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PALAEOMAGNETIC INVESTIGATIONS IN THE BIELE KARPATY MTS. UNIT, FLYSCH BELT OF THE WESTERN CARPATHIANS

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Abstract: Palaeomagnetic investigations into the Flysch Belt of the Western Carpathians of the present work were concentrated in the area of the Biele Karpaty Mts.. This area is formed by Campanian to Early Eocene flysch sequences, lying mostly in subhorizontal position. The samples were subjected to complex analyses of remanence and magnetic stability. With each sample Zijderveld diagrams were constructed and the multi-component analysis of remanence carried out. Fold tests of stability were applied to the separated remanence components. After final processing, 9 sites yielded samples of Late Senonian and 2 localities of Palaeocene sediments with suitable palaeomagnetic properties. With the use of Fisher's statistics (1953), the following was determined for the B-remanence components: the Late Senonian data corrected for the dip of rocks gave $k = 86.04$, $\alpha = 5.58°$; the data uncorrected for the dip of rocks gave $k = 11.95$, $\alpha = 15.53°$, while fold tests were not applicable to Palaeocene sediments. Thus the B remanence components of Late Senonian rocks originated prior to folding, and they exhibited both normal and reverse polarizations. The computed positions of virtual poles or the position of the mean palaeomagnetic pole fall within the domain of Cretaceous pole positions for the African Plate. The palaeomagnetic declination points to a palaeotectonic anti-clockwise rotation. These results are coincident with the palaeomagnetic data, from the former investigations into the Outer Flysch units of the Western Carpathians. They indicate an affinity of the palaeopole positons of Carpathian Flysch Belt to the comuted positions of palaeopole of the African Lithospheric Plate.

Key words: Western Carpathians, Biele Karpaty Mts. Unit, flysch, Senonian, Palaeocene, multi-component analysis, remanence, palaeomagnetics.

Introduction

Palaeomagnetic investigations in the Slovak territory of the Western Carpathians pointed out some new interpretation aspects in global-tectonics models for the Carpathian part of the Alpine tectonic belt. The flysch sequences are in tectonically disturbed positions, the Flysch Belt, as a whole, forms a prominent regional arc of uprooted nappes. The initial object of palaeomagnetic investigations was to gain additional data along the Carpathian arc to the later palaeogeographic reconstructions of the curvature of individual arc segments. Palaeomagnetic investigations into the Flysch Formation in regions of Silesia, Orava and Dukla have shown, that the deviations of the palaeomagnetic declination do not follow the regional curvature of the Flysch Belt arc, but they are related to the age of the rocks under study (Krs et al. 1991).

The Biele Karpaty Mts. Nappe displays a minimum tectonic stress affliction amongst Flysch and Klippen Belt units (Hrouda & Potfaj in press; Hrouda 1993). This guarantees that the sediments were not affected by tectonic movements to the grade that could destroy their original texture. Samples of different rock types (sandstones, siltstones and mudstones) were collected at the sites that were only slightly disturbed tectonically. Laboratory research of palaeomagnetic characteristics was performed with the MAVACS apparatus, which guarantees a highly non-magnetic demagnetization medium. All the samples were subjected to a complex analysis of magnetization, magnetic stability was studied in the course of thermal treatment. Zijderveld diagrams were constructed for each sample, and the multi-component analysis of remanence was made (LINEFIND, least - squares fitting of lines). Fold tests of stability were applied to individual remanence components. These procedures were supposed to assure maximum reliability of the palaeomagnetic data inferred.

Geological structure of the Biele Karpaty Mts. Unit

The opinions on the structure of the Biele Karpaty Mts. Unit have considerably changed lately. A new succession of strata was established and a more detailed classification of the structure made by Stráník et al. (1986, 1989), Potfaj et al. (1986), Began et al. (1988).

The simplified succession of strata of the Biele Karpaty Mts. Unit from the Campanian until the Early Eocene from the base to the top is as follows: Gbely variegated Beds, Javorina Formation, Svodnica Formation, Rajkovec Formation and Chabová Beds. In the Moravian part of unit also the Nivnice Formation with Suchov Beds and successive Kuželov Formation occur. All the formations have essentially the flysch character, the proportion of sandstones and claystones being different.

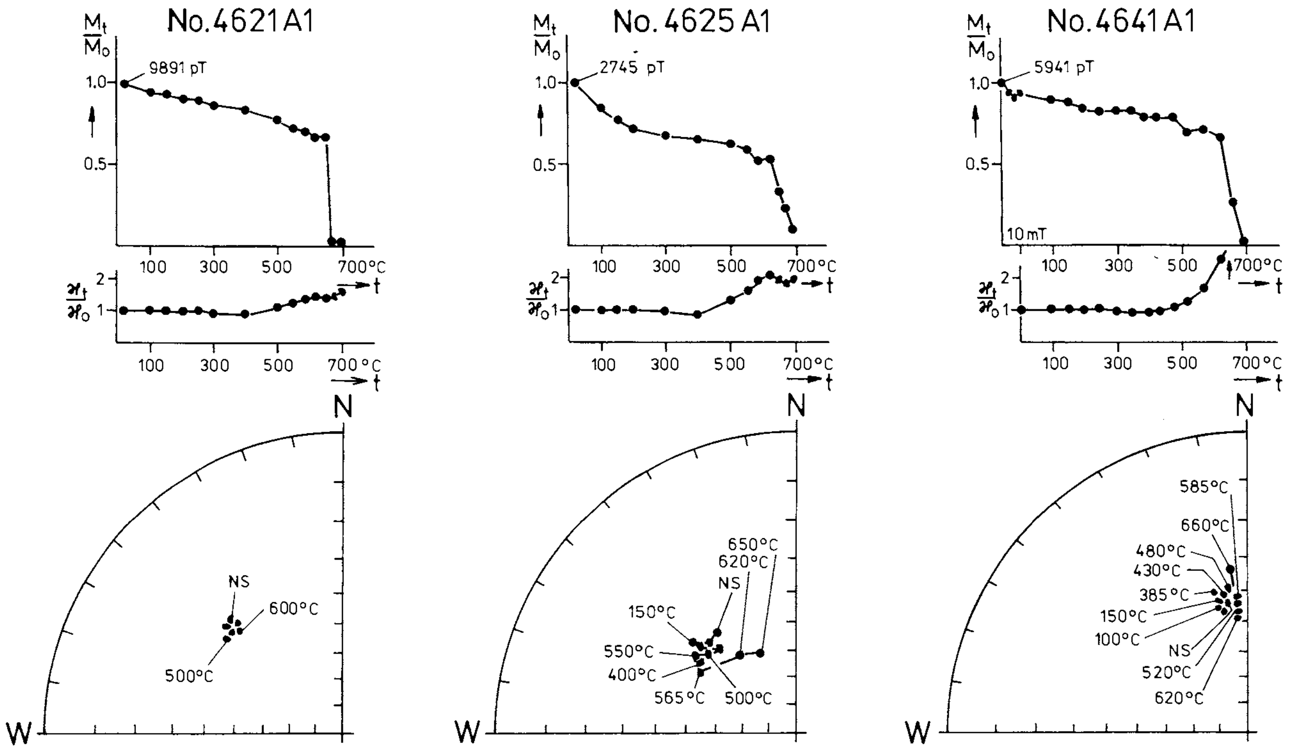


Fig. 1. Thermal demagnetization of representative samples of Late Senonian grey sandstone. Site 17b: Sample No. 4621A1; Site 17c: Sample No. 4625A1; Site 19: Sample No. 4641A1.

Gbely (variegated) Beds (Campanian - Maastrichtian?): alternating fine-grained carbonatic sandstones of a thickness up to 30 cm, green-grey and brick-red calcareous claystones, and dark-grey and violet claystones. The maximum thickness of the beds attains 340 m.

Javorina Formation (Campanian? - Maastrichtian): fine-grained and medium-grained sandstones with carbonatic fragments predominate, in the beds up to 20 cm thick, somewhere even more. In the higher part, bodies of microconglomerates are found. The claystones are grey, green-grey, only few layers are calcareous. Sporadically, there occur layers of white-grey pelocarbonates. The formation thickness is about 500 m.

Svodnica Formation (Palaeocene - Early Eocene): it contains strata of greywacke sandstones up to 30 cm thick or more, alternating with thick (0.5 - 2.5 m) layers of grey and brown-grey claystones mostly with a silt admixture, largely calcareous. There are local occurrences of pale-grey beds of the pelocarbonates. The formation thickness is about 700 m.

Rajkovec Formation (Palaeocene): it is predominantly a sandstone-flysch sequence with intercalations of claystones up to 10 cm thick. The sandstones are fine- to medium-grained in strata of a thickness up to 20 cm. We presume close relations to the Javorina Formation (lithological) and to the Svodnica Formation (biostratigraphical).

Chabová Beds (Early Eocene): a complex of medium- to coarse-grained greywacke sandstones with streaks and intercalations of fine-grained conglomerates. Claystones are subordinate, the total sequence thickness attains about 300 m. The sequence is interpreted as a submarine fan-lobe deposit.

Nivnice Formation (Late Palaeocene): it is a thin-rythmical flysch sequence of sandstones from several to 40 cm thick and calcareous claystones up to 50 cm thick. Sandstones are fine to medium grained, some of the strata with abundant organic detritus. A few thick beds of coarse-grained unsorted sandstones with clay clasts are interpreted as fluxoturbidites. Claystones are of pale-grey, brownish and green, often with pelagic interval at the top of the bed. The formation thickness is about 600 m.

Kuželov Formation (Latest Palaeocene to Early Eocene): this flysch-like sequence overlies the Nivnice Formation. Thick pelitic horizons (up to 2 m) are dominant in the lithology. In the lower part they are grey-brown, in the upper part of formation they are of variegated, mostly pale-grey colours. Sandstones are fine-grained, brown-grey, mostly ripple-laminated (Tc of Bouma's interval). A few thin beds of rusty-brown pelocarbonates were found at the upper part of formation. Total thickness of Kuželov Formation does not exceed 250 m.

From the point of wiew of heavy mineral content the main composition of associations consists of garnet, zircon, turmaline, rutile and apatite. The formations were classified to the zircon (Gbely and Nivnice Formation) or to the garnet facies (Peslová 1986; Peslová in Stráník et al. 1989). Typical, though in accessoric amount, for Biele Karpaty Mts. Unit is presence of the staurolite, common accessoric mineral is ilmenite. No magnetite was found except in few samples of more than 250. Presence of haematite was not mentioned.

As a whole, the Biele Karpaty Mts. Unit is overthrust towards NW on the Rača unit (in southern part) and on the Bystrica unit (in the north) with a folded nappe plane proved by boreholes KLK-1 (Potfaj et al. 1986), Blatnička-1 (Menčík & Pesl 1966). The nappe overthrust is at minimum to 28 km. The contact with

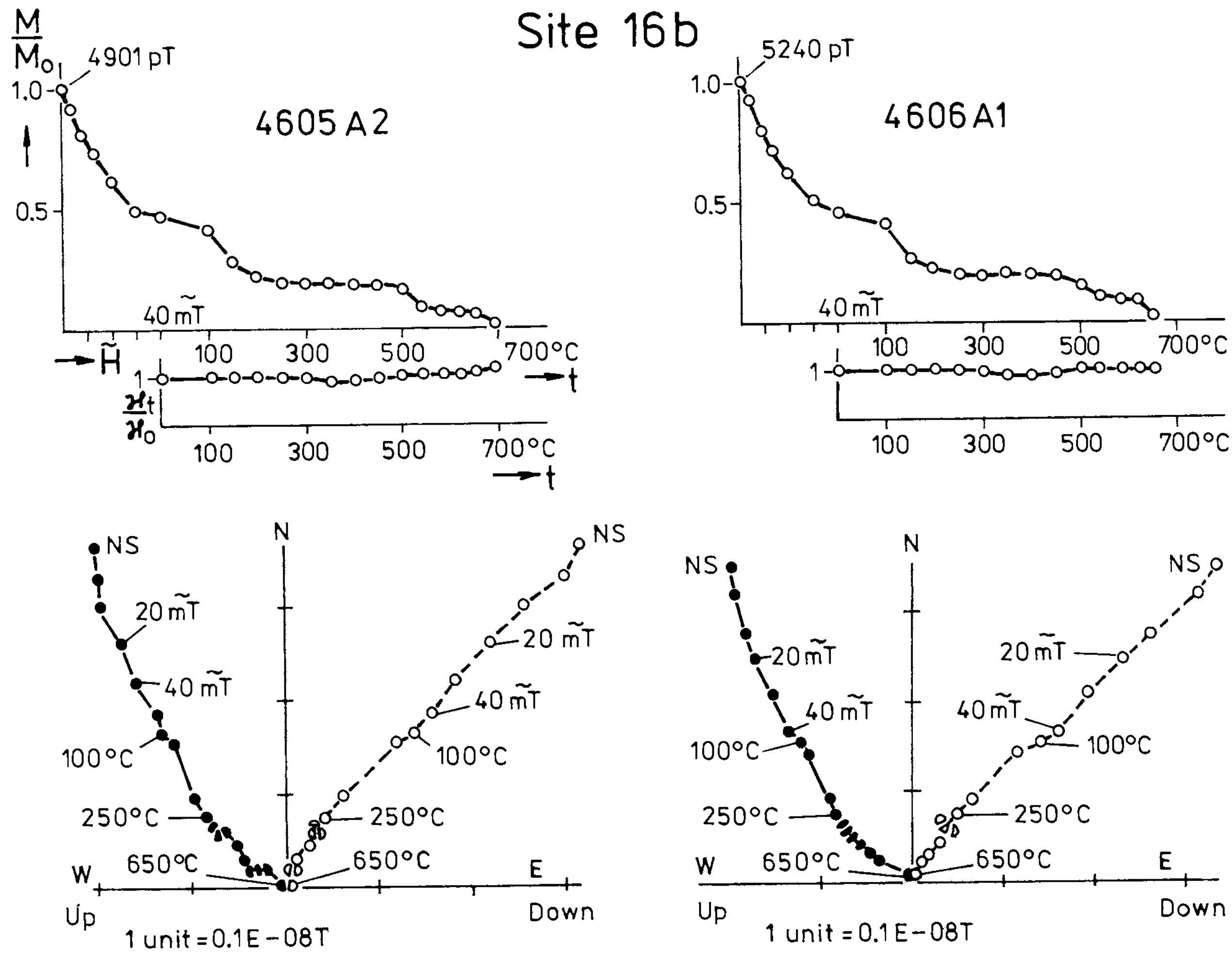


Fig. 2. Combined (alternating-field and thermal) demagnetization of representative samples of Late Senonian grey sandstone, site 16b.

the Klippen Belt along the SE margin is tectonic. Within the unit, in the region of Mt. Javorina and Mt. Lopeník the Javorina Nappe was defined, which is flat-lying on the Svodnica Formation of the lower structures of the Biele Karpaty Mts. Unit. According to the regional geological arrangement, this partial nappe was rooted between the Klippen Belt and the outer Biele Karpaty Mts. structures, with minimum displacement 9 km in the NW direction.

Collection of oriented samples

In collecting samples, we respected the principle that the sample should not come from the site markedly disturbed by local tectonics. A large part of the Biele Karpaty Mts. Nappe is deposited horizontally or subhorizontally. In the present work, palaeomagnetic directions were computed on the basis of statistically processed palaeomagnetic directions of individual strata and the respective localities and they are computed also from the values for sites. By a site we understand such a collection place, where more samples can be collected from different strata, single sites being at least several tens of meters apart. Within one locality there can be available more sites, depending on the size of exposures of the rocks investigated. The localities are spread over a vast space so that the sites of the entire region encompass a larger area. If there are more sites in one locality, the samples invariably represent mutually different stratigraphic positions, but the stratigraphic classification is always in accordance with the age given in Tab. 1.

Investigations of palaeomagnetic directions by laboratory methods

Studies of the remanence stability by means of the alternating field with the use of apparatus Schonstedt GSD-1 did not prove effective enough, and therefore, the whole collections of samples were demagnetized by the thermal field using the MAVACS apparatus (Magnetic Vacuum Control System, cf. Příhoda et al. 1989) or by the alternating and thermal fields in combination. This apparatus assures a highly nonmagnetic demagnetization medium, the offset of the rotating coil magnetometer - the magnetic field sensor - varied within ± 0.05 nT, the gradient of the demagnetization space of samples did not exceed the value of ± 2 nT.

On the whole, the samples of the Flysch Belt are very weakly magnetic. To measure remanence, we used spinner magnetometer JR-4 (Jelínek 1966), and for measuring magnetic susceptibility the kappa-bridge KLY-2 (Jelínek 1973). Attention

Table 1: Review of collection of oriented samples (Western Slovakia).

Loc. No.	Locality	Nos. of oriented samples	Geogr. coordinates		Age, lithology
			Latitude	Longitude	
16	Right tributary Predpolomský r. Janegov mill	4595A-4614A	48.902°N	17.803°E	L. Senonian grey sandstones red claystones
17	-"-	4615A-4628A	48.903°N	17.801°E	L. Senonian grey sandstones
18	Settlement Grúň S. of Lopeník	4629A-4638A	48.905°N	17.791°E	L. Senonian partly weathered sandstones
19	Valley "Predpolomská dolina", Dzurákovec	4639A-4641A	48.890°N	17.817°E	L. Senonian grey sandstones
20	Slope of Javorina Mt., "U zabitého Žida"	4642A-4661A	48.855°N	17.669°E	L. Senonian grey claystones siltst., sandst.
21	Brook "Liešanský potok", SW of Chabová	4662A-4673A	48.956°N	17.906°E	L. Senonian grey sandstones
22	Horná Súča - Kučiak	4674A-4695A	48.999°N	17.947°E	L. Palaeocene calc. sandstones
23	Horná Súča - Biele potoky	4696A-4702A	49.015°N	17.955°E	L. Palaeocene grey sandstones
24	-"-	4703A-4712A	49.012°N	17.952°E	-"-
25	Rivulet "Luborča"	4713A-4724A	49.002°N	18.051°E	L. Palaeocene sandstones
26	300 m W of the Mt. "Vrch Slobodných"	4725A-4731A	48.833°N	17.614°E	Palaeocene (?) calcareous sandstones
27	Approx. 1500 m NW from previous outcrop	4732A-4742A	48.841°N	17.617°E	Palaeocene (?) calcareous sandstones
28	SW of the Mt. "›Čapec"	4743A-4751A	48.845°N	17.617°E	-"-
29	Valley "Filipovské údolí" SE of Javorník	4752A-4763A	48.845°N	17.572°E	Palaeocene grey sandstones
30	Approx. 100 m from previous outcrop	4764A-4772A	48.845°N	17.572°E	-"-
31	Approx. 200 m from previous outcrop	4773A-4779A	48.845°N	17.572°E	-"-
32	Horné Srnie old quarry near Sietne	4780A-4794A	49.006°N	18.114°E	(L.) Palaeocene grey calcareous sandstones
33	Rajkovec	4795A-4807A	49.018°N	18.095°E	L. Palaeocene grey sandstones

was also given to fold tests of palaeomagnetic stability, and above all, to different procedures of the multi-component analysis of remanence. All the collected samples were subjected to progressive thermal demagnetization, Zijderveld diagrams were constructed, and in each sample we studied the mineralogical stability investigating the dependence of magnetic susceptibility on temperature. Only some exposures proved to yield samples, whose characteristic magnetization can be well reproduced. The samples of all exposures that exhibited phase changes in the course of thermal demagnetization, or contained magnetically very soft minerals, are not discussed further in this work.

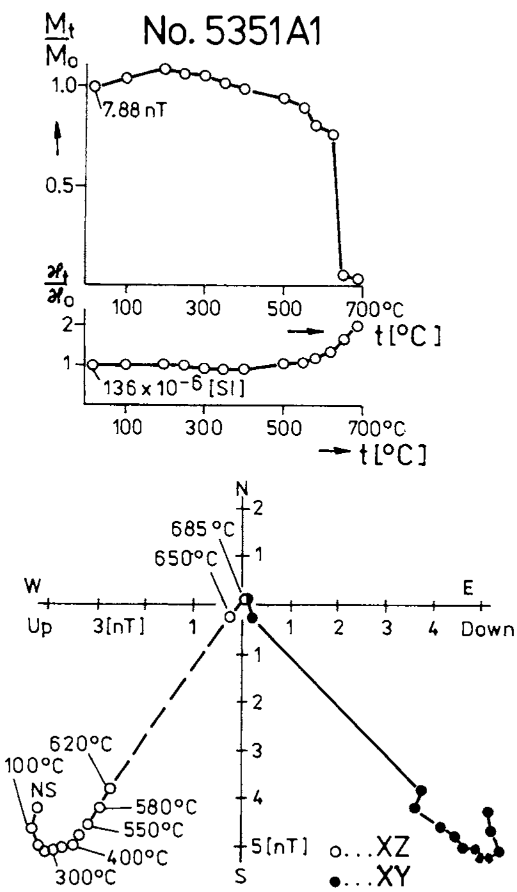
Examples of thermal or combined demagnetization for Late Senonian rocks are presented in Figs. 1 and 2. *Mt* means the modulus of the remanent magnetic moment demagnetized by the thermal field (at temperature t). *Mo* denotes the magnitude of the modulus of the natural remanent magnetic moment. For the apparent volume magnetic susceptibility, only the temperature dependence is represented. In the lower part of Fig. 1 we present stereographic projections of remanence directions for the respective steps of progressive demagnetization. The projection onto the lower (upper) hemisphere is denoted by a full (open) circle, *NS* denotes a sample in natural state.

Table 2: Optimum cleaning during progressive thermal treatments.

Site	Mean direction of remanent magnetization		α_{95}(°)	k	n	Natural state / Optimum demagnetizing field
	D (°)	I (°)				
16a	327.1	37.8	5.0	95.5	10	natural state
	314.8	40.4	5.2	87.0	10	400 °C
16b	338.0	32.9	3.7	118.4	14	natural state
	315.5	21.4	5.0	65.1	14	500 °C
16c	329.1	42.0	8.8	59.4	6	natural state
	314.7	46.6	11.4	35.5	6	400 °C
17b	323.9	43.4	6.9	93.9	6	natural state
	322.5	44.8	7.2	87.8	6	550 °C
17c	328.9	38.9	8.4	34.1	10	natural state
	326.0	41.0	15.0	12.9	10	620 °C
19	352.1	50.1	8.1	69.0	6	natural state
	356.0	47.2	9.8	48.1	6	385 °C
20a	47.0	34.6	9.4	24.5	11	natural state
	122.9	-33.6	10.6	19.5	11	240 °C
20b	43.6	27.6	12.9	14.9	10	natural state
	141.9	-51.7	14.5	12.1	10	250 °C
21	16.9	34.3	6.6	55.2	10	natural state
	162.5	-48.1	10.1	23.8	10	340 °C

Table 3: Results of multi-component analyses.

Site	Mean direction of remanent magnetization interval		α_{95}(°)	k	n	Predominant temperature interval	Multi-component analysis	Correction for dip of rocks
	D (°)	I (°)						
16a	312.0	41.7	4.6	110.7	10	> 620 °C	LINEFIND	yes
	292.9	62.5	4.6	110.7	10			no
16b	341.3	38.2	4.2	89.8	10	< 300 °C	LINEFIND	yes
	343.3	61.3	8.8	21.2	10			no
16c	324.2	47.8	20.8	11.3	6	> 580 °C	LINEFIND	yes
	296.1	74.7	20.8	11.3	6			no
17b	322.5	44.7	7.1	90.8	6	> 500 °C	least squares fitting of lines	yes
	24.8	60.2	7.1	90.8	6			no
17c	320.0	46.3	10.9	20.8	10	300 - 600 °C	least squares fitting of lines	yes
	15.7	63.5	10.9	20.8	10			no
19	307.9	43.8	27.2	7.0	6	300 - 520 °C	least squares fitting of lines	yes
	328.6	51.4	27.2	7.0	6			no
20a	131.7	-38.4	12.0	15.5	11	> 350 °C	least squares fitting of lines	yes
	128.0	-32.2	12.0	15.5	11			no
20b	133.0	-43.8	16.3	10.9	9	> 350 °C	least squares fitting of lines	yes
	127.6	-36.2	16.3	10.9	9			no
21	152.7	-44.7	10.5	34.0	7	300 - 500 °C	least squares fitting of lines	yes
	147.8	-29.5	11.0	30.9	7			no



For representative samples from the site 16b, Fig. 2 gives both the normalized graphs of remanence as well as susceptibility and Zijderveld diagrams. In all the sites studied it is evident that haematite is the magnetization carrier. The rocks are grey sandstones, haematite is not formed by pigment, but must be contained in very fine grains, magnetization is evidently of detritic origin.

Analogous procedures were applied to processing all the samples listed in Tab. 1. Samples with well defined characteristic magnetization were only found in the sites encompassed in Tab. 2. The table summarizes the mean magnetization directions of the samples, corrected for the dip of rocks evaluated by Fisher's (1953) statistics. The table gives the directions obtained under optimum cleaning (mostly by the thermal field), and for a comparison also the mean remanence directions are given for samples in natural condition. Extreme differences in the mean directions were established in samples with reverse palaeomagnetization (sites 20a, 20b, 21).

The magnetization directions presented in Tab. 3 correspond to B component, which was derived by the multi-component analysis (LINEFIND, least-squares fitting of lines). Application of the fold test to this component revealed, it had originated prior to folding. In samples uncorrected for the dip of rocks $\alpha = 15.53°$, $k = 11.95$, and in samples corrected for the dip of rocks $\alpha = 5.58°$, $k = 86.04$. The fold test is positive and statistically significant. For the computation we used the mean directions for the considered sites $N = 9$ (including 75 samples subjected to the multi-component analysis).

The Nivnice strata (Late Palaeocene) yielded similar results of remanence analysis. Fig. 3 represents a typical example of progressive thermal demagnetization procedure using the MAVACS apparatus (Přihoda et al. 1989). Haematite was found as principal carrier of palaeomagnetization on all sites of the Nivnice strata.

Fig. 3. Thermal demagnetization of representative sample of Late Palaeocene grey sandstone. Site 51a: Sample No. 5351A1 (locality Nivnice).

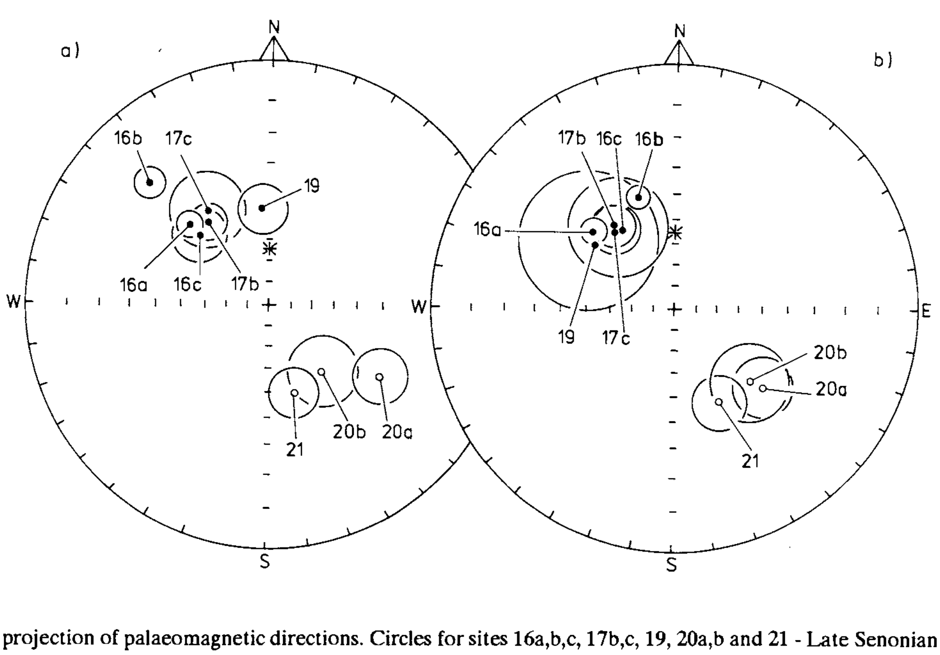


Fig. 4. Stereographic projection of palaeomagnetic directions. Circles for sites 16a,b,c, 17b,c, 19, 20a,b and 21 - Late Senonian sandstones and claystones of Javorina Fm. **a** - mean directions with the optimum Fisherian grouping during progressive thermal demagnetization, cf. Tab. 2; **b** - mean directions derived by multi-component analysis, cf. Tab. 3.

Table 4: Virtual pole positions for Upper Senonian flysch sediments in the Western part of the Magura Unit, determined in this study.

Site	Virtual pole position		Ovals of confidence		Notes, stability tests[1)]
	Palaeolatitude	Palaeolongitude	δ_p	δ_m	
16a	45.11°N	88.08°W	3.44°	5.63°	A.F. and thermal treatment (MAVACS)
16b	58.80°N	127.04°W	2.94°	4.97°	- „ -
16c	56.18°N	95.23°W	17.67°	27.12°	- „ -
17b	53.28°N	96.32°W	5.64°	8.95°	- „ -
17c	52.71°N	92.15°W	8.96°	13.98°	- „ -
19	43.63°N	82.78°W	21.23°	33.98°	- „ -
20a	43.18°N[2)]	90.16°W[2)]	8.44°	14.24°	- „ -
20b	46.90°N[2)]	87.49°W[2)]	12.72°	20.36°	- „ -
21	59.03°N[2)]	109.07°W[2)]	8.35°	13.24°	- „ -

[1)] cf. Tab. 3 (corrected for dip of rocks); [2)] reverse palaeomagnetic direction transfered to normal direction.

Table 5: Mean palaeomagnetic direction and pole positions for Late Senonian sediments in the Western part of the Magura Unit.

Mean palaeomagnetic direction		α_{95}	k	n	N	Palaeomagnetic pole position		Ovals of confidence	
D	I					Palaeolatitude	Palaeolongitude	δ_p	δ_m
320.58°	43.75°	5.58°	86.04	75	9	51.57°N	95.04°W	4.35°	6.97°

Mean geographic coordinates: Latitude 48.901°N; longitude 17.799°E; n = number of samples; N = number of sites.

Mean pole position calculated from virtual pole positions.

Palaeomagnetic pole position		α_{95}	k	N
Palaeolatitude	Palaeolongitude			
51.61°N	94.97°W	6.57°	62.45	9

Table 6: Mean palaeomagnetic directions and pole positions for Late Palaeocene sediments in the Western part of the Magura Unit (localities Louka and Nivnice).

Mean palaeomagnetic direction		α_{95}	k	n	N	Palaeomagnetic pole position		Ovals of confidence	
D	I					Palaeolatitude	Palaeolongitude	δ_p	δ_m
[1a]121.0°	-41.6°	11.4°	46.2	31	5	37.96°N	78.89°W	8.52°	13.93°
[1b]125.8°	-39.8°	7.5°	13.0	31	5	40.14°N	84.12°W	5.41°	9.01°
[2]134.6°	-35.5°	6.4°	10.3	18	2	43.43°N	94.91°W	4.28°	7.40°

[1a,1b)] mean geographic coordinates for sites 45a,b,c (locality Louka): latitude 48.941°N, longitude 17.547°E;
[2)] mean geographic coordinates for sites 51a,b (locality Nivnice): latitude 48.977°N; longitude 17.642°E; n = number of samples; N = number of sites.

Mean pole position calculated from virtual pole positions.

Palaeomagnetic pole position		α_{95}	k	N
Palaeolatitude	Palaeolongitude			
37.76°N	78.26°W	12.65°	37.52	5

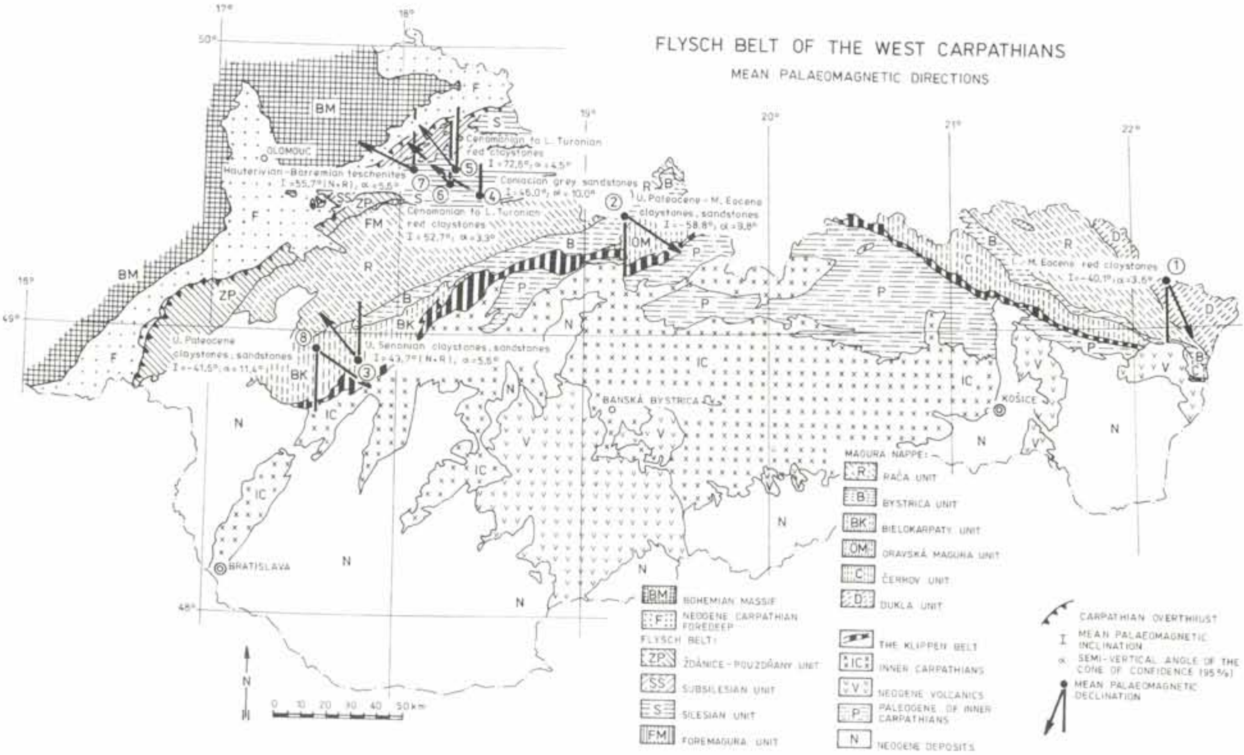


Fig. 5. Geological sketch map of the western part of the Carpathian Flysch Belt. Mean palaeomagnetic declinations are drawn for respective formations. 3 - Javorina Formation, Late Senonian; 8 - Nivnice Formation, Late Palaeocene.

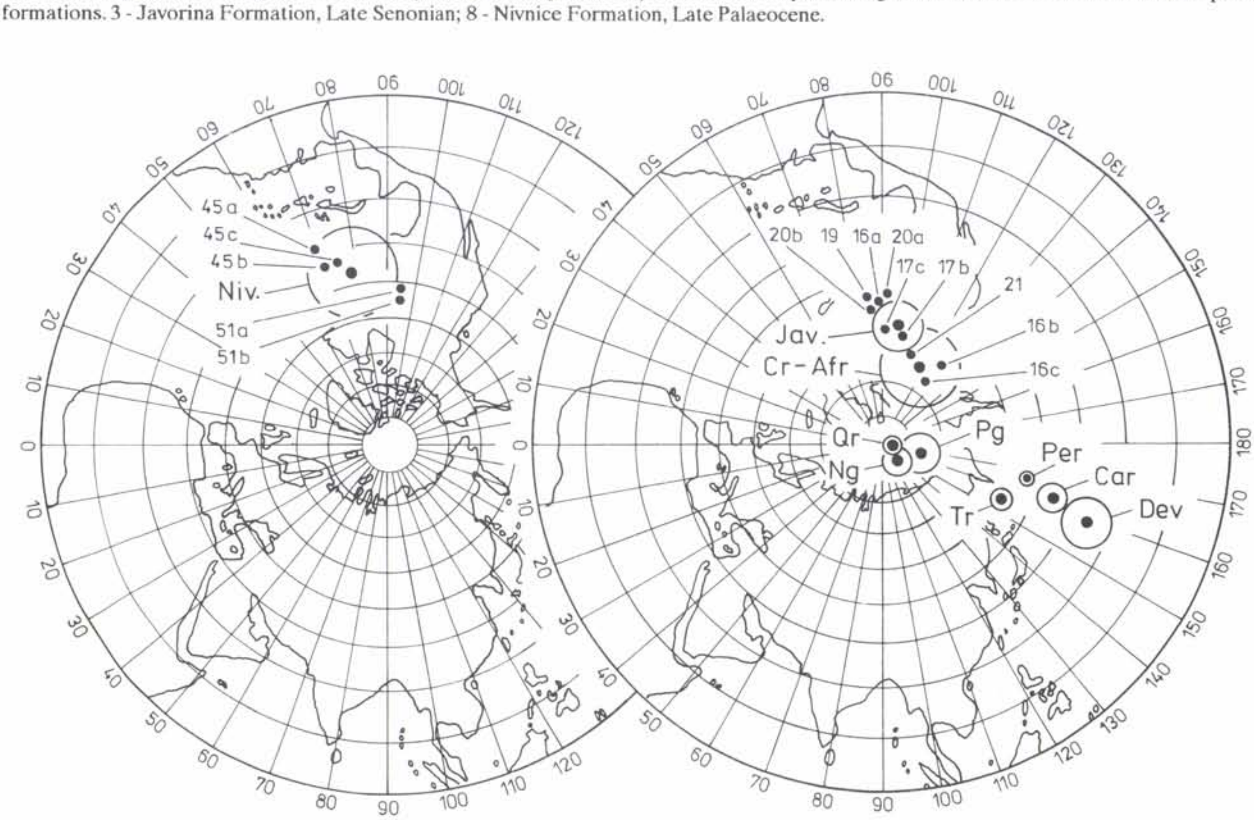


Fig. 6. Stereographic projection of the mean palaeomagnetic pole positions for the North European Platform (Krs 1982): Q - Quaternary; Ng - Neogene; Pg - Palaeogene; Tr - Triassic; Per - Permian; Car - Carboniferous; Dev - Devonian; Cr- Afr - mean Cretaceous palaeomagnetic pole position derived statistically for Africa (Krs 1982). Jav. - mean palaeomagnetic pole position derived for Late Senonian of the Javorina Formation, Nos 16 - 21; Niv. - mean palaeomagnetic pole position derived for Late Palaeocene of Nivnice Formation, Nos. 45, 51.

are plotted to stereographic projection displayed in Fig. 4. The samples with normal and reverse magnetization are another criterion suggesting a palaeomagnetic origin (any secondary remanence components of different orientation would disturb the normal-reverse relationship).

We arranged calculated virtual pole positions into the Tab. 4, whereas in the Tab. 5 we present the mean directions and the corresponding palaeo-coordinates of the mean palaeomagnetic pole for Late Senonian rocks. We confirm in this study the methodological conclusion, that different statistical approaches to the computation of the mean position of the palaeomagnetic pole yield the same results within the limits of statistical errors.

Tab. 6 summarizes palaeomagnetic data for five sites (45a,b,c; 51a,b) of Nivnice strata (Late Palaeocene) on localities Louka and Nivnice. In Tabs. 5 and 6, *n* means the number of rock samples from different strata, *N* denotes the number of sites.

The palaeomagnetic data inferred in this study fit to the previous results and confirm the anti-clockwise rotation of the palaeomagnetic directions. This rotation seems to be the most characteristic feature of the Flysch Belt complexes. A detailed interpretation and reevaluation of the data will be presented in the next issue of this journal. The values of palaeo-declination are given in Fig. 5, number 3 denoting the data for Late Senonian and No. 8 for Late Palaeocene of the Biele Karpaty Mts.

As shown already in the earlier research (Krs et al. 1991), the pole positions derived on the Western Carpathian Flysch Belt formations fall within the realm of the pole positions for the African Lithospheric Plate. The results obtained in the Biele Karpaty Mts. comply with this scheme, see Fig. 6. These results are confirmed by several independent procedures of deriving palaeomagnetic directions: the positive fold test of the interpreted B-component of remanence, proof of normal and reverse palaeomagnetizations, derivation of palaeomagnetic directions in grey sandstones and siltstones with detritic magnetization, whose carrier are haematite grainlets, and finally complete Zijderveld diagrams of a greater part of samples.

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