The virtual geomagnetic pole positions of the Neogene volcanics from Kremnické vrchy Mts., Slovakia: Field-reversal versus self-reversal hypothesis (Part XIV)

O. Orlický
Geophysical Institute of the Slovak Academy of Sciences[1]

A b s t r a c t: The virtual geomagnetic pole (VGP) positions have been computed from the stable directions of the remanent magnetization (RM) of the Neogene volcanics from the Kremnické vrchy Mts. The rocks from 97 localities were tested. The rocks from only 33 localities (16 of them were the rhyolites) have shown VGP positions which could correspond to nearly regular position of the field. The VGP positions of rocks of other 64 localities, regardless the polarity of RM of rocks and the name of geological formation, are dispersed casually, mostly at lower geographical latitudes. They have not reflected any consistency, neither with the VGP derived for year 1983, nor with those derived mean VGP positions for the Jastrabá formation, the Vlčí vrch formation, and for the selected localities of the Kremnický štít, Krahule and Flochová formations. The direction of the RM and the derived VGP positions have been largely dispersed. These large dispersions of the VGP positions for the respective directions of the RM of the rocks have not been explained by any casual - irregular dynamics of the field. The too complex magnetizing processes from the time of origin of the rocks and during their survival in the field are responsible for the very variable directions of the RM of the rocks, and consequently for the casual - irregular VGP positions.

Key words: casual-irregular VGP positions, too complex magnetizing processes of the Neogene volcanics

1. Introduction

The majority of specialists dealing with the study of the geomagnetic field and paleomagnetism have supported the idea, that the dipole magnetic field of the earth has changed its polarity during the geological history. So far the evidence is overwhelming in favour of the reversals of the earth's magnetic

[1] Dúbravská cesta 9, 845 28 Bratislava, Slovak Republic; e-mail: geoforky@savba.sk

field, but one needs to consider whether any physical or chemical processes or exceptional properties exist, whereby the magnetic material could acquire a magnetization opposite in direction to that of the ambient field. A review of the examples of the self-reversal magnetization of volcanic rocks has been summarized in *Jacobs (1984)* and *Orlický (2001).* Since 1978 I arranged laboratory experiments to induce the self-reversed RM in a normally oriented ambient field. So far I induced in normally oriented laboratory field (of intensity H=0.048 mT) the partial thermoremanent magnetization (PTRM) of many types of the Neogene volcanics from about 247 localities. The rocks from 145 localities acquired the reversed PTRM of the self-reversal origin. A correlation of the PTRM with the type of the Fe-Ti oxides in the rocks was made (*Orlický, 2001, 2002, 2002a, 2002b, 2002c, 2003*). I revealed very important phenomenon in paleomagnetism - the superparamagnetic (SP) behaviour of titanium-rich titanomagnetites (Ti-Mt-es) (*Orlický, 2004*). Moreover there has been evidenced a very peculiar nature and behaviour of the so called low-temperature inversion magnetic phase (*Orlický, 2005*).

So far the polarity of the stable RM has been dominantly applied to the correlation of the age of the rocks. But more effective way could be to use the directions of the RM and the derived virtual geomagnetic poles (VGP), because if the geomagnetic field has changed its direction in the regular mode during the time, it should be reflected also in the direction of the induced RM of rocks and in the derived VGP positions (the VGP is defined as the pole of the dipolar field which gives the observed direction of magnetization at the site under consideration, in *Jacobs, 1984*). Various mechanisms have been proposed to explain magnetic reversals that involve several types of models of the earth's internal magnetic field *(Jacobs, 1984).* However, because no independent physical phenomena have been reliably correlated with the magnetic reversal record, these models remain essentially as speculation, and so there is no real theoretical phenomenon by which it would be possible to unambiguously decide on the preference of the field-reversal hypothesis.

I present the explanations for the very variable directions of the RM and the derived VGP positions for very well geographically and geologically defined volcanic formations of Kremnické vrchy Mts, central Slovakia.

2. Methodological setting

Briefly about geology

Together the rocks of 10 geological formations from 97 localities were studied. The geological descriptions of the rocks of the formations are in (*Orlický, 2002b*). According to *Lexa et al. (1993)* the andesite and the rhyolite products have been involved in the *areal type andesite volcanic activity including differentiated rocks.* This activity started during the Lower Badenian time in the northwestern part of the Pannonian basin and during the Upper Badenian time in the northeastern and eastern parts of the basin and continued in the areas until the Lower Pannonian time. Its spatial distribution is influenced strongly by backarc extension tectonics associated *with diapiric uprise of mantle.* Geochemistry has indicated the previous subduction influenced mantle source magmas with variable crustal component; in the area in question there is the association of the intermediary to basic andesites including the acidic rhyolite and dacite rocks.

The stability of RM of rocks

The magnetic and directional stability of RM of rock samples was originally tested by stepwise alternating field (AF) demagnetization. The basic results, the detailed geological map of the Kremnické vrchy Mts., with the location of outcrops of investigated rocks are in *Orlický (1992)*; To strengthen the trustworthiness of the results, additionally the thermal demagnetization of each rock sample was performed. The mean direction of RM of sample was computed from the data after demagnetization. Because the Fisherian's coefficients k and α_{95} are dependent on the number of items involved, they have been computed from 11 data for each sample after thermal demagnetization at temperatures 25, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500° C. The examples of the results are in Figs 1, 2. Except of the change of the intensity and direction of RM, the change of κ of each sample with the temperature was detected. The position of rocks of sampled outcrops are defined by the geographical latitude φ_L and longitude λ_L and they are in the Tabs 1, 2, 3. The equations according to *McElhinny (1973)* have been applied to compute the VGP for the rocks of each locality (the directions of RM of rocks and the geographical coordinates of the locality were used). All data, short petrographical description, including the results of a study of Curie temperatures of rocks, expressed only as the magnetic phases are in the Tabs 1, 2, 3. The data are grouped according to volcanic formations. The basic characteristics (κ, NRM, Q) for each tested sample is given in the form of graph, cf. Figs 1, 2. The change of the intensity and direction of RM and κ with the temperature, including thermomagnetic curves are the primary issues when considering the carriers, origin, type and the stability of magnetization of rocks in question. Moreover the stability of the direction of RM of the rocks is characterized by Fisherian's coefficients k and α_{95}. The computed VGP positions are plotted also in Figs 3–6.

Previously I induced a reproducible self-reversed PTRM of the rocks (*Orlický, 2002*). This self-reversed PTRM of rocks was originally explained by the presence of the disordered ilmenite-hematite (Ilm-Hem) solid solution with Ilm 15 to 20%. Because a new approach for the source of the reversed PTRM has been revealed, I present these results in the Tabs 1–3. Now I can predict that this self-reversed PTRM of rocks has been linked with the SP behaviour of oxidized Ti-Mt-es, but not with those of the thermodynamically stable domain structure of Fe-Ti oxides.

3. Evaluation of data

The way of evaluation of the results of the thermal demagnetization of all samples: Fig. 1, sample FlF8-0 - the resultant RM is of the normal sense. The dominant normal component of the RM corresponds to more oxidized Ti-Mt of the Curie temperature cca 600° C with the developed domain structure. The second of the primary origin component carries still reversed RM which was screened in the low-temperature inversion magnetic phase. The laboratory induced normal PTRM is linked with the magnetic phase with the thermodynamically stable domain structure. Fig. 1, sample FlF13-1 - there are two relatively stable components in the andesite sample. One of them of normal RM with more oxidized Fe-Ti oxide with the developed domain structure and the second one of the self-reversed origin Ti-Mt, probably of the SP magnetic state. The vertical component of the normal sense prevails over the vertical one of the reversed component, but the horizontal components of the reversed sense still dominate over the normal ones. For that reason the declination of the resultant RM is of the negative sense. The curves of κ_T/κ_0 and J_T/J_0 prove two component system. The

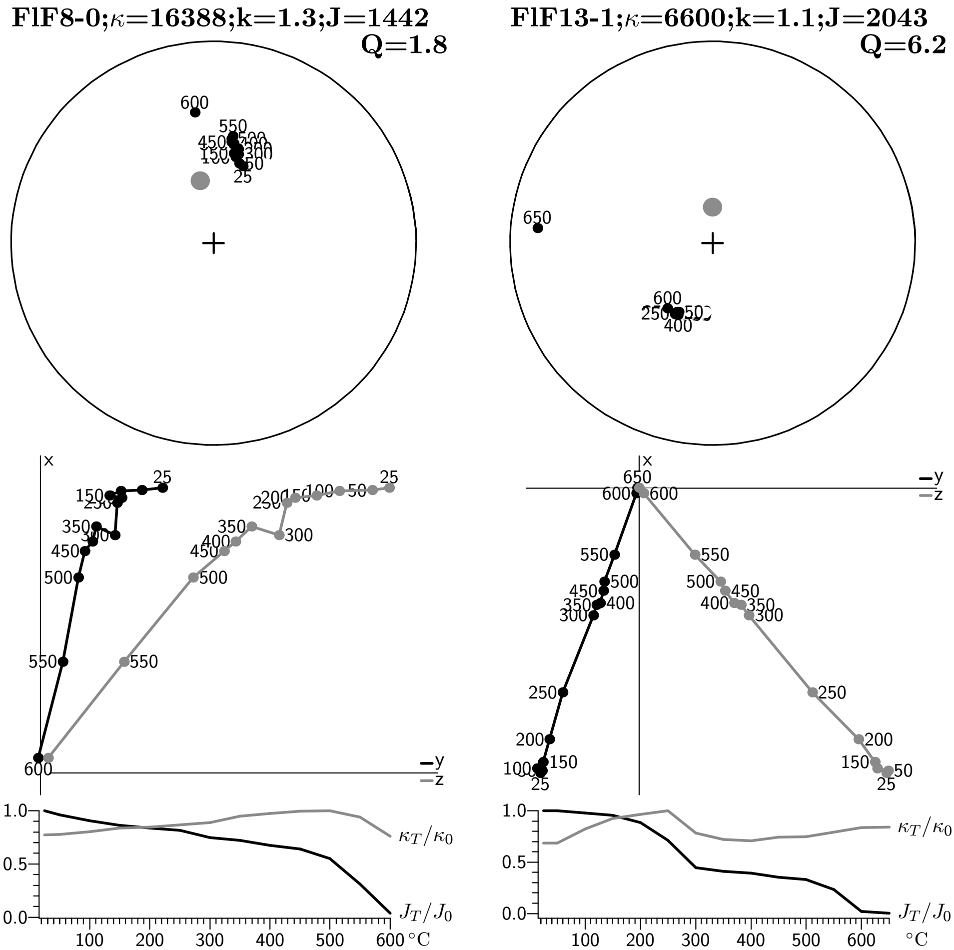

Fig. 1. Thermal demagnetization of the samples, stepwise heating to 650°C; Zijderveld diagrams and stereographic projections; • (○) means positive (negative) polarity of RM; large • (○) means positive (negative) polarity of PTRM of the sister's sample induced in the laboratory field of H=0.048 mT; κ_T (κ_0) - magnetic susceptibility at T (at 25°C, respectively); J_T (J_0) - remanent magnetization at T (at 25°C, respectively); FlF, (Fvv) - Flochová, Vlčí vrch formation, respectively; 8-0 - number of the sample; κ - volume magnetic susceptibility in 10^6 SI units of the sample; k - maximum κ at T over κ_{25}° C; J - intensity of natural remanent magnetization (NRM) of the sample in nano Tesla (nT); Q - Koenigsberger coefficient.

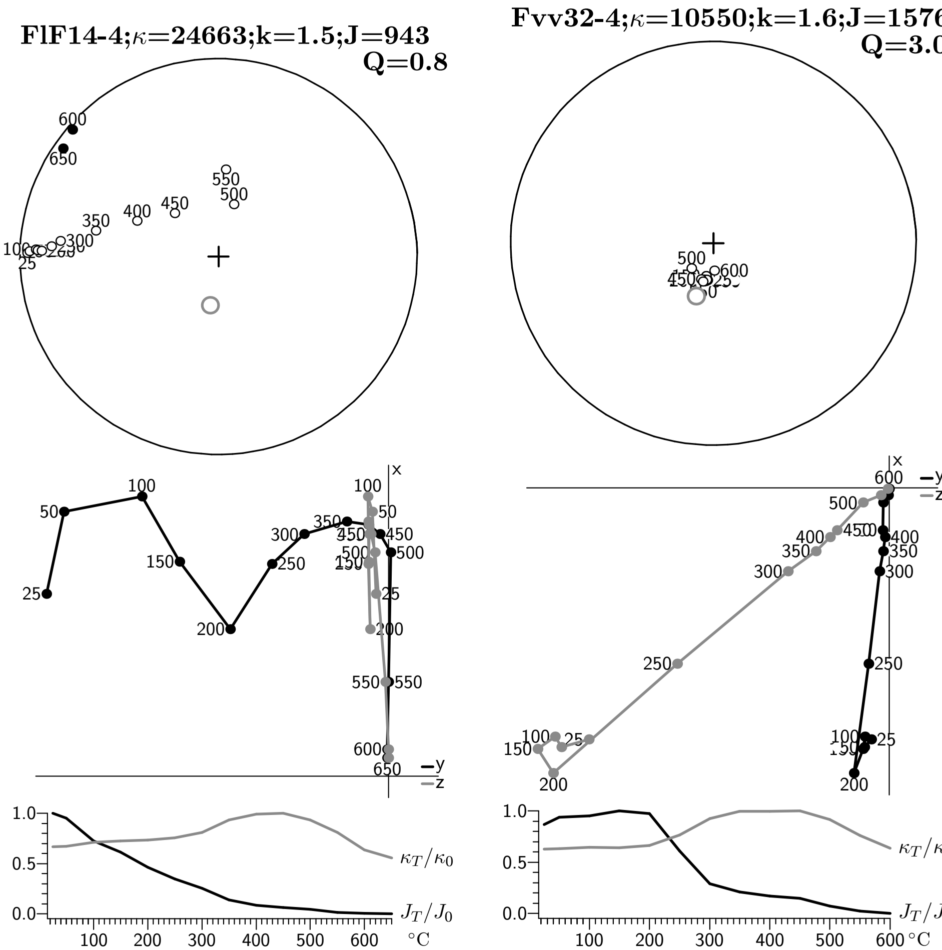

Fig. 2. Thermal demagnetization of the samples, stepwise heating to 650°C; Zijderveld diagrams and stereographic projections. The explanations see in Fig. 1.

laboratory induced normal PTRM is linked to the magnetic phase with the developed domain structure. A program to compute the individual components of the resultant RM of the samples was constructed, but so far it has not been successfully applied. The samples FlF14-4, Fvv32-4 in Fig. 2 contained the low-temperature inversion magnetic phase, which is documented by the increase of κ from about 220-250° C and the decrease of

Tab. 1. Basaltic andesites of Vlčí vrch formation (Loc.27-44; Middle Pannonian); rhyolites of Jastrabá formation (Loc.16-96; late Upper Sarmatian to early Pannonian)

Locality, Sample No	Geographical coordinates		I°	D°	k	α_{95}	Derived pole positions		Laboratory inducing of PTRM		Magnetic phases T_{C1}, T'_{C1}
	φ_L	λ_L					φ_p	λ_p	I°	D°	
27-3	48.757	18.972	-50.0	221.6	376	3.8	53.9	123.2	-4.8	0.6	605,570
28-3	48.757	18.976	-38.3	231.5	184	3.8	41.2	124	60.6	4.4	600,570
29-3	48.757	18.978	-57.1	208.1	3644	0.8	67	127	-68.7	338	600,600,535
30-3	48.754	18.960	-49	226.3	11	17	50.3	120			610,605
31-3	48.753	18.968	-71.7	233	19.2	13	57.8	74.7	-65.4	237.6	590,565
32-4	48.753	18.982	-69.6	195.1	647	1.8	79.4	77	-65.3	198	600,570
33-2	48.751	18.985	-56.4	185.6	111	4.6	77.6	178	-56.3	193	590,555
36-3	48.748	18.988	-62.9	183.5	1526	1.2	85	169	30.6	357	605,570
38-4	48.744	18.988	-36.5	257.6	119	6.2	23.2	104.2	-78	169	600,560
42	48.741	18.997	-81.3	239.8	160	10	54.7	44.8			595,560
44	48.736	18.991	-36.1	283	2	116	6.7	86			590,565
16-3	48.779	18.935	-52.9	194.5	1905	1.0	71.2	158.4			610,570
19-2	48.776	18.931	-56.5	191.2	625	1.6	75.7	159.9			600,580
20-3	48.776	18.936	-64.8	215.9	1119	1.2	66.0	100.3			595,575
69	48.673	18.918	52.6	330.1	6588	1.3	62.9	94.9W			605,575
70-2	48.669	18.916	45.1	322.9	761	1.7	53.9	95.0W			620,620
71-3	48.668	18.836	54.2	3.2	13	17.8	75.9	172.2W			605,605
72-3	48.669	18.911	25.6	353	1577	1.4	54.3	168.3W			600,595
74-1	48.665	18.827	42.7	356.1	3432	0.8	65.9	152.5W			595,595
75-3	48.663	18.840	25.9	30.3	1668	1.5	46.9	152.9			605,605
76-3	48.659	18.844	23.5	345.5	95	6.3	51.7	137.9W			620,620
78-3	48.660	18.917	53.1	354.2	611	2.1	74.4	142.8W			615,615
80-3	48.658	18.927	73.1	291.8	23	12.8	50.3	28.5W			620,620
81-3	48.652	18.924	35.9	320.0	15	16.4	47.0	98.7W			615,615
82-3	48.652	18.919	-47.6	251.3	239	3.3	33.2	101.7			605,595
84-2	48.642	18.920	62.2	344.2	315	2.9	78.0	90.4W			620,620
89-2	48.662	18.918	63.4	45.3	2387	0.9	59.2	98.4			625,625
94-3	48.610	18.903	53.8	35.1	1676	1.3	60.5	124.6			625,625
96-3	48.595	18.914	72.6	29.5	297	3.2	70.3	69.6			615,615

I°, D° – inclination, declination of remanent magnetization of rocks; k – precision parameter; α_{95} – semiangle of cone confidence for probability P=0.05; φ_p, λ_p – derived coordinates of virtual geomagnetic pole; W – West longitude; λ_p without any designation is the East longitude. The explanations are valid also for Tabs 2, 3.

Tab. 2. Pyroxene andesite of Turová formation (Loc.68-92; the Pannonian, or the Upper Sarmatian), Remata formation (Loc.22-50; Lower to Middle Sarmatian) and Flochová formation (Loc.2-14; the Lower Sarmatian); hornblende-pyroxene andesite of Sielnica formation (Loc.88-95; Middle to Upper Sarmatian); biotite-hornblende andesite of Krahule formation (Loc.59-83; Lower Sarmatian, or Upper Badenian age)

Locality sample No	Geographical coordinates						Derived pole positions		Laboratory inducing of PTRM		Magnetic phases T_{C1}, T'_{C1}
	φ_L	λ_L	I°	D°	k	α_{95}	φ_p	λ_p	I°	D°	
68-4	48.673	19.080	-3.0	265.4	6908	2.0	4.1	111.5	-48.0	196.4	608,565
85-4	48.626	18.982	-29.6	225.0	23	12.7	40.3	133.0	-59.4	175.3	600,560
86-3	48.624	18.981	-4.3	94.1	953	1.8	4.3	107.3	-62.9	171.0	595,565
87-3	48.623	18.979	-82.6	288.5	837	1.7	42.3	18.9	-63.6	179.7	605,560
92-4	48.610	18.980	-52.7	122.7	19.2	12.0	45.3	69.0W	-10.0	110.4	605,565
22-0	48.765	18.808	-36.4	26.8	14.1	17.0	17.0	172.5	63.4	7.2	565,565
24-0	48.762	18.813	-29.3	195.8	10.3	15.0	54.4	171.8	67.2	359.0	585,575
25-0	48.760	18.809	51.1	275.7	10.8	14.6	30.8	47.6W	66.4	17.0	400,580,570
26-0	48.757	18.817	-40.0	317.2	20.7	9.3	8.9	121.8W	66.1	352.6	620,620
35-0	48.748	18.837	-46.1	25.0	18.8	11.4	10.6	176.4	56.4	356.3	595,575
48-1	48.733	18.820	-47.4	160.9	4795	0.6	65.1	118.2W	65.0	5.0	600,575
50-3	48.730	18.817	14.0	316.7	10.3	13.6	34.7	106.3W	68.6	11.3	615,615
2-0	48.811	18.904	69.1	63.0	375	2.4	51.2	59.6	-36.2	308.6	585,565
3-4	48.808	18.908	-69.8	324.2	50	7.9	16.9	40.1	-63.4	177.9	605,565
4-0	48.806	18.916	-26.1	222.1	150	3.6	40.8	139.5	69.3	3.2	575,545
5-0	48.806	18.923	8.9	55.7	11	14.3	25.4	133.2	-34.6	294.6	280,590,555
6-1	48.805	18.933	42.0	358.8	1072	2.3	65.4	158.3W	22.7	285.3	605,555
8-0	48.803	18.938	39.2	13.4	276	2.6	61.3	172.3	61.6	347.9	600,590
10-3	48.799	18.950	73.1	329.4	190	3.2	69.6	30.5W	-46.1	41.2	610,570
11-0	48.797	18.972	6.4	75.4	105	5.4	12.0	118.2	67.2	3.1	390,580,580
13-1	48.792	18.948	47.6	206.8	11262	0.4	8.9	175.4	73.9	359.7	615,580
14-4	48.792	18.984	-16.8	277.8	14	13.2	1.4	97.5	-67.5	189.5	570,550
88-3	48.623	19.020	8.8	355.0	581	2.0	45.6	153.8W	-59.2	182.9	590,570
90-3	48.622	19.020	10.8	32.5	69	5.6	38.8	155.7	65.2	327.0	625,605
93-9	48.608	19.039	5.9	33.5	1779	1.1	36.0	155.9	58.8	12.0	610,610
95-3	48.602	19.047	2.0	53.1	293	3.5	24.1	137.8	65.3	20.0	615,610
59-0	48.699	18.971	-60.6	197.3	1819	3.0	75.9	132.8			620,620
66-4	48.683	18.983	27.7	286.5	43	7.9	21.9	73.5W	65.1	2.4	615,615
67-2	48.673	18.973	39.7	13.9	166	3.6	61.6	171.1	-57.7	215.4	595,555
79-3	48.658	18.955	57.6	5.6	3995	0.8	78.8	175.9			595,565
83-4	48.650	18.952	30.9	303.5	9	21.7	34.4	85.6W	63.1	18.3	585,575
47P	48.728	18.936	44.2	107.4	5.0	65.7	8.4	78.9			610,600

Tab. 3. Lower Sarmatian to Upper Badenian andesites of Kremnický štít formation (Loc.34-63), Turček formation (Loc.1-56), and Zlatá studňa formation (Loc.43-91)

Locality sample No	Geographical coordinates						Derived pole positions		Laboratory inducing of PTRM		Magnetic phases T_{C1}, T'_{C1}
	φ_L	λ_L	I°	D°	k	α_{95}	φ_p	λ_p	I°	D°	
34-0	48.806	18.916	-53.9	167.7	748	1.7	73.0	124.1W	44.7	315.9	600,575
37-0	48.706	18.857	-45.0	182.0	138	4.1	66.8	177.7	48.2	342.0	590,575
39-0	48.703	18.848	-48.1	113.9	574	2.0	36.9	67.2W	36.8	320.6	590,575
40-0	48.702	18.850	-84.9	284.6	63	6.2	45.3	32.8	40.5	310.0	590,570
41-0	48.702	18.853	-52.4	179.1	665	1.8	74.2	158.4W	12.9	295.7	600,600
53-2	48.725	18.976	-51.3	243.4	4467	0.9	8.4	31.1W	43.8	292.8	609,580
54-2	48.722	18.980	-64.6	259.7	26	11.1	38.7	79.4	54.1	326.6	600,575
60-1	48.693	18.969	-23.9	141.6	332	2.6	41.9	106.5W	66.7	28.4	605,575
61-2	48.689	18.970	-57.8	202.7	3727	0.7	70.7	132.5	66.7	353.5	600,575
63-4	48.684	18.970	-37.8	285.4	487	2.2	6.2	83.6	65.4	347.9	610,575
1-0	48.812	19.000	-40.0	255.5	36	7.4	26.3	103.8			380,590,575
7-2	48.804	18.880	0.8	324.1	128	4.3	32.6	117.0W	66.8	6.0	615,615
9-1	48.802	18.887	-7.7	357.0	678	1.9	37.3	157.3W	55.0	325.6	610,610
12-3	48.793	19.020	-38.6	250.4	1148	1.3	28.9	108.3	-68.1	191.7	610,570
15-2	48.779	18.882	70.2	15.5	132	4.8	78.9	73.8			610,575
17-1	48.778	18.886	19.7	309.4	46	8.3	33.0	96.0W	64.8	354.5	605,575
18-1	48.777	18.887	72.2	48.0	25	11.3	60.6	73.9			605,575
21-2	48.772	18.902	74.5	90.7	309	2.6	40.9	58.6	-61.7	183.2	610,575
23-4	48.763	18.911	64.6	69.2	97	4.4	45.0	84.2	68.5	42.6	605,600
55-2	48.716	18.992	-73.3	301.4	104	4.8	27.9	48.7	64.2	20.6	615,580
56-2	48.715	18.991	-3.0	321.9	49	9.6	29.9	115.6W	-67.4	181.5	600,570
43-3	48.739	19.013	-85.7	192.1	2408	1.0	57.1	22.3	24.3	313.0	615,572
45-4	48.738	19.012	-3.2	196.6	5419	0.5	40.8	176.9			630,630
46-3	48.735	19.010	-49.7	78.4	221	3.5	15.5	42.0W	65.6	5.5	615,615
47-1	48.733	19.011	-20.5	102.3	387	2.2	16.0	73.1W	-76.4	49.1	620,620
49-2	48.732	19.003	-30.3	196	143	4.0	55.0	171.4	-58.0	182.6	605,575
51-3	48.730	19.005	-17.0	128.9	4.6	22.9	31.5	96.5W	-65.7	188.3	585,560
52-3	48.729	19.005	-50.7	0.7	2049	1.0	10.0	161.6W	-67.4	181.5	600,585
57-2	48.704	18.900	-75.8	112.2	450	2.4	51.8	23.3W	-74.9	170.3	605,570
58-3	48.699	18.982	-41.0	86.3	305	3.2	15.1	52.4W	-75.5	197.5	610,570
62-0	48.687	19.064	-52.6	268.8	407	2.4	25.0	86.5			430,570
64-3	48.685	19.060	-45.2	92.8	98	6.1	21.5	54.5W	46.3	262.8	620,600
65-2	48.685	19.063	-52.6	221.5	331	3.3	55.6	120.2	62.4	7.0	600,585
73-4	48.668	18.982	-79.4	280.9	131	4.9	41.3	46.2	-75.3	209.6	610,570
77-3	48.654	18.997	-63.0	263.1	4	34.5	35.6	79.6	-68.1	210.6	605,565
91-1	48.662	18.986	-55.9	234.1	625	2.4	49.2	105.6	67.9	6.7	600,580

κ from about 460° down to the higher temperatures. In the sample FlF14-4 the reversed RM is carried probably by the primary Ti-Mt of the SP state. But there is also the second weak component of normal sense, which is linked to the magnetic Fe-Ti oxide with the developed domain structure. The resultant vector of RM is still of the reversed inclination, but the declination of RM is in quadrants corresponding to normal sense at the stereographic projections. In the sample Fvv32-4 the reversed RM is dominantly carried by the SP state Ti-rich Ti-Mt, but the negligible intensity is influenced with the more oxidized Ti-Mt which is screened in the low-temperature inversion magnetic phase. Both samples (Fig. 2) contained the SP highly oxidized Fe-Ti oxides which carry the laboratory induced self-reversed PTRM.

Considering the results of the thermal demagnetization of all andesitic rocks there are 34 samples with relatively good directional stability (Tabs 1–3, high k and low α_{95}), but 44 samples have shown lower directional stability of RM after thermal demagnetization. In the rhyolites of the Jastrabá formation, there is an opposite relation. The 14 samples have shown relatively high directional stability of RM (Tab. 1, high k and low α_{95}). Only two samples have shown lower directional stability of RM. The samples from the three outcrops (80-3, 81-3, 82-3) have not been considered for derived data for the rhyolites. The 55 samples of andesites possess the reversed inclination of RM and 23 samples have normal polarity of RM after thermal demagnetization. The 13 samples of the rhyolites have shown normal RM, the sanidine rhyolites of the three localities (16, 19, 20) have shown reversed and very stable RM. In the sanidine rhyolites small portion of Ti-Mt-es and Ilm-Hem-es was detected by the microprobe analysis and the Curie temperature measurements.

The following analysis and comparison of VGP positions for rocks of the localities of volcanic formations can be made (Fig. 3 - Fig. 6): According to the theory the directions of the RM of the rocks should be the same as those of the geomagnetic field by which the RM was induced. If we knew the directions of the RM of the rocks, and positions of the rocks, defined by geographical coordinates, the VGP could be derived. E.g. the direction of the geomagnetic field in the central Slovakia volcanic field for 1983 year was: Inclination I = 64.6°, declination D = 359.5°. The derived VGP positions were: $\varphi_p = 88.4°$, $\lambda_p = 119.6°$W (West longitude). The dynamics of the field during the Neogene time was probably similar to that which has been registered in the observatories since 1540 year up to the present day *(Orlický, 2002a).* The declination of the field changed in the range of about $\Delta D = 35°$ and the inclination in the range of about $\Delta I = 10.0°$. I suppose that the derived VGP positions for the rocks of all geological formations should have been very near to those presented for the 1983 year.

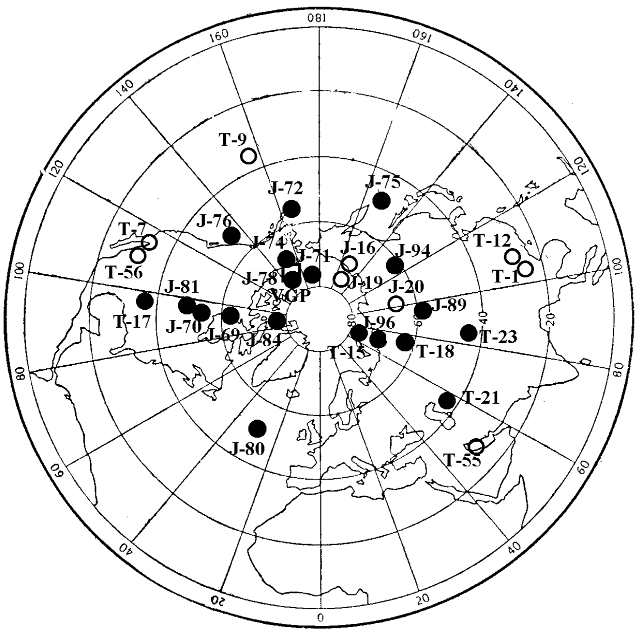

Fig. 3. The virtual geomagnetic pole positions (φ_p, λ_p) of the rhyolite Jastrabá formation (J) and of the pyroxene and basaltic andesites of the Turček formation (T). J–16; T–1 – designation of the locality; Full, outlined circles – normal and reversed polarity of RM, respectively. Outlined square – means VGP position computed from the data of 16 localities of the Jastrabá formation.

Jastrabá formation (Fig. 3): the positions of VGP of the rocks of individual localities do not fit precisely with each other, but they have been grouped around of mean computed position - $\varphi_p = 69.2°$ and $\lambda_p = 147.7°$, with the dimensions of the reliability oval for pole position $\delta_p = 30.4$, $\delta_m = 45$. Despite the relatively high $\delta_p = 30.4$, $\delta_m = 45$, the average position of VGP could correspond to real situation. The rocks contain the most oxidized Fe-Ti oxides among of all volcanic rocks from the area in question.

From the andesitic rocks only the basaltic andesites of the Vlčí vrch formation (except of rocks of locality Vv-44, Fig. 4) appear with the preferred tendency of VGP positions. The VGP of individual localities have been grouped around the mean position - $\varphi_p = 60.5°$ and $\lambda_p = 110.4°$, with the

$\delta_p = 13.4$, $\delta_m = 17.8$. The basaltic rocks of this formation contained the Ti-Mt-es with high content of titanium, when they had cooled on the earth's surface, and now some remnants of these Fe-Ti oxides are present in the rocks. We see in Tab. 1, that in most of the tested rocks the self-reversed PTRM was induced in the laboratory.

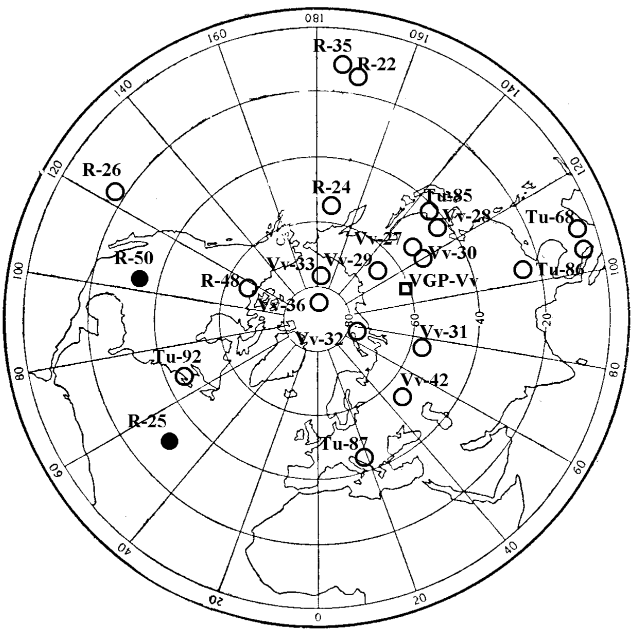

Fig. 4. The virtual geomagnetic pole positions (φ_p, λ_p) of the basaltic andesites of the Vlčí vrch formation (Vv) and of the pyroxene andesites of the Turová (Tu) and the Remata (R) formations. Vv–27, Tu-68, R-22 – designation of the locality; Full, outlined circles – normal and reversed polarity of RM, respectively. Outlined square- VGP-Vv – mean VGP position computed from the data of 9 localities of the Vlčí vrch formation.

The preferred tendency of the VGP positions is shown also by the andesites of the four localities (Fig. 5, Kš-34, Kš-37, Kš-41, Kš-61) of the Kremnický štít formation. The mean position of the VGP is $\varphi_p = 74.6°$ and $\lambda_p = 168.3°$ W, with $\delta_p = 10.9$, $\delta_m = 15.8$. The VGP positions of rocks of other 6 localities are mostly dispersed with dominantly low φ_p and casually located λ_p. The rocks contain also the Ti-Mt-es but most of them have shown higher oxidation than the rocks of the Vv formation. In all tested rocks of the formation only normal PTRM was induced in the laboratory.

The biotite-hornblende andesites of the 3 localities (Fig. 6, Kr-59, Kr-67, Kr-79) have shown quite consistent positions of the VGP. The mean VGP is $\varphi_p = 72.1°$, $\lambda_p = 163.4°$, with $\delta_p = 17.3$, $\delta_m = 25.0$. The VGP positions of rocks of other 2 localities are inconsistent. The rocks of this formation contain dominantly magnetic Fe-Ti oxides of high oxidation degree. Only one of three tested rocks has shown the self-reversed PTRM after inducing in the laboratory.

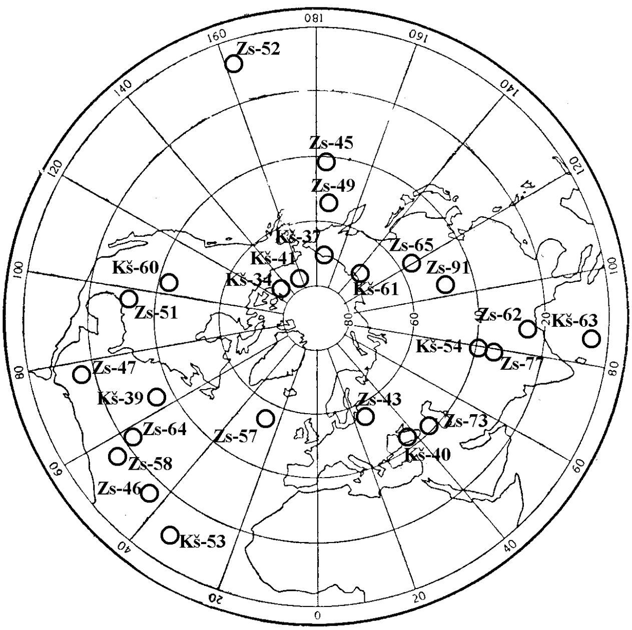

Fig. 5. The virtual geomagnetic pole positions (φ_p, λ_p) of the pyroxene, hornblende-pyroxene and biotite hornblende- pyroxene andesites of the Kremnický štít formation (Kš) and of the pyroxene and hornblende-pyroxene andesites of the Zlatá studna formation (Zs). Kš-34, Zs-45 – designation of the locality; Full, outlined circles – normal and reversed polarity of RM, respectively.

Similarly to the exceptional rocks of previous two formations, also the rocks of the 2 localities of the Flochová formation have shown consistent VGP positions - $\varphi_p = 63.3°$ $\lambda_p = 179.0°$ W (Fig. 6, Md-6, Md-8). The VGP positions of the rocks of other 8 localities are inconsistent. The rocks of the 7 localities have shown normal polarity of RM after thermal demagnetization, but in 5 cases there was induced the self-reversed PTRM in the laboratory. The rocks of the Flochová formation contain dominantly more oxidized Fe-Ti oxides.

The consideration of the RM components: From the thermal demagnetization (the examples seen in Figs 1, 2) and the Curie temperature measurement results of each sample (the thermomagnetic curves have not been documented) it follows that: The composition and the magnetic state

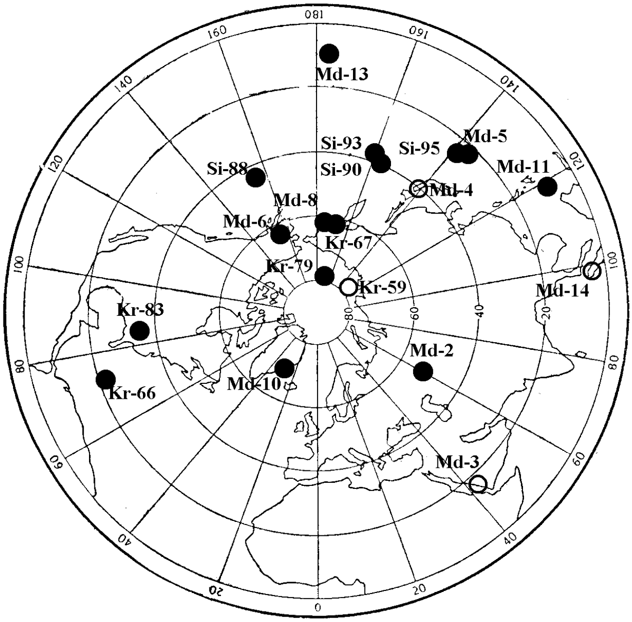

Fig. 6. The virtual geomagnetic pole positions (φ_p, λ_p) of the pyroxene andesites of the Flochová formation (Md), hornblende-pyroxene andesites of the Sielnica formation (Si) and the biotite- hornblende andesites of the Krahule formation (Kr). Md-2, Si-88, Kr-59 – designation of the locality; Full, outlined circles – normal and reversed polarity of RM, respectively.

of the Fe-Ti oxides in situ state is different with regard to that of their initial volcanic state. The cause is the high-temperature and low-temperature oxidations of the original Ti-Mt-es. It was commented e.g. by *Orlický (2001).* The primary magnetization of the andesitic rocks was acquired during cooling of hot magma which contained the Ti-rich Ti-Mt-es. It was not of the TRM origin, but due to the SP behaviour of the thermo-viscous origin. The orientation of this thermo-viscous RM was dominantly of antiparallel sense with respect to the ambient geomagnetic field - of the self-reversal origin. The dominant portion of the andesitic bodies in the area has shown the reversed RM (the rocks of 55 localities), only minor portion of volcanic bodies has shown normal RM (only the rocks of 23 localities). The results of the induction of the self-reversed PTRM of many andesitic rocks are presented in the Tabs 1, 2, 3. These results concern the oxidized Ti-Mt-es of the rocks. But those self-reversely magnetized rocks have probably contained the Ti-Mt-es in the SP state. The self-reversed RM was induced in the normally oriented ambient field also in the synthetic Ti-rich Ti-Mt-es of the compositional parameter $x \approx 0.6$ by *Petersen and Bleil (1973)*. The self-reversal origin of the reversed RM of the Laschamp and Olby Quaternary volcanics from France has been referred by *Heller and Petersen (1982)*. As was described above, the original Ti-Mt-es have not survived up to the present. Their composition has been continuously changed mainly due to the low-temperature and high-temperature oxidations. Today, there are present at least two components, one of them corresponds to the presence of the original Ti-Mt-es - SP particles and the second one corresponds to the oxidized part of the Ti-Mt-es, which were created by the oxidation process, dominantly by the low-temperature oxidation. Very important from the paleomagnetic point of view is, that in these oxidized parts of the Ti-Mt-es the partly or fully thermodynamically stable domain structure was developed. The whole newly formed system of the original and oxidized Ti-Mt-es undergoes the internal magnetic field of the primary reversely magnetized SP grains and that of the geomagnetic field. The resultant RM of the respective sample will be a vector sum of the components concerned. The oxidized Ti-Mt grains, or only part of the Ti-Mt grain with the developed domain structure have a tendency to adopt preferable normal direction of the RM, corresponding to the ambient geomagnetic field, but if the reversed RM of the original part is strong enough, it can overprint this magnetization and the resultant RM may have the reversed, or partly reversed polarity. The detected directions of the RM of the andesitic rocks are supposed to be very variable - inhomogeneous. These directions of RM have reflected such above described two component model of magnetization.

Only the sanidine rhyolites of the three localities contained the ilmenite - hematites, and so they have shown reversed, of the self-reversal origin, RM. The rhyolites of other 13 localities have possessed only highly oxidized Fe-Ti oxides with the presence of the crust material. They have shown also the most coherent directions of the RM and thus also the quite consistent VGP.

Let me briefly comment on the problematic detection of the domain structure in Ti-rich titanomagnetites to support my idea about the SP behaviour of these type of the Ti-Mt-es. *Orlický et al. (2005)* has not proved the domain structure of the grains of the Ti-Mt-es in basalts. The problematic detection of the domain structure in Ti-rich Ti-Mt-es of the Tertiary basalts was referred also by *Soffel (1977)*. *Appel et al. (1990)* studied the basalts using the magneto-optical Kerr effect in natural grains of Ti-Mt-es (T_C about 240° C). According to the authors internal stress in naturally occurring Ti-Mt-es is high and varies strongly in amount and directions within short distances. *Halgedahl (1987)* has referred that intermediate to high x values Ti-Mt-es largely exhibit complex patterns with a distinctly non-cubic style, although simple patterns of broadly-spaced, roughly planar walls are sometimes observed. Undoubtedly, complex patterns in Ti-rich compositions result from stress. Very different domain pattern styles observed through the titanomagnetite series indicate the increasing importance of stress with titanium content. According to this author, whether this stress is intrinsic or an artifact of the surface preparation methods still remains unclear.

Small particles, 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 states, rather than classical domains, prevail. Even if anomalous, continuous magnetic microstructures do not look like domains, this does not mean that domain models, in which continuous transitions are replaced by domains and walls, are useless. 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, thick becomes increasingly difficult with decreasing particle size. Non-oriented permanent magnets cannot achieve large values of the energy product and can be applied in low-cost bonded materials only. The domain patterns inside single-domain particles are impossible or at least unstable, in contrast to the large grains of nucleation-type magnets *(Hubert and Schäfer, 1998).*

4. Discussion and conclusions

From the rocks of the 97 localities, the rocks from only 33 localities have shown some consistent VGP positions. The VGP positions of rocks of other 64 localities, regardless the polarity of RM of rocks and the name of geological formation, are dispersed casually, mostly at lower geographical latitudes. They have not reflected any consistency, neither with the VGP derived for 1983 year, nor with those derived mean VGP positions for Jastrabá formation, Vlčí vrch formation and for the selected localities of the Kremnický štít, Krahule and Flochová formations. From the predictions it follows that if the geomagnetic field changed its direction in the regular mode, it should be reflected also in the direction of the induced RM of rocks of the respective area, and thus also in the derived positions of the VGP, which should be well clustered. But both the direction of the RM and the derived VGP positions have been largely dispersed. How do we explain this discrepancy?

We cannot look for the cause in such an irregular behaviour of the field as follows from the inconsistent VGP positions of rocks. There cannot be defined some VGP position from the time of cooling magmas and inducing the RM of the rocks. *Orlický (2002a)* has postulated that the reversed RM of the Neogene volcanic rocks was acquired by the self-reversal process. The excursions of the field from one polarity to another, or the change of polarity of the geomagnetic field from positive to reversed polarity did not exist in the geological history. The dynamics of the field was predicted as above.

The source of some irregularities in the directions of RM of rocks could have resulted from some tectonic movements of individual volcanic bodies from which the samples were collected. No corrections of the direction of RM for tilting or any horizontal movements of rocks has been made. No data for the concrete volcanic body have been in a disposal for such procedure. There have been presented some dips of the basement surface derived from gravity measurements and the dips of the surface derived from morphological investigation in nearer areas (*Nemčok and Lexa, 1990*), but these data are not appropriate for our purpose. I suppose that the respective collected geological bodies were probably influenced only negligibly by some tectonic movement.

The problem of magnetization of rocks: It is evident from the results that the magnetization of the rocks during their origin and stay in the field is a too complicated process. The resultant RM of andesitic rocks is at least of the two component origin. The original one of the self-reversed origin corresponds to the SP Ti-rich Ti-Mt-es and the other one corresponds to the oxidized Ti-Mt-es with the developed domain structure, which has been acquired during the oxidation of the primary Ti-Mt-es. The magnetization, which is linked with the magnetic phase of developed domain structure is either of chemical origin (CRM), or the thermochemical origin. In the andesitic rocks there is frequently present the low-temperature inversion magnetic phase in volcanics. Its composition and the magnetic behaviour has been described by *Orlický (2005a)*. The RM of this complicated system is of viscous or thermoviscous and the thermochemical origin. It means that the intensity and the direction of the resultant RM of the rock is dependent on the relation of individual components in the whole system. We can conclude that the direction of the RM of the rocks is usually very heterogeneous, which reflects the conditions described above. We are not able to find the rocks with the same direction of RM, not only in the same quarry or outcrop, but even in the larger sample of the rock in the field. It means that the derived VGP of the rocks are also very variable, as has been documented by the results of rocks of andesitic formations.

Stacey and Banerjee (1974) were concerned with TRM induced by fields comparable with that of the earth, i.e., not more than $H \approx 1\,\mathrm{Oe}$. This allows an important simplification, because in terms of domain theory the external field energy of a grain is small compared with the internal contributions to magnetic energy, and therefore imposes only a minor perturbation on domain structure. The authors have supposed the existence of domain structure in magnetic minerals, and that all of the conclusions about domain structure and magnetic properties remain valid, while they merely introduced a slight bias of magnetization; this is a statistical alignment of single domain or small displacement of domain walls in multidomains. For an explanation of the TRM magnetization of rocks the compromise between multidomain and singledomain theories have been accepted in paleomagnetism (in *Stacey and Banerjee, 1974*). It consists in appearance of some single-domain type properties in multidomain grains. It has been called the pseudo-single domain (p.s.d.) effect. Its significance is a strong function of grain size, being insignificant above about 20 μm but increasingly important at progressively smaller sizes. The reason is simply that multidomain TRM is a grain volume effect, but the p.s.d. TRM is a grain surface effect and the grain surface effect, while the grain surface area per unit volume of magnetic mineral are proportional to the reciprocal grain diameter. These theoretical assumptions have introduced very complicated explanation into the experimental TRM in the rocks. The theory of thermoremanence in independent single-domain grains follows directly from the discussion of superparamagnetism (*Stacey and Banerjee, 1974*). There is some improved approach for the single-domain theory of the RM by *Moon and Merrill (1988)*. They referred that the quasi-equilibrium theory of Néel is in good shape, but that there are problems with the dynamic part of the theory. Which one of the theories is supposed to be the indefinable? They take into account dominantly the properties of simple magnetic oxides, as e.g. the magnetite or the hematite. But the magnetic behaviour of the titanomagnetites, which are the dominant carriers of magnetism in the basic and the intermediary volcanics as well as the ilmenite-hematites, which are frequently present in acidic volcanics, is supposed to be more complex. In some specific conditions the rocks with such Fe-Ti oxides have acquired the self-reversal magnetism. The magnetization of the rocks with the above mentioned Fe-Ti oxides calls for deriving a completely new theory.

The volcanological aspects of origin of rocks and magnetic Fe-Ti oxides: *Nemčok and Lexa (1990)* have proposed that the basin in the intra-Carpathian region and range structure in the central Slovakia area, including voluminous calc-alkaline volcanics reflects an active diapiric uprise in the mantle during the Badenian to Sarmatian or early Pannonian time. Extension caused by the diapiric uprise of hot mantle material was compensated by continuing subduction in the Eastern Carpathians and in the NW part of the region it was coupled with sinistral strike-slip motion along NE-SW trending faults induced by the evolution of the Carpathian arc. Active diapiric uprise in the mantle should be considered together with transform faulting and passive crustal stretching as a possible process leading to evolution of basins in the intra-Carpathian region. A probable generation of silicic magmas by partial melting within the crust requires diapiric uprise in the mantle as a source of heat.

In the basaltic and the other types of andesites the Ti-Mt-es are very similar in the composition and the magnetic state. It appears that during the active diapiric uprise in the mantle the adiabatic conditions supported the generation of the magma with the Ti-rich Ti-Mt-es. These Ti-Mt-es are dominantly able to survive also during cooling of the magma on the earth's surface. But some parts of ascendant magma was contaminated by the crustal material, so the more oxidized Ti-Mt-es might have been present in the rocks. During the cooling of magma there have developed in some positions also more oxidized magnetic phases due to local alterations (high and low temperature oxidation) of original Fe-Ti oxides, in some of them also due to autometamorphism. The origin of the rhyolite rocks was influenced strongly by the high association of crustal material during ascent of magmatic material on the earth's surface. It means that a high portion of secondary material with highly oxidized Fe-Ti oxides is present in these rocks. It has been revealed by *Orlický (2004)* that the high content ulvöspinel titanomagnetites behave as superparamagnetic (SP) particles. Moreover there is evidence for very peculiar nature and behaviour of the so called low-temperature inversion magnetic phase (*Orlický, 2005*). The type of the Fe-Ti oxide, its chemical composition, the state of alteration, but especially its magnetic state have the basic influence on all magnetic characteristics, including the polarity of the RM of rocks *Orlický (2001)*.

Acknowledgments. The author is grateful to VEGA, the Slovak Grant agency (grant No. 2/4042/24) for the partial support of this work.

References

Appel E., Hoffmann V., Soffel H. C., 1990: Magneto-optical Kerr effect in (titano) magnetite, pyrrhotite and hematite. Phys. Earth. Planet. Inter., **65**, 36–42.

Graham J. W., 1949: The stability and significance of magnetism in sedimentary rocks. J. Geophys. Res. **54**, 131 p.

Halgedahl S. L., 1987: Domain pattern observations in rocks magnetism: progress and problems. Phys. Earth. Planet. Inter., **46**, 127–163.

Heller F., Petersen N., 1982: Self-reversal explanation for the Laschamp/Olby geomagnetic field excursion. Elsevier Scientific Publishing Company, Phys. Earth. Planet. Inter., **30**, 358–372.

Hubert A., Schäfer R., 1998: Magnetic Domains. The Analysis of Magnetic Microstructure. Springer: Berlin, Heidelberg, New York, Barcelona, Budapest, Hong Kong, London, Milan, Paris, Singapore, Tokyo. 685 p.

Jacobs J. A., 1984: Reversals of the Earth's magnetic field. Adam Highler Ltd. Techno House, Bristol, 230 p.

Lexa J., Konečný V., Kaličiak M., Hojstričová V., 1993: A space-time distribution of volcanics in the Carpatho-Pannonian region. Geodynamic model and deap-seated pattern of the West Carpathians. GUDŠ, Bratislava, 57–69 (in Slovak).

McElhinny M. W., 1973: Palaeomagnetism and plate tectonics. Cambridge: Cambridge University Press, 358 p.

Moon T., Merrill R. T., 1988: Single-Domain Theory of Remanent Magnetization. Jour. Geophys. Res., **93**, B8, 9202–9210.

Nemčok M., Lexa J., 1990: Evolution of the Basin and Range Structure around the Žiar Mountain Range. Geol. Zbor. Geol. Carpath. **41**, 3, 229–258.

Orlický O., 1992: Paleomagnetism - Kremnické vrchy Mts., MGII - Regional Geologica Research in Slovakia. Report - Manuscript, Geofyzika, Brno, Plant Bratislava, 1–58 (in Slovak).

Orlický O., 2001: Field-reversal versus self-reversal hypothesis: Paleomagnetic properties and magnetic mineralogy of the Neogene andesites of central Slovakia (Part I). Contr. Geophys. Geod., **31**, 4, 653–681.

Orlický O., 2002: Field-reversal versus self-reversal hypothesis: Paleomagnetic properties and magnetic mineralogy of the Neogene andesites of central Slovakia (Part II). Contr. Geophys. Geod., **32**, 1, 1–40.

Orlický O., 2002a: Field-reversal versus self-reversal hypothesis: Paleomagnetic properties, magnetic mineralogy and the reproducible self- reversal RM of the Neogene andesites from the Javorie and Poľana mountain range (Part III). Contr. Geophys. Geod., **32**, 2, 91–128.

Orlický O., 2002b: Field-reversal versus self-reversal hypothesis: Paleomagnetic properties, magnetic mineralogy and the reproducible self- reversal PTRM of the Neogene andesites from the Kremnické vrchy mountain range (Part V). Contr. Geophys. Geod., **32**, 4, 309–333.

Orlický O., 2002c: Field-reversal versus self-reversal hypothesis: Paleomagnetic properties, magnetic mineralogy and the reproducible self- reversal PTRM of the Neogene volcanics from the East-Slovak Lowlands, Zemplínske vrchy Mts., and the Slánske vrchy Mts. (Part VI). Contr. Geophys. Geod., **32**, 4, 359–373.

Orlický O., 2003: Field-reversal versus self-reversal hypothesis: Paleomagnetic properties, magnetic mineralogy and the reproducible self- reversal PTRM of the Neogene andesites of the Vihorlat Mts. (Part VII). Contr. Geophys. Geod., **33**, 1, 57–76.

Orlický O., 2004: Magnetic mineralogy and anomalous magnetic susceptibilities of basalts from central and southern Slovakia. Contr. Geophys. Geod., **34**, 3, 227–249.

Orlický O., 2005: An origin and the source of extreme high intensity of natural remanent magnetization (NRM) of oxidized titano-magnetite bearing basaltic and andesitic rocks. Contr. Geoph. Geod., **35**, 2, 95–112.

Orlický O., Lipka J., Tóth I., 2005: An explanation of some effects of the titanomagnetite solid solutions ($Fe_{3-x}Ti_xO_4$) based on the magnetic susceptibilities, the Curie temperature measurements and the Mössbauer spectra measurements. Contr. Geophys. Geod., **35**, 1, 79–94.

Petersen N., Bleil U., 1973: Self Reversal of Remanent Magnetization in Synthetic Titanomagnetites. Zeitschrift für Geophysik, Band **39**, Physica-Verlag, Würzburg, 965–977.

Soffel H. C., 1977: Domain structure of titanomagnetites and its variation with temperature. Adv. Earth Planet. Sci., **1**, 45–52.

Stacey F. D., Banerjee S. K., 1974: The physical principles of rock magnetism. Elsevier Scientific Publishing Company, 195 p.