GEOLOGICA CARPATHICA, APRIL 2007, 58, 2, 185–193

Paleomagnetic detection of Tertiary rotations in the Southern Pannonian Basin (Fruška Gora)

VESNA LESIĆ[1], EMŐ MÁRTON[2] and VESNA CVETKOV[3]

[1]Geomagnetic Institute, Kraljice Natalije 45, 11000 Belgrade, Serbia; vlesic@drenik.net
[2]Eötvös Loránd Geophysical Institute of Hungary, Palaeomagnetic Laboratory, Columbus út. 17–23, H-1145 Budapest, Hungary; paleo@elgi.hu
[3]University of Belgrade, Faculty of Mining and Geology, Department of Geophysics, Đušina 7, 11000 Belgrade, Serbia; cvetkov@rgf.bg.ac.yu

(Manuscript received January 3, 2006; accepted in revised form June 22, 2006)

Abstract: Fruška Gora is an inselberg in the Southern Pannonian Basin. It is partially covered and surrounded by Miocene sediments, which were the main targets of our paleomagnetic study. The aim was to see if Fruška Gora participated in the young counterclockwise rotation observed at several points in the western part of the Southern Pannonian Basin. Nevertheless, we also sampled Oligocene latites and a few Mesozoic localities. From 16 localities 14 yielded results. Geographically distributed Miocene and pre-Miocene localities with a Miocene overprint (overall-mean paleomagnetic direction: $D=320°$, $I=54°$, $k=26$, $\alpha_{95}=12°$) indicate that the Fruška Gora rotated in co-ordination with the western Southern Pannonian Basin close to the end of the Miocene (Early Pliocene). This rotation must have been driven by the Adriatic microplate. The overall-mean paleomagnetic direction for Oligocene latite and contact metamorphosed Upper Cretaceous flysch is $D=220°$, $I=-43°$, $k=25$, $\alpha_{95}=16°$ (corrected for the general tilt of the Miocene sediments), suggesting about 40° clockwise rotation with respect to the present North. This means a total clockwise rotation of about 80°, occurring before the mid-Miocene and after the intrusion of the latite, possibly confined to one of the blocks of the Fruška Gora horst. It is equally possible that the clockwise rotation affected a larger area. In any case, both the clockwise and the counterclockwise rotations are important for the kinematic reconstruction of the Fruška Gora with respect to the Vardar Zone, to which it belonged originally. Future work should provide paleomagnetic data from the Vardar Zone in order to facilitate this reconstruction.

Key words: Tertiary rotations, Southern Pannonian Basin, Fruška Gora, paleomagnetism.

Introduction

Encircled by the Eastern Alps, by the Western and Eastern Carpathians and by the Dinarides, the Pannonian Basin is mostly covered by Quaternary sediments. Basements rocks outcrop as inselbergs in the Southern Pannonian Basin including the Medvednica, Moslavačka Gora, Slavonian Mountains and the Fruška Gora. These basement rocks are of different types: in the Medvednica they belong to the Mid-Hungarian mobile zone, in Moslavačka Gora and in the Slavonian Mountains they are of Tisia type and in the Fruška Gora they are related to the Vardar Zone (Dimitrijević 1997; Haas et al. 2000). The inselbergs are enveloped by Neogene sediments.

During the Alpine orogeny important displacements took place between the above mentioned basement units. It is a generally accepted view that relative rotations between the blocks of the Pannonian Basin lasted until about 16 Ma (Balla 1984; Csontos et al. 1992; Kováč et al. 1994).

Paleomagnetic studies of recent years have documented rotations younger than 16 Ma from several parts of the Pannonian Basin, among them the Medvednica and the Slavonian Mts areas (Márton et al. 1999, 2002b). The question was whether the Fruška Gora behaved like the more westerly part of the Southern Pannonian Basin. That is why we started a project on the Miocene sediments of Fruška Gora. The paleomagnetic study, however, included older than Neogene rocks, which were interesting from the viewpoint of possible pre-Miocene rotation of the Fruška Gora with respect to the rest of the Vardar Zone, since the structural trend of the former is quite different from the latter (Fig. 1).

Geology and tectonics

Fruška Gora is situated South of Novi Sad, on the right bank of the Danube River. It is an east-west extending horst that is bounded by two regional normal faults in the North and South, respectively (Fig. 2). Several normal faults of local importance cross the area.

The oldest rocks in Fruška Gora are metamorphics of Paleozoic age that are in tectonic contact with low and Middle Triassic sediments. Upper Triassic through mid-Jurassic strata are missing. In the central part of the mountains there are Upper Jurassic deep-water sediments. After a long hiatus, Upper Cretaceous sediments were deposited. South of the Srem dislocation (Fig. 2), these are shallow water clastics with reef limestones, while north of it there are deep-water flysch deposits. Dislocation zones in the Fruška Gora are marked with the occurrence of serpentinite

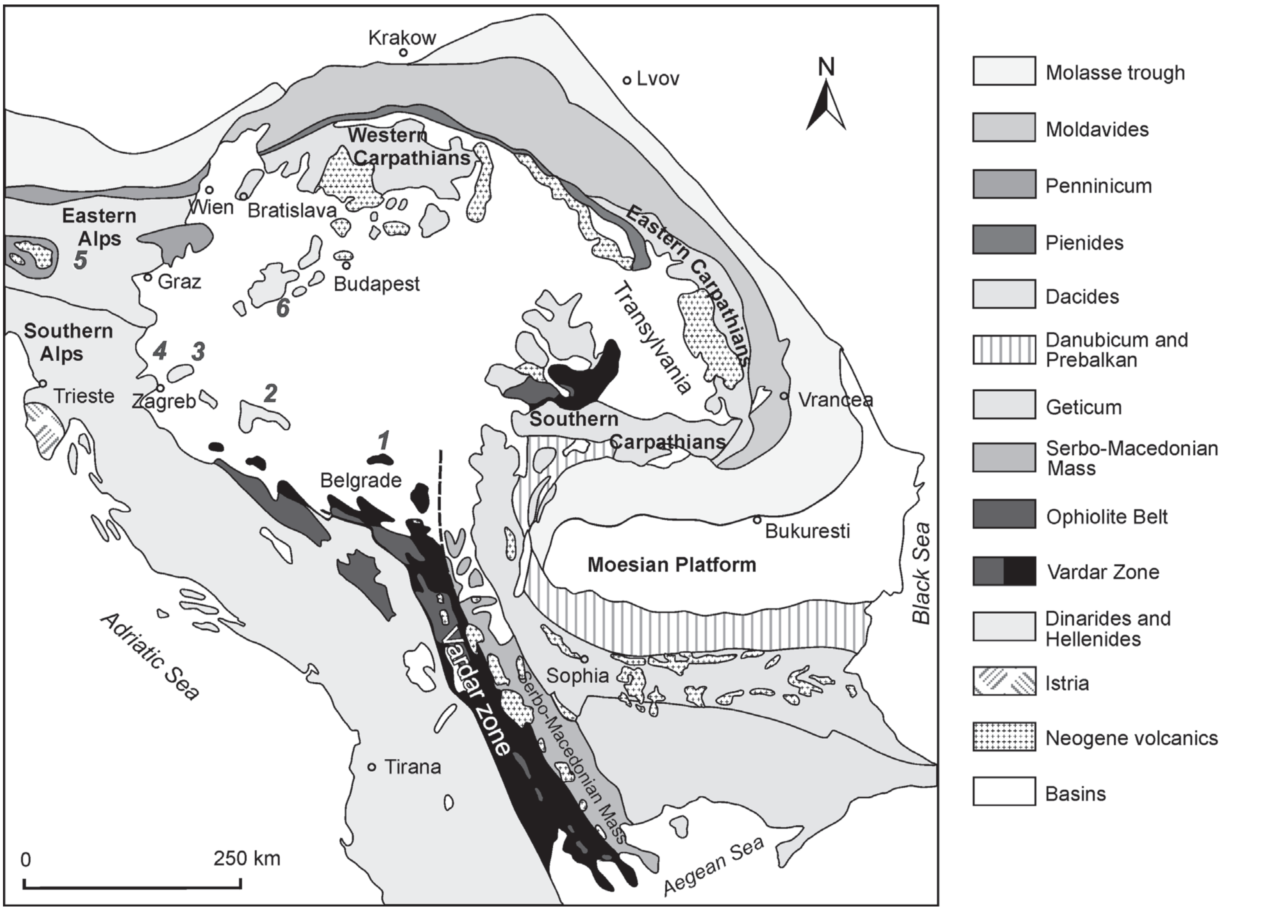

Fig. 1. Geological sketch map of the Pannonian Basin and the surrounding area with indication of the structural trend of Fruška Gora and the Vardar Zone. **1** — Fruška Gora, **2** — Slavonian Mts, **3** — Medvednica, **4** — Mura-Zala Basin, **5** — Intramontane basins of the Eastern Alps, **6** — Transdanubian Range.

(Fig. 2; Čičulić-Trifunović & Rakić 1971a,b; Čupković 1997; Dimitrijević 1997). After the Cretaceous, the Fruška Gora was strongly tectonized and uplifted. The flysch and the serpentinite are locally intruded by latite (K/Ar age 35±5 Ma, Knežević et al. 1991).

A new sedimentary cycle started in the Miocene, with lake sediments indicating deposition in separate basins on the northern and southern flanks of Fruška Gora, respectively. Dacites, andesites (south side) and pyroclastics (northern flanks) are due to Miocene volcanic activity which hydrothermally affected older rocks, particularly serpentinites. In the Middle Miocene, the sea invaded the area. The depositional environment became brackish, and then caspi-brackish during the Late Miocene. Sedimentation was restricted to the west side of the horst. In the same area, freshwater Pliocene sediments overlay the Miocene strata with angular discomformity.

Cross-sections of the Fruška Gora (Čičulić-Trifunović & Rakić 1971a; Čupković 1997) show that Miocene sediments occur on both sides of the crest, moderately tilted on the north side towards the North and subhorizontal on the south side. The flysch and the older rocks are heavily tectonized. The tectonic phase which deformed the flysch is obviously post-Cretaceous, and Dimitrijević (1997) suggests that the products of various depositional environments were also brought into contact during this tectonic phase, along the Srem dislocation (SD) and the Fruška Gora dislocation (FGD) (Fig. 2).

Concerning the structure and the original formation place of the Paleozoic-Mesozoic of the Fruška Gora, there are different opinions that were discussed by Grubić et al. (1998). Fruška Gora is conceived as a huge anticline or, as a nappe pile; some consider it as part of the Vardar subduction zone (Karamata & Krstić 1996; Dimitrijević 1997), while others relate it to the Eastern Alps (Grubić et al. 1998).

Paleomagnetic sampling, measurements and results

We drilled 196 cores from 16 localities, using a portable drill and oriented them in the field with magnetic compass. The sampled rocks (Fig. 2) are latites (localities 1a, 3a and 9), Maastrichtian flysch from the neighbourhood of latite localities 1a and 3a (localities 1b and 3b) and far from the latite intrusion (localities 7 and 13). An Upper Cretaceous limestone was drilled at one locality (11) and so was serpentinite (locality 12). Middle Miocene (locali-

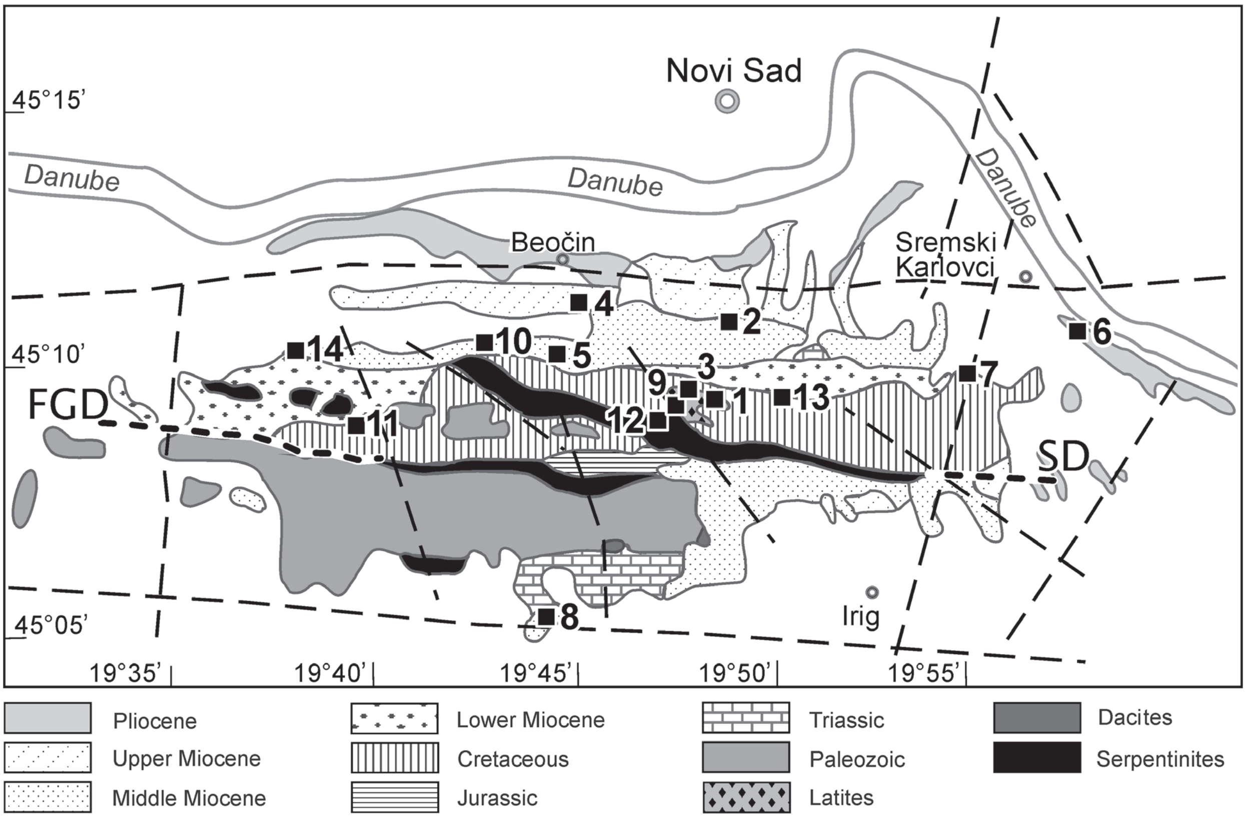

Fig. 2. Geological sketch map of Fruška Gora modified after Dimitrijević (1997) with the paleomagnetic sampling localities. **SD** — Srem dislocation, **FGD** — Fruška Gora dislocation, ---- — normal faults, ■ — paleomagnetic sampling localities 1–14 (localities 1 and 3 are composite: 1a and 3a are latites, 1b and 3b are flysch): the numbers are used throughout the text, in figures and in tables.

ties 2, 5, 8, 10 and 14), Upper Miocene (locality 4) and middle Pliocene (locality 6) sediments that have been sampled, were mostly marls deposited in a marine, lake or swamp environment. Locality 8 is a special one: here red clays were sampled from several paleokarst holes in white biogenic limestone, which is accessible in several quarries south of the Fruška Gora horst.

From the drill cores, standard-size specimens were cut in Belgrade. The paleomagnetic measurements were subsequently carried out in Budapest using JR-4 and JR-5A spinner magnetometers, Schoenstedt AF and thermal demagnetizers, and an AF demagnetizer built at the Technical University of Budapest (peak field 0.23T), KLY-2 kappabridge and a pulse magnetizer.

First the natural remanent magnetization (NRM) of each specimen was measured, followed by measurements of the magnetic susceptibility anisotropy. Then, selected specimens from each locality were subjected to detailed stepwise alternating field (AF) or thermal demagnetization, until the NRM signal was lost. Based on the behaviour of the pilot specimens, either AF or thermal demagnetization or, less frequently, the combination of the two was chosen for demagnetizing the rest of the samples, also in many steps. Demagnetization curves were analysed for linear segments (components of the NRM, method by Kirschvink 1980) and the components were subjected to statistical evaluation. Although the behaviour of the NRM and the susceptibility often yielded sufficient information about magnetic minerals, we also carried out special experiments, like isothermal remanent magnetization (IRM) acquisition experiments and thermal demagnetization of a three component IRM.

The latites were successfully demagnetized both by AF and thermal methods. The results of the thermal demagnetization did not yield only components, but also information about magnetic minerals. As Fig. 3 shows, the magnetic minerals are maghemite and magnetite (see susceptibility/intensity versus temperature curves), and the characteristic remanence appears after the transformation of maghemite to hematite. Latites exhibit well defined paleomagnetic directions with easterly declinations and steep negative inclinations (Table 1).

The flysch intruded by latite (Fig. 4, specimens YM 3007'1 and YM 3113) was very efficiently demagnetized by AF. The directions before tilt corrections fit with the characteristic remanence of the latite. We also tested flysch localities far from the latites: one of them was unstable, therefore rejected (locality 13), the other exhibited moderate instability. Nevertheless, the demagnetization path in the latter case (locality 7, Fig. 4, specimen YM 3098B) was sufficiently good to yield a line, which, however, did not decay towards the origin. Thus, we interpret the isolated component as an overprint acquired during the Miocene (see below).

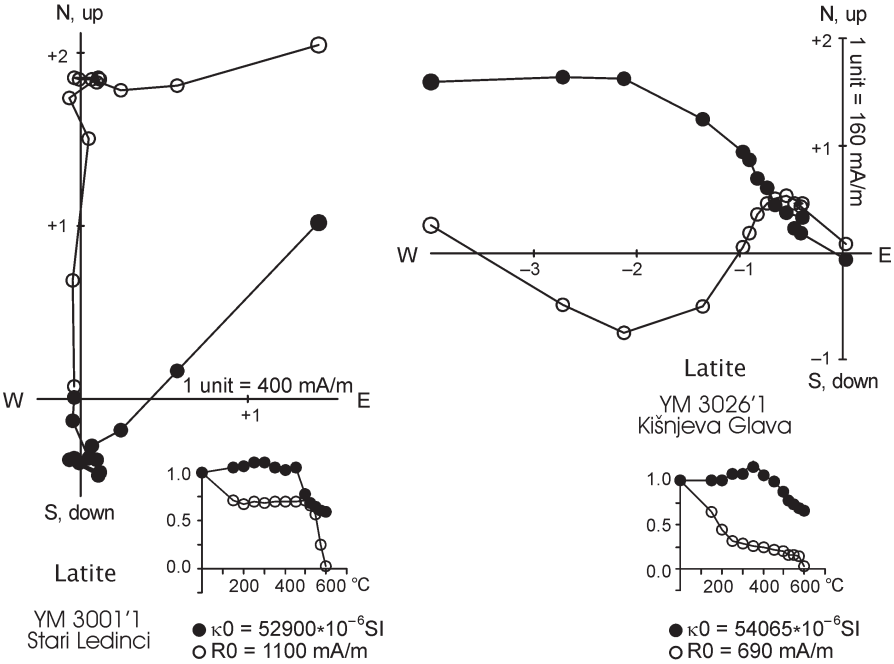

Fig. 3. Fruška Gora, latites. Typical demagnetization curves. Key: Zijderveld diagrams and intensity/susceptibility versus temperature curves. During thermal demagnetization the remaining intensity of the NRM was measured after heating the specimen to a given temperature and cooling it back to room temperature. In the Zijderveld diagrams full/open circles: projection of the NRM in the horizontal/vertical plane; in others susceptibility: dots, NRM intensity: circles. **R0** — initial intensity of the NRM, **k0** — initial susceptibility.

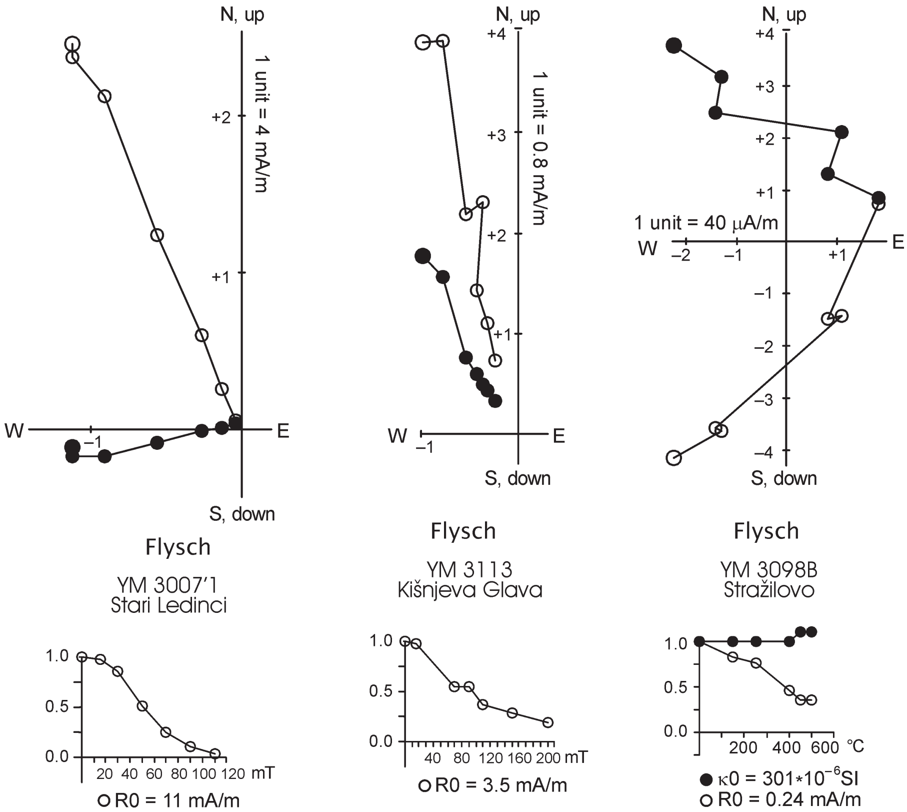

Fig. 4. Fruška Gora, flysch. Typical demagnetization curves. Flysch intruded by latite (specimens YM 3007'1 and YM 3113) and a flysch far from latite (specimen YM 3098B). Key as for Fig. 3.

The Upper Cretaceous red limestone from locality 11 failed on AF demagnetizitation. On thermal demagnetization up to 710 °C, the NRM direction moved along great circles. A linearity test yielded two well-defined components: one of them a Miocene overprint (see below), while the other was different. A third direction was obtained from the end points of the demagnetization (step 710 °C). The serpentinite yielded good result on AF demagnetization (locality 12). The results for localities 11 and 12 are tabulated in Table 1.

The Miocene sediments were successfully AF demagnetized (specimen YM 3128B) except for the red clay filling paleokarst holes (locality 8, specimen YM 3108). Thus, we employed thermal demagnetization (Fig. 5) for this locality as well as for the dark grey Pliocene clay where the suspected carrier of the remanence was greigite (Fig. 5, specimen YM 3078A).

Statistically well-defined paleomagnetic directions were obtained for all Miocene localities (Table 2), except 4. At locality 4 the failure was unexpected, since fresh material was collected from a working quarry and the magnetic mineral was magnetite (Fig. 6, specimen YM 3056A). The principal magnetic mineral was magnetite also at other Miocene localities, occasionally accompanied by goethite that carried an overprint (Fig. 5, specimen YM 3108). In the Pliocene sediment the NRM seems to reside in magnetic iron sulphide (Fig. 5, locality 6, specimen YM 3078A).

Discussion and conclusions

Paleomagnetic results from Fruška Gora can be subdivided into three groups. The first contains Miocene and Pliocene sediments deposited after mid-Cretaceous metamorphism (Milovanović et al. 1995), the post-Cretaceous intensive folding and the build-up of the Fruška Gora horst from different tectonic blocks. These came into contact along dislocation zones,

Table 1: Fruška Gora, pre-Miocene localities. Paleomagnetic directions with statistical parameters. **n/no** — number used/collected (the samples are independently oriented cores); ***D, I*** (***D_c, I_c***) — declination, inclination before (after) tilt correction; ***k*** and α_{95} — statistical parameters (Fisher 1953); bolded directions are used in tectonic interpretation. Localities 7, 11 and 12 are Miocene overprints.

	Locality	n/no N(n)	D°	I°	k	a_{95}°	D_c°	I_c°	k	a_{95}°	dip	Remark
Fruška Gora, (Oligocene?) latites												
1a	Stari Ledinci–quarry Srebro YM 3000-005	6/6	**233**	**–74**	26	13						
3a	Quarry Kišnjeva Glava YM 3026-035	9/10	**298**	**–52**	22	11						
9	Gradac YM 3120-127	7/8	**294**	**–72**	43	9						
Fruška Gora, Upper Cretaceous flysch												
1b	Stari Ledinci–quarry Srebro YM 3006-011	4/6	**260**	**–68**	271	6	208	–8	271	6	7/75	
3b	Quarry Kišnjeva Glava YM 3113-119	6/7	**331**	**–63**	459	3	116	–60	459	3	313/54	
7	Stražilovo YM 3096-105	10/10	**317**	**+37**	19	12	344	+14	19	12	38/58	
Fruška Gora, Cretaceous limestone and Jurassic serpentinite												
11	Srednje Brdo, red limestone YM 3137-145	6/9 8/9 8/9	**341** 169 209	**+51** +44 –28	70 60 17	8 7 14	321 179 204	+54 +35 –42	30 109 19	12 5 13	variable	less stable component more stable component last demag. step (710 °C)
12	Zmajevac, serpentinite YM 3146-151	5/5	**342**	**+71**	141	6						

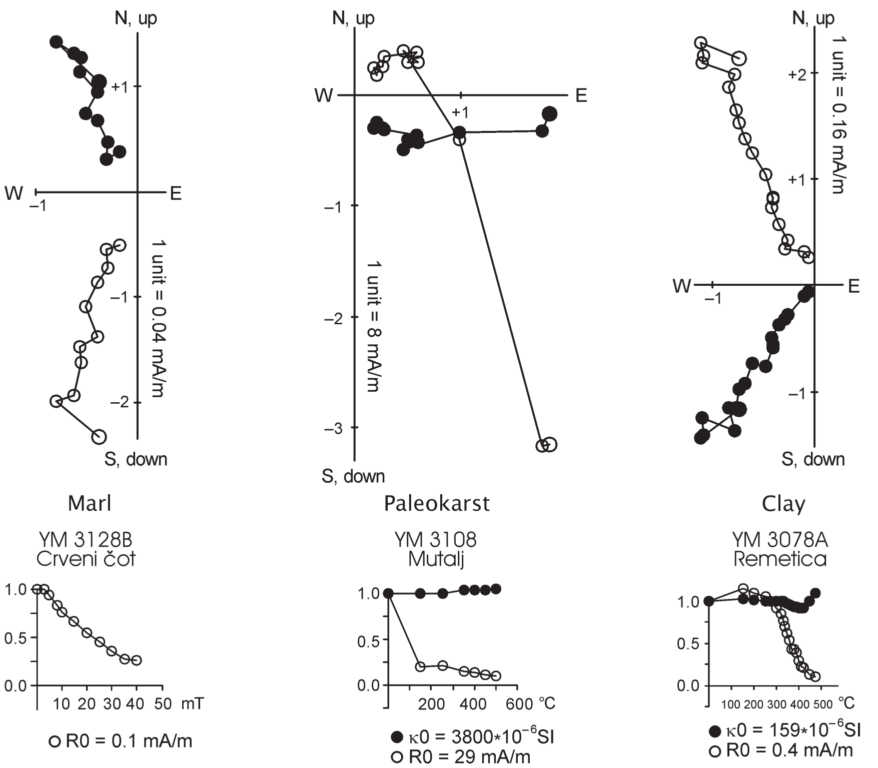

Fig. 5. Fruška Gora, Miocene and Pliocene localities. Typical demagnetization curves for a Miocene marl (specimen YM 3128B), for paleokarst filling (specimen YM 3108) and for Pliocene clay (specimen YM 3078A). Key as for Fig. 3.

which are marked by serpentinite (Fig. 2). The second comprises Upper Cretaceous flysch, locally intruded by latite of 35 Ma (Knežević et al. 1991). Two localities fall into the third group, which sustained at least two phases of deformation as well as metamorphism.

In the first group, there is a dramatic change in orientation, for the Pliocene locality is characterized by the "stable European" declination (reversed polarity direction, Fig. 7, locality 6), while Miocene localities show counterclockwise rotated declinations, in the geographical as well as in the tectonic co-ordinate systems (Table 2, Fig. 7). An exception is locality 5, which is suspected of slumping. Thus, we calculated overall-mean paleomagnetic direction in two versions: with and without this locality (Table 3). The two versions have different statistical parameters, but the overall-mean paleomagnetic directions are practically the same which shows that our data set is robust. By adding to them three pre-Miocene

Table 2: Fruška Gora, Miocene–Pliocene localities. Paleomagnetic directions with statistical parameters. Key as for Table 1.

	Locality	n/no N(n)	D°	I°	k	α_{95}°	D_c°	I_c°	k	α_{95}°	dip
Fruška Gora, Middle Miocene											
2	Stari Rakovac, marl YM 3012-025	13/14	316	+33	22	9	**301**	**+53**	22	9	168/25
5	Opčište, marl and tuff YM 3066-077	7/12	**33**	**+62**	57	8	28	+74	57	8	220/12
8	Mutalj, limestone with paleokarst										
	YM 3106-112	5/6	135	–50	13	22	135	–50	13	22	horizontal
	YM 3275-287	5/13	147	–74	20	15	147	–74	20	15	horizontal
	YM 3106-112 + YM 3275-287	10/19	140	–63	13	13	**140**	**–63**	13	13	
10	Crveni čot, marl YM 3128-136	7/9	**336**	**+43**	64	8	340	+6	64	8	356/40
14	Grabovo, tufite YM 3169-174	6/6	327	+70	71	8	**292**	**+51**	71	8	263/26
Fruška Gora, Middle Pliocene											
6	Remetica, clay YM 3078-091	5/10	209	–51	64	10	**207**	**–55**	64	10	225/5

localities with Miocene overprints (serpentinite, which was affected by Miocene hydrothermal activity, the red limestone of Late Cretaceous age, both belonging to the third group, and a flysch locality, far from the latite intrusion, belonging to the second group) we obtain a paleomagnetic direction which is not only the statistically best defined for characterizing the end of Miocene (Early Pliocene?) counterclockwise rotation of Fruška Gora, but it is also the best areal representation of it.

Pre-Miocene localities 1a, 1b, 3a, 3b and 9 show a good cluster of paleomagnetic directions, with quite steep negative inclinations and consistent declinations in the geographical co-ordinate system (Table 1 and Fig. 8). This paleomagnetic direction suggests large clockwise rotation, in contrast to the younger moderate counterclockwise rotation. The difference is so large, and the tectonic implication is so shocking, that the possibility of dealing with an artifact clockwise rotation should be discussed. One of the possibilities is that declination is biased by tilting strata around an oblique axis, instead of a horizontal one. This effect can safely be excluded, since the post-deformation age of the remanence in the flysch at the contact with the latite, and the intrusion of the latite after folding is beyond doubt (Table 3). A second effect could be bias of the paleomagnetic direction due to magnetic anisotropy towards lineation direction. However, lineation directions are scattered, which excludes the systematic

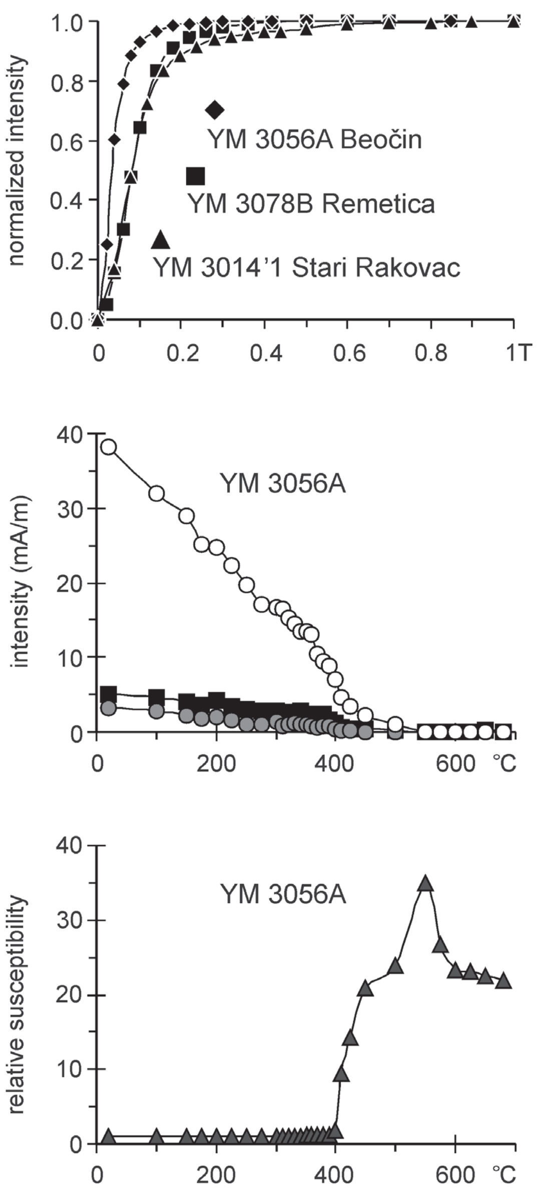

Fig. 6. Fruška Gora, Miocene–Pliocene sediments. Magnetic mineralogy. IRM acquisition behaviour (upper row) for Miocene (specimens YM 3056A and YM 3014'1) and Pliocene sediments (specimen YM 3078B). The three-component IRM (Lowrie 1990) behaviour on thermal demagnetization (second row) and the change in the susceptibility on heating (last row) for Miocene sediment (specimen YM 3056A). The hard (squares), the medium hard (dots) and soft (circles) components of the composite IRM were acquired in fields of 1 T, 0.36 T and 0.2 T respectively.

Table 3: Fruška Gora, summary of the overall-mean paleomagnetic directions used in tectonic interpretation. Key as for Table 1.

Locality	N	*D*°	*I*°	*k*	a_{95}°	D_c°	I_c°	*k*	a_{95}°
Oligocene latites + accompanying Cretaceous flysch (localities 1a, 1b)	5	**290**	**–69**	25	16	232	–70	4	45
Miocene (localities 2, 8, 10, 14)	4	324	+53	20	21	**313**	**+54**	30	17
All Miocene (localities 5, 2, 8, 10, 14)	5*	334	+57	13	22	**319**	**+60**	16	20
All Miocene + localities 7,11,12	8*	333	+56	17	14	**324**	**+58**	18	13
Miocene + localities 7,11,12	7*	327	53	23	13	**320**	**+54**	26	12

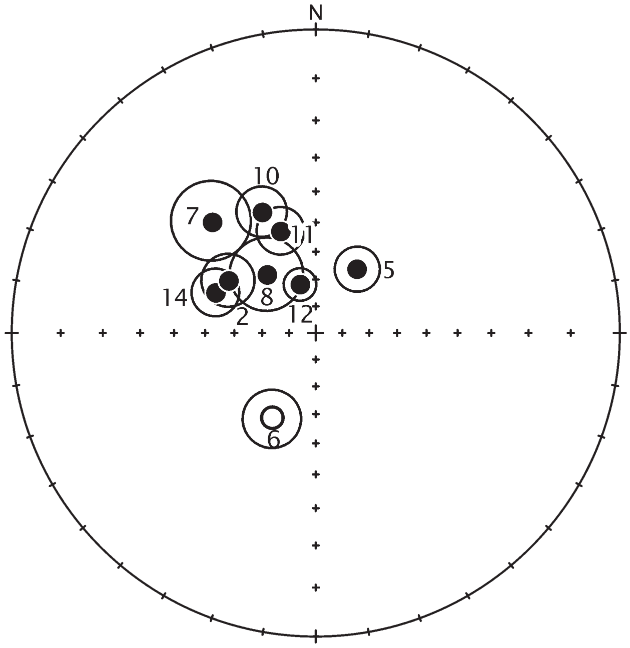

Fig. 7. Fruška Gora, Miocene and Pliocene localities. Locality mean paleomagnetic directions with α_{95}. Stereographic projection. In addition, Miocene overprint directions are plotted for three localities. Key: full circles: positive; open circles: negative inclination.

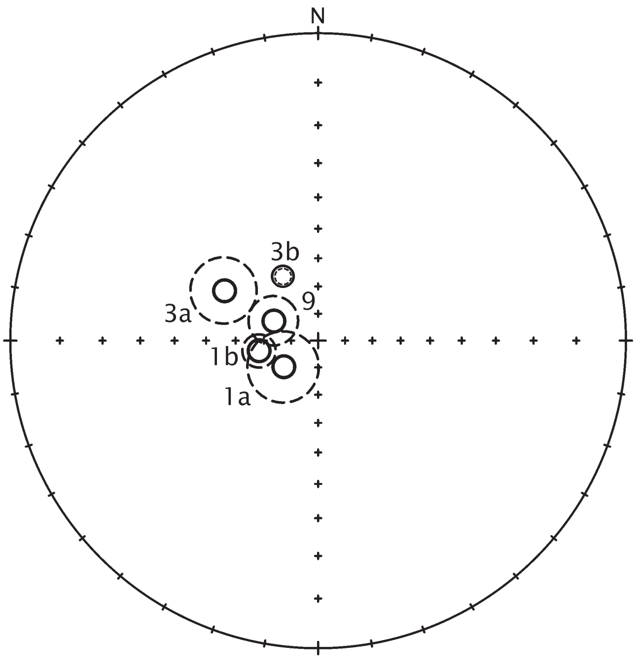

Fig. 8. Fruška Gora, latite and intruded flysch localities. Locality mean paleomagnetic directions with α_{95}. Stereographic projection. Key as in Fig. 7.

influence of either flow or deformation on the direction of the paleomagnetic overall mean vector (Fig. 9). A third explanation can be that the latite and remagnetized flysch were tilted together with the oldest Miocene sediments, therefore, the directions need a partial and uniform tilt correction. Such correction cannot be taken from direct measurements in the field, but it can be estimated. Two geological cross-sections through the Fruška Gora (Čičulić-Trifunović & Rakić 1971a; Čupković 1997) show that the tilt angle of the oldest Miocene sediments is maximum 46° towards 15° N. When this correction is applied, the paleomagnetic direction (D=220°, I=–43°, k=25, α_{95}=16°) exhibits a moderate clockwise rotation with respect to the North and seems to be more realistic than the uncorrected one. Even with this smaller angle of clockwise rotation we have to calculate with about 80° clockwise rotation before the mid-Miocene and after the intrusion of the latite.

The end-of-Miocene counterclockwise rotation documented by the present study compares well with observations from several parts of the Southern Pannonian Basin (Medvednica-Hrvatsko Zagorje area and Slavonian Mountains, Márton et al. 2003; Krsko-Karlovac Basin, Márton et al. 2006; Mura-Zala Basin, Márton et al. 2002) and even from the Eastern Alps (Márton et al. 2000; Scholger & Stingl 2004; Thöny et al. 2006) and from the Transdanubian Range (Márton & Fodor 2003). The practically coinciding overall declinations measured on late Middle Miocene and Upper Miocene rocks from the above mentioned areas and the lower age limits of the rotations, constrained by the stratigraphic ages of youngest sediments still showing westerly declination deviation from the present North (Fig. 10) imply that this rotation was of interregional character and can be attributed to a common driving force. A counterclockwise rotating Adriatic microplate could have provided such force (e.g. Márton 2005).

In contrast to the straightforward tectonic interpretation and interregional character of the above discussed counterclockwise rotation, the pre-Miocene clockwise rotation observed for the Fruška Gora calls for alternative interpretations. The reason is that the latites and related flysch localities are all situated north of the Srem dislocation (Fig. 2), while the Fruška Gora was assembled from differ-

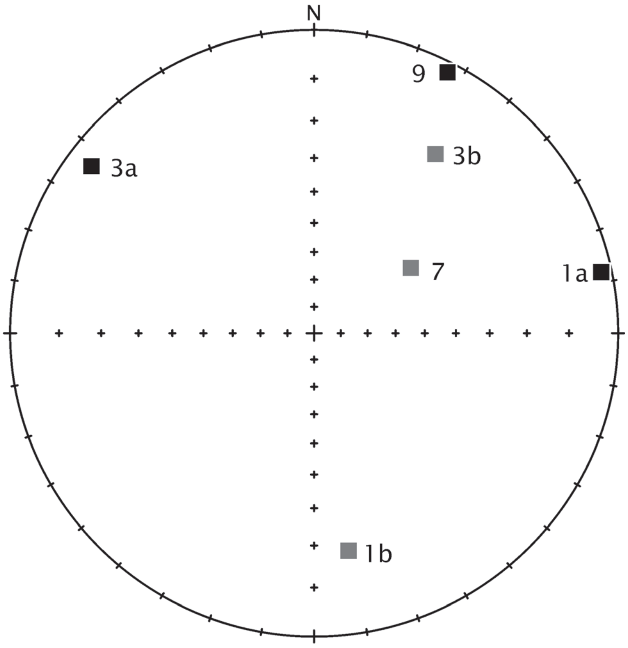

Fig. 9. Fruška Gora, latite and flysch localities. Lineation directions on a stereonet. Geographic co-ordinate system.

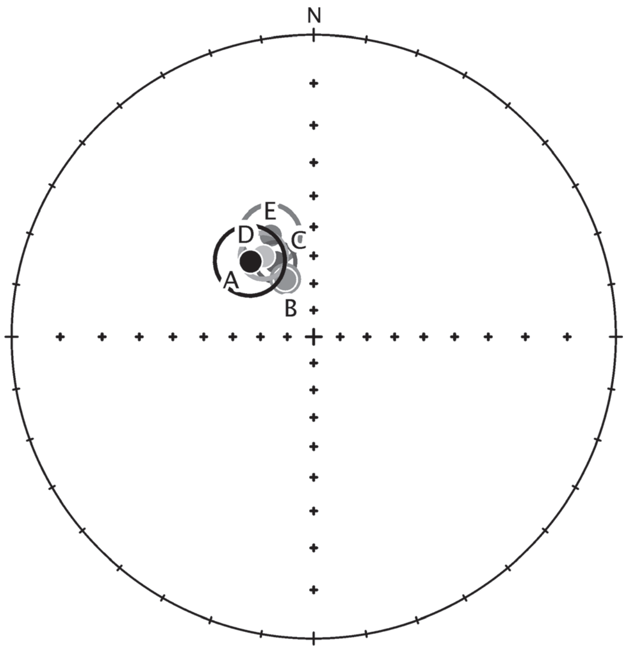

Fig. 10. Overall-mean paleomagnetic directions with α_{95} for: **A** — Fruška Gora rotation younger than 13 Ma; **B** — Medvednica-Hrvatsko Zagorje area and Slavonian Mountains rotation younger than 6 Ma; **C** — Eastern Alps rotation younger than 12 Ma; **D** — Mura-Zala Basin rotation younger than 4 Ma; **E** — Intramontane basins of the Eastern Alps. Stereographic projection.

ently moving units, after the Cretaceous, and before the Miocene: the boundaries of theses units are the Srem and Fruška Gora dislocations (Dimitrijević 1997). South of the Srem dislocation zone, we sampled an Upper Cretaceous limestone, (locality 11) for comparison, which, however, yielded only an overprint magnetization of Miocene age (Table 1). The rest of the outcrops of pre-Miocene age south of the mentioned dislocation were not even promising for reasons of weathering and extremely complicated tectonization.

If we interpret the clockwise rotation observed for the latite and related flysch as evidence for differential movements within the Fruška Gora, the implication is that such displacements should have taken place after the intrusion of the latite, that is between 35 Ma and the mid-Miocene. We cannot exclude, however, that the whole Fruška Gora rotated clockwise during the same period. In this case, our results must be relevant to the detachment of the area from the Vardar Zone, which is one of the most important subduction zones in the Alpine tectonic history of the central and eastern Mediterranean. Several scientists having insight into the stratigraphy, tectonics and metamorphism of this zone, regard the Fruška Gora as an integral part of the Vardar Zone during Paleozoic and Mesozoic so much so that the closing of the zone was recently dated from the Fruška Gora (Milovanović et al. 1995). Today respective structural trends in the Fruška Gora and in the Vardar Zone differ by about 70°, suggesting counterclockwise deviation of the former from the latter.

The paleomagnetic results of the present study show that the end-of-Miocene counterclockwise rotation, assuming that the Vardar Zone did not rotate, is only 40°. Moreover, the pre-Miocene clockwise rotation for the Fruška Gora implies that the present difference in structural orientation came into being during two tectonic events. Since the Vardar Zone is not yet represented by paleomagnetic data of suitable ages, it is not yet possible to reconstruct the process of the separation of the Fruška Gora from this zone.

To summarize the tectonic implications of the present study, we recognized a latest Miocene-pre-middle-Pliocene counterclockwise rotation which involved the whole Fruška Gora. Before this rotation, there was a rotation in the opposite sense, which must have taken place after the intrusion of the Oligocene latite and before the deposition of the mid-Miocene sediments. This rotation surely affected the Fruška Gora north of the Srem dislocation, but could have involved the whole study area. In either case, the rotation seems to be of regional significance. In contrast, the younger, counterclockwise rotation makes interregional correlation possible between the Fruška Gora on one hand and the more westerly parts of the Southern Pannonian Basin, the Eastern Alps and the Transdanubian Range, on the other hand. The young counterclockwise rotation involved basements of different origin (Dinaric, South Alpine, East Alpine), and was most probably induced by the rotating Adriatic microplate.

Acknowledgments: The authors thank M. Bielik, E. Petrovský, R. Scholger and I. Túnyi for revising the manuscript. The laboratory experiments were partially supported by Hungarian Scientific Research Fund (OTKA) Project No. T 034364.

References

Balla Z. 1984: The Carpathian loop and the Pannonian basin: a kinematic analysis. *Geophys. Trans*. 30, 313–353.

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

Čičulić-Trifunović M. & Rakić M. 1971a: Basic geological map of (former) Yugoslavia. 1:100,000 sheet Novi Sad. *Federal Geological Institute,* Belgrade.

Čičulić-Trifunović M. & Rakić M. 1971b: Explanatory notes for the basic geological map of (former) Yugoslavia. 1:100,000 sheet Novi Sad. *Federal Geological Institute,* Belgrade, 1–52 (in Serbian).

Čupković T. 1997: Geological characteristics and geomorphological evaluation of the Fruška Gora Mt. *Master Thesis, Univ. Belgrade,* 1–133 (in Serbian).

Dimitrijević M.D. 1997: Geology of Yugoslavia. *Geol. Inst. GEMINI,* Belgrade, 1–187.

Fisher R.A. 1953: Dispersion on a sphere. *Proc. Roy. Soc*. A217, 295–305.

Grubić A., Đoković I. & Marović M. 1998: Contribution to the study of older tectonics of Fruška Gora. Vol. 2: Regional geology, stratigraphy and paleontology. *13th Congress of Geologist of Yugoslavia,* 15–20 (in Serbian with English abstract).

Hass J., Mioč P., Pamić J., Tomljenović B., Árkai P., Bérczi-Makk A., Koroknai B., Kovács S. & Felgenhauer E.R. 2000: Complex structural pattern of the Alpine-Dinaric-Pannonian triple junction. *Int. J. Earth. Sci.* 89, 377–389.

Karamata S. & Krstić B. 1996: Terranes of Serbia and neighbouring areas. Terranes of Serbia. In: Knežević-Đordević V. & Krstić B. (Eds.): Terranes of Serbia. The formation of the geological framework of Serbia and the adjacent regions. *Fac. Min. Geol., Univ. Belgrade, Comm. Geodynamics Serb. Acad. Sci. Arts,* 25–40.

Kirschvink J.L. 1980: The least squares line and plane and the analysis of paleomagnetic data. *Geophys. J. R. Astr. Soc.* 62, 699–718.

Knežević V., Széky-Fux V., Steiger R., Pécskay Z. & Karamata S. 1991: Petrology of Fruška Gora latites-volcanic precursors at the southern margin of the Pannonian Basin. Geodynamic evolution of the Pannonian Basin. *Proc. Int. Symposium*, 243–235.

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

Lowrie W. 1990: Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. *Geophys. Res. Lett.* 17, 159–162.

Márton E. 2005: Paleomagnetic evidence for Tertiary counterclockwise rotation of Adria with respect to Africa. In: Pinter N., Grenerczy Gy., Weber J., Stein S. & Medak D. (Eds.): The Adria microplate: GSP geodesy, tectonics and hazards. *Kluwer Academic Publisher*, 55–64.

Márton E. & Fodor L. 2003: Tertiary paleomagnetic results and structural analysis from the Transdanubian Range (Hungary); sign for rotational disintegration of the Alcapa unit. *Tectonophysics* 363, 201–224.

Márton E., Pavelić D, Tomljenović B., Pamić J. & Márton P. 1999: First paleomagnetic results on Tertiary rocks from the Slavonian Mountains in the Southern Pannonian Basin, Croatia. *Geol. Carpathica* 50, 273–279.

Márton E., Kuhlemann J., Frisch W. & Dunkl. I. 2000: Miocene rotations in the Eastern Alps — Paleomagnetic results from intramontane basin sediments. *Tectonophysics* 323, 163–182.

Márton E., Fodor L., Jelen B., Márton P., Rifelj H. & Kevrić. R. 2002a: Miocene to Quaternary deformation in NE Slovenia: complex paleomagnetic and structural study. *J. Geodynamics* 34, 627–651.

Márton E., Pavelić D., Tomljenović B., Avanić R., Pamić J. & Márton P. 2002b: In the wake of a counterclockwise rotating Adriatic microplate: Neogene paleomagnetic results from Northern Croatia. *Int. J. Earth Sci.* 91, 514–523.

Márton E., Drobne K., Ćosović V. & Moro A. 2003: Palaeomagnetic evidence for Tertiary counterclockwise rotation of Adria. *Tectonophysics* 377, 143–156.

Márton E., Jelen B., Tomljenović B., Pavelić D., Poljak M., Márton P., Avanić R. & Pamić J. 2006: Late Neogene counterclockwise rotation in the SW part of the Pannonian Basin. *Geol. Carpathica* 57, 41–46.

Milovanović D., Marchig V. & Karamata S. 1995: Petrology of crossite schist from Fruška Gora Mts. (Yugoslavia), relic of a subduction slab of the Tethyan oceanic crust. *J. Geodynamics* 20, 289–304.

Scholger R. & Stingl K. 2004: New paleomagnetic results from the Middle Miocene (Karpatian and Badenian) in Northern Austria. *Geol. Carpathica* 55, 199–206.

Thöny W., Ortner H. & Scholger R. 2006: Paleomagnetic evidence for large en-block rotations in the Eastern Alps during Neogene orogeny. *Tectonophysics* 414, 169–189.