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Post-Cretaceous differential block rotation in the Slovenský raj Mts (Western Carpathians, Slovakia): inferences from paleomagnetic data

IGOR TÚNYI[1], JADWIGA KRUCZYK[2], MAGDALENA KĄDZIAŁKO-HOFMOKL[2] and JÁN MELLO[3]

[1]Geophysical Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 845 28 Bratislava, Slovak Republic; geoftuny@savba.sk
[2]Institute of Geophysics Polish Academy of Sciences, Ks. Janusza 64, 01 452 Warszaw, Poland; magdahof@igf.edu.pl
[3]State Geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic

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Abstract: Results of paleomagnetic study of Triassic limestones, sandstones and serpentinites of the Stratená and Bôrka Nappes (Silicic and Meliatic Units), as well as of the Upper Cretaceous sandstones (Gosau Group) from the area of the Slovenský raj Mts and Dobšiná area are presented. Characteristic components of remanence were isolated in six localities representing several nappe slices. The isolated characteristic remanences are carried by secondary minerals. They are of chemical origin and normal polarity. They were probably acquired during the latest Cretaceous at paleolatitudes of about 28°N to 22°N showing that the area was in that time of African affinity. The whole study area moved from the South to North, nappes and nappe slices formed due to intensive compressive Paleoalpine tectonics. During the transtensive and extensive Neoalpine periods of Alpine orogenesis they disintegrated into different blocks which moved mainly horizontally, some of them were backthrusted, or rotated. Finally they were amalgamated into the recent megablocks. The individual rotations calculated against the reference declination Dref = 6° for European data for the Miocene are as follows: Dolka 1: 21° CW (Clockwise), Dolka 2: 15° CW, Dedinky: 14° CCW (Counter-clockwise), Kopanec: 41° CCW, Dobšiná: 55° CCW, Dobšinská ľadová jaskyňa: 16° CW.

Key words: Western Carpathians, Silicic and Meliatic Tectonic Units, Triassic limestones, Cretaceous sandstones, paleomagnetism, paleorotations.

Introduction

Paleomagnetic study has been widely used in recent years for successful reconstruction of geodynamic development of geologically complicated regions. Such study has been carried out for several years in southern parts of the Western Carpathians, as well (Márton et al. 1991, 1995; Kruczyk et al. 1998; Túnyi et al. 2004).

The present paper extends the previous study concerning Triassic rocks from the southern part of the Silicic Unit (Silica Nappe, Slovenský kras Mts) in the area of Rožňava (Kruczyk et al. 1998). There, in the studied Hallstatt limestones, we were able to discern two secondary components of NRM (Natural Remanent Magnetization) of different polarity that were acquired in two different times: the reversed component originated during the Oligocene and the normal component originated during the Middle Miocene. The inclination of the Middle Miocene component indicates that it was acquired at a paleolatitude of about 35°N. Values of declinations of R (Reverse) and N (Normal) components indicated two CCW rotational phases of the whole region: about 50° between Oligocene and Middle Miocene and 30–40° in the post-Middle Miocene times. These results agreed with earlier conclusions by Márton et al. (1995 and papers cited there) concerning the Pelso tectonic megaunit which also comprises the Silica Nappe.

Now we present the results obtained for the Triassic limestones and serpentinites as well as Upper Cretaceous sandstones sampled in several exposures situated further to the North, in the area of Slovenský raj Mts and vicinity of Dobšiná town. They belong to the northern part of Silicic Unit (Stratená Nappe), to the Meliatic Unit (Bôrka Nappe) and to the postnappe Gosau Formation. According to their geological description (see the following part) each exposure represents a separate (partial) nappe slice. Our previous interpretation (Túnyi et al. 2004), based on preliminary collection of samples suggested the presence of a primary component of NRM in the studied rocks. But, as we were not quite satisfied with the results, we took new samples from some of the same exposures and from several new ones. Our new results added to the previous ones lead to the new interpretation — it seems that the studied rocks carry secondary remanence acquired during or shortly after the Late Cretaceous. Nappe slices were independently rotated later, in connection with younger Alpine movements.

Geological outline

The paleomagnetic study was focused on the area of the Slovenský Raj Mts and vicinity of Dobšiná (Fig. 1). Samples were taken from rocks which were previously attributed to the so called "North Gemeric Mesozoic" (Maheľ in Maheľ et al. 1967). Recently interpretation became more complicated — 4 Alpine tectonic units in tectonic superposition (from the base upward): Veporic, Gemeric, Meliatic (including the Bôrka Nappe) and Silicic (Stratená and Vernár Nappes) are distin-

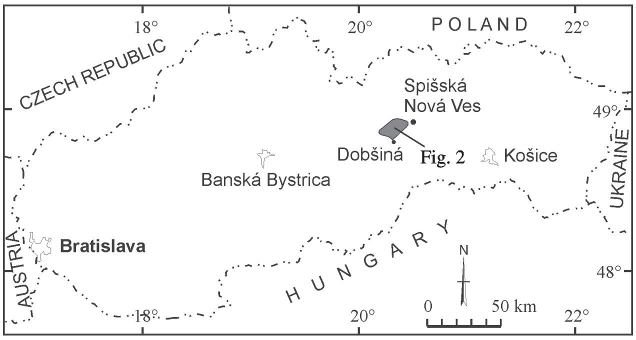

Fig. 1. Situation sketch of the studied area.

guished here (Fig. 2). The Upper Cretaceous (Gosau Group) and Paleogene sediments represent the overstepping post-nappe complexes.

Structural measurements and facies relations have led to the conclusion that the nappes were thrust one above the other in the direction from the South to the North (in today's coordinates), most probably in the Early Cretaceous. This was followed by emersion and denudation of strata (prevailingly of the upper parts of the Silicic Unit), and later by transgression of the Upper Cretaceous formations (Gosau Group) over mostly Triassic, to lesser extent Jurassic formations of the Silicic Unit.

Geological structure was later modified by sinistral transpressional movements along the Muráň strike-slip fault. These movements resulted in origination of partial tectonic units and slices of the Stratená Nappe, mainly that of the Glac partial unit with the Červený Štros slice and Geravy partial unit with Hýl slices (Mello et al. 2000a,b) (Fig. 2). Partial tectonic units and slices were backthrust upon the Upper Cretaceous sediments. Together with the Vernár partial nappe from the opposite side of the Muráň fault they form a typical fan-like structure. The origin of this structure is very well dated in the Laramian period, because the above mentioned backthrusting involved the Senonian sediments (Fig. 3) and predated deposition of the Eocene transgressive basal conglomerates of the Borové Formation (Mello et al. 2000a,b).

Compressional and transpressional movements ceased at the beginning of the Cenozoic period. No more nappes or tectonic slices were formed later in the Inner Western Carpathians. The Paleogene formations are only slightly folded and disturbed with several fault systems (E–W, NE–SW and NW–SE directions, Filo in Mello et al. 2000b).

Due to the lack of Neogene sediments in the area it is not possible to document reliably the Neogene tectonic movements, but from the records in older formations and from studies of Neogene formations in neighbouring lowland areas it is obvious, that for the Neogene Period an extensional

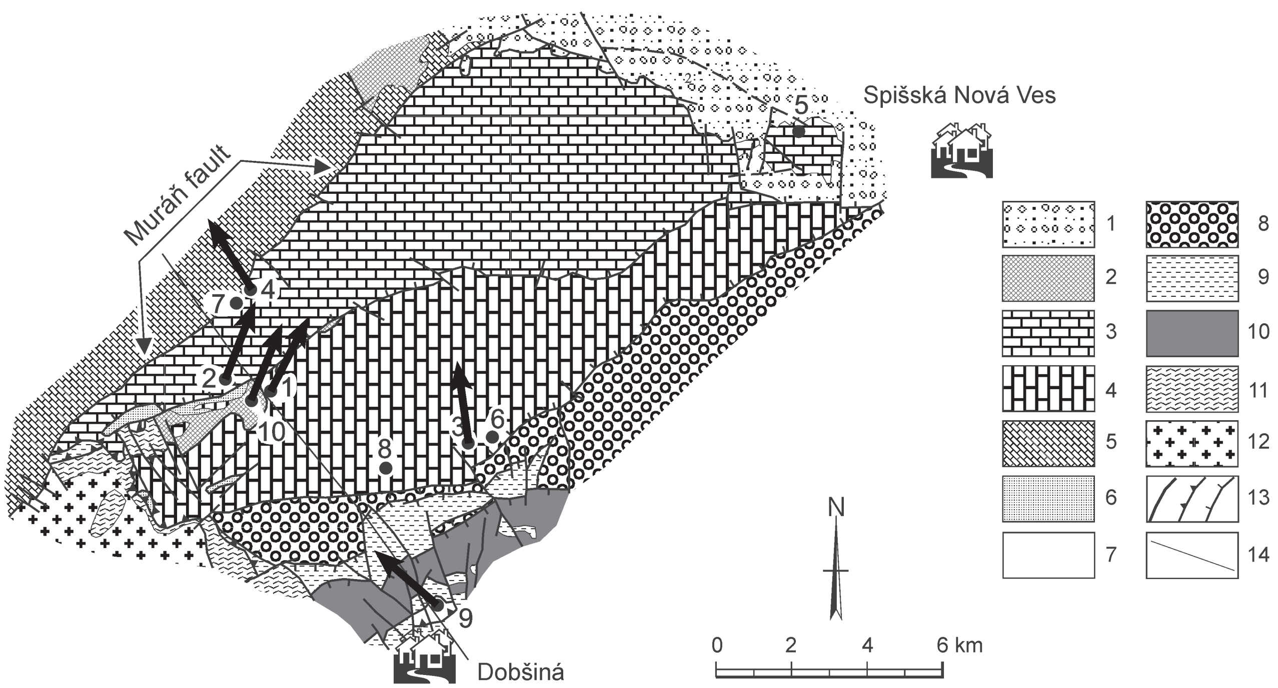

Fig. 2. Geological units in the area of the Slovenský raj Mts and Dobšiná vicinity (according Mello et al. 2000) and sampling localities. **Post-nappe Formations: 1** — Podtatranská Group (Paleogene), **2** — Gosau Group (Late Cretaceous). **Paleoalpine Nappes:** ***SILICIC UNIT*****: Stratená Nappe: 3** — Glac partial unit with Červený Štros slice, **4** — Geravy partial unit with Hýľ slices, **5** — Vernár Nappe. ***MELIATIC UNIT:*** **6** — "Meliatic Unit s.s.", **7** — Bôrka Nappe. ***GEMERIC UNIT:*** **8** — Krompachy Group (Permian), **9** — Dobšiná Group (Carboniferous), **10** — Klátov and Rakovec Group (Devonian–Early Carboniferous). ***VEPORIC UNIT:*** **Sedimentary cover: 11** — Foederata and Revúca Group (Carboniferous–Triassic). **Crystaline complexes: 12** — Kráľova hoľa Complex, **13** — Faults, Alpine thrust contacts, contacts of partial units and backthrusts, **14** — Line of geologic cross-section (Fig. 3). **Sampling localities: Silicic Unit (Middle and Late Triassic):** 1 — Dolka 1, 2 — Dolka 2, 3 — Dedinky, 4 — Kopanec, 5 — Smižanská Maša, 6 — Biele Vody, 7 — Pod Kopancom, 8 — Stratená. **Meliatic Unit (Bôrka Nappe):** 9 — Dobšiná (abandonned quarry). **Gosau Group:** 10 — Dobšinská ľadová jaskyňa. Arrows — paleomagnetic directions (see Fig. 9).

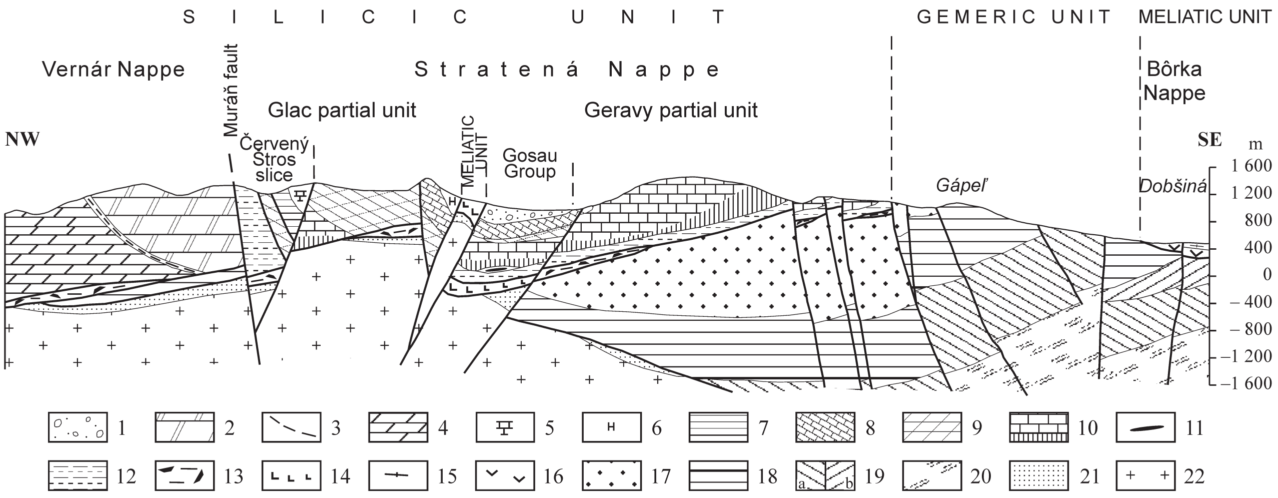

Fig. 3. Geological cross-section through the SE part of the Slovenský raj Mts and Dobšiná vicinity (according Mello et al. 2000, partly modified). **Postnappe Formations: 1** — Gosau Group (Late Cretaceous). **Paleoalpine Nappes:** ***SILICIC UNIT*****: Vernár Nappe: 2** — Dachstein Dolomite (Late Carnian–Norian?), **3** — Lunz Member (Late Julian–?Tuvalian), **4** — Wetterstein Dolomite (Fassanian–Early Julian). **Stratená Nappe (Glac and Geravy partial Units): 5** — Dachstein Limestone (Late Carnian–Norian), **6** — Hallstatt Limestone (Norian), **7** — Reingraben and Mürztal Member (Julian), **8** — Waxeneck Limestone (Carnian), **9** — Wetterstein Dolomite (Langobard–earliest Carnian), **10** — Wetterstein and Steinalm Limestone (Late Anisian–Cordevolian), **11** — Gutenstein Formation (Early Anisian), **12** — Werfen Formation (Scythian). ***MELIATIC UNIT*****: "Meliaticum s.s.": 13** — claystones, radiolarites (Late Jurassic), **14** — mèlange of shales, radiolarites, paleobasalts and serpentinites (Late Jurassic or younger). **Bôrka Nappe: 15** — phyllites with metabasalt tuffs (Triassic–Jurassic?), **16** — serpentinites (Triassic?). ***GEMERIC UNIT:*** **17** — Krompachy Group (Permian), **18** — Dobšiná Group (Carboniferous), **19** — Rakovec (a) and Klátov (b) Group (Devonian–Early Carboniferous), **20** — Gelnica Group (Ordovician–Devonian). ***VEPORIC UNIT:*** **21** — Sedimentary cover (Carboniferous–Triassic), **22** — Kráľova hoľa Crystaline Complex.

tectonics is characteristic. It is expressed mainly by faults with different directions.

Sampling

For paleomagnetic measurements, 48 hand samples were taken from 10 localities (Fig. 2):

A. Silicic Unit, Stratená Nappe — *limestones* of Middle and Late Triassic: Dolka (1), Dolka (2), Dedinky (3), Kopanec (4), Smižanská Maša (5), Biele Vody (6); *sandstones* of Early Triassic: Pod Kopancom (7), Stratená (8).

B. Meliatic Unit (Bôrka Nappe) — Middle Triassic *serpentinites:* Dobšiná (9).

C. Gosau Group — Upper Cretaceous *sandstones*: Dobšinská ľadová jaskyňa (10).

Methodology

Rock-magnetic experiments leading to identification of magnetic minerals — carriers of natural remanence were performed in the Warsaw Paleomagnetic Laboratory. They comprised thermal demagnetization of saturation isothermal remanent magnetization (SIRM) acquired in the field of 5 T, during heating in air to 700 °C in non-magnetic space in the air (apparatus of TUS-Poland). The thermal demagnetizing curves bring blocking temperatures Tb,s characteristic for ferromagnetic minerals present in the studied specimen. Another thermomagnetic method, called Lowrie method (Lowrie 1990) consists on magnetizing a specimen in three mutually perpendicular directions in high field (1.4 T), intermediate field (0.4 T) and low field (0.1 T). Thermal demagnetization of these three components discerns between minerals of different coercivities and blocking temperatures. For several specimens mineralogical analysis in reflected light was also performed, unfortunately amount of magnetic minerals — carriers of natural remanence was very low in all specimens except the serpentinites where magnetite was observed (analysis was done by Siemiątkowski from the Polish Geological Institute, Wrocław).

Standard paleomagnetic study was performed mainly in the Slovak Paleomagnetic Laboratory where Natural Remanent Magnetization (NRM) was cleaned thermally by consecutive heating using non-magnetic furnace and measured with a JR-5 magnetometer from AGICO comp. Only a few specimens were demagnetized in the Warsaw Laboratory with alternating field AF (cryogenic SQUID magnetometer with AF demagnetizer from 2G Enterprises, USA). All results of demagnetization were analysed in the Warsaw Laboratory with the special program package of Lewandowski et al. (1997). The final paleomagnetic results were obtained only for six localities. They are included in Table 1 and shown in Fig. 9a,b. The mean data of isolated characteristic components are presented in situ and after corrections in Fig. 9a,b.

Results

Silicic Unit

(1) Dolka (settlement) 1, Stratená Nappe, Geravy partial unit, Dachstein organodetritic limestone (Late Triassic) — 5 hand samples. Thermomagnetic analysis (Fig. 4a) indicates some amount of maghemite and hematite as carriers of magnetic remanence. Magnetic susceptibility attains small negative values (from -8 to -5×10^{-6} uSI) indicating domination of diamagnetic minerals, nevertheless specimens possessed natural remanence of 40–550 μA/m, measurable with both SQUID and JR-5 equipment. From the 5 hand samples 16 specimens became demagnetized thermally to 650 °C and 5 with alternating field to 120 mT (Fig. 6a,b). Thermal treatment was effective up to 300–400 °C, at higher temperatures the intensity of NRM increased and its directions became chaotic. Alternating field demagnetization was effective up to about 50–80 mT, in higher fields specimens acquired spurious remanences. Analysis of demagnetization curves shows the presence of one or two components: one isolated at lower temperatures (up to 150–250 °C) and, sometimes, the second one isolated at higher temperatures. Fig. 7a presents the directions of all the isolated components of NRM. The cluster formed in the first quadrant and composed of the lower temperature component of NRM is treated as the component of characteristic remanent magnetization (ChRM, Fig. 8a). It was obtained for 9 specimens (from the 5 hand samples) only from thermal demagnetization results, results obtained from AF cleaning lie far outside the cluster. The paleomagnetic results are included in Table 1, as described above.

(2) Dolka (settlement) 2, Stratená Nappe, Glac partial unit, Hallstatt limestone (Late Triassic) — 10 hand samples. Magnetic susceptibility is negative and ranges from -8 to -10×10^{-6} uSI, but despite the dominance of diamagnetic minerals these rocks possess natural remanence with intensi-

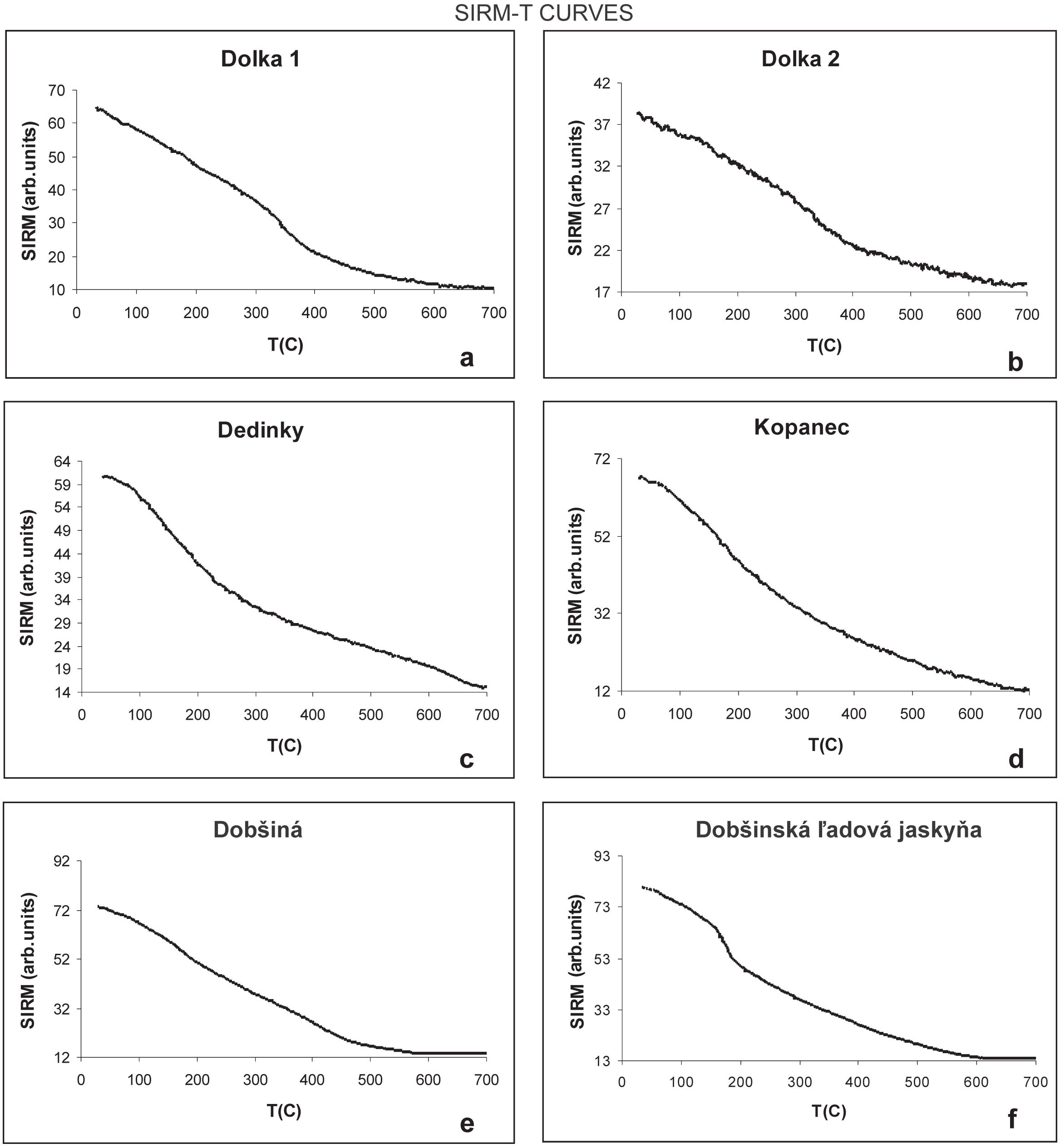

Fig. 4. Saturation isothermal remanent magnetization versus temperature (SIRM-T) curves characteristic for the studied localities.

Table 1: Final paleomagnetic results.

Locality N/n	**φ/λ [°]**	**Bedding Az/dip [°]**	**Dm/Im in situ [°]**	**α°95/k**	**Plat m [°]**	**Dabc/Iabc [°]**	**Plat abc [°]**	**Rotation [°] ΔD=Dref-Dm**
Dolka 1 5/9	48.83/20.32	300/35	**27/51**	10/30	**31**	353/38	21	21CW
Dolka 2 5/11	48.85/20.33	290/10	**21/47**	9/25	**28**	10/46	28	15CW
Dedinky 6/12	48.83/20.34	300/25	**352/47**	12/15	**28**	338/29	15	14CCW
Kopanec 7/19	48.90/20.32	*0/50 **350/40	**328/37**	10/13	**21**	335/8	4	41CCW
Dobšiná 3/15	48.78/20.33	***0/15	**311/39**	12/41	**22**	318/28	15	55CCW
Dobš. ľadová jaskyňa 2/4	48.82/20.28	270/70	**22/40**	8/131	**23**	325/29	16	16CW

Geographical position of the region: Lat: 48.90N, Long: 20.30E. Reference direction for the study area for Miocene calculated according to the Stable European data of (Besse & Courtillot 2002): Dref = 6°, Iref = 62°. * — bedding coordinates for samples nr 11–14; ** — bedding coordinates for samples nr 53–58; *** — coordinates of the bedding of overlying sediments; **N** — number of hand samples; **n** — number of directions taken for calculations; **φ/λ** — geographical coordinates of locality; **Az** — azimuth; **Dm/Im** — declination and inclination of characteristic magnetization for sample positions in situ; **α°95/k** — parameters of Fisher statistics; **Plat m** — paleolatitude for samples position in situ; **Dabc/Iabc** — declination and inclination of characteristics magnetization for samples position after bedding correction; **Plat abc** — paleolatitude for samples position after bedding correction.

ty ranging from 2 to 400 μA/m (in one sample intensity acquired ca. 1100 μA/m). It was easily measurable in both Laboratories. Thermomagnetic results indicate dominance of hematite. Its presence is visible on the SIRM-T curve (Fig. 4b) and on the Lowrie thermal curve obtained for the highest coercivity component acquired in 1.4 T (Fig. 5a). 17 specimens were demagnetized thermally and 4 with AF. NRM usually consisted of one, rarely of two components (Fig. 6c,d). Thermal demagnetization curves revealed two components of remanence — one isolated at low temperatures (up to 150 °C) and another one at higher temperatures. In the AF treated specimens, in the field of 20–30 mT, we isolated the characteristic component of remanence with directions close to the directions of the low temperature component isolated thermally. In specimens cut from the single strongly magnetic sample, the component with the same direction was isolated along the whole curve of demagnetization (20–500 °C). Taking all this into account we treat the described component as the characteristic one, the directions of all isolated components are shown in Fig. 7b and the directions of ChRM — in Fig. 8b. The final paleomagnetic results are included in Table 1 and in Fig. 9a,b.

(3) Dedinky (village), Stratená Nappe, Geravy partial unit, Steinalm-limestone (Middle Triassic), 7 hand samples, 15 specimens demagnetized thermally and 3 — with AF. Susceptibility ranges from –5 to 23×10^{-6} uSI showing the dominating presence of dia- and/or paramagnetic minerals. Various amounts of ferromagnetic minerals are responsible for the natural remanence which remains in a broad range: 2–800 μA/m. Thermomagnetic analysis performed by heating of the SIRM (Fig. 4c) and by the Lowrie method (Fig. 5b) indicate the dominant presence of hematite. Because hematite is clearly discernible on high-coercivity and intermediate-coercivity heating curves (Fig. 5b) we suppose that it appears in two different grain sizes, perhaps connected with different metamorphic events. The same plot shows the presence of magnetite and some phase with a blocking temperature of about 250 °C (goethite?). Alternating field demagnetization reveals presence of single component NRM demagnetized along the whole spectrum of fields (Fig. 6f). Thermal cleaning usually revealed the presence of two components out of which one had a direction corresponding to the direction isolated with AF (Fig. 6c). This component was isolated in various ranges of unblocking temperatures — low (up to 150 °C), intermediate (up to 250 °C) and high range (up to 500–650 °C). The directions of all the isolated components are shown in Fig. 7c and the distribution of characteristic directions — in Fig. 8c. The final paleomagnetic results are presented in Table 1 and Fig. 9.

(4) Kopanec (saddle), Stratená Nappe, Červený Štros slice, Reingraben Member (dark sandy shales, Late Triassic) — 9 hand samples. Thermomagnetic analysis indicates the presence of hematite, magnetite and goethite (Fig. 4d, Fig. 5c,d). Magnetic susceptibility ranges from –10 to -6×10^{-6} uSI proving the dominance of diamagnetic minerals, but the intensity of NRM is measurable and ranges from 6 to 300 μA/m. The results of these rocks did not correspond to AF demagnetization — after cleaning with 120 mT 70–90 % of initial NRM was left (Fig. 6g), due to a high amount of high-coercivity minerals. Thermal cleaning revealed the presence of either one or two components of NRM isolated at lower (up to 150–300 °C) and higher temperatures (400–650 °C). The directions of all of them are shown in Fig. 7d. Out of this distribution we isolated the characteristic component of NRM in unblocking temperatures of 400–600 °C, their directions are presented in Fig. 8d. The final results are given in Table 1 and Fig. 9.

Four of the sampled localities from this unit: (5) Smižanská Maša (6 hand samples), (6) Biele Vody (4 hand samples), (7) Pod Kopancom (2 hand samples) and (8) Stratená (2 hand samples) did not provide reliable paleomagnetic results and will not be further discussed here.

Meliatic Unit (Bôrka Nappe)

(9) Dobšiná (abandoned quarry), serpentinites (probably Middle Triassic in age), 3 hand samples. Thermomagnetic study shows the presence of magnetite (Fig. 4e) and some

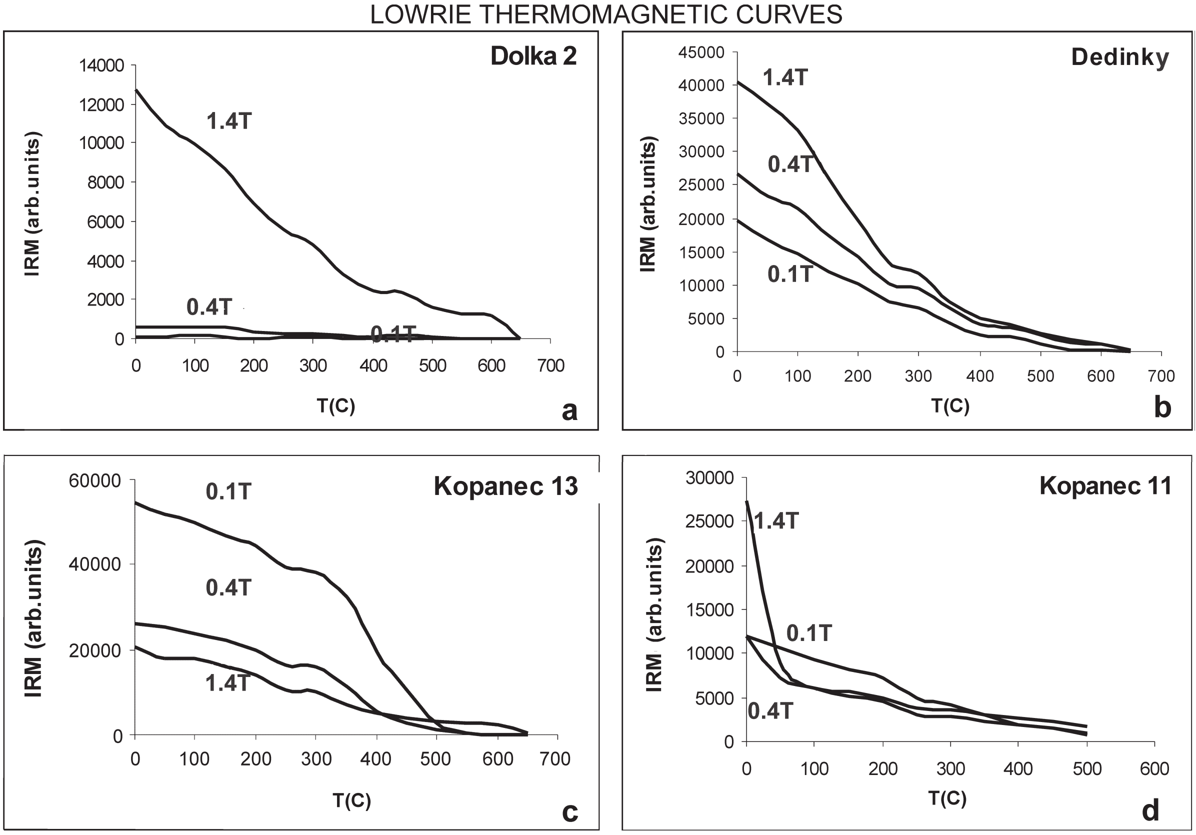

Fig. 5. Results of the Lowrie method obtained for Dolka 2, Dedinky and Kopanec.

hematite, small grains of magnetite were also identified microscopically in reflected light. Magnetic susceptibility ranges from 2800 to $27,000\times10^{-6}$ uSI and intensity of NRM attains 15,000–20,000 μA/m. Thermal cleaning of five specimens cut from 3 hand samples usually revealed two components of NRM, one isolated at lower temperatures (50–300 °C) and another one isolated at high temperatures (350–650 °C) — Fig. 6j. The higher temperature component is treated as the characteristic one. Fig. 7d shows the distribution of the directions of all the isolated components, and Fig. 8d — distribution of directions of ChRM. The final results are included in Table 1 and Fig. 9.

Gosau Group (post-nappe formation)

(10) Dobšinská ľadová jaskyňa (railroad cut), sandstones (Upper Cretaceous). Here only 2 hand samples were taken in the field, nevertheless we performed the standard rock-magnetic and paleomagnetic experiments on them. Thermomagnetic analysis reveals the presence of goethite and magnetite and/or maghemite (Fig. 4f). Magnetic susceptibility ranges between 600 and 1100×10^{-4} uSI and the intensity of NRM — between about 200 and 570 μA/m. 4 specimens were demagnetized thermally, revealing the presence of either one or two components of NRM (Fig. 5j). In specimens where two components were isolated, the directions of the one, isolated at lower temperatures (350 °C), corresponded to the direction of the single component isolated over the whole temperature range (till 600 °C) in specimens from the other demagnetized sample. Components with these directions were treated as characteristic ones and their directions are shown in Fig. 8f, while the directions of all isolated components are given in Fig. 7f. The final results are included in Table 1 and Fig. 9.

Discussion

As we have shown in the previous part, the NRM from five localities (Nos. 1–4, 9) comprising sediments is carried by a small amount of ferromagnetic minerals identified as magnetite/maghemite and hematite, and, more rarely — goethite. The main mineral in serpentinites is magnetite which appears there in a great amount of small grains. According to the knowledge of the serpentinization processes (see O'Hanley 1996) it is a secondary mineral that is usually formed in several stages of serpentinization. The studied sliver of serpentinite probably originated somewhere to the south as a fragment of an ophiolite suite and became obducted upon the Gemeric Unit as a part of Bôrka Nappe (Meliatic tectonic unit, see Mello et al. 1998) in the Late Jurassic–Early Cretaceous. Magnetic minerals identified in all other localities — maghemite, hematite, goethite also seem to be secondary.

According to investigations of the Slovak karst Mts in Kruczyk et al. (1998), the temperature in this area did not ex-

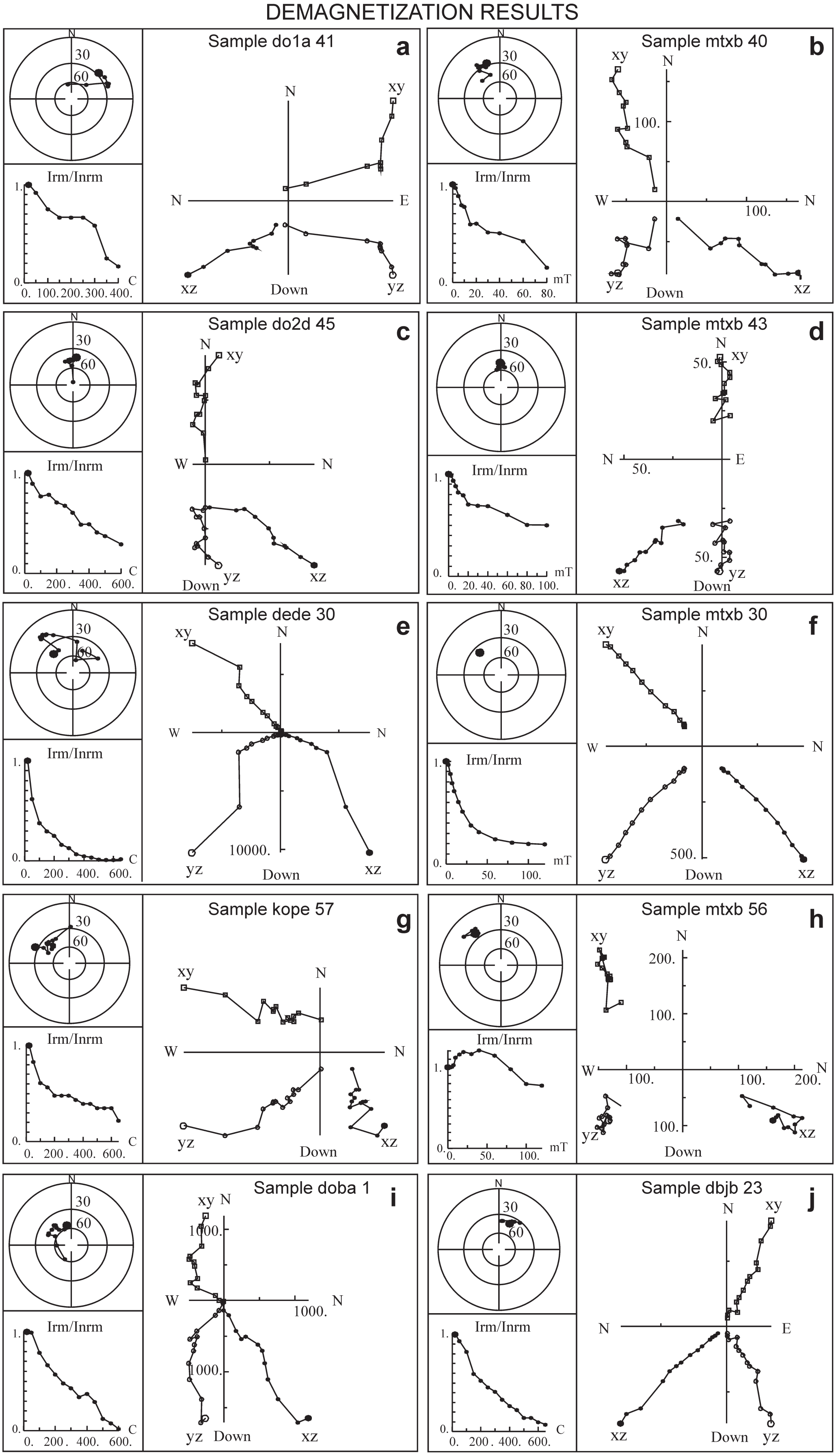

Fig. 6. Demagnetization results characteristic for the studied localities; thermal demagnetizations for Dolka 1 (a), Dolka 2 (c), Dedinky (e), Kopanec (g, h), Dobšinská ľadová jaskyňa (i, j). AF demagnetizations for Dolka 1 (b), Dolka 2 (d), Dedinky (f). Left up — changes of directions during demagnetization, left down — changes of intensity during demagnetization, right — Zijderveld diagrams in three mutually perpendicular planes.

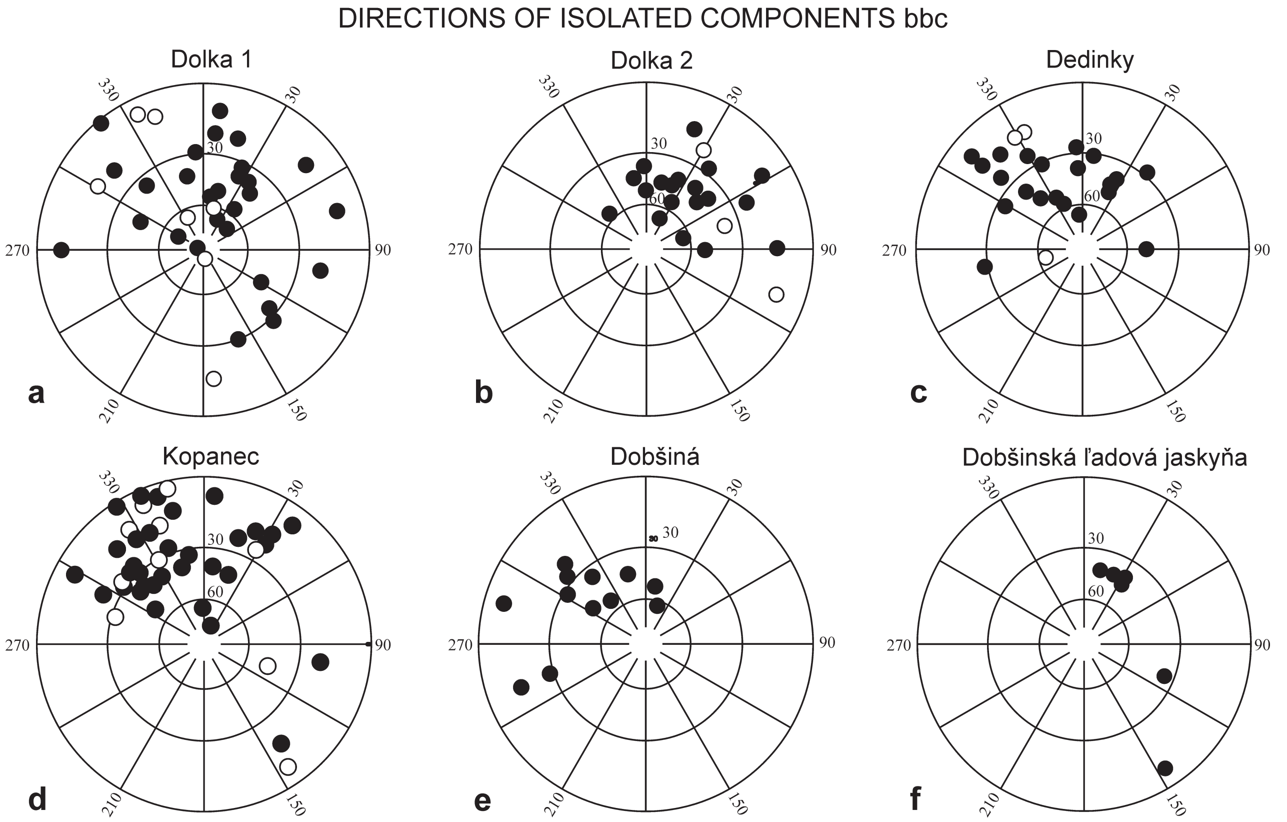

Fig. 7. Directions of all components isolated during demagnetization experiments for the studied localities (bbc — before bedding correction).

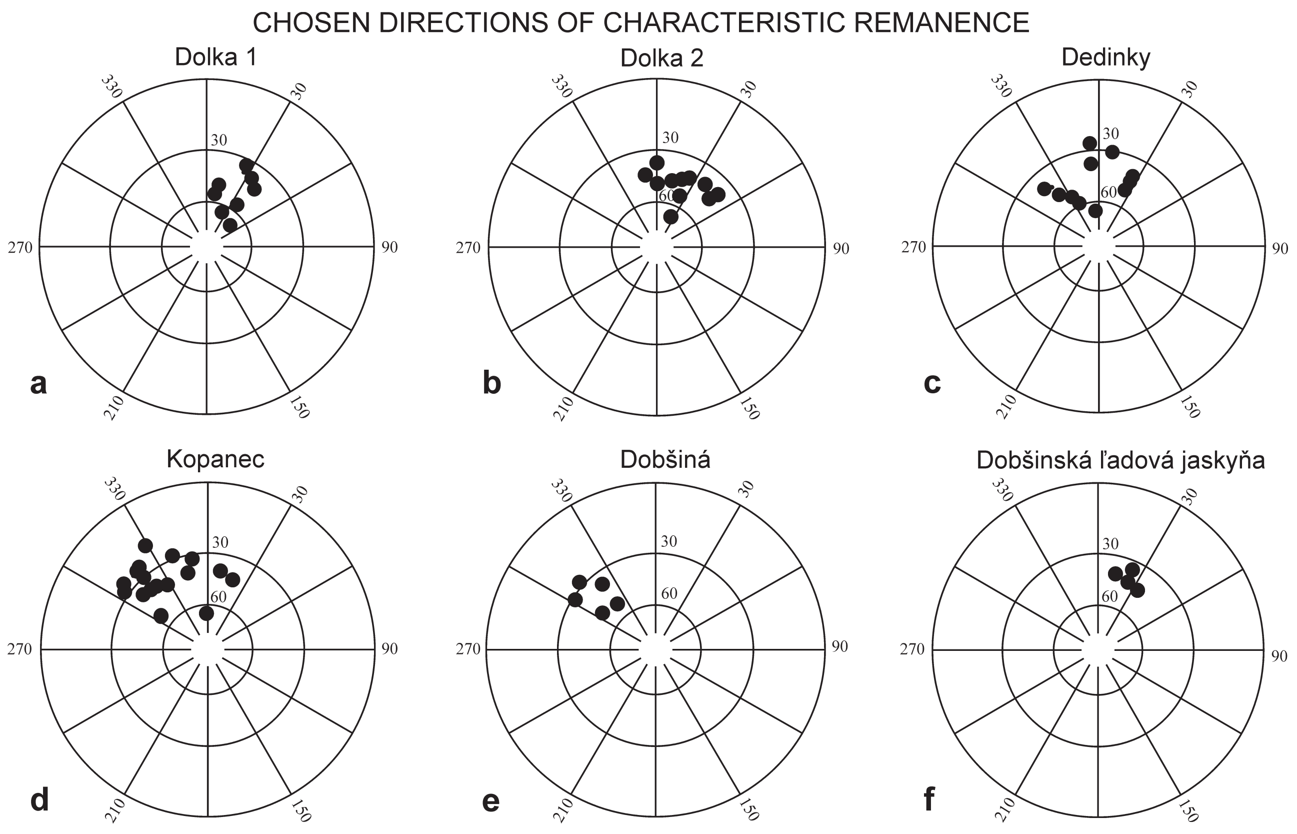

Fig. 8. Directions of the component of characteristic remanent magnetization (ChRM) for each locality.

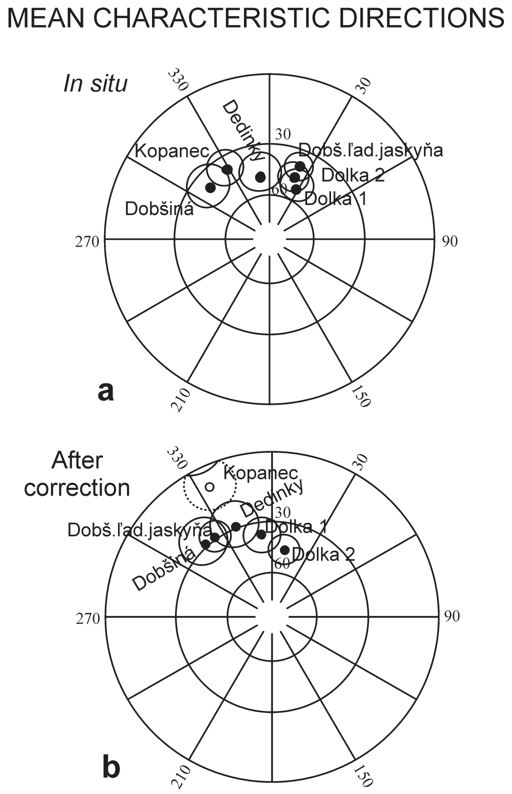

Fig. 9. Mean ChRM's in situ (a) and after correction for bedding (b).

ceed 250 °C after its emplacement and it was justified that characteristic remanence, which most probably is of chemical origin, was often isolated in the low temperature ranges.

The situation in the Stratená Nappe is different. Studies of the CAI (Conodont Colour Alteration Indices, Gawlick et al. 2002), have revealed that in contrast to the Silica Nappe in the region of the Slovak karst, the sedimentary sequences of the Stratená Nappe show a high thermal alteration (CAI 5.5–6.0). It coincides with our results obtained for Dedinky village where secondary ChRM was isolated in low, intermediate and high temperature ranges. In all localities the ChRM is of normal polarity.

The geological description brings some constraints concerning the age of the characteristic component — it had to be acquired during or after the Late Cretaceous — the age of the sandstones from the Dobšinská ľadová jaskyňa locality. The post-Late Cretaceous age of this component is also implied by similarities of its directions obtained for limestones from localities Dolka 1 and Dolka 2 — exposures situated on different sides of the backthrust plane (Laramian in age) separating the Glac and Geravy partial nappes of the Silicic Unit. All this suggests that the characteristic chemical remanence isolated here is of post-Laramian age.

Figure 9a,b presents distributions of mean directions obtained for each exposure with their appropriate ovals of confidences *in situ* (a) and after correction for tectonics (b). The *in situ* pattern seems to be more logical and easier interpreted than the pre-tectonic one. From Fig. 9 and Table 1 it is readily seen that the *in situ* inclinations are not much different, as well as the paleolatitudes, whereas after correction their scatter increases. The rocks have obtained their ChRM during shifting to the North when the layers were partially tilted.

Table 1 and Fig. 9a show that the *in situ* directions of localities Dolka 1, Dolka 2 and Dobšinská ľadová jaskyňa lie very close together — statistically they represent one direction of: Dm = 23°, Im = 46° and paleolatitude 27°N. A similar paleolatitude (28°N) is shown by rocks from Dedinky, although their declination is different (352°). Kopanec and Dobšiná reveal slightly lower inclinations and paleolatitudes and declinations different from each other and from the remaining localities. We therefore surmise that the rocks from Kopanec saddle and Dobšiná quarry acquired their remanences at lower latitudes than those from the previous four localities.

The paleolatitudes of 31°N, 28°N and 21–23°N obtained here are lower than the paleolatitude of 35°N obtained for Triassic limestones from the region of the Slovak karst Mts in the southern part of the Silica Nappe (Kruczyk et al. 1998). In the cited paper we stated that these rocks acquired their secondary remanence during the Miocene and were later shifted to the North and rotated against the Stable European Plate. Comparing paleolatitudes obtained from the Silica Nappe in the area of the Slovak karst Mts and from area studied here we suppose that the latter rocks acquired their secondary remanence earlier than the former ones, when the region of Silica was in more southern latitudes. Such low inclinations implies an African affinity of the studied region when it acquired the isolated chemoremanent CRM. According to Westphal et al. (1986) the inclination calculated after African data for the Late Cretaceous is about 48°N and our results indicate that the studied rocks were remagnetized at that time or only shortly afterwards. Later, the whole studied area, especially the Silicic Unit was shifted from the South to North and became faulted, folded and divided into smaller tectonic units (nappe slices). The observed differences in declinations (Fig. 9a, Table 1) may reflect Tertiary rotations of individual tectonic slices which took place over the whole Carpathian range during the younger periods of the Alpine orogeny. This tectonic activity ended during the Miocene. Kruczyk et al. (1998) stated that final rotation of the Slovak karst area took place after the Middle Miocene. We assume that similar events took place during the same time in the area of the Slovenský raj Mts and Dobšiná vicinity and compare the presented data with the reference ones calculated from data for the Stable European Plate for the Miocene (Besse & Cortillot 2002) Dref = 6°N, Iref = 62° as we did for rocks from the Slovenský karts Mts. The amounts of rotations are included in Table 1 — they are different for different localities because they represent different nappe slices rotated independently: 15–21° CW slices containing Dolka 1, Dolka 2, and Dobšinská ľadová jaskyňa, 14° CCW slice of Dedinky, 41° CCW slice of Kopanec and 55° CCW slice of Dobšiná. The obtained values are the final results, we are not able to discern whether rotations took place during one or more episodes or when they happened. The rotations calculated against the Miocene data encompass all rotational episodes that could take place since the individual slices acquired their ChRM. We suppose that the different mean directions of ChRM found in Kopanec and Dobšiná are due to near-by faults. It is also probable that the small sliver of the Meliatic Unit represented by serpentinite from the locality Dobšiná moved differently than the nappe slices of the Stratená Nappe. The results can be compared with paleomagnetic studies of Mesozoic carbonates in the Strážovské Vrchy Mts in the Central Western Carpathians (Grabowski et al. in print) where secondary magnetization probably dating from the Late Cretaceous was also identified. In comparison with results from the Southern and Eastern Slovakia as well as from the Spišsko Gemerské Rudohorie Mts (Inner Western Carpathians) we can conclude that the Miocene paleodirections obtained from the sedimentary and alternated rocks of those areas have similar trends (Márton et al. 1996, 2000; Kruczyk et al. 2002).

Conclusions

Characteristic components of remanence were isolated in six localities representing different nappe slices. Characteristic remanences are carried by secondary minerals and are overprints by remanence of chemical origin and normal polarity. They were acquired in the Upper (or uppermost) Cretaceous at paleolatitude of about 28°N to 22°N showing that the area was at that time of African affinity.

The whole study area moved from South to North, and the nappe slices were formed due to intensive tectonics and rotated during the younger periods of Alpine orogenesis in coincidence with tectonic movements of the Slovak Western Carpathians.

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