GEOLOGICA CARPATHICA, 50, 3, BRATISLAVA, JUNE 1999
273–279

FIRST PALEOMAGNETIC RESULTS ON TERTIARY ROCKS FROM THE SLAVONIAN MOUNTAINS IN THE SOUTHERN PANNONIAN BASIN, CROATIA

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(Manuscript received August 17, 1998; accepted in revised form March 17, 1999)

Abstract: Five sedimentary localities (Ottnangian through early Pannonian age) and one igneous site (K/Ar age 17 Ma) were studied paleomagnetically. Apart from one sedimentary locality, all yielded excellent or good paleomagnetic results, with declinations indicating counterclockwise (CCW) rotations. The declinations are between 300 and 340° and seem to vary in space and not in time. Since the youngest rock exhibiting CCW rotation is of early Pannonian age, it is reasonable to connect the rotations to the "intra-Pannonian" or "Rhodanian" tectonic phase, i.e. the most marked and last Tertiary tectonic event manifested in thrusts and strike-slip movements in the south-western part of the Tisza (Tisia) or South Pannonian megatectonic unit. The new paleomagnetic results are in harmony with CCW rotations postulated for the Slavonian Mts. However, the Tertiary paleomagnetic data from the Slavonian Mts. and the Mecsek Mts. point to extreme mobility within the south-west part of the Tisza megatectonic unit. This seems to be in conflict with current tectonic models which work with a rigid Tisza megatectonic unit in the Tertiary.

Key words: Southern Pannonian Basin, paleomagnetism, rotations.

Introduction

The importance of paleomagnetic data as indicators of tectonic movements has long been recognized. Such data have also been obtained and interpreted in terms of tectonics for the Carpatho-Pannonian region (e.g. Márton & Márton 1981, 1983; Márton 1986, 1987). In recent years, Tertiary rocks have been intensively studied, especially north of the Hungarian Mobile Belt (e.g. Márton & Márton 1995; Márton et al. 1996; Túnyi & Márton 1996). Acquisition of data, however, in the Tisza (Tisia) Unit (south of the same mobile belt) has been hampered by the scarcity of suitable outcrops. In Hungary, only the Mecsek area, is accessible for paleomagnetic sampling, but the quality of the rocks is not always satisfactory (coarse grain size, deep weathering etc.).

The paleomagnetic data from the Mecsek Mts. obtained from 1995 onward (Márton & Márton, in prep.) have clearly indicated that the work has to be extended to other parts of the Tisza Unit as well. Nearest to the Mecsek area, the Slavonian Mountains in Croatia seemed to be a natural choice for extension and, as a first step, a pilot sampling was carried out there in 1997. It was supported by a joint project between the Croatian and Hungarian Academies of Sciences.

The Slavonian Mountains, consisting of the Psunj, Ravna Gora, Papuk, Krndija, Dilj and Požeška Gora Mts., are located in the central part of Slavonia in Northern Croatia (Fig. 1). The Požega Valley lies in the centre of the study area and is encircled by all the above mentioned mountains. Most of the Psunj, Papuk and Krndija Mts. are composed of Variscan and Alpine formations which are unconformably covered by the Neogene sedimentary rocks of the Pannonian Basin. The Phanerozoic formations of the Slavonian Mountains have been penetrated by a number of oil-wells in the surrounding basement, particularly in the adjacent Drava Depression (Pamić 1986). These have been summarized in Pamić & Lanphere (1991) for Paleozoic crystalline rocks and in several explanatory texts for the Mesozoic and Cenozoic formations accompanying separate sheets of the 1:100,000 geological map covering this area of northern Croatia (Jamičić et al. 1987, 1989; Korolija & Jamičić 1989; Šparica et al. 1980, 1987).

Most of the Papuk, Krndija and Psunj Mts. are composed of Variscan greenschist and amphibolite facies metamorphic rocks associated with larger masses of penecontemporaneous migmatites and S-type granites with subordinate I-type granites. These rocks are accompanied by Silurian to Early Carboniferous very low-grade metapelites and metapsammites intruded by metabasic sills which probably represented the protolith for the Variscan crystalline complex (Raffaelli 1965). Mesozoic formations are subordinate and are represented mainly by Triassic and to smaller extent, by Jurassic and Late Cretaceous clastic and carbonate rocks in the Papuk and Krndija Mts. and by the Late Cretaceous igneous and sedimentary rocks in the Požeška Gora Mt. (Fig. 1).

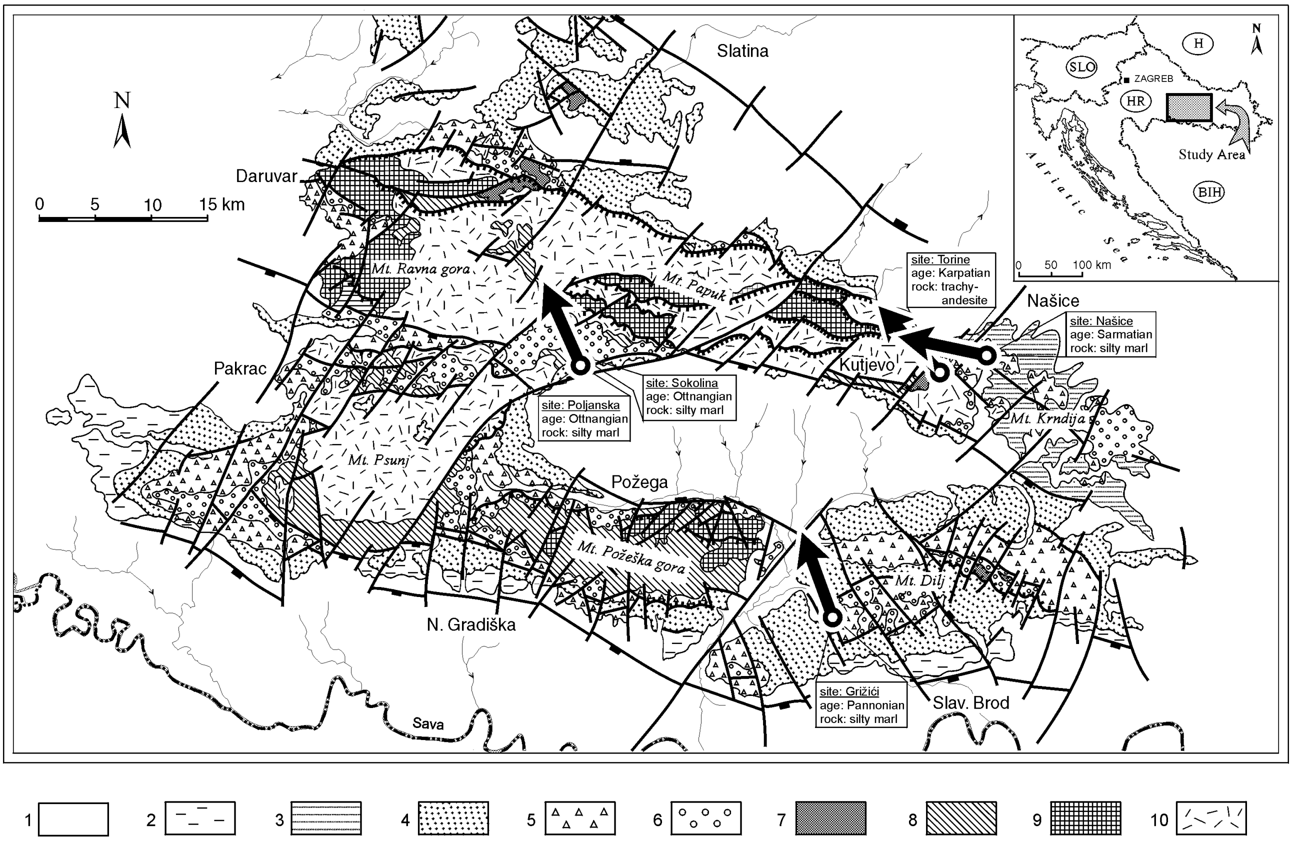

Fig. 1. Simplified geological map of the Slavonian Mountains area based on data of the Geological Map of the Republic of Croatia 1:300,000 (Institute of Geology, Zagreb, Croatia, 1997). Legend: 1 — Quaternary and Quaternary-Pliocene sedimentary rocks; 2 — Dacian-Romanian Paludina Beds; 3 — Miocene-Pliocene sands and clays; 4 — Pontian clastics with coal seams; 5 — Early Sarmatian-Pannonian limestones and clastics; 6 — Badenian Lithotamnium limestones, clastics, volcanics and pyroclastics; 7 — Karpatian-Badenian larger volcanic bodies, basalts, trachyandesites and rhyolites; 8 — Ottnangian-Karpatian carbonate and clastic sedimentary rocks; 9 — Mesozoic sedimentary and igneous rocks; 10 — Paleozoic metamorphic rocks, migmatites and granites.

In the Tertiary fill of the Slavonian part of the South Pannonian Basin the following formations can be distinguished: 1) Ottnangian–Karpatian clastic and carbonate sedimentary rocks; 2) Karpatian–Badenian volcanic rocks represented by basalts, trachyandesites, andesites and rhyolites; 3) Badenian lithotamnium limestones, clastic, volcanic and pyroclastic rocks, mainly of andesite-basalt composition; 4) Early Sarmatian-Pannonian limestones and clastics; 5) Pontian clastic sediments with coal-seams; 6) Miocene–Pliocene sands and clays and 7) Dacian and Romanian coarse to fine-grained clastics. These formations are unconformably overlain by Plio-Quaternary and Quaternary clays, sands and gravels of alluvial, eolian and deluvial origin.

Geological setting and the paleomagnetic sampling localities

North of the northern margin of the Dinarides, which emerged in Late Eocene/Oligocene times, numerous isolated deep to shallow water, marine, brackish to freshwater basins originated (Paratethys). In some parts of the present Pannonian Basin clastic sedimentation started in these isolated basins during the Oligocene transpression phase. In the study area, there are not sufficient observations to support the occurrence of the Oligocene formations. Most recently, however, Oligocene andesites, dacites and pyroclastic rocks have been quite positively identified at the base of the Neogene formations of the Drava Depression (Pamić 1997). On the basis of oil well data K. Kalac (pers. comm. 1998) is of the opinion that Oligocene sedimentary rocks are also present in this depression.

In the area of the Slavonian Mountains, the Early Miocene basin evolution started after the Oligocene transpression phase. The Miocene rift formations are characterized by different lithologies originating in different, tectonically unstable environments.

Sedimentation of breccias, alluvial conglomerates and sands over subsided Paleozoic, Mesozoic and Paleogene formations started in the Ottnangian. Penecontemporaneous salina-type lake existed only locally, and silty sediments, as at the site Poljanska (Fig. 1) associated with some coarse-grained clastics and pyroclastics were deposited in them (Ščavničar et al. 1983). The whole area of the Slavonian Mountains was affected by further subsidence which gave rise to a freshwater lake development in which marls, clays, silts, (e.g. site Sokolina — Fig. 1), sands and gravels, accu-

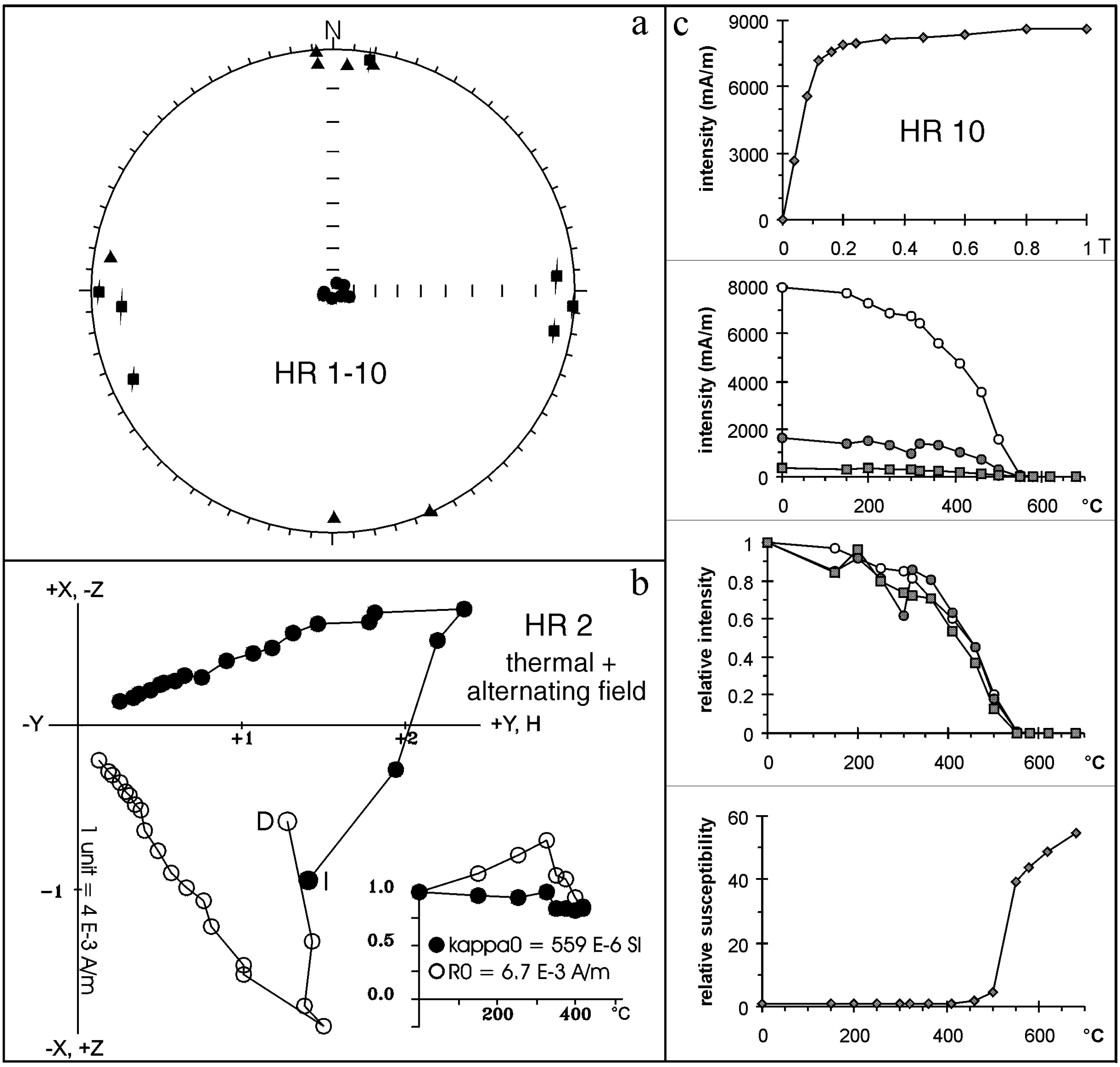

Fig. 2. Poljanska: **a** — Stereographic plot of principal axes of anisotropic susceptibility (full squares: maximum axis, full triangles: intermediate axis, full circles: minimum axis). **b** — Modified demagnetization (Zijderveld) plot showing directional (D: declination, I: Inclination) as well as intensity (R) and susceptibility (kappa) (see inset) changes for specimen HR 2 during thermal demagnetization. **c** — Uppermost box: IRM — (Isothermal Remanent Magnetization) acquisition curve of specimen HR 10. Underlying two boxes: Thermal demagnetization curves of a 3-component IRM (same specimen). Symbols are as follows: hollow circles: low; full circles: medium, full squares: high coercivity component. Lowermost box: Susceptibility changes during demagnetization (same specimen).

mulated. The lake was probably deep and hydrologically open (Pavelić 1991). Possibly, due to a connection with the Mediterranean Sea (Rögl & Steininger 1983) a new marine regime started during the Karpatian, in which marls, sands and gravels accumulated. In the area of Krndija Mt. comparatively large masses of trachyandesites erupted (site Torine — Fig. 1) during this period (Pamić et al. 1992/1993). At the end of the Karpatian, mainly sands were deposited in shallow water environments.

At the beginning of the Badenian, sedimentation of sands and gravels continued which, however, owing to subsequent transgression, changed into marls, calcarenites and gravels typical of offshore environments (Pavelić 1991). In several areas submarine volcanic activity is indicated by the common interlayering of pyroclastic rocks with sediments.

The Sarmatian is characterized by the predominance of marls (e.g. site Našice — Fig. 1), and limestones with sporadic interlayering of sands and silts, all related to environments that turned from marine into brackish (Korolija & Jamičić 1989; Jamičić et al. 1987; Šparica et al. 1987).

In the Pannonian, the environment became "caspibrackish" and more freshwater, characterized by deposition of shallow water limestones which are overlain by younger, deep water marls (e.g. site Grižići — Fig. 1), (Šparica et al. 1980). Similar sedimentary environments existed during the Early Pontian. In the Late Pontian, during the main filling phase of the Pannonian Basin, sands, clays and gravel were deposited. Freshwater sedimentation prevailed during the Pliocene (Jamičić et al. 1987; Šparica et al. 1980, 1987; Korolija & Jamičić 1989).

Paleomagnetic sampling and laboratory procedure

From the above mentioned five localities, 45 paleomagnetic samples were drilled in the field and magnetically oriented in situ. From each core, one or more standard-size (one inch diameter, two cm long) specimens were cut. The natural remanent magnetization (NRM) and the susceptibility of each specimen were measured on Cryogenic and JR-4 magnetometers and KLY-2 Kappabridge, respectively. These measurements were followed by stepwise demagnetization of the NRM, either by the AF (alternating field) or thermal method or the combination of the two, until the magnetic signal was lost. Additional magnetic measurements were carried out for the identification of the magnetic minerals, such as Curie temperature measurements, IRM (isothermal remanent magnetization) acquisition experiments and thermal demagnetization of a three-component IRM (method published by Lowrie 1990). The anisotropy of magnetic susceptibility was measured for two localities.

Paleomagnetic results

The locality at Poljanska (Fig. 1) yielded an excellent paleomagnetic result. After the removal of an overprint component by demagnetization, a single component remanence was obtained (Fig. 2b) which is of reversed polarity. The carrier of this remanence is magnetite as shown by the IRM demagnetization characteristics (Fig. 2c). The locality mean paleomagnetic direction is well-defined (Table 1). All the mineral magnetic properties as well as the anisotropy of the susceptibility (Fig. 2a) suggest that the characteristic remanence is primary. Therefore, it is the tilt-corrected paleomagnetic direction (Table 1 and Fig. 5) which we will interpret in terms of tectonics.

Study of samples from the locality at Sokolina (Fig. 1) was unsuccessful, probably, because the rock has not retained its original magnetization (the NRM directions are widely scattered and the NRM is lost already on moderate demagnetization).

Sampling in the Našice Quarry (Fig. 1) required special care because the available outcrops showed clear signs of weathering (yellow staining). The grey coloured samples which were eventually taken were seemingly fresh. Nevertheless, the NRM turned out to be very weak and only a few samples could be used to define the characteristic magnetization (Table 1). The magnetic minerals present are pyrrhotite and hematite as shown by the thermal demagnetization curve(s) of the three-component IRM (Fig. 4c).

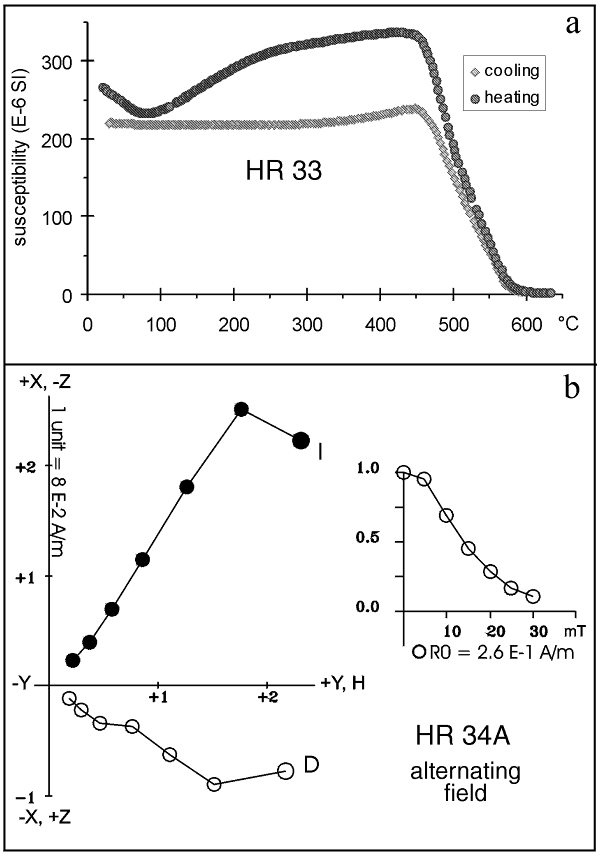

Fig. 3. Torine: **a** — Susceptibility versus temperature curve showing a Curie-temperature of 575 °C for specimen HR 33. **b** — Modified AF — (Alternating Field) demagnetization (Zijderveld) plot showing directional as well as intensity changes during demagnetization of specimen HR 34A.

Table 1: Paleomagnetic results. Locality mean paleomagnetic directions before (D°, I°) and after tilt correction (D_C°, I_C°) with statistical parameters (k, α_{95}°, Fisher 1953). n/no number of used/collected samples on which the calculation of the overall mean is based. Remark **a**: locality mean direction is based on fully demagnetized samples and the results of component analysis (Kent et al. 1983), remark **c**: locality mean direction is based on the combination of stable end points and remagnetization circles (McFadden & McElhinny 1988).

Slavonian Mountains

	locality	n/no	D°	I°	k	α_{95}°	D_C°	I_C°	k	α_{95}°	dip	Remark
1	Poljanska HR 1-10, Ottnangian	10/10	146	-24	363	3	156	-41	363	3	108/23	a
2	Našice HR 17-28, Sarmatian	5/12	282	65	43	12	223	+55	43	12	178/33	c
3	Torine HR 29-35, Karpatian	7/7	137	-54	130	5	137	-54	130	5	-	a
4	Grižići HR 36-45, Pannonian	9/10	344	+50	36	9	340	67	36	9	170/17	a

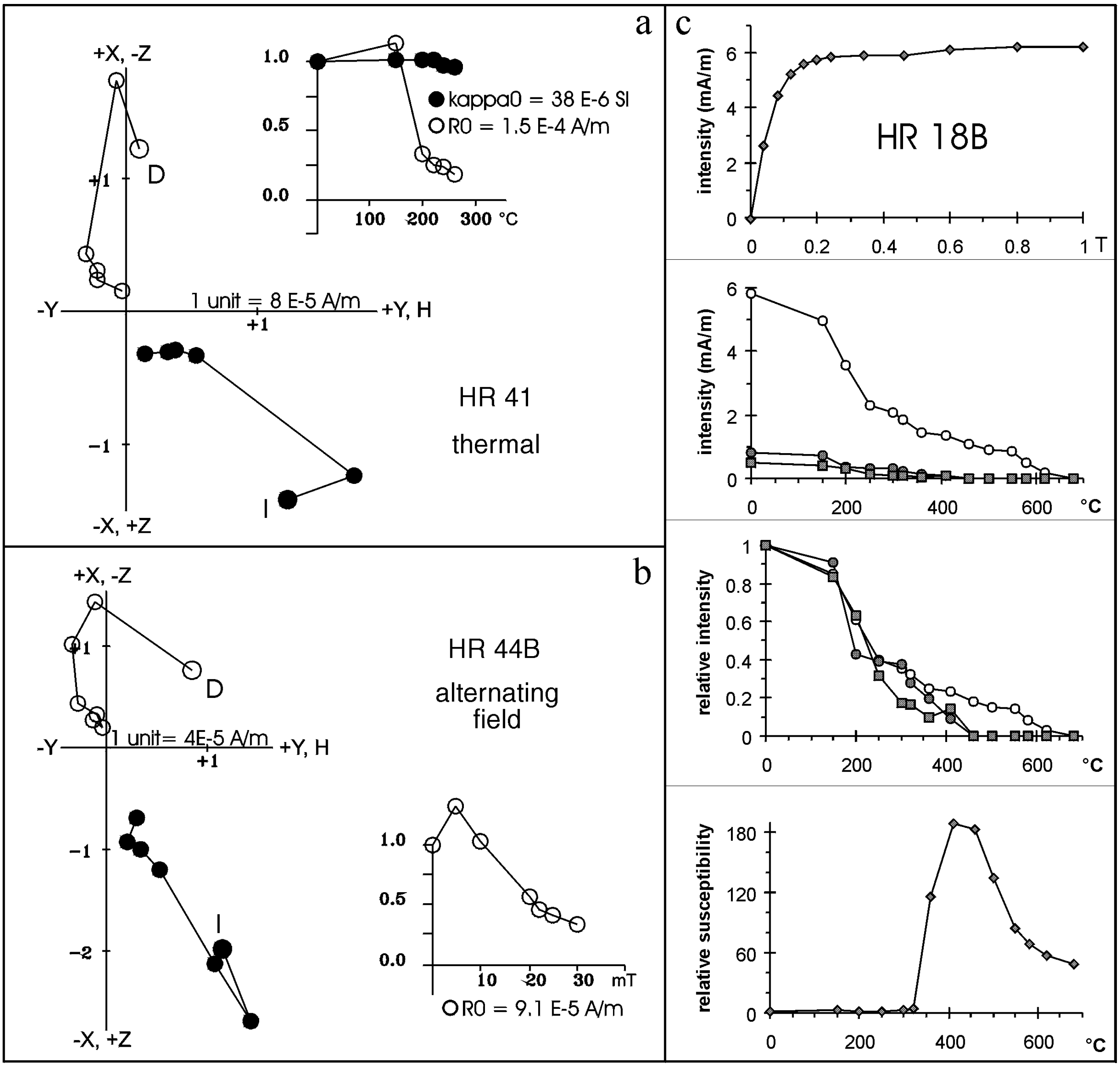

Fig. 4. Grižići and Našice. **a** — As in Fig. 2b for specimen HR 41. **b** — As in Fig. 3b for specimen HR 44B. Specimens HR 41 and HR 44B are from Grižići. **c** — As in Fig. 2 c for specimen HR 18B from Našice.

Site Torine (Fig. 1), the only igneous site collected, gave similarly well-defined paleomagnetic direction as Poljanska. The AF-demagnetization behaviour is essentially that of a single-component remanence (Fig. 3b). The Curie-temperature curve (Fig. 3a) shows that the remanence carrier is magnetite.

Site Grižići (Fig. 1) also gave meaningful result, though the samples were weakly magnetized and easily demagnetized (Fig. 4a,4b).

Discussion and conclusions

From the paleomagnetic localities of the present study, Poljanska and Torine are of excellent quality and both show moderate but significant counterclockwise rotation. The quality and precision of the Našice result are much poorer and, in addition, it is only consistent with Poljanska and Torine if Našice is not corrected for tectonic tilt, i.e. with the assumption that the remanence is younger than the tilting. However, since Našice is strongly tectonized, the secondary nature of the remanence, which is carried by pyrrhotite, is very likely. Grižići is also rotated to some extent irrespective of the direction being taken before or after tilt correction and the sense of rotation is as above.

Although the general trend of the paleomagnetically indicated rotations is counterclockwise, the mean paleomagnetic directions are statistically different from one another. The largest rotation was observed for Našice, somewhat smaller for Torine and the rotation angle is even smaller for Poljanska and Grižići. Obviously, these differences stem from local effects and cannot be attributed to decreasing the angle of rotation with time. The rotation of the Slavonian Mountains is con-

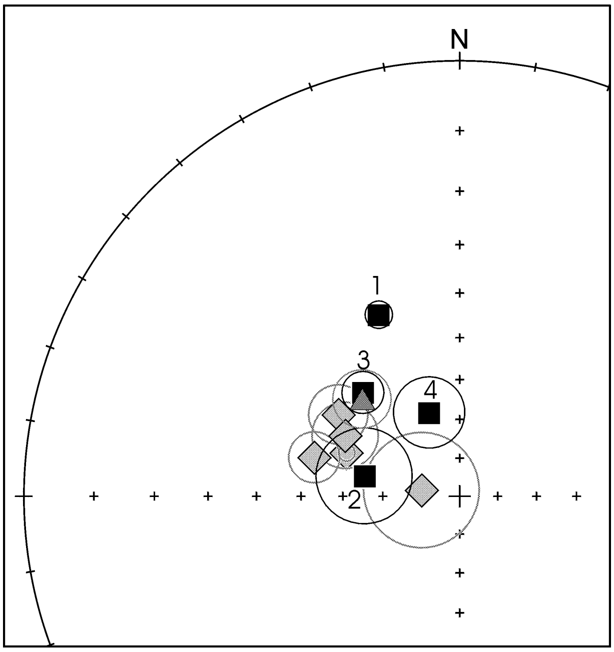

Fig. 5. Comparison of paleomagnetic directions with confidence circles from the Slavonian Mountains (numbered, see Table 1), from the ignimbrite of Sárszentmiklós (triangle, Márton & Márton 1989) and from the ignimbrites of the northern margin of the Mecsek Mountains (grey diamonds, Márton & Márton, in preparation). Stereographic projection, all inclinations are positive.

strained by the Našice result to have taken place after the Sarmatian. The moderate rotation of Grižići is just an indication that the rotation can be, at least partly, post-Early Pannonian.

Similar counterclockwise rotations were observed recently for the Tertiary of the northern margin of the Mecsek Mountains (Márton & Márton, in prep.), and earlier for a single isolated occurrence of Tertiary ignimbrite in the Mid-Hungarian Mobile zone, further to the north (Márton & Márton 1989).

The observations of counterclockwise rotations in these areas are somewhat surprising since both the Mecsek and the Slavonian Mountains are thought to be parts of the Tisza megatectonic province which has been thought of as a single tectonostratigraphic unit in the Tertiary (Kovács et al. 1988) and a unit that must have rotated in the clockwise sense in post-Cretaceous times (e.g. Márton 1986; Balla 1986; Pătraşcu et al. 1994).

As for the tectonics of the Slavonian Mts., they form a horst between the Drava (North) and Sava (South) basins. These basins were formed as a result of a general N-S compression during the Neogene (Bergerat & Csontos 1988; Bergerat 1989) which was accommodated by movements along NW–SE trending, dextral strike-slip faults during the Neogene and Quarternary (e.g. Jamičić 1988; Royden 1988). The dextral strike-slip movements led to an overall transpression in the intervening area (Slavonian Mts.) which was accompanied by clockwise rotations, en-echelon folding and formation of a Riedel-type conjugate fault system, consisting of NW-SE striking dextral and NE-SW striking sinistral faults (Jamičić 1995). According to Jamičić (1988, 1995) most movements occurred along the sinistral set of faults which should have caused an overall counterclockwise rotation as well as folding of the fault-separated blocks leading eventually to a reduction of the width of the area between the Drava and Sava rivers.

In the Hungarian part of the South Pannonian Basin, the counterclockwise rotations seem to be older than in the Croatian part (Márton & Márton in prep.). Thus the northern margin of the Mecsek Mts. and the Slavonian Mts. must have moved independently, despite of the similar sence and magnitude of rotations.

Contrary to what was found for the northern margin of the Mecsek Mts. the paleomagnetic study of the Tertiary in the main body of the Mecsek Mts. revealed clockwise rotations, that must have occurred during the Pannonian. The event of clockwise rotation in the Mecsek may be correlated with an intra-Pannonian compressional event which has been documented recently by Benkovics (1997).

It has been shown very recently by Tari-Kovačić & Pamić (1998), that compressive tectonics took place in the whole South Pannonian Basin at the beginning of the Pliocene. Reflection seismic data indicate that some units of the Northern Dinarides are thrust over the Tisza megaunit, at about 5–6 Ma or later. This is a new tectonic regime which reflects an increase of intraplate compressional stress producing localized deformations and broad buckling and uplift of the Pannonian Basin. The deformation phase is probably an expression of the persisting convergence of Africa–Arabia and Europe.

Acknowledgements: The fieldwork was financed by a joint project of the Academies of Sciences of Croatia and Hungary. Additional support was provided by the Hungarian Scientific Research Fund (OTKA), Project No. T 01708.

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