Magnetic properties and magnetic mineralogy of selected young volcanics from different places of the Earth globe

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Abstract: The contemporary, historical and recent volcanic rocks were studied. An intention of the work was to identify a presence of the so-called low-temperature oxidized titano-maghemite (Ti-Mgh) phase (if any) in the young volcanic rocks. In the previous works it has been revealed that this phase is a source of the self-reversal remanent magnetization (RM) in volcanic rocks (*Orlický, 2006, 2009; Orlický and Funaki, 2008*). The thermal demagnetization of the samples and inducing of partial thermoremanent magnetization (PTRM) of the samples in the laboratory field, the measurements of the change of magnetic susceptibility (κ) at selected temperature intervals of the compact samples and the measurements of the Curie temperatures and the study of behaviour of magnetic susceptibility (κ) of samples in the low and high temperature intervals were carried out. In the macroscopically evidenced oxidized basaltic scoria from the Tenerife volcano a small portion of the low-temperature oxidized Ti-Mgh phase was revealed. A small portion of the low-temperature oxidized phase was revealed also in the andesite from the Rainier volcano (20 000 years old). But a behaviour of magnetic susceptibility with temperature, characteristic for a presence of the low-temperature oxidized Ti-Mgh phase, was revealed in older basaltic scoria of the Death Valley (age either 700 000 years or more). All other 12 laboratory investigated volcanic rocks have not possessed the low-temperature oxidized Ti-Mgh phase.

Key words: young volcanics, low-temperature oxidized Ti-Mgh phase

1. Introduction

Experimental evidences have revealed that the volcanic rocks, containing the low-temperature oxidized Fe-Ti phase (except of that of the Ti-rich titanomagnetite – Ti-Mt phase) are characterized by the self-reversed chemical remanent magnetization (CRM) *(Orlický, 2009).* The reversed RM of such type of natural basalts has survived mostly up to about 450° C, under the thermal demagnetization. These types of basalts have shown a sharp increase of magnetic susceptibility (κ) with a maximum peak at about 425 to 475° C. During step-wise magnetization of such rocks in the magnetic field of $H \approx 48.0\,\mu$T, the partial thermoremanent magnetization (PTRM) has started to decrease at around 300° C with a minimum at about 450° C or more (this decrease of PTRM coincides with an increase of κ of the sample). The decrease of PTRM of the sample is due to an acquisition of the self-reversed component of PTRM in the rock. This behaviour of κ and PTRM is characteristic for the low-temperature oxidized Ti-Mt (titanomaghemite, Ti-Mgh) bearing rocks. It consists in the rearrangement of magnetic ions and some properties of the spontaneous magnetization of the crystalline sub-lattices of the ferrimagnetic oxide (partial theoretical explanation of this effect has been outlined by *Orlický, 2009*). *Krása et al. (2005)* have proposed that this low-temperature oxidized Fe-Ti phase occurred directly during the initial cooling of magma on the earth's surface. So, applying the above mentioned effects we can test if the Fe-Ti low-temperature phase is present also in young or recent volcanics. According to *Lindsley (1991)* the Ti-Mt solid solutions of different compositions are preferably present in basaltic rocks. But they may be found also in intermediate and acidic volcanics. Thus, all types of recent or very young volcanics can be tested to reveal if the so-called low-temperature oxidized phase has been developed in these rocks. If we would approve that no such low-temperature oxidized phases are present in the young or recent volcanics, we would need to find another source for their existence in older rocks. Some knowledge about the origin of the Fe-Ti oxides indicates that at high magmatic temperatures (∼ 1 200° C) the structural lattice of the magnetic mineral is built up in a very disordered state. One can find there the ions of very diverse atom's radii which have no chance to enter this lattice under the atmospheric temperature conditions. Therefore, these high-temperature magnetic minerals are metastable or unstable and they have a tendency to be destroyed or unmixed over their lifetime on the earth's surface. So, at these conditions also the magnetic properties of alterated rocks have been changed. Some simplicity and advantage arise in the application of this method. No oriented samples are needed for the application of this method. A very useful method for this purpose is the laboratory acquisition of partial thermoremanent magnetization (PTRM) of the samples at selected temperatures in artificially generated magnetic field or in the today's geomagnetic field (in our laboratory of the intensity $H \approx 48\,\mu$T). In addition, the change of magnetic susceptibility (κ) at selected temperature intervals of the sample was measured. Also, the measurement of the Curie temperatures and the study of behaviour of magnetic susceptibility (κ) of samples in the low and high temperature intervals is very useful. The above mentioned methods were applied to study the rocks from the following localities: The Kilauea volcano, Hawaii, USA, the Mazama-Crater Lake Volcano, USA, the Rainier Volcano, USA, the Etna Volcano, Italy (the results of the Curie temperature measurements, including the description of rocks and list of authors who collected the samples from the mentioned localities were published in *Orlický et al. (2003)*). Newly collected volcanic rocks from localities Mount Tenerife, Canary Islands, Spain, the rocks from the Mount Telica, Nicaragua the rocks from the Mount St. Helens, USA, the rocks from a larger area of the Kilauea Volcano and the rocks from the Death Valley, USA have been studied. The results will be useful not only for extending the current knowledge about the possible self-reversal origin of the reversed RM of rocks, but also for an explanation of decreased magnetic properties of some marine basalts.

2. Experimental works and main results

The selected types of magnetizing curves of Fe-Ti oxides, a preliminary analysis of the results

In this part of article we describe the basic laboratory results for rocks from individual localities. The positions of individual localities have been localized by the geographical coordinates – the latitude (λ) and the longitude (φ). They are given in the round brackets in the figure captions or in the associated text.

Three different types of magnetizing curves of basaltic rocks are drawn in Fig. 1. The first type of the curve is characteristic to the volcanic rocks containing dominantly the Fe-Ti oxide near to non-stoichiometric magnetite with the Curie temperature (T_C) close to 580° C and the Verwey temperature close to −154° C. It has a thermodynamically stable domain structure.

An inducing of PTRM of samples with normal and reversed RM; these results have been used as the examples and have been taken over from the previous work.

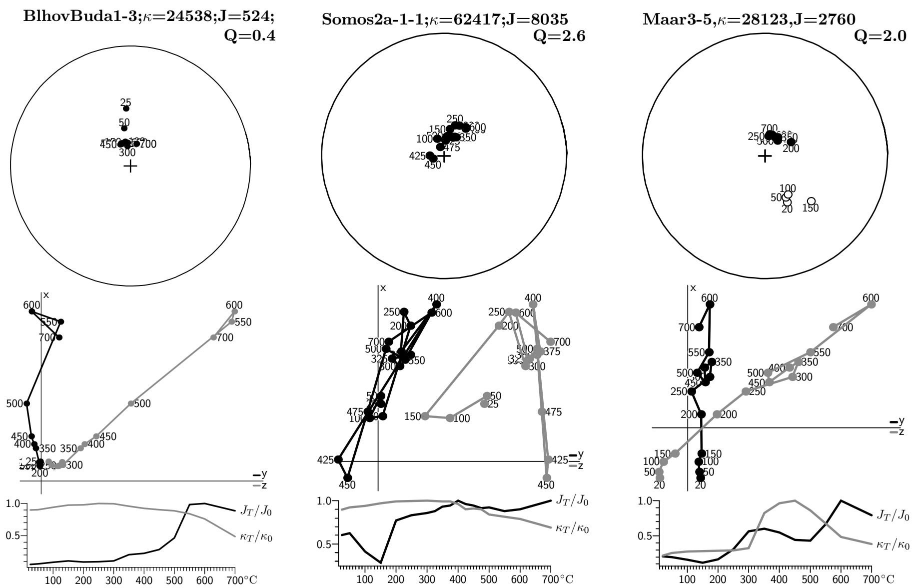

Fig. 1. Thermal inducing of natural basalt samples BlhovBuda1-3 (48.266°, 19.957°) and Somos2a-1-1 (48.170°, 19.842°) both with normal RM and Maar3-5 (48.250°, 19.990°) with reversed RM. Zijderveld diagrams and stereographic projections; • (○) - positive (negative) polarity of RM; κ - magnetic susceptibility (above the pictures: the κ is $\times 10^{-6}$ SI Units, and remanent magnetization J is in nano Tesla (nT)); κ_T at T, κ_0 - at 25° C; J_T (J_0) - remanent magnetization at T and at 25° C, respectively; Q - Koenigsberger ratio.

It carries only normal, relatively stable RM. The second curve corresponds to basalt Somos2a-1-1 with the Ti-rich Ti-Mt with low T_C of 130, 220° C and normal RM. The third curve corresponds to basalt from Maar3-5, containing partly the Ti-rich Ti-Mt phase, but dominantly the Ti-Mgh oxidized phase of only reversed RM, of the self-reversed origin. The decrease of the PTRM from about 300° C to about 450 − 500° C and an increase of magnetic susceptibility (κ) with a maximum peak at around 450 − 475° C (as for the sample Maar 3-5) are characteristic to volcanics with the self-reversal, reversed RM. So, if some newly tested samples would show the similar behaviour of PTRM and κ, or the same as that of the sample Maar 3-5, they can be considered as a self-reversally magnetized in the field.

The basaltic scoria from the Tenerife Volcano

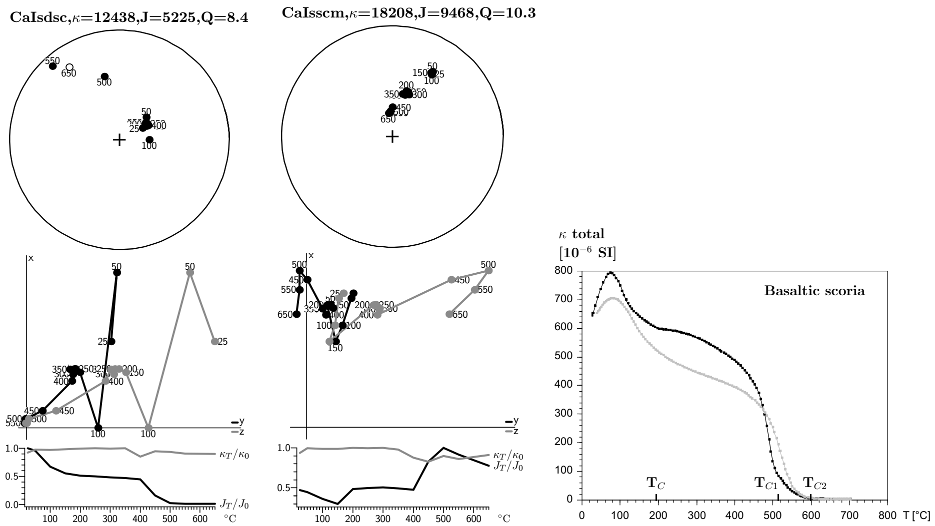

Fig. 2. Thermal demagnetization, inducing of PTRM and Curie temperature measurements (from the left to the right) of basaltic scoria from the Tenerife Volcano (28.289° - 28.109° N, 16.668° - 16.808° W). Zijderveld diagrams and stereographic projections; • (○) - positive (negative) polarity of RM; κ - magnetic susceptibility (above the pictures: the κ is $\times 10^{-6}$ SI Units, and remanent magnetization J is in nano Tesla (nT)); κ_T at T, κ_0 - at 25° C; J_T (J_0)- remanent magnetization at T and at 25° C, respectively; Q - Koenigsberger ratio. T_C, T_{C1}, T_{C2} - Curie temperatures.

The investigation of the samples from the Tenerife Volcano, Canary Islands

Two samples of basaltic scoria and two samples of basaltic obsidian were tested in the laboratory (the samples were collected by I. Orlický). The results of the samples of basaltic scoria are given in Figs. 2, 3. The samples are from the places delineated by the geographical coordinates described below. No radiometric ages of the samples have been determined. I suppose that the samples belong among the volcanic products which were erupted either during the 1798 eruption of the Pico Viejo Volcano, or in the last 1909 eruption (the data are from *Wikipedia, the free encyclopedia*). The basaltic scoria samples (the results of less oxidized sample are shown in Fig. 2, the results of more oxidized basaltic scoria in Fig. 3): Three magnetic phases are present in both samples. But they differ in the Curie temperatures. First sample (Fig. 2): small portion of Ti-rich Ti-Mt with $T_C = 190°$ C,

The oxidized basaltic scoria from the Tenerife Volcano

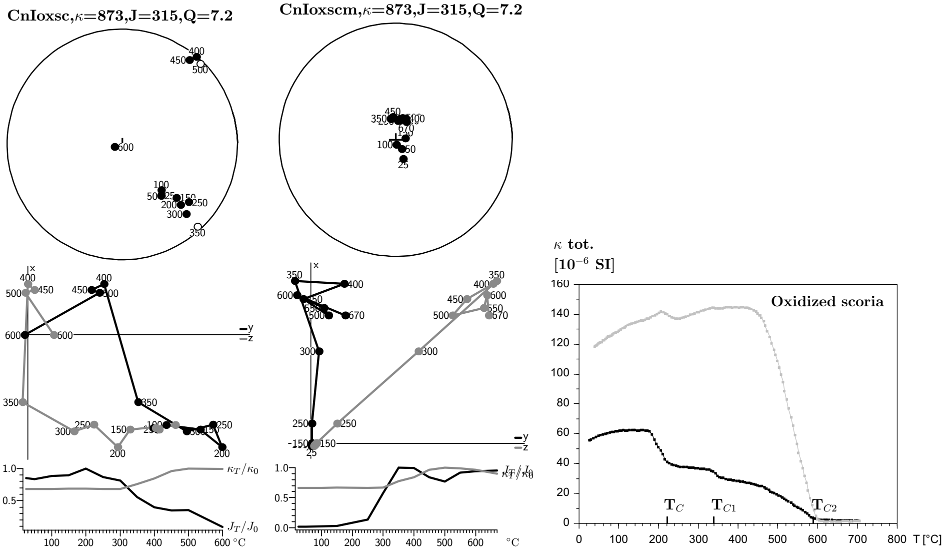

Fig. 3. Thermal demagnetization, inducing of PTRM and Curie temperature measurements (from the left to the right) of the oxidized basaltic scoria from the Tenerife Volcano (28.289° - 28.109° N, 16.668° - 16.808° W). Zijderveld diagrams and stereographic projections; For other explanations see Fig. 2.

dominant portion of oxidized Ti-Mt with $T_C = 520°$ C, small portion of more oxidized Fe-Ti mineral with $T_C = 600°$ C. The different phases are detected also by the different directions of RM after thermal demagnetization. No low-temperature oxidized Ti-Mgh phase with the self-reversal properties was detected by the PTRM and κ behaviour in the sample. More oxidized basaltic scoria (Fig. 3): small portion of Ti-rich Ti-Mt with $T_C = 220°$ C, the more oxidized Ti-Mt phase with $T_{C_1} = 340°$ C and the most oxidized phase with $T_{C_2} = 600°$ C. While the phases up to about 350° C are relatively stable, the most oxidized phase is supposed to be of low stability, according to the distribution and scattering of directions of RM after thermal demagnetization of the sample. Small portion of low-temperature oxidized Ti-Mgh phase with the self-reversal properties is present in this sample.

Basaltic obsidian: two Fe-Ti phases are present in both samples. In one sample there is a small portion of Ti-rich Ti-Mt with $T_C = 210°$ C, while in the second-more oxidi phase with $T_C = 590 - 600°$ C phase is present. In the second sample the first phase is with $T_C = 410°$ C and the second

The basaltic andesite from a boulder from the Telica Volcano

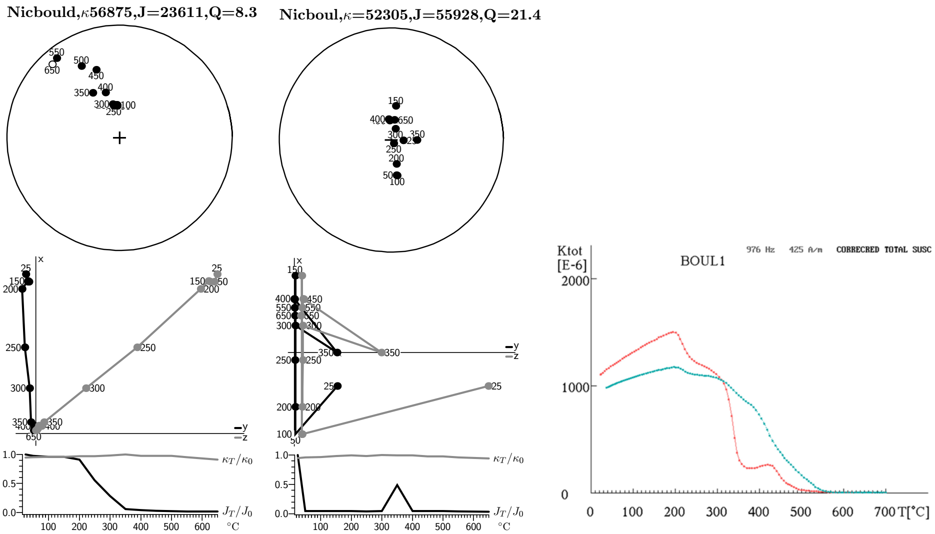

Fig. 4. Thermal demagnetization, inducing of PTRM and Curie temperature measurements (from left to right) of basaltic andesite from the Telica Volcano (12.603° N, 86.845° W). Zijderveld diagrams and stereographic projections. For other explanations see Fig. 2.

phase with $T_C = 590 - 610°$ C. After thermal demagnetization and thermal magnetization of the samples the directions of RM and PTRM were found to be quite homogeneous in both samples. No low-temperature oxidized Ti-Mgh phase with a self-reversal tendency was detected in both samples of basaltic obsidian.

Basaltic andesites from the Telica Volcano, Nicaragua

The basaltic andesite from larger boulder of the 1999–2000 eruption and basaltic andesite from the lava flow of the 1529 eruption from the Telica Volcano were studied (the samples were collected by Dr. J. Lexa). Three magnetic phases are present in the basaltic andesite from the boulder (Fig. 4). Ti-rich Ti-Mt phase with $T_C = 250°$ C, more oxidized Ti-Mt phase with $T_C = 360°$ C and an inversion phase with $T_C = 520°$ C. All three phases contribute to RM and PTRM of the rock on the basis of thermal demagnetization and magnetization of the sample. Two magnetic phases are present

The basaltic andesite of the lava flow from the Telica Volcano

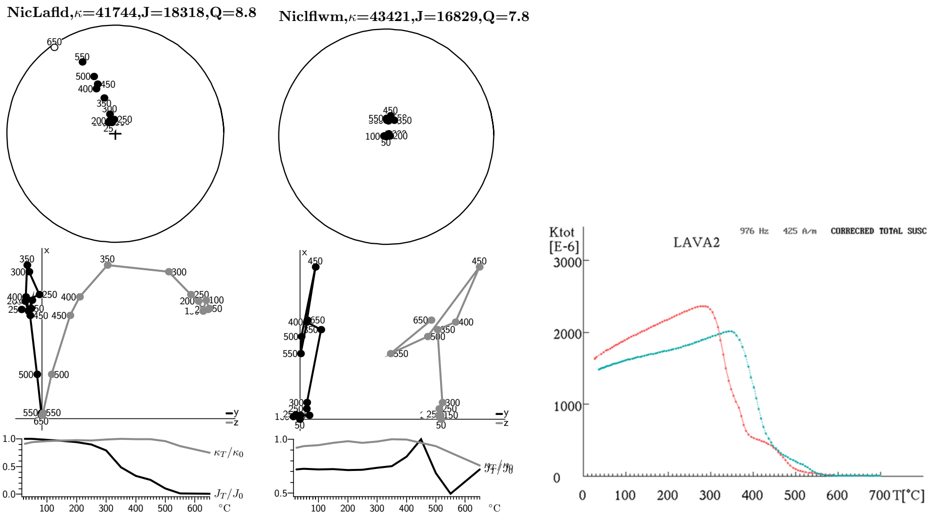

Fig. 5. Thermal demagnetization, inducing of PTRM and Curie temperature measurements (from left to right) of basaltic andesite from the Telica Volcano (12.603° N, 86.845° W). Zijderveld diagrams and stereographic projections. For other explanations see Fig. 2.

in the basaltic andesite from the lava flow (Fig. 5): oxidized Ti-Mt phase with $T_C = 390°$ C and more oxidized Ti-Mt phase with $T_C = 570°$ C. Similar to the sample from boulder, a scatter in the direction of RM and PTRM has shown a low stability of the Fe-Ti minerals. No low-temperature oxidized Ti-Mgh phase with the self-reversal properties was detected in both samples.

The volcanoes and volcanics of the Cascade Mountain Range of North Western part of the USA

The volcanic rocks of the St. Helens, Crater Lake and Rainier volcanoes belong into the Cascade Mountain Range of North Western Parth of the USA (*Wikipedia, the free encyclopedia*). The St. Helens volcano is relatively young (40 000 years). It had been dormant since 1857. Frequent dacitic eruptions during the previous 2 500 years had produced pyroclastic flows, ash falls, debris flows, lava domes, and lava flows of andesite and basalt.

The Crater Lake, Oregon lies on the crest of the Cascade Mountain

The rhyodacite from the St. Helens Volcano

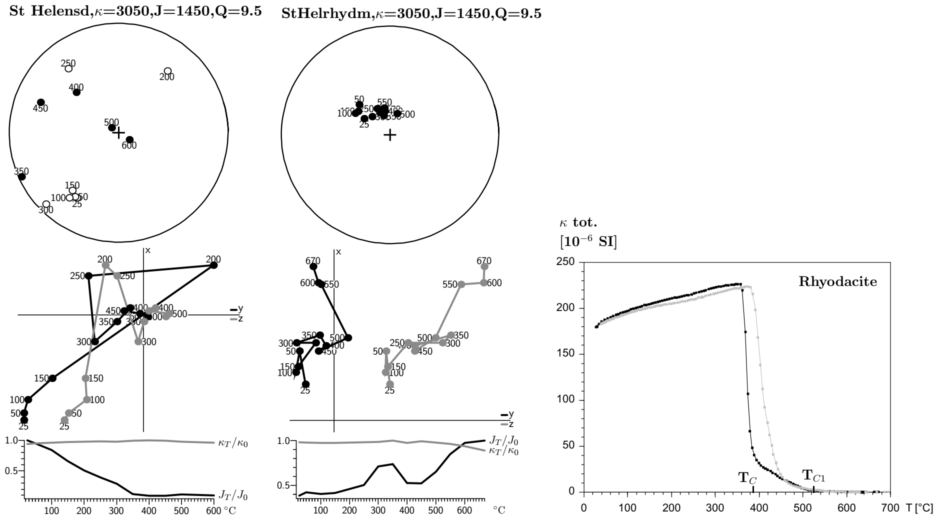

Fig. 6. Thermal demagnetization, inducing of PTRM and Curie temperature measurements (from the left to the right) of rhyolite dacite from the St. Helens Volcano (46.184° N, 122.184° W). Zijderveld diagrams and stereographic projections; For other explanations see Fig. 2.

Range. It lies inside the caldera, or volcanic basin of the Mount Mazama.

The Mount Rainier is an active volcano that first erupted about half million years ago. Rainier is known to have eruption as recently as in 1940s and large eruptions took as recently as about 1 000 and 2 300 years ago.

The dacite pumice and dacite of the Mount St. Helens

One investigated sample is the rhyodacite pumice (a young rock, but of not precisely known age; the results are shown in Fig. 6) and the second sample is a dacite coming from the lava flow, may be from the 1980 eruption (the samples were collected by I. Vacek and I. Orlický). The rhyodacite pumice contains the hematite-ilmenite (Hem-Ilm) phase with $T_C = 390°$ C, and the second oxidized Ti-Mt phase with $T_C = 520°$ C. The Hem-Ilm phase carries probably the reversed RM (of self-reversal origin), the Ti-Mt phase carries RM of normal polarity. Both phases are supposed to be of lower stability. Two magnetic Fe-Ti phases are also in the dacite of the 1980 eruption (in Fig. 7). The Hem-Ilm phase carries probably a reversed RM

The rocks from the St. Helens, the Mazama and the Rainier Volcanoes

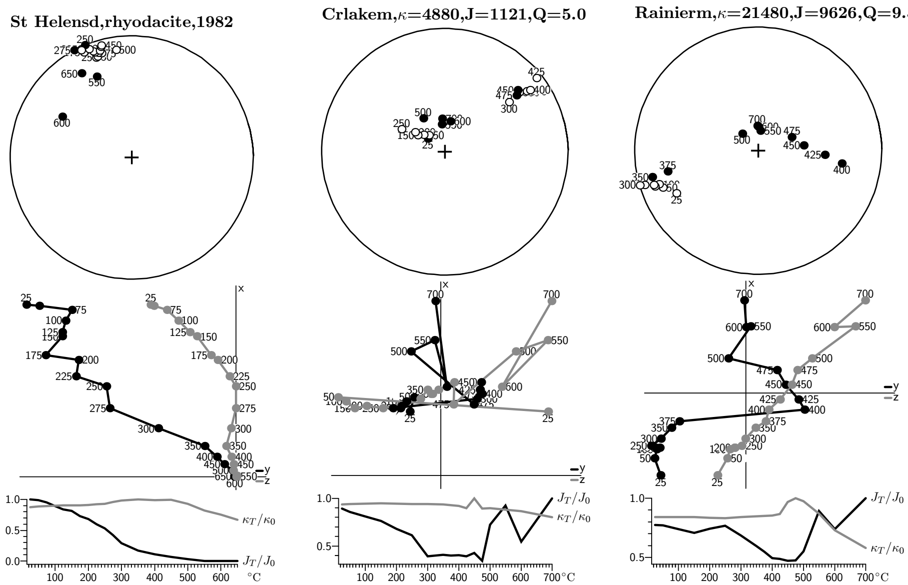

Fig. 7. Thermal demagnetization of rhyolite dacite from the St. Helens Volcano (46.184° N, 122.184° W), inducing of PTRM of dacite from the Mazama Mt., the Crater Lake Volcano (42.993° N, 122.008° W) and of andesite from the Rainier Volcano (46.85° N, 121.842° W). Zijderveld diagrams and stereographic projections; For other explanations see Fig. 1.

(of a self-reversal origin) and the Ti-Mt phase carries RM of normal polarity. Because of dominant Hem-Ilm composition of Fe-Ti oxides in the above mentioned dacites, there is no chance to find the low-temperature oxidized Ti-Mgh phase of the self-reversal behaviour in both investigated samples. The Hem-Ilm solid solutions of the composition Ilm_{50-75} were also found in the dacitic pumice blocks from Mt. Shasta, California by *Lawson et al. (1987)*. These solid solutions were considered to be as the source of the self-reversed RM in the dacitic pumice rocks by the mentioned authors. The Mount Shasta belongs also into the Cascade Range Volcanoes of the North Western Part of the USA.

The dacite of the Crater Lake and the andesite of the Rainier Volcanoes

The dacite from the volcanic area of the Crater Lake is about 10,000 years old. The age of the andesite of the Rainier volcano is about 20,000 years (the samples were collected by Dr. J. Lexa). The dacite of the Crater Lake contains dominantly the Ti-Mt phase with $T_C = 480°$ C and small portion of more oxidized phase with $T_C = 565°$ C. After heating of the sample to 700° C and its cooling a new phase with $T_C = 445°$ C was created according to *Orlický (2003)*. The distribution of the directions of PTRM indicates the presence of two magnetic phases in the rock (Fig. 7). So far, no low-temperature oxidized Ti-Mgh phase have been developed in this dacite. The andesite of the Rainier volcano contains dominant oxidized Ti-Mt phase with $T_C = 530°$ C and small portion of more oxidized Fe-Ti phase with $T_C = 560°$ C. After heating of the sample to 700° C and its cooling a new phase of a lower κ, compared to the original sample was created. The distribution of the directions of PTRM has shown a presence of two Fe-Ti phases during magnetizing procedure. We suppose that there is a small portion of the low-temperature oxidized Ti-Mgh phase with a self-reversal behaviour in the andesite.

The Mount Etna and the Mount Kilauea volcanoes

Mount Etna is the most active volcano in Europe. It was formed from the shield basalt eruptions which began about 500 000 years ago. Stratovolcano began forming about 35 000 years ago from more trachytic lavas. Etna's current activity consists of continuous summit degassing, explosive Strombolian eruptions and frequent basaltic lava flows. One investigated basaltic sample is from the 1983 eruption and the second basaltic scoria sample is from the 1992 eruption.

The basalt from the 1983 eruption contains dominantly the Ti-Mt phase with $T_C = 520°$ C and a small portion of more oxidized Fe-Ti phase with $T_C = 565°$ C. Both phases contribute to a rather homogeneous directions of PTRM during magnetizing in the laboratory (Fig.c 8). No low-temperature oxidized Ti-Mgh phase was so far developed in this basalt. Basaltic scoria from the 1992 eruption contains dominantly Ti-rich Ti-Mt phase with $T_C = 250°$ C and a small portion of more oxidized Ti-Mt phase with $T_C = 500 - 550°$ C. The presence of two magnetic phases is detected also by the distribution of PTRM during step-wise laboratory magnetizing procedure. No low-temperature oxidized Ti-Mgh phase was detected in this basaltic scoria sample.

About 90% of the surface of Kilauea is formed by lava flows less than 1 100 years old. About 70% of the volcano's surface is younger than 600 years. The latest Kilauea eruption began in January 1983 along the E-rift zone. The tholeitic basalt comes from the 1971 eruption. This basalt contains dominantly the Ti-rich Ti-Mt phase with $T_C = 125°$ C and more oxidized Ti-Mt phases with $T_C = 420$ and $560°$ C, respectively. During the inducing of PTRM in the sample, a quite homogeneous distribution of PTRM directions was detected. No low-temperature oxidized Ti-Mgh phase has so far been developed in this tholeitic basalt. Except of this basalt, three samples from the Hawaii area (basaltic sample from the 1984 eruption, near the Papa Village - cca 70 km SW of Kilauea volcano, two basaltic scoria samples, one from the 1982 eruption and one from the 1972 eruption, both from volcanic field around the Kilauea volcano (19.430°, 155.290° W) were

The basalts from the Etna and the Kilauea Volcanoes

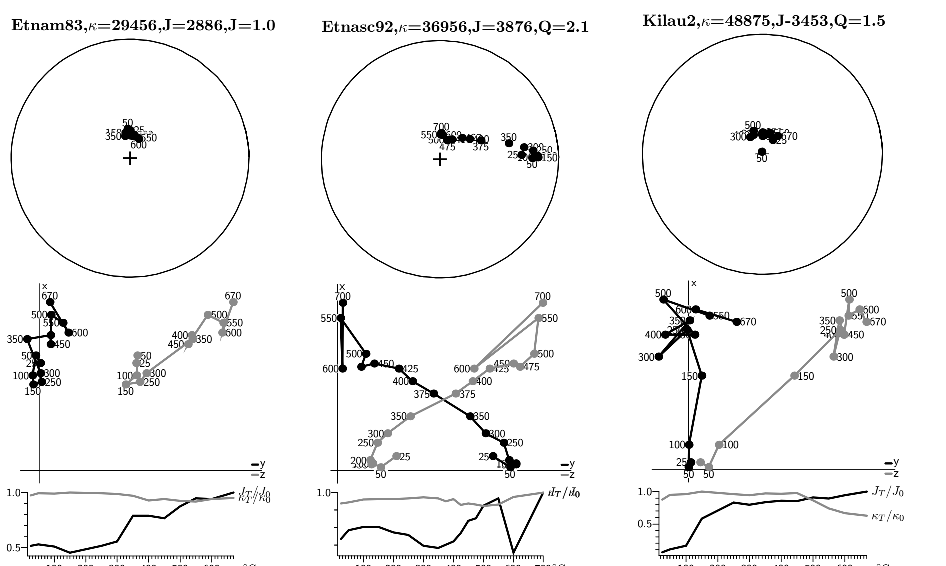

Fig. 8. Thermal inducing of PTRM of basalts from the Etna volcano (37.73° N, 15.00° E) and the Kilauea Volcano (19.430°, 155.290° W). Zijderveld diagrams and stereographic projections; For other explanations see Fig. 1.

laboratory tested (the samples were collected by I. Vacek). Similar to the tholeitic basalt, no low-temperature oxidized Ti-Mgh phase with the self-reversed tendency was detected also in these samples.

Apart from the results described above, the two basaltic scoria samples from the places near the small cinder cone of the Death Valley, USA (36.308° N, 117.08° W) were tested (the samples were collected by I. Orlický). The age of these samples may be in the range of 700 000 to 12.0 million years *(Wikipedia, the free encyclopedia)*. In both samples a low-temperature oxidized Ti-Mgh phase with a self-reversal properties has been detected on the basis of the increase of magnetic susceptibility in the interval from 300° C with a maximum peak at about 410° C.

3. Discussion and conclusions

This work has been focused on the investigation of young volcanic rocks from different places of the globe. A goal of the work was to identify the low-temperature oxidized Ti-Mgh phase, in the young or recent volcanics. The thermal demagnetization tests and laboratory partial thermoremanent magnetization (PTRM) of the samples at selected temperatures in the field of intensity $H \approx 48\mu\,\mathrm{T}$ were applied. In addition, the change of magnetic susceptibility (κ) at selected temperature intervals of the compact samples and the measurement of the Curie temperatures and study of behaviour of κ in the low and high temperature intervals were investigated.

Only a small portion of the low-temperature oxidized Ti-Mgh phase was detected in the oxidized basaltic scoria from Tenerife volcano (no self-reversal of PTRM was identified), in the andesite from the Rainier volcano (20 000 years old). But in the older basaltic scoria of the Death Valley (age either 700 000 years or more) the characteristic increase of κ in the samples was detected. All other 12 laboratory tested volcanic rocks did not possess the low-temperature oxidized Ti-Mgh phase.

I have considered these results as the preliminary ones. Further studies of other collections of young volcanics to gather more information about the magnetic Fe-Ti minerals and their magnetic behaviour are in progress.

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