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EVIDENCE OF THE ILLAWARRA REVERSAL IN THE PERMIAN SEQUENCE OF THE HRONIC NAPPE (WESTERN CARPATHIANS, SLOVAKIA)

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Abstract: The magnetostratigraphic investigation on the profile of the Upper Carboniferous–Permian belonging to the Hronic Nappe in the Nízke Tatry Mts (Western Carpathians, Central Slovakia) revealed occurrence of the first order time marker, the so-called Illawarra Reversal (265 Ma), within the 2nd megacycle of the Malužiná Formation sequence.

Key words: Carpathians, Hronic Unit, Late Paleozoic, magnetostratigraphy, Illawarra Reversal.

Introduction

Magnetic polarity stratigraphy is now thoroughly integrated into biostratigraphy and chemostratigraphy. It is ordering of sedimentary or volcanic rock strata complexes into intervals characterized by the direction of characteristic remanent magnetic polarization of the rocks, being either normal polarity (in the direction to the north pole of that time) or reversed polarity (to the south pole of that time). The dipole nature of the main geomagnetic field means that polarity reversals are globally synchronous with the process of reversion taking 10^3–10^4 years. Magnetic polarity stratigraphy can therefore provide global stratigraphic time lines.

A sequence from the time span 300–250 Ma has been analysed using a combination of lithostratigraphic, biostratigraphic, isotope-geochronometric and magnetostratigraphic temporal information. This sequence is continuously preserved from the underlying Upper Carboniferous rocks to the overlying Lower Triassic rocks.

The objective of this paper is especially to put forward a more precise ordering of the Carboniferous-Permian strata of the Hronic Nappe by the method of magnetostratigraphy. The complete profile of the Upper Carboniferous-Permian sequence of the Hronic Unit in the Nízke Tatry Mts was analysed by standard magnetostratigraphic methods. We chose the localities in the Ipoltica and Dikula Valleys (Fig. 1) which consist of non-metamorphosed as well as relatively good outcropped volcano-sedimentary sequences. In this sedimentary rock complex we assume the preservation of primary remanent magnetic polarization.

Geological setting and brief lithostratigraphic characteristics

The Late Paleozoic volcano-sedimentary complexes in the basal part of nappes of the Hronic Unit are denoted as the Ipoltica Group, which consists of the Nižná Boca and Malužiná Formations (Vozárová & Vozár 1981, 1988). The tectonic basement of the Ipoltica Group, located in the Ipoltica and Dikula Valleys to the S of the Čierny Váh river on the northern slopes of the Nízke Tatry Mts, consists of the Veporic Unit, mostly of the Mesozoic of the Veľký Bok Group. The internal structure of the Ipoltica Group sedimentary sequences is affected by Alpine thrusting and faulting processes. Variable tectonic reduction is evident mainly in the sedimentary rock sequences of the Nižná Boca Formation.

The ***Ipoltica Group*** is a volcano-sedimentary sequence consisting of many small-scale autocyclic sedimentary cycles repeatedly occurring one above another. Varied siliciclastic sediments, andesite-basalt volcanics associated with minor volcaniclastics, absolutely dominate in the entire complex. Occurrences of evaporites and caliche horizon are rare. The whole sequence of the Ipoltica Group shows typical coarsening upward and change in the colour of sediments from grey to red-grey and red. The cumulative thickness is estimated at 2500–2800 m.

Nižná Boca Formation. It is generally a coarsening upward siliciclastic sedimentary sequence consisting of numerous repeated small-scale autocyclic fining-upward cycles. The facies distribution of the Nižná Boca Formation indicates channel and overbank deposits, alternating with interdistributary-channel and lacustrine sediments deposited in permanent humid climate. The deposits are predominantly grey to black coloured. This fluvial and/or fluvial-deltaic and lacustrine sedimentary association was interrupted by synsedimentary subaerial volcanism. It is manifested by abundant redeposited volcanogenic detrital material mixed with non-volcanic detritus and the sporadic occurrences of thin layered dacitic tuffs as well as exceptionally dacitic lava flows. The gabbro-diorite dykes are integral part of the Nižná Boca Formation. They are comagmatic with the Permian andesitic-basaltic volcanites of the Malužiná Formation.

The Nižná Boca Formation is characterized by macroscopically conspicuous stratification. The thickness of these beds is almost constant, but laterally variable. Tabular bodies of sand-

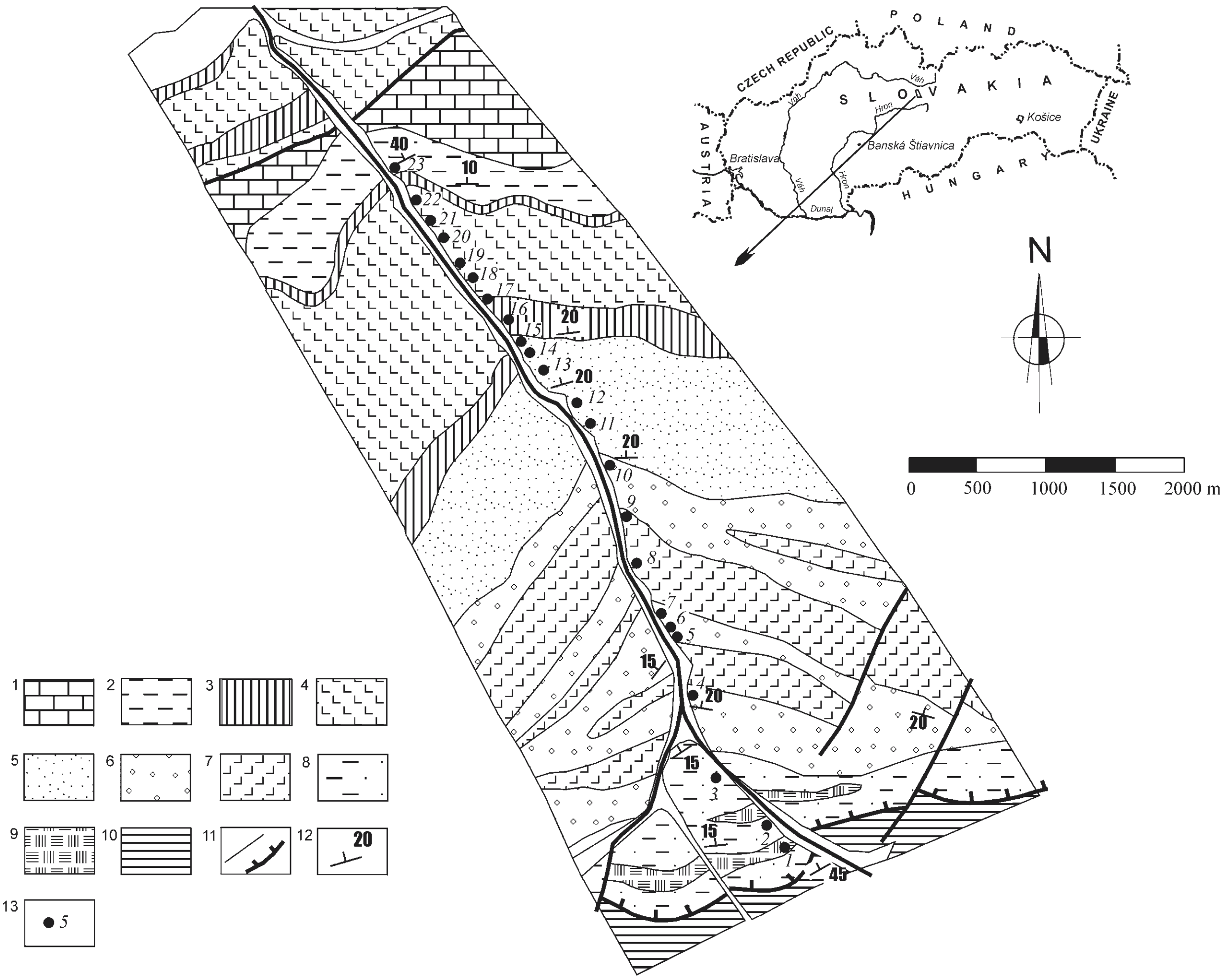

Fig. 1. Schematic geological map (modified according to Vozár in Biely et al. 1992) with indication of measured profile and sample locations in the northern slope of the Nízke Tatry Mts. *Explanation:* **1.** Middle Triassic carbonate rock complexes. **2.** Lower Triassic clastic sediments. **3–7.** Malužiná Formation: 3 — 3rd megacycle sediments; 4 — andesite-basalts of the 2nd eruption phase; 5 — 2nd megacycle sediments; 6 — 1st megacycle sediments; 7 — andesite-basalts of the 1st eruption phase. **8–9.** Nižná Boca Formation: 8 — sediments; 9 — Permian dioritic sills and dykes. **10.** Mesozoic metasediments of the Veľký Bok Group. **11.** Overthrust line. **12.** Strike and dip bed. **13.** Location of investigated localities.

stones are dominant. They are massive and/or graded bedded and cross-bedded, rarely with parting lineation. The horizontal planar lamination is typical of finer-grained sediments, very fine-grained sandstones, siltstones and mudstones. It is characterized by alternating laminae of sedimentary material of variable grain-size and colour. Finer-grained laminae are darker and contain flakes of clastic micas and carbonized plant detritus. The colour of sediments changes according to grain-size, mineral composition of detrital material, amount of primary matrix and carbonized plant detritus.

Macroflora from the uppermost part of the Nižná Boca Formation proved the Stephanian B–C age (Sitár & Vozár 1973). The palynological analysis of Planderová (1973) distinguished the Stephanian A–B and the Stephanian C–D microflora assemblages.

Malužiná Formation. The Malužiná Formation sequence is developed gradually from the underlying Nižná Boca Formation. It comprises a thick succession of red-beds (more than 2000 m in places), which consists of alternating conglomerates, sandstones and shales. Lenses of dolomites, gypsum and calcrete/caliche horizons occur locally. Small-scale fining-upward sedimentary cycles in the order of several meters, as well as three regional megacycles arranged one above the other, are the most typical sedimentary feature. The polyphase synsedimentary andesitic-basaltic volcanism of tholeiitic magmatic trend is the further significant phenomenon. Fossil remnants of the channel bar and point bar deposits associated with flood plain and natural levee sequences are dominant within the lower part of the three megacycles. The sediments of the Malužiná Formation were generally deposited in a fluvial and fluvial/lacustrine depositional system during permanent semiarid/arid climate.

The microflora proved the Early and Late Permian age of the Malužiná Formation. The following assemblages were described by Planderová (in Planderová 1973; Planderová & Vozárová 1982): 1. The Autunian assemblage, corresponding approximately to the 1st megacycle sediments; 2. The Saxonian assemblage, specifying age of the 2nd megacycle sediments; 3. The Thuringian assemblage, determining age of the 3rd megacycle sediments.

Distinct fining upward is a dominant lithological feature of all the three megacycles. The lower part of the megacycles consists of coarse-grained sediments: conglomerates and very coarse-grained sandstones. The beds are mostly thicker than 1 m. Erosive contacts between beds are frequent. Sediments in the lower part of the megacycles are of light-grey colour with greyish-pink, rusty-grey and light green-grey shades. In contrast to the base, the middle parts of the megacycles show distinct fining upward small-scale cyclicity, relatively decreasing thickness of beds, as well as dominance of finer-grained sediments over sandstones and significant ascent of red or violet-red colour of sediments. The top parts of the megacycles consists of the finest sediments, thin-bedded very fine-grained sandstones and siltstones alternating with thicker dominant mudstones. Prevalent are red, red-violet and greyish-red sediments. These fine-grained sediments contain layers of calcrete/caliche horizons, variable lenses of dolomite limestones, dolomite and scarce gypsum. They represent playa and continental sabcha deposits.

In the eastern part of the 2nd megacycle a local member was defined — the Kravany Beds (Novotný & Badár 1971). They consists of grey and greenish-grey sandstones and siltstones with redeposited plant debris and thin uraniun-bearing horizons.

The Autunian-Saxonian microflora assemblages correspond approximately to the 1st and 2nd megacycles. This assumption is supported by $^{206}Pb/^{238}U$ and $^{208}Pb/^{235}U$ dating of 263–274 Ma from uranium-bearing layers of the 2nd megacycle (Legierski in Rojkovič et al. 1992).

Magnetic properties of sediments and volcanics

Generally, the Upper Carboniferous-Permian continental sediments of the Hronic Unit have stable remanent magnetization carried by two distinct phases of magnetic minerals, one detrital and another authigenic.

The dominant detrital magnetic mineral in the Nižná Boca Formation sandstones is ilmenite. It is associated with scarce grains of magnetite. The burial of organic matter can result in reducing diagenetic conditions and the formation of iron sulphides. Authigenic pyrite is the most common iron sulphide in sediments and it can originate by reduction of detritital magnetite or titanomagnetite. It grew during diagenesis and could carry a high fidelity record of the geomagnetic field. Titanomagnetite and pyrrhotite are the main magnetic minerals in the gabbro-diorite dykes.

The Permian continental "red-beds" of the Malužiná Formation have stable magnetization carried by two distinct phases of hematite, one detrital and one authigenic. The magnetization of relatively coarser-grained sandstones is dominated by detrital "specular" hematite. Finer-grained sediments (siltstones and mudstones) as well as primary matrix in sandstones tend to be dominated by fine-grained "pigmentary" hematite. Within the Kravany Beds uranium-bearing stratiform horizons originated authigenic pyrite as a result of the bacterial activity in reducing diagenetic conditions.

Magnetic minerals of the Malužiná Formation andezitic basalts are represented by phenocrysts of titanomagnetite and as well as a hematite within the recrystallized glass matrix.

According to blocking temperatures, the followed magnetic minerals were identified: magnetite with blocking temperature 580 °C (Fig. 4 — sample 31B), hematite with blocking temperature 675 °C (Fig. 2 — sample 20D), hematite with Fe-oxides with blocking temperatures in the interval 200–500 °C (Fig. 6 — sample 39B; Fig. 8 — sample 42A; Fig. 10 — sample 51A), somewhere hematite and magnetite or goethit with blocking temperature ca. 120 °C.

Paleomagnetic measurements

351 rock samples from 23 outcrops of the investigated profile were studied. Each sample was subjected to thermal magnetic cleaning. Paleomagnetic measurements were carried out in the Paleomagnetic Laboratory of the Geophysical Institute of the Slovak Academy of Sciences, Bratislava. The demagnetization step of 50 °C from the natural stage up to 650 °C was

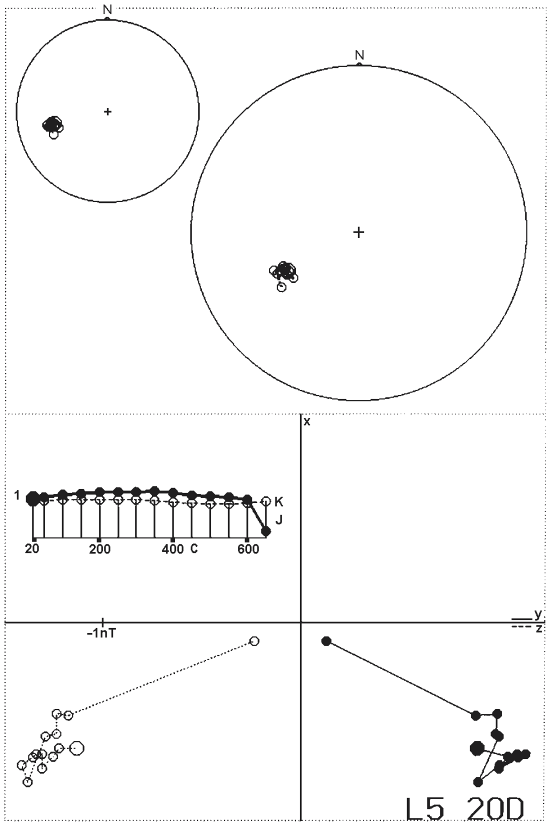

Fig. 2. Graphs of thermal demagnetization of the Malužiná sandstones from Loc. 5 for sample 20D. **Top** — stereoprojections of the directions of remanent magnetization (small circle — directions before bedding correction (in situ), great circle — directions after bedding correction; N — north) after each demagnetization step; the biggest point means beginning of demagnetization. Full points — downward, empty points — upward direction of remanent magnetization. **Bottom** — thermal behaviour of magnetization (curve J; J = J_o/J_t, where J_o is magnetization at laboratory temperature (ca. 20 °C) and J_t magnetization after thermal step t °C), and magnetic bulk susceptibility (curve K; K = K_o/K_t, where K_o is magnetic susceptibility at laboratory temperature (ca. 20 °C) and K_t after thermal step t °C). Zijderveld diagrams of XY and XZ elements of remanent magnetization (McElhinny & McFadden 2000).

used. The remanent magnetic polarization as well as volume magnetic susceptibility were measured after each demagnetization step. Thermal cleaning was performed according to the Magnetic Vacuum Control System, magnetic polarization was measured on the spinner magnetometer JR-5 and volume magnetic susceptibility on Kappabridge KLY-3 (all instruments come from the AGICO Comp. of Brno). The demagnetization graphs, so-called Zijderveld-diagrams of the XY and XZ components and stereographic projection of the remanent magnetization were analysed. The mean paleodirection of each locality (outcrops) was calculated using the Fisher statistics (Fisher 1953).

Characteristic paleodirection of the measured sample was chosen according to demagnetization graphs (even numbers of Figs. 2–11). Two ways were used for analysis of paleomagnetic data. At the first we considered the vectors of remanent magnetic polarization as primary data. At the second one we took vector differences between the steps of demagnetization, which means the change of direction of magnetic polarization during heating from temperature $T_{(i)}$ to temperature $T_{(i+1)}$. The dividing of thermal steps on three intervals (20–200 °C, 200–400 °C and 400–650 °C) was performed and used in both analyses. The characteristic direction was chosen according to Fisher statistical parameters from the six results (2 ways, 6 thermal intervals). Many samples as well as 8 localities with remagnetization and a large dispersion of remanence directions were rejected.

The odd numbers of Figs. 2–11 present the stereoprojections of paleodirections for 5 localities together with the mean direction and the circle into which the mean direction lies with 95% probability. Table 1 presents data of measured paleomagnetic characteristics. We can see that the localities are represented by varying numbers of samples (from 3 samples of Loc. 9 — Fig. 5, Table 1 — to 14 samples of Loc. 12 — Fig. 9, Table 1). The different scatter of paleodirections reflects the limited number of samples. The half angle of cone of confidence varies from 8.9° to 25.0° (Table 1). Table 1 points to fact that some of the investigated rocks were weakly magnetized. Magnetic bulk susceptibility varies from 3.7 to 942.0×10^{-6} u. SI and remanent magnetic polarization from 0.061 nT to 6.867 nT (Table 1). The α_{95} circles of confidence are comparable or equal before and after bedding correction. Locality 6 is the only one, in which the fold test was positive. The value of angle α_{95} in position before bedding correction (22.7 — Table 1) is greater than after bedding correction (19.1 — Table 1). Magnetic declination varies from 179° (Loc. 17; Table 1) to 237° (Loc. 21; Table 1) and magnetic inclination from −44° (Loc. 21; Table 1) to −14° (Loc. 9; Ta-

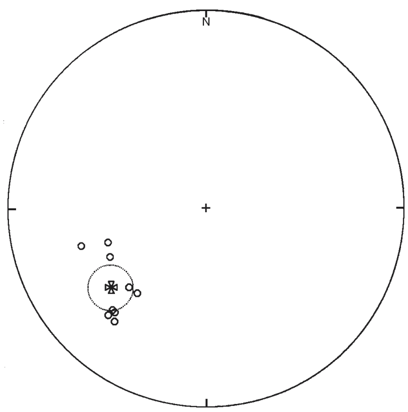

Fig. 3. Stereoprojections of the paleodirections of 9 samples of the Malužiná sandstones from Loc. 5. **N** — north. **Maltese cross** — mean direction (full — downward (see Fig. 9), empty — upward); **circle around mean direction** — cone of confidence into which mean direction (in position after bedding correction — see Table 1) lies with 95% probability (Fisher 1953; Table 1).

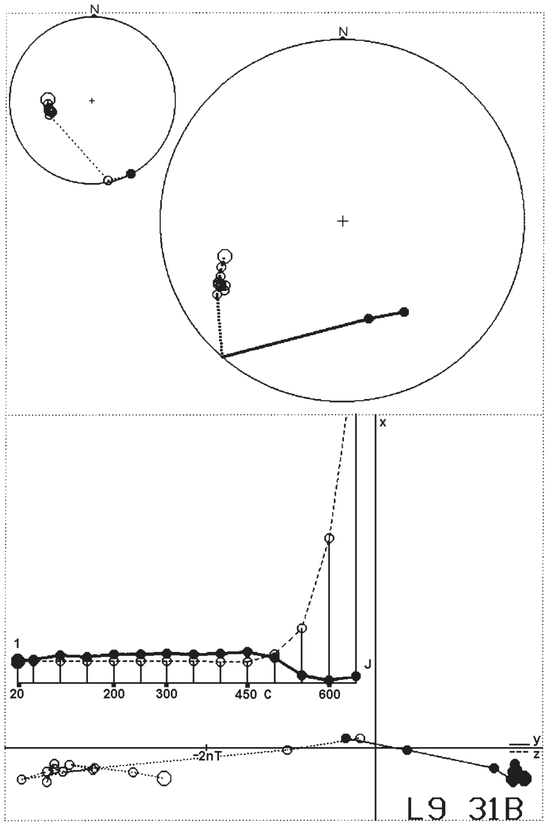

Fig. 4. Graphs of thermal demagnetization of the Malužiná volcaniclastic sediments from Loc. 9 for sample 31B (see Fig. 2).

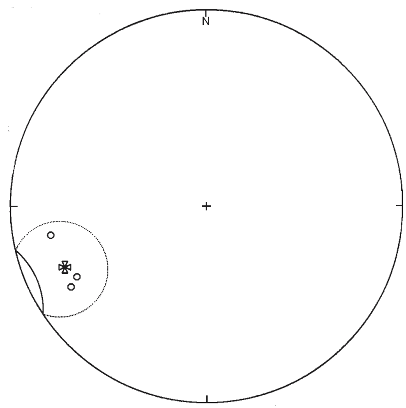

Fig. 5. Stereoprojections of paleodirections of 3 samples of the Malužiná volcaniclastic sediments from Loc. 9 (see Fig. 3).

Table 1: Paleomagnetic characteristics of the Malužiná Formation (sediments and volcanics). Loc. — number of locality; N — number of measured samples, n — number of used samples; D°, I° — declination and inclination of characteristic remanent magnetization; k — statistical precision parameter; $\alpha°_{95}$ — half angle of circle of confidence into which the mean paleodirection is located with 95% probability; BBC — before bedding correction; ABC — after bedding correction; J [nT] — mean intenzity of remanent magnetization in natural state (at 20 °C); κ [$\times 10^{-6}$ u. SI] — mean value of bulk magnetic susceptibility in natural state (at 20 °C); Pol. — polarity (N — normal, R — reversed, I — intermediate).

Loc.	N/n	BBC				ABC				J [nT]	$\kappa \times 10^{-6}$u. SI	Pol.
		D°	I°	k	$\alpha°_{95}$	D°	I°	k	$\alpha°_{95}$			
1	27/16	133	-57	31.8	6.6	133	-57	31.8	6.6	1.170	676.6	I
2	19/12	352	63	10.7	13.9	351	43	10.7	13.9	0.256	593.6	N
3	23/ -	-	-	-	-	-	-	-	-	-	-	–
4	30/10	206	-34	15.8	12.5	200	-19	15.8	12.5	0.633	82.6	R
5	18/9	241	-21	31.5	9.3	230	-26	31.5	9.3	0.906	56.9	R
6	15/5	212	-53	12.3	22.7	184	-30	17.0	19.1	0.304	39.2	R
7	20/5	94	-41	14.3	20.9	126	-33	14.3	20.9	0.183	61.7	I
8	10/6	61	82	16.5	17.0	4	37	16.5	17.0	0.068	213.1	N
9	4/3	260	-30	53.8	17.0	247	-14	53.8	17.0	1.119	267.0	R
10	19/ -	-	-	-	-	-	-	-	-	-	-	–
11	16/9	251	-38	13.1	14.8	220	-24	13.1	14.8	0.245	31.3	R
12	18/14	36	61	12.7	11.6	11	38	12.7	11.6	0.244	38.5	N
13	12/ -	-	-	-	-	-	-	-	-	-	-	–
14	13/6	70	32	18.8	15.9	57	33	18.8	15.9	0.239	63.4	N
15	15/9	99	40	25.8	10.3	60	35	25.8	10.3	0.254	118.5	N
16	4/ -	-	-	-	-	-	-	-	-	-	-	–
17	5/5	183	-48	10.3	25.0	179	-24	10.3	25.0	0.061	3.7	R
18	9/3	318	60	48.2	18.0	318	60	48.2	18.0	6.795	272.5	I
19	21/ -	-	-	-	-	-	-	-	-	-	-	–
20	13/ -	-	-	-	-	-	-	-	-	-	-	–
21	8/6	274	-30	59.4	8.8	237	-44	57.3	8.9	6.867	942.0	R
22	16/ -	-	-	-	-	-	-	-	-	-	-	–
23	15/ -	-	-	-	-	-	-	-	-	-	-	–

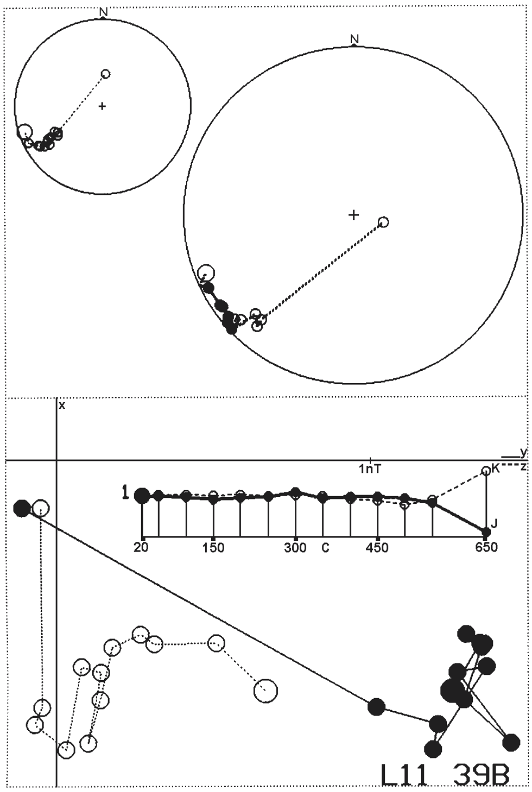

Fig. 6. Graphs of thermal demagnetization of the Malužiná sandstones from Loc. 11 for sample 39B (see Fig. 2).

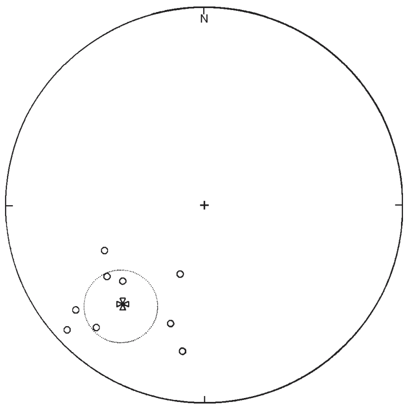

Fig. 7. Stereoprojections of the paleodirections of 9 samples of the Malužiná sandstones from Loc. 11 (see Fig. 3).

ble 1) in the case of reversed magnetic polarization. Normal magnetized samples have declinations between 351° (Loc. 2; Table 1) and 60° (Loc. 15; Table 1) as well as inclinations between 33° (Loc. 14; Table 1) and 43° (Loc. 2; Table 1). If following criterions for antiparallel directions are used: reversed when declination is 210°±40° and inclination is –30°±20° and normal when declination is 30°±40° and inclination is 30°±20°, the localities 1, 7, and 18 show intermediate directions (Table 1). They cannot be used for magnetostratigraphic interpretations.

Discussion and conclusion

The results are summarized in a schematic magnetostratigraphic profile for the Late Paleozoic of the Hronic Unit (Fig. 12).

The set of the measured Upper Carboniferous samples is small. The samples from Loc. 1 correspond to a system of gabbro-dioritic dykes, which is coinstantaneous with the

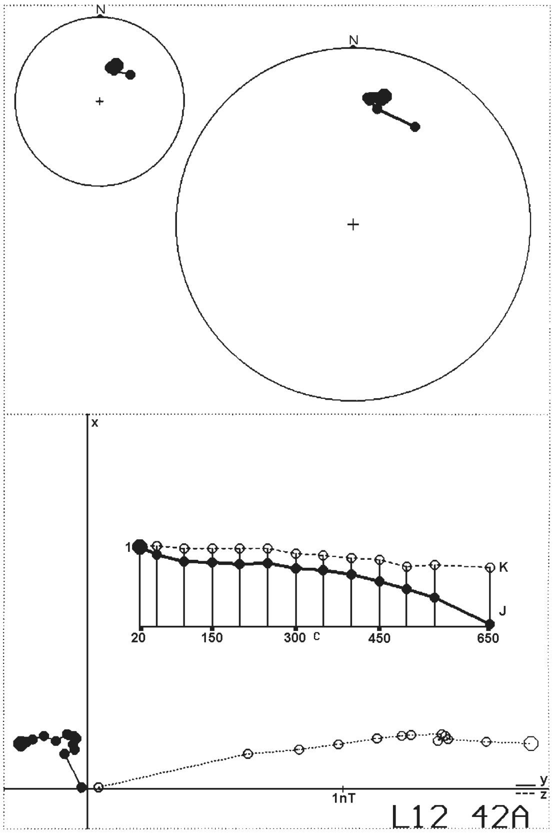

Fig. 8. Graphs of thermal demagnetization of the Malužiná sandstones from Loc. 12 for sample 42A (see Fig. 2).

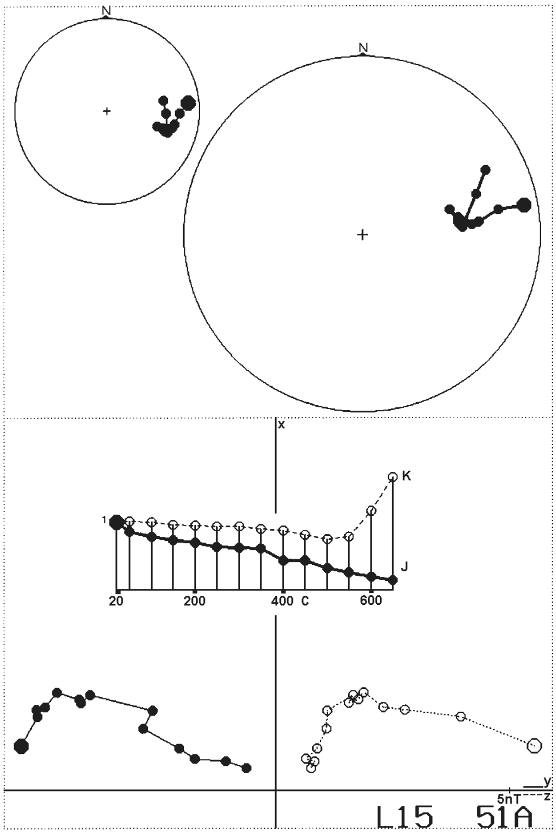

Fig. 10. Graphs of thermal demagnetization of the Malužiná mudstones and sandstones from Loc. 15 for sample 51A (see Fig. 2).

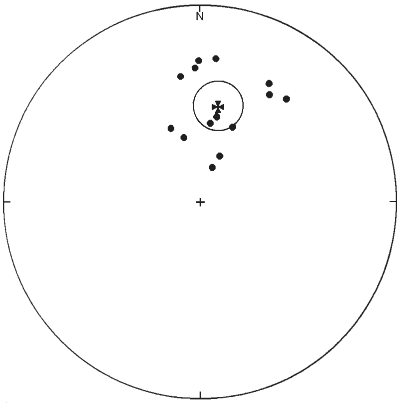

Fig. 9. Stereoprojections of the paleodirections of 14 samples of the Malužiná sandstones from Loc. 12 (see Fig. 3).

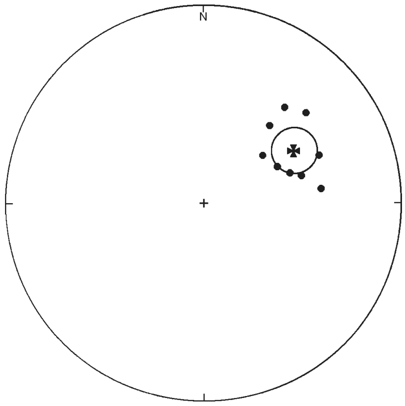

Fig. 11. Stereoprojections of the paleodirections of 9 samples of the Malužiná mudstones and sandstones from Loc. 15 (see Fig. 3).

Malužiná Formation andesite-basalt lava flows. The obtained data polarity are intermediate (Table 1). The Upper Carboniferous sediments of the Nižná Boca Formation from Loc. 2 are normally magnetized.

Indications of reversed magnetization were practically found within the whole sedimentary sequence of the first megacycle and the lowest part of the second megacycle of the Malužiná Formation, localities 4, 5, 6, 9 and 11. Locality 7 is intermediately magnetized (Table 1). There are significant indications for normally magnetized samples from Loc. 8, which corresponds to andesite/basalts of the first erruption phase. A significant change in the polarity occurs between the outcrops 11 (reversed) and 12 (normal) in the lower part of the 2nd megacycle (Fig. 12). Locality 13 is inhomogeneously magnetized ($\alpha_{95} = 43°$), it shows an intermediate direction, and 9 of the 12 samples are not used for the calculation of the mean direction. Therefore, locality 13 cannot be used for magnetostratigraphic interpretations (Table 1). The middle and the upper part of the second megacycle has indications only for normal polarity (Fig. 12). The direct overlier of

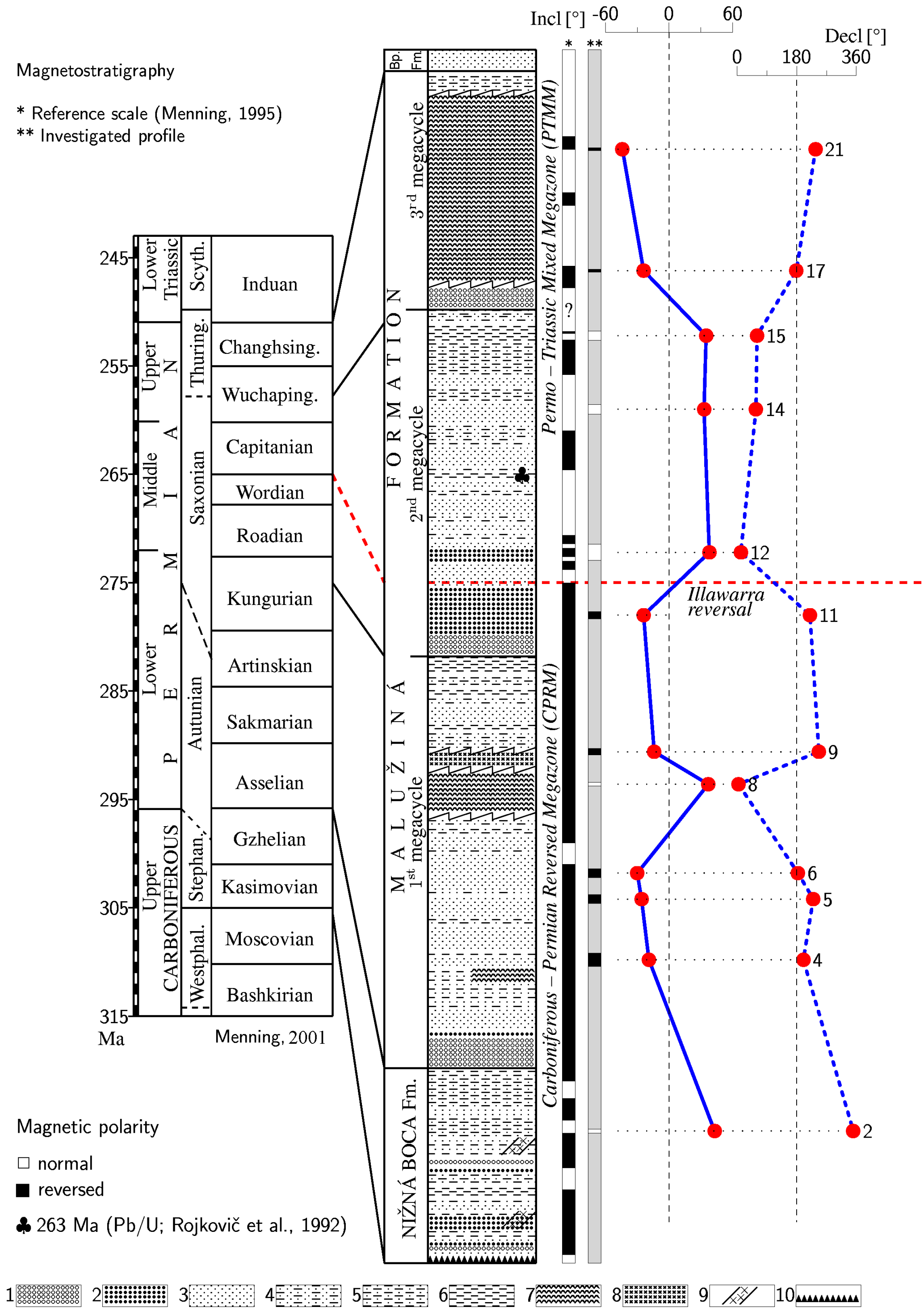

Fig. 12. Results of magnetostratigraphic investigation of the Late Paleozoic Hronic Unit (full bold line — mean inclination of the characteristic remanent magnetization; interrupted line — mean declination of the characteristic remanent magnetization). *Explanation:* **1.** polymict conglomerate; **2.** coarse-grained sandstone; **3.** medium- to fine-grained sandstone; **4.** alternation of sandstone and shale; **5.** shale, mudstone and siltstone; **6.** shale; **7.** andesitic basalt; **8.** volcaniclastic sediment; **9.** gabbro-dioritic sill and dyke; **10.** overthrust plane.

Loc. 13 (Figs. 1 and 12) was correlated with the uranium-bearing horizon, from which come 263 Ma Pb/U radiometric dating (Rojkovič et al. 1992). Pure microfloristic data proved the Autunian-Saxonian assemblages: *Latensina trileta, Potonieisporites radiosus, P. novicus, Limitisporites rectus, Jugasporites delassaucei, Vittatina ovalis* (Planderová in Planderová & Vozárová 1982). Therefore the Illawarra Reversal could be between locality 11 and 12 within the lower part of the second megacycle. Such a position agrees best with the Pb/U age of 263 Ma (Rojkovič et al. 1992), because the Illawarra Reversal has 265 Ma (Menning 1995).

A further strong change in the inclination and declination occurs between localities 15 and 17 (locality 16 must be excluded of its big $\alpha_{95} = 55.5°$), probably at the base of the 3rd megacycle. The major part of the 3rd megacycle consists of andesite/basalt volcanites. The localities 17 and 21 have reversed polarity, wheras locality 18 has an intermediate direction (Table 1).

We assume, that the sediments of the Nižná Boca Formation and the whole 1st megacycle of the Malužiná Formation, as well as the lower part of the 2nd megacycle, belong to the Carboniferous-Permian Reversed Megazone (Menning 1995; formerly the Kiaman Magnetic Interval — Irving & Parry 1963, later abandoned by Irving & Pullaiah 1976 and replaced by the Permo-Carboniferous Reversed Superchrone). Within the Carboniferous-Permian Reversed Megazone (CPRM), several normal zones (according to Menning (2001) at least five horizons) were described. Two were identified near the Carboniferous-Permian boundary of the Transcaucasus succession (296 Ma; Khramov & Davydov 1991). Two further normal zones occur in the volcanics of the Tholey Subgroup of the Saar-Nahe-Basin (291 Ma; Berthold et al. 1975). A fifth normal zone is found in the Garber Sandstone (Oklahoma, about 280 Ma; Peterson & Nairn 1971).

There is evidence that within the lower part of the 2nd megacycle (Fig. 12) a systematic change in the polarity occurs. This zone could be correlated with Illawarra Reversal. This assumption is supported by the radiometric data 263 Ma from the uranium-bearing horizon which is lithostratigraphically correlated approximately with the middle part of the second megacycle. The age of IR is first-order time marker by Menning (1995) at about 265 Ma. Thus, the middle and the upper part of the 2nd megacycle as well as the 3rd megacycle should be correlated with the Permian-Triassic Mixed Megazone (Menning 1995).

The following facts were obtained by magnetostratigraphic investigations:

1. The Autunian-Saxonian sequence is subdivided by a strong change of polarity, which is interpreted as the Illawarra Reversal. The magnetostratigraphic boundary represented by this strong change of polarity falls within the 2nd megacycle of the Malužiná Formation. Changes in the polarity are not connected with lithological boundaries. Thus, facies below and above the assumed Illawarra Reversal are similar.

2. The polarity determination in the whole complex of collected sediments is complicated. Additional investigations must be carried out using more outcrops and finer-grained samples, as far as possible, to confirm our results.

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