Selection of Basalts for Paleointensity Studies

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The selection of basalt samples for the determination of paleointensity, proposed by SENANAYAKE et al. (1982) based mainly on the low-temperature susceptibility variation, may not be adequate for the purpose. Besides the Type 2 basalts in their classification, the magnetic mineral Fe$_{2.9}$Ti$_{0.1}$O$_4$ (TM10), which occurs commonly in basalts, also shows an increase in the susceptibility at low temperatures. It is shown that these two could be distinguished from each other by using an extra criterion like coercive force or Curie temperature and the TM10 bearing basalts, not quite suitable for paleointensity measurements, could be separated.

1. Introduction

Paleointensity methods involving repeated heatings of the rock samples, such as the one by THELLIER and THELLIER (1959) assume that the sample under consideration consists of only one magnetic mineral phase and it does not change due to the heating. Even for using the methods requiring only one heating like the one proposed by BANERJEE and MELLEMA (1974), it would be preferable if the sample consists of one size of single-domain grains of one mineral phase. From the extensive studies made on basalts of different ages, it has been shown that mixed mineral phases and domain states occur commonly in basalts (RADHAKRISHNAMURTY et al., 1981). However, simple schemes of classification of basalts are useful for wider studies, and one such with four types of states was proposed by RADHAKRISHNAMURTY et al. (1977) but it was later expanded for the identification of different members of the titanomagnetite series and their domain states (RADHAKRISHNAMURTY et al., 1981). A different classification suggested by SENANAYAKE and MCELHINNY (1981), was based on three types of samples and it did not deal with any implications arising from mixed compositions or domain states of the grains in the rocks. One of the main objectives of this scheme (SENANAYAKE and MCELHINNY, 1982) was to select basalt samples for the purpose of paleointensity determination and even in this respect there could be some confusion because two entirely different mineral phases, one suitable and the other not quite so suitable, obey the selection criterion. The purpose of this paper is to clear away the ambiguity.

2. Variation of Susceptibility with Temperature

The low temperature variation of susceptibility of basalts was extensively used first by RADHAKRISHNAMURTY et al. (1977) to understand the nature of the magnetic grains in different samples. Subsequently, a comparative study of the properties of
synthetic titanomagnetites and basalts, together with a suggestion on the possible inherent formation tendencies of the various mineral phases, was reported (RADHAKRISHNAMURTY et al., 1981). It was noticed during this investigation that the mineral $\text{Fe}_{2.9}\text{Ti}_{0.1}\text{O}_4$ (TM10), and an oxidized state of magnetite, referred as cation deficient (CD) magnetite, show an increase in their respective susceptibility values at low temperatures. But the Curie point ($T_c$) and coercive force ($H_c$) of TM10 were found to be less than the respective values of CD magnetite and these features could be used to distinguish between these two minerals. The classification scheme of SENANAYAKE and MCELHINNY (1981) did not envisage the similarity in the variation of susceptibility of TM10 and CD and hence could lump them together inadvertently. Nevertheless, it is imperative to distinguish between these two mineral phases for the magnetic granulometry studies of basalts.

The properties of TM10 and CD are illustrated schematically in Fig. 1. For TM10 the susceptibility at 77 K is 1.3 times that at 300 K and its $T_c$ is about 813 K; the coercive force and the relative remanence (ratio of remanence to saturation magnetic moment, $M_r/M_s$) are 10 mT and 0.15 respectively. These parameters determined for synthetic TM10 correspond very well to those obtained for basalts inferred to contain

![Fig. 1. Schematic diagrams illustrating the variation of susceptibility with temperature and hysteresis loops for titanomagnetite (TM10–Fe$_{2.9}$Ti$_{0.1}$O$_4$) and cation deficient (CD) magnetite.](image-url)
Selection of Basalts for Paleointensity Studies

1367

a single phase of this mineral. Before the magnetic properties of TM10 were clearly known, it was discovered that some basalt samples showed a decrease in their $H_c$ at low temperatures and these were inferred, though indirectly, to contain cation deficient magnetite grains (Radhakrishnamurty et al., 1971). Further studies indicated that this mineral phase occurs commonly in basalts; occasionally as a single component but more often in association with other phases (Radhakrishnamurty and Deutsch, 1974). For several years after the first observations, it was presumed that the CD, with some variation in composition and domain state, could have $T_c$ in the range 793 to 913 K and $H_c$ from 7.5 to 50 mT. But the critical studies made by Radhakrishnamurty et al. (1981) enabled the separation of TM10, which was hitherto grouped with CD, and the properties of the latter became evident. As depicted in Figs. 1(c) and 1(d), for the CD phase the increase in susceptibility at 77 K is 1.5 times that at 300 K, $T_c$ can be in the range 843 to 913 K, $H_c$ is from 40 to 50 mT and $M_r/M_s$ will be close to 0.5. These parameters indicate that there could be some little variation in the composition of CD, possibly due to some titanium or other cations in solid solution, but the magnetic state will most probably be single-domain, as can be surmised from the large values of $M_r/M_s$ and $H_c$. The CD phase differs in behaviour from that of single-domain magnetite in that the latter will show a decrease in susceptibility at low temperatures (Radhakrishnamurty et al., 1981).

3. Discussion

It was from critical, but indirect, studies carried out on some rare basalts showing a decrease in $H_c$, and hence an increase in susceptibility, at low temperatures, the inference that these samples contained an oxidized phase of single-domain magnetite was arrived at (Radhakrishnamurty et al., 1971, 1978). However, Senanayake and McElhinny (1981) surmised from microscopic observations that such properties for basalts could have their origin in the titanomagnetite grains with exsolved ilmenite lamelle, the effective grains possibly behaving like elongated single-domain magnetite grains. Whatever might be the actual reason for the peculiar behaviour of these CD grains, the basalts containing them do suit well for paleomagnetic and paleointensity studies. However, it should be emphasised here that basalts containing only pure CD grains are rare but in composite form with other types of grains their prevalence is more common. The frequent association of CD with multidomain magnetite grains in basalts, which can easily be identified by a superposition of a peak over an increasing susceptibility at low temperatures, indicates that the single-domain fraction of the original magnetite grains might have been oxidized to CD, leaving the multidomain portion in tact. As matter of fact, the Type 3 basalts in the classification scheme put forth by Senanayake and McElhinny (1981, 1982) belong to the mixed (CD + MD) category and these authors never acknowledged the existence of the pure states of these two types of grains, even though their individual characteristics have been well documented (Radhakrishnamurty et al., 1977, 1978). Also, it was observed that the behaviour of the CD grains can change irreversibly in some samples if heated to temperatures close to 893 K (Radhakrishnamurty et al., 1971, 1978). Hence it is suggested that basalts with predominantly CD grains may be selected for paleointensity studies using one extra criterion like $H_c$ or $T_c$, in addition to the increase in susceptibility at low temperatures. Moreover, if such samples are heated to
temperatures close to 893 K, it would be better to ascertain that no change had taken place due to the heating.

There have been some attempts by COE and GROMME (1973), KONO (1978) and SENANAYAKE et al. (1982) to compare the different methods of determining the paleointensity. However, only SENANAYAKE et al. (1982) preselected the samples using the criterion of an increase in susceptibility at low temperatures, which assured them that all such samples to have a $T_c$ greater than 793 K. Nevertheless, even these samples would have contained grains of either pure CD or pure TM10 or a mixture of these two types. Since basalts with pure CD or TM10 grains are rare in nature, many of the samples selected might have contained a mixture of the two. The standard errors of 10% observed by Senanayake et al. as between sample-values within a site might have had a dependence on the mixed grain nature of the samples used by them.

REFERENCES


