An intricate magnetization of volcanics containing the Ti-rich titanomagnetites: Problematic application of the Thellier method

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A b s t r a c t : The results have shown that the basalts with Ti-rich Ti-Mt-es do not possess the magnetically stable component to determine the paleointensity. The Ti-rich titanomagnetites behave dominantly as small magnetic particles, very close to superparamagnetic state. These magnetic minerals do not have thermodynamically stable domain structures. The exchange coupling state dominates over all other interaction mechanisms in small magnetic particles in the Ti-rich Ti-Mt bearing rocks. So, the flower state and the vortex state are dominant magnetization processes in these type of Ti-Mt bearing rocks.
On the other hand, if there are rocks with un altered Fe-Ti magnetic minerals with Fe-rich Ti-Mt-es with well-developed domain structures, the magnetization by the irreversible domain wall movement is actual and so, there is a good magnetic and paleomagnetic stability of RM and there is a chance to derive the corresponding paleointensity of the rocks.

Key words: Ti-rich titanomagnetite bearing basalts, Fe-rich Ti-Mt bearing young altered biotite hornblende pyroxene andesites, paleointensity

1. Introduction

In a paleomagnetic investigation a stable remanent magnetization (RM) of rocks has played a dominant role in any interpretation. In volcanic rocks, the thermoremanent magnetization (TRM) is of dominant importance. An important characteristic for an enrichment of paleomagnetic results of rocks is their paleointensity. Commonly the Thellier method has been applied to determine the latter characteristic. In the recent time, the paleointensity of the volcanic lava flows of the age 22 to 165 ka from the San Quintin

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from the Baja California were studied by *Böhnel and Dekkers (2006).* The authors applied the microwave method to induce the partial thermoremanent magnetization (PTRM) in the samples and they compared it with the results obtained by the multispecimen parallel differential PTRM paleointensity method. The authors demonstrated the enormous importance of thermal alterations of magnetic minerals affecting the paleointensity of volcanics even at very low temperatures. According to *Dekkers and Böhnel (2006)* a *multispecimen parallel differential pTRM method* has been developed to provide the absolute paleointensity independent of magnetic domain state. Despite of this presented certainty I would like to show the complicated picture of magnetization of several basaltic samples with a presence of the titanomagnetites of different magnetic state. Is there any possibility to determine the paleointensity of basaltic rocks which contain the Ti-rich titanomagnetites of different magnetic state, grain size, and domain state? To meet the basic criteria for the application of the Thellier method, the rocks must contain magnetic single domain particles, the natural remanent magnetization must be of thermoremanent (TRM) origin and no chemical changes of original magnetic materials are allowed to be actual during the thermal treatment of the rock sample. The theory of the magnetization of both, single-domain and the multi-domain grains has been presented in many scientific journals and books (for example in *Stacey and Banerjee, 1974,* or in *McElhinny and McFaden, 2000*). Majority of specialists have not commonly verified the validity or adequacy of the theory, despite of are very serious discrepancies with respect to magnetic properties of magnetic Fe-Ti oxides which are dominantly present in volcanics. So, the theory has been applied mostly without any corrections, and unfortunately, the results, because not precisely analyzed, have often lead to ambiguous interpretations.

This article has presented the interpretation of the results of laboratory magnetization of the selected young andesitic rock from Kammeno Chorio from Methana Peninsula from Greece and of basaltic rock from Brehy locality from Slovakia - Western Carpathians.

2. Experimental works and basic results

The two investigated samples come from the following localities: the biotite hornblende-pyroxene andesite of the extrusive body of the Kammeno Chorio from Methana Peninsula from Greece (($\varphi_L = 37.618°$; $\lambda_L = 23.332°$; the extrusive body erupted around 2250 years ago, according to *Orlický (1980)*). This andesite contains dominantly the Fe-rich titanomagnetite, with the Curie temperature closely over 520° C (FeO=88.97, TiO_2=5.41 on the basis of microprobe analysis). The rock sample is of very high magnetic and paleomagnetic stability, probably with very well developed thermodynamically stable domain structure).

The second sample - nepheline basanite of the lava flow-comes from the Brehy locality (($\varphi_L = 48.410°$; $\lambda_L = 18.650°$; the effusive body arose in the interval 0.13 to 0.16 Ma, according to geomorphologic position of terrace sediments, Konečný in *Orlický (2004)*). This nepheline basanite contains the Ti-rich titanomagnetites (Ti-Mt) of the dominant Curie temperature around 250°C, dominantly of the paramagnetic magnetic state. There is also more oxidized magnetic phase with the Curie temperature around of 550°C in Ti-rich Ti-Mt-es present. The previous results have proven a superparamagnetic-like (SP) behaviour of small magnetic particles in these nepheline basanites. It means that there is a lack of classical domain structures in Ti-rich Ti-Mt-es. The small magnetic particles are rather exchange coupled in dominant portion of the nepheline basanite body. Magnetic domains are not a universal feature of magnetic materials. Small, including the SP particles contain no domain pattern even if they are commonly called single-domain particles. *In low-anisotropy materials there is an intermediate range in which continuous micromagnetic vortex state prevails.* We need to comment that the principal problem in small particle magnets is their orientation. While magnets consisting of larger particles can be readily oriented in a field before compaction, this becomes increasingly difficult with decreasing particle size. According to *Hubert and Schäfer (1998)* if a particle is too small, no domain structure will develop. Most micromagnetic calculations are based on a specific anisotropy, but different calculations for materials with small anisotropy agree in the basic results. Above a certain size an inhomogeneous magnetization state with a low average magnetization takes over. This state is not continuously related to the uniformly magnetized state any more. The initial high-remanence or single-domain configuration is called the flower state. The low remanence state, which has a lower energy beyond the single-domain limit, is called the curling or vortex state.

Methodology: The common procedure of the Thellier method was applied to determine the paleointensity of samples (the method has been described in *Túnyi, Hovorka, Orlický (2006)*. A laboratory magnetization was also applied to induce the PTRM in selected samples. The results of laboratory measurements are presented in Figs. 1, 2.

3. Description and the interpretation of the results

From the results on Fig. 1 is evident that the sample of biotite hornblende pyroxene andesite GrKajmH5-6 has shown very good magnetic and paleomagnetic stability up to 475° C. The original directions of RM have been changed only very softly, despite the thermal magnetization of the sample was realized under permanent influence of the laboratory magnetic field of the intensity H = 48 μT. Similar situation has been reflected on the basis of the Thellier method of the sample. Very consistent magnetization and demagnetization curves, namely the linear relations of the demagnetization with respect to magnetizations data up to 475°C are detected in Fig. 2 for the sample from the same petrographical type of the sample from the same locality. I suppose that the original RM of the sample was acquired during cooling of the volcanic body and it corresponds probably to TRM. The derived coefficient k = 1.63 (Fig. 2) has shown that the intensity of magnetic field during cooling of the andesitic body (cca 2250 years ago) was around of 1.63 times bigger than the present intensity of geomagnetic field. The derived intensity is in quite a good agreement with that presented by Bucha (1975) in *Túnyi (2006)* on the basis of archeomagnetic data for Czech Republic and for the Central Europe.

We see from Figs. 1, 2 that there is also the other, more oxidized magnetic component in the sample (in the interval over 500°C), which corresponds probably to secondary magnetization. This was originated due to alteration of the primary magnetic phase and it is probably of the chemical remanent magnetization (CRM). We can only assess the k coefficient, (from the line 500–600°C), which is about $k_2 = 0.9$. It means that this magnetization was acquired probably during recent time.

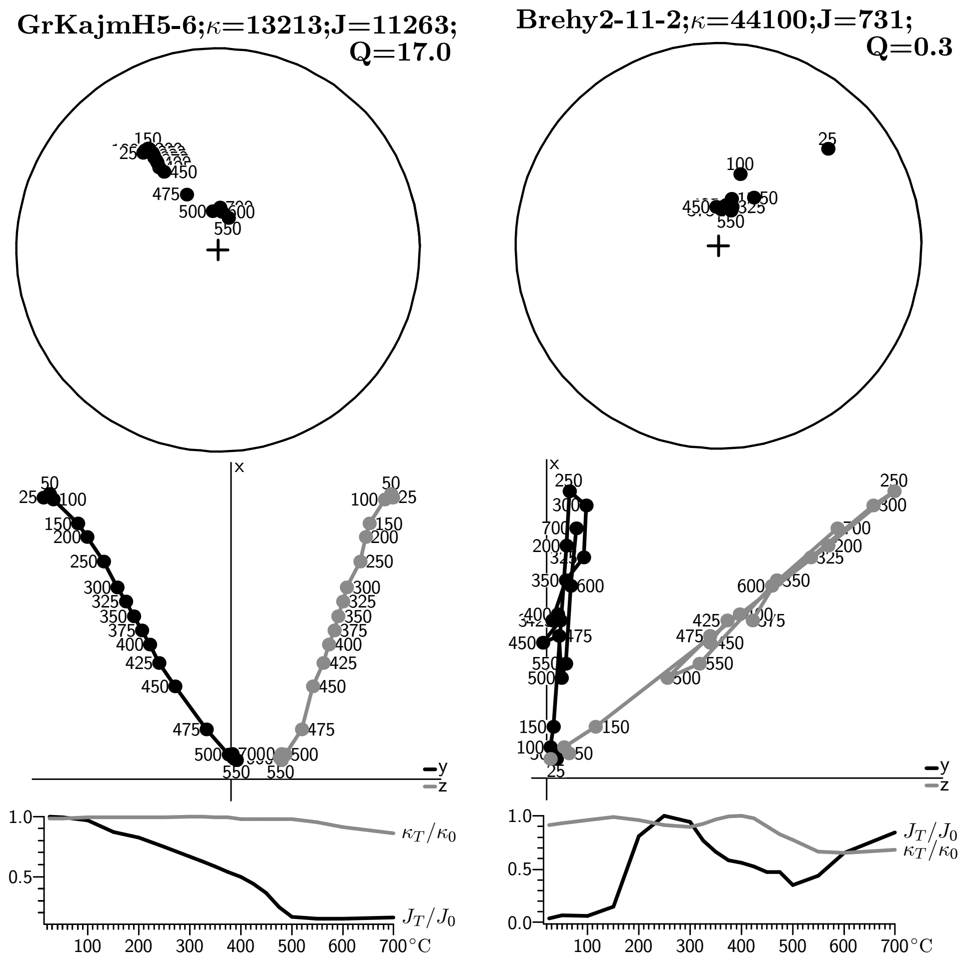

Fig. 1. Partial thermoremanent magnetization of samples induced in the laboratory magnetic field of the intensity H = 48 μT. GrKajmH5-6 - the sample of biotite hornblende-pyroxene andesite from Kammeno Chorio, Greece; Brehy2-11-2 - sample of nepheline basanite from Brehy, Slovakia; κ - magnetic susceptibility x 10^{-6} SI Units; J - remanent magnetization in nano Tesla (nT); Q - Koenigsberger coefficient.

What is very important with respect to the idea about a possibility of deriving the paleointensity of volcanic rocks: If we have rock samples with altered magnetic minerals, with a well developed domain structure, there is

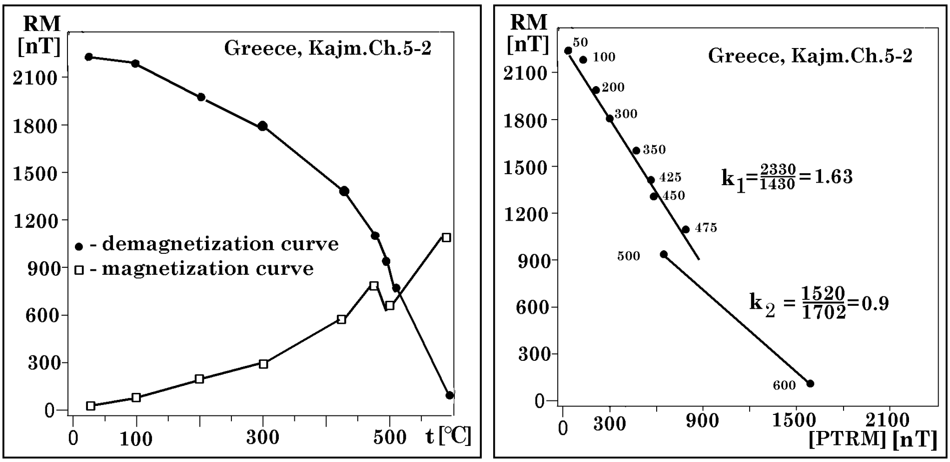

Fig. 2. Thermomagnetic demagnetization results by Thellier's method of samples of the biotite hornblende pyroxene andesite from Kammeno Chorio. RM - remanent magnetization; PTRM - partial thermoremanent magnetization; nT - nano Tesla; t - temperature. Full dots in Fig. 2 (picture on the right side) denote the coordinate of RM and PTRM for discrete temperature step (see numbers along the line: 50, 100, - 600°C). k_1, k_2 - derived coefficients: k_1 for computing of the intensity of the field for the time of origin of volcanic body, k_2 valid for recent time.

a good magnetic and paleomagnetic stability of RM and there is a chance to derive the corresponding paleointensity.

There is the other example in the Fig. 1, the results of magnetization of the sample of nepheline basanite with dominant portion of Ti-rich Ti-Mt-es. As we see from Fig. 1, there have followed two non-intensive processes up to about 150°C - demagnetization and magnetization of the sample. The temperature interval within 25 to 150°C is supposed to be inadequate for the realization of the Thellier method. In the interval from 150° to 250°C, there is the extensive increasing of magnetization, from about 750 nT to about 19150 nT, what is about 25 times more than the value after demagnetization of the sample. This extreme increase of PTRM is probably due to particular state, probably the exchange coupled small magnetic particles, and due to the acquiring of the high-remanence flower state in Ti-rich Ti-Mt-es. The computed data from the common Thellier method are inconsistent and they have provided an extreme high paleointensity. It means that in this temperature interval there is not a real chance to derive an adequate paleointensity of the basalt. In the interval from 250° to about 500°C, there is evident expressive decreasing of PTRM, despite of the tendency of the increase of the κ of the basalt at the beginning of this temperature interval. There has probably appeared the SP particle effect. Despite the high magnetic susceptibility, very low positive PTRM has been induced in the sample (this effect has been studied in detail for many basalts with Ti-rich Ti-Mt-es by the author of this article). In the interval 500° to 700°C, there is evident alteration of magnetic Fe-Ti oxides with the presence of more oxidized titanomaghemites. But this alteration was affected by heating of the sample during laboratory experiment. If such alterations appeared in the investigated basalts in the field, they do not correspond to the original state, but only to secondary - altered state. So, the corresponding magnetization would be of the secondary origin.

4. Conclusion

The samples of different magnetic state were studied to consider the adequacy of derived paleointensity from the magnetizing data.

The results have shown that the basalts with dominant portion of Ti-rich titanomagnetites are not appropriate objects for the study of paleointensity. The Ti-rich titanomagnetites behave dominantly as the small magnetic particles, they have not developed thermodynamically stable domain structures. So, the flower state and the vortex state are dominant magnetization processes in these type of Ti-Mt bearing rocks.

On the other hand if there are rocks with the non altered magnetic minerals with the well developed domain structures the magnetization by the irreversible domain wall movement is actual and so, there is a good magnetic and paleomagnetic stability of RM and there is a chance to derive the corresponding paleointensity.

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