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MAGNETIC INTERACTION IN SELF-REVERSING ANDESITIC PUMICE IN RELATION TO IRON ALLOYS

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Abstract. – Andesitic pumice erupted in 1985 from Nevado del Ruiz volcano (Colombia) has been magnetized in opposite direction to the present geomagnetic field. This self-reversal is probably due to an exchange mechanism between two phases of the haematite-ilmenite series, which is similar to the magnetic coupling observed in synthetically grown antiferromagnetic-ferromagnetic FeMn-FeNi films produced under ultra high vacuum conditions.

One of the fundamental principles of palaeomagnetism and rock magnetism states that a rock specimen – when cooled in the earth’s magnetic field – will acquire a natural remanent magnetization (NRM) which is usually parallel to the applied field. However, the NRM of andesitic pumice emitted during the 1985 eruption of Nevado del Ruiz volcano (Colombia) shows a direction opposite of the present geomagnetic field [1]. For the first time these rocks present firm evidence that a self-reversal process actually has controlled the acquisition of NMR.

The self-reversing properties are demonstrated in the laboratory during repeated cycles of heating (up to 165 °C) and subsequent cooling (to room temperature) in air and zero magnetic field, see figure 1. The reversal from negative to positive polarity near 130 °C upon heating and from positive back to negative polarity on cooling can be clearly seen. From the reversibility of the NMR behaviour during heat treatment and from additional strong field magnetization measurements it is concluded that the magnetic phases are stable up to at least 700 °C.

Self-reversing remanent magnetization was first discovered in dacitic rocks from Japan by Nagata [2] and co-workers [3-5]. Two major interaction models leading to self-reversing properties have been proposed [6, 7]; firstly Néel’s N-type with two sublattices in a one phase model, and secondly different types of two phase models with magnetostatic (i.e. dipole-dipole) or (super)exchange interaction. The energies involved in these interactions are usually assumed to be different by orders of magnitude.

Estimates of the interaction energy may be obtained from the applied field amplitude needed to suppress the self-reversing mechanism. This was achieved by thermoremanent magnetization measurements, which simulate the natural magnetization process between the maximum Curie temperatures measured in the samples (ca 400 °C) and room temperature in magnetic DC fields of increasing amplitude.

Figure 2 shows that the critical field necessary to completely suppress self-reversal is very weak, about 10⁸ A/m. This low field value excludes the N-type model which requires an exchange interaction field strength of the order of 10⁶ A/m. Therefore a two phase model only is capable of explaining the self-reversing phenomenon.

Ore microscopy and microprobe analysis reveal the presence of magnetic grains of the haematite-ilmenite series with an average composition of Fe₁.₃₈Ti₀.₆₂O₃. In some of these, lamellae structures have been observed, but their composition cannot be identified be-
cause of small size (< 1 μm). We ascribe these structures to a second phase of the same solid solution series. Earlier findings suggest that during cooling a chemical disorder-order transition leads to a microstructure consisting of two phases with different titanium content [3-5].

The self-reversing mechanism is then induced by cooling through the higher Curie point of the Ti-poorer haemoilmenite phase with low saturation magnetization (M_s) but high coercive force (H_c). This phase then induces an antiparallel magnetic ordering to the ferrimagnetic, Ti-richer haemoilmenite with high M_s but low H_c, which leads to a net negative magnetization, when the temperature drops below its lower Curie temperature.

Whether this antiparallel coupling is due to the magnetization of the Ti-rich haemoilmenite in the demagnetizing field of the Ti-poor haemoilmenite or due to an exchange field between the Ti-poor canted antiferromagnet and the Ti-rich ferrimagnet, cannot be decided. One could object that the weak critical field needed to suppress the self-reversing mechanism is in contradiction to strong fields usually needed to overwhelm an exchange field.

The same problem, however, exists for synthetically grown pure antiferromagnetic-ferrimagnetic FeMn-FeNi films produced under ultra high vacuum conditions where a magnetostatic interaction can be excluded [8]. Nevertheless the measured “exchange bias” field – which is identical to our “critical” field to suppress the self-reversing mechanism – is only of the order of 10^3 – 10^4 A/m [7], much less than typical exchange fields.

The discrepancy can be solved by a domain wall model [9, 10]. The strong exchange interaction between the two phases is not influenced by the small external field. Domain wall creation and movement, however, is readily achieved by fields of the order of 10^3 A/m. Therefore we explain the results of figure 2 by the creation of a domain in the ferrimagnetic phase whose magnetization is parallel to the external field. With increasing applied field, the domain with parallel magnetization grows at the cost of the domain which is locked antiparallel by the exchange coupling across the boundary of the two phases. This finally leads to a change in polarity of the magnetization and further increase of the net positive magnetization with higher applied fields.

Therefore, in analogy to the FeMn-FeNi system, the self-reversing mechanism in the Nevado del Ruiz andesitic pumice can easily be explained by an exchange interaction between two haemoilmenite phases in combination with a domain model.

Moreover, magnetostatic coupling is known to work only under very special and strictly kept boundary conditions; we propose an exchange rather than dipole coupling.

It could be interesting to investigate the self-reversing mechanism in samples with single domain phases where no domain walls can be built. We expect a strong enhancement of the critical field.

Fig. 2. – Thermoremanent magnetization M vs. applied magnetic DC field H. The experiment was performed by numerous cycles of heating to 400 °C, cooling in an increasing applied field to room temperature, and measuring the remanent magnetization. Critical field to suppress self-reversal: H_{crit} = 10^3 A/m (≈ 12 Oe).

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