

III.—*On the Magnetic Constituents of Rocks and Minerals.*

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ALL minerals are supposed to be either magnetic or diamagnetic, and in a large number, exact measurements have been made of the relative amount of magnetic force in each mineral. As was to be expected, the compounds of Iron and Nickel are, in the great majority of cases, the cause of the magnetism in mineral; but there exists a large border land of slightly magnetic mineral substances, the cause of whose magnetism has never been very clearly shown. I do not intend, in this paper, to deal with those which are only faintly magnetic, but with those whose magnetism is quite distinct, such as Obsidian, Basalt, &c. The method used for testing the relative amount of magnetism in any specimen was as follows. A strong but light magnet was suspended from the hook above the pan of a delicate balance, (that in question turning with  $\frac{1}{10}$  of a milligram when loaded with the magnet and counterpoise) and the mineral placed on a little table over the pan, a rack and pinion motion allowing the table to be raised or lowered quickly when wanted. The balance was left free to swing, and the mineral slowly raised till nearly touching the magnet, then if any deflection was noticed the table was lowered to obtain the greatest amount of angular inclination of the beam, which was then noted. If no deflection was caused, the beam was made to swing slightly, so as to make the pointer move one division to right and left of the zero point on the ivory scale, and, while the end with the magnet was at his highest point, the mineral was approached to it and lowered with it, following the swing of the balance, so that if magnetic, the mineral aided the swing. When the magnet was at its lowest point, the mineral was lowered about two inches from it, so that it might have no influence in retarding the upward motion of the beam. After repeating this operation several times, the increase in the swing was noted, and if sufficient,

the mineral was laid aside for examination. The question which I wished to answer was this:—are slightly magnetic rocks and minerals homogeneously magnetic, that is, slightly magnetic throughout their entire substance, or are they magnetic by virtue of small particles of magnetic substances interspersed throughout their substance. The principle consideration which led me to this investigation, was that, (putting aside magnetic iron ore), the purer and more homogeneous the mineral the less its magnetic power, and conversely the more mixed or impure the mineral the more magnetism did it display. On making careful analyses of those substances, which, not being very pure, showed a stronger magnetic condition than pure specimens, I found that in every case there was an excess of iron. The following estimations of iron in different specimens will, I think, show this. Column A shows the amount of iron in specimens slightly magnetic, and column B shows that in those more so.

ROCKS AND MINERALS.	A	B
Porphyry .. .. .	2·86	4·29
Pyrochlore .. .. .	1·25	3·67
Obsidian .. .. .	1·82	3·26
Serpentine .. .. .	0·85	3·43
Natrolite .. .. .	0·18	1·65
Basalt .. .. .	14·65	18·22
Pitch-stone .. .. .	1·00	3·18
Rhodonite .. .. .	0·65	6·28
Red Clay .. .. .	1·55	3·67
Gneiss .. .. .	0·08	2·26
Crystalline Lava from Herculaneum ..	6·18	7·04

Some specimens of these substances were reduced to powder in wedgewood and agate mortars, and from a portion of that powder (about 50 grammes) the magnetic particles were separated out. This process is exceedingly tedious, as it takes at least a day's work and sometimes more, to completely separate the purely magnetic portion.

The specific gravity of the original substance, of the demagnetized portion, and of the magnetic portion, were then determined, and analyses made of both the magnetic and non-magnetic portions. The following table represents the numbers so obtained for several substances whose examination I have been able to finish.

	Sp. Gr. of Mineral.	Demagnetical portion.	Magnetic portion.
Obsidian ..	2·668	2·625	3·295
Basalt .. ..	2·538	2·522	3·265
Pitch-stone ..	2·312	2·297	3·258
Serpentine ..	2·557	2·529	3·284
Lava .. ..	2·869	2·838	3·294
Gneiss .. ..	2·635	2·610	3·271

To show the necessity of having the minerals very finely pulverized, so as to obtain their real specific gravities, I may state that the lava, No. 5, on being pulverized as finely as is usual for analysis gave 2·820 as its Sp. Gr., when more finely pulverized it rose to 2·828, then 2·832, 2·835, 2·837 and 2·838, in this last case the pulverization being carried so far that the mineral, on being boiled with water in the Sp. Gr. bulb to expel adhering air, took an hour to settle sufficiently clear to render the bulb transparent. This shows clearly that in some instances at least there are small interstitial spaces which are generally neglected in taking a Sp. Gr. The amount of magnetic substance contained in these minerals varied from 0·3 to 1·7 per cent., and was determined directly by weighing the magnetic portion obtained from a known weight of the mineral.

The experimental numbers were checked by calculation, one method used being given in the following formula, which would show if any serious error had been committed in the separation or Sp. Gr. of the magnetic and non magnetic portions.

$$\frac{D}{100} = \frac{1}{\frac{x}{\Delta} + \frac{x'}{\Delta'}}$$

- Where D = Density of the Original Mineral.
- x = Percentage of Magnetic portion.
- x' = " " Nonmagnetic "
- Δ = Density of Magnetic "
- Δ' = " " Nonmagnetic "

As the original density is easily obtained with great accuracy, by equating all those quantities in which error might be against it, we detect any serious mistake. Now the principal result obtained from these numbers is that the magnetic portions from widely different sources have practically the same Specific Gravity, and

that it is always higher than that of the original mineral. The rocks and minerals differ very much in composition, as the following analyses will show, but the magnetic constituents are remarkably alike.

	1	2	3	4	5	6
Si O <sub>2</sub>	74·26	48·83	72·56	43·18	46·87	70·24
Fe <sub>2</sub> O <sub>3</sub>	3·25	13·97	2·25	3·27	7·04	3·00
Fe O	—	2·56	0·87	0·04	—	—
Al <sub>2</sub> O <sub>3</sub>	11·48	18·25	13·44	0·19	35·42	16·40
MnO	—	—	—	0·43	0·04	—
CaO	2·93	6·53	1·78	0·73	0·14	0·77
MgO	0·85	2·88	4·27	40·30	3·87	0·05
K <sub>2</sub> O + Na <sub>2</sub> O	6·12	2·01	3·04	—	4·20	6·98
H <sub>2</sub> O	1·01	5·82	1·99	12·07	1·85	1·84
	99·90	100·85	100·20	100·21	99·43	99·28

The above substances were those in which the excess of iron showed itself to be magnetic by trials against normal specimens by the method explained, and the following analyses show the composition of the magnetic constituent, when purified as much as possible from adhering mineral.

	1	2	3	4	5	6
Fe <sub>3</sub> O <sub>4</sub>	51·07	58·81	62·18	61·33	62·07	60·21
Fe <sub>2</sub> O <sub>3</sub>	3·04	2·82	1·05	1·84	0·25	1·85
MnO	—	—	—	0·09	—	—
SiO <sub>2</sub>	40·82	36·57	36·22	35·73	36·28	36·88
Al <sub>2</sub> O <sub>3</sub>	5·01	2·12	0·82	1·05	1·30	1·28
	99·94	100·32	100·27	100·04	99·94	100·22

With the exception of the magnetic portion of the Obsidian No. 1, these figures show that the substance which causes the magnetism in the above minerals has the same composition, as in each case the numbers show a remarkable similarity, considering the difficulty in obtaining the substance pure. Even in the case of No. 1, it seems that the difference is caused chiefly by adhering Obsidian, as the excesses of silica and alumina occur almost in the proportion to form that mineral. The numbers agree pretty well with a body having the formula Fe<sub>3</sub>O<sub>4</sub>, 2 SiO<sub>2</sub> which requires 65·91 per cent. of magnetic oxide, and 34·09 of Silica. Supposing Silicic acid to be a tetra-basic acid, this would be a perfectly normal compound, just as we might have the salt Fe<sub>3</sub>(SO<sub>4</sub>)<sub>4</sub> or Fe<sub>3</sub>O<sub>4</sub>, 4 SO<sub>3</sub>, so we have Fe<sub>3</sub>Si<sub>2</sub>O<sub>8</sub> or Fe<sub>3</sub>O<sub>4</sub>, 2 SiO<sub>2</sub>.

It is rather curious that substances obtained from such widely different sources should yield magnetic particles of the same composition, (for, I think, the excess of silica may safely be attributed to adhering mineral), and further it is a significant fact that the more magnetic the substance the greater is the per centage of the magnetic constituents. This, I think, points to the conclusion that many of the minerals at present considered magnetic are not so by any magnetism inherent in their pure substance, but by reason of an intermixture of magnetic particles, and, as far as I have yet gone, I feel confident that many substances at present considered magnetic will require to be classed when pure as diamagnetic. I have not yet been able to determine, with any degree of certainty, the crystalline form of the magnetic constituent, because, as was to be expected, the pulverization of the mineral fractures the particles, and I have not been able to pick out a suitable crystal, but from some faces, and especially from one portion of a pyramid, as seen through the microscope, I am inclined to think the crystalline form of the mineral is hexagonal. I am making an extended examination of the subject, and shall be able, I hope, to get more conclusive results for publication in a future paper.