

NOTICES OF MEMOIRS.

ARRHENIUS' THEORY OF THE PHYSICAL CAUSES OF VULCANICITY.¹ By R. H. RASTALL, M.A., F.G.S., Fellow of Christ's College, Cambridge.

[*Note*.—As this paper in its original form is very inaccessible to most readers, its importance has perhaps scarcely been appreciated in this country; the following short abstract has been made at the suggestion of Professor Bonney, in the hope that it may be of use to students of geology and others.]

(1) *The Condition of the Earth's Interior.*

THE conclusions of astronomers and physicists are irreconcilable with the hypothesis of the existence of any considerable amount of matter in the liquid form in the interior of the earth. This idea rests for the most part on a misconception of the physical properties of matter under the enormously high pressures which prevail at great depths. Nearly all known substances, with the notable exception of water, contract in volume on solidifying, and in consequence their melting-point is raised by pressure. The investigations, however, of Damien, Barus, and especially of Tammann, have shown that at very high pressures this relation no longer holds. Tammann found that the maximum melting-point of dimethylethyl-carbinol is reached under a pressure of 4,750 atmospheres, and at higher pressures the melting-point falls; it seems probable that other substances would behave in a similar manner under similar conditions. Hence it appears that at great depths the constituents of the globe must be in reality in the gaseous state, since pressure cannot keep them solid or even liquid by raising the melting-point. But the physical properties of gases under such conditions must be very unlike those with which we are acquainted. The true difference between a liquid, a solid, and a gas lies in the rate at which they respectively undergo deformation under stress. The necessary physical constants have been determined by Reinganum in the case of isopentane at the highest attainable pressures, and from these it is calculated by extrapolation that at a depth of 1,000 kilometres the compressibility of gaseous isopentane must be about equal to that of steel. The temperature in this case must be far above the critical point, and the material is actually gaseous, though its physical properties resemble those which are commonly associated with the idea of a solid. Rock-magma under similar conditions would undoubtedly possess a still lower compressibility.

Assuming the temperature-gradient to be 3° C. per 100 metres, the melting-point of most rocks, about 1,200° C. is attained at a depth of about 40 kilometres, while below this lies a liquid zone. At a still greater depth the critical point is passed, and the magma is in the gaseous state, though intensely rigid. From the high density of the earth as a whole, compared with that of the visible portion, it appears that the inner nucleus consists of some metallic substance,

¹ Arrhenius, "Zur Physik des Vulcanismus": Geologiska Foreningens i Stockholm Forhandlingar, Band xxii (1900), p. 395.

probably iron. From the known data it is easy to calculate that about 80 per cent. of the earth's diameter must be occupied by gaseous iron, 15 per cent. by gaseous rock-magma, and 4 per cent. by liquid magma; the rest, less than 1 per cent., forms the solid crust.

These theoretical conclusions are supported by the results of earthquake observations. The seismograph record of a distant earthquake shock shows a clear division into two phases, viz. preliminary tremors and the principal shock. The explanation of this fact is, as Milne pointed out, that the principal shock is propagated along the crust, while the preliminary tremors travel along the chord of the arc. Since these latter are much diminished in intensity, it follows that the internal friction of the material of the inner parts of the globe must be very great, which is in harmony with the assumption of a liquid or gaseous condition rather than with the solid state.

(2) *Volcanic Phenomena.*

It is unnecessary to prove in detail that in all volcanic eruptions great quantities of gases, and in particular water-vapour, are given off, and the pressure of this gaseous water at a temperature above its critical point is undoubtedly the chief motive-power of the eruption. Each explosion relieves the pressure for the time being, but the frequent recurrence of eruptions from the same vent shows that further supplies of water must by some means reach the magma, and this in spite of enormous counter-pressure. The ocean-floor, with its capillaries, may be supposed to act as a semi-permeable membrane, through which the water penetrates by osmotic pressure. Assuming the density of the magma to be about 2.7, it can easily be calculated that in order to overcome the pressure of the overlying column of rock the osmotic pressure at a depth of 10,000 metres must be about 1,700 atmospheres, and this in itself is not inconceivable. But since the dissolved constituents of the magma show this high osmotic pressure they must enter into chemical combination with the water.

According to Thomsen's measurements water at the ordinary temperature is a very weak acid, about 100 times weaker than silicic acid, but on raising the temperature these relations no longer hold. While silicic acid, which has a heat of neutralization equal to those of nitric and hydrochloric acids, does not change its strength notably, the case is very different with water. From the data with regard to the behaviour of water between 0° and 50°, it can be calculated by a well-known extrapolation formula that at 300° water and silicic acid are equally strong, at 1,000° water is 80 times, and at 2,000° 300 times as strong as silicic acid. It is true that this result is obtained purely by extrapolation, but it is of no practical importance whether water is 300 times or only 100 times as strong as silicic acid, so long as it is distinctly the stronger, and this the calculation shows with certainty.

(3) *The Chemical and Physical Action of Water on the Magma.*

Let us now suppose water to be in contact through a semi-permeable membrane (the sea-floor), with a magma between 1,000° and 2,000° C. Water penetrates into the magma by osmosis and acts as a relatively powerful acid on the silicates, by which means silicic

acid and bases are set free. These combine with more magma, and form acid and basic silicates. Further addition of water then sets up new decompositions, but some water always remains free in the magma, although on account of its relatively small amount it has a very low vapour-pressure, in accordance with Raoult's law. The process can go on till a great part of the magma is decomposed. The magma must also increase in volume on taking up water, by very nearly the volume of the water absorbed.

The swollen magma, which has also become more fluid, exerts pressure on all sides, and the column rises still further in the vent which is in connection with the magma-basin. On rising, the magma is cooled in the narrow vent, the water continuously becomes a weaker acid, and is displaced by silicic acid from the hydrates; the pressure of the aqueous vapour rises in spite of the fall of temperature, and if the watery layer comes near enough to the surface, and therefore under sufficiently low external pressure, steam explosions will occur.

According to this theory a volcano acts very like a geyser. As the water rises in a geyser, so it does in a volcano, though in this case it is mostly in chemical combination with the magma. At great depths, and therefore under high pressures, the water in the geyser and the watery magma in the volcanic vent are under higher pressures than those corresponding to the maximum tension of the water-vapour, and no explosion is possible. When a magma enters the vent of the volcano and rises in it, it at last reaches a point where, on account of separation of water from the magma through cooling, the pressure of the water-vapour exceeds the external pressure. Then an explosion occurs, blowing a passage through the overlying layers, and thus leading to renewed explosions by relief of pressure. This goes on till so much water has separated from the magma that the remainder cannot overcome the external pressure. Then ensues a period of temporary quiescence, with slow loss of water-vapour by diffusion, until after a sufficient lapse of time so much water penetrates into the magma-basin that the process begins anew.

R E V I E W S .

I.—NEW GEOLOGICAL SURVEY MAPS AND MEMOIRS.

1. THE GEOLOGY OF FALMOUTH AND TRURO AND OF THE MINING DISTRICT OF CAMBORNE AND REDRUTH. By J. B. HILL, R.N., and D. A. MACALISTER, A.R.S.M., F.G.S.; with Petrological Notes by J. S. FLETT, M.B., D.Sc. 8vo, cloth; pp. x and 336, 24 plates. Pages 1–112 form Part I, Geology; pp. 113–314 form Part II, Mining; pp. 315–324 are Bibliography; and pp. 325–335, Index. Price 7s. 6d.; in explanation of colour-printed map, Sheet 352, 1s. 6d. (E. Stanford: London, 1906.)
2. THE GEOLOGY OF THE COUNTRY NEAR NEWQUAY. By CLEMENT REID, F.R.S., F.L.S., F.G.S., and J. B. SCRIVENOR, M.A., F.G.S.; with contributions by J. S. FLETT, M.A., D.Sc., W. POLLARD, M.A.,