Field-reversal versus self-reversal hypothesis: Different intensities of TRM of the reversely magnetized natural basalts and those of the same origin of artificial samples magnetized in laboratory

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A b s t r a c t : The thermoremanent magnetization (TRM) of artificially prepared Fe-Ti containing grinded basaltic grains and those of the reversely magnetized natural basaltic rocks from southern Slovakia was studied. The dominant carriers of magnetic properties are supposed to be the ilmenite-hematites (Ilm-Hem-es) in the basalts under study. As the representative parameter, the Q ratio of the artificial samples was used, to compare the tendency of the artificial samples for acquiring the TRM in the laboratory field. The average value of Q = 12.8 (derived from 21 individual data of laboratory induced TRM) and the average value of volume magnetic susceptibility of $\kappa = 21113 \times 10^{-6}$ SI Units (computed from 94 individual data of natural basaltic rocks) were used to derive the probable intensity of TRM of natural basalts in the time of their origin. This intensity should be 14400 nT, instead of 956 nT, computed from 94 data of individual rock samples. The results have shown that the absolute value of intensity of the laboratory induced TRM (induced in normal field of intensity H = 48 μT) of artificial samples is in average by about 15 times higher than that of the reversed intensity of TRM of natural samples. It has been deduced that these low values of intensity of reversed TRM of basalts have reflected the self-reversal origin of magnetization. The normal polarity geomagnetic field existed during the origin of basaltic rocks under study. The reversed remanent magnetization of these basaltic rocks was acquired by the self-reversal process in non-magnetically ordered particles of Ilm-Hem solid solutions.

Key words: basaltic rocks with Ilm-Hem-es, artificial Fe-Ti oxide containing samples, high values of laboratory induced TRM, low values of TRM of natural samples, self-reversed origin of low intensity TRM natural basalts

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1. Introduction

In my previous work *(Orlický, 2004)* the origin of reversed remanent magnetization (RM) of basalts of the Central and Southern Slovakia was interpreted using the self-reversal hypothesis. Because there is no chance to argue against the *field-reversal* hypothesis applying the theoretical reasons we need to accumulate the experimental evidence which can support the *self-reversal hypothesis* about the origin of the reversed magnetization of rocks. The solution of this problem is not important only with respect to paleomagnetism itself, but this can play decisive role also in correct knowing of the dynamics of the geomagnetic field in the geological past. I will try to face my attention to the idea of *Cox (1973)* who has written the sentences: "In view of complexity and nonreproducibility of many types of self-reversal, what approaches are open to the investigator attempting to assess the prevalence of self-reversal in rocks? One is to look for correlation between mineralogical properties and magnetic polarity. If all the reversely polarized members of a suite of rocks possess a unique mineralogy, self-reversal is probable even if it cannot be reproduced in the laboratory." It means that except of direct inducing of the reversed RM by self-reversal mechanism in the normal field we can find the correlation of some petrographic or mineralogic relations to explain the different magnetic or paleomagnetic characteristics in rocks. But the comparison between the intensity of remanent magnetization (RM) of natural samples of basalts and that of laboratory induced thermoremanent magnetization (TRM) of artificial samples can support a self-reversal origin of reversed TRM of original basalts.

I have revealed that there are alternatively the two different types of basalts which carry the reversed RM, in the areas of volcanic fields of Slovakia. One group, which has contained dominantly the titanium rich titanomagnetite (Ti-Mt) solid solutions and the second group which has contained dominantly the ilmenite-hematite (Ilm-Hem) solid solutions. I have selected the paleomagnetic results of the second group of basalts. It consists of the larger volcanic body which is represented by the localities Veľké Dravce, Husina, Poličko, NE of Šavoľ, N of Šíd, Bulhary and Konrádovce (see in *Orlický, 2004*). These types of basalts contain dominantly the Ilm-Hem solid solutions as the carriers of reversed RM, which are relatively stable against the oxidation.

2. Shortly about geology

Alkali basalt volcanism in the Southern Slovakia (Lučenec basin, Cerová vrchovina hills, extending over the state boundary into northern Hungary) was active since the Late Miocene to Quaternary time. More comprehensive interpretation using dominantly the radiometric dating has been presented by *Konečný et al. (2001).* A local updoming in Southern Slovakia is contemporaneous with alkali basalts in the Cerová vrchovina. Highland may indicate the presence of spatially limited mantle plume responsible for generation of basalt magmas. According to *Huraiová and Konečný (1994)* an estimation of equilibrium in pressure and temperature for mantle xenoliths indicates adiabatic uprise of mantle material. The first volcanic phase in Central Slovakia field with interval 8.00–6.59 Ma corresponds to the Pannonian up to Early Pontian age. Slightly younger are the products of the Podrečany basalt Formation, including the two maars and lava flows dated on 7.2-6.4 Ma. The following volcanic activity started in the southern part of the Cerová vrchovina Highland and/or northern Hungary, in close relation with gradual uplift of this area (2nd volcanic phase). In the 3rd volcanic phase the eruptive centres migrated to the margins of the uplifted area. Afterwards the main volcanic activity expanded beyond the limits of uplift, but still continued in a restricted extent in its centre (4th and 5th volcanic phase). Volcanic activity finished with phreatomagmatic explosions giving rise to several maars situated on the periphery of the uplifted area (Fiľakovo, Hodejov, 6th volcanic phase). The seventh volcanic phase (Quaternary) in Central Slovakia is represented by Brehy - lava flows and scoria cone Pútikov vršok (near Nová Baňa). The lava flows started at the scoria cone and during their movement to the north they overlaid the fluvial terrace of the Paleohron river. According to geomorfologic position of terrace sediments their formation during the Riss time is supposed in interval 0.13-0.16 Ma. From several radiometric datings the age is selected as 0.25-0.12 Ma nearer to that of the interval of geological time.

I have choosen the basalts which can belong to the second above mentioned group. They are probably of the age about 1.16 to 1.6 Ma and are represented by the localities Veľké Dravce, Husina, Poličko, NE of Šavoľ, N of Šíd, Bulhary and Konrádovce. Relatively large lava flow was formed from the hot more oxidized magma with dominant presence of magnetic

Ilm-Hem-es. The Ilm-Hem-es was originated from the original titanomagnetites during ascending of hot magma onto the Earth's surface. The Fe-Ti oxides in the intrusive conditions tend to re-equilibrate readily during cooling. This behaviour leads to a complex series of re-equilibration reactions. At high temperatures these reactions involve inter-grain exchange of ferric iron and Ti between titanomagnetites (Ti-Mt-es) and ilmenite (Ilm) with the consequent enrichment of Fe_3O_4 in spinel and $FeTiO_3$ in rhombohedral phase. At intermediate temperatures Ti-Mt re-equilibrates by process of oxyexsolution in which the Fe_2TiO_4 component of the Ti-Mt oxidizes to form granules of Ilm within or around the spinel. At lower temperatures the process produces lamellae of Ilm of the host spinel (*Lindsley, 1991*). The presence of these types of Ilm-Hem associations were detected by the results of Curie temperature measurements of the mentioned types of basalts (*Orlický, 2004*).

3. Experimental

The subject of this work is the study of basalts which occur in the areas of volcanic fields in the southern Slovakia. The localities under study are in Fig. 1.

The basic idea is to induce the intensities of the thermoremanent magnetization (TRM) of artificially prepared samples and some original basaltic rocks in the laboratory field and compare these results with those of the same petrographical types of original basalts from the area in question. The artificially prepared samples have an advantage that the grains of magnetic material are disseminated in an arbitrary direction within the sample (when the samples are prepared in the place without any presence of ambient magnetic field), so they do not carry a preferable direction of RM. The following methodical setting was held:

The five original cylindrical basaltic samples were used (the samples were previously thermally demagnetized) and the 16 artificial samples with the presence of grinded grains of original basalts were prepared. In these samples the TRM was induced in the laboratory field of the intensity H = 48 μT.

Preparation of artificial samples and basic measurements

The samples were prepared by grinding the original (*in situ volcanics*) in ceramic bowl. The grinded material of the samples was sieved to preserve the sizes of the grains around of $\oslash$ 0.2 mm ($\oslash \leq 0.16$, $\oslash \geq 0.16 \leq 0.2$, $\oslash \geq 0.2$, $\oslash \leq 0.2 \leq \oslash$, see in Table 1). The bar permanent magnet was used to separate the magnetic grains from the grinded material. The magnetic grains were fixed in nonmagnetic gypsum. The powdered gypsum was per-

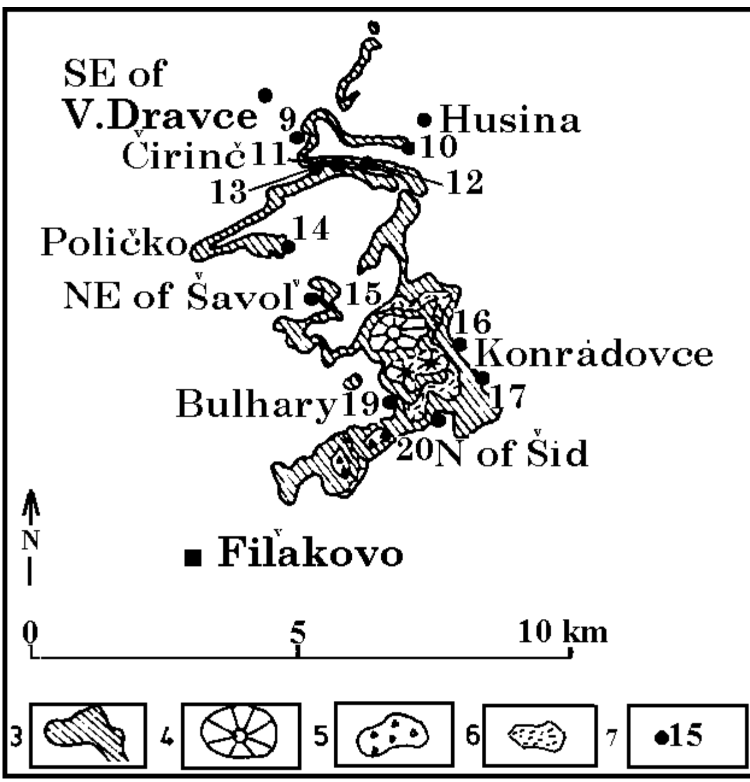

Fig. 1. A sketch map of selected localities; (The original map according to *Konečný et al., 2001* was modified by author of this article); 9–20 - localities with basaltic rocks under consideration, located in the northern part of Fiľakovo Town; Explanations for Cerová basalt formation (Middle pliocene - Pleistocene): 3–basalt lava flows; 4–cinder cones; 5–agglomerates; 6–lapilly tuffs; 7–designation of localities.

manently mixed with the magnetic grains and water in the ceramic bowl. This mixture of an appropriate consistency was poured out into the plastic form of the cylindrical shape with the diameter of 25 mm and heigh of 22 mm. Above mentioned procedures including the drying of the samples in free air were performed at room temperature.

After drying of the samples, they were heated in nonmagnetic oven up to 700° C in fully compensated magnetic field. Any magnetic components of the samples were demagnetized. During controlled cooling of the samples the total TRM was induced in the interval from 700° C to laboratory temperature. The direction of the laboratory field was respected during inducing of TRM of samples. The TRM of the samples was measured by spinner magnetometer JR-5 and magnetic susceptibility by the cappa bridge KLY-2. The results are in Table 1. The average value of direction of TRM (declination and inclination of TRM) computed from 21 individual data is D = 1.5°, I = 67.2°.

Stability of TRM against the thermal demagnetization

The examples of the thermal demagnetization of four selected samples with the laboratory induced TRM are given in Figs. 2, 3. But similar behaviour to presented results on Figs. 2, 3 have shown also all samples (see Table 1) with a laboratory induced TRM.

The results of thermal demagnetization have shown that the laboratory induced TRM of the samples is of high directional stability (in natural samples up to 550°, and up to 500° in artificial samples). The Fe-Ti oxides with the Curie temperatures closely over 550° are in non-magnetically ordered state and they are almost unstable. The stability of TRM is comparable with that acquired during the cooling of basaltic magma in the field. The Curie temperatures correspond to Ilm-Hem solid solutions with the ilmenite content of about 15 to 18%, similarly as was published by *Orlický (2001, 2002, 2002a, 2002b, 2002c, 2003, 2003a)* for andesitic and some rhyolite rocks.

4. Evaluation of experimental data

In the previous work the high magnetic intensities of RM were interpreted by existing viscous remanent magnetization (VRM) of the secondary

Table 1. Magnetic characteristics of artificial samples and basaltic rocks from Cerová vrchovina upland (Southern Slovakia).

Locality No., Sample, grain size [mm]	TRM induced samples			Original samples			Rock type
	$\kappa \times 10^6$ SI Un.	TRM	Q	$\kappa \times 10^6$ SI Un.	NRM	Q	
9, Veľ.Dravce1, ⊘≤0.16	1615	1284	15.9	25895	749	0.6	Basalt
9, Veľ.Dravce1a, ⊘≤0.16	1563	1016	13.0	25895	749	0.6	Basalt
9, Veľ.Dravce2, ⊘≥0.16≤0.2	2204	1425	12.9	25895	749	0.6	Basalt
9, Veľ.Dravce2a, ⊘≤0.2≤⊘	2348	1176	10.0	25895	749	0.6	Basalt
9, Veľ.Dravce3, ⊘≥0.2	1235	746	12.1	25895	749	0.6	Basalt
10, Husina3-1, ⊘≤0.2≤⊘	1501	836	11.1	28309	613	0.4	Basa lt
10, Husina3-3, ⊘≤0.2≤⊘	843	540	12.8	28309	613	0.4	Basalt
10, Husina3-3-3,com.b.	12000	9967	16.6	22444	515	0.5	Basalt
10, Husina3-3-4,com.b.	13602	11819	17.4	26296	453	0.3	Basalt
14, Poličko1-2-1, com.b.	13611	13402	19.7	26222	1075	0.8	Basalt
14, Poličko1-1-1, com.b.	16452	14639	17.8	26333	936	0.8	Basalt
14, Poličko1-1, ⊘≤0.2≤⊘	3290	1956	11.9	28409	860	0.6	Ba salt
15, NE of Šavoľ1, ⊘≤0.2≤⊘	2131	785	7.4	19413	848	0.9	Basalt
16,17, Konrádovce1-1,com.b.	12377	9306	15.0	11313	924	1.7	Basalt
16,17, Konrádovce2-2, ⊘≤0.2≤	2400	1625	13.5	11313	924	1.7	Basalt
16,17, Konrádovce1, ⊘≤0.16	1496	1010	13.5	11313	924	1.7	Basalt
16,17, Konrádovce2, ⊘≥0.16≤0.2	1379	870	12.6	11313	924	1.7	Basa lt
16,17, Konrádovce3, ⊘≥0.2	2015	1161	11.5	11313	924	1.7	Basalt
19, Bulhary-1, ⊘≤0.16	1399	1113	15.9	27220	943	0.7	Basalt
19, Bulhary2, ⊘≥0.16≤0.2	1523	699	9.2	27220	943	0.7	Basalt
19, Bulhary-3, ⊘≥0.2	3168	938	5.9	27220	943	0.7	Basalt

Veľ.–Veľké; κ–bulk magnetic susceptibility; NRM, TRM–natural remanent magnetization (NRM), Thermo-remanent magnetization (TRM) in nano Tesla (nT); Q–Koenigsberger ratio; com.b.-compact basalt; ⊘-grain size in mm.

magnetic phases (of low or high temperature oxidation) in basalts. As we know there is a difficulty to identify precisely a type of magnetization in the natural rocks. For this reason the artificial samples were prepared. In the Table 1, there are basic magnetic data of the artificially prepared samples

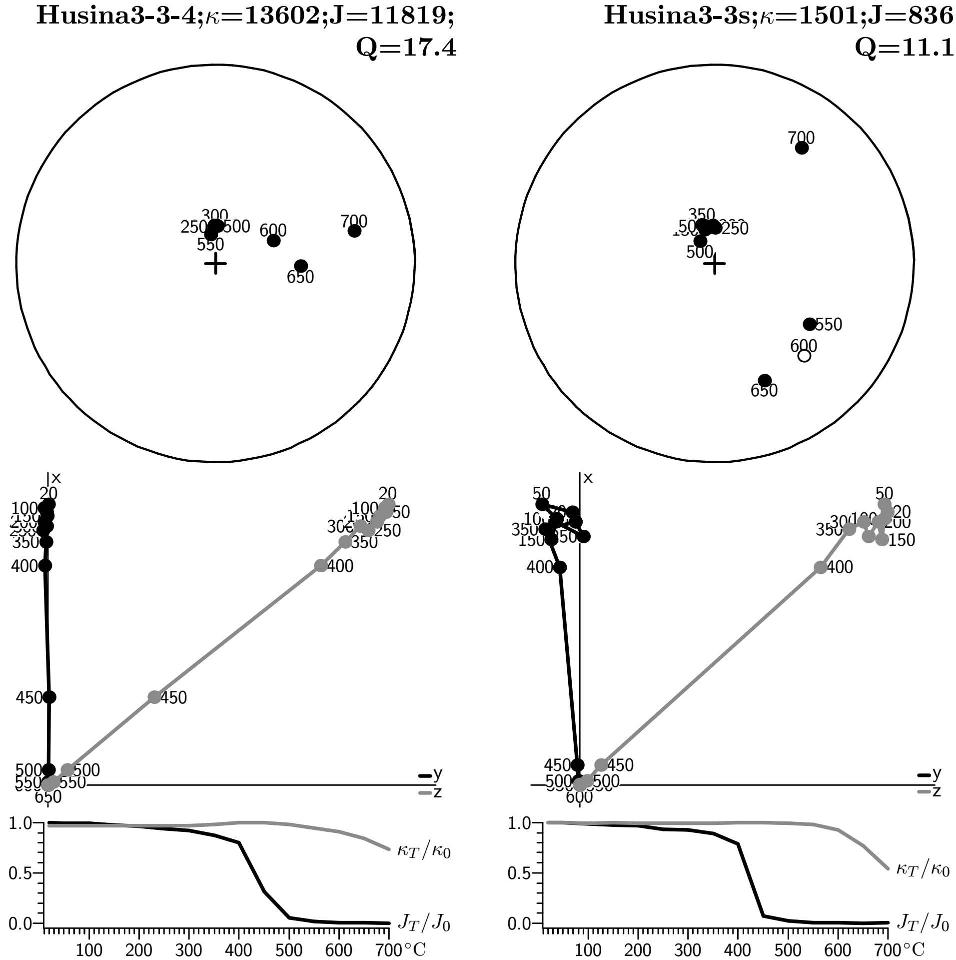

Fig. 2. Thermal demagnetization of original natural basalt - the sample Husina3-3-4 and an artificial sample - Husina3-3s; stepwise heating to 700° C; Zijderveld diagrams and stereographic projections; • (○) means positive (negative) polarity of RM; κ_T (κ_0) - magnetic susceptibility at T (at 25° C, respectively); J_T (J_0) - remanent magnetization at T (at 25° C, respectively).

and those of natural basalts. It has been quite a surprising knowledge that the values of induced detrital remanent magnetization and so the Q ratio of artificial samples of the Husina, Poličko and NE of Šavol localities was

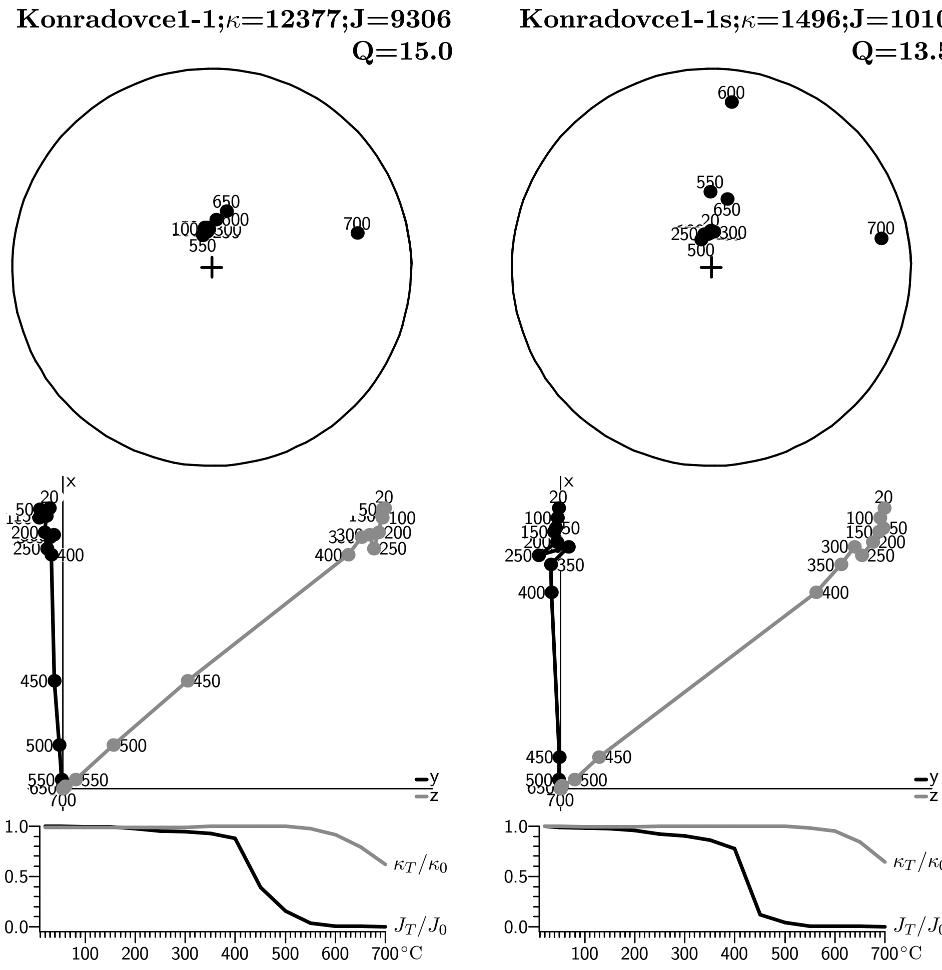

Fig. 3. Thermal demagnetization of original natural basalt - the sample Konrádovce1-1 and an artificial sample - Konrádovce1-1s; stepwise heating to 700° C; Zijderveld diagrams and stereographic projections; • (○) means positive (negative) polarity of RM; κ_T (κ_0) - magnetic susceptibility at T (at 25° C, respectively); J_T (J_0) - remanent magnetization at T (at 25° C, respectively).

higher than that of the TRM values of the samples from the same localities (*Orlický, 2005*).

As has been described above, the artificial samples have been prepared from the grinded basaltic grains of the preferable size less than 0.2 mm or slightly over (see the grain size range in the Table 1.). Commonly, such size of the grain belongs to the multi-domain (MD) range. We need to consider that there are present not pure grains of magnetic Fe-Ti minerals, but grains of grinded basaltic rock in the artificial samples. We can predict that there are present the magnetic Fe-Ti grains of a variable range, not only MD, but also single-domain (SD) grains, maybe super-paramagnetic (SP) particles are inside individual basaltic grains. The behaviour of dominant different size particles corresponds probably to pseudo-single domain (PSD) grains. As we see from Table 1, there are not equivalent portions of magnetic grains and the same grain sizes in artificial samples (it can be controlled by κ values). It means that there was not the same amount of magnetic material mixed with each gypsum sample. So, with regard to this fact the Q ratio (induced TRM x $20/\kappa$) of each sample is the most representative parameter to compare the magnetization of the samples among each other. As we see, there are only negligible differences in the values of Q ratio among of individual artificial samples, regardless of the grain sizes. Very similar to artificial samples are the values of Q ratio of compact basalts, which were laboratory magnetized as well. The inducing of the total TRM of artificial and original basaltic samples was probably controlled according to the equation of *Halgedahl and Fuller (1980, 1983)* - in *McElhinny and McFadden, 2000*). According to the theory of these authors for PSD magnetization that might apply in the intermediate range, the TRM of metastable SD grains depends on the probability that no domain walls will have nucleated and therefore becomes a fraction of the SD remanence. For a given grain size some of the grains will have no domain walls and other will have differing numbers of walls. The TRM for any given grain size will therefore be a combination of the metastable SD grains (no domain walls) and the MD TRM from the remaining grains. The basic equations are presented in *McElhinny and McFadden (2000)*, and some relationship according to *Fuller (1984)*, to compute the TRM of magnetic materials with SD and MD particles. We know that in the rocks the magnetic Fe-Ti grains are in variable shape and very variable size range, so the conditions for a computing of TRM of the rocks are supposed to be rather idealized, but I suppose that the equations according to the mentioned authors can be applied with respect to a theoretical point of view.

5. Discussion and conclusions

The idea of applying the laboratory induced TRM of artificially prepared samples for searching some relations between this parameter and that of the natural basalts is the following: As has been described above the studied basalts come from large lava flow which was formed from the hot more oxidized magma with dominant presence of magnetic Ilm-Hem-es. The Ilm-Hem-es were originated from the original titanomagnetites during ascending of hot magma onto the Earth's surface. All studied original basaltic samples from the lava flow under study have the reversed polarity of RM. This RM is relatively very stable according to the AC and thermal demagnetization tests. The RM corresponds probably to TRM of this magnetization. In large collection of andesitic rocks and basaltic andesites (with a similar Curie temperatures like that of the investigated basaltic samples) from the volcanic fields of central Slovakia the self-reversed partial thermoremanent magnetization (PTRM) was previously induced in normal polarity laboratory field. If we are willing to accept the field-reversal hypothesis, it means that if we accept that these volcanics were magnetized by the geomagnetic field of reversed polarity (of a similar intensity like that of the today's normal geomagnetic field of H $\approx 50\ \mu$T) during their origin, the absolute value of the intensity of the reversed TRM of these samples should be roughly the same or very near to that of induced in the laboratory. The results have shown that the Ilm-Hem solid solutions are the dominant magnetism carriers in these basalts and with respect to their stability we suppose that no dominant changes of these magnetic minerals have occurred during their existence in the field.

As has been mentioned above the Q ratio is the most relevant parameter to compare, how the magnetic material is willing to acquire the remanent magnetization. The average Q ratio computed from the laboratory induced values of TRM and magnetic susceptibilities of 16 artificial samples and 5 original basaltic rocks (see Table 1) is 12.8. We see that the magnetic Fe-Ti oxides of the samples are very willing to acquire the total TRM in the laboratory. According to thermal demagnetization tests the laboratory induced TRM of the artificial samples and those of 5 original basaltic rocks is very stable.

We would like to assess what situation was probably actual during cooling of original basaltic magma in the time of its origin. There have been in a disposal the data of 94 basaltic samples from 7 localities which characterize the basaltic body under consideration (mostly the lava flows - maximum distance in N-S direction of about 7 km, and in W-E direction about 1.5 km, see Fig. 1). The average value of volume magnetic susceptibility of basaltic body is $\kappa = 21113 \times 10^{-6}$ SI Units, average value of natural remanent magnetization (NRM) of the basaltic body is NRM = 956 nT. The average value of Q ratio is only Q = 0.91. The whole basaltic body carries the reversed RM of D = 172.04° and I = -61.1° (it is nearly symmetrically anti-parallel to the present geomagnetic field). The computed value of NRM corresponds probably to thermo-remanent magnetization (TRM) which was acquired during cooling of basaltic magma in the field. If the intensity of the magnetic field was approximately similar to that in present, it means about 50 μT in the place of the geographical position of basaltic body in the field, and the direction of total geomagnetic field (declination D and inclination I) was reversed with respect to today's field, the reversed absolute value of intensity of TRM would be very similar to the value computed from the data of artificial samples derived from the average value of magnetic susceptibility of the basaltic body and the Q ratio 12.8. This value of NRM (TRM) of the samples of basaltic body would be in average of NRM $\approx$ 14400 nT, instead of only 956 nT. If we consider the lower intensity of the geomagnetic field during cooling of basaltic magma, it would be about 15 times less than that of the today's field, only about 3.2 μT, which is not a realistic value. The radiometric ages of samples from 4 respective localities are from 1.16 m.y. (NE of Šavol) to 1.6 m.y. (Bulhary) in *Orlický (2004)*. If we take into account the permanent influence of normal intensity geomagnetic field a demagnetization of original TRM of basaltic body might have been continued till now. But the existence only of low values of viscous remanent magnetization (VRM) of normal polarity in natural samples has proven that the magnetic Ilm-Hem associations in basalts are stable enough against the demagnetization by the fields of low intensity. We are due to find other idea and mechanism to explain such low values of intensity of reversed NRM of natural samples. In many previous works I presented the results of a reproducible laboratory inducing of the partial thermoremanent magnetization (PTRM) of andesitic, basaltic andesite and rhyolite samples of rocks (*Orlický, 2001, 2002, 2002a, 2002b, 2002c, 2003,* *2003a*). In the mentioned laboratory procedures the intensities of PTRM in the range of about 2.0 to about 200 nT were acquired. According to the author's interpretation the Ilm-Hem solid solutions in non-magnetic ordered state were able to acquire the stable PTRM. No total TRM was induced in such laboratory procedures. The present laboratory equipment and the specialists are not able to repeatedly induce the total self-reversed TRM in common rocks, because we do not known precise conditions (petrological, but especially the magnetic ones) under which the cooling magma is able to acquire the stable self-reversal TRM. For this reason a comparison of data of laboratory induced TRM of artificially prepared samples and those of natural basalts may be an appropriate way for verifying the idea about the self-reversal origin of the reversely magnetized natural rocks.

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