GEOLOGICA CARPATHICA, 51, 3, BRATISLAVA, JUNE 2000
133–144

TECTONIC AND STRUCTURAL IMPLICATIONS OF PALEOMAGNETIC AND AMS STUDY OF HIGHLY METAMORPHOSED PALEOZOIC ROCKS FROM THE GEMERIC SUPERUNIT, SLOVAKIA

JADWIGA KRUCZYK[1], MAGDALENA KĄDZIAŁKO-HOFMOKL[1], MARIA JELEŃSKA[1], IGOR TÚNYI[2], PAVOL GRECULA[3] and DANIEL NÁVESŇÁK[4]

[1]Institute of Geophysics of the Polish Academy of Sciences, Ks. Janusza 64, 01-452 Warsaw, Poland
[2]Geophysical Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic
[3]Geological Survey of the Slovak Republic, Mlynská Dolina 1, 817 04 Bratislava, Slovak Republic
[4]Geological Survey of the Slovak Republic, Werferova 1, 040 11 Košice, Slovak Republic

(Manuscript received March 1, 1999; accepted in revised form May 16, 2000)

Abstract: Paleozoic highly metamorphosed rocks were sampled in 4 localities situated along the Košice-Margecany shearing zone (East-Carpathian dextral system), on two sites situated close to the Dobšiná shearing zone (West-Carpathian sinistral system), and on one site situated within the Gemeric Superunit. The West-Carpathian and East-Carpathian shearing systems resulted in the division of Gemeric Superunit into a mosaic of small tectonic blocks. Each site sampled for this study represents one such block. Our paleomagnetic study revealed that the rocks became remagnetized in the Middle Miocene after a regional CCW rotation, probably during the period between anomaly 6 (20 Ma) and anomaly 5 (10 Ma). After the remagnetization episodes the blocks underwent rotations (around their vertical axes) associated with activity of respective dextral or sinistral shearing zones. The results of the AMS study suggest a correlation between the magnetic fabric and the Alpine tectonic deformation episodes.

Key words: Gemeric Superunit, Paleozoic, paleomagnetism, AMS, tectonic deformations.

Introduction

The Gemeric Superunit, which belongs to the Alpine-Carpathian-Pannonian (ALCAPA) block is situated at the southern edge of the Central Western Carpathians, Figs. 1a, 1b. It has a distinct belt structure, often with narrow lithological strips of the length up to several tens of kilometers. The Gemeric Superunit is built by the Early and Late Paleozoic and Triassic rocks. Paleogene and Neogene sediments cover its marginal parts with the exception of the eastern margin, which is in tectonic contact with the crystalline complex of Veporic Superunit (Čierna Hora Mts). The superunit is cut into numerous blocks by two systems of shearing zones trending NW-SE and NE-SW. Rocks building the Gemeric Superunit underwent polyphased deformation and metamorphism that took place during the Variscan movements as well as during the Alpine orogenies. It is supposed, that one deformational episode took place in the Gemeric Superunit during the Variscan Orogeny and that formation of nappe structures marked the end of Variscan events. The present geological frame of the Gemeric Superunit is due to Alpine tectonics (Grecula 1997; Plašienka et al. 1997).

The purpose of this study is twofold:

- to reveal this part of geodynamic history of the Gemeric Superunit that became preserved by paleomagnetic characteristics of its highly metamorphozed Paleozoic rocks;
- to find correlations between the anisotropy of magnetic susceptibility (AMS) and the shearing zones.

Geological setting and sampling

General remarks concerning the geodynamic features

During the Upper Mesozoic and the Tertiary the ALCAPA area was subject to significant tectonic processing. The convergence of the Afroarabian and the Euroasian litospheric plates led to final collision of the Bohemian Massif with the Apulia. This collision resulted in a formation of Alpine nappes and northeastern shifting (escape) of fragments of the Alpine and the Dinaric units, grouped in the Inner Carpathian, Tissia and Dacides terranes. Csontos et al. (1992) and Márton et al. (1995) argue, that the escape was driven from behind by pushing forces caused by the Bohemian Massif- Apulia collision, but influence of pulling forces caused by subduction of the Euroasian Plate under the Inner Carpathians also contributed to this process. The escape movements started after the Cretaceous folding in the Alps; these were most intensive after the pre-Oligocene folding and extinguished during the Early Miocene. The escaping fragments approached European Plate in different periods; for Gemeric Superunit it happened during the Early Eocene (Márton et al. 1995).

According to Peresson & Decker (1996) the Early and Middle Miocene tectonics of the ALCAPA region was dominated by the N-S directed compression and E-W directed extension. During the Late Miocene the direction of the compression changed to an E-W trend. This, and the final oblique collision

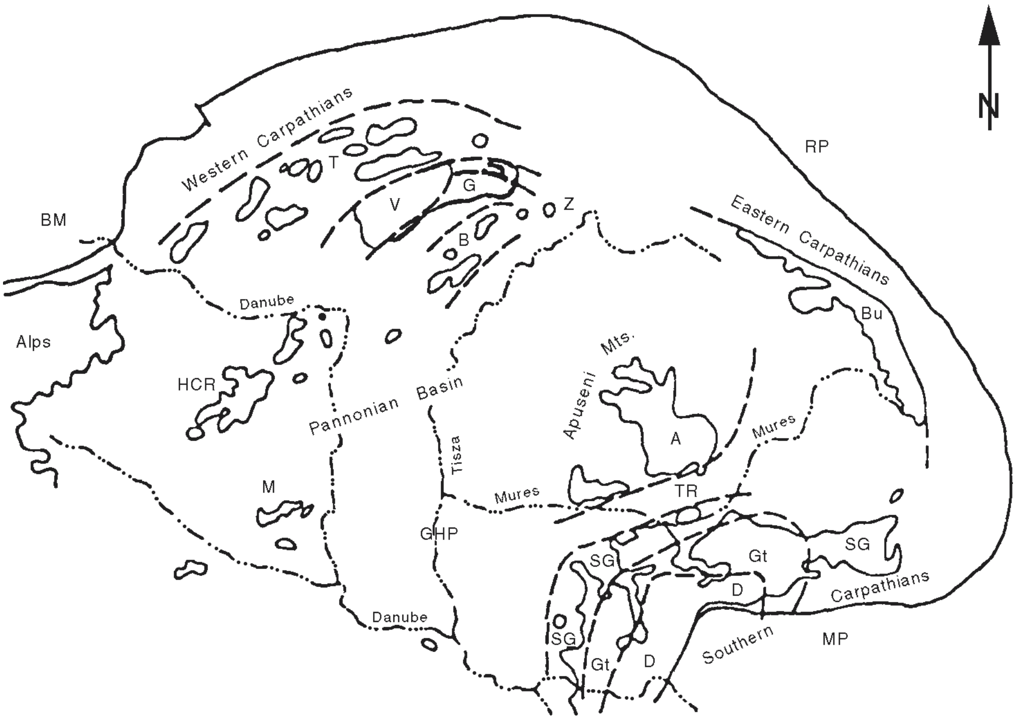

Fig. 1a. Position of the Gemeric Superunit in the frame of the Carpathian mountain system. BM — Bohemian Massif, RP — Russian Platform, MP — Moesian Plate, HCR — Hungarian Central Range, GHP — Great Hungarian Plane, T — Tatric Superunit, V — Veporic Superunit, G — Gemeric Superunit, B — Bükkic units, Bu — Bucovinian units, Z — Zemplín units, SG — Supragetic units, Gt — Getic units, D — Danubian units, TR — Transsylvanides, A — Apuseni Mts., M — Mecsek Mts. (From Grecula et al. 1995, reprinted with permission of Geocomplex Bratislava).

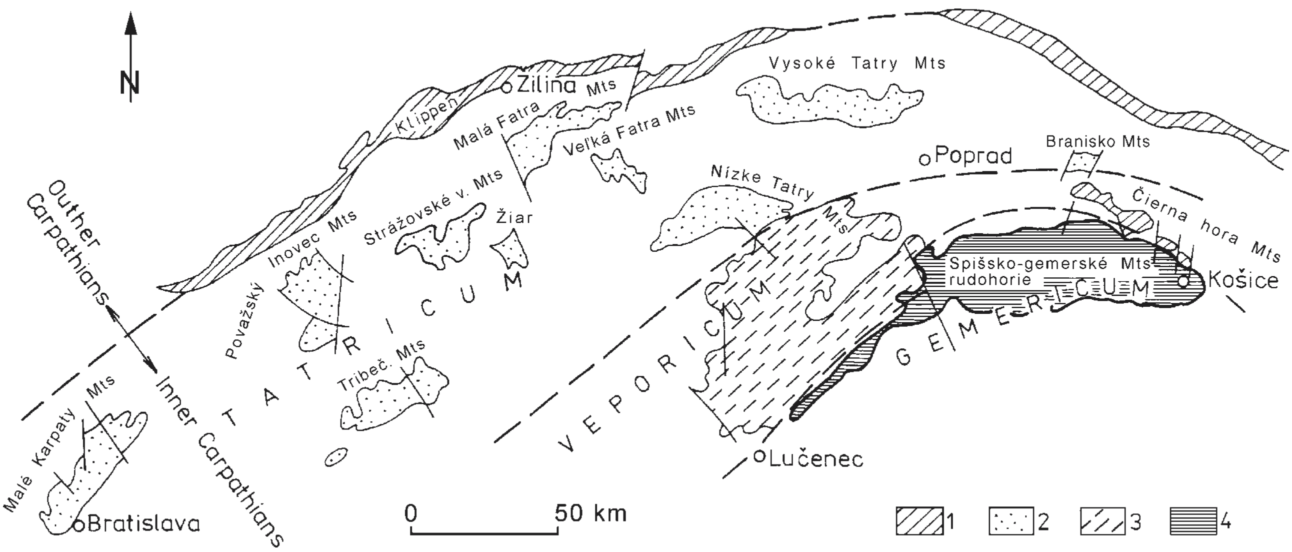

Fig. 1b. Position of the Gemeric Superunit in the West-Carpathian mountain system. 1 — Klippen belt, 2 — Tatric Superunit, 3 — Veporic Superunit, 4 — Gemeric Superunit. (From Grecula et al. 1995, reprinted with permission of Geocomplex Bratislava).

of the escaping Inner Carpathian units with the North European Platform, caused their counterclockwise rotation and uplift of the rigid basement rocks (Plašienka et al. 1997; Peresson & Decker 1996). The paleomagnetic study by Márton et al. (1995) and Márton & Márton (1996) performed in Southern Slovakia and North Hungarian Central Range suggest, that this rotation of the whole region ended at the Early-Middle Miocene boundary (Karpatian-Badenian). In the present study we show that the Middle and Late Miocene kinematics caused local rotations of blocks comprising the Gemeric Superunit.

Along with the processes leading to the northeastward escape, the above mentioned compressional stresses were com-

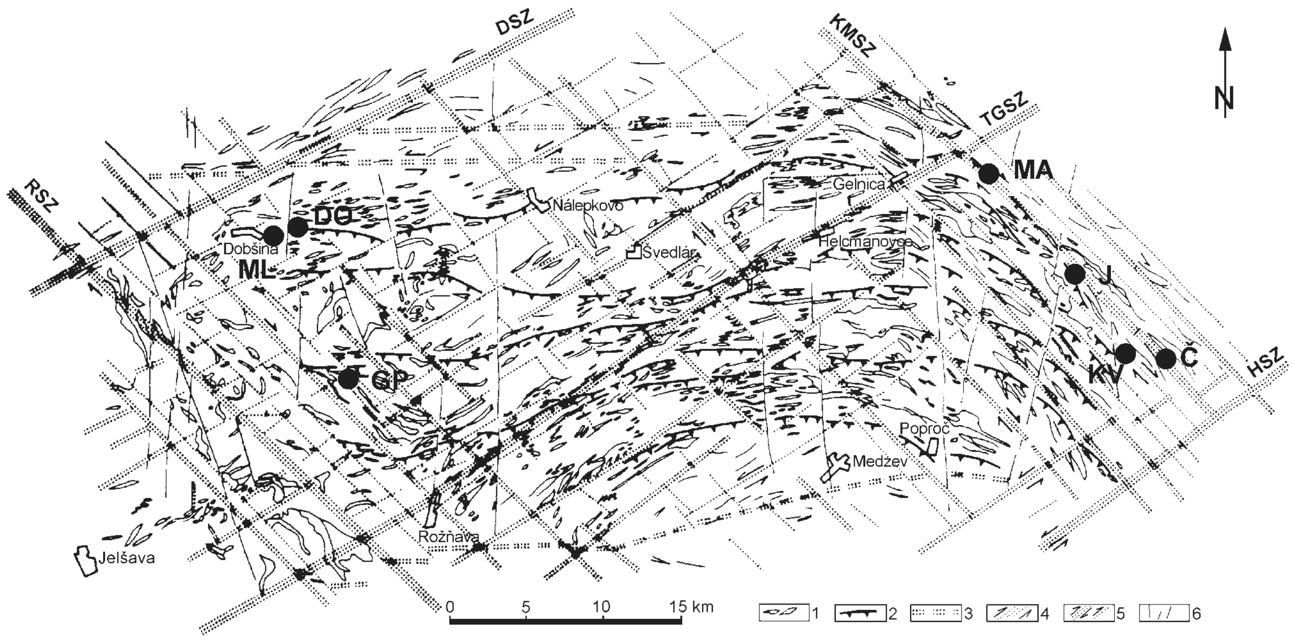

Fig. 2. Map of the shear zones of the Gemerides. RSZ — the Rejdová shear zone, DSZ — the Dobšiná shear zone, KMSZ — the Košice-Margecany shear zone, TGSZ — the Transgemeric shear zone, HSZ — the Hodkovce shear zone. 1 — course of lithological units, 2 — Variscan nappes, 3 — Alpine rejuvenated Variscan (?) shear zones, 4 — principal shear zones (Alpine), 5 — shear zones of lower order, 6 — faults with a character of pure shear (the youngest ones), black circles — sampling localities: Č — Črmeľ, KV — Vyšný Klátov, J — Jahodná, MA — Margecany, DO — Dobšinská Priehrada, ML — Mlynky, GP — Gemerská Poloma. (From Grecula et al. 1990, reprinted with permission).

pensated along the wedge system by paired shear zones, one trending NW-SE (the Košice-Margecany shearing zone (KMSZ), the dextral strike-slip fault, the East-Carpathian system), and the second shear zone trending NE-SW (the Transgemeric shear zone (TGSZ), the sinistral strike-slip fault, the West-Carpathian system). These paired zones resulted in creating an arc structure of the Gemeric Superunit and its division into a mosaic of blocks that could have been subjected to local rotations, Fig. 2 (Grecula et al. 1990). In the megascale the shear zones are demonstrated by the change of the course of rock complexes, by retraction, as well as destruction of the Variscan veins and the stratiform mineralization (Návesňák 1993). The deformation of the Paleozoic rocks associated with these events is of a brittle–ductile character.

The age of the shear zones is estimated on the basis of geological features as well as the Rb/Sr isotopic dating. As this research was not performed specifically for the dating of the shear zones, we may only assume that movements on them started before the Cretaceous and ended during the Styrian phase (the Middle Miocene) — Grecula et al. (1990), Návesňák (1993).

Návesňák (1993) distinguishes within the Gemeric Paleozoic rocks three systems of mylonitic schistosity (S2, S3, S4) and two lineations (L2, L3) caused by the Alpine tectonics. The S1 and L1 systems linked with the Variscan deformation stage are visible only within large blocks that were not influenced by the Alpine shearing. The E-W trend of lineation L1 indicates the direction of an old shear system, the foliation S1 indicates surfaces of metamorphic schistosity corresponding to L1. The most characteristic lineation L2 (azimuth of 230°–240° or 60° with a low dip) associated with the TGSZ and LSSZ, mylonitic foliation S2 (azimuth of about 165°, dip of about 40° with scatter from 0° to 70°) and foliation S3 (azimuth of 293°–335°, shallow dip) are due to a compression linked with the TGSZ and LSSZ (the Lacemberská dolina Valley-the Stará Voda shearing zone, parallel to the TGSZ zone) shear zones. The L3 lineation trends to 290° or 100° with a shallow dip. The S4 foliation (azimuth of 230°–235°, dip of about 45°) is associated with the KMSZ zone.

Metamorphism

The mineral association of the majority of rocks of the Gemeric Superunit corresponds to the metamorphic facies of green shists. In several zones of the Gemeric Superunit, also in the enclaves of high pressure and middle temperature, metamorphites and rocks of amphibolite facies (Grecula 1997; Radvanec 1994, 1997) with important retrograde metamorphic reworking have been preserved.

These processes, as well as strong folding, granitization, local granite intrusions and ore mineralizations begun during the Variscan orogeny. During the Alpine orogeny metamorphic and tectonic processes continued. The Variscan and Alpine metamorphic events resulted in well-developed blastesis of magnetite, hematite and chlorite. The presence of martite within magnetite grains, as well as transformation of sulphides into Fe-hydroxides indicate that blastesis took place during a retrograde phase. The influence of tectonic factors is reflected in the general presence of the mylonitic foliation. Márton et al. (1995) argue, that the activation of astenosphere associated with the tectonic escape caused reheating of crust. This assumption is supported by Peresson & Decker (1996) who show the uplift of the astenosphere under the Pannonian Basin caused by extension tectonics during the Middle Miocene. We believe that this process induced physico-chemical conditions suitable for the Middle Miocen remagnetizations of older rocks.

Sampling

62 hand samples were collected for the present study. The sampling was carried out in the following areas: along the KMSZ shear zone forming the eastern border of the Gemeric Superunit (exposures KV, Č, J, MA), in the vicinity of the Dobšiná shear zone (DSZ — one of shear zones belonging to TGSZ system) in the western part of the Gemeric Superunit close to its northern border (exposures DO, ML) and one exposure (GP) lying in the middle part of the unit, see Fig. 2. The rocks represent strongly metamorphosed and mylonitized sericitic schists (Č, J), cataclasites (MA, KV), phyllites and schists rich in carbonates (ML, DO, GP). Oriented hand samples taken in the field were drilled into standard paleomagnetic specimens in the laboratory.

Experimental procedure

All experimental work was performed in the Paleomagnetic Laboratory of the Institute of Geophysics of the Polish Academy of Sciences in Warsaw. Natural remanent magnetization (NRM) was measured with a cryogenic magnetometer of 2G, specimens were demagnetized thermally with the Magnetic Measurements non-magnetic furnace or with a 2G alternating field device. All apparatuses are installed within the Magnetic Measurements compensating cage. The magnetic susceptibility and its anisotropy was measured with the KLY-2 Geofyzika Brno bridge before the demagnetization procedure. The obtained parameters (Tarling & Hrouda 1993) that will be discussed later comprise:

— mean low field magnetic susceptibility

$K_m = 1/3(K_{max} + K_{int} + K_{min})$ where

$K_{max}, K_{int}, K_{min}$ — the maximum, intermediate and minimum susceptibilities, respectively

— anisotropy parameter

$$P' = \exp\sqrt{2((\eta_1-\eta_m)^2+(\eta_2-\eta_m)^2+(\eta_3-\eta_m)^2)},\ \text{where}$$

$\eta_1 = \ln(K_{max})$, $\eta_2 = \ln(K_{int})$, $\eta_3 = \ln(K_{min})$, $\eta_m = \sqrt{\eta_1\eta_2\eta_3}$

— shape parameter $T = (2\eta_2 - \eta_1 - \eta_3)/(\eta_1 - \eta_3)$; the anisotropy ellipsoid is prolate (prevailing lineation) if $T < 0$, the anisotropy ellipsoid is oblate (prevaling foliation) if $T > 0$

— directions of K_{max} and K_{min} axes of the susceptibility elipsoid.

Mean magnetic susceptibility was measured also after consecutive heating steps in order to monitor mineralogical changes caused by heating. Results of paleomagnetic experiments were analyzed with the program package PDA of Lewandowski et al. (1997), results of the AMS study — with the ANISO 11 program of Jelínek (1977) and Spheristat 2 program of Pangea Scientific.

The identification of magnetic minerals was done through a microscopic examination of polished sections (performed by Siemiatkowski from the State Geological Institute, Wroclaw), a thermomagnetic analysis, and a study of hysteresis parameters. The thermomagnetic analysis consisted of studying the thermal decay of isothermal remanence Ir acquired in 1 T field during the heating to 700 °C in the air with the use of the TUS Warsaw device. The blocking temperatures Tb obtained here indicate that magnetic minerals are present in the rock. The hysteresis parameters were measured with the vibrating magnetometer VSM of Molspin with the highest available field of 1 T.

General characteristics of sampled rocks and their magnetic mineralogy

Sites situated along the KMSZ shear zone:

Čermeľ (Č) — schistosity (azimuth/dip) 245/50, mylonitic schists, 8 hand-samples. Paleontologic age is supposed to be the Tournaisian–Viséan; according to Grecula et al. (1990) they became modified due to the Late Variscan shearing, but mylonitisation originated during the Alpine tectonics. The microscopic study reveals parallel texture manifested by mylonitic smears, calcite veins cutting the rock were also visible. Fe-hydroxides, pyrrhotite and chalcopyrite in clasts of 0.1 mm represent opaque minerals. Rocks are magnetically weak — isothermal remanence Ir of fresh specimens was too low for a thermomagnetic analysis. Heating to 600 °C resulted in increase of Ir by about 30 times due to formation of new magnetite. The hysteresis parameters (see Table 1) indicate the presence of magnetic material with low and intermediate coercive force. The mean magnetic susceptibility Km ranged between 400 and 800×10^{-6} SI and increased after heating to 500 °C.

Vyšný Klátov (KV) — no tectonic parameters, amphibolite schists (cataclasites) belonging to the gneissic amphibolite Klátov complex, 12 hand samples. The tectonic position is ambiguous, the complex may be treated either as a small nappe, or as a highly metamorphosed part of the Rakovec nappe. The radiometric age (K-Ar and Ar-Ar) spans the time from 448 to 383 Ma (the Upper Ordovician, Lower Devonian). The metamorphic processes perhaps underwent here in the amphibolite facies conditions which are indicated by the presence of chloritized amphiboles with magnetites and post-plagioclase smears composed of epidote–albite–calcite. The microscopic study reveals the presence of automorphic magnetite with martite lamellae of 0.03–0.3 mm. Hematite forms smears of 0.1 mm, tablets of 0.001–0.1 mm and flakes. Single sulphides are present within the hematite grains as well as clusters of Fe-hydroxides with relicts of pyrites. Automorphic and framboidal pyrites are also visible. The thermomagnetic analysis shows the presence of magnetite with Tb 560–575 °C, accompanied in some specimens with phase with Tb of about 200 °C (goethite?) and hematite with Tb of about 650 °C (Fig. 3a,b). The hysteresis parameters (see Table 1), despite the presence of hematite and perhaps goethite visible in polished sections, are characteristic for multidomain magnetite (Day et al. 1977). The magnetic susceptibility Km is high and ranges from 3200 to 22000×10^{-6} SI, it increases after heating to temperatures exceeding 600 °C in all specimens.

Jahodná (J) — schistosity 220/55, very fine-grained sericitic schists (mylonites) with quarz lens, 5 hand samples.

Table 1: Hysteresis parameters measured for particular specimens.

Locality	Specimen	Ms μA.m^2	Mr μA.m^2	Hc mT	Hcr mT
Č	105 –1	0.6	0.3	19	43
	107 –1	0.7	0.1	4	47
KV	134 – 1	443	25	7.5	35
	135 – 1	272	11	5	30
	138 – 2	239	9.5	5	30
J	113	2.7	0.8	44	310
	114	3.9	0.7	29	280
MA schist	124 –1	260	17	7	27
sandstone	132 – 1	0.2	0.06	24	62
sandstone	133 –1	0.2	0.08	20	70
DO	174 – 1	0.5	0.2	28	160
	174 – 2	1.23	0.24	41	65
	175	0.3	0.09	8	48
	176 – 1	0.5	0.17	12	30
	176 – 2	0.35	0.09	3	35
ML	157 –1	15	13	312	330
	160 -1	?	0.7	175	330
	161 –1	?	0.3	127	170
	162 –1	2.1	1.9	237	250
	163	6.4	5.0	108	115
	167	?	0.4	52	230
GP	179 –1	0.35	0.27	29	65
	181	0.21	0.06	13	65
	182	0.24	0.06	22	60
	185 – 2	0.21	0.06	16	55

Ms – saturation magnetization, Mr – saturation remanence, Hc – coercivity, Hcr – remanence coercivity

The paleontologic age of the rocks is supposed to be the Lower Permian, whereas the radiometric K-Ar dating gives 126 Ma (the Lower Cretaceous) as the age of the metamorphic changes. The microscopic analysis reveals the presence of automorphic hematites with sulphide grains, spherical agglomerates of hematite grains probably of a post-pyrite origin, and single hematite tablets. Ilmeno-magnetite pseudomorphs were also visible. The thermomagnetic analysis indicates hematite as the only magnetic mineral, the curves of Ir vs. T are very similar to those shown in Fig. 3c. This conclusion is supported by the hysteresis parameters (cf. Table 1) revealing high values of coercivity, and by the saturation field exceeding the maximum field of the experiment. The Km values were low and ranged from 200 to 250×10^{-6} SI. Heating to 600 °C resulted in a significant increase of the Km.

Margecany (MA) — schistosity 190/40, chlorite-sericite schists, and polymict sandstones, both highly mylonitized. Some 10 hand samples were taken from 3 sites, but only 8 samples from 2 sites (one site containing schists and the second — sandstones) were suitable for measurements. This locality is situated at the crossing of two shear zones: KMSZ and TGSZ. The radiometric (Ar-Ar) unpublished age is 329.6 Ma, placing the rocks in the Upper Carboniferous. The microscopic analysis was performed only for one specimen representing polimict sandstones and did not reveal the presence of magnetic minerals. The thermomagnetic analysis that was performed on several specimens shows the presence of magnetite and goethite in schists and magnetite in sandstones — the Ir vs. T curves are similar to the one shown in Fig. 3a. The study on hysteresis parameters suggests the dominance of multidomain magnetite in sericitic schists and SD and PSD magnetite in sandstones (Day et al. 1977) — see Table 1. The obtained values of the Km for schists were very high (6500–70000×10^{-6} SI) for sandstones — low (190–220×10^{-6} SI), after heating to 550–600 °C the Km increases.

Localities situated at the DSZ shear zone:

Dobšinská Priehrada (DO) — bedding 180/34, chlorite schists (mylonites) with calcite smeared veins, 11 hand samples. The assumed age is the Upper Carboniferous. Within the veins plagioclases in clasts, epidotes, chlorites, albites are encountered. The age of metamorphism is uncertain, likely occurring during the large time span from the Neovariscan to the Jurassic or even the Cretaceous. The microscopic analysis reveals the presence of post-pyrite Fe-hydroxides with pyrite relicts. The thermomagnetic study supports this result revealing various Ir vs. T curves showing the presence of phase with Tb of 200 °C, hematite and low amounts of magnetite (the Ir-T curves are similar to those shown in Figs. 3a and 3c). After the heating new magnetite appears. The Km ranges from 400 to 750×10^{-6} SI and increases after heating to 600 °C. The values of hysteresis parameters (Table 1) should be regarded only as estimates because the rocks here are too weak for reliable measurements with our VSM.

Mlynky (ML) — bedding 320/65, 12 hand samples, strongly carbonatized pyroclastic phyllites belonging to the diabase series of the Rakovec Nappe. Their estimated age is the Upper Devonian–Lower Carboniferous, they became metamorphosed during the Variscan orogeny in the greenschist facies conditions, but the Alpine events erased the Variscan features. The microscopic analysis revealed hematite in tablets of 0.01–0.03 mm and less than 0.001 mm as the main magnetic mineral. The thermomagnetic analysis supports this conclusion (Fig. 3c), the hysteresis parameters attain values characteristic for hematite (Table 1) as well. The Km ranges from 190 to 750×10^{-6} SI and increases after heating.

Locality siutated outside the main shear zones:

Gemerská Poloma (GP) — bedding 350/51, 9 hand samples, ankeritic carbonaceous beds cut by calcite veins, product of regional metasomatosis. The assumed age of the rocks is Upper Silurian–Lower Devonian, the age of metasomatic alteration is supposed to be either Variscan, or Alpine. The polished sections have intensive brownish colouring characteristic for fine Fe-hydroxides. The thermomagnetic analysis reveals the presence of goethite and, perhaps, a small amount of magnetite. Pyrite is probably also present, because after the heating pyrrhotite appears on the Ir vs. T curves. Heating to 650 °C results in a thousandsfold increase of Ir due to the appearance of pyrrhotite and magnetite. Here, as in DO, results of measurements of the hysteresis parameters are only estimations. The Km ranges from 230 to 600×10^{-6} SI and in-

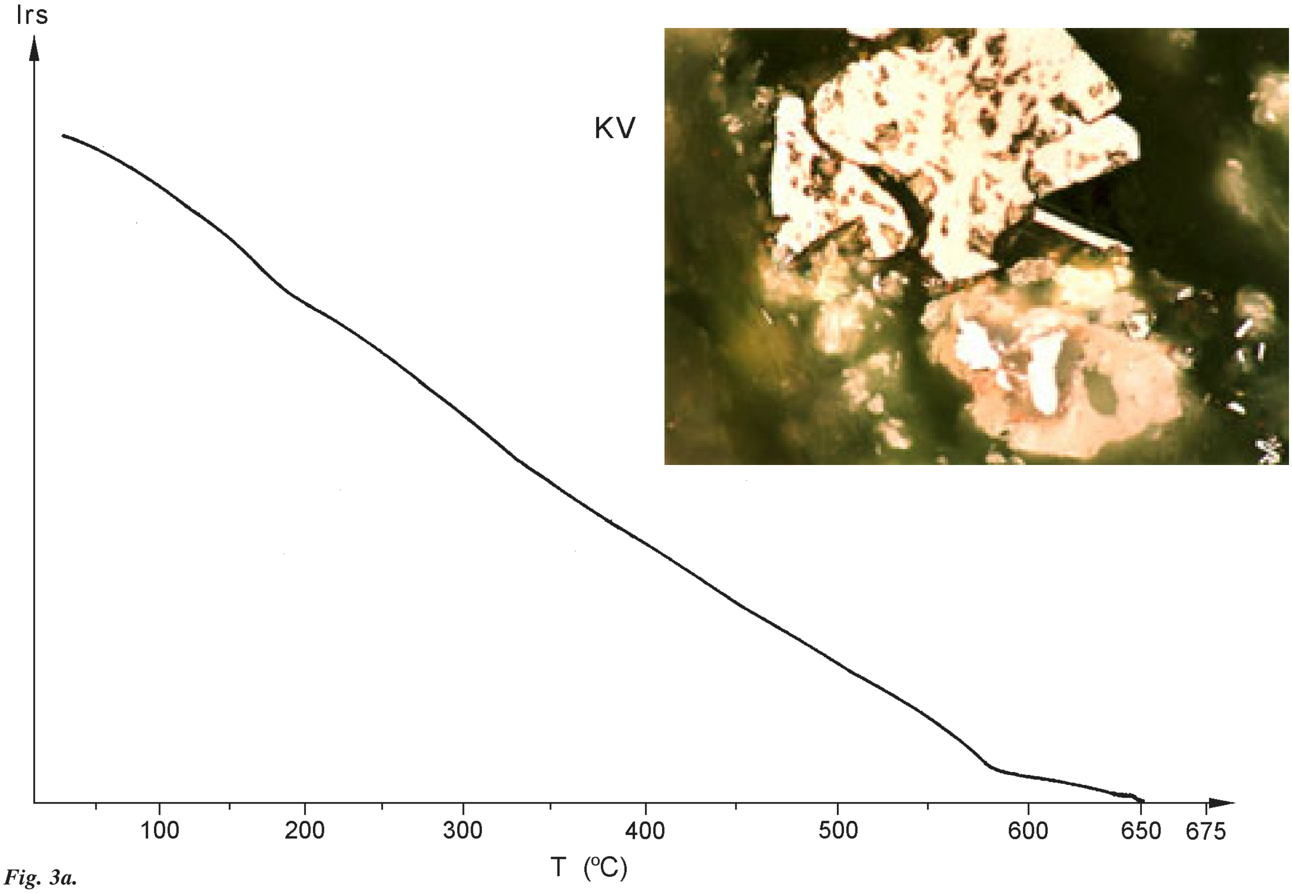
Irs
KV
100
200
300
400
500
600
650
675
T (ºC)

Fig. 3a.

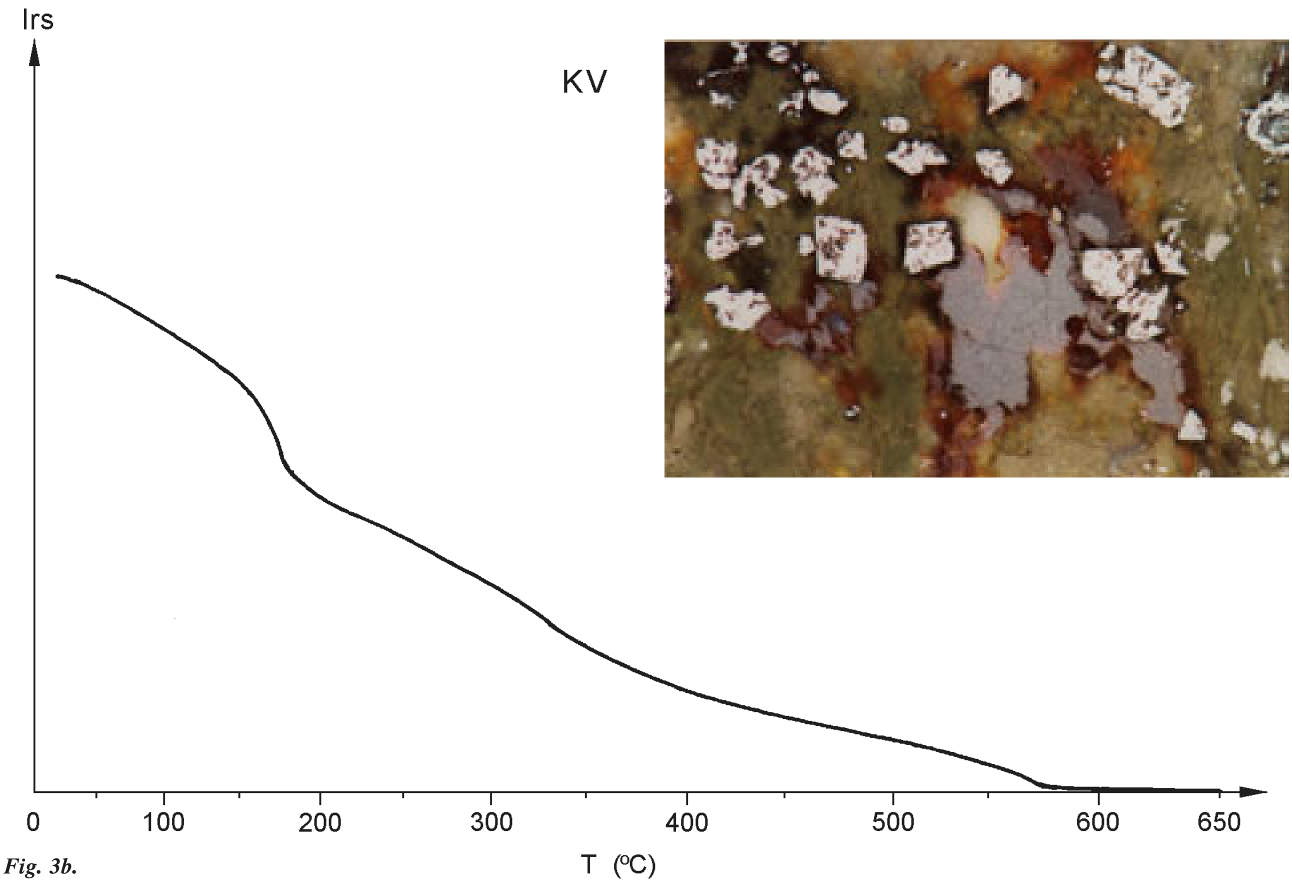
Irs
KV
0
100
200
300
400
500
600
650
T (ºC)

Fig. 3b.

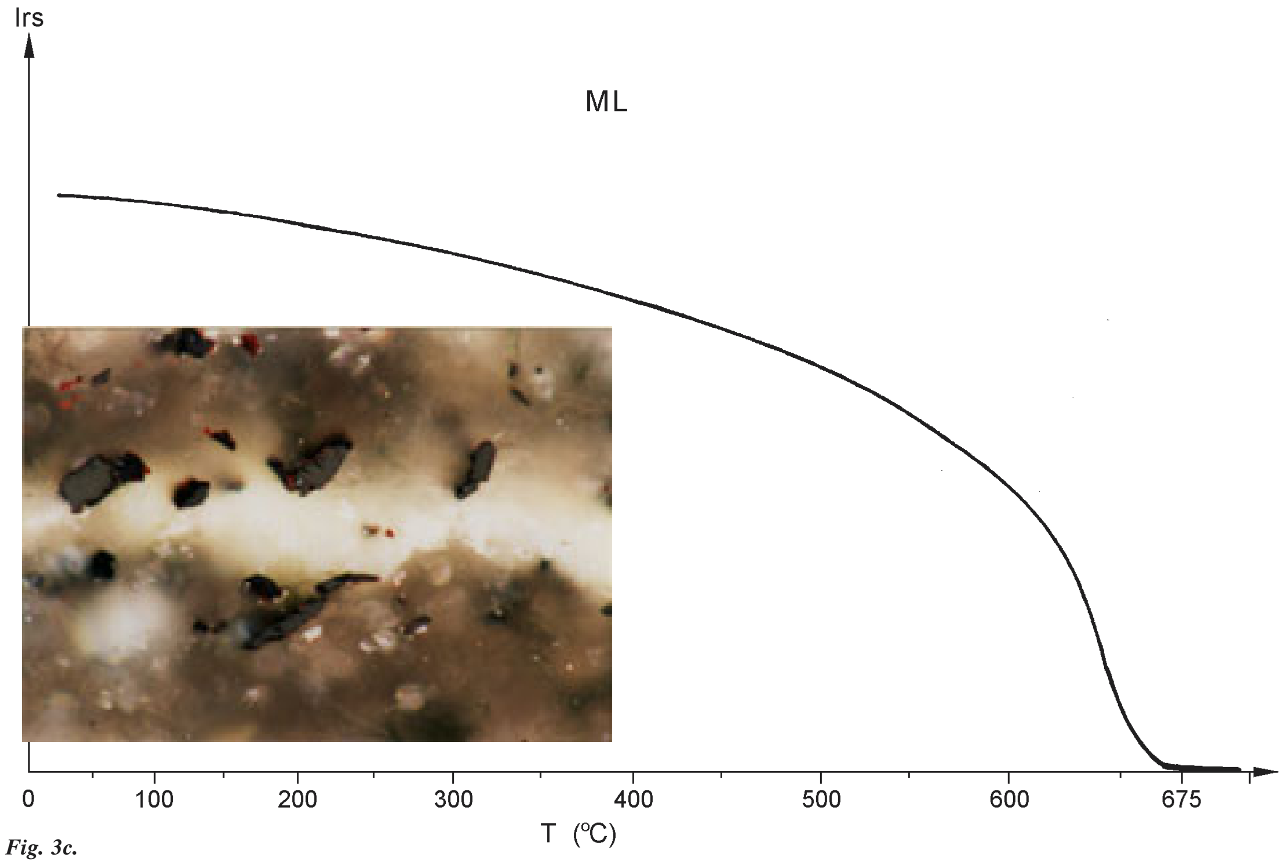

Fig. 3c.

Fig. 3. Results of the thermomagnetic analysis along with corresponding polished sections. a — specimen from KV containing magnetite ×500 and hematite lamelae and post-pyrite + hydro-Fe-oxydes ×200, b — specimen from KV containing goethite, c — specimen from Mlynky containing hematite ×500. Irs — isothermal remanence acquired in the field of 1 T.

creases considerably after heating to 450 °C; at this temperature pyrite transforms into pyrrhotite.

Paleomagnetic results and discussion

The pilot specimens were demagnetized thermally and with an alternating field (AF). As the thermal demagnetization was much more effective than the AF, the bulk of the collection was demagnetized thermally (to temperatures 500 –675 °C) and results of this procedure were taken for interpretation. The isolation of the characteristic (CHRM) components of the NRM was performed by the program package of Lewandowski et al. (1997) based on the principal component analysis of Kirschvink (1980). The previous section shows that the studied rocks have various lithologies, are highly metamorphosed and contain inhomogeneously distributed and varied magnetic minerals of secondary origin occurring in various forms. Hence, the demagnetization curves are complicated and difficult to resolve. Nevertheless, we were able to isolate the CHRM in six localities in sufficient amount of specimens for mean directions to be calculated for each of them. The analysis of the demagetization results of majority of specimens reveals the presence of more than one component of the NRM. We tried to find among them the components with relatively high unblocking temperatures (Tub) appropriate to the magnetic mineralogy of specimens ignoring the components appearing in temperatures lower than 200 °C. The mean directions in situ and after tectonic correction together with the parameters of the Fisher's statistics are summarized in Table 2.

Localities situated along the KMSZ shear zone:

Črmeľ (Č) — intensity of the NRM ranges from 0.7 to 3.5 mA/m. There is no data for this locality because we were not been able to isolate any characteristic component of the NRM.

Vyšný Klátov (KV) — intensity of the NRM is in the range 12–300 mA/m. The CHRM found in 7 specimens from 6 hand samples in the Tub range of 475 to 575 °C is carried by magnetite. An example of demagnetization results is shown in Fig. 4a.

Jahodná (J) — intensity of the NRM ranging from 0.1 to 0.6 mA/m is carried by hematite grains of various generations. The thermal treatment does not demagnetize it fully, beacuse the remanence remaining after annealing in 550–600 °C becomes unstable — it changes in intensity and direction during the measurement procedure. Nevertheless we

Table 2: Directions of the characteristic CHRM component for the Gemerides. Geographic position: 20.5°E, 48°N. Reference data after Besse & Courtillot (1991) for Middle Miocene D = 6, I = 62.

Loc.	N N/n	D/I *In situ*	D/I f.cor.	D/I p.cor.	α_{95}	k	plat	pol	ΔD=Do–Dref
KMSZ									
KV	6/7	**313/-60**	-	-	13	21	41	R	127 CW
J	3/6	**190/-65**	-	-	18	18	47	R	92 CCW
MA	3/5	**275/65**	-	-	20	16	47	N	4 CW
DSZ									
DO	9/12	320/51	265/66	**303/61 45%**	13	11	42	N	63 CCW
ML	5/8	68/70	342/30	**2/61 45%**	9	42	42	N	4 CCW
Outside main shearing zones									
GP	5/8	109/72	13/46	**25/62 65%**	6	98	43	N	17 CW

Loc. — locality; N/n — number of hand samples in which this CHRM was found/number of specimens taken for calculations; D/I *in situ* — declination/inclination before tectonic correction; D/I corrected — declination/inclination after correction; f.cor. — full correction; p.cor. — partial correction; 45% (65%) untilt. — 45% (65%) untilting; α_{95}, k — parameters of Fisher's statistics; plat — paleolatitude; pol — polarity of CHRM; CW — clockwise; CCW — counterclockwise; Do — declination obtained in this study; Dref — reference declination; R — angle of local rotation. KMSZ — Košice-Margecany shearing zone; DSZ — Dobšiná shearing zone. The directions taken for interpretation are in bold letters.

isolated the CHRM in 6 specimens from 3 hand samples in the Tub range of 250–450 °C. An example of demagnetization result is shown in Fig. 4b.

Margecany (MA) — intensity of the NRM in schists is 27-300 mA/m and about 0.2 mA/m in sandstones. The demagnetization results indicate that the NRM is carried mainly by magnetite, small components carried by goethite demagnetize very quickly. The directions of the CHRM isolated in specimens from both lithologies have normal and reversed directions and are highly scattered. Only in five specimens (from 1 sandstone and 2 schists samples) we were able to isolate the group of similar CHRM directions. Its Tub did not exceed 400 °C. Fig. 4c presents an example of the demagnetization results.

Localities situated along the DSZ schear zone:

Dobšiná (DO) — intensities of the NRM range from 0.2 to 3 mA/m. The remanence is carrried mainly by magnetite and hematite present in various ratios. Fig. 4d shows an example of the demagnetizing curve for specimen with predominance of magnetite, the NRM for specimens with hematite predominance did not demagnetize during the thermal treatment but became unstable after the heating to 600 °C. The CHRM was isolated in 12 specimens from 9 hand samples in Tub of 575 °C (only in one specimen this component had Tub of about 200 °C).

Mlynky (ML) — intensity of the NRM ranges from 0.8 to 40 mA/m. The NRM is carried by magnetite and hematite of various generations. In some specimens remanence, after heating to 600 °C became unstable. The CHRM was isolated in 8 specimens from 5 hand samples in Tub ranges 500–550 °C or 625–675 °C. An example of the demagnetization results for specimen with NRM carried by hematite is shown in Fig. 4e.

Locality situated outside main shear zones:

Gemerská Poloma (GP) — intensities of the NRM range from 0.1 to 0.4 mA/m. The natural remanence demagnetized completely or in great percent in the temperatures 300–350 °C (see Fig. 4f) indicating that it is carried mainly by pyrrhotite. As this mineral was identified neither by the microscopic analysis nor by the thermomagnetic analysis we suppose that it appears as very fine (submicroscopic) grains, probably due to alterations of pyrite which is present here in abundance. In temperatures exceeding 400 °C the remanence increases very quickly. The CHRM was isolated in 8 specimens from 5 samples in the Tub range of 300–350 °C.

The plot of the mean directions obtained for investigated localities in situ are presented in Fig. 5a. This plot and the data in Table 2 show that the in situ directions for KV, J and MA differ in declinations, but their inclinations are similar to each other. Lack of bedding parameters enables tectonic correction of them, but the similarity of inclinations suggests the post-folding origin of the CHRM and mutual rotations of the blocks represented by the exposures. The mean directions obtained for the three remaining localities differ in declinations and inclinations from each other both in situ and after full correction and differ from the in situ directions of the KV, J and MA (Table 2, Fig. 5b). In order to see whether part untilting of the DO, ML and GP will move their inclinations closer to the other three we performed the inclination-only fold test of Enkin (1994), Enkin & Watson (1996). This test is used for finding the degree of untilting that gives minimum dispersion of inclinations. This degree is indicated by the maximum of the plot of the Fisher's precision parameter k versus degree of untilting. In this way we may answer the question of whether the remanence studied is pre-tilting, post-tilting or was aquired at some intermediate stage. The result of this test performed for the directions of all six localities shows that the best fit would be obtained by 50% untilting of the DO, ML and GP, the value of k attains here maximum of 221. Another trial performed for 45% untilting of DO nad ML and 65% of untilting of the GP gave better estimate: the maximum of k increased to 572 — Fig. 6. The results of this test for all six exposures combined are presented in Fig. 5c. The mean directions calculated for the

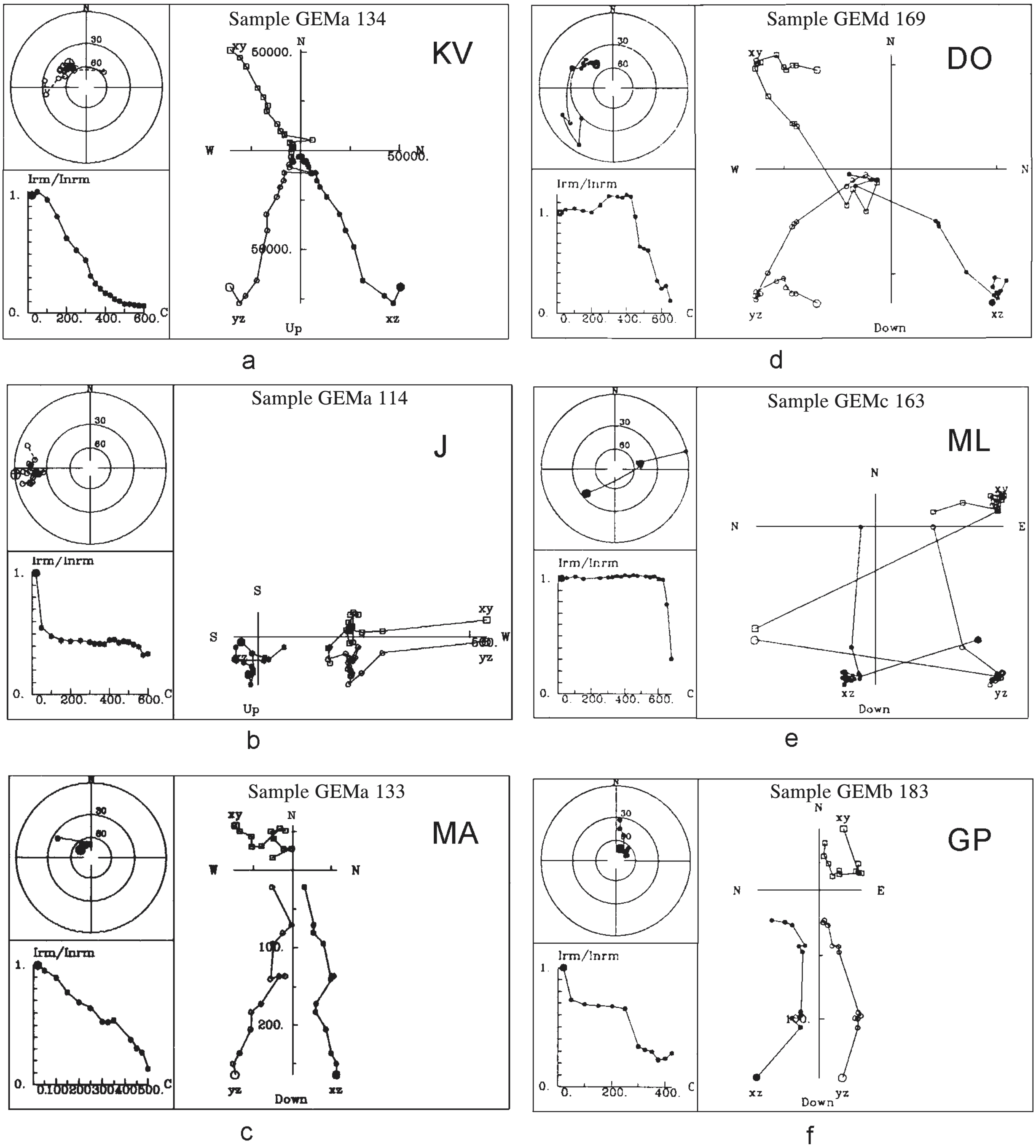

Fig. 4a-f. Examples of the thermal demagnetization experiments. (The names of localities in abbreviated form are assigned to respective figures).

appropriate unfolding ratios are summarized in Table 2 and shown in Fig. 5c together with the in situ directions of the KV, J and MA. Their inclinations remain in the narrow range of 60–65° but declinations differ considerably. We believe that each locality is situated within an individual small tectonic block and explain the differences in declinations as result of local rotations of the blocks connected with the shearing zones.

The inclinations obtained here are close to the inclinations calculated for the Gemeric Superunit for the Middle Miocene (10–20 Ma) after the European reference data of Besse & Courtillot (1991): $D_{ref}=6$, $I_{ref}=62$. The observed differences between the final declinations Do and the Dref reflect the amount and sense of local rotations of blocks that took place after their remagnetization. Angles and sense of rotations are summarized in the respective column in Table 2 as $\Delta D = D_o - D_{ref}$.

The presented results show that according to paleomagnetic data blocks situated along the dextral KMSZ zone (KV and J) rotated clockwise, the block represented by MA situated at the crossing of KMSZ (dextral) and TGSZ (sinistral) zones rotated counterclockwise as well as those situated along the sinis-

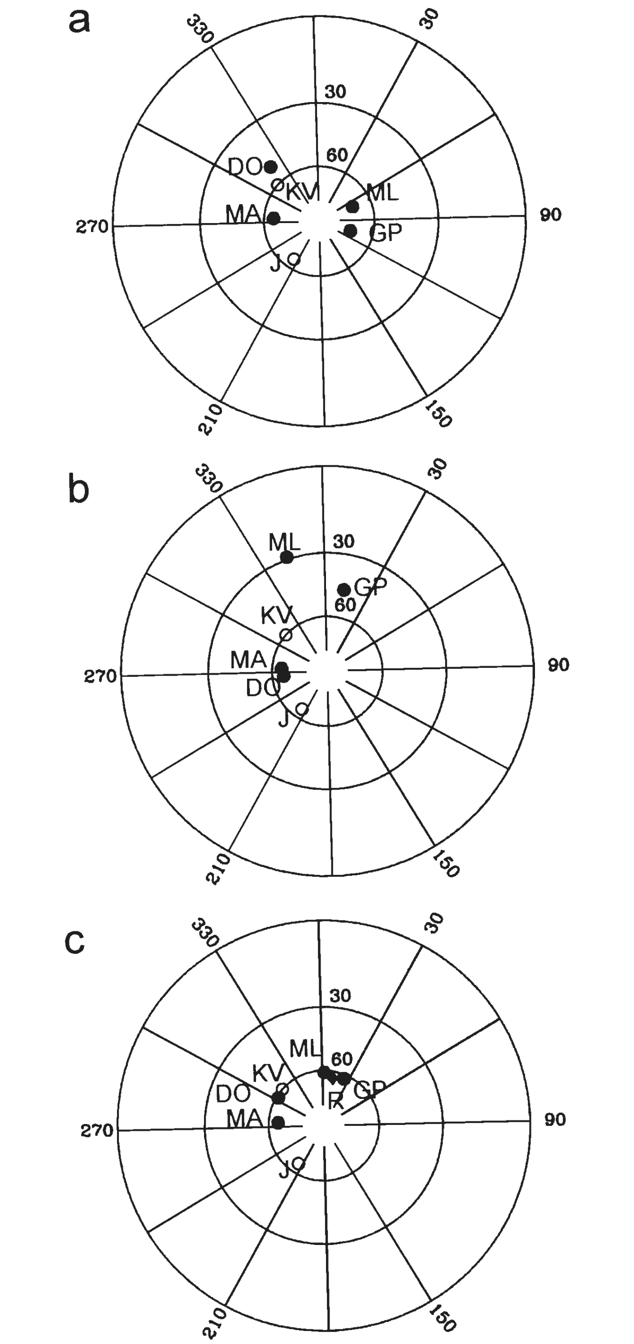

Fig. 5. Mean directions of the characteristic component of remanence (CHRM) isolated in HT range in studied localities. **a** — in situ, **b** — KV, J, MA — in situ, DO, ML, GP — after full tectonic correction, **c** — the best fit: KV, J, MA — in situ , DO and ML — after 45% untilting, GP — after 65% untilting. Diamond R denotes the reference field.

tral DSZ (DO, ML) zone. The block represented by GP situated within the unit rotated clockwise. The senses of rotations agree with character of respective shearing zones.

The first paleomagnetic research in the area of the Gemeric Superunit was performed by Hanuš & Krs (1963). They studied problems of hydrothermal mineralization on metasomatic sideritic deposits in the region of Dobšiná, Mlynky, Rožňava and others, and metasomatic magnesitic deposits in

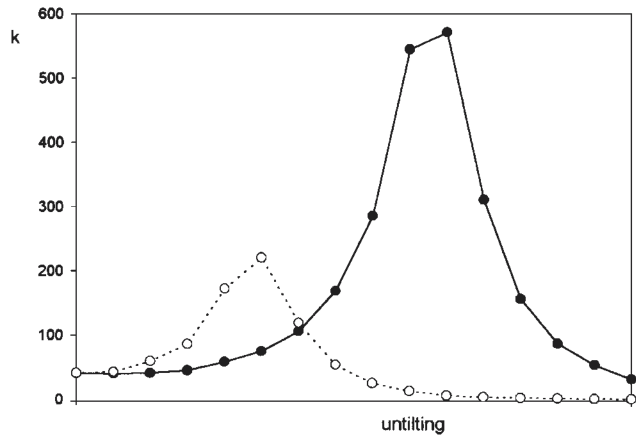

Fig. 6. The results of the inclination-only test, Enkin (1994) for KV, J, MA in situ , DO, ML, GP — after 50% untilting (open symbols) and KV, J, MA in situ, DO and MA — after 45% untilting, GP — after 65% untilting (full symbols). k — Fisher's precision parameter.

Bankov nearby Košice. On the basis of the study performed on undemagnetized rocks containing hematite they concluded, that there were no rotations in the region of the post-dating mineralization study. The interesting thing is, that their mean paleomagnetic direction in situ of undemagnetized NRM specimens sampled in the siderite vein-filling in the mine in Mlynky (D = 77°, I = 56°, α_{95} = 13°) is very close to the Mlynky in situ result of the present paper for which the CCW rotation is very small. The same is true for their result from the magnesite at Bankov near Košice (D = 198°, I = –70°, α_{95} = 4°40') and Jahodná of the present study — both results suggest the CW rotation (29° in Jahodná and 12° in Bankov).

The timing of events suggested by paleomagnetic study seems to be as follows: the Middle Miocene remagnetization of rocks — postfolding along the KMSZ zone, synfolding along the DSZ zone and in the GP locality. The magnetization in GP seems to be acquired during a stage of folding later than that along the DSZ. The presence of both normal and reversed polarity remanences suggests, that remagnetization processes were not synchroneous, but took place in the Gemeric Superunit during respective periods of reversed and normal polarity. The time span of remagnetization episodes is limited by the tectonic events that took place in the Gemeric Superunit to the period between the end of regional rotation (Karpatian–Badenian according to Márton et al. 1995 and Márton & Márton 1996) and extinction of activity along the shear zones (the Styrian phase, end of the Middle Miocene). Taking these constraints into account we believe that remagnetization processes took place during the time span between anomalies 6 (20 Ma) and 5 (10 Ma), when, according to the geomagnetic polarity time scale of Merril et al. (1996), the polarity of the geomagnetic field changed many times.

AMS study

The measurements of the anisotropy of magnetic susceptibility show that in all studied localities the values of the anisotropy parameter remain in a broad range (Table 3). The directions of the maximum and minimum anisotropy ellipsoid cluster reasonably well everywhere with the exception of the GP. The mean directions of Kmax and Kmin axes in situ and that of tectonic lineations L and foliations S (Návesňák 1993) corresponding to the magnetic anisotropy directions in respective localities are summarized in Table 3. Fig. 7 presents mean directions of Kmax and Kmin and the magnetic foliation planes together with the corresponding tectonic lineations and foliation planes. In the localities from the KMSZ zone there are no correlations of the magnetic and tectonic lineations, with the exception of MA where the Kmax direction is close to the L3. The magnetic foliation (Kmin) corresponds to the tectonic (mylonitic) foliation S4 in three localities from the KMSZ zone (C, J, MA) whereas in the KV which is perhaps situated within an independent tectonic unit (see chapter Geological setting and sampling) the magnetic foliation does not correspond to any tectonic one. The situation in MA suggests, that magnetic fabric reflects both shearing systems: East-Carpathian through magnetic foliation and West-Carpathian through magnetic lineation. In the DSZ zone the situation is different: in the chlorite schists of DO magnetic foliation corresponds with the S2 and the magnetic lineation with the L2 , whereas in the phyllites of the ML — with S3 and L3 systems, respectively. Systems L2, S2 are related to the TGSZ zone, systems S3, L3 — to the LSSZ zone, both belonging to the same West-Carpathian system. Figure 8 summarizes the magnetic foliation planes (with the exception of the result for KV) and the tectonic foliation planes. The presented pattern shows distinct relations between the magnetic foliation in localities from the KMSZ zone and the tectonic foliation S4 associated with this zone (East-Carpathian shearing system). Magnetic foliations in localities from the DSZ zone are close to both tectonic foliations linked with the West-Carpathian shearing system proving that the magnetic anisotropy originated due to the Alpine deformations. The rotations suggested by the paleomagnetic research (see chapter Paleomagnetic results and discussion) agree with the sense of shearing.

Table 3: The characteristics of the anisotropy of magnetic susceptibility together with the corresponding directions of the tectonic lineation L and the foliation planes S after Návesňák (1993).

Locality	Kmax *in situ*	Kmin *in situ*	P’	L	S
KMSZ					
Č	257/53	38/29	1.08–1.17	-	S4
KV	354/70	250/7	1.04–1.21	-	-
J	196/46	32/23	1.03–1.10	-	S4
MA	295/9	45/57	1.10–1.28	L3	S4
DSZ					
DO	66/24	320/31	1.06 – 1.13	L2	S2
ML	258/22	135/51	1.03 – 1.6	L3	S3
Outside Main Shearing Zones					
GP	scattered results		1.03 – 1.10	-	-

P’ — anisotropy parameter, for formulas see text; L — mineral lineation; S — mineral foliation; KMSZ — Košice-Margecany shearing zone; DSZ — Dobšiná shearing zone.

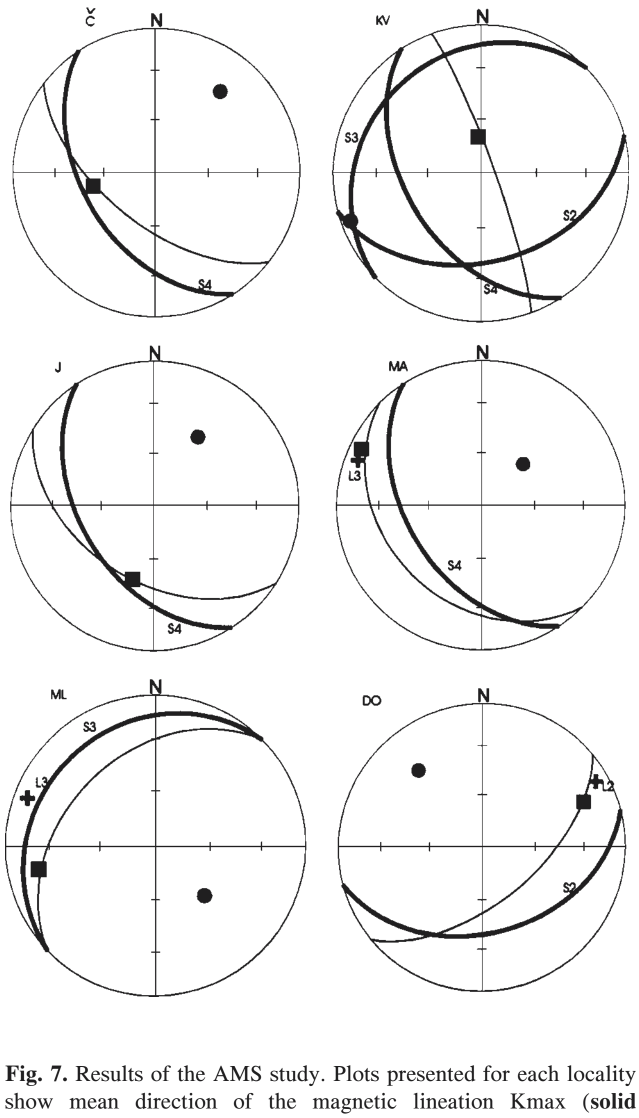

Fig. 7. Results of the AMS study. Plots presented for each locality show mean direction of the magnetic lineation Kmax (**solid square**), mean direction of Kmin (**solid circle**), magnetic foliation plane (**thin line**), direction of tectonic lineation fitting best magnetic lineation (**cross**), tectonic foliation plane fitting best magnetic foliation (**bold line**). Appropriate labels denoting the tectonic lineations and foliations systems are also included. Abbreviations denoting the localities are the same as in Fig. 3.

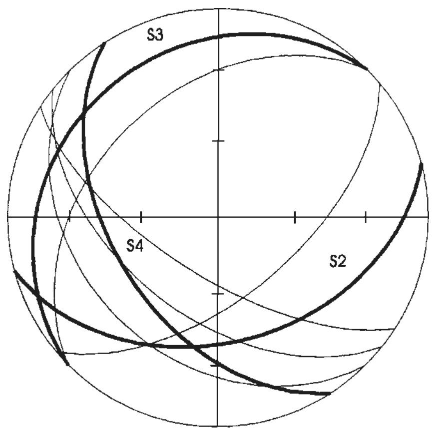

Fig. 8. Plot of the magnetic foliation planes obtained in this study with the exception of KV together with the corresponding tectonic foliation planes.

Conclusions

1 — The NRM of the studied rocks is carried by secondary magnetic minerals and represents secondary overprinting.

2 — The presence of reversed polarity of CHRM in KV and J and normal polarity in remaining localities indicates that remagnetization was not synchronous.

3 — In the localities situated along the KMSZ zone the remagnetization took place after folding, in the localities situated along the DSZ zone and within the unit — during folding.

4 — All the studied Paleozoic metamorphic rocks of the Gemeric Superunit became remagnetized during the Middle Miocene probably between anomaly 6 (20 Ma) and anomaly 5 (10 Ma).

5 — After the remagnetization episodes the particular tectonic blocks became rotated due to the activity of the shearing systems, blocks lying close to the dextral KMSZ zone rotated clockwise (with the exception of MA that was influenced by both systems), blocks lying close to the sinistral DSZ zone rotated counterclockwise.

6 — The AMS originated due to the activity of the shearing zones, the magnetic fabric agrees with the tectonic fabric: S4 fits the magnetic foliation in the KMSZ localities, S2 and S3 fit the magnetic foliation in the DSZ localities.

Acknowledgments: The work was done in the frame of the scientific cooperation between the Slovak Academy of Sciences and the Polish Academy of Sciences with support of the Institute of Geophysics, Polish Academy of Sciences, Warsaw, Project 5/1998 and the Slovak Grant Agency VEGA, Project 2/5136/98.

References

Besse J. & Courtillot V. 1991: Revised and Synthetic Apparent Polar Wander Paths of the African, Eurasian, North American and Indian Plates, and True Polar Wander since 200 Ma. *J. Geophys. Res.* 96, 4029–4050.

Csontos L., Nagymarosy A., Horváth P. & Kováč M. 1992: Tertiary evolution of the Intra-Carpathian area: A model. *Tectonophysics* 208, 221–241.

Day R., Fuller M. & Schmidt V.A. 1977: Hysteresis properties of titanomagnetites: Grain size and compositional dependence. *Phys. Earth Planet. Int.* 13, 260–267.

Enkin R.J. 1994: A computer Program Package for Analysis and Presentaiton of Paleomagnetic Data. *Unpublished*.

Enkin R.J. & Watson G.S. 1996: Statistical analysis of palaeomagnetic inclination data. *Geophys. J. Int.* 126, 495–504.

Grecula P., Návesňák D., Bartalský B., Gazdačko L., Németh Z., Ištván J. & Vrbatovic P. 1990: Shear zones and arc structures of Gemericum, the Western Carpathians. *Miner. Slovaca* 22, 97–110.

Grecula P. and co-authors 1995: Contribution of the Slovak working group to realization of the IGCP Project No 276 "Paleozoic in the Tethys". *Geocomplex*, Bratislava, 1–123.

Grecula P. 1997: Deformation Related to the Alpine Transpression in the Western Carpathians. In: Sinha A. K., Sassi F. P. & Papanikolau D. (Eds.): *Geodynamic domains in the Alpine-Himalayan Tethys. Oxford & IBM Publ. CO.,* New Delhi, 339-346.

Hanuš V. & Krs M. 1963: Paleomagnetic Dating of Hydrothermal Mineralization on Example of Spišsko-gemerské Rudohorie Area—Czechoslovakia. *Rozpravy Československ. Akad. Věd, Ser. 14, Ř.7*, 33–88.

Jelínek V. 1977: The statistical theory of measuring anisotropy of magnetic susceptibility and its application. *Geofyzika*, Brno, 5–88.

Kirschvink J.L. 1980: The least squares line and plane and the analysis of paleomagnetic data. *Geophys. J. Roy. Astron. Soc.* 62, 699–846.

Lewandowski M., Nowożyński K. & Werner T. 1997: PDA—package of FORTRAN programs for palaeomagnetic data analysis. *Unpublished.*

Márton E. & Márton P. 1996: Large scale rotations in North Hungary during the Neogene as indicated by paleomagnetic data. In: Morris A. & Tarling D.H. (Eds.): Paleomagnetism and Tectonics of the Mediterranean Region. *Spec. Publ. (Geol. Soc. London),* 105, 153–173.

Márton E., Vass D. & Túnyi I. 1995: Late Tertiary rotations of Pelso Megaunit and adjacent Central Western Carpathians. *Knihovnička ZPN,* 16, 97–108 (in Slovak, English abstract).

Merril R.T., Mc Elhinny M.W. & Mc Fadden P.L. 1996: The Magnetic Field of the Earth. *Int. Geophys. Ser. 63, Acad. Press.*, London, 1–527.

Návesňák D. 1993: Manifestation of shear zons in the north-eastern part of Gemeric Unit, Western Carpathians. *Miner. Slovaca* 25, 263–273 (in Slovak, English summary).

Peresson H. & Decker K. 1996: From extension to compression: Late Miocene stress inversion in the Alpine-Carpathian-Pannonian transition area. *Mitt. Gesell. Geol.- Bergbaustud. Wien* 41, 75–86.

Plašienka D., Grecula P., Putiš M., Kováč M. & Hovorka D. 1997: Evolution and structure of the Western Carpathians: an overwiew. In: Grecula P., Hovorka D & Putiš M. (Eds.): Geological evolution of the Western Carpahtians. *Miner. Slovaca—Monograph,* 1–24.

Radvanec M. 1994: Petrology of Gemeric gneis-amphibolite complex on the northern margin of the Rudňany Ore Field, Part I. and II. *Miner. Slovaca* 26, 223-249.

Radvanec M. 1997: High-pressure metamorphism of Carboniferous sediments in the Gemericum (in Slovak). *Proc. IIth Sem. Czech Tect. Group,* Ostrava, 60-61.

Tarling D.H. & Hrouda F. 1993: The Magnetic Anisotropy of Rocks. *Chapman and Hall,* London, 1–217.