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# PALEOMAGNETISM AND RADIOMETRIC AGES OF BASALTS OF CENTRAL AND SOUTHERN SLOVAKIA (WESTERN CARPATHIANS)

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**Abstract:** Recently a paleomagnetic investigation, an analysis of magnetic minerals and radiometric (K/Ar) ages of the Pliocene-Pleistocene basalts of Central and Southern Slovakia has been performed. The analyses of the magnetic fraction of basalts revealed that the main carriers of magnetic properties are the titanomagnetites $Fe_{3-x}Ti_xO_4$ with the compositional parameters $x \approx 0.3$-$0.7$. AF and thermal demagnetization tests were employed to consider the paleomagnetic stability of basalts. Stable remanent magnetization is thought to be linked to the more oxidized magnetic phase in basalts, comparing the results of the Curie temperature measurements with those of the thermal demagnetization tests of the rocks under consideration. The interpretation of the results is based mainly on the polarity of the stable remanent magnetization, using the combination of radiometric ages of the rocks and comparing it with the polarity intervals of the geologic time scale of Harland et al. 1989. Seven volcanic phases of basaltic activity were established. First volcanic phase: products of the Kalvária Basalt Complex and volcanics of the Podrečany Formation. The former were emplaced during normal geomagnetic field (NF — 7.17-7.56 Ma), the latter arose in the course of reversed geomagnetic field (RF — in the interval, either 6.33-6.66, or 6.79-7.01 Ma). The second volcanic phase: (NF — 4.79-5.08 Ma, RF — 5.08-5.69 Ma and 4.48-4.79 Ma). The third volcanic phase: (NF — 2.48-2.92 Ma). The fourth volcanic phase: (RF — 2.09-2.48 Ma, NF — 1.65-1.88 Ma). The fifth volcanic phase (RF — 0.97-1.65 Ma). The sixth volcanic phase: (NF — either 0.0-0.72, or 0.91-0.97 Ma). The seventh volcanic phase contains lava flows of the nepheline basanites of the Putikov vŕšok Complex, which is the youngest volcanic body among of all volcanic complexes in the Western Carpathians. These basalts originated during the Brunhes epoch.

**Key words:** Pliocene to Pleistocene basalts, paleomagnetic dating, K/Ar ages of basalts.

## Introduction

Alkaline basaltic volcanism in Central and Southern Slovakia was active during the Pliocene to Pleistocene. Basaltic volcanism in the Western Carpathians is represented only by smaller geological units. Generally, effusive forms prevail over the explosive or intrusive basaltic bodies.

Few authors have used paleomagnetic data for a more precise determination of the time of an emplacement of basalts under consideration. Nairn (1966) assumed that volcanic activity produced basalts around the Pliocene-Pleistocene boundary, during the period of reversed geomagnetic field. The end of basaltic activity coincided with the period of normal geomagnetic field. Basalts from the Brehy and Kysihýbeľ localities were investigated by Dublan (1967). According to his interpretation, the age of these basalts is supposed to be less than one million years. Orlický et al. (1982) studied basalts from several localities in Central and Southern Slovakia. They used the K/Ar ages (published by Balogh et al. 1981) and the time-scale of the geomagnetic field of McDoughal (1967) to get more precise dates for the origin of the basaltic products of the area under consideration. According to their interpretation the age of basalts from the Brehy and Tekovská Breznica localities coincided with the Brunhes normal epoch, the ages of basalts from the Hajnačka, Blhovce and Hodejov coincided with the Gauss normal epoch, whereas basalts from the Kalvária and Kysihýbeľ (both near of Banská Štiavnica) and Podrečany locality should be emplaced during the epoch 7 (within the interval 6.55-7.9 Ma) of the above mentioned scale. The age of basalts from the localities around Fiľakovo, with the reverse polarity of the RMP coincided with the Matuyama reverse epoch. Balogh et al. (1995) studied basalts of the Cerová Basalt Formation. Their development schemes show that after the Pontian five phases of basaltic volcanism took place in the Cerová vrchovina Upland. Three of them occured in the Pliocene. Age of the oldest basalts oscilates around 4.0 to 4.5 Ma. The Pliocene volcanism corresponds to the development of the dome in the centre of the Cerová vrchovina Upland.

New geological knowledge, including the K/Ar ages of the Podrečany and the Cerová Basalt Formations, and all so far obtained paleomagnetic data have been compiled to improve on the previous interpretation and to suggest the succession of the time evolution of the basaltic activity in Central and Southern Slovakia.

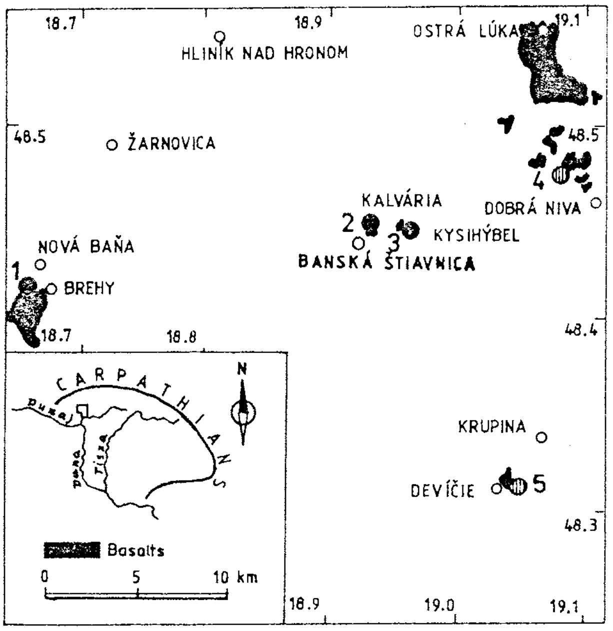



**Fig. 1.** Basaltic rocks of Central Slovakia. 1, 2 — normal, reversed polarity of the RMP of rocks, respectively. 1-5 number of the locality.

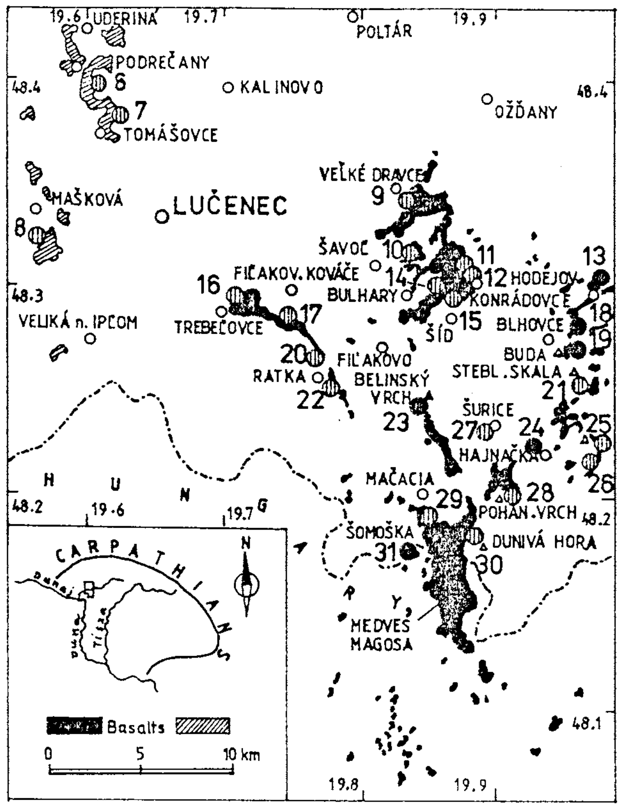



**Fig. 2.** Basaltic rocks of Southern Slovakia. 1 — Podrečany Basalt Formation, 2 — Cerová Basalt Formation. 3, 4 — normal, reversed polarity of the RMP of rocks, respectively. 6-31 — number of the locality.

## Experimental methods and basic results

Investigated basalts come from 31 localities (see Figs. 1, 2). Three basic petrographical types of rocks were distinguished. Nepheline basanite (loc. No. 1, 3, 9, 10, 11, 14, 18, 23, 24), olivine basalt (loc. No. 2, 6, 15, 20, 25, 26, 29), and limburgitic basanite (loc. No. 27). There was investigated also basaltic tuff from the loc. No. 13.

### *Study of magnetic minerals*

Sixty seven samples of the magnetic fraction of basalts were studied by measuring the change of their magnetic susceptibility (κ) with temperature (thermomagnetic curves of selected samples are presented in the Figs. 3, 4). Mössbauer spectroscopy, X-ray powdered diffraction as well as the electron microprobe analyses of samples were performed (Orlický et al. 1982, 1992; selected Mössbauer spectra are given in Fig. 5). The main carriers of magnetic properties of the basalts under consideration are the titanomagnetites $Fe_{3-x}Ti_xO_4$, with the compositional parameter x ≈ 0.3-0.7 (x = 0.3 corresponds to samples like No. 1/2 Fig. 3, with a characteristic two sextet pattern of the Mössbauer spectrum, and high values for the Curie temperatures, e.g. $T_C$ ≈ 580 °C; x = 0.7 corresponds to samples like 7/1, Figs. 4, 5, with the very low Curie temperatures of main magnetic phase, e.g. $T_C$ ≈ 130 °C, and with a typical very broad, non Lorentzian Mössbauer spectrum).

Study of magnetic minerals showed that Fe-Ti oxides with a prevailing very low Curie temperature occur. A magnetic phase with a low $T_C$ ≈ 130-220 °C was revealed in basalts from 21 localities. The second — more oxidized phase ($T_C$ ≈ 510-580 °C) was always detected in the samples from these 21 localities (e.g. Fig. 3, sampl. No. 1/11, 5/3, 6/1, 7/1, 8/2. Fig. 4, sampl. No. 9/1, 14/1, 16/1, 22/3, 25/2, 31/1). The proportion of the second phase to that with the low Curie temperature is too variable. The samples of basalts from the nine localities (loc. No. 3, 4, 10, 11, 12, 18, 19, 27, 28) contain either only one magnetic phase with the high Curie temperature ($T_C$ ≈ 560-580 °C), or negligible portion of a phase with the low $T_C$ (e.g. Fig. 4, sample No. 10/2) is also present. The presence of the magnetic phase with the high Curie temperature in these basalts shows that both — forming and cooling of basaltic magma took place in a stage of oxidative conditions. Two magnetic phases with very close values of the Curie temperatures were exceptionally detected in some samples of basalts (Fig. 3, sample 2/7, $T_{C1}$ ≈ 520 °C, $T_{C2}$ ≈ 565 °C).

### *Laboratory procedures*

Individual cube-shaped samples of rocks were measured using the spinner magnetometer JR-4. AF demagnetization in the range H = 0-50 mT, as well as the thermal demagnetization in the range 25-650 °C were applied to test the magnetic and paleomagnetic stability of rocks. The demagnetization of rock samples by the thermal field was more efficient than the demagnetization by the alternating field. Therefore it was used as the standard method for stepwise demagnetization. Samples of rocks were subjected to progressive thermal demagnetization using the MAVACS apparatus (Příhoda et al. 1989). In order to obtain the most correct results, all measurements of the RMP of rocks were performed by the spinner magnetometer JR-4, the pick-up unit of which was placed in the centre of the Helmholtz's coils. All operations with the rock samples

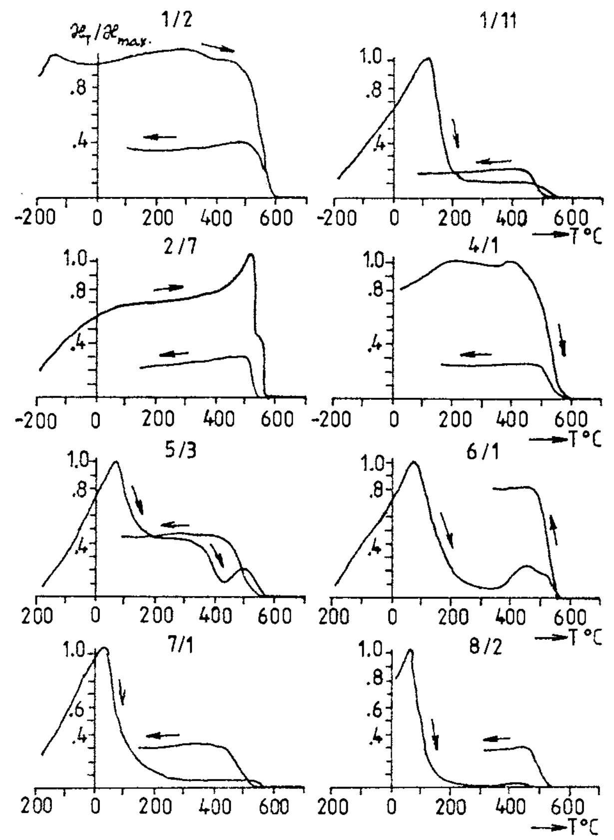



**Fig. 3.** Thermomagnetic curves of magnetic minerals of basaltic rocks. 5/3 — number of the sample. $\kappa_T$, $\kappa_{Max}$— magnetic susceptibility of the sample at the temperature T ($\kappa_T$), maximal value from the set of data ($\kappa_{Max}$).

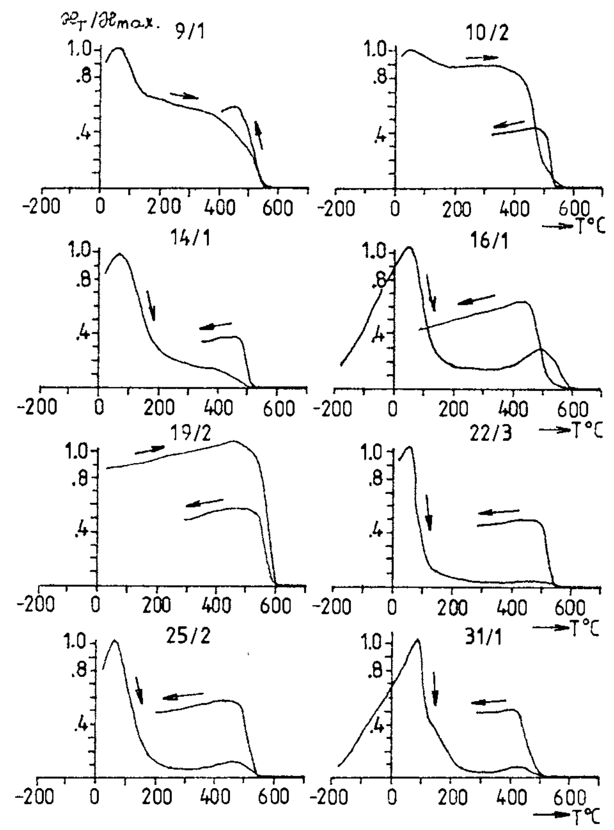



**Fig. 4.** Thermomagnetic curves of magnetic minerals of basaltic rocks. Explanations as in Fig. 3.

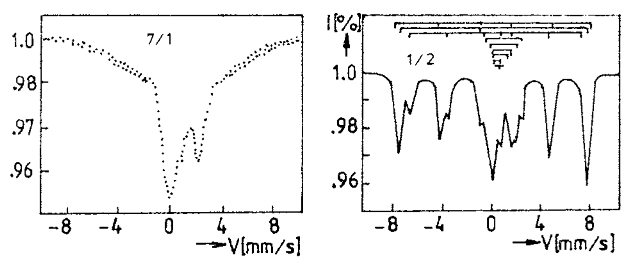



**Fig. 5.** Mössbauer spectra of magnetic fraction of basaltic rocks.

were shielded against any influence of an external magnetic field. After each step of the thermal demagnetization the rock sample was placed into a special container (constructed from the supermalloy material) and transfered from the magnetic vacuum of the MAVACS system into the pick-up unit of the JR-4 spinner magnetometer. For selected samples we constructed Zijderveld diagrams for the dependence of the standardized value of the remanent magnetization on temperature $J_T/J_0$ (designated as J), and the dependence of the standardized value of magnetic susceptibility on temperature $\kappa_T/\kappa_0$ (designated as $\kappa$). The examples of the thermal demagnetization of selected rock samples are illustrated in Figs. 6-8. Whereas the intensity of the remanence (J) of samples with a dominant magnetic phase of the low Curie temperature usually shows a more or less significant decrease in the range 50-300 °C (or 350 °C), the magnetic susceptibility ($\kappa$) of most of these samples increases very sharply in the range 200-400 °C, and then decreases (e.g. Fig. 6, sample 6/2). The intensity of remanence (J) of basalts with only one-magnetic phase of the high Curie temperature shows significant variations of its values up to T ≈ 450 °C (or 500 °C) and then decreases. The magnetic susceptibility of these basalts remains mostly stable within the whole temperature interval (25-600 °C, e.g. Fig. 8, sample 28/2). The results have shown that stability of the RMP increases proportionally to the portion of the more oxidized Fe-Ti oxide in basalts. The most stable are thought to be the basalts which contain only magnetic phase of the high Curie temperature ($T_C$ ≈ 560-580 °C). The stable direction of the RMP of these basalts is preserved in all the steps of the thermal demagnetization, in the range 25-600 °C (Fig. 8, sample 28/2). A good stability of the RMP is also found in basalts, which contain a higher portion of the more oxidized magnetic phase (with high $T_C$), besides that of the low Curie temperature (e.g. Fig. 7, sample 16/3). A very low dispersion of the direction of the RMP of this sample within the interval 25-550 °C has been detected. Samples of basalts with both, dominant content of the low Curie temperature phase, as well as a very low content of the second magnetic phase (of low $T_C$) have shown currently higher dispersion of the direction of the RMP within applied temperature intervals (25-600 °C). The stable direction of the RMP has been preserved in the interval 50-350 °C, 50-500 °C (Fig. 6, samples 6/2, 8/2 respectively), 50-450 °C (Fig. 7, sample 22/6), or 25-500 °C (Fig. 8, sample 31/1A1). The Fe-Ti oxide with $T_C$ ≈ 180 °C is supposed to be the dominant magnetic phase in the sample 8/2 (Fig. 3); the content of the more oxidized Fe-Ti oxide of

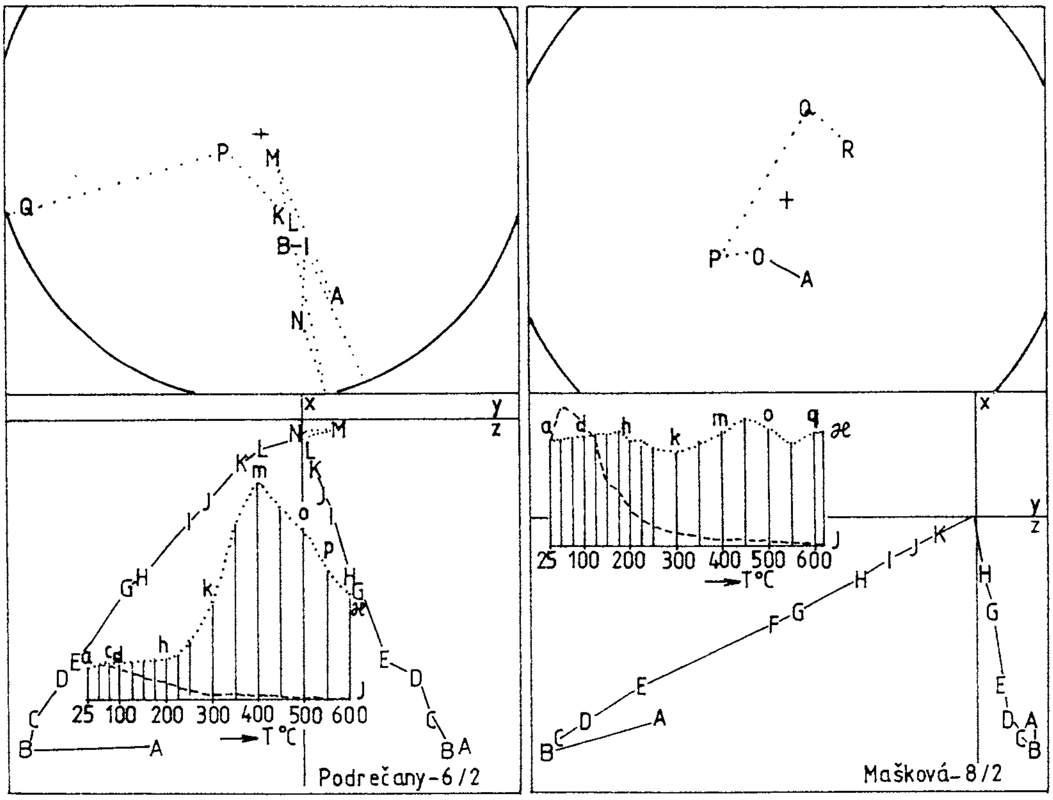



**Fig. 6.** Thermal demagnetization, Zijderveld diagrams and stereographic projections of RMP of selected basaltic rocks.

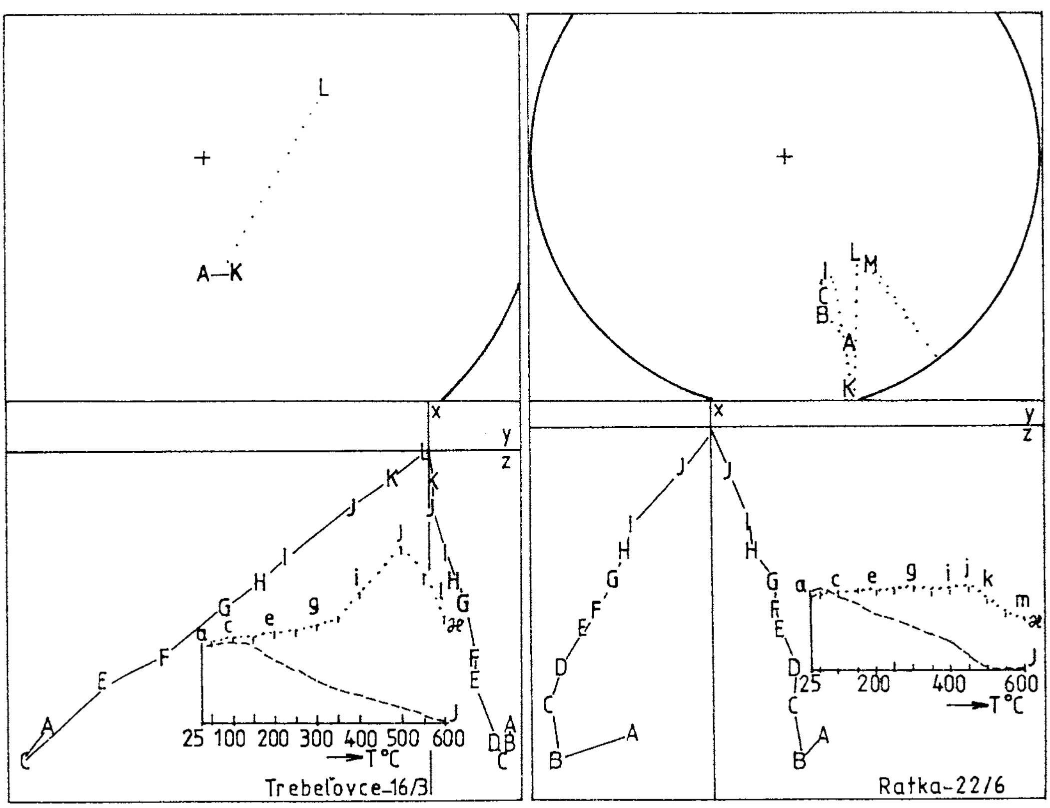



**Fig. 7.** Thermal demagnetization, Zijderveld diagrams and stereographic projections of RMP of selected basaltic rocks.

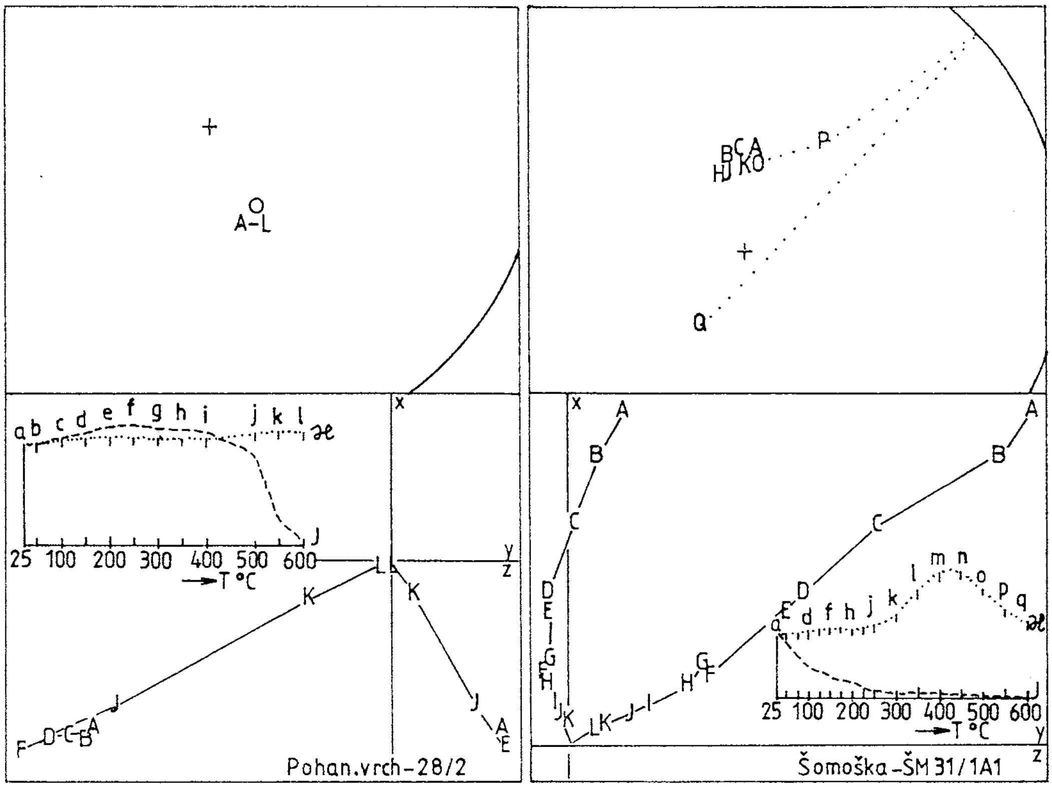



**Fig. 8.** Thermal demagnetization, Zijderveld diagrams and stereographic projections of RMP of selected basaltic rocks.

$T_C \approx 500$ °C is quite negligible. The results of the thermal demagnetization of this sample have shown an insignificant dispersion of the direction of the RMP within the interval 50-500 °C (Fig. 6, sample 8/2). We may assume that the stable component of the RMP of basaltic rocks is linked to the more oxidized Fe-Ti oxides. We can remark that the effective field for the demagnetization of all the samples of basalts from an individual locality was chosen according to the results of the

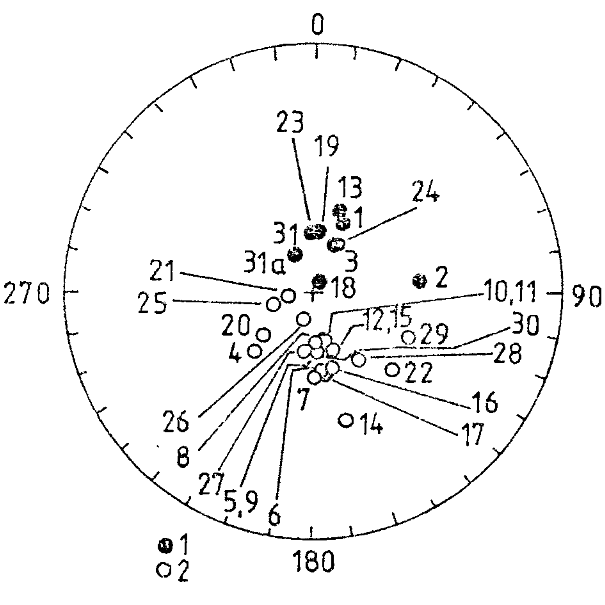



**Fig. 9.** Stereographic projections of mean RMP of basalts of individual localities. 1, 2 — normal, reversed polarity of RMP of basalts, respectively. 1-31 — number of locality.

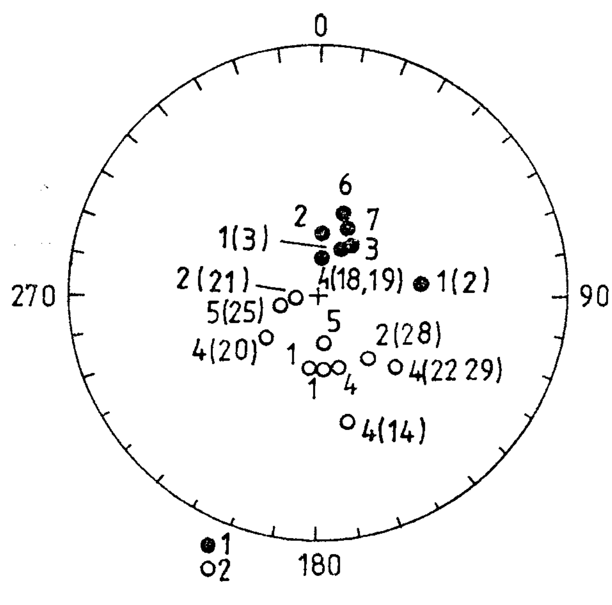



**Fig. 10.** Stereographic projections of summarized directions of RMP of basalts of selected volcanic phases. 1, 2 — normal, reversed polarity of RMP of basalts of volcanic phase, respectively. 1-7 — number of volcanic phase.

**Table 1:** Paleomagnetic data of basaltic rocks of Central and Southern Slovakia.

| Number of locality | Name of locality | Number of samples | Geographic coordinates | | Mean palaeomagnetic directions | | k | $\alpha_{95}$ | Virtual pole positions | | Ovals of confidence | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\varphi_L$ | $\lambda_L$ | I° | D° | | | $\varphi_{P(N)}$ | $\lambda_{P(E)}$ | $\delta_m$ | $\delta_p$ |
| 1 | Brehy, near Nová Baňa | 11 | 48.410 | 18.650 | 58.5 | 20.3 | 82.0 | 5.0 | 72.8 | 133.4 | 8.0 | 8.0 |
| 2 | Kalvária | 7 | 48.460 | 18.917 | 43.0 | 83.0 | 541.0 | 3.0 | 22.9 | 96.5 | 4.0 | 3.0 |
| 3 | Kysihýbeľ | 12 | 48.460 | 18.941 | 69.0 | 23.0 | 17.0 | 14.0 | 74.9 | 84.8 | 23.0 | 20.0 |
| 4 | NW of Dobrá Niva | 4 | 48.486 | 19.067 | -54.9 | 222.2 | 97.0 | 26.0 | 56.5 | 116.1 | 36.0 | 26.0 |
| 5 | Devíčie | 11 | 48.317 | 19.030 | -60.8 | 176.7 | 59.0 | 6.0 | 83.1 | 219.9 | 9.0 | 7.0 |
| 6 | Podrečany | 18 | 48.399 | 19.608 | -53.8 | 175.9 | 111.0 | 5.0 | 75.6 | 213.5 | 9.6 | 5.9 |
| 7 | Podrečany - Tomášovce | 5 | 48.390 | 19.625 | -50.8 | 178.3 | 359.1 | 4.0 | 73.1 | 204.5 | 5.5 | 3.7 |
| 8 | Mašková | 14 | 48.320 | 19.576 | -66.6 | 178.5 | 115.0 | 4.0 | 88.7 | 331 | 6.0 | 5.0 |
| 9 | SE of Veľké Dravce | 6 | 48.348 | 19.842 | -63.4 | 172.3 | 1171.0 | 2.2 | 83.9 | 259.9 | 2.2 | 1.1 |
| 10 | NE of Šavoľ | 18 | 48.310 | 19.855 | -68.5 | 175.4 | 596.0 | 1.6 | 85.5 | 341.0 | 2.7 | 2.3 |
| 11 | Konrádovce | 8 | 48.296 | 19.879 | -68.7 | 173.1 | 892.0 | 2.2 | 84.2 | 332.8 | 3.7 | 3.2 |
| 12 | Konrádovce | 11 | 48.294 | 19.883 | -64.4 | 160.9 | 280.0 | 3.3 | 76.9 | 287.9 | 5.3 | 4.2 |
| 13 | Hodejov | 13 | 48.290 | 19.988 | 51.0 | 19.0 | 18.0 | 14.6 | 68.0 | 152.2 | 19.7 | 13.3 |
| 14 | Bulhary | 8 | 48.288 | 19.862 | -34.3 | 166.6 | 31.0 | 12.2 | 58.6 | 225.0 | 19.9 | 8.0 |
| 15 | N of Šíd | 7 | 48.287 | 19.873 | -63.5 | 158.2 | 541.0 | 3.0 | 74.8 | 285.9 | 4.0 | 3.0 |
| 16 | Trebeľovce | 4 | 48.287 | 19.716 | -55.1 | 161.0 | 2003.0 | 2.1 | 71.1 | 254.6 | 2.9 | 2.1 |
| 17 | Fiľakovské Kováče | 4 | 48.284 | 19.747 | -53.4 | 168.0 | 1165.0 | 2.7 | 73.1 | 236.2 | 3.7 | 2.6 |
| 18 | Blhovce | 11 | 48.278 | 19.957 | 88.0 | 11.0 | 115.0 | 5.2 | 52.2 | 21.2 | 10.4 | 10.4 |
| 19 | Blhovce - Buda | 6 | 48.266 | 19.957 | 61.0 | 3.7 | 4327.0 | 1.0 | 83.3 | 176.0 | 1.6 | 1.24 |
| 20 | WWS of Fiľakovo (Ratka) | 9 | 48.264 | 19.790 | -60.0 | 230.0 | 18.0 | 14.6 | 54.3 | 102.6 | 22.0 | 16.7 |
| 21 | Steblová skala | 7 | 48.250 | 19.986 | -78.0 | 261.5 | 107.6 | 5.8 | 46.5 | 54.2 | 11.0 | 10.3 |
| 22 | SW of Fiľakovo (Ratka) | 10 | 48.250 | 19.786 | -43.2 | 132.4 | 24.6 | 12.4 | 46.3 | 264.6 | 15.4 | 9.6 |
| 23 | Belinský vrch | 7 | 48.237 | 19.863 | 60.8 | 358.7 | 407.0 | 3.8 | 83.5 | 331.5 | 5.8 | 4.4 |
| 24 | Hajnáčka - Castle | 15 | 48.219 | 19.957 | 63.0 | 31.0 | 19.0 | 5.2 | 68.4 | 108.3 | 8.2 | 6.4 |
| 25 | Hajnáčka - Ragáč | 2 | 48.224 | 19.990 | -70.0 | 255.0 | 96.5 | 8.0 | 44.8 | 73.2 | 12.0 | 9.0 |
| 26 | E of Hajnáčka | 6 | 48.216 | 19.988 | -76.0 | 195.0 | 315.0 | 5.2 | 72.7 | 42.8 | 9.6 | 8.8 |
| 27 | Soví hrad, WS of Šurice | 7 | 48.228 | 19.908 | -64.3 | 187.3 | 543.0 | 3.2 | 84.6 | 131.0 | 4.6 | 3.3 |
| 28 | Pohanský vrch | 11 | 48.200 | 19.922 | -55.8 | 143.9 | 726.0 | 1.7 | 61.1 | 279.1 | 2.4 | 1.7 |
| 29 | Mačacia | 6 | 48.187 | 19.858 | -42.7 | 115.4 | 18.7 | 21.8 | 34.9 | 289.1 | 26.2 | 16.6 |
| 30 | Dunivá hora | 3 | 48.176 | 19.871 | -62.8 | 170.2 | 67.0 | 15.2 | 82.2 | 262.8 | 23.8 | 18.7 |
| 31 | Šomoška | 18 | 48.170 | 19.842 | 60.8 | 4.3 | 115.0 | 3.0 | 82.9 | 173.1 | 5.0 | 4.0 |
| 31a | Šomoška | 22 | 48.170 | 19.842 | 72.1 | 334.8 | 80.0 | 3.0 | 72.4 | 330.0 | 6.0 | 5.0 |

I°, D° - inclination, declination of RMP of rocks, respectively
k - precision parameter; $\alpha_{95}$ - semi-vertical angle cone of confidence at P=0.05

thermal demagnetization of a representative sample. It was mostly within the interval 150-350 °C.

We constructed the review statistical table for each group of samples from all localities giving the mean values of stable directions of the RMP, mean virtual pole positions as well as derived statistical parameters (see Tab. 1). Mean paleomagnetic directions of basalts of individual localities are graphically illustrated in Fig. 9. Basalts from 9 localities have shown the normal RMP, whereas basalts from other 22 localities (mostly from the Podrečany and the Cerová Formations) have shown the reverse RMP. Basalts of the thirteen localities with the reverse RMP show quite consistent directions of the RMP, whereas the directions of the RMP of the basalts of other localities are mostly inconsistent. We summarized the paleomagnetic data for the seven established volcanic phases. They are presented in Tab. 2, and in the Fig. 10.

## Interpretation of results and conclusions

It has been shown that the main carriers of magnetic properties in the basalts under consideration are the oxidized titanomagnetites $Fe_{3-x}Ti_xO_4$ with the compositional parameter $x \approx 0.3$–$0.7$. Most basalts contain two or more magnetic phases. The results of Curie temperature measurements and those of the thermal demagnetization procedures of samples show that stable RMP is mostly linked to the second — more oxidized magnetic phase (magnetic Fe-Ti oxides with the higher $T_C$). As has been mentioned above, two main alteration processes determine the state of the Fe-Ti oxides in basaltic rocks. The deuteric oxidation, which is active between 800-500 °C during initial cooling of the basaltic magma and the regional hydrothermal alteration, acting between atmospheric temperature and 300 °C, during the post-eruptive burial of younger

**Table 2:** Summarized paleomagnetic data.

| Volcanic phase | Localities (locality No) | Number of localities | Mean geographic coordinates | | Mean palaeomagnetic directions | | k | $\alpha_{95}$ | Virtual pole positions | | Ovals of confidence | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $\varphi_M$ | $\lambda_M$ | I° | D° | | | $\varphi_{p(N)}$ | $\lambda_{p(E)}$ | $\delta_m$ | $\delta_p$ |
| 7 | Brehy - 1 | 1 | 48.410 | 18.650 | 58.5 | 20.3 | | | 72.8 | 133.4 | | |
| 6 | Hodejov, 13<br>Fiľakovo | 1 | 48.290 | 19.988 | 51.0 | 19.0 | | | 68.0 | 152.2 | | |
| 5 | Veľ. Dravce - 9<br>Šavol - 10<br>Konrádovce - 11,12,<br>E of Hajnáčka - 26<br>WS of Šurice - 27<br>Dunivá hora - 30 | 7 | 48.267 | 19.889 | -67.2 | 175.0 | 169 | 5.0 | 86.4 | 318.4 | 8 | 6 |
| | Ragáč - 25 | 1 | 48.224 | 19.990 | -70.0 | 255.0 | | | 44.8 | 73.2 | | |
| 4 | Bulhary - 14 | 1 | 48.288 | 19.862 | -34.3 | 166.6 | | | 58.6 | 225.0 | | |
| | N of Šíd - 15<br>Trebeľovce - 16<br>Fiľakovské Kováče - 17 | 3 | 48.286 | 19.779 | -57.4 | 162.8 | 179 | 9.0 | 73.9 | 256.6 | 14 | 10 |
| | Ratka - 20 | 1 | 48.264 | 19.790 | -60.0 | 230.0 | | | 54.3 | 102.6 | | |
| | Ratka - 22<br>Mačacia - 29 | 2 | 48.219 | 19.822 | -43.8 | 123.9 | 85 | 27.4 | 40.8 | 282.8 | 34 | 21 |
| | Blhovce - 18<br>Blhovce-Buda - 19 | 2 | 48.272 | 19.957 | 74.5 | 4.2 | 18.1 | 63 | 77.0 | 29.0 | 114 | 103 |
| 3 | Hajnačka -24 | 1 | 48.219 | 19.957 | 63.0 | 31.0 | | | 68.4 | 108.3 | | |
| 2 | Steblová skala - 21 | 1 | 48.250 | 19.986 | -78.0 | 261.5 | | | 46.5 | 54.2 | | |
| | Pohanský vrch -28 | 1 | 48.200 | 19.922 | -55.8 | 143.9 | | | 61.1 | 279.1 | | |
| | Belinský vrch -23<br>Šomoška - 31 | 2 | 48.204 | 19.853 | 60.8 | 1.5 | 1760 | 6.0 | 83.6 | 189.8 | 9 | 7 |
| 1 | Kalvária -2 | 1 | 48.460 | 18.917 | 43.0 | 83.0 | | | 22.9 | 96.5 | | |
| | Kysihýbeľ - 3 | 1 | 48.460 | 18.941 | 69.0 | 23.0 | | | 74.9 | 84.8 | | |
| | Podrečany - 6<br>Podrečany - Tomášovce - 7<br>Mašková - 8 | 3 | 48.370 | 19.603 | -57.1 | 177.5 | 93 | 13.0 | 79.1 | 210.3 | 19 | 14 |
| | NW of Dobrá Niva - 4<br>Devičie - 5<br>Podrečany - 6<br>Podrečany - Tomášovce - 7<br>Mašková - 8 | 5 | 48.382 | 19.381 | -58.7 | 186.5 | 42 | 12.0 | 79.9 | 169.6 | 18 | 13 |

Explanations of I°, D°, k, $\alpha_{95}$, $\delta_p$, $\delta_m$ see for Tab. 1.

material. We suppose that the stable component of the RMP of the basalts under consideration is of chemical origin.

The main task of the interpretation of our results is to suggest the most objective succession of basaltic activity. We have used preferentially the polarity of the stable RMP of basalts, available geological knowledge and radiometric K/Ar data. We have compared it with the polarity intervals of the geologic time scale according to Harland et al. (1989). All available data have been summarized into Tab. 3, and they are illustrated in Fig. 11. These comprehensive conceptions can be considered as the most objective schemes for the development of basaltic activity in Central and Southern Slovakia. According to these schemes, the succession of activity of all basaltic formations and complexes under consideration of the Pliocene-Pleistocene period took place in the following seven volcanic phases:

**First volcanic phase:** the oldest basalts are thought to be the lava necks of the Kalvária Basalt Complex in Central Slovakia and the lava flows of the Podrečany Basalt Formation in the Southern Slovakia. The basalts of the Kalvária Basalt Complex originated during the normal geomagnetic field, probably in the time interval 7.17-7.56 Ma (less probably in the interval 7.01-7.1 Ma). The basalts of the Podrečany Formation arose in the course of the reverse geomagnetic field in the interval 6.33-6.66, or 6.79-7.01 Ma. According to a resemblance paleomagnetic and petrophysical features with those of the Podrečany Formation, the basalts of the localities

**Table 3:** Chronostratigraphy and polarity of RMP of basalts of the Central and Southern Slovakia.

| Region | Locality | Number of locality | Name of unit | Volcanic form | K/Ar Age (Ma) | Isochronic Age (Ma) | Volcanic phase | Polarity of RMP | Stratigraphy | |
|---|---|---|---|---|---|---|---|---|---|---|
| Central Slovakia | Brehy-near Nová Baňa | 1 | Pútikov Vršok Complex | Lava flow | $0.53 \pm 0.16$ | | 7 | N | RISS | PLEIS- |
| Southern Slovakia | Hodejov | 13 | Cerová Formation | Maar | | | 6 | N | GUNS | TOCE- |
| | Fiľakovo | | | Maar | | | | | MINDEL | |
| Southern Slovakia | Dunivá hora | 30 | Cerová Formation | Dyke | | $1.32 \pm 0.1^u$ | 5 | R | | NE |
| | Borkút - Roháč (Ragáč) | 25 | | Lava flow | $1.39 \pm 0.12^x$<br>$1.28 - 1.48^u$ | $1.35 \pm 0.32^x$ | | R | RO- | |
| | Konrádovce | 11, 12 | | Lava flow | $1.51 \pm 0.2^x$ | | | R | MA- | |
| | Veľké Dravce | 9 | | Lava flow | $1.9 \pm 0.13^x$ | $1.62 \pm 0.32^x$<br>$1.27 \pm 0.15^u$<br>$1.29 \pm 0.34^u$ | | R | NI- | |
| Southern Slovakia | Bulhary | 14 | Cerová Formation | Linear intrus. | $2.19 \pm 0.16^x$<br>$1.6 - 2.44^x$ | $1.47 \pm 0.31^x$<br>$1.6 - 1.7^x$ | 4 | R | AN | |
| | Blhovce-Buda | 19 | | Lava flow | $1.73 \pm 0.1^u$ | | | N | | |
| | Hajnačka | | | Maar | | | | N | MN- | |
| | Fiľakovské Kovače | 17 | | Lawa flow | $2.15 \pm 0.13^x$<br>$2.30 \pm 0.4^u$ | | | R | 16 | |
| | Trebeľovce | 16 | | Lava flow | $2.59 \pm 0.12^x$ | | | R | 1.8- | PLI- |
| | Ratka | 20,22 | | Lava flow | $1.93 \pm 0.23^u$<br>$1.94 \pm 0.16^u$ | | | R | 2.0 | OCE- |
| | Mačacia | 29 | | Lava flow | $1.82 \pm 0.1^x$ | | | R | Ma | |
| | Medvedia výšina | | | Lava flow | $2.01 \pm 0.96^x$<br>$2.30 \pm 0.65^x$<br>$2.25 \pm 0.3^6$<br>$2.30 \pm 0.65^6$ | | | | | NE |
| Southern Slovakia | Hajnačka | 24 | Cerová Formation | Dyke within diatreme | $2.58 \pm 0.22^x$<br>$2.87 - 3.02^u$ | $2.75 \pm 0.44^x$ | 3 | N | | |
| Southern Slovakia | Šomoška | 31 | Cerová Formation | Lava neck | $4.59 \pm 0.52^x$<br>$4.65 - 5.96^u$ | $4.06 \pm 0.06^u$<br>$4.08 \pm 0.03^u$ | 2 | N | | |
| | Steblová skala | 21 | | Lava flow | $4.63 \pm 0.2^u$ | | | R | DA- | |
| | Belina | 23 | | Lava flow | $4.76 - 5.80^u$ | 4.3 | | N | CI- | |
| | Pohanský vrch | 28 | | Lava flow | $5.03 \pm 0.26^u$<br>$5.92 \pm 0.31^u$ | $4.7 \pm 0.31^u$ | | R | | |
| Southern Slovakia | Podrečany | 6 | Podrečany Formation | Lava flow | $6.44 \pm 0.27^k$ | $6.17 \pm 0.47^k$ | 1 | R | AN | |
| | Mašková | 8 | | Lava flow | $7.17 \pm 0.47^k$ | | | R | | |
| Central Slovakia | Kysihýbeľ near Banská Štiavnica | 3 | Kalvária Basalt Complex | Lava neck | $6.77 \pm 0.48^k$ | | | N | | |
| | Kalvária (Banská Štiavnica) | 2 | | Lava neck | $7.29 \pm 0.41^k$ | | | N | | |

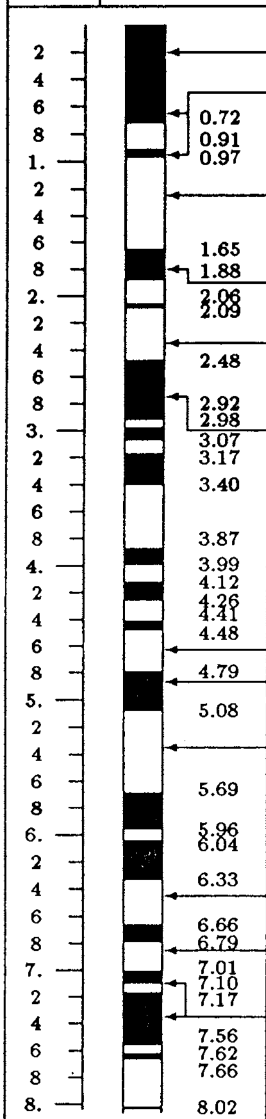
N,R - normal, revered polarity of remanent magnetic polarization (RMP) of basalts, respectively; x,6 - published by Balogh et al. 1981, 1986; u - unpublished (Balogh); k - published by Kantor - Wiegerová, 1981.

NW of Dobrá Niva-4 and Devičie-5 were also included in these intervals.

**Second volcanic phase:** this phase includes basalts of both polarities of the RMP. The basalts of the localities Belinský vrch-23 and Šomoška-31 arose during the normal geomagnetic field, in the time interval 4.79-5.08 Ma, whereas basaltic activity of the localities Pohanský vrch-28 and Steblová skala-21 took place during the reverse geomagnetic field, in the time intervals 5.08-5.69 Ma and 4.48-4.79 Ma, respectively.

**Third volcanic phase:** the dyke body within the diameter of the locality Hajnačka arose in the course of the normal geomagnetic field, probably in the time interval 2.48-2.92 Ma.

**Fourth volcanic phase:** during the fourth volcanic phase in the territory of the Cerová vrchovina Upland many basaltic




| Name of locality--locality No | K/Ar Age (Ma) | Polarity of RMP of basalts | Volcanic phase |
|---|---|---|---|
| Brehy-1, near Nová Baňa | $0.53 \pm 0.16$<br>0.13 – 0.22<br>(according to geological data) | N | 7 |
| Hodejov-13, Fiľakovo | | N | 6 |
| Dunivá hora-30 | $1.32 \pm 0.1$, $1.39 \pm 0.12$ | . | 5 |
| Borkút-Roháč (Ragač)-25 | $1.35 \pm 0.32$, 1.28 – 1.48 | | |
| Konrádovce-11,12 | $1.51 \pm 0.2$ | R | |
| Veľké Dravce-9 | $1.9 \pm 0.13$, $1.62 \pm 0.32$, $1.27 \pm 0.15$ | | |
| Šavoľ-10 | $1.29 \pm 0.34$, $1.16 \pm 0.3$(10) | | |
| E of Hajnačka-26, WS of Šurice-27 | | | |
| Blhovce-18, Blhovce-Buda-19<br>Hajnačka | $1.73 \pm 0.1$ | N | 4 |
| Bulhary-14 | $2.19 \pm 0.16$, $1.47 \pm 0.31$, 1.6 – 2.49, 1.6 – 1.7 | | |
| Fiľakovské Kováče-17, Trebeľovce-16 | $2.15 \pm 0.30$, $2.30 \pm 0.4$, $2.59 \pm 0.12$ | | |
| Ratka-20, 22, N of Šíd-15 | $1.93 \pm 0.23$, $1.94 \pm 0.16$ | R | |
| Mačacia-29 | $1.82 \pm 0.1$ | | |
| Hajnačka-24 | $2.58 \pm 0.22$, $2.75 \pm 0.44$, 2.89 – 3.02 | N | 3 |
| Steblová skala-21 | $4.63 \pm 0.2$ | R | 2 |
| Belinský vrch-23, Šomoška-31 | 4.76 – 5.80, $4.59 \pm 0.52$, $4.06 \pm 0.06$<br>$4.08 \pm 0.03$, 4.65 – 5.96 | N | |
| Pohanský vrch-28 | $5.03 \pm 0.26$, $4.7 \pm 0.31$, $5.92 \pm 0.31$ | R | |
| Podrečany-6, Podrečany-Tomášovce-7 | $6.44 \pm 0.27$, $6.17 \pm 0.47$ | | 1 |
| Mašková-8, NW of Dobrá Niva-4 | $7.17 \pm 0.47$ | R | |
| Devíčie-5 | | | |
| Kalvária-2, Kysihýbeľ-3 | $7.29 \pm 0.41$, $6.77 \pm 0.48$ | N | |

■, □ - normal (N), reversed (R) polarity

Fig. 11. Correlation of remanent magnetization polarities with age of basalts and the modified geological time-scale for the last 8 million years, according to W.B. Harland et al. (1989); (see below the Fig. 11).

bodies were formed. Basalts of the localities of Bulhary-14, Trebeľovce-16, Fiľakovské Kováče-17, Ratka-20, 22, N of Šíd-15, Mačacia-29 arose in the course of the reverse geomagnetic field, probably in the time interval 2.09-2.48 Ma, whereas basalts of the localities of Blhovce-18, Blhovce Buda-19 and Hajnačka (maar) arose during the normal geomagnetic field, probably in the time interval 1.65-1.88 Ma.

**Fifth volcanic phase:** the basalts of this volcanic phase are thought to be very consistente with respect to K/Ar, as well as paleomagnetic data. This phase is represented by basalts of the localities of Veľké Dravce-9, Šavoľ-10, Konrádovce-11, 12, Borkút-Roháč-25, E of Hajnačka-26, WS of Šurice-27 and Dunivá hora-30. The activity took place during the reverse geomagnetic field, probably in the time interval 0.97-1.65 Ma.

**Sixth volcanic phase:** this phase in the Cerová vrchovina Upland is characterized exclusively by the explosive activity of several eruptive centres. Paleomagnetic characteristics were gained only on the basaltic tuffs from the maar of the locality Hodejov. Radiometric data for the volcanism of this phase are missing. According to Balogh et al. (1995) volcanics of this phase are supposed to be the youngest ones among those from the Cerová vrchovina Upland. The volcanics arose in the course of the normal geomagnetic field, probbably in the time interval 0.0-0.72, or 0.91-0.97 Ma.

**Seventh volcanic phase:** this phase contains nepheline basanite of the Putikov vŕšok Complex, represented by the locality Brehy-1, near Nová Baňa. These basanites are the youngest volcanics in the Western Carpathians on the Slovak territory. They arose during the normal Brunhes epoch, in the interval 0.0-0.72 Ma, (according to K/Ar age around 0.53 Ma, according to geological knowledge in the interval 0.13-0.22 Ma).

Using a combination of the paleomagnetic results, radiometric K/Ar data, the results of a detailed geological mapping of basaltic products, and comparing these data with the polarity intervals of the geologic time scale of Harland et al. (1989) has provided a possibility to construct comprehensive development schemes for the basaltic activity in Central and Southern Slovakia.

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