below the critical point, i.e., at a temperature of a dull red heat just visible in the dark.   The exact temperature may have varied considerably, since, if the pressure were not sufficiently great, the water might remain in the form of steam until the rock had cooled somewhat more.   This would easily explain why the temperature indicated by another quartziferous rock from Ponza, more allied to trachyte than to granite, and very analagous to some of the least granitic elvans of Cornwall, is only about 361° C.   This closely corresponds with the mean temperature deduced from the fluid

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* Annales des Mines, 5e livraison, 1857.

cavities in the ejected blocks of Somma, which varies from about 340° to 380° in different minerals; or at all events, in the different cases which have come under my observation.   As Scheerer has shewn, the properties of pyrognomic minerals prove that many granite rocks cannot have consolidated at a materially higher temperature.   All these facts therefore strongly point to the extremely probable conclusion that the critical point in the formation of granitic and other allied rocks was most intimately connected with the critical point of water; and, if so, we have a true and definite physical cause for the production of most important chemical and crystalline changes, at the temperature indicated by a variety of entirely independent physical and chemical phenomena.
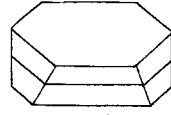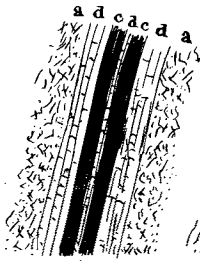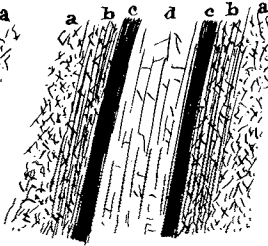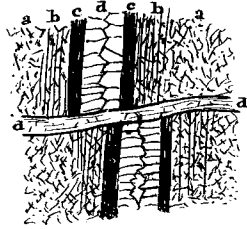
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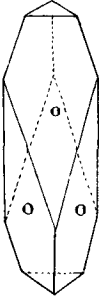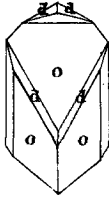
Fig 1.

Fig. 2.
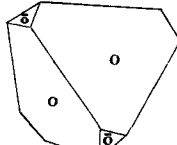
Fig. 3.

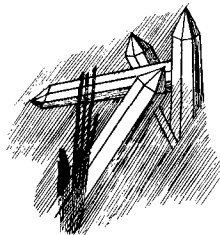Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8. × 150.

Fig. 9. × 150.

Fig. 10. Nat. Size.