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The Change of Isothermal Saturation Remanent Magnetization of Basalts as a Result of Cyclic Elastic Deformation

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Abstract. The effect of uni-axial cyclic elastic compression with a constant stress amplitude on the isothermal saturation remanent magnetization of basalts, containing generalized titano-magnetites, was studied. The largest irreversible changes are generated during the first elastic deformations, however, also the subsequent deformation cycles result in a decrease of the remanent magnetization. For the higher values of the cycles ($n > 3$) the linear dependence of the irreversible changes of the remanent magnetization on $\sqrt{\log n}$ is well satisfied. The experimental results are analogous to the results of the cyclic asymmetric overmagnetizing of ferromagnetic substances which are explained by Néel's theory of the reptation effect.

Key words: Rock magnetism – Stress demagnetization – Cyclic elastic deformation.

1. Introduction

As a result of external mechanical stresses the magnetic properties of magnetic minerals and rocks change considerably (*e.g.* Nagata, 1970; Nagata and Carleton, 1968; Ohnaka and Kinoshita, 1968). In a previous paper (Kapička, 1975a) the irreversible changes of the remanent magnetization of some basalts as a result of increasing uni-axial elastic compression were studied, and it was shown that the remanent magnetization varies in a characteristic manner. Fig. 1 shows this dependence for the saturation remanent magnetization as the initial state, measured after unloading. If the initial state is different, the dependence of the irreversible changes of the remanent magnetization on mechanical stress changes qualitatively and quantitatively.

The results of some experiments (Carmichael, 1968; Kapička, 1975b) indicate that if the elastic deformation is repeated under the same stress, a further irreversible change of the remanent magnetization occurs. However, no system-

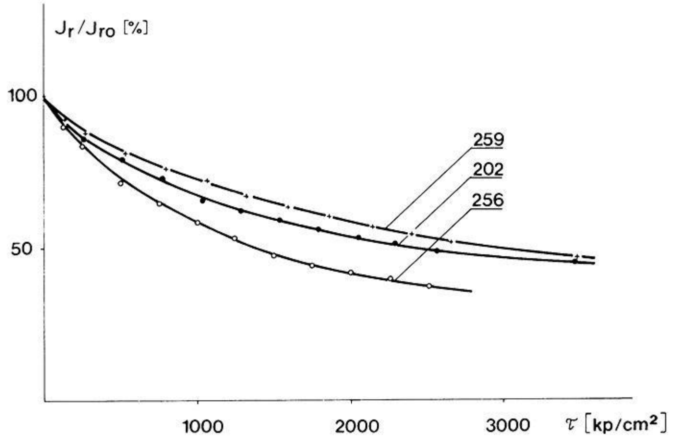

Fig. 1. The normalized remanent magnetization measured after unloading (J_r/J_{ro}) as a function of stress (τ) for the basalts (with sample numbers indicated) under investigation. The initial state of the samples is saturation remanent magnetization

atic observations of this kind with a larger number of deformation cycles have been made nor discussed so far. However, the results of studying the effect of short-term periodic shocks on the remanent magnetization of basalts and magnetite (Shapiro and Ivanov, 1967; Nagata, 1971; Pohl *et al.*, 1975) imply that the overall irreversible change of the remanent magnetization depends on the number and strengh of the mechanical shocks.

The purpose of the present paper is to study the effect of the cyclic uni-axial elastic compression with constant stress amplitude on the remanent magnetization of basalts. The experimental results obtained are compared with some dynamic experiments.

2. Samples and Experimental Procedure

The measurements were taken on basalt samples from the Bohemian Massif, which contain as the magnetic fraction generalized titano-magnetites of different chemical composition (Kropáček and Pokorná, 1974). The volume concentration of the titano-magnetites in the samples was as follows: 13.5% (sample no. 202), 7.8% (256) and 9.1% (259). The granularity of the magnetic fraction: 0.003–0.04 mm (202), 0.01–0.1 mm (256), 0.015–0.05 mm (259). The specific saturation remanent magnetization amounted to 180×10^{-3} Gcm^3/g (202), 197×10^{-3} Gcm^3/g (256) and 99×10^{-3} Gcm^3/g (259). For the purpose of measurement the samples were worked into the shape of a cube with 2 cm sides and their surfaces were ground plane parallel.

The interval of elastic stress deformations of the individual samples was read off the stress-strain curves, obtained with the aid of an electronic deformation machine. The elastic deformation by uni-axial stress was effected in a hydraulic press, between the clams of which and the surface of the samples ground plates of titanium were inserted. The stress direction was parallel to the direction of the remanent magnetization. The rate-of-stress increase in all experiments was approximately constant at 80 kpcm$^{-2}s^{-1}$. The remanent magnetization was measured by an astatic magnetometer. The samples were magneti-

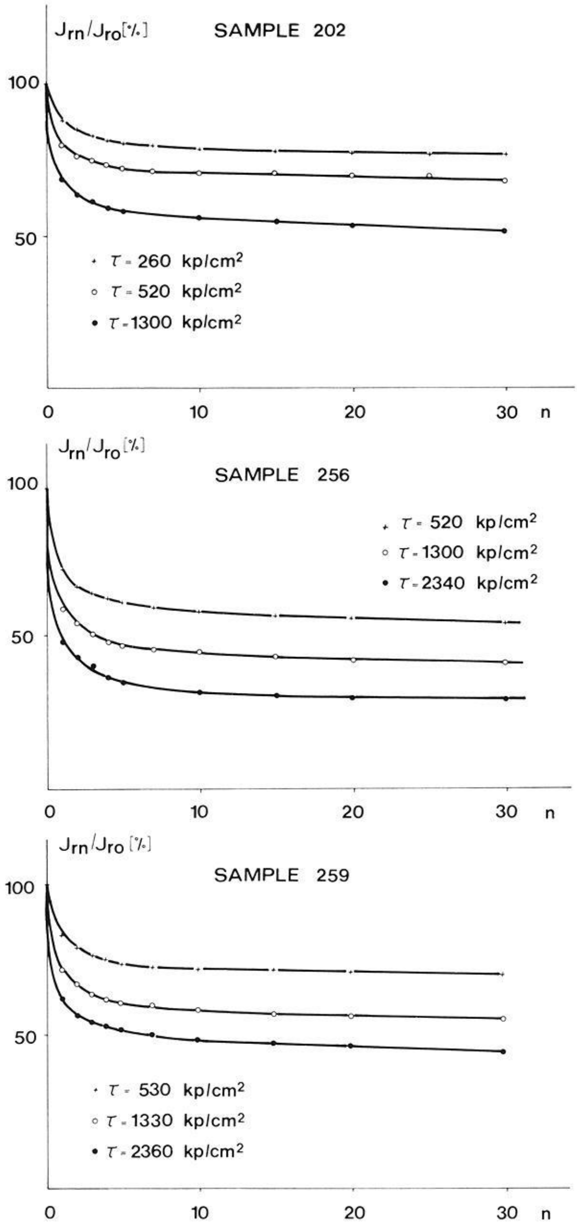

Fig. 2. The normalized saturation remanent magnetization (J_{rn}/J_{ro}) as a function of the number of deformation cycles (n) for various values of the stress

cally saturated with the aid of an electromagnet and their remanent magnetization (J_{ro}) measured. They were then cyclically deformed ($n_{max}=30$) by the chosen stress and, after the individual deformation cycles (n), the remanent magnetization (J_{rn}) was measured in unloaded state. All these measured values were normalized relative to the initial state of the sample. The values of the deformation stress were chosen uniformly within the elastic regions of deformation of the individual samples and ranged from 260 to 2360 kp/cm^2.

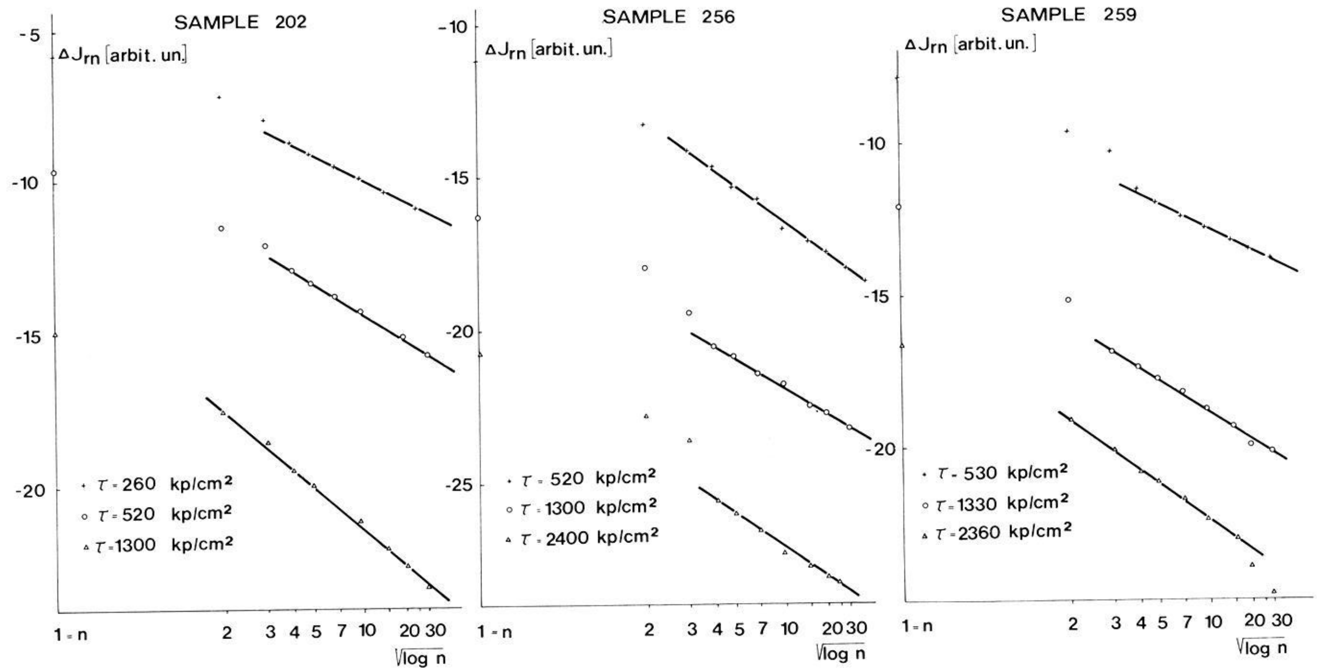

Fig. 3. The changes of the saturation remanent magnetization ΔJ_{rn} as a function of $\sqrt{\log n}$ for various deformation stresses

The observed patterns indicate that the process of cyclic elastic loading of the samples with constant stress results in a gradual irreversible decrease of the saturation remanent magnetization, the pattern of these changes being the same qualitatively for all the basalt samples investigated, as well as for all the values of the stress. The largest decrease of the remanent magnetization occured during the first elastic deformation. Larger changes were also observed in a few subsequent cycles, which agrees well with the dynamic experiments (*e.g.*, Pohl *et al.*, 1975). With increasing n the magnitude of the changes decreases. However, even at the maximum number of deformation cycles ($n=30$) the remanent magnetization displayed a measurable change. The magnitude of the overall decrease is proportional to the magnitude of the applied stress, and the quantitative differences between the individual types of basalts correspond to the observed dependences of the irreversible changes of the remanent magnetization on stress (Fig. 1).

The dependence of the decrease of the remanent magnetization ΔJ_{rn} on $\sqrt{\log n}$, where n is the number of cycles, is plotted in Fig. 3. The change of the remanent magnetization is given as $\Delta J_{rn}=J_{rn}-J_{ro}$, where J_{rn} is the magnitude of the remanent magnetization after the n-th deformation cycle, and J_{ro} is the initial remanent magnetization of the sample. These dependences indicate that a linear relation of ΔJ_{rn} on $\sqrt{\log n}$ is satisfied for higher values of n (in general for $n>3$) for all basalt samples investigated as well as for all applied stresses. The systematic deviation for sample 259 at a stress of $\tau=2{,}360$ kp/cm^2, which is at the limit of elastic deformations, is probably caused for a large number of cycles by the fact that the deformation was no longer purely elastic and that the sample was subject to a slight permanent deformation. The linear dependence of the irreversible changes of the remanent magnetization on $\sqrt{\log n}$ observed for higher values of n, agrees with the paper of Daniel-Szabó and Potocký (1969), in which the effect of the cyclic tensile elastic deformation on the remanent magnetization of metal ferromagnetic samples was studied.

4. Discussion

The experimental results indicate that gradual irreversible changes of the saturation remanent magnetization of basalts occur under cyclic elastic deformation (Fig. 2). The largest decrease is associated with the first elastic deformations. However, also the subsequent deformation cycles result in a slight irreversible decrease of the remanent magnetization. The differences between the individual types of basalts are only in the magnitude of the overall changes of the remanent magnetization. In analysing the dependence of the changes of the remanent magnetization (ΔJ_{rn}) on the number of deformation cycles (n) it comes out that for a higher number of cycles ($n>3$) the linear relation

$$\Delta J_{rn}=K_1-K_2\sqrt{\log n},$$

where K_1 and K_2 are constants, dependent on the magnitude of the stress applied and on the properties of the samples investigated, is satisfied. It can also be seen that this dependence is relatively complicated for small values of n.

The experimental results obtained are analogous to the results of cyclic asymmetric overmagnetizing of ferromagnetic samples between two constant values of the magnetic field H_a and H_b, $H_b \neq -H_a$ (*e.g.*, Dang, 1964; Hajko *et al.*, 1962). According to Néel's phenomenological theory the so-called reptation and bascule-negative effects are responsible for the irreversible changes which occur under cyclic overmagnetizing (Néel, 1957, 1958). The former results in the same $\sqrt{\log n}$ proportional changes of the remanent magnetization at both ends of the overmagnetizing curve, the latter takes effect only in several initial cycles and results in the rotation of the overmagnetization curve. Since our measurements of the changes of the remanent magnetization due to cyclic deformation were only carried out in an unloaded state, which analogously only corresponds to one value of the magnetic field (one usually adopts $H_b=0$), one cannot analyse the pattern of the changes of the remanent magnetization for small values of n according to the analogy mentioned above. However, the dependence found for the higher values of n (Fig. 3) is analogous to the reptation effect.

The direct observations of the domain structure of metal ferromagnetic materials indicate that irreversible motions of the domain walls occur under cyclic asymmetric overmagnetizing (Gengnagel *et al.*, 1962), the magnitude of these changes being proportional to the concentration of the structural defects in the samples. Irreversible changes of the domain structure also occur during cyclic elastic deformations of ferromagnetic samples (Trenkler *et al.*, 1972). These changes are analogous in both cases, because the repeated cycles cause the motion of at least part of the various domain walls, some of which have a tendency to stabilize their position.

The irreversible changes of the domain structure of magnetic minerals, contained in rocks, under elastic deformations can be explained by the change of the internal mechanical microstructure of these minerals (Carmichael, 1968). This change, caused by the external mechanical stress, is mostly associated with the motion of existing structural dislocations. Since the magnitude of the remanent magnetization is a function of n under cyclic elastic deformation, as implied by our experiments, the configuration of the domain walls must differ after the repeated application of the same external stress from that one following the previous deformation cycle. It is probable due to the reversible motion os some structural dislocations (Kapička, 1975b).

The qualitative pattern of the changes of the remanent magnetization under cyclic elastic deformation (Fig. 2) is similar to the results of the demagnetization of basalts due to repeated mechanical chocks (*e.g.*, Pohl *et al.*, 1975). It seems, therefore, that the effect of the cyclic uni-axial elastic compression and the effect of repeated short-term shocks on the remanent magnetization of rocks are closely associated.

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