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COUNTERCLOCKWISE ROTATIONS OF THE NEOGENE ROCKS IN THE EAST SLOVAK BASIN

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Abstract: Paleomagnetic investigation of sedimentary and volcanic rocks of the East Slovak Basin gave information about the counterclockwise (CCW) rotation of the Neogene units of Eggenburgian to Middle Sarmatian age. The Eggenburgian sediments (1 loc. 20 spec.) show about 80° CCW rotation, the zeolitized rhyolite tuffs of Lower Badenian age (2 loc. 19 spec.) show a 40°–60° CCW rotation, the rhyolites (1 loc. 3 spec.) of Upper Badenian age about 50° CCW rotation, the sediments of Lower-Middle Sarmatian age (1 loc. 6 spec.) gave CCW rotation of about 20° and the youngest post-Sarmatian rhyolite (1 loc. 9 spec.) did not yield any rotation. The rotation was preceded by left lateral penetration of the Tissia units into the West- and East-Carpathian boundary zone.

Key words: Western Carpathians, East Slovak Basin, Neogene sedimentary and volcanic rocks, paleomagnetism, counterclockwise rotation.

Introduction

Recent communications, concerning paleomagnetism (Orlický 1996) and paleomagnetism plus isotope dating (Márton & Pécskay 1995) of the north-eastern corner of the Inner Carpathians suggest that the counterclockwise declination rotations observed on late Badenian-Sarmatian volcanics might be of tectonic significance.

Orlický interpreted observations from the East Slovak Basin (ESB) in terms of fault-related small-scale block movements, while Márton and Pécskay envisage a kind of triangle, bordered by the Hornád/Hernád-line, the Szolnok-Maramures flysch belt and the NE Outer Carpathians, which could have rotated as a unit in late Sarmatian–early Pannonian times. This rotation would be about 4–5 Ma younger than the final counterclockwise rotation of the central part of the Inner Western Carpathians (Márton & Márton 1996; Márton et al. 1996).

The aim of the present study is to seek support for the counterclockwise rotation in the East Slovak Basin also from sediments or volcano-sedimentary rocks and constrain the timing. The sampling sites and localities of the present study are shown on a schematic geological map in Fig. 1, and on a schematic geological map of the pre-Tertiary basement (Fig. 2).

Geology and tectonics

The ESB started to open as a shear basin in the early Miocene (Eggenburgian, about 22 Ma B.P.). At the beginning, a narrow furrow opened along the Pieniny Klippen Belt. The marine transgression reached the basin from the remnant flysch basins of the Outer Carpathians. At the end of the Eggenburgian, prograding deltas (Čelovce, Lada) entered the basin, marking its temporary closure. Deposits of Ottnangian age (19–17.5 Ma B.P.) are missing (Fig. 3).

The ESB started to re-open in the early Karpatian (17.5 Ma B.P.), by extension (Kováč et al. 1994a). Later, the character of the paleostress field progressively changed, and shear became the dominant factor in the evolution of the ESB. Shear controlled basin evolution (Fig. 3) characterizes the late Karpatian through late Sarmatian period (17–11.5 Ma B.P.). During this period, the basin had the features of a typical pull-apart basin, including the migration of subsidence centres (from NW to SE, in recent coordinates) and rapid subsidence (Vass et al. 1988). The thickness of the deposits during this period is more than a thousand metres and the whole basin fill is 8000–9000 m thick in the centre. Other pull-apart features of the basin are the "en echelon" arrangement of faults, flower structures on major fault zones, and dismatch between units of the basement.

The basement of the ESB is built of very different tectonic units (Fig. 2). These are the Veporic Superunit represented by the Krížna Nappe, Humenné Mesozoic Horst and Veporic Superunit of the Čierna Hora Mts. partly covered by Central Carpathian Paleogene. The Kritchevo-Iňačovce Unit formed by metamorphic rocks, including slightly metamorphosed Eocene marine deposits considered by Soták et al. (1993) to be equivalent of the Vahic/Penninic Superunit. This superunit may correspond to the Nádudvar Formation, or the Szolnok-Maramures Flysch; the Zemplinic (Zemplén) Unit, which probably belongs to the Tisza (Tissia) Superunit (Körössy 1963; Grecula & Együd 1977); the Gemeric Superunit, Bükk Unit and Meliatic Unit (which may represent the NE promontory of the Pelsó Megaunit which escaped from the Central Alpine and NW Dinarides area (Kázmér & Kovács 1985; Haas et al. 1995).

By the end of the pull-apart evolution of the ESB, a strong andesite volcanic activity started. This volcanic activity is considered as subduction related and during the Sarmatian the basin was in an interarc position (Vass et al. 1988).

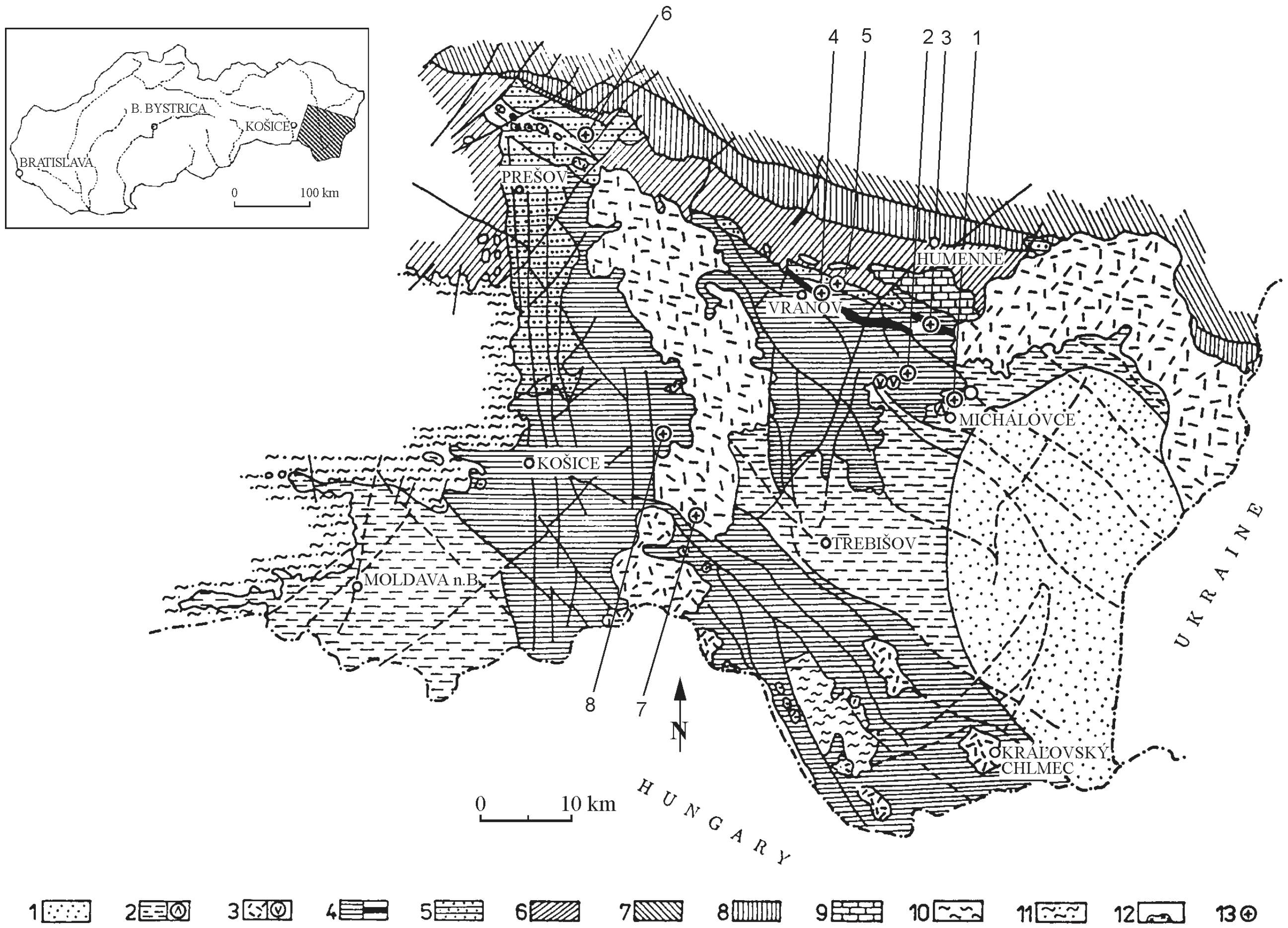

Fig. 1. Simplified geological map of the East Slovak Basin and sampled sites. *Explanation*: 1–5: Neogene sedimentary basin fill and neovolcanics. 1 — Pliocene; 2 — Late Miocene, a — sediments, b — rhyolite; 3 — neovolcanics Middle and Late Miocene in age, a — predominantly andesites and andesite volcano-clastics, b — rhyolite; 4 — Middle Miocene, a — sediments, b — zeolitized tuff (Hrabovec Tuff); 5 — Early Miocene (Karpatian); 6 — Central Carpathian Paleogene; 7 — Outer Carpathian Flysch; 8 — Klippen Belt; 9 — Mesozoic of Krížna Nappe Unit; 10 — Paleozoic and Mesozoic of Zemplinic Unit; 11 — Peleozoic and Mesozoic of Silicic Superunit, Meliatic Unit and Veporic Superunit undivided; 12 — Proterozoic of Zemplinic Unit; 13 — sample sites, see Fig. 2 and Table 1.

The recent geophysical evidence of the former pull-apart character of the basin is the thin continental crust in the south (including 8–9 km of basin fill deposits 27 km) which becomes thicker (32 km) in the North-Northwest (Šefara et al. 1987), the high heat flow (more than 110 Wm^{-2}) and the high geothermal gradient (53 °C/km, Král et al. 1985).

The pull-apart history of the basin ended with the Sarmatian. During the Pannonian the subsidence significantly slowed down and the Pannonian deposits are only a few hundred metres thick.

During or after the Pontian, basin inversion took place. Pliocene deposits are fluvio-lacustrinal and are restricted to the SE corner of the basin.

Sampling and laboratory measurements

We drilled the Eggenburgian sediment at one, and the zeolitized tuff of Badenian age at three localities. All these are in well-controlled tectonic positions. Sarmatian volcanosedimentary rocks and andesite were collected at three localities.

In addition to the sediments and sediment-like deposits, two rhyolite domes were also sampled. At one of them, which was earlier sampled by one of the authors (I. Túnyi) hand samples were taken and subsequently drilled in the laboratory, the other was drilled in the field. A total of 92 independently and magnetically oriented samples were taken.

Standard-size cylinders were cut from the drill-cores, measured and stepwise demagnetized by the thermal and AF methods or by combining the AF and thermal methods, IRM and low susceptibility versus temperature experiments were also carried out to help the identification of the magnetic minerals. Stepwise thermal demagnetization was carried out in Bratislava, the other experiments in Budapest.

Results and assessment of data

The samples from the two rhyolite domes yielded excellent paleomagnetic directions. The NRMs are in both cases single-component (Fig. 4), the carrier of the remanence is magnetite (Figs. 5a and 6a) and the site mean directions are statistically very well defined (Table 1).

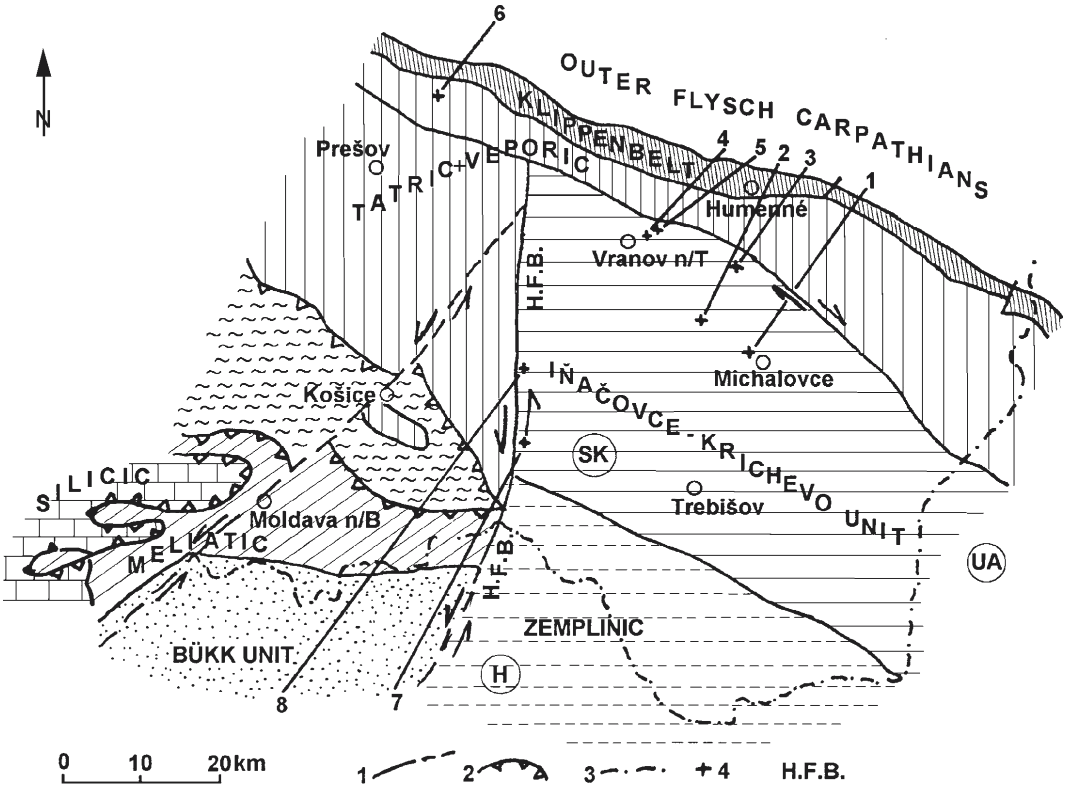

Fig. 2. Recent situation of the pre-Tertiary units in the East Slovak Basin basement and in its surroundings. 1 — faults or unspecified boundaries of tectonic unit; 2 — overthrust lines; 3 — state boundaries; 4 — sample sites, loc. Nos. (see Table 1); H.F.B. — Hornád/Hernád fault belt.

Table 1: East Slovak Basin site and locality mean paleomagnetic directions of the present study.

loc. no.	locality/site	n/no	D°	I°	k	α_{95}°	D_C°	I_C°	age	dip°
1	**Hrádok** *rhyolite* SM 1111–19	9/9	183	–53	363	3	**183**	**–53**	10.5–13.2 Ma	-
2a	**Lesné** *rhyolite* SM 1131–32	3/4	312	63	249	8	**312**	**63**	late Badenian	-
2b*	**Lesné** *rhyolite* SM 1133	16/2	311	66	1080	3	**311**	**66**	late Badenian	-
3	**Oreské** *zeolitized tuff* SM 1120–30	11/11	2	44	28	9	**319**	**60**	early Badenian	226/35
4	**Kučín** *zeolitized tuff* SM 1134–42	8/9	8	24	61	17	**304**	**75**	early Badenian	200/55
5	**Nižný Hrabovec** *zeolitized tuff* SM 1192–1203	6/12	**95**	**–54**	34	12	63	–20	middle Badenian	208/50
6	**Lada** *claystone* SM 1143–69	20/21	**289**	**57**	14	9	281	30	Eggenburgian	269/28
7	**Slančík** *andesite* SM 1176–83	6/8	**338**	**56**	24	14	338	46	middle Sarmatian	336/10
8*	**Svinica** *tuff* SM 1184–91	11/8	17	61	50	6	0	62	late Sarmatian	272/9

n/no — numbers used/collected samples; D°,I° (D_C°, I_C°) — declination, inclination before (after) tilt correction; k and α_{95}° — statistical parameters (Fisher 1953);
* — statistics is based on number of speciment (n).

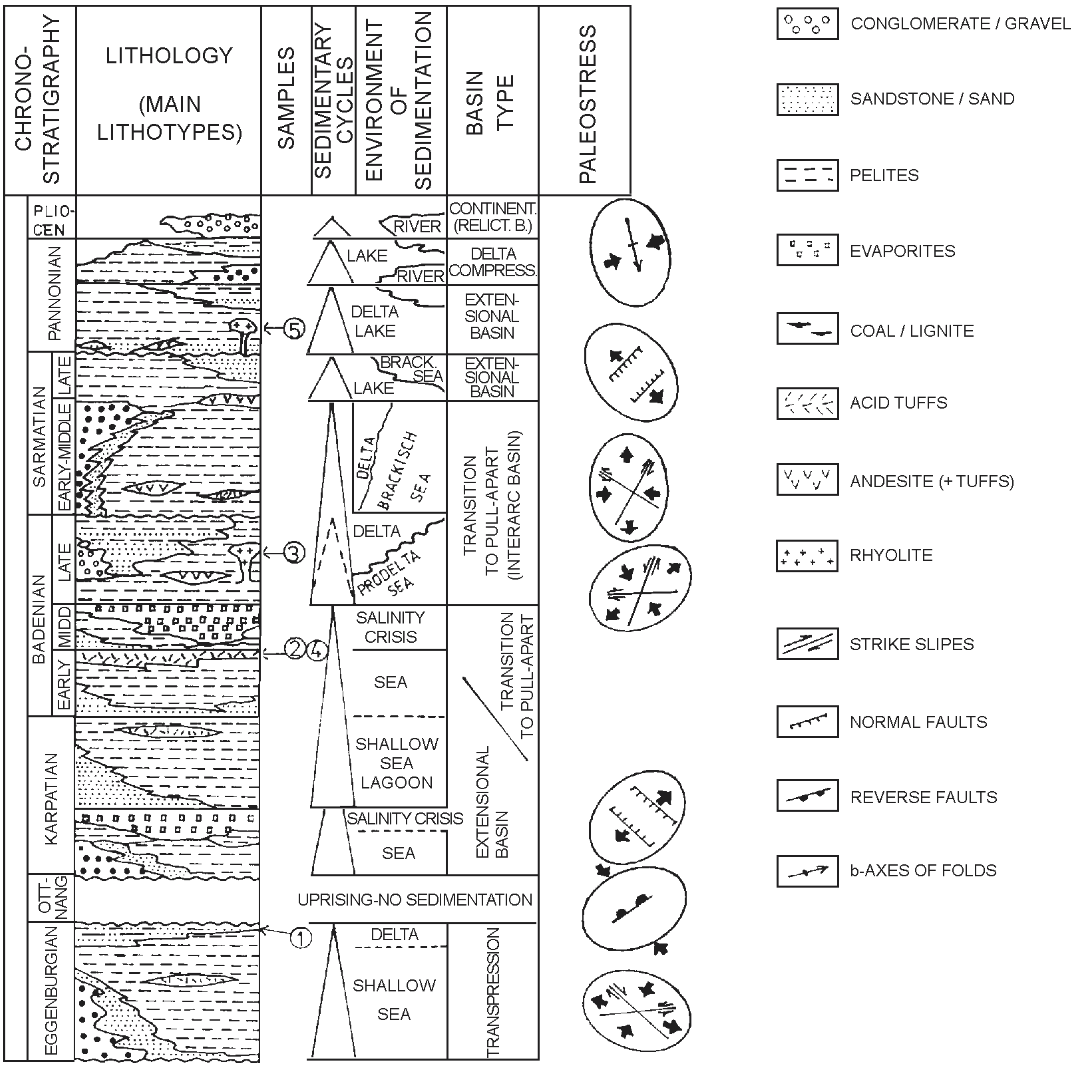

Fig. 3. Schematic lithology, sedimentary cycles and paleostress diagrams of the East Slovak Basin (according to Kováč 1994a, modified).

The zeolitized rhyolite tuffs are weakly magnetic. This explaines that the demagnetization curves of the NRM are less smooth than those of the rhyolites. Nevertheless, the components of the NRM are well defined (Fig. 7). The IRM acquisition curves suggest that the magnetic mineral is soft (Fig. 6b), and this combined with the stability (Fig. 5b) or moderate increase (Fig. 7) of the susceptibility on heating, suggest that the NRM is most likely residing in magnetite. The site mean paleomagnetic directions are statistically fairly well defined and depart significantly from that of the local direction of the present Earth's magnetic field (Table 1).

The sediments are of different ages and of different lithologies. The Eggenburgian locality, Lada, where several horizons of the clay stone intercalations in the thick sandstone sequence were sampled, yield a good paleomagnetic direction. The Zijderveld diagrams reveal that the NRM is practically single-component (Fig. 8), the main carrier of the magnetization is magnetite (Fig 8a, Fig. 6b), though sometimes goethite may also contribute to the NRM (Fig. 8b). At Lada, the majority of the samples carry characteristic remanence, with direction significantly different from that of the Earth's present field at the sampling area (Table 1). Of the sediments collected at other localities, Nižná Myšľa was unstable, while Svinica yielded a mean direction which is interpreted as a recent overprint (Table 1 and Fig. 9). At Slančík, 6 samples of the collected 8 are clustered away from the present field direction (Table 1 and Fig. 10), while two are aligned with the present field (rejected when computing the locality mean direction).

Discussion

The East Slovak Basin is situated on the ALCAPA (and Tissia) overriding plate of a subduction/collision zone, close to the inner margin of the accretionary prism. The present (assumed) configuration of the flysch accretionary prism (Outer Carpathians and the arcuate shape of the Carpathians) suggests that the collision between the subducting North European and the overriding Carpathian-Pannonian plates was oblique. The oblique collision, proceeded by oblique subduction resulted in

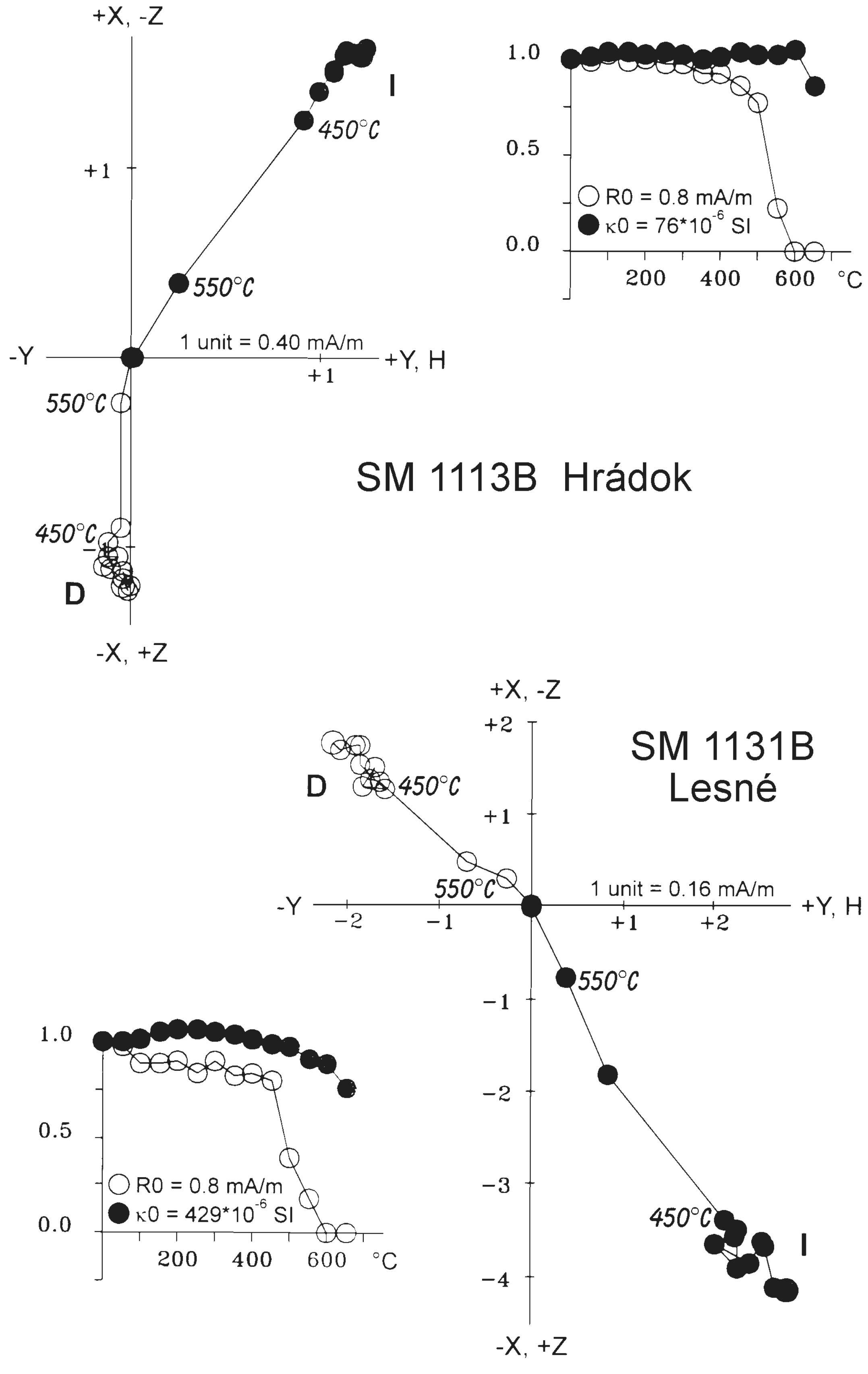

Fig. 4. Typical behaviour of the rhyolites on thermal demagnetization. Modified Zijderveld diagrams and normalized intensity/susceptibility (circles/dots) curves.

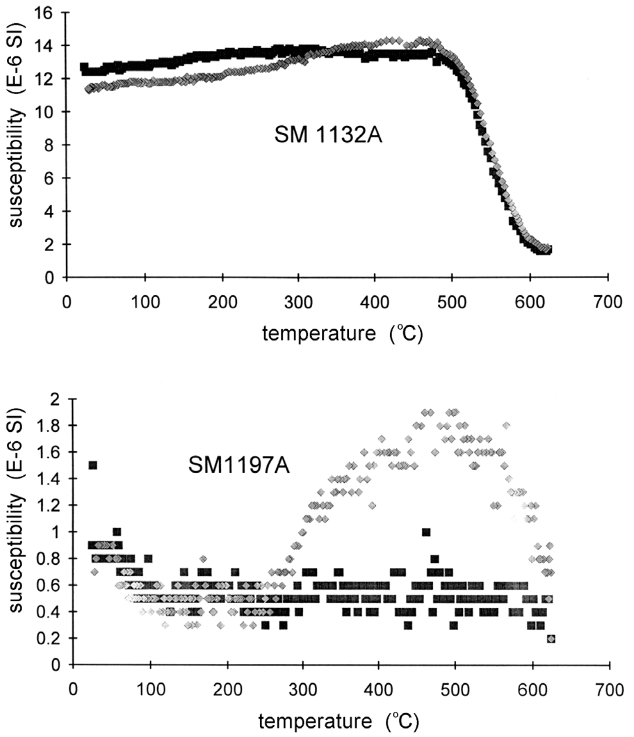

Fig. 5. Low-field susceptibility versus temperature curves for Lesné (upper diagram) and Nižný Hrabovec (lower diagram). Heating curves are of darker, cooling curves are of lighter colour.

compression oblique to the convergence zone, and produced shear stress along it. It is generally accepted that in the Carpathians the oblique convergence led to bending and final formation of the accretionary prism, i.e. to the whole arcuate shape of the Outer Carpathians. Along and near the convergent margin, pull-apart or shear basins were generated. Such basins connected to the Western Carpathians are the Vienna Basin, the narrow furrows along the inner side of the Pieniny Klippen Belt in NW Slovakia, the Transcarpathian Basin, including its autonomous western part, the ESB.

The ESB was regarded as a pull-apart basin opened by a major right-lateral strike-slip fault of NW-SE direction (Royden & Báldi 1988; Vass et al. 1988). The lateral displacement or wrench faulting caused the breaking up of the area into elongated blocks by "en echelon" faults and the blocks moved relative to each other along faults, corresponding to Riedel Shears of the strain ellipsoid. The elongated blocks, termed "Riedel Flakes" (Dewey 1982) when generated by right lateral strike slip, are expected to suffer clockwise rotation. Contrary to the prediction of the model by Royden & Báldi (1988), the paleomagnetic results from the ESB suggest counterclockwise rotation.

The oldest rock where we observed CCW rotation is Eggenburgian. The angle is about 80°. This locality (Lada) is in the transition zone between the Central Carpathian flysch basin and the ESB (in fact, it is lying on the Central Carpathian Paleogene).

East of this locality, in the ESB proper, the angle of rotations is smaller at the same time, the rocks studied here are also younger. The oldest of them are the zeolitized rhyolite tuff, which yields an overall mean direction of D = 297° I = 64°, k = 28, α_{95} = 24° (the statistics are based on the number of sites, which is 3) when sites 3 and 4 are corrected, site 5 is not corrected for the local tilts (in all other combinations the tilt test is negative, tilt test by Watson & Enkin 1993). Among the younger rocks, sampling points 2 and 8 are characterized by moderate CCW declination deviation and point 1 shows no deviation from the present North (Fig. 10).

Orlický (1996) and Nairn (1967) observed similar rotations on late Badenian-Sarmatian igneous rocks in the southern margin of the basin. Thus we can conclude that with the exception of 1 site, i.e. the youngest one, all observations suggest that the major part of the ESB basin (i.e. the part that started to open after the Ottnangian, and subsided most intensively in the Sarmatian) rotated in a CCW sense by an average angle of about 45°. The rotation observed at Lada seems to be larger and is difficult to relate to the history of the major part of the ESB. Perhaps it characterizes the movements of the Central Carpathian area more than that of the ESB.

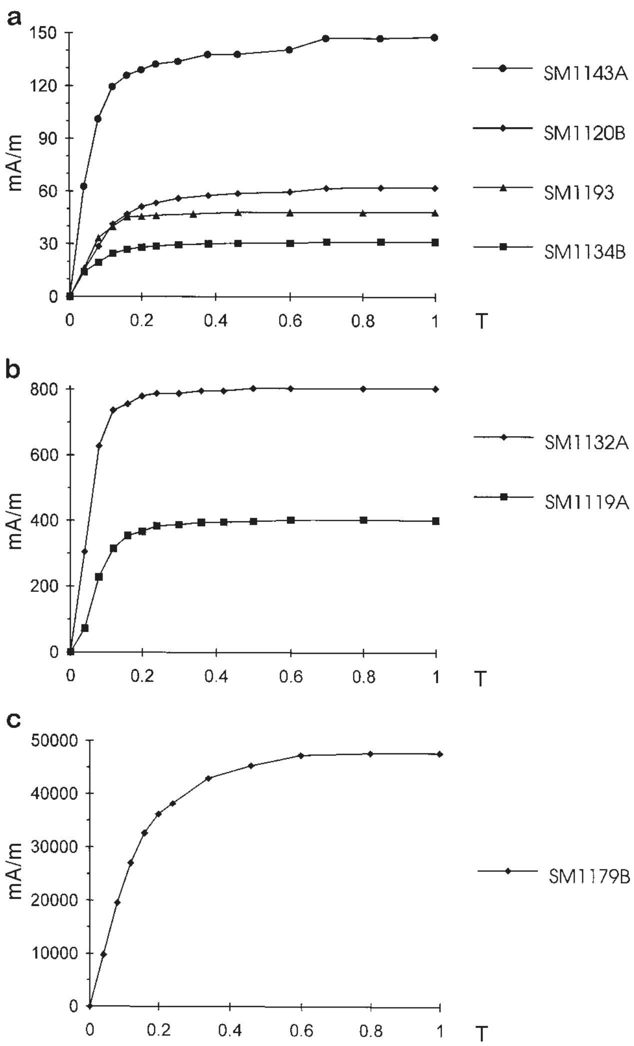

Fig. 6. IRM acquisition curves. **a** — Lada (SM1143A) and examples for zeolitized rhyolite tuffs; **b** — rhyolite doms; **c** — Sarmatian sediment Slančík.

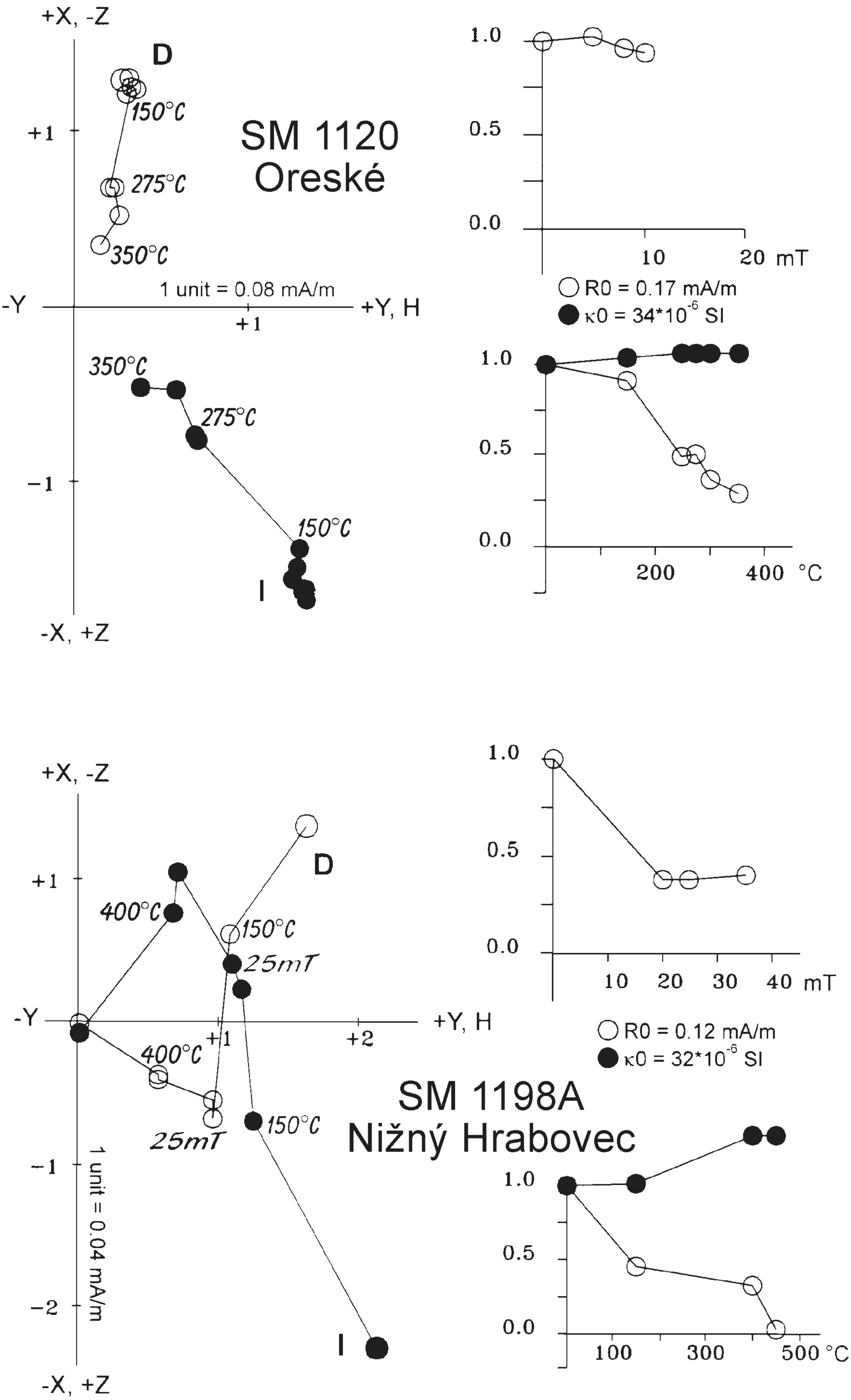

Fig. 7. Typical behaviour of the zeolitized rhyolite tuffs on combined thermal and AF demagnetization. Modified Zijderveld diagrams and normalized intensity/susceptibility (circles/dots) curves.

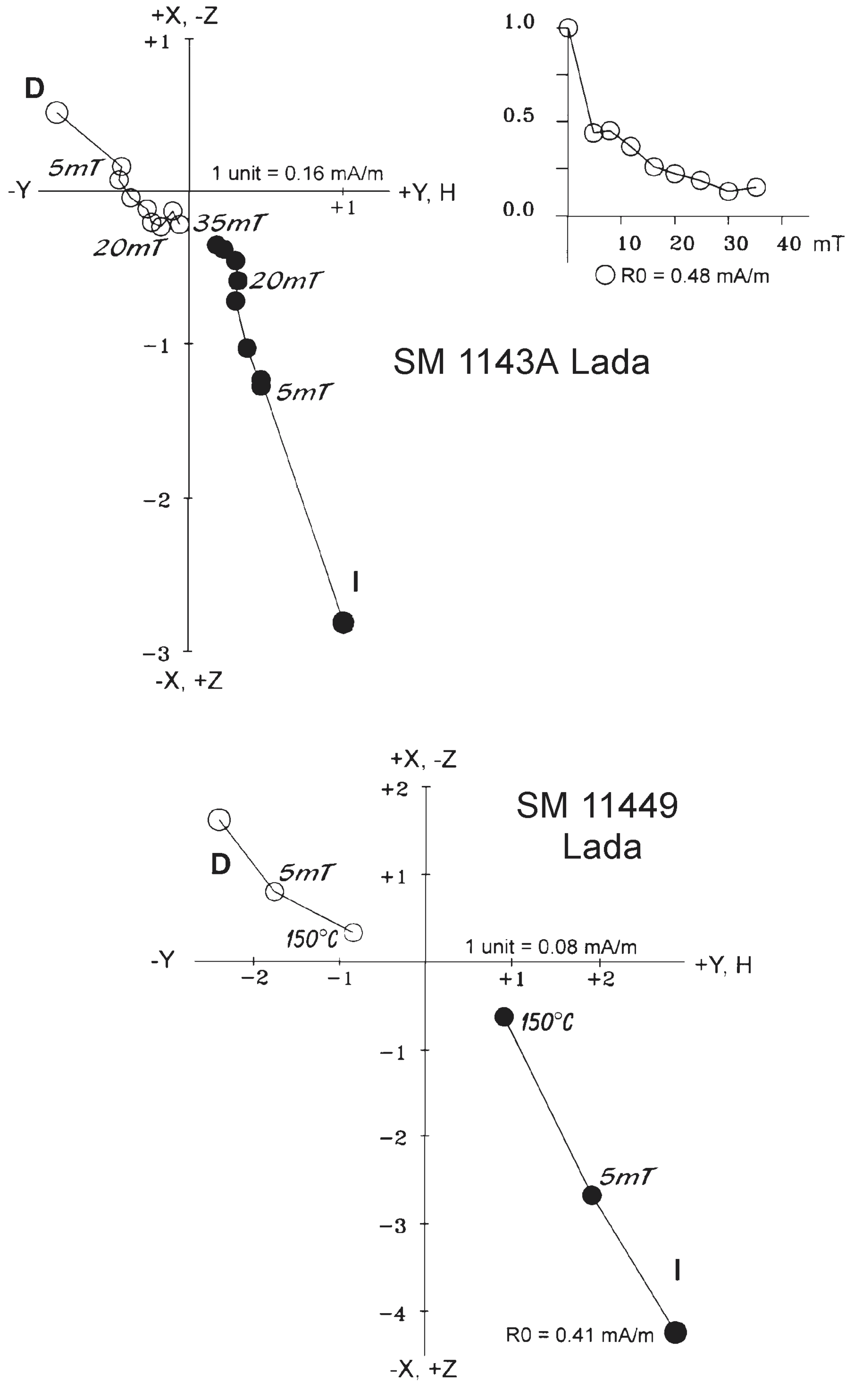

Fig. 8. Typical behaviour of samples from Lada on AF (upper diagram) and combined thermal and AF (lower diagram) demagnetization. Modified Zijderveld diagrams and normalized intensity (circles) curves.

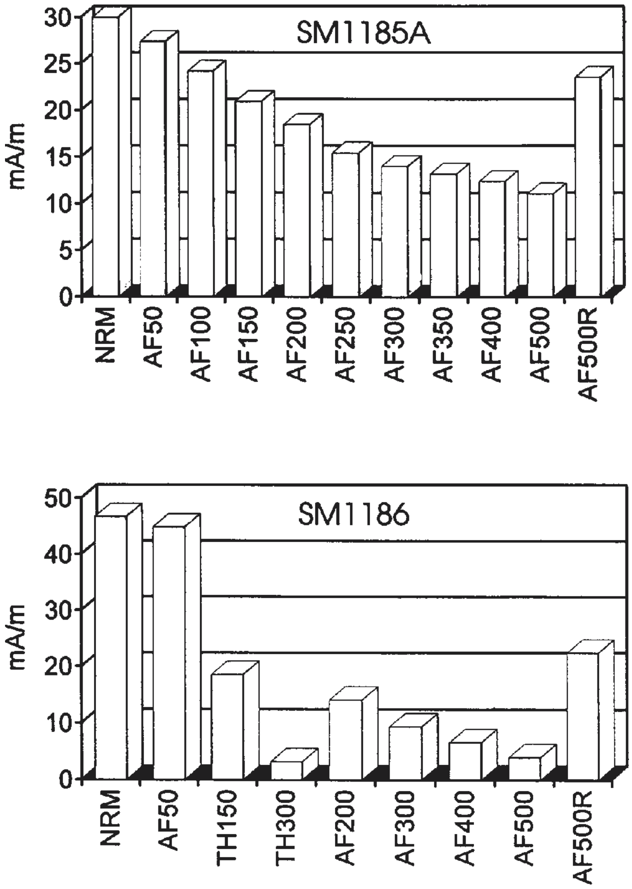

Fig. 9. Svinica. Two examples showing the viscous character of the remanence. Upper diagram: the Z component of the NRM on AF demagnetization up to 50 mT (AF500), stored in the laboratory in a vertical position for 3 weeks and measured again (AF500R). Lower diagram: the Z component of the NRM on combined AF and thermal demagnetization up to 300 °C, stored in the laboratory in a vertical position for two months, demagnetized in an AF field of 20 mT (AF200) measured and demagnetized up to 50 mT (AF500). Stored for another 3 weeks in the lab with Z in the same vertical position and remeasured (AF500R). It is important to note that when the specimens are stored in the laboratory field between demagnetization runs, the original NRM directions, which were close to the present field, are not recovered during the new demagnetization run.

However, the rotation of the ESB may be connected to that of the Tokaj Mts., due to the similar angle and timing of the rotation (Márton & Pécskay 1995). Concerning the exact timing of the rotation, the CCW rotation of the mid-late Sarmatian Slančík, in addition to the previously existing indications obtained on igneous rocks of Sarmatian age, points to the late Sarmatian–early Pannonian time. We cannot be more precise, since the only reliable paleomagnetic result in our data set, showing affinity to stable European directions, is Hrádok at Michalovce, (rhyolite extrusion) with K/Ar ages ranging from 10.9 to 14.3 Ma B.P. (Merlich & Spitkovskaya 1974; Vass et al. 1978)

Nevertheless, the constraint on timing is precise enough to suggest that the major part of the ESB together with the Tokaj area must have been emplaced 4–5 Ma later than the

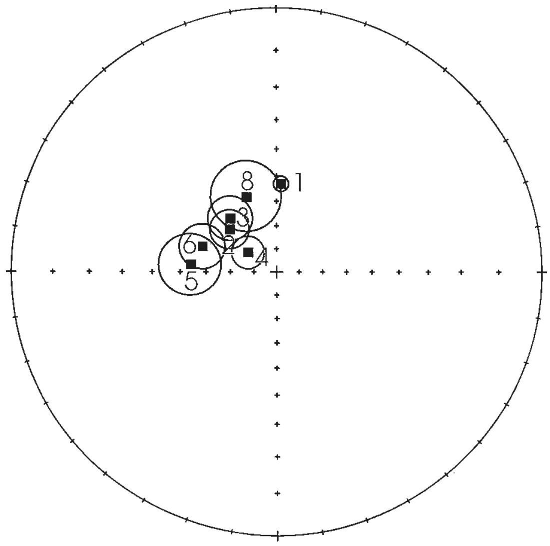

Fig. 10. Site and locality mean paleomagnetic direction with confidence circles. The numbers refer to Table 1 (data in heavy print). Stereographic projection. All inclinations are positive on the plot, i.e. site mean directions with reversed polarity (1 and 5) are shown as equivalent normal polarity directions.

Central Carpathian-North Hungarian block, with the North-South running zone as the best candidate for a boundary between them in the area of the present Slánské vrchy Mts. in the Hornád/Hernád fault zone. The structural unroofing of the basement of the East Slovak Basin (in the sense of Soták et al. 1993), when the Iňačovce-Krichevo Unit was exhumed during the Miocene extension can be corelated with the above mentioned CCW rotation of the basin sedimentary fill contemporaneus with volcanics.

The origin of the CCW rotation in the area of the East Slovak Basin may also be explained in another way. At least two basement units, the Zemplinic Unit and Iňačovce-Kritchevo Unit, have affinities to the Tissia Superunit. The Zemplinic Unit was correlated with the Tissia and/or Mecsek Mts. (Körössy 1963; Grecula & Együd 1977 and others). The Iňačovce-Kritchevo Unit and especially its Iňačovce part, i.e. the unit directly proved by wells as the ESB basement, according to Vozár et al. (1993) may belong to the Szolnok-Maramures Flysch and/or Nádudvar Formation. The Fig. 2 shows that both units could come to present position by left lateral strike-slip from the SW. This left lateral motion preceded the left that is CCW rotation of the ESB. The relation between sens of the strike-slip motion and the following block rotation is documented by Torres & Slivester and Sengör, Gorur & Saroglu (in Allen & Allen 1992).

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References

Allen P.A., Allen J.R. 1992: Basin analysis, principles and applications. *Blackwell,* London, 1–145.

Dewey J.F. 1982: Plate tectonics and the evolution of the British Isles. *J. Geol Soc. London* 139, 371–414.

Fisher R. 1953: Dispesion on a Sphere. *Proc. of the RAS.* A 217, 295.

Grecula P. & Együd K. 1977: Position of the Zemplin Inselberg in the tectonic frame of the Carpathians. *Miner. Slovaca* 9, 6, 449–462 (in Slovak, English summary).

Haas J., Kovács M., Krystyn L. & Lein R. 1995: Significance of Late Permian-Triassic facies zones in terrane reconstructions in the Alpine-North Pannonian domain. *Tectonophysic* 242, 19–40.

Kázmér M. & Kovács S. 1985: Permian-Paleogene paleogeography along the Eastern part of the Insubric-Periadriatic Lineament system: Evidence for continental escape of the Bakony-Drauzug Unit. *Acta Geol. Acad. Sci. Hung.* 281, 2, 71–84.

Kováč P., Vass D., Janočko J., Karoli S. & Kaličiak M. 1994a: Tectonic history of the East Slovak Basin during the Neogene. *ESRI Occassional Publication New Series* No. 11 A-B, South Carolina, U.S.A., 1–15.

Kováč M., Kráľ J., Márton E., Plašienka D. & Uher P. 1994b: Alpine uplift history of the Central Western Carpathians: geochronological, paleomagnetic, sedimantary and structural data. *Geol. Carpatica,* 45, 2, 83–96.

Körössy L. 1963: Comparison study of rock composition of the Pannonian Basin. *Földt. Közl.* 93, 2, 153–172 (in Hungarian).

Král M., Lizoň I. & Janči J. 1985: Geotermal investigation in SSR. *Manuscript, Archív Geol. úst. D. Štúra,* Bratislava (in Slovak).

Márton E. & Márton P. 1996: Large scale rotations in North Hungary during the Neogene as indicated by palaeomagnetic data. In: Morris A. & Tarling D.H. (Eds): *Palaeomagnetism and Tectonics of the Mediterranean Region. Geological Society Special Publication* No. 105, 153–173.

Márton E. & Pécskay Z. 1995: The Tokaj-Vihorlát-Oas-Ignis Triangle: Complex Evaluation of Palemagnetic and Isotope Age Data from Neogene Volcanics. *IGCP Project 356 "Plate Tectonic Aspect of Alpine Metallogeny in the Carpatho-Balkan Region", 3rd Annual Meeting. Athens,* 18-19 September 1995. Volume of Abstract, 30.

Márton E., Vass D. & Túnyi I. 1996: Rotation of the North Hungarian Paleogene and Lower Miocene rocks indicated by paleomagnetic data (S. Slovakia, N-NE. Hungary). *Geol. Carpathica* 47, 1, 31–41.

Merlich B.V. & Spitkovskaya S.M. 1974: Deep faults, Neogene magnetism and mineralization of Zakarpatia. *Lvov state University*, 1–175 (in Ukrainian).

Nairn A.E.M. 1967: Paleomagnetic investigations of the Tertiary and Quarternary igneous rocks: III A paleomagnetic study of the East Slovak Province. *Geol. Rdsch.*, Band 56, 408–419.

Royden L.H. & Báldi T. 1988: Early Cenozoic Tectonics and Paleogeography of the Pannonian and Surrounding regions. In: Royden L.H. & Horváth F. (Eds.): *The Pannonian basin a study in Basin evolution. AAPC Memoir 45. Am. Ass. of Petroleum Geol. Oclahoma, U.S.A.,* Budapest, 1–16.

Orlický O. 1996: Paleomagnetism of neovolcanics of the East-Slovak Lowlands and Zemplínske Vrchy Mts.: A study of the tectonics applying the paleomagnetic data (Western Carpathians). *Geol. Carpathica* 47, 1, 13–20.

Soták J., Rudinec R. & Spišiak J. 1993: The Penninic "pull-apart" dome in the pre-Neogene basement of the Transcarpathian depression (Eastern Slovakia). *Geol. Carpathica* 44, 11–16.

Šefara J. et. al. 1987: Structural-tectonical map of the Inner Western Carpathians for the purposes of depositional prognoses. *Manuscript, Archives Geofyzika,* Bratislava (in Slovak).

Vass D., Tözsér J., Bagdasaryan G.P., Kaličiak M., Orlický O. & Ďurica D. 1978: Chronology of vulcanic events in Eastern Slovakia on the grounds of isotopical–paleomagnetical researches. *Geol. Práce, Spr.* 71, 77–88 (in Slovak, English summary).

Vass D., Began A., Kahan Š., Köhler E., Krystek I., Lexa J. & Repčok J. 1988: Regional geological break-up of the Western Carpathians and northern headlands of Pannonian Basin on the area of ČSSR. *GÚDŠ–Geofond Bratislava,* Vojenský kartografický ústav Harmanec (in Slovak).

Vass D., Kováč M., Konečný V. & Lexa J. 1988: Molasse basins and volcanic activity in Western Carpathian Neogene — its evolution and geodynamic character. *Geol. Carpathica* 39, 5, 539–561.

Vozár J., Tomek Č. & Vozárová R. 1993: Reinterpretation of pre-Neogene basement of the East Slovak Basin. *Miner. Slovaca* 25, 6, Geovestník 1–2 (in Slovak).

Watson G.S. & Enkin R. 1993: The fold test in paleomagnetism as a parameter estimation problem. *Geophysical Research Letters* 20, 19, 2135–3137.