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Effect of Hydrostatic Pressure on Isothermal Remanent Magnetization of Rocks

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Abstract—The effect of hydrostatic pressure (up to 1.3 GPa) on the isothermal remanent magnetization of rocks is studied experimentally using a new-type nonmagnetic high-pressure cell produced at the Institute of High-Pressure Physics (Troitsk, Moscow oblast). The experiments were carried out at the European Center for Research and Education in Environmental Geoscience (CEREGE), France.

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INTRODUCTION

Direct measurements of the geomagnetic field of the Earth have been started as early as 400 years ago. The whole history of the geomagnetic field was reconstructed with the paleomagnetic method, which provides information about the ancient geomagnetic field on the basis of natural remanent magnetization of ancient rocks of different geologic age [1]. As is known, deep rocks are subjected to a quasi-hydrostatic pressure, which may significantly change their magnetic properties in situ, including natural remanent magnetization. Therefore, a paleomagnetic signal from ancient rocks cannot be correctly interpreted without taking into account the effect of hydrostatic pressure on their magnetic properties [2]. Below, we report on the results of studying this effect in laboratory conditions.

EXPERIMENTAL METHOD AND SETUP

A series of experiments was performed to study the effect of hydrostatic pressure (up to 1.3 GPa) on the saturation isothermal remanent magnetization of rocks. A new-type nonmagnetic composite cell for high hydrostatic pressure was produced from titanium and nickel–chromium–aluminum alloys at the Institute of High-Pressure Physics, Russian Academy of Sciences (Troitsk), on demand of the Faculty of Physics, Moscow State University. The remanent magnetic moment of the pressure chamber amounted to 3×10^{-8} A m^2, which is by two or three orders of magnitude lower than the measured saturation remanent magnetic moment of the rock samples under study (on the order of 10^{-6}–10^{-5} A m^2 for samples mass in the 0.2–0.4 g range). Therefore, the cell can be considered as nonmagnetic here. All the experiments were conducted at the European Center for Research and Education in Environmental Geoscience (CEREGE), France.

The high-pressure cell used in the experiments is shown in Fig. 1. An inertial polyethylsiloxane fluid was used as a medium transmitting hydrostatic pressure.

The experiments were performed according to the following scheme. First, the sample to be studied was magnetized up to saturation by the application of a pulse magnetic field with strength $B = 3$ T at room temperature, i.e., the isothermal remanent magnetization was produced. Then, the sample was placed into the pressure cell into a Teflon ampoule with a pressure-transmitting medium; the chamber with the sample inside was set under the Eurolabo–Graseby Specac 15011 press, which can exert an effort of up to 15 t; and pressure p_1 was produced. The pressure in the working cell was fixed by retention screws *2* and *14* (see Fig. 1). Then, the cell with the sample was removed from the press and placed into a 2G Enterprises DC SQUID magnetometer for room-temperature measurement of the remanent magnetic moment of the sample in the conditions of hydrostatic pressure p_1. Next, a higher pressure $p_2 > p_1$ was produced and the remanent magnetic moment under the pressure p_2 was measured again and so on until the pressure reached the maximum value of 1.3 GPa.

The SQUID magnetometer used in the experiments allowed magnetic moments of up to 10^{-4} A m^2 to be measured accurately to within 10^{-11} A m^2.

The pressure chamber was calibrated with the use of a high-pressure manganin sensor. The friction losses were approximated at 10%.

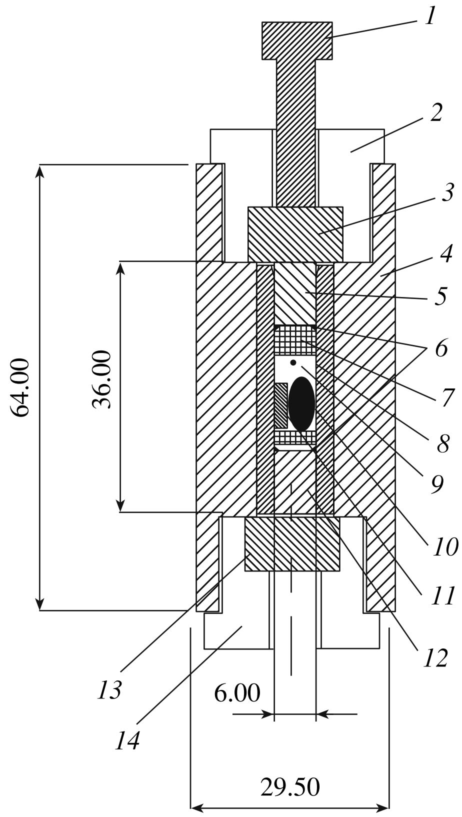

Fig. 1. Scheme of nonmagnetic high-pressure cell: (*1*) external piston, (*2*) upper retention screw, (*3*) bearing, (*4*) cell's body, (*5*) internal piston, (*6*) antiextrusion rings, (*7*) Teflon plug, (*8*) Teflon cavity, (*9*) pressure-transmitting fluid (PES-1), (*10*) sample, (*11*) Teflon spiral to keep sample fixed, (*12*) internal piston, (*13*) bearing, and (*14*) lower retention screw. The dimensions are given in mm.

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 represents the pressure dependence of normalized isothermal remanent magnetization IRM(p)/IRM_s of the rock samples, where IRM_s is the saturation remanent magnetization.

Curve *1* corresponds to the sample of quartzitic microdiorite from the southeast shore of France, with its remanent coercive force B_{cr} = 19.1 mT; curve *2*, to alkaline basalt (France) with B_{cr} = 14.3 mT; and curve *3*, to the sample of rhyolite pyroclastic rock from the Southeastern coast of France, B_{cr} = 406 mT. The main magnetic carriers in the above samples are magnetite, titanomagnetite, and hematite, respectively.

As is seen from Fig. 2, the remanent magnetization of the rock samples decreases with the growth of the applied pressure. It should be noted, however, that the resistance of the remanent magnetization against hydrostatic pressure is not a direct function of magnetic hardness B_{cr} but strongly depends on the sample's mineralogy. For example, B_{cr} of the microdiorite sample is larger than that of the basalt sample, but at p = 1.3 GPa, the former loses more than 80% of its initial magnetization. This is by more than 30% larger than the demagnetization value for the basalt sample.

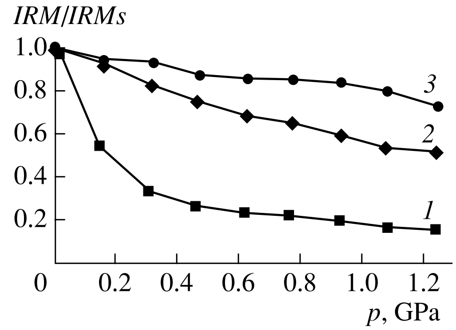

Fig. 2. Normalized isothermal remanent magnetization IRM/IRM_s vs. the applied pressure for the samples of (*1*) quartzitic microdiorite (magnetite), (*2*) alkali basalt (titanomagnetite), and (*3*) rhyolite pyroclastic (hematite). IRM_s is the saturation isothermal remanent magnetization.

CONCLUSIONS

The behavior of the isothermal remanent magnetization of rocks containing magnetite, titanomagnetite, and hematite under hydrostatic pressure p is studied. It is found that, at p = 1.3 GPa, the samples can lose more than 80% of the initial remanent magnetization. It is important to note that no one-to-one correspondence between the remanent coercive force, which characterizes the magnetic hardness of the samples, and the pressure-induced demagnetization is observed. This fact suggests that demagnetization value depends mostly on the mineralogy of samples and not only on their magnetic hardness.

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