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STRUCTURAL ROTATIONS FROM PALEOMAGNETIC DIRECTIONS OF SOME PERMO-TRIASSIC RED BEDS, HUNGARY

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Oriented samples of Permo-Triassic red beds were collected at five localities in the Balaton Highlands, one locality in the Bükk Mountains, and two localities in the Mecsek Mountains. The objective was to obtain paleomagnetic directions, and poles calculated therefrom, for the evaluation of possible structural rotations for these different tectonic blocks.

Statistically well defined paleomagnetic directions were obtained following stepwise thermal cleaning and the analysis of measured and removed remanence at each step for four localities in the Balaton Highlands (normal polarity) and for two localities in the Mecsek Mountains (reversed polarity).

The directions depart significantly from the present field direction indicating an ancient remanence. However the carriers of the magnetization appear complex and may contain post-folding as well as pre-folding components of magnetization. Nonetheless, tilt-corrected directions that support the results of an earlier paleomagnetic study indicate that Balaton Highlands are rotated about 50° in a counter-clockwise sense with respect to the Mecsek Mountains (Mecsek Mountains Decl. 177.4°, Incl. −5.0°, reversed polarity; Balaton Highlands, Decl. 307.2°, Incl. 11.0°, normal polarity).

Comparison is made with paleomagnetic results from rocks of comparable age in the Mediterranean area.

Keywords: palaeomagnetism, complex magnetization, thermal demagnetization, structural rotation, central Mediterranean

1. Introduction

From the viewpoint of plate tectonics, Hungary belongs to the tectonically complicated Mediterranean region. Paleomagnetic measurements have already shown that even a small area, such as that of Hungary, can be subdivided into terranes that have had different rotational histories arising from Alpine orogenesis [MÁRTON–MÁRTON 1978, 1980].

In view of the lack of fully oriented drill cores, paleomagnetic studies for tectonic analysis have been restricted to the sampling of outcrops. Results of this work have shown that minimum two units lie west of the River Danube

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(Transdanubia), one including the Transdanubian Central Range*, and the other including Southeast Transdanubia comprising the Mecsek Mts. and Villány hills.

East of the Danube River, we have only a very limited knowledge of the subdivision and the history of rotations. Outcrops of rock older than Pannonian age are found in the North Hungarian Mountain Range. The paleomagnetic directions known from that area [Márton 1980/a, Márton 1981, Márton 1983] lead to the conclusion that at least certain parts of the North Hungarian Mountain Range were rotated in a counter-clockwise sense prior to occupying their present position. Thus the North Hungarian Mountain Range could have moved in coordination with the Transdanubian Central Range, but the estimate of the duration and the degree of the coordination cannot yet be made.

The paleomagnetic technique has been most commonly applied for continental-scale tectonic studies. Each continent has a unique apparent polar wandering path (successive determinations of the position of the magnetic poles relative to a continent), which represents its movements relative to the Earth's axis of rotation. Because the paths represent the movements of continents with respect to one another, the past positions of the continents can be reconstructed by matching polar wander curves. This principle can be applied across all levels, because not only the major continents, but even small tectonic units can have unique polar paths. Eventually, we should be able to reconstruct the relative motions of the Mediterranean fragments, although the recognition of the paleomagnetically different units and the construction of their respective polar paths will be a long process. Nevertheless, each new determination contributes to the general solution, and at the same time places new constraints on any plate-tectonic reconstruction model.

Paleomagnetically, the Permian Period is poorly defined in Hungary. We decided to attack the problem of determining paleomagnetic poles from fine-grained clastic red beds by joining forces. The method developed in the United States on collecting suitable samples and isolating the remanence residing in detrital hematite [for example, Elston–Purucker 1979], was integrated with experience accumulated in Hungary on analyzing complex magnetizations in general [Márton 1980/b, Márton 1984], and unraveling of multi-component remanence of red limestones in particular [Márton et al. 1980].

2. Sampling and laboratory treatment

In 1982, we collected samples at five localities in the Balaton Highlands (part of the Transdanubian Central Range), one locality in the Bükk Mountains (North Hungarian Mountain Range), and two localities in the Mecsek Mountains (Southeast Transdanubia, *Fig. 1*).

* In an attempt to unify geographical names, the editors use "Transdanubian Central Range" in accordance with former usage of Geophysical Transactions. The authors used "Transdanubian Central Mountains", and in some references it appears as "Transdanubian Middle Mountains"

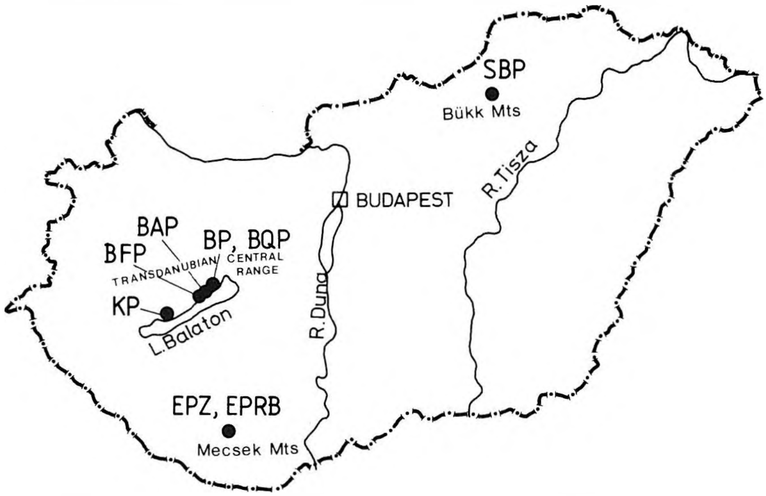

Fig. 1. Sampling localities in Permo-Triassic red beds of Hungary
Balaton Highlands: *BP* — Balatonalmádi, Vadvirág utca;
BQP — Balatonalmádi, quarry; *BAP* — Balatonarács; *BFP* — Balatonfüred; *KP* — Kővágóörs
Mecsek Mountains: *EPZ* — Egédpuszta; *EPRB* — Boda
Bükk Mountains: *SBP* — Szilvásvárad, Bácsóvölgy

1. ábra. Permo-triász vörös üledékek mintavételi helyei Magyarországon
Balatonfelvidék: *BP* — Balatonalmádi, Vadvirág utca; *BQP* — Balatonalmádi, kőfejtő;
BAP — Balatonarács; *BFP* — Balatonfüred; *KP* — Kővágóörs
Mecsek hegység: *EPZ* — Egédpuszta; *EPRB* — Boda
Bükk hegység: *SBP* — Szilvásvárad, Bácsóvölgy

Рис. 1. Места взятия образцов пермо–триасовых красноцветных отложений в Венгрии
Прибалатонске горы: *BP* — с. Балатоналмады, улица Вадвираг; *BQP* — с. Балатоналмады, карьер; *BAP* — с. Балатонарач; *BFP* — г. Балатонфюред; *KP* — с. Кёвагоёрш
Мечекские горы: *EPZ* — Эгедпуста; *EPRB* — с. Бода
Горы Бюкк: *SBP* — Силвашварад, дол. Бачо

The remanence and the susceptibility of each sample was measured in the natural state. Pilot samples, selected to represent each of the localities, were partially cleaned by stepwise heating and cooling in a magnetically field-free space. The remanence and the susceptibility were measured after each step.

The pilot studies indicated that the natural remanence cleans readily, i.e., the plot of the vectors trace as lines that project to the origins of orthogonal demagnetization diagrams at an early stage of the demagnetization analysis *(Figs. 2a, 2c, 3a, 3c, 4a, 4c)*. All pilot samples exhibited decreases in susceptibility at moderate temperatures *(Figs. 2b, 2d, 3b, 3d, 4b, 4d)* due to the conversion of maghemite to the stable mineral hematite. In some pilot samples, the susceptibility remained unchanged on further heating *(Figs. 2b, 2d, 3b, 4b)*, whereas in other samples the susceptibility increased abruptly *(Figs. 3d, 4d)* indicating the formation of a new magnetic phase. Increases in susceptibility were accompanied by the onset of spurious magnetizations *(Figs. 3c, 4c)*, i.e., the end points of the magnetic vectors that formerly plotted as straight line traces (slight deviations from a line being permitted), became erratic.

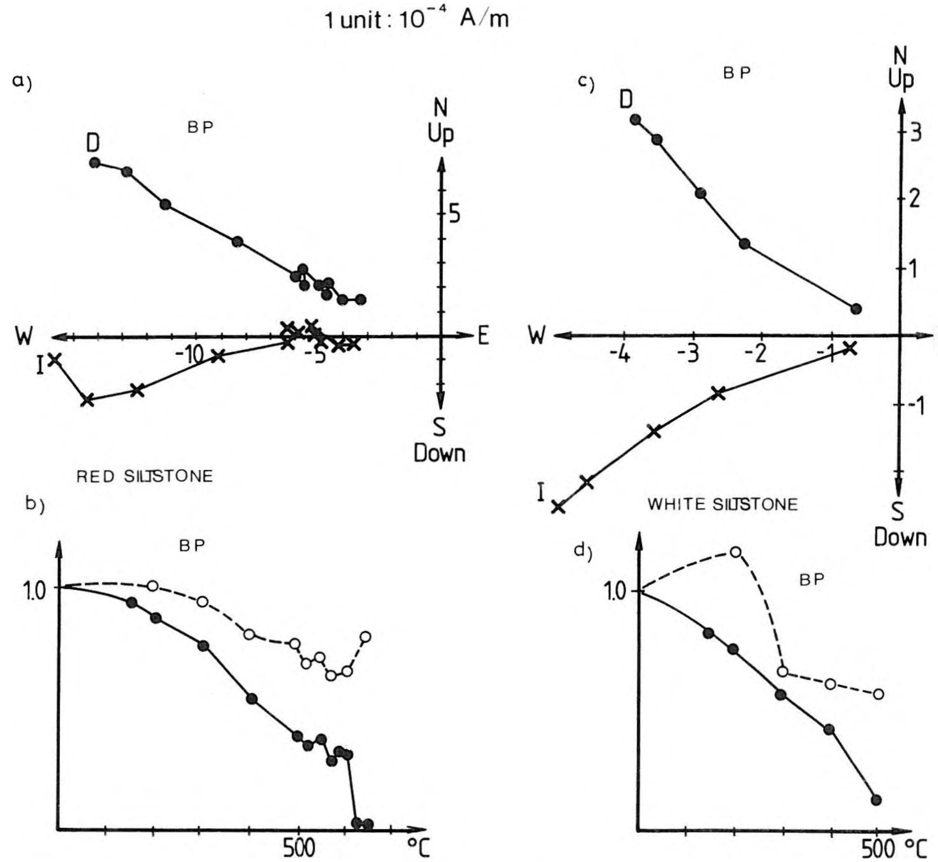

Fig. 2. a) and *c)*. Orthogonal plots of the change in direction and intensity of the natural remanence on stepwise heating: *D*, declination; *I*, inclination
b) and *d)*. Change of the intensity (solid circle) and the susceptibility (open circle) on stepwise heating, both normalized with respect to initial values

2. ábra. a) és *c)*. A természetes remanens mágnesezettség irányának és intenzitásának változása lépcsőzetes hőkezelésre: *D*, deklináció, *I*, inklináció. Ortogonális vetületek
b) és *d)*. A kezdeti értékre normalizált intenzitás (teli körök) és a szuszceptibilitás (üres körök) változása lépcsőzetes hőkezelésre

Рис. 2. a) и *c)*. Изменение направления и интенсивности естественной остаточной намагничанности при ступенчатой термообработке: *D* — склонение, *I* — наклонение. Ортогональные проекции
b) и *d)*. Изменение отнесенных к исходным значениям интенсивности (полные круги) и восприимчивости (пустые круги) при ступенчатой термообработке

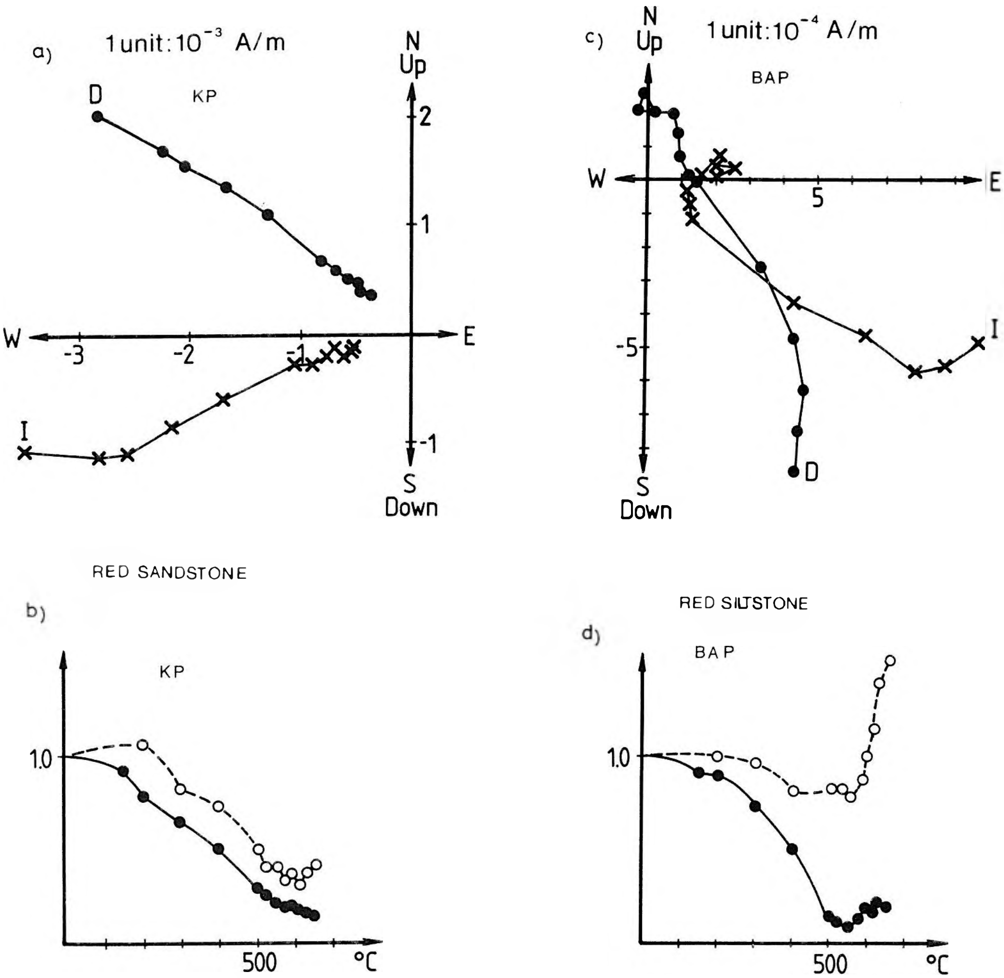

Fig. 3. a) and *c).* Orthogonal plots of the change in direction and intensity of the natural remanence on stepwise heating: *D*, declination; *I*, inclination
b) and *d).* Change of the intensity (solid circle) and the susceptibility (open circle) on stepwise heating, both normalized with respect to initial values

3. ábra. a) és *c).* A természetes remanens mágnesezettség irányának és intenzitásának változása lépcsőzetes hőkezelésre: *D*, deklináció, *I*, inklináció. Ortogonális vetületek
b) és *d).* A kezdeti értékre normalizált intenzitás (teli körök) és a szuszceptibilitás (üres körök) változása lépcsőzetes hőkezelésre

Рис. 3. а) и *с).* Изменение направления и интенсивности естественной остаточной намагниченности при ступенчатой термообработке: *D* — склонение, *I* — наклонение. Ортогональные проекции
b) и *d).* Изменение отнесенных к исходным значениям интенсивности (полные круги) и восприимчивости (пустые круги) при ступенчатой термообработке

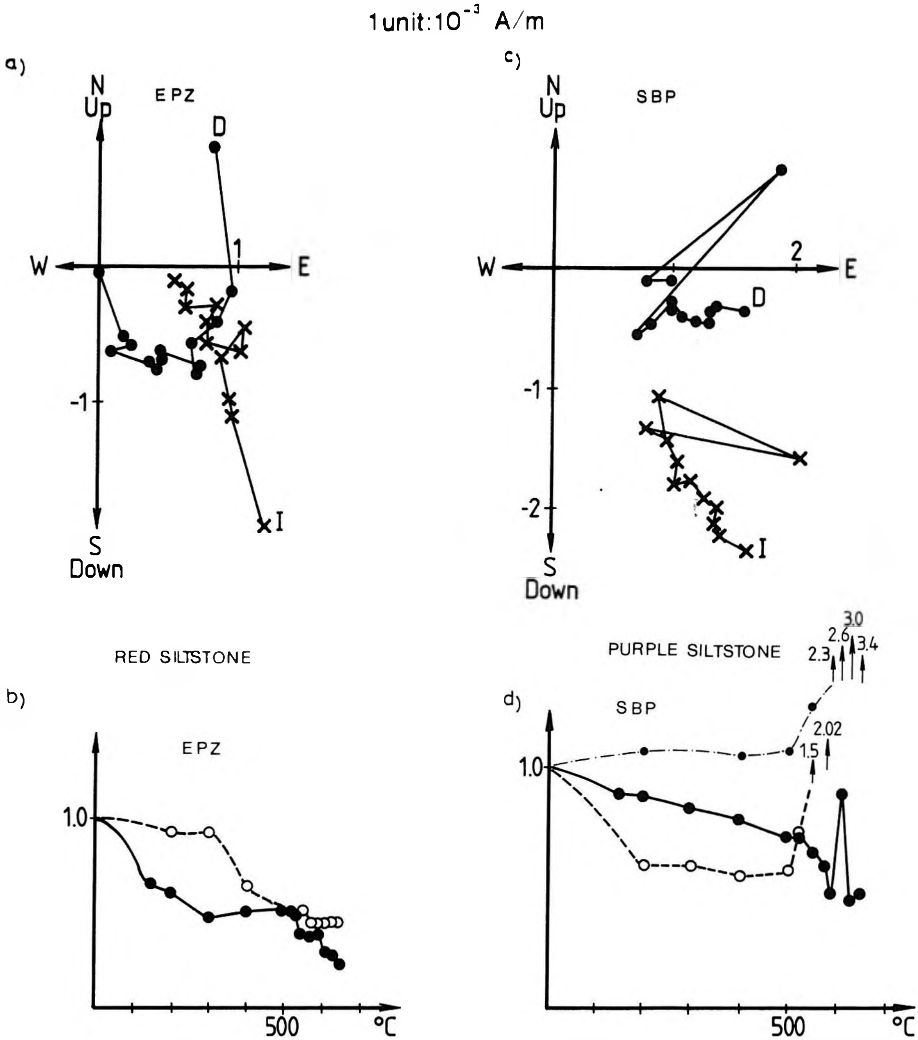

Fig. 4. a) and *c)*. Orthogonal plots of the change in direction and intensity of the natural remanence on stepwise heating: *D*, declination; *I*, inclination
b) and *d)*. Change of the intensity (solid circle) and the susceptibility (open circle) and the degree of susceptibility anisotropy (small dots in Fig. 4d) on stepwise heating, all normalized with respect to initial values

4. ábra. a) és *c)*. A természetes remanens mágnesezettség irányának és intenzitásának változása lépcsőzetes hőkezelésre: *D*, deklináció, *I*, inklináció. Ortogonális vetületek
b) és *d)*. A kezdeti értékre normalizált intenzitás (teli körök) és a szuszceptibilitás (üres körök), valamint a szuszceptibilitás anizotrópia fok (pontok a 4/d ábrán) változása lépcsőzetes hőkezelésre

Рис. 4. a) и *c)*. Изменение направления и интенсивности естественной остаточной намагниченности при ступенчатой термообработке: *D* — склонение, *I* — наклонение. Ортогональные проекции
b) и *d)*. Изменение отнесенных к исходным значениям интенсивности (полные круги) и восприимчивости (пустые круги), а также степени анизотропии восприимчивости (точки на рис. 4/d) при ступенчатой термообработке

Optimum cleaning temperatures for the individual collections were selected based on the behavior of the pilot samples. The following criteria were used:

1) the remanence becomes single-component, with intensities adequate for measurement;
2) magnetization residing in undesirable magnetic minerals, such as maghemite and hydrated iron oxides, is removed;
3)new mineral phases with high susceptibilities are not formed.

All samples were cleaned at the optimum temperatures selected for the individual localities, and commonly at lower and higher temperatures than optimum, as well.

Stable directions: Partial demagnetization of the samples at the optimum temperatures yielded statistically well-defined directions for two sample groups from the Mecsek Mountains (*EPZ* and *EPRB*, Fig. 1) and for one group from the Balaton Highlands *(BP*, Fig. 1 and *Table I)*. These groups are designated as reliable in the traditional sense.

Sites *BQP* from the Balaton Highlands and *SBP* from the Bükk Mountains (Fig. 1) exhibited large scatter at all cleaning temperatures. Thus, they are useless for tectonic evaluation.

The traditional approach of isolating a stable direction failed for three sample groups from the Balaton Highlands. We found, however, that the remanences of sites *BAP* and *BFP* (Fig. 1) are statistically well defined and plot away from the present field direction at lower than optimum temperatures *(Fig. 5)*. We could even improve the statistics of the groups by calculating the locality means from subtracted vectors (removed remanence) instead of the measured ones (Table I). The demagnetization analysis indicates that the "meaningful" signal in these rocks resides in the metastable mineral maghemite rather than in hematite.

Subtracted vectors proved to be extremely useful for locality *KP*. The measured vectors here exhibit a great-circle distribution throughout, i.e., the overprint along the present field direction could not be removed. Examination of the subtracted vectors, however, revealed two components of the composite magnetization: one plotting close to and the other plotting well away from the present field direction *(Fig. 6)*. The locality mean direction, of course, was calculated from the directions that lay well away from the present field (Table I).

Sampling location	Code	N/N_0	$\bar{D}^0$	$\bar{I}^0$	k	α_{95}	$\bar{D}^0_c$	$\bar{I}^0_c$	Cleaning	Remarks
Balaton Highlands										
Balatonalmádi	*BP1*	20/20	323	49	21	7.8	319	9	500 °C	red siltstone + with marl, maghemite decays below 500 °C
Balatonfüred	*BFP1*	9/9	308	29	15	13.8	295	0	400 °C	scatter too large abowe 400 °C,
	BFP1	9/9	301	24	53	7.1	293	−8	subtracted vectors 400–500 °C	maghemite decays below 400 °C
Balatonarács	*BAP1*	29/29	327	55	14	7.3	309	21	NRM subtracted vectors	scatter too large at 525 °C
	BAP1	29/29	322	53	25	5.7	307	18	NRM — 525 °C	no explanation for the scatter
Kővágóörs	*KP1*	8/12	309	47	113	4.9	310	24	subtracted vector 400–500 °C	maghemite decays at 525 °C
Mecsek Mountains										
Egédpuszta	*EPZ1*	11/11	167	−20	35	6.1	185	−10	525 °C	maghemite decays below 525 °C
Boda	*EPRB1*	17/17	188	−31	25	9.8	170	0	500 °C	maghemite decays at 500 °C

N_0 – number of samples collected
N – number of useful samples
$\bar{D}^0$ – mean paleomagnetic declination in the present system of coordinates
$\bar{I}^0$ – mean paleomagnetic inclination in the present system of coordinates
k – Fischer's precision parameter
α_{95} – radius of circle of confidence at 95 % probability level
$\bar{D}^0_c$ – mean paleomagnetic declination after tilt correction
$\bar{I}^0_c$ – mean paleomagnetic inclination after tilt correction

Table I. Summary of paleomagnetic results on Permo-Triassic red beds, Hungary

I. táblázat. A magyarországi permo-triász kőzeteken meghatározott paleomágneses irányok összefoglalása

Таблица I. Сводка палеомагнитных направлений, определенных на пермо-триасовых породах Венгрии

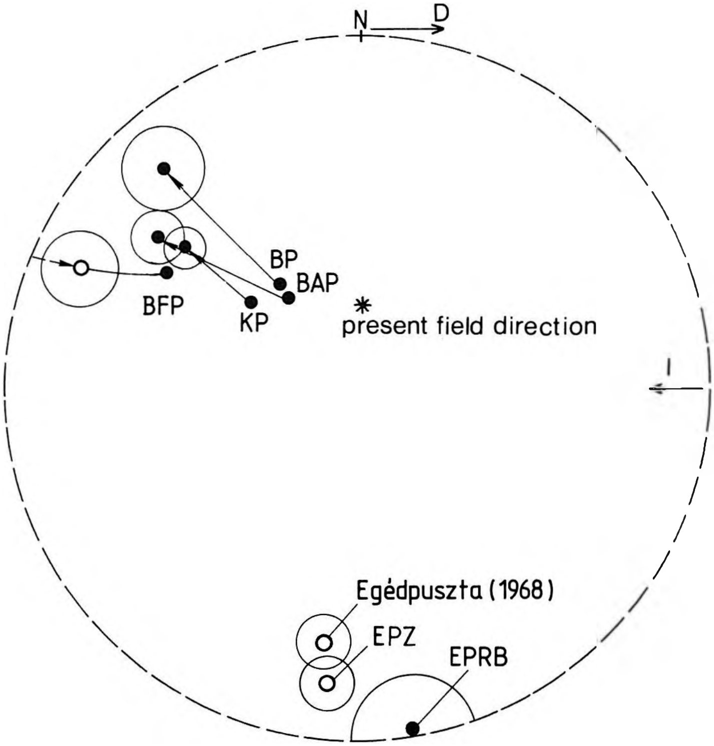

Fig. 5. Stereographic plot showing locality means after tilt correction (enclosed by circles drawn at the 95 percent confidence level). Sites from the Balaton Highlands without confidence circles are directions before correction for tilt. For labels refer to Fig. 1. An earlier result from Egédpuszta (same locality as *EPZ*) is show for comparison. Although the confidence circles are similar, the new result is an improvement, because the *k* value, indicating the degree of divergence of the vectors, is better for *EPZ* than for Egédpuszta, 1968

5. ábra. A mintavételi helyek dőlés-korrigált középirányai α_{95}-tel. A konfidencia körök nélküli középirányok a Balaton-felvidéki mintavételi helyek középirányai tektonikai korrekció előtt. A jelölések magyarázatára lásd 1. ábra. Összehasonlításképpen egy korábbi meghatározás eredményét is ábrázoltuk Egédpusztáról (*EPZ*-vel azonos mintavételi hely). Bár a konfidencia körök hasonlóak, az új eredmény mégis jobb minőségű, mint a régi, mert *k* értéke, amely a vektorok párhuzamosságát jellemzi, jobb *EPZ*-re, mint az Egédpuszta 1968-as meghatározásé

Рис. 5. Средние направления мест взятия образцов после внесения поправки за наклон с α_{95}. Средние направления без кругов доверия представляют собой средние направления мест взятия образцов Прибалатонских горах перед внесением тектонической поправки. Условные обозначения даны на рис. 1. Для сопоставления изображены также результаты прежнего определения с Эгедпуста (место одинаковое с *EPZ*). Хотя круги доверия похожи, новый результат все-таки отличается по качеству по сравнению со старым результатом, потому что значение *к*, которое обозначает параллельность векторов, лучше для *EPZ*, чем определение на Эгедпуста в 1968 г

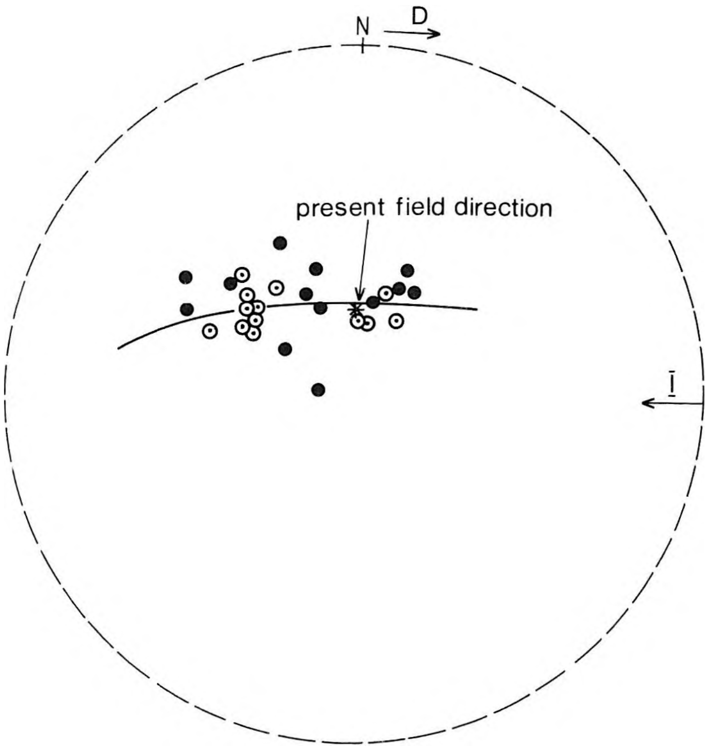

Fig. 6. Balaton Highlands, site *KP*. Stereographic plot showing measured vectors at 500 °C (solid circles) and removed vectors between 500 °C and 400 °C (points encircled)

6. ábra. Balaton-felvidék *KP* jelű mintavételi hely. Az 500 °C-os tisztítási lépésben mért (teli körök) és az 500 és 400 °C között elveszített (bekarikázott pontok) mágnesezettség irányai szögtartó vetületen

Рис. 6. Место взятия образца с обозначением *KP* в Прибалатонских горах. Приведены направления намагниченности, замеренной в шагу очищения в 500 °C (полными кругами) и потеренной между 500 и 400 °C (обведенные кружком точки), на стереографической проекции

3. Discussion

The locality mean directions for the statistically well defined groups are shown in Figure 5. The directions, corrected for local tilt, are plotted with their confidence circles at the 95 per cent probability level. As seen in Figure 5, all directions depart significantly from the present field direction, indicating high stability and an ancient age for the remanence no matter what the carrier of the magnetization is. Moreover, the locality mean directions from the Mecsek Mountains plot in a different part of the sphere than directions from the Balaton

Highlands. This latter observation supports the earlier conslusion of MÁRTON and MÁRTON [1978, 1980] that the Transdanubian Central Range and the Mecsek Mountains have undergone different rotations.

The foregoing conclusions are not influenced by the actual age of the magnetization, which we cannot demonstrate to be older than the tectonic phase responsible for the local tilts.

Unfolding, i.e. correction for local tilts, is one of the most powerful tests for establishing an early age for remanent magnetization. When the scatter in directions significantly increases on unfolding, the characteristic remanence postdates tilting of the strata. In contrast, if the scatter decreases significantly, the remanence is older than the folding. When a magnetization is sufficiently stable to survive a tectonic episode, there is a reasonable chance that the magnetization was acquired early, either during or shortly after accumulation of the strata.

The fold test was not conclusive for the sampled localities because neither a significant decrease nor an increase in scatter was observed on application of tilt corrections. One reason is that the differences in the local positions are small with respect to the uncertainty of the individual mean directions (as expressed in the value of α_{95}, see Table I). Alternatively, some of the localities may exhibit pre-folding remanences, whereas others may exhibit postfolding remanences.

Although a better control on the actual ages of the statistically well defined magnetizations is desirable, results from the present study are not inferior to results obtained from rocks of similar age elsewhere in the Mediterranean area.

Rotations of areas relative to their present positions, and with respect to other tectonic units, are best shown by declinations. The mean declination for the Balaton Highlands points to the western-southwestern connection of the Transdanubian Central Range, whereas the mean declination of the Mecsek Mountains points to an eastern–southeastern connection *(Fig. 7)*, similar to declinations for other than Permian rocks [MÁRTON 1984, 1985].

The actual age of the magnetization is not critical for the analysis of rotations because the declinations, corrected and uncorrected for tilt, are very similar. However, inclinations are more of a problem. The tilt-corrected inclinations fit the overall picture (Fig. 7), i.e., they are low and indicate that, as in other parts of the Mediterranean, the units sampled in Hungary accumulated at a near-equatorial latitude.

However, the inclinations obtained for the Balaton Highlands disagree with inclinations obtained from somewhat younger Hungarian strata to an extent that it appears to contradict their supposedly close geologic ages (late Permian and early Triassic). Moreover, even the highest corrected inclination (*KP1*, Table 1) is much lower than the inclinations obtained from Triassic marine strata (+38°, +41°, +35°, +35°, +33°, oldest Scythian, youngest Carnian) [MÁRTON–MÁRTON 1983]. In order to solve this problem, studies need to be continued in two directions. On the one hand, additional work is needed on red beds that display significantly different tilts. On the other hand, the possibility of the existence of an inclination error in the red beds will have to be investigated (and eliminated?) and the reason(s) for the existence of markedly different inclinations between the red beds and the somewhat younger gray marls elucidated and resolved.

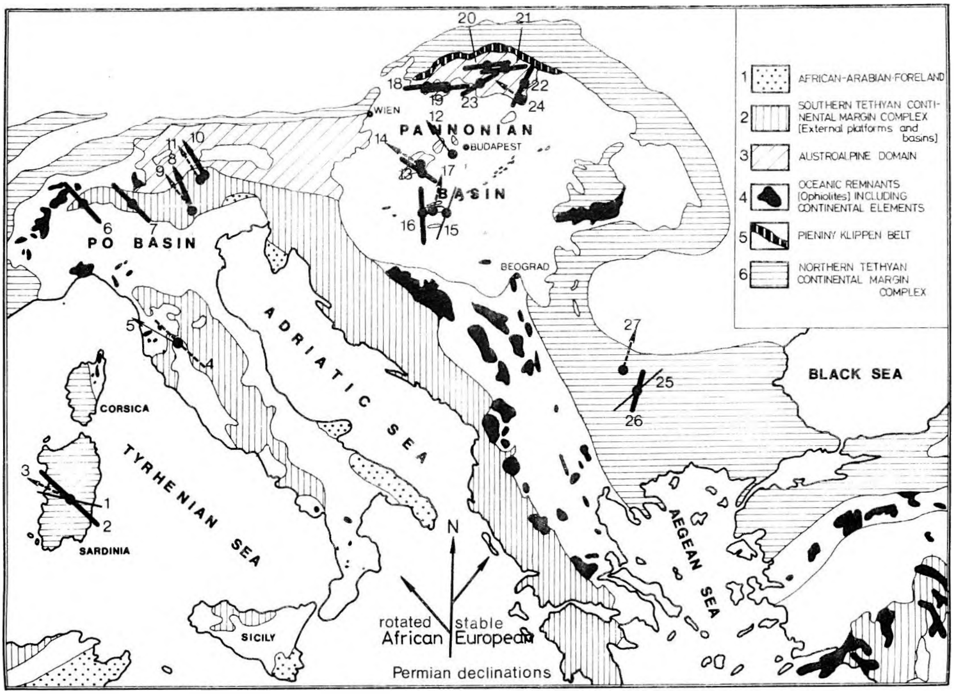

Fig. 7. Declinations measured on Carboniferous, Permian, and Triassic rocks of the Central Mediterranean.

References: 1. Edel et al. 1981; 2. Zijderveld et al. 1970 a, Westphal et al. 1976; 3. Horner–Lowrie 1981; 4. VandenBerg 1979; 5. VandenBerg–Wonders 1976; 6. Heiniger 1979; 7. Heiniger 1979; Zijderveld et al. 1970/b, Förster et al. 1975; 8. Zijderveld et al. 1970/b; 9. Manzoni 1970; 10. Manzoni 1970; 11. Manzoni 1970; 12. Márton 1984; 13. Present paper; 14. Márton–Márton 1983; 15. Márton 1984; 16. Present paper; 17. Márton, unpublished; 18–23. Krs et al. 1982; 24. Márton, unpublished; 25–27. Nozharov et al. 1980

7. ábra. A középső Mediterrán területről karbon, perm és triász kőzeteken meghatározott deklinációk irányai

1 — Afrikai–Arábiai előtér; 2 — a Tethis déli kontinentális szegély üledékei; 3 — Ausztro-alpi terület; 4 — óceáni maradványok (ofiolitok), kontinentális elemekkel; 5 — Pieniny szirtöv; 6 — a Tethis északi kontinentális szegély üledékei

Рис. 7. Направления склонения, определенные на породах карбона, перма и триаса со средней части бассейна Средиземного моря

1 — Афро-Арабский форланд; 2 — осадки южно-континентального борта Тетиса; 3 — Австро-альпийская территория; 4 — океанические остатки (офиолиты) с континентальными элементами; 5 — зона Пьенинских утесов; 6 — осадки северо-континентального борта Тетиса

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MAGYARORSZÁGI PERMO-TRIÁSZ VÖRÖS ÜLEDÉKEK PALEOMÁGNESES VIZSGÁLATA

MÁRTONNÉ SZALAY Emő és Donald P. ELSTON

Irányított mintákat gyűjtöttünk öt permo-triász vörös homokkő feltárásból a Balaton-felvidéken, egy feltárásból a Bükk hegységből és két feltárásból a Mecsek hegységből. Célunk az volt, hogy paleomágneses irányokat és pólusokat határozzunk meg, amelyek alkalmasak a különböző tektonikai egységek lehetséges rotációinak kiértékelésére.

Statisztikusan jól definiált irányokat sikerült meghatározni a Balaton-felvidék négy, a Mecsek hegység két feltárásából származó kőzetein több lépésben végzett termikus tisztítás és a mért és eltávolított remanencia elemzésének eredményeként.

Az irányok szignifikánsan eltérnek a mai tér irányától és ez a remanencia idős korát bizonyítja. Ennek ellenére a mágnesezettség hordozói komplexek és egyaránt lehetnek gyűrődés előttiek és utániak is. Mégis, a helyi dőléssel korrigált irányok, amelyek a korábbi paleomágneses eredményekkel összhangban vannak, azt mutatják, hogy a Balaton-felvidék kb. 50°-ot fordult el a Mecsek hegységhez képest (Mecsek hegység: deklináció: 177,4°, inklináció: −5,0°, fordított polaritás; Balaton-felvidék: deklináció: 307,2°, inklináció: 11,0°, normál polaritás).

A meghatározott irányokat összehasonlítjuk a Mediterrán területről ismert hasonló korú paleomágneses eredményekkel.

ПАЛЕОМАГНИТНОЕ ИССЛЕДОВАНИЕ ПЕРМО-ТРИАСОВЫХ КРАСНОЦВЕТНЫХ ОТЛОЖЕНИЙ В ВЕНГРИИ

Эмё МАРТОН и Доналд П. ЭЛСТОН

Ориентированные образцы были собраны из пяти обнажений пермо-триасовых красноцветных песчаников в Прибалатонских горах, из одного обнажения в горах Бюкк и двух обнажений в горах Мечек. Наша цель заключалась в определении палеомагнитных направлений и полюсов, которые позволяют оценить возможные вращения различных тектонических единиц.

Удалось определить статистически надежные направления на породах, езятых из четырех обнажений Прибалатонских гор и двух обнажений Мечекских гор, в результате ступенчатой термической чистки и анализа замеренной и удаленной при чистке остаточной намагниченности.

Направления характерно отклоняются от направления настоящего поля, что подтверждает дверность остаточной намагниченности. Несмотря на это, носители намагниченности являются сложными и могут происходить из доскладчатой или послескладчатой эпохи. Все-таки, направления, поправленные за местные наклоны, которые согласуются с прежними палеомагнитными результатами, показывают, что район Прибалатонских гор совершил поворот на ок. 50° по сравнению с Мечекскими горами (горы Мечек: склонение: 177,4°, наклонение: −5,0°, обратная полярность; Прибалатонские горы: склонение: 307,2°, наклонение: 11,0°, нормальная полярность).

Определенные направления были сопоставлены с палеомагнитными разультатамы для пород подобного возраста, которые известны в бассейне Средиземного моря.