

Chemical-pressure Remanent Magnetism in Sedimentary and Metamorphic Rocks

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Abstract

Magnetization were produced by a chemical reaction in which ferrous hydroxide was transformed to α - and γ -hematites by dehydrating the former by heating under a one-directed pressure and at the same time by letting the water-vapour get out of the pressure vessel.

The produced remanent magnetism was found to possess a large component perpendicular to the one-directed pressure, resulting a great deviation of direction of remanent magnetization from that of an applied field. Since upon horizontally lying sediments, a one-directed and vertical pressure due to a gravity load of overlying strata might have acted, the above-mentioned difference should be called attention in the interpretation of Palaeomagnetic data, when rock sample contains such hematites that have been made from dehydration of ferrous hydroxide.

In the "Lectures on Rock Magnetism" written by BLACKETT¹⁾ the following arguments for the acquisition of remanent magnetism of sediments are very strongly emphasized: "*Ferrous carbonate ($Fe(HCO_3)$) is produced by the action of rain water on the iron-bearing silicates of igneous rocks. When the solution becomes less acid, ferric hydroxide is precipitated as a colloidal gel among the silica particles of a loose sandstone. On moderate drying, yellow ochre ($Fe_2O_3 \cdot H_2O$) is produced. When further dried and on moderate heating to over, say, 200°C, such as may occur on deep burial by overlying geological strata, the yellow and very weakly magnetic yellow ochre changes into hematite $\alpha(Fe_2O_3)$, which is moderately magnetic and red in colour when in small particles. Virtually nothing is known about the details of such processes of chemical magnetization.*"

The present writers were strongly attracted to his statements in that by the deep burial due to the overlying strata there might be produced the so-called vertically directed pressure which might have acted upon the sediments during

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and after the dehydration of the yellow ochre into α -hematite. The one-directed pressure thus produced might have rendered the direction of magnetization to be found in a horizontal plane due to the gravity load *in situ*.

In order to clarify whether or not this kind of effect plays in nature an important role upon the remanence, and how the chemical remanence may be affected

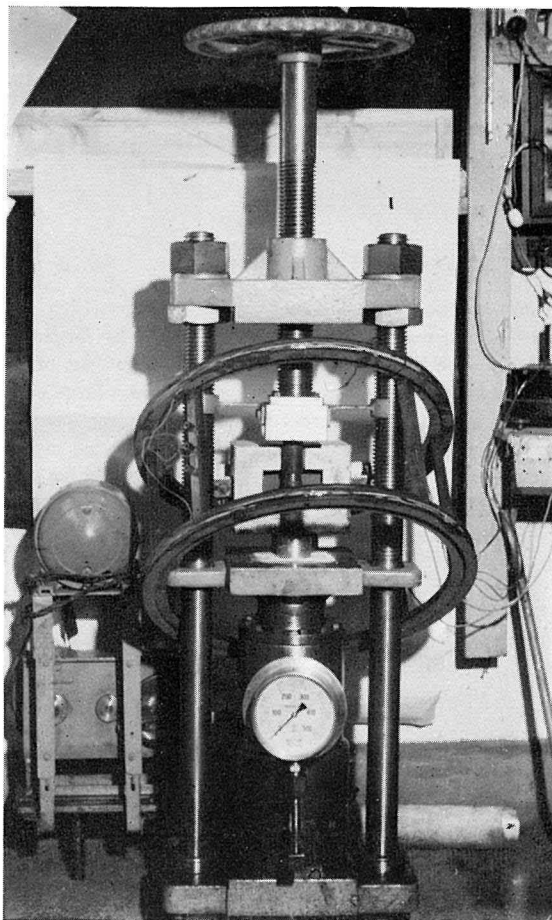


Fig. 1. Squeezer.

by the above-mentioned one-directed pressure, we have studied experimentally the effect of the dehydration upon the remanent magnetism by using göthite and lepidocrocite as test materials. All of the samples were squeezed by the apparatus as shown in Fig. 1 so that their dehydration may occur under the existence of vertical pressure.

Fig. 2 shows a non-magnetic vessel in which the chemical reaction took place, and Figs. 3 and 4 show the schematic diagram illustrating the experiments and the results.

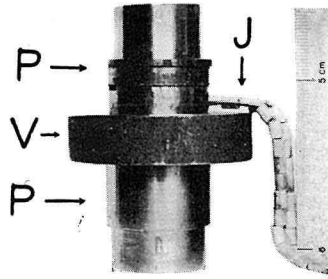


Fig. 2. The non-magnetic vessel in which the chemical and pressure remanences were made.

P: Piston V: Vessel J: Thermo-Junction

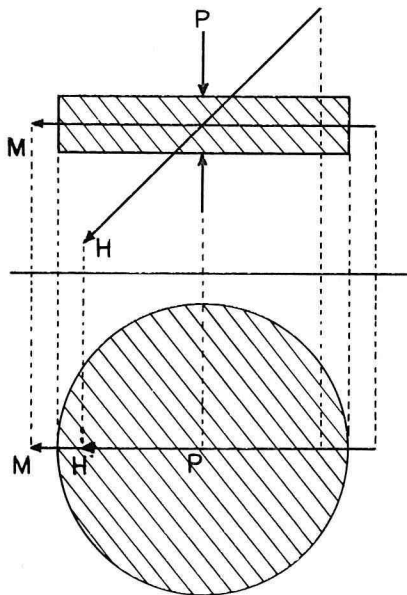


Fig. 3. The schematic diagram showing the interrelation between applied field, one-directed pressure and direction of obtained magnetization.

P : Pressure
M : Magnetization
H : Applied Field

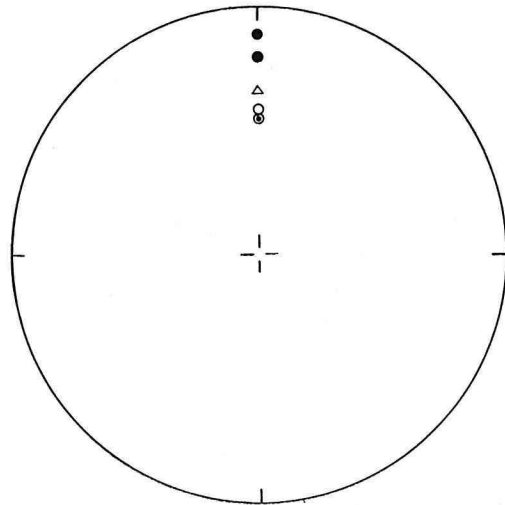


Fig. 4.

- Direction of remanent magnetism acquired by the process of dehydration of $\text{FeO}(\text{OH})$ to $\alpha\text{-Fe}_2\text{O}_3$ under the condition at 400°C and 2500 atm acting for 11 hours.
- Direction of remanent magnetism acquired by the process of dehydration of $\text{FeO}(\text{OH})$ to $\alpha\text{-Fe}_2\text{O}_3$ under the condition at 450°C and 1 atm acting for 11 hours.
- ⊙ Direction of the applied field of 10 Oe.
- △ Direction of remanent magnetism acquired by the process of dehydration of $\text{FeO}(\text{OH})$ to $\gamma\text{-Fe}_2\text{O}_3$ under the condition at 270°C and 2500 atm acting for 15 hours.

In Table I are tabulated the obtained remanent magnetism under various conditions. Both lepidocrocite and göthite were only sprinkled in a mass of alumina having a form of circular disk and the susceptibility of the specimen should be

Table I.

Chemical reaction	One-directed pressure	Dehydration temperature	Applied magnetic field		Obtained remanent magnetization (dip)	Duration of compression
			dip	intensity		
$2\text{FeO}(\text{OH}) \rightarrow \alpha\text{-Fe}_2\text{O}_3 + \text{H}_2\text{O}$	2500 atm	350-400°C	40°	10 Oe	22°	11 h
	2500 atm	400°C	40°	10 Oe	12°	11 h
	1 atm	450°C	45°	10 Oe	40°	11 h
$2\text{FeO}(\text{OH}) \rightarrow \gamma\text{-Fe}_2\text{O}_3 + \text{H}_2\text{O}$	2500 atm	270°C	40°	100 Oe	35°	15 h

considered to be very weak. Therefore, anisotropy in the demagnetizing affect can be ignored, and the results should be considered to have been caused by the one-directed pressure.

From the diagram and the table obtained from dehydration of göthite under 2500 atm, we can see that the dip angle of α -hematite is very small, despite of the large dip angle of the applied magnetic field. On the other hand, in the same specimen obtained under no directed pressure the deviation of the remanence from that of the applied field can hardly be found. Therefore, it is likely that the origin of the above-mentioned nearly horizontal magnetization lies in the dehydration which occurred under one-directed pressure (vertical).

As for γ -hematite obtained from dehydration of lepidocrocite, it can be inferred that the similar pressure effect as above observed with α -hematite has not taken place or has done only slightly.

We have experienced that complete dehydration under a high pressure requires an extremely long duration which has made our experiments so difficult. The data given in Table I are only four successful results of a series of experiments done for each condition.

The tendency of producing difference between the direction of the applied magnetic field and that of remanence is very remarkable, maximum deviation we have obtained being 22° under 2500 atm. This difference may become larger as the pressure upon the specimen is increased.

HAIGH²⁾, and NAGATA and KOBAYASHI³⁾ have proposed a mechanism by which a remanent magnetism can be induced in a rock by a chemical change of ferromagnetic crystals contained in it. The pressure they have referred to is 1 atm and not a high pressure. They called this kind of magnetization "chemical remanent magnetism or C. R. M."

Present authors would like to proposed to call the magnetization we obtained "chemical-pressure remanent magnetism or C. P. R. M."

KAWAI⁴⁾ and DOMEN⁵⁾ examined the effect of one-directed pressure upon acquisition of remanent magnetism of magnetite in case no chemical change took place during prolonged compression. They found a large magnetization which appears in a direction perpendicular to the pressure axis and considered this fact to be due to the positive magnetostriction coefficient of the sample coupled with the one-directed pressure. And they came to infer that an easy axis of magnetization appears in the plane of elongation and the magnetic domains in this plane increase with time. They called this magnetization "piezo-remanent magnetism or P.R.M."

In some sedimentary rocks α -hematites which have been derived from hydroxide or ferrous carbonate under a one-directed pressure are so common, and some metamorphic rocks contain specular-hematite or hematite-ilmenite solid solution, which has been formed at the time of recrystallization, at which time the one-directed pressure might have been greater. Thus, the phenomenon of the chemical-pressure effect seems to play an important role in nature.

Next, it may be plausible to assume that, even after the dehydration or recrystallization had been place, a one-directed pressure might have continued to act upon these derived ferrites to increase the P.R.M. with time and then magnetism superimposed to the C.P.R.M.. These two magnetization make the direction of magnetization of these rocks to be found more sensitive to the gravity field or the deviatoric geological pressure than to the geomagnetic field. YASKAWA⁶⁾ found in metamorphic rocks an extreme magnetization whose direction is nearly parallel to the schistosity plane of metamorphism.

The above-mentioned factors should be taken into account in the interpretation of palaeomagnetic investigations.

Acknowledgments

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References

- 1) P. M. S. BLACKETT: "Lectures on Rock Magnetism", 12, Weizmann Science Press, Jerusalem, (1956).
- 2) G. HAIGH: *Phil. Mag.*, **3**, 267, (1958).
- 3) T. NAGATA and K. KOBAYASHI: *Proc. Japan Acad.*, **34**, 269, (1958).
- 4) N. KAWAI: *Jour. Geomag. Geoele.*, **9**, 140, (1957).
- 5) H. DOMEN: *Bull. Fac. Education, Yamaguchi Univ.*, **7**, 41, (1958).
- 6) K. YASKAWA: *Mem. Coll. Sci., Univ. Kyoto, Series B*, **26**, 225, (1959).