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PALEOGENE SEDIMENTS BELOW THE BASE OF A MESOZOIC NAPPE IN THE HUMENSKÉ VRCHY MTS. (PODSKALKA BOREHOLE): STRATIGRAPHIC CONSTRAINTS FOR TERTIARY THRUST TECTONICS

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Abstract: The footwall unit below the Mesozoic nappe complex of the Humenské vrchy Mts. has been reached by the MLS-1 Podskalka borehole. The lowermost (1769–1833 m) sandstone/claystone formation in this borehole it is constrained to be Late Cretaceous? but rather Paleogene in age (according to the youngest nannofossils). The hangingwall of these sediments consists of the Krížna Nappe complex which comprises formations from Middle Triassic up to Albian in age. The observations from the MLS-1 borehole point to the underthrusting of the externally seated flysch units beneath the collisional edge of the Centrocarpathian plate. The Paleogene formations may be attributed to the same unit which being deeply underplated, buried, and than exhumed in the East Slovak Basin floor (Iňačovce-Krichevo Unit). The Paleogene formations of this unit suffered sub-greenschist metamorphism and they are overlapped by ultrabasic thrust slices (Zbudza-1 borehole).

Key words: Western Carpathians, Tertiary thrust tectonics, suture zone, Mesozoic biostratigraphy, litostratigraphy.

Introduction

The Humenské vrchy Mts. represent the easternmost mountain range of the Western Carpathians, formed by the Central Carpathian nappe pile (Fig. 1). Three tectonic units were distinguished here by Maheľ (1986): the Strážske Unit with Tatric affinities, the Staré Unit similar to the Veporic Veľký Bok Unit and the Humenné Unit compared with the Vysoká Unit of the Fatric Krížna Nappe system. The structure of the Humenské vrchy Mts. was significantly affected by younger tectonic deformation, namely by the slicing of nappe complexes and south-vergent reverse faulting (Maheľ 1983, 1986; Jacko jun. & Schmidt 1994).

The close neighborhood of the Humenské vrchy Mts. with the Pieniny Klippen Belt and their overprinting by young collisional tectonics predetermines this mountain range for study of relations between Central and Outer Carpathians. The structural MLS-1 Podskalka borehole was projected with this aim, and, in particular, with the aim to verify possible allochthonous position of the Mesozoic units of the Humenské vrchy Mts. However, the interpretation of Kullmanová & Maheľ et al. (1975), despite of the find of Jurassic peculiar facies (dark marlstones and sandy limestones with ostracods) below the base of the Triassic complexes of the Krížna Nappe, did not fully confirmed this assumption. The problem of allochthonity of the Humenské vrchy Mts. structure became topical in the context of new findings from the East Slovak Basin floor, where the Mesozoic nappe remnants directly overlay the metamorphic rocks of the Iňačovce-Krichevo Unit (Soták et al. 1993a,b). Under these stimuli, we subjected the whole Podskalka borehole log to a new reinterpretation. It resulted in a proof of Late Cretaceous? or likely Paleogene sediments in the lowest known structural level of the Humenské vrchy Mts.

Geological characteristics of the Podskalka MLS-1 borehole log

The lithostratigraphy and structure of the Mesozoic complexes in the Podskalka borehole was firstly described by Kullmanová & Maheľ et al. (1975). These authors distinguished two partial digitations of the Humenné Unit in the borehole profile.

The upper digitation, penetrated by the interval of 20.6 to 810.0 m, is built up by Upper Triassic up to Cenomanian formations. The thickest part of the upper digitation consists of Upper Albian to Lower Cenomanian marly shales (Poruba Formation, 20.6–466.0 m). Below them, Barremian-Aptian limestones of Urgonian type (466.0–512.8 m) and marly limestones (512.8–619.0 m) with Lower Cretaceous ammonites occur. The lowest part of the Lower Cretaceous sequence is formed by Berriasian calpionellid limestones (619.0–623.8 m). Jurassic members of the upper digitation represented by Tithonian calpionellid limestones (623.0–638.0 m), Kimmeridgian *Saccocoma* and *Protoglobuligerina* limestones (638.0–648.5 m), Middle Jurassic crinoidal limestones (648.5–657.0 m) and Liassic sandy crinoidal limestones (657.0–807.8 m) remind the Vysoká type sequence. The base of the sequence forming the upper digitation is formed by variegated Keuper shales and laminated sandstones (807.8–810.0 m). This upper interval of the Podskalka

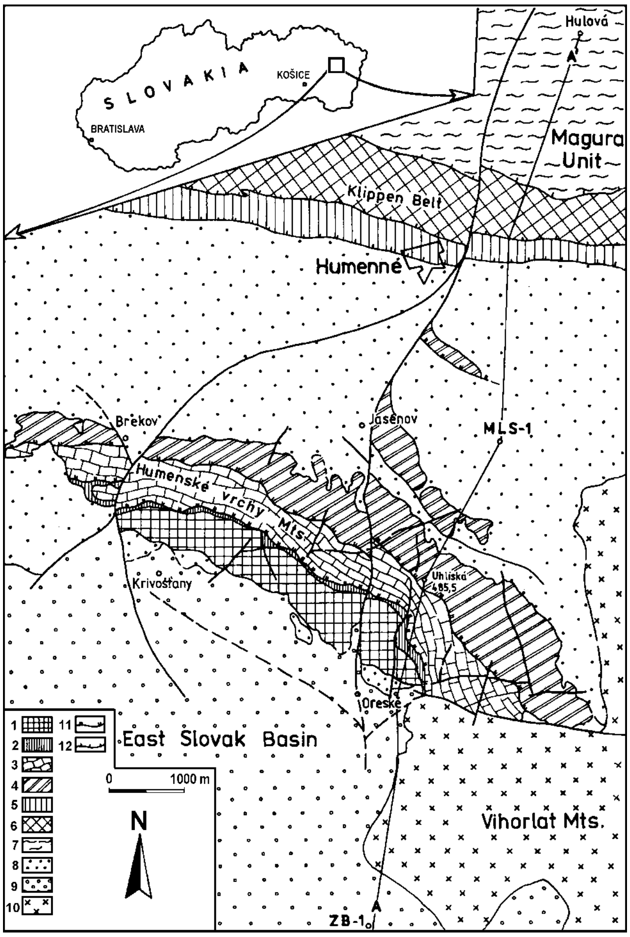

Fig. 1. Geological sketch-map of the Humenské vrchy Mts. and adjacent areas simplified according to Maheľ (1971, 1986), Roth (1956), Jacko jun. & Schmidt (1994) and others. **1** — Staré Unit; **2** — Strážske Unit; **3** — Humenné Unit (sole part — T, J_1); **4** — Humenné Unit (cover part — T_3, J, K_{1-2}); **5** — Upper Cretaceous formations of the Pieniny Klippen Belt; **6** — Kyjov Beds, **7** — Magura Unit; **8** — Neogene sediments of the East Slovak Basin; **9** — Central Carpathian Paleogene; **10** — neovulcanites; **11** — reverse faults; **12** — fault tectonics of the Pieniny Klippen Belt.

borehole is comparable with the the Uhliská slice of the Humenské vrchy Mts. structure (Maheľ 1986).

The lower digitation was penetrated by the interval 810.0–1725.4 m of the MLS-1 borehole. It consists of Middle Triassic dolomites with interlayers of grey micritic limestones and cherty limestones resembling the Reifling Limestone (1217–1725.4 m). Upper Triassic strata are composed of variegated shales and dolomites of the Keuper Formation (838.0–1217 m) and of the Rhaetian Fatra Formation limestones with bivalves, brachiopods and corals (810.0–838.0 m). Thick limestone-dolomite complex of the lower digitation is exposed by the Krivoštianka Ridge.

The interval 1739.3–1833.1 m, where the Liassic formation with an uncommon character is the most noteworthy part of the MLS-1 borehole log. It is separated from the overlying limestone-dolomite complex by a horizon of Keuper shales and sandstones (1725.4–1739.3 m). The formation consists of dark grey to black marly shales, calcareous sandstones and organodetritic limestones with ostracods *Ognoconcha* and bivalves *Plagiostoma* cf. *punctatum* Sowerby, *Parallelodon sp.*, *Pseudolimea* sp. and others. Apart from ostracods and bivalves, the formation was also attributed to the Lower Jurassic by the sporomorphs *Leiotriletes* cf. *braevilaesuratus* Kedves-Simoncsics, *Concavisporites martoni* De Jersey, *Sphaeripollenites* cf. *subgranulatus* Couper, *Foveosporis* cf. *irregularis* Tralau and others. The lithology of this formation differs from other Liassic formations in the higher intervals of the Podskalka borehole log in having more pelitic character and darker colouring, abundant ostracods and sporomorphs, while intercalations of crinoidal, crinoidal-sandy and cherty limestones are less frequent. According to Kullmanová & Maheľ et al. (1975), the finding of this Liassic formation below the Triassic carbonate complex is an remarkable argument speaking in favour of the allochthonous concept of the Humenské vrchy Mts. nappe structure. Later Maheľ (1986) correlated this formation with younger members of the Strážske Unit, cropping out from below the Gutenstein limestones of the Krížna Unit along the Krivoštianka Fault.

Results of a new revision of the Podskalka MLS-1 borehole log

Several important contributions to the lithostratigraphy and microfacies of the Mesozoic formations (Fig. 2) have been obtained by a new supplementary detailed study of the Podskalka borehole log.

The sediments from the interval 20.6–466.0 m represent the Albian–Cenomanian formations of the Humenné Unit (Jasenov Succession). Their mostly marly character corresponds to the Homôlka Marlstone Member of the Poruba Formation (Jablonský in Samuel et al. 1988), in which intervals of flysch sedimentation also appear with the development of hieroglyphs (Senkovci Member). The Middle Cretaceous sediments of the Jasenov Succession also comprise bodies of polymict conglomerates, which probably belong to the Ludrová Member. Another possible interpretation of the Middle Cretaceous formation from the Podskalka borehole was given by Ondra et al. (1990). These authors pointed to the petrophysical and lithofacies affinity of these sediments with the Cretaceous formations of the Klippen Belt. Similarly, Ivan & Sýkora (1993) pointed to the proximity of source areas of the Cretaceous conglomerates from both Jasenov and the Klippen Belt. They see similarity mainly in the presence of pebbles of glaucophanic rocks. The Jasenov conglomerates are also rich in pebbles of Urgonian limestones with abundance of dasycladacean algae and orbitolinid foraminifers (Soták & Mišík 1993).

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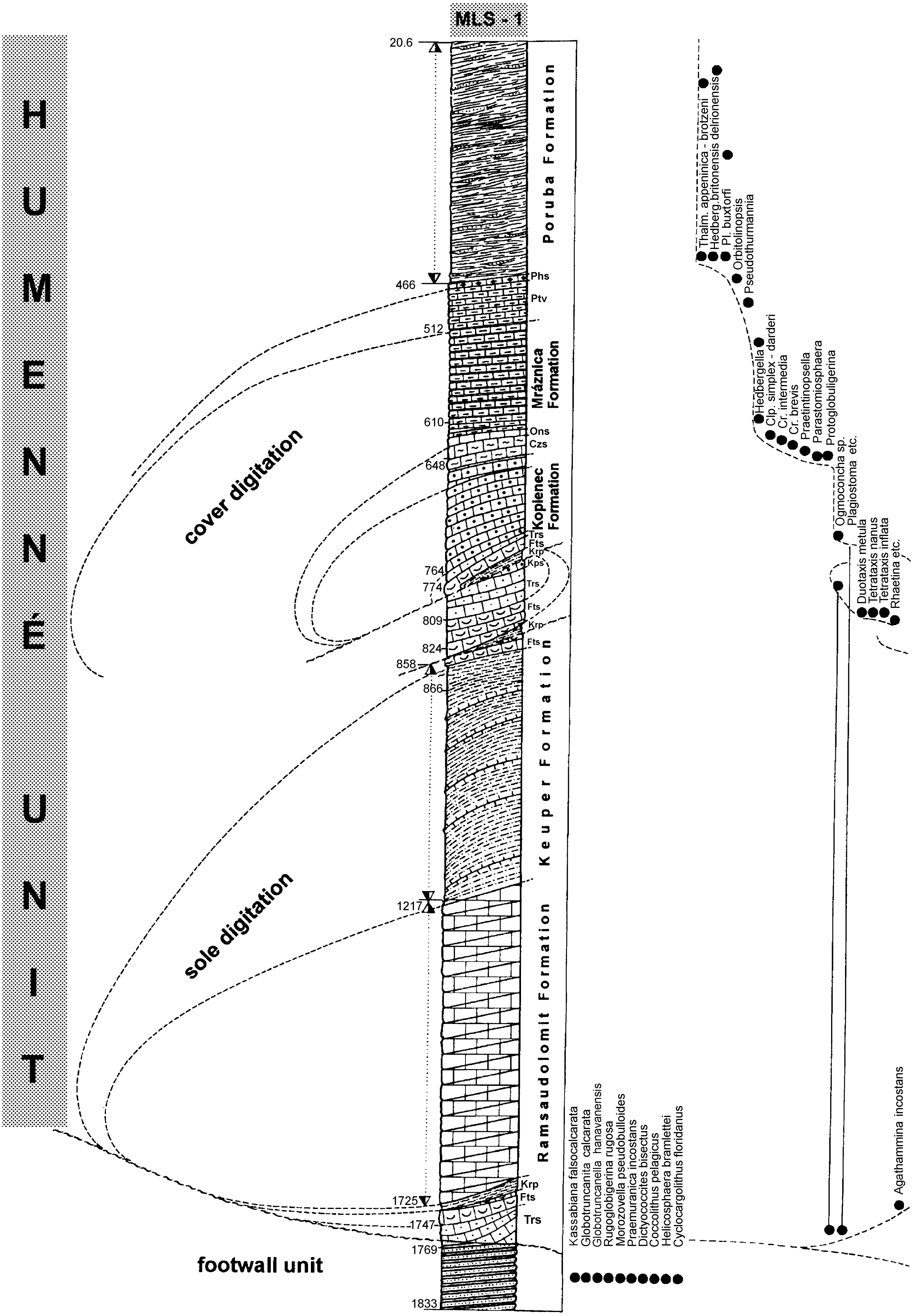
Fig. 2. Geological profile of the MLS-1 Podskalka borehole with lithostratigraphic subdivision and structural interpretation of drilled sequences. **Krp** — Keuper Fm., **Fts** — Fatra Fm., **Trs** — Trlenská Fm and Kopienec Fm, **Czs** — Tegernsee Fm, **Ons** — Padlá voda Fm, **Ptv** — Pseudothurmannia Beds, **Phs** — Bohatá Fm. The distribution of index microfossils is shown on the right side.


HUMENNÉ UNIT
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466
512
610
648
764
774
809
824
858
866
1217
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1747
1769
1833
Poruba Formation
Phs
Ptv
Mráznica Formation
Ons
Czs
Kopienec Formation
Trs
Fts
Krp
Kps
Keuper Formation
Ramsaudolomit Formation
cover digitation
sole digitation
footwall unit
Thalm. appeninica - brotzeni
Hedberg.britonensis delrionensis
Pl. buxtorfi
Orbitolinopsis
Pseudothurmannia
Hedbergella
Clp. simplex - darderi
Cr. intermedia
Cr. brevis
Praetintinopsella
Parastomiosphaera
Protoglobuligerina
Ogmoconcha sp.
Plagiostoma etc.
Duotaxis metula
Tetrataxis nanus
Tetrataxis inflata
Rhaetina etc.
Agathammina incostans
Kassabiana falsocalcarata
Globotruncanita calcarata
Globotruncanella havanensis
Rugoglobigerina rugosa
Morozovella pseudobulloides
Praemuranica incostans
Dictyococcites bisectus
Coccolithus pelagicus
Helicosphaera bramlettei
Cyclocargolithus floridanus

The Lower Cretaceous succession of the Podskalka borehole is similar to a marginal Fatric (Vysoká or Havran) succession comprising the Bohatá Limestone (466–470.6 m), marlstones of the Mráznica Formation (512.8–619.0 m) with an interval belonging to the Pseudothurmannia Beds (470.6–512.8 m), and hemipelagic limestones of the Osnica/Padlá Voda Formation (619–630 m). The latter mentioned formation contains Berriasian and Early Valanginian microfossils of the Calpionella, Calpionellopsis and Calpionellites Zones. Biomicrites with subordinate clay admixture contain *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch, *Tintinnopsella carpathica* (Murg. & Filip.), *Tintinnopsella longa* (Colom), *Calpionellopsis simplex* (Colom), *Calpionellopsis oblonga* (Cadisch), *Remaniella fillipescui* Pop, *Remaniella ferasini* (Catalano), *Remaniella cadischiana* (Colom), *Lorenziella hungarica* Knauer, *Lorenziella plicata* Remane, *Calpionellites darderi* (Colom), aptychi, crinoids, bivalves, ostracods, globochaetes, radiolarians and calcareous dinoflagellates (Pl. I: Figs. 1–2).

The Upper Jurassic sediments are reduced to the interval of 630–646 m in the borehole log. Stratigraphic condensation mainly of the Upper Tithonian Brevis Subzone interval (630–641 m) is responsible for small thickness of the formation. Pale limestones with stylolites dominated by clay infiling, but also brownish and red nodular limestones are typical lithofacies. Calpionellid association consists of *Crassicollaria brevis* Remane, *Crassicollaria massutiniana* (Colom), *Crassicollaria parvula* Remane, *Calpionella alpina* Lorenz and *Tintinnopsella carpathica carpathica* (Murg. & Filip.). The limestones also contain juvenile ammonites, aptychi, globochaetes, radiolarians and crinoids. Pale micritic limestones of the "majolica" facies with microplankton belonging to the early Late Tithonian of the Remanei Subzone (641–643 m). Organodetrital wackestone contain calpionellids *Crassicollaria intermedia* (Durand Delga) and *Crassicollaria massutiniana* (Colom), less frequently also *Crassicollaria parvula* Remane and *Calpionella alpina* Lorenz, aptychi, radiolarians, foraminifers, ostracods, globochaetes, dinocysts and crinoids. At a depth of 643.8 m, microfossils of the early Late Tithonian Praetintinopsella Zone were recorded micritic limestones. Below them, up to a depth of 646 m, brownish-grey micritic limestones with Saccocoma–Globochaete and radiolarian–Globochaete microfacies occur. *Parastomiosphaera malmica* (Borza), *Cadosina parvula* Nagy, *Cadosina fusca fusca* Wanner, *Protoglobuligerina* sp. and others microfossils co-occurring with abundant *Saccocoma* sp. and *Globochaete alpina* Lombard pointing their Kimmeridgian–Early Tithonian age.

Crinoidal packestones (Pl. I: Fig. 3) represent the Lower and Middle Jurassic strata in the structure of the upper digitation. Besides of them, ostracodal limestones of the same type as those found below the limestone-dolomite complex at a depth of 1747 to 1769 m (Pl. I: Fig. 4) were also recorded here (780.5–795.5 m). The peculiar character of these ostracodal limestones compared with another Liassic lithofacies of the Krížna Unit, is therefore not so unique as emphasized by Kullmanová & Maheľ et al. (1975). The fact that we also recorded them in Prešov-1 borehole in the strata overlying above the Fatra Formation (2845–2850 m) also testifies to the assignment of the ostracod limestones to the Liassic Tatric or Fatric sequence.

The complex fold-slice structure in the Podskalka borehole is also documented by a repetition of the Rhaethian Fatra Formation. It forms the interval 767–835 m and another one at a depth of 1723–1747 m below the Middle Triassic limestone-dolomite complex. The upper slice consists of darkgrey detrital and muddy limestones. The detrital limestones have a biosparruditic structure formed mainly by black coated molluscs shells, crinoid ossicles, micro-gastropods, algal nodules formed by *Girvanella* filaments, punctate brachiopod shells and other allochems. The muddy limestones have the character of foraminiferal biomicrites with numerous tests of *Tetrataxis inflata* Kristan, *Tetrataxis nanus* Kristan & Tollmann, *Duotaxis metula* Kristan and others (Pl. I: Fig. 5). The Rhaetian limestones from the underside of the Middle Triassic carbonate complex are also represented by biosparrudites and foraminiferal biomicrites. However, the associations of foraminifers are formed almost exclusively by small forms of "*Glomospira*" and "*Glomospirella*" only, which were described from the Fatra Formation by Michalík et al. (1979) and emended by Zaninetti et al. (1986) as the cummulative taxon of *Agathammina inconstans* (Pl. I: Fig. 6).

Kullmanová & Maheľ et al. (1975) placed the main tectonic boundary between the lower and upper digitation at the depth of 807.8 to 810 m. This boundary should be indicated by a horizon of red-brown micaceous sandstones, which the authors attributed to the Keuper Formation. The sandstones are overlain by lower Liassic Kopienec Formation, sandy-crinoidal limestones and underlain by the Rhaetian Fatra Formation. These relations show that the sandstones are part of the Rhaetian-Liassic sequence and not a tectonically inserted slice of Keuper rocks. Their "Keuper" appearance is not decisive, since sandstones of the Schattwald Beds occurring at the base of the Liassic Kopienec Formation in the Tatric and Krížna Units also have a similar lithological character, with redish brown colour, well developed lamination and a high concentration of detritic mica. In such a case, the Rhaetian-Liassic sequence not interrupted at the interval of 807.8–810 m, but continues from the Fatra Formation through the Schattwald Beds to the Kopienec Formation proper.

However, the fundamental importance for the geological interpretation of the Podskalka borehole and the whole structure of the Humenské vrchy Mts. comes from the finding of the Late Cretaceous? but rather Paleogene sediments in the lowermost borehole intervals (1769–1833.1 m).

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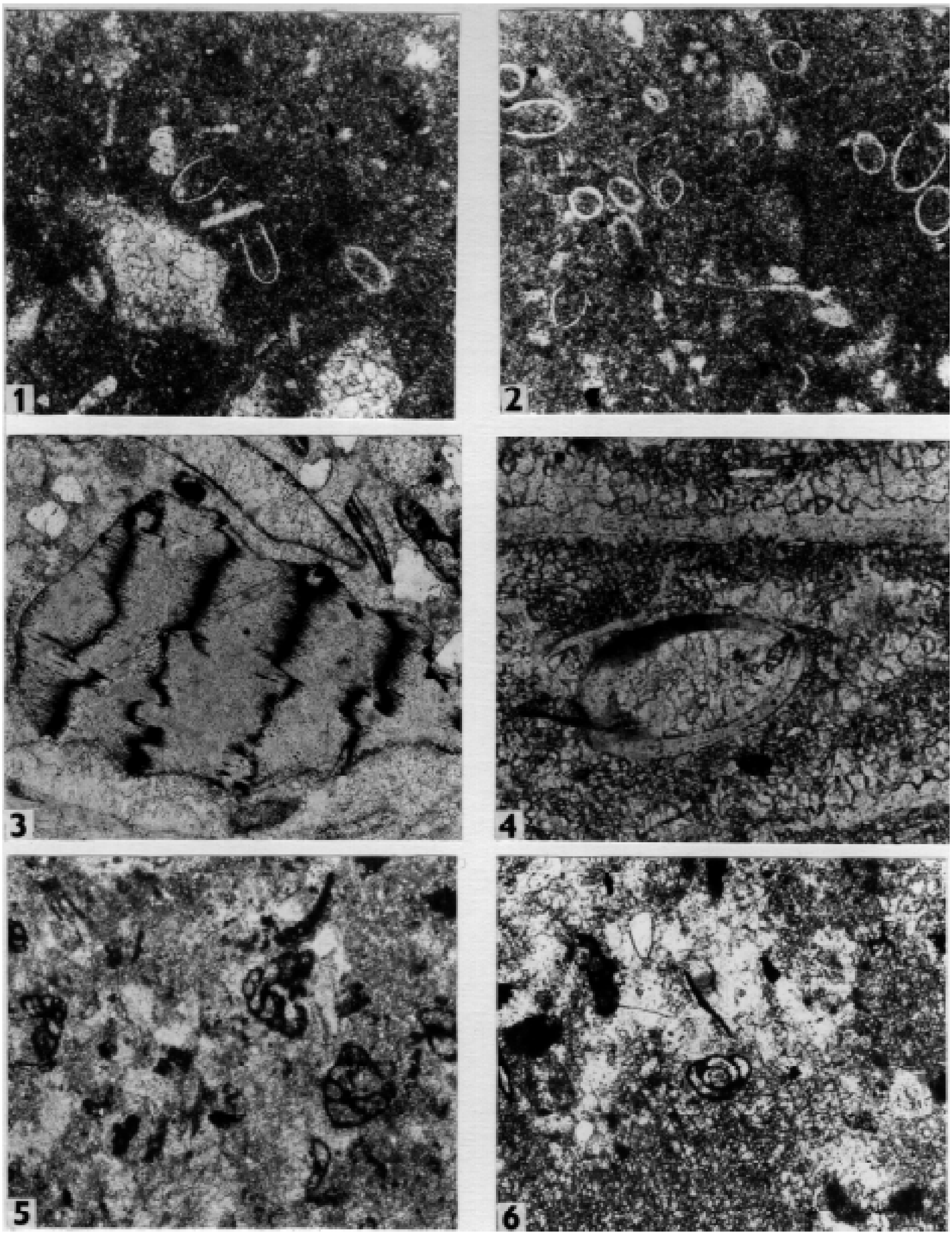
Plate I: Microfacies and microfauna of the Mesozoic formations in the Podskalka MLS-1 borehole. **Fig. 1** — Berriasian limestone with *Calpionellopsis simplex* (Colom) and *Tintinnopsella carpathica* (Murg. & Filip.), 627.3 m, magnif. 20×; **Fig. 2** — Berriasian limestone with *Remaniella fillipescui* Pop, *Calpionella elliptica* Cadisch and *Lorenziella plicata* Remane, 624.5 m, magnif. 20×; **Fig. 3** — Liassic organodetrital limestone with crinoid ossicles, 784 m, magnif. 7×; **Fig. 4** — Liassic biosparitic limestones with abundance of ostracods, 780.5 m, magnif. 45×; **Fig. 5** — Rhaetian microbiosparitic limestone rich in foraminiferal fauna of *Tetrataxidae* (*T. inflata* Kristan and *Duotaxis metula* Kristan), 812.5 m, magnif. 20×; **Fig. 6** — Rhaetian foraminiferal limestone with *Agathammina inconstans* (Michalík et al.).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The lithology and stratigraphic constraints of the sediments from below the base of the Mesozoic nappe complex

The deepest interval of the Podskalka borehole log is formed by sandstone-claystone beds. The upper part of this interval has a pelitic character (1779–1806 m), while in the lower part, homogeneous sandstones become dominant (1806–1833.1 m).

The grain size of the sandstones is variable. Prevalence of siliciclastic components is characteristic of the fine-grained types of sandstones, while lithic grains make up a larger proportion of the coarse grained sandstones. The content of lithic components (mainly carbonates) clearly distinguishes these sandstones from Keuper and Liassic sandstones from the hanging wall units. They are also specific by a higher content of polycrystalline quartz, fragments of phyllitic rocks, skeletal detritus of organisms and presence of spinel grains (in contrast, the older sandstones have a monotonous composition with dominance of plutonite detritus, monocrystalline quartz and feldspars including microcline). Carbonate detritus of the underlying sandstones is composed of mainly dolomites and dolomitic limestones, while clasts of calpionellid and filamentous limestones are less abundant. They also contain clasts of crypto-crystalline silicites, radiolarites, vitrophyric volcanites and occasionally serpentinites. The bioclastic content of the sandstones is composed of rare alga fragments, crinoid particles and foraminiferal tests (*Textularia, Miliolina* and *Rotalia*). The sandstones have a quartzose-clayey matrix which is partly recrystallized to phyllosilicate cement. The associations of accessory minerals are formed by zircon, spinel and rutile. Oval structures with colloidal infill, clusters of framboidal pyrite and apparently also idiomorphic crystals of tourmaline are authigenic in origin.

Dark calcareous claystones of the underlying formation are distinguished from the claystones of both the Fatra and Kopienec Formations mainly by their increased mica content, which clearly documents a change in the mechanisms of their deposition. The concentration of detritic mica is clearly a result of the hydrodynamic separation of currents in turbidite environment. Under microscope, the claystones have a microschlieren texture given by the preferred orientation of fine mica leaflets (microlites). The structure of the claystones is aleuropelitic, the silt admixture being dispersed in the clayey material or graded into laminae. At the base of the graded siltstone laminae, signs of current erosion can frequently be observed. The claystones are impregnated with a dark earthy substance and framboidal pyrite. X-ray powder diffraction analysis of whole rock preparations revealed the following composition of the claystones: Qz, I, Ch, Pg (probably albite) and carbonates. The fine fractions of claystones (< 2 μm) are formed by illite and chlorite. Cross sections of foraminifers are clearly outlined in the aleuropelitic material of the shales: the smaller tests regularly filled with pyrite, while the tests of the larger forms are not pyritized.

The highest abundance of foraminifers was observed in the claystone interval of 1784–1794 m. They are represented almost exclusively by planktonic forms. So far the more detailed systematic assignment of the foraminifers from thin section studies, only is possible since they have not been successfully obtained from washing of claystones. However, as already clear from cross sections, calcareous, perforated and trochospiral tests occur here belonging mostly to the representatives of the Upper Cretaceous foraminiferal plankton. It has been proved that foraminifers from the globotruncanid group are present here. Their closer determination was possible for the species *Kassabiana falsocalcarata* (Kerdany & Abdelsalam), *Globotruncanita calcarata* (Cushman), *Globotruncanella havanensis* (Voorwijk), *Rugoglobigerina* cf. *rugosa* (Plummer), *Globotuncana* cf. *arca* (Cushman) and *Globotruncana* sp. Apart from the Upper Cretaceous globotruncanid foraminifers, cross-sections of the Globigerina and Globorotalia- like tests, which could be Paleogene foraminifers, were identified in the thin sections as well. These are the species *Subbotina triloculinoides* (Plummer), *Morozovella pseudobulloides* (Plummer) and *Praemuranica* aff. *inconstans* Subbotina. The rotalid foraminifers *Kathina* cf. *selveri* Smout should also be a Paleogene species. It is not possible to unambiguously determine the age of the formation from the interval 1769–1833.1 m on the base of above mentioned foraminiferal association. However, the presence of planktonic foraminifers excludes the assumption of the Early Jurassic age of the formation (Kullmanová & Maheľ et al. 1975). The Upper Cretaceous planktonic species (Maastrichtian) were mostly identified here. However, stratigraphic evidence of the Upper Cretaceous foraminifers does not have to be valuable, because the presence of some younger forms points out to recyclicity. Therefore the age of the formation can also be a younger — Paleogene.

The study of nannoplankton also contributed to the age determination of the formation from the interval 1769–1833.1 m. The distribution of nannoplankton in the borehole profile is as follows (the Eocene forms are denoted by asterisk):

1774–1779 m: *Watznaueria barnesae* (Black) Perch-Nielsen, *Lithraphidites carniolensis* Deflandre, *Eiffellithus turriseiffeli* (Deflandre) and *Dictyococcites bisectus** (Hay et al.). The association contains Lower and Middle Cretaceous species and Upper Eocene coccoliths.

1784–1789 m, sample No. 175: *Watznaueria barnesae* (Black) Perch-Nielsen, *Nannoconus* cf. *steinmannii* Kamptner, *Lithraphidites carniolensis* Deflandre, *Cyclagelosphaera deflandrei* (Manivit) Roth, *Lotharingius* sp., *Discorhabdulus* sp., *Staurolithites crux* (Deflandre) Caratini. In this interval, nannoplankton association is poor, but represented by Jurassic and Lower Cretaceous species.

1784–1789 m, sample No. 175-B: *Watznaueria barnesae* (Black) Perch-Nielsen, *Eiffellithus turriseiffeli* (Deflandre) Reinhardt, *Zeugrhabdotus embergerii* (Noel) Perch-Nielsen,

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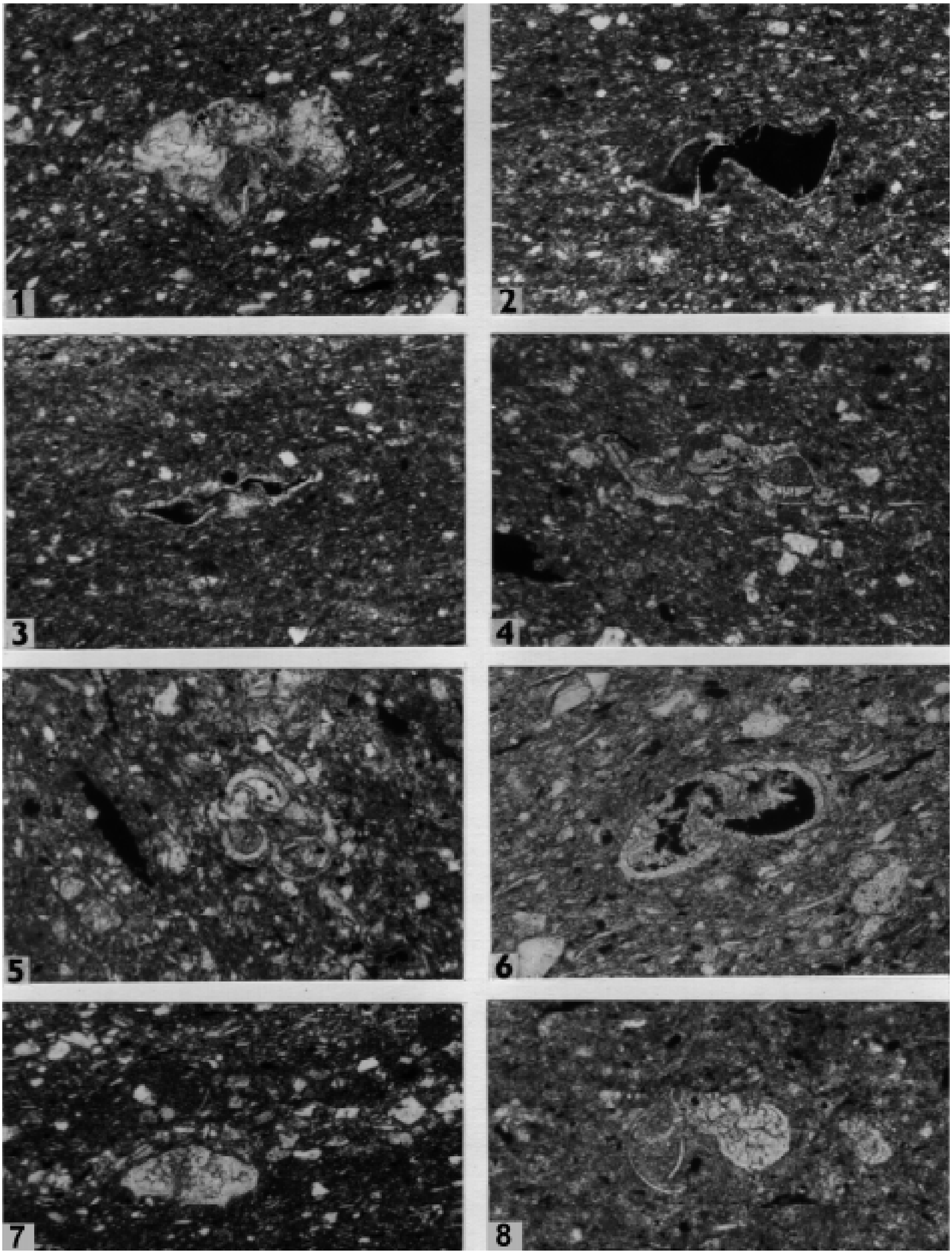
Plate II: Planktonic foraminifers in the Late Cretaceous? or likely Paleogene sediments from the base of the Mesozoic nappe complexes in the Podskalka MLS-1 borehole (1769-1806 m). **Fig. 1** — *Kassabiana falsocalcarata* (Kerdany & Abdelsalam), 1784-1789 m, magnif. 38×; **Figs. 2–4** — *Globotruncanita calcarata* (Cushman), 1784-1789 m, magnif. 38×; **Fig. 5** — *Rugoglobigerina* cf. *rugosa* (Plummer), 1792-1799 m; magnif. 38×; **Fig. 6** — *Globotruncanella hanavanensis* (Voorwijk); 1781-1785 m, magnif. 38×; **Fig. 7** — *Globotruncana* cf. *arca* (Cushman), 1792-1799 m, magnif. 38×; **Fig. 8** — *Morozovella* sp., 1784-1789 m, magnif. 38×.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*Coccolithus pelagicus** (Wallich) Schiller, *Tranolithus manifestus* Stover, *Helicosphaera bramlettei** (Müller) Jafar & Martini, *Biscutum constans* (Gorka) Black, *Rhagodiscus angustus* (Stradner), *Lotharingius hauffii* Gün & Zweili, *Lithraphidites carniolensis* Deflandre, *Dictyococcites bisectus** (Hay et al.) Bukry & Percival, *Gartnerago obliquum* (Stradner) Reinhardt, *Polycostella beckmannii* Thierstein and *Cyclagelosphaera margerelii* Noel. This nannoplankton association consists of Jurassic, Lower and middle Cretaceous forms and species from the Middle and Upper Eocene.

1792–1794 m, sample No. 177: *Nannoconus steinmanni* Kamptner, *Cyclagelosphaera margerelii* Noel, *Watznaueria barnesae* (Black) Perch-Nielsen, *Lithraphidetes carniolensis* Deflandre, *Lotharingius* cf. *hauffi* Grün & Zweili, *Cyclagelosphaera deflanderei* (Manivit) Roth and *Cyclicargolithus floridanus** (Roth & Hay) Bukry. The association contains some Lower Cretaceous species and Eocene coccoliths.

1792–1794 m, sample No. 177-B: *Watznaueria barnesae* (Black) Perch-Nielsen, *Rhagodiscus angustus* (Stradner) Reinhardt, *Eiffellithus* sp., *Zeugrhabdotus embergerii* (Noel) Perch-Nielsen, *Eprolithus antiquus* Perch-Nielsen, *Micrantolithus hoschulzii* (Reinhardt) Thierstein, *Lithraphidites carniolensis* Deflandre and *Cyclagelosphaera margerelii* Noel. The identified species belong to the Lower and Middle Cretaceous nannofossils (Hauterivian–Aptian).

1798–1800 m: *Watznaueria barnesae* (Black) Perch-Nielsen, *Rhagodiscus asper* (Stradner) Reinhardt, *Lotharingius velatus* Bown & Cooper, *Zeugrhabdotus embergerii* (Noel) Perch-Nielsen, *Nannoconus* sp., *Eiffellithus turriseiffelii* (Deflandre) Reinhardt, *Cyclagelosphaera deflandrei* (Manivit) Roth and *Cyclicargolithus floridanus** (Roth & Hay) Bukry. In the sample, Jurassic and Lower Cretaceous nannofossils are associated with Middle to Upper Eocene species.

The associations of nannoplankton in the claystones from the interval 1769–1833.1 m are formed mostly by a mixture of Jurassic, Lower and middle Cretaceous species. Apart from these clearly redeposited nannofossils, the species *Dictyococcites bisectus* (Hay et al.), *Coccolithus pelagicus* (Wallich), *Helicosphaera bramlettei* (Müller) and *Cyclicargolithus floridanus* (Roth & Hay) were also found in the associations. These species are known from the upper part of the Middle and Upper Eocene (zones NP 17–NP 19). The nannofossils from the claystones are apparently deformed and recrystallized. The youngest elements in the association also show these effects, which reduces the possibility of their contamination. Therefore, the occurrence of the youngest elements of the nannoplankton, which date the claystones to the Eocene, should be decisive for their stratigraphic assignment.

Tectonic reinterpretation of the Podskalka MLS-1 borehole

The Mesozoic formations in the Podskalka borehole show a fold-nappe structure with partial digitations, internal disconformities, stratigraphic repetitions, tectonic selection for thrust detachements etc. (Fig. 2).

The upper section of the Podskalka borehole is formed by cover part of the Humenné Unit having a structure of recumbent digitation. Lower Cretaceous, Jurassic and Rhaetian formations occur in its normal limb. The fold closure of the digitation structure occur in the underlying Keuper sediments (774 m), in which the detachment plane is based. In the overturned limb of the digitation, younger stratigraphic members are squeezed out, and only a synclinal bend with a comprimed sequence of Fatra and Trlenská Formation occurs beneath the Keuper sediments (“connective syncline”). At a depth of 835–836.5 m, a disturbed zone occurs dividing the cover digitation from the lower sole digitation of the Humenné Unit. It is based in the Keuper sediments of sole digitation, the core of which is built by a rigid limestone-dolomite complex at a depth of 1217–1723 m. The asymmetrical structure of the lower sole digitation is documented by the reduced sequence of Keuper, Fatra and Trlenská Formation sediments below the limestone-dolomite complex at the depth of 1723–1769 m.

The main tectonic division in the Podskalka borehole occur at a depth of 1769 m, at the contact between the allochthonous Mesozoic units and the underlying sediments. This division is not very significant structurally. It is shown only by the increased mechanical deformation in the top wall Rhaetian limestones (1723–1747 m) and the more moderate inclination of the underlying formation (15 to 20°). However the presence of a structural boundary here is provable by the significant discontinuity between the top wall Rhaetian–Liassic formation and the flat wall Late Cretaceous? or likely Paleogene formation.

Discussion and conclusions

The reinterpretation of the Podskalka borehole brought evidence of the presence of Late Cretaceous? or likely Paleogene sediments in the base of the Mesozoic nappe complexes of the Humenské vrchy Mts. This is a further fact testifying the allochthonity of the frontal parts of the Central Carpathian nappe units, which, in western territory, has been also proved by Soblahov-1 and Lubiná-1 boreholes (Kullmanová 1978; Leško et al. 1978). Soblahov-1 Borehole penetrated the formations of the Manín Unit, and in its basement reached a slice system of Keuper sediments, of Jurassic sediments with black shalles lithology and Upper Cretaceous Globotruncana-rich marls (Kullmanová 1978; Maheľ 1981, 1988). The Liassic “black-shalles” formation belongs to the sedimentary cover of the Tatric Inovec Unit (Kullmanová 1978), but in facies already approaches the “Bündnerschiefer” lithology regarding to that from the Vahic/Penninic domain (Maheľ 1988). However, the presence of deeply seated and overthrusted Lower Campanian sediments in the Soblahov-1 borehole convincingly documents the “post-Gosauian” movements of the frontal parts of the Central Carpathians nappes. Similar situation was also recorded in Lubiná-1 borehole, where the Eocene flysch formations of the Magura Unit were reached in the basement of the Manín or Drietoma Unit (Leško et al. 1978, 1982). According to Salaj & Priechodská (1987), the Paleogene formations from the deepest intervals of Lubina-1 borehole (2607–3230 m) could also belong to the Myjava Paleogene Group. Apart of borehole occurrences, the underthrusted Upper Cretaceous sediments come to the surface in the Považský Inovec Mts., where they crop out from below the Tatric crystalline basement nappe (Belice Unit — Plašienka et al. 1994). Considering the youngest member of outcropped sediments (Hranty Beds — Campanian up to Maastrichtian), the Belice Unit had been overthrusted by the Tatric basement nappe during the latest Cretaceous–earliest Paleogene (Plašienka 1995).

The structure of the Humenské vrchy Mts. long ago led to their allochthonous position being supposed. At the same time, it pointed mainly to intensive slice imbrication of the nappe units of this mountain range (Kullmanová & Maheľ et al. 1975; Maheľ 1986). However the most serious arguments in favour of the allochthonity of their structure derive from geophysical data. On the basis of interpretations of the gravity field, Pospíšil & Filo (1982) showed the possibility of a gravitational shifting of the Mesozoic nappe complexes of the Humenné vrchy Mts. onto the Klippen Belt and flysch area. They think that the movement of the Mesozoic nappe complexes into an allochthonous position was induced by the ascension of a mantle diapir from the SW into the area of the Iňačovce-Krichevo Unit. The extending of the Klippen Belt and flysch units into the basement of the Humenné structure is also interpreted in the geophysical profiles of Šútora et al. (1990a,b). Hovever, the direct evidence for allochthonity of the Humenné structure has been obtained from the Podskalka borehole only.

The solution of the assignment of the Paleogene sediments from the underlier of the Mesozoic nappe complexes in the Podskalka borehole gives several possibilities. Among these, the least probable is their assignment to the Central Carpathian Paleogene, which could have been inserted into the deep structure of the Humenské vrchy Mts. in the course of later backthrusting. The Central Carpathian Paleogene on the northern edge of the Humenské vrchy Mts. is represented by a basal sandstone-conglomerate formation and Súľov type conglomerates, the steep bedding of which points to the strong influence of post-Paleogene deformation. Therefore, the solution of the assignment of the basement unit is determined more by the relationship of the Mesozoic nappe complexes of the Humenské vrchy Mts. to the reduced parts of the Periklippen Zone and the more external flysch units.

A zone of intensive shortening and deformation of the Paleogene flysch formations occurs at the contact of the Central

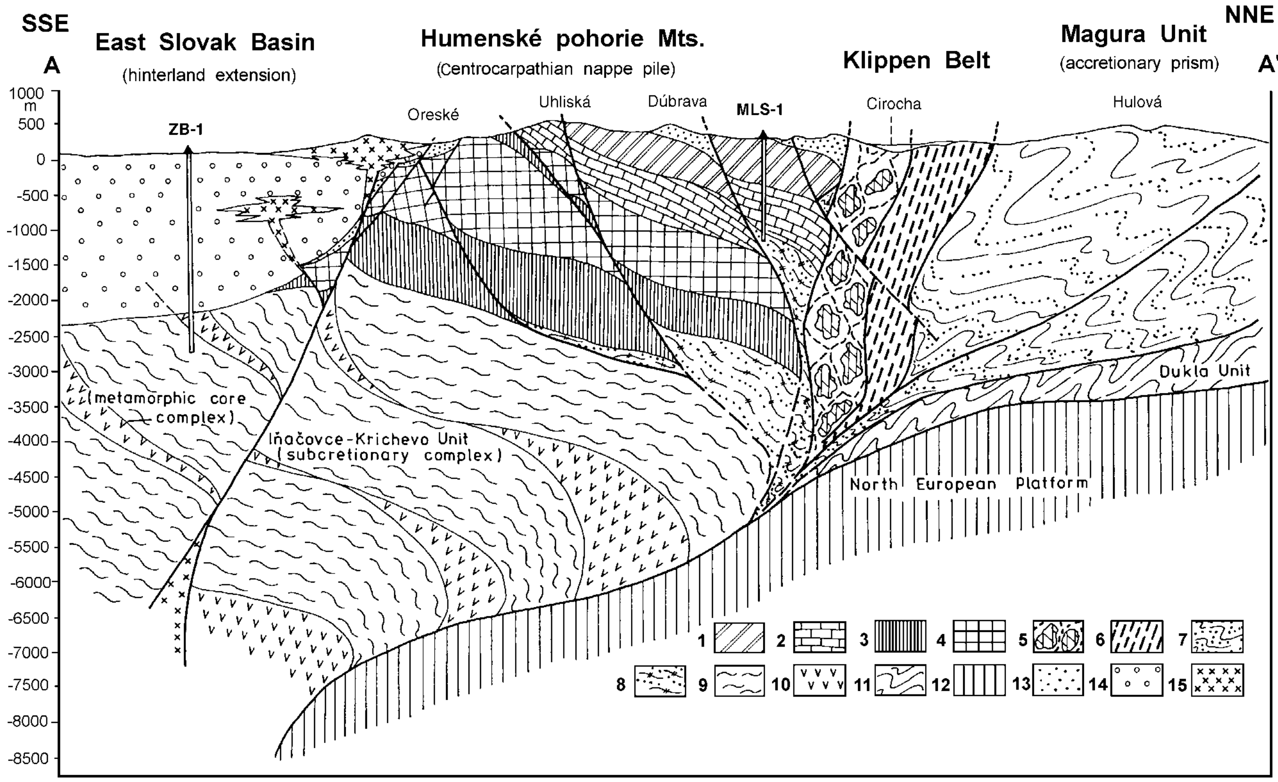

Fig. 3. Geological cross-section from the northern margin of the East Slovak Basin, passing through the Humenské vrchy Mts. to the Klippen Belt and Outer Flysch Carpathians. **1–4** Mesozoic units of the Humenské vrchy Mts. (Central Carpathian nappe system): *1* — Humenné Unit — cover part; *2* — Humenné Unit — sole part, *3* — Staré Unit, *4* — Strážske Unit; **5–6** Pieniny Klippen Belt: *5* — klippes with envelope of Púchov marls, *6* — Kyjov Beds; **7** — Magura Unit (detached and folded flysch sediments in the inner part of accretionary prism — out-of-sequence thrust); **8** — the Upper Cretaceous–Paleogene? formations beneath the Mesozoic nappe units of the Humenské vrchy Mts.; **9–10** Iňačovce-Krichevo Unit (rock complexes subcreted from subducting slabs and underplated sediments of external terranes); *9* — metasedimentary formations (Upper Triassic variegated phyllites and marbly limestones, Jurassic and Cretaceous formations of dark phyllitic schists, the Eocene metasediments with flysch lithology — EM, *10* — rocks derived from oceanic crust, mainly serpentinites (SE); **11** — Dukla Unit; **12** — North European Platform, **13** — Central Carpathian Paleogene — Jasenov-type lithofacies; **14** — Neogene infill of the East Slovak Basin; **15** — neovulcanites.

Carpathian Paleogene Basin and the Pieniny Klippen Belt in Eastern Slovakia (Šambron-Kamenica Zone). The fold-and-thrust deformation of this zone affected not only the Paleogene flysch formations but also the Mesozoic basement complexes (their tectonic slices in flysch sediments were sometimes interpreted as intraformational carbonate bodies, e.g. in the Plavnica 2 borehole). The significant intensity of shortening probably led to the tectonic amputation of this zone, while a part of the Paleogene formations in front of the collisional edge of the Central Carpathian units could have been pushed into their basement. A similar but much more developed mechanism of collisional shortening and underthrusting affected the more external units of the Pieniny Klippen Belt and flysch accretionary wedge. Therefore, the Paleogene sediments in the basement of the Humenské vrchy Mts. could also represent an underthrusted formations of the Pieniny Klippen Belt or Magura Zone. The tendency for underthrusting of the Klippen Belt and Magura Unit beneath the Central Carpathian units could be also inferred from the Hanušovce-1 borehole which was situated in the Pieniny Klippen Belt at the northern edge of the Hanušovce Horst, that is the western continuation of the Humenné elevation (Leško et al. 1984). Hanušovce-1 borehole penetrated Upper Cretaceous formations of the Pieniny Klippen Belt and at a depth of 4000–6003 m reached the Magura Unit (Leško et al. 1984). From the situation in Hanušovce-1 borehole, a shallower position could be assessed for the underthrusted units in the elevation structure of the Humenské vrchy Mts., where MLS-1 Podskalka borehole found them. However, from the lithological properties of these sediments, it is not possible to determine more closely their attribution to the external units, since the characteristic horizons are lacking (e.g. variegated pelites, menilite shales etc.). Flysch lithology, Upper Cretaceous redepositions and content of detrital spinels are common features of the Šambron Beds as well as of some Paleogene formations of the Pieniny Klippen Belt and Magura Unit (cf. Starobová 1962; Snopková 1990; Nemčok et al. 1977; Ďurkovič 1993 etc.). Therefore the Paleogene formations in the MLS-1 borehole do not have a closer specification from the point of view of their identity with external units. However the presence of these formations in the deep structure of the Humenské vrchy Mts. does not correspond only to a frontal overthrust of the Central Carpathian units, but to a deeper underthrust of the external units into the basement of the East Slovak Basin, where their metamorphic equivalents occur (Fig. 3).

The basement of the East Slovak Basin is formed by the Iňačovce-Krichevo Unit, which probably goes into the substratum of the Humenské vrchy Mts. (Leško et al. 1977). The Iňačovce-Krichevo Unit is composed of the Mesozoic metasedimentary and metaophiolitic rocks with Penninic lithologies (calcareous phyllites, black phyllitic schists, metaarenites, marbles, metaultramafites, metatuffites etc.). The youngest formations of the Iňačovce-Krichevo Unit become more flysch-like in character and belong to the Paleogene (Soták et al. 1994). They also suffered the metamorphic alteration under higher anchizone conditions up to lower epizone (Soták et al. 1995; Biroň et al. 1995). This metamorphism probably occurred under the Central Carpathian units nappe pile, since relicts of the nappes lie directly on the metamorphic complexes of the Iňačovce-Krichevo Unit in places (Hrušov-1 borehole). In this case, the metamorphosed Paleogene sediments from the basement of the East Slovak Basin would represent formations of the same unit as in the Podskalka borehole, but from a deeper level of underplating and accretion (10 km). The accretion-related structures of the Iňačovce-Krichevo Unit are developed mostly as underplate duplexes which were preferentially detached in the ductile horizons of the ultrabasic rocks. Such duplex structures are obvious since the metasedimentary Paleogene formations were also overlapped by the ultrabasic thrust slices (e.g. Zbudza-1 borehole, see Soták et al. 1993). The Paleogene sediments in the Podskalka borehole differ from those in the Iňačovce-Krichevo Unit by the absence of metamorphism. Therefore they may represent shallower parts of underthrusted units incoming into subduction in the final step of the convergence.

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