Upper Cretaceous to Lower Miocene of the Subsilesian Unit (Western Carpathians, Czech Republic): stratotypes of formations revised.

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Abstract: Type sections/areas for all four formations distinguished in the sedimentary succession of the Subsilesian Unit on Czech territory were revisited and described. New data on lithology, sedimentology, fossil record, biostratigraphy, heavy-minerals and geochemical proxies are based on observations and analysis of these sections. The historical type section of the Frýdek Formation was destroyed during railway construction in 19th century. Outcrops of Campanian to Maastrichtian marls and sandstones on the southwestern slope of "Castle hill" at Frýdek, are proposed as a new type section. The Ostravice riverbed in Frýdlant nad Ostravicí was originally designated as the type area, not mentioning the particular section. This area, even when supplemented with Sibudov Creek, does not show all typical facies of the formation. The outcrops range from lowermost Eocene to Eocene–Oligocene transition. In the original description of the Menilite Formation Glocker mentioned several localities in the area covering the Ždánice, Subsilesian and Silesian units, not mentioning the principal one. The single sections, each not exceeding a thickness of 2 m, are not sufficient to be a type section. Instead of that, we propose the area between Paršovice and Bystřice pod Hostýnem, covering the historical localities, as the type area. The type locality of the Ženklava Formation is an outcrop in an unnamed creek in Ženklava according to the original definition. It seems to be reasonable to extend the type section to the whole 500 m long section of the creek with the outcrops that better illustrate the lithological variability of the formation. New biostratigraphic data allow assignment to late Egerian (Eggenburgian?).

Key words: Subsilesian Unit, Outer Flysch Carpathians, Cretaceous, Palaeogene, Miocene, lithostratigraphy, biostratigraphy, heavy minerals, geochemistry.

Introduction

Geological studies of the Outer Flysch Carpathians in northern Moravia and Silesia started around the middle of the 19th Century. Generations of geologists accumulated a huge complex of knowledge. The delimitation of the Subsilesian Unit as a distinct nappe was done relatively late in connection with the development of micropalaeontology and biostratigraphy after the Second World War (Książkiewicz 1951; Hanzlíková et al. 1953). Formal lithostratigraphic subdivision of the sedimentary succession in the studied area into four formations was finished by Eliáš (1993, 1998). This complex of knowledge, nevertheless, contains a number of inadequate definitions and synonyms that caused further confusion. Inadequate description and confusion about the type locality led to the question of what actually is the Ženklava Formation. If we are correct, no attempt has been made since Glocker's geological studies in 1843 to choose a definite type locality from seven localities mentioned in the original paper. Finally, neither a detailed description, nor details of the position of the type sections for the Frýdek and Frýdlant formations have been published since these formations were described. These problems still need to be fixed for the sake of a definite and stable lithostratigraphy.

Type sections are an essential clue in the case of any doubt about the nature and position of a lithostratigraphic unit. Any revision or redefinition of units has to be based on study of the type section that serves as the standard documenting the true nature of the unit erected by the original author.

In today's open Europe the borderlines play a much smaller role then in the past. It is no longer acceptable that geological units stop at these borders just because of the isolation and traditionalism of national geological communities. Projects of European geological maps will demand more correlation and unification and the type sections may be needed for such a task.

The main objective of this paper is to provide adequate description of the type sections for all four valid formations of the Subsilesian Unit in its western sector (Moravo-Silesian Beskydy and its foothills) and select one type section from several original localities where needed.

Geological setting

The Subsilesian Unit is a part of the Outer Group of Nappes of the Outer Flysch Carpathians. It is exposed in a zone along the margin of the Outer Flysch Carpathians and also in several tectonic windows within the Silesian Nappe (Fig. 1). The zone runs for a distance of about 100 km from the vicinity of Kelč in Moravia to the vicinity of Bielsko-Biała in Poland (Eliáš 1998). In the broader concept of Polish authors the unit extends even much further to the Eastern Carpathians with possible equivalents in Ukraine (Ślączka et al. 2006). Eliáš (1998) compared this eastern sector of the Subsilesian Unit with the Kelč facies of the Silesian Unit. He interpreted the western continuation of the Subsilesian Unit as a part of the Eastern Alpine Helveticum.

Roth and Hanzlíková (1967) unified the Ždánice Unit and Waschbergzone in the South with the Subsilesian Unit in the North under the term "Ždánice-Subsilesian Unit". They argued with uniform facies development during the Late Cretaceous–Eocene. The Subsilesian Unit can still be understood as a distinct tectonic unit based on its specific structural features. Intense compression and the load of the robust and competent overlying Silesian Nappe deformed the sediments much more intensively compared with the same sediments in the Ždánice sector, outside the influence of the Silesian Nappe. The pelitic formations of the Subsilesian Nappe possess complicated structure with frequent tectonic slices, lenses, flat overturned folds and zones of tectonic breccia (Roth 1971; Menčík et al. 1983). The complexity of deformation increases at the base of the nappe. The upper part of the nappe includes slices of the overlying Silesian Unit.

The sedimentary succession of the Subsilesian Unit in Czech territory is subdivided into four formations: the Frýdek, Fýdlant, Menilite and Ženklava fms. (see Fig. 2). In Polish teritory the subdivision into formations was proposed by Olszewska (1997) on the basis of an unpublished lithostratigraphy elaborated by the working group of A. Wójcik for the general map of Poland. They distinguish (from base): Frýdek Fm., Węglówka Fm., Bachórz Fm. (="Hieroglyphic Beds"), Znamirowice Fm. (="Globigerina Marls"), and Rudawka Rymanowska Fm. (=Menilite Fm.). These formations are not widely accepted and various authors distinguish numerous informal units not assigned to any formation (e.g. Waśkowska 2011; Cieszkowski et al. 2012).

The sedimentary succession of the unit was deposited on the northern slope of the Silesian Basin and on the Subsilesian Ridge (Golonka 2011). Particularly the grey marls and siltstones of the Frýdek Formation in the western sector of the Subsilesian Unit represent typical slope facies. Red and variegated marls of Węglówka type were deposited under oligotrophic conditions and low sedimentary rates what indicate the setting of a submarine elevation (Subsilesian Ridge).

Material

Biostratigraphical, petrographical, mineralogical and geochemical data mentioned in description of the type sections are based mostly on newly collected rock samples. The small reference samples (rock pieces) are stored at sample depository of the Czech Geological Survey in Brno. Micropalaeontological residues, picked microfossils, thin sections and heavy mineral samples are stored in the same place.

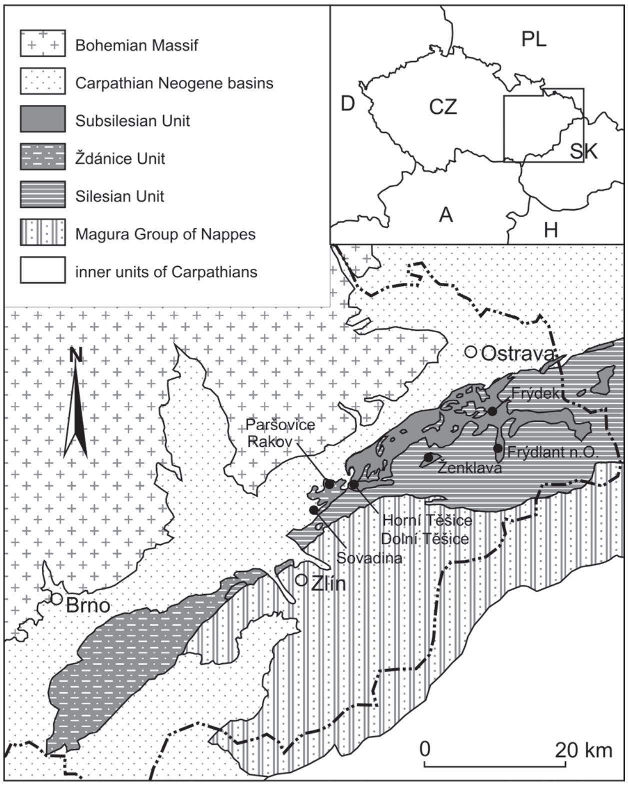

Fig. 1. Overview tectonic map with situation of type sections and areas in the Subsilesian Unit in Moravia.

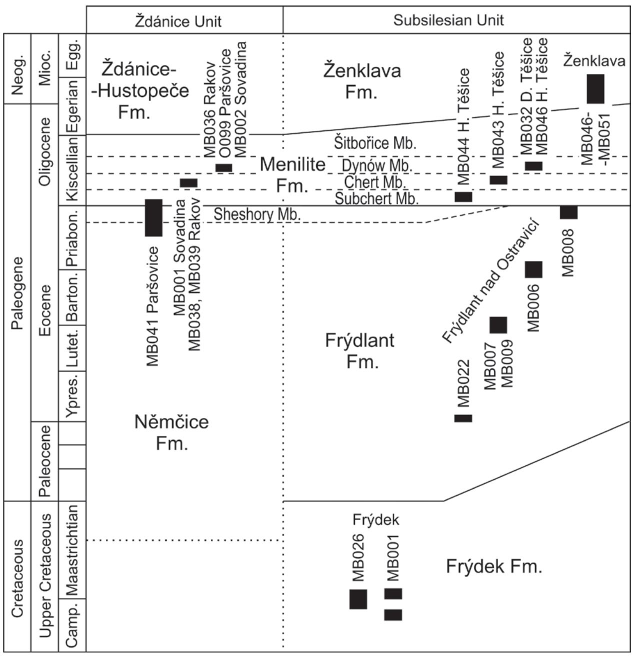

Fig. 2. Lithostratigraphic chart with stratigraphic ranges of studied sections.

Field observations including description of exposures, lithology, structures, GPS position, and photodocumentation are recorded in the documentation database of the CGS.

Methods

During the field observations the most complete sections were measured and described bed-by-bed. GPS position of sections was recorded using Garmin 60CSx (Table 1). The geological layer in the situation maps is based on the on-line geological map 1:50,000 of the Czech Geological Survey (www.geology.cz) but modified according to new field observations. The samples for microfossils were disintegrated in solution of sodium bicarbonate and washed on sieves of mesh size 0.063 mm. Microfossils from hard carbonate rocks were retrieved by an acetolysis using 80 % acetic acid following Lirer (2000). Microfossils were manually picked under binocular microscope. Smear slides for calcareous nannofossils were prepared using a decantation method (Švábenická 2012). Nannofossil data were correlated applying Upper Cretaceous UC (Burnett 1998) and Palaeogene NP (Martini 1971) and NNT (Varol 1998) nannoplankton zones. Photodocumentation of microfossils was done using an SEM microscope Jeol JSM-6380 microscope Nikon SMZ1500 equipped with camera ProgResCT3. Nannofossils were observed and documented using a Nikon Microphot-FXA transmitting light microscope. For study of heavy minerals the psammitic rocks were crushed and the size fraction 0.063–0.25 mm washed on sieves. Heavy minerals were separated from the sieved fraction using tetrabromethane ($C_2H_2Br_4$). When needed, opaque magnetic minerals were removed using a magnetic separator. The translucent heavy minerals were quantitatively analysed from counts between 200 and 1200 grains. The recorded % value reflects a grain number. The ZTR maturity index expresses total percentual quantity of zircon, tourmaline and rutile grains in the association. The index increases with both chemical and mechanical maturity of the psammitic fraction. Total inorganic carbon, total organic carbon and total sulphur (TIC, TOC and TS) were analysed using the ELTRA elementar analyser. Nannofossil slides, thin sections and heavy mineral fractions were prepared at the CGS laboratory in Prague. Processing of foraminifer samples and geochemical analysis were done at the CGS laboratory in Brno.

Frýdek Formation

History of studies

Hochstetter (1852) was the first to study the geology of the outcrop on the right bank of the Ostravice River below the Frýdek castle/chateau. Based on this outcrop he introduced a new stratigraphic unit "Friedek-Mergel" or "Friedek Schichten", now classified as the Frýdek Formation. Originally he characterized the strata as 20 to 30 feet thick ash grey marls, sandy in places, containing fine mica, frequent calcite veins, pyrite nodules and small gypsum crystals covering crack surfaces. At the base of the outcrop he reported a one-foot thick bank of calcareous sandy conglomerate composed of quartz grains, mica and coal fragments. Hochstetter (l.c.) also reported in detail finds of *Baculites* ammonite fauna within the marls. Based on these finds Hohenegger (1852) assigned the "Baculiten-Schichten" to the Gault and later (1861) correlated them with the "Plänermergel" (Turonian–Coniacian) of the Bohemian Cretaceous Basin. Finally Liebus and Uhlig (1902) produced a systematic description of the ammonites and recognized the "upper Senonian" age of this fauna. Růžička and Beneš (1949) conducted the first micropalaeontological investigations and reported rich Upper Cretaceous foraminifer fauna. Eliáš and Hanzlíková (1964) informed about the results of petrographical and microbiostratigraphical study. Based on planktonic foraminifers, they assigned the strata at "Castle hill" to the Maastrichtian. Systematic study of foraminifers was done by

Table 1: Overview of the studied sections and their GPS position.

locality	section/ point	map sheet	latitude-longitude beginning	latitude-longitude end	formation
Frýdek	MB001	25-221	N49 41 05.0 E18 20 46.2	N49 41 03.1 E18 20 49.9	Frýdek Fm.
	MB026	25-221	N49 41 09.4 E18 20 34.8	N49 41 08.4 E18 20 37.9	
Frýdlant n. O.	MB006	25-223	N49 35 03.3 E18 21 55.9		Frýdlant Fm.
	MB007	25-223	N49 35 07.3 E18 21 55.7	N49 35 04.9 E18 21 55.7	
	MB008	25-223	N49 35 11.4 E18 21 54.9	N49 35 10.1 E18 21 55.5	
	MB009	25-223	N49 35 19.5 E18 21 56.5	N49 35 18.0 E18 21 55.7	
	MB010	25-223	N49 35 29.0 E18 21 58.1	N49 35 24.3 E18 21 55.9	
	MB021	25-223	N49 34 39.2 E18 22 02.8		
	MB022	25-223	N49 34 41.4 E18 22 01.6		
	MB023	25-223	N49 34 41.4 E18 22 01.6		
	MB024	25-223	N49 35 16.3 E18 21 57.9	N49 35 14.3 E18 21 58.5	
Sibudov	MB011	25-223	N49 34 51.0 E18 22 48.5	N49 34 51.1 E18 22 49.6	
	MB012	25-223	N49 34 49.3 E18 22 43.1	N49 34 50.5 E18 22 43.2	
	MB013	25-223	N49 34 46.4 E18 22 25.1		
	MB014	25-223	N49 34 45.0 E18 22 16.7	N49 34 44.4 E18 22 17.3	
Dolní Těšice	MB032	25-141	N49 29 34.1 E17 48 04.1		Menilite Fm.
	MB033	25-141	N49 29 16.3 E17 47 58.9		
Rakov	MB034	25-141	N49 29 09.0 E17 42 22.6		
	MB035	25-141	N49 29 03.6 E17 42 30.3		
	MB036	25-141	N49 29 04.6 E17 42 45.7		
	MB037	25-141	N49 29 02.7 E17 42 52.3		
	MB038	25-141	N49 29 19.4 E17 43 05.2		
	MB039	25-141	N49 29 11.9 E17 43 05.9		
	MB040	25-141	N49 29 04.7 E17 42 24.0		
Paršovice	MB041	25-141	N49 30 10.0 E17 42 18.4	N49 30 10.1 E17 42 19.4	
Sovadina	MB001	25-134	N49 25 12.0 E17 39 26.0		
	MB002	25-134	N49 25 19.2 E17 39 28.7		
Horní Těšice	MB043	25-141	N49 29 29.6 E17 47 42.7	N49 29 29.3 E17 47 41.8	
	MB044	25-141	N49 29 32.6 E17 47 33.0	N49 29 32.2 E17 47 33.1	
	MB046	25-141	N49 29 26.4 E17 47 42.6		
Ženklava	MB046	25-213	N49 33 44.8 E18 06 03.1	N49 33 44.5 E18 06 09.2	Ženklava Fm.
	MB047	25-213	N49 33 44.9 E18 06 09.7	N49 33 45.5 E18 06 11.7	
	MB048	25-213	N49 33 46.2 E18 06 13.1		
	MB049	25-213	N49 33 46.3 E18 06 16.9		
	MB050	25-213	N49 33 46.8 E18 06 19.8		
	MB051	25-213	N49 33 46.7 E18 06 22.8		

Hanzlíková (1969 and 1972), later supplemented with evaluation of calcareous nannofossils (Hanzlíková et al. 1982).

Description of outcrops

The south-western steep slope of the "Castle hill" in Frýdek has outcrops at two locations (Fig. S1 in the Supplementary Material file): below Hasičská street (section MB001) and below an orchard (section MB026). The slope is covered by dense growth of bush and trees.

MB001. At the present time, claystones and sandstones crop out in a few small flat isolated outcrops (Fig. 3A) over a distance of 96 m. Brown grey silty marls prevail over sandstones. The grey laminated fine-grained calcareous sandstones occur in banks up to 1 m thick. Locally, sandstone banks are deformed by gravity folds. The measured bedding dip indicates fold deformation (280/35°, 313/48°, 152/65°).

Fig. 3. Outcrops of the Frýdek Formation at Frýdek: **A** — calcareous sandstone at the type section (MB001), photograph: M. Bubík, 2012; **B** — Gravity fold consisting of calcareous sandstone below an orchard (MB026), photograph: M. Bubík, 2014.

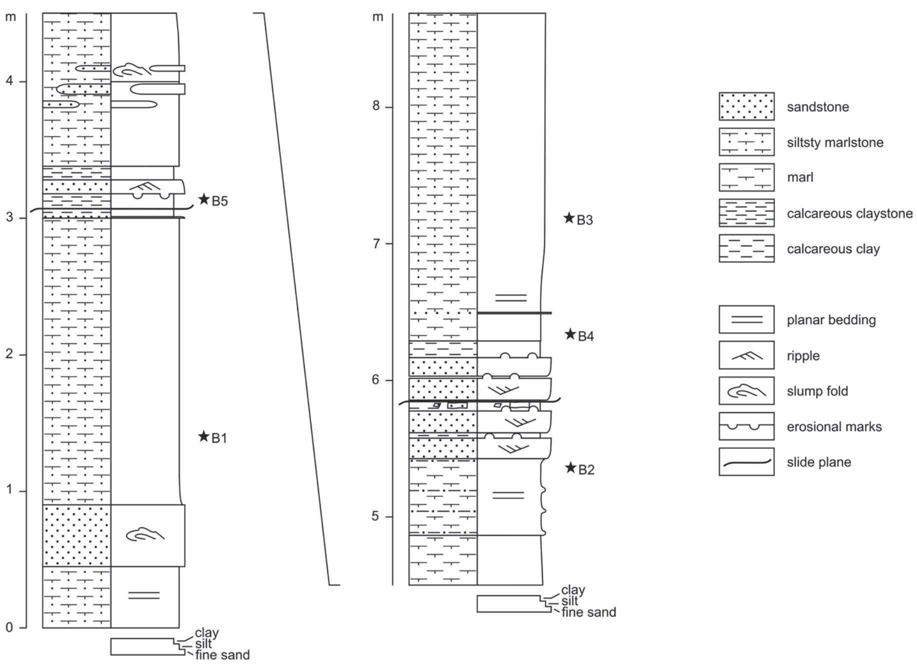

Fig. 4. Lithology and sedimentology of the MB026 Frýdek below an orchard with samples indicated by asterisk.

MB026. The isolated exposures are situated in a steep upper part of a railway cut below the old orchard over a distance of 70 m. At the north-western end of the cut, slope debris of coarse-grained biodetritic sandstone was observed. The largest exposure in the middle part of the cut represents an 8.5 m thick continuous section (Fig. S2 in the Supplementary Material file). Brown grey silty marls prevail over the grey marls and isolated banks of grey calcareous sandstone. Some sandstone banks are deformed to gravity folds (Fig. 3B).

Lithology and sedimentology

Grey brown calcareous silty marls are the prevailing rock type in the outcrops. Brownish grey weathered fine- to medium-grained calcareous sandstones occur in isolated banks 10 to 100 cm thick (Fig. 4). According Eliáš and Hanzlíková (1964) claystones comprise 50–60 % of silt and 5–10 % of sand. Greywacky sandstones comprise 30–45 % of calcite, 20–30 % of clay matrix, 25–45 % of subangular quartz, 1–2 % of feldspars, 1–2 % of bioclasts, 1 % of clayey clasts and accessoric muscovite, biotite, chlorite, pyrite, glauconite, siderite and dolomite.

Fine-grained calcareous sandstone to sandy limestone (MB001Z4) shows in thin section carbonate basal cement, that corrodes clastic grains. Silicification is observed in places. Well-sorted clasts comprise monocrystallic and aggregate grains of quartz (dominant), bioclasts (about 10 mod. %: mainly small calcareous benthic foraminifera, calcified sponge spicules, inoceramid prisms and phytodetrite), K-feldspar and plagioclase (20 mod. %), glauconite (3–5 mod. %), muscovite, biotite and chlorite (1 mod. %). Plagioclases prevail over K-feldspars. They used to be both sericitized.

Coarse-grained calcareous sandstone to sandy limestone (sample MB026A2; Fig. 5) has carbonate basal cement corroding clastic grains. The clastic component comprises sub-oval to subangular grains of monocrystallic and aggregate of quartz ranging between 0.5 and 0.75 mm (dominant), K-feldspar and plagioclase (20 mod. %), bioclasts (20 mod. %: mainly bryozoans, coralline algae, echinoid spines, small calcareous benthic fora-

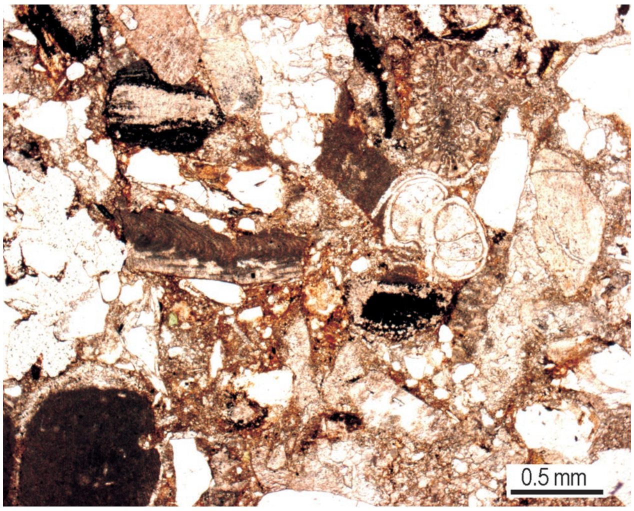

Fig. 5. Thin section of coarse-grained biodetritic sandstone with calcareous algae, bryozoans and benthic foraminifer *Gyroidinoides* sp. (sample Frýdek MB026A2).

minifera and plant debris), sub-oval pebbles of gneisses and mica schists (7 mod. %), muscovite, biotite, chloritized biotite and chlorite (5 mod. %), glauconite (2–3 mod. %) and rarely lithoclasts of carbonatized volcanite, granitoids and quartzites.

The sandstones represent turbidites with wavy lamination, ripple marks and burrowings. Silty marls with positive gradation were probably also deposited from turbidite currents. Gravity folds indicate high sedimentary rate and submarine slope failures that may locally disturb the stratigraphic order of strata. Hemipelagic sedimentation is indicated by the presence of deep-sea agglutinated foraminifer fauna (*Saccorhiza, Bathysiphon, Arthrodendron*) in the terminal part of graded marl rhythms.

Fossil record and biostratigraphy

Hohenegger (1861) reported from the type locality a mollusc fauna with *Baculites faujasi* Lam., *Belemnites lanceolatus* Sow., *Turrilites* cf. *undulatus* Sow., *Pinna nodulosa* Reuss and *Inoceramus latus* Mant. and compared it with the Turonian–Coniacian fauna of the Bohemian Cretaceous Basin. Based on revision of an old collection from Frýdek, Liebus and Uhlig (1902) described stratigraphically important ammonites *Baculites hochstetteri* Liebus and *Puzosia* aff. *planulata* Sow. indicating upper Senonian age. No ammonite finds have been reported since these times. Marls of the Frýdek Formation contain rich foraminiferal taphocoenosis. Hanzlíková (1969) assigned the Frýdek Formation based on the finds of *Abathomphalus mayaroensis* from test trenches on the slope of the Castle hill to the upper Maastrichtian. Later revision of biostratigraphy supplemented by calcareous nannofossils revealed that the main part of the section is lower Maastrichtian (Hanzlíková et al. 1982). The authors considered that the finds of *Abathomphalus mayaroensis* at the base of the section could come from another tectonic slice.

Newly collected micropalaeontological samples gave taphocoenosis dominated by small planktonic foraminifera (*Heterohelix, Macroglobigerinelloides* and *Rugoglobigerina*). Benthic foraminifera are represented by tiny calcareous taxa: *Quinqueloculina* sp., *Buchnerina* sp., *Patellina* sp., *Cribroconica* sp., *Praebulimina reussi*, *P. triangularis*, *Eouvigerina serrata*, *Globimorphina* sp., *Pyramidina cimbrica*, *Alabamina dorsoplana*, *Rotorbinella supracretacea*, *Pullenia marssoni*, *Pararotalia* cf. *bandyi*, *Gyroidinoides* spp., *Gavelinella* spp. etc. accompanied by scarce agglutinated forms *Spiroplectammina* spp. Sample MB001Z3). The coarser size fraction of residues contains usually robust forms of benthos like *Lenticulina* cf. *discrepans*, *Nodosaria* spp., *Siphonodosaria* spp., *Hemirobulina hamuloides*, *Praebulimina petroleana*, *Allomorphina obliqua*, *Nuttallinella florealis*, *Remesella varians* and keeled plankton *Globotruncana* spp. Claystones from the top of graded rhythms (samples MB026 B3, B4, B5) contained abundant large agglutinated taxa *Saccorhiza* sp., *Bathysiphon* spp. and *Arthrodendron* sp. Preliminary results of planktonic foraminifer study does not allow biostratigraphical subdivision within the upper Campanian–Maastrichtian interval.

The foraminifer fauna is accompanied by abundant calcite prisms from destroyed inoceramid shells. Less common are sponge spicules, calcispheres, coalified plant debris (tissues, seeds, and cuticles), echinoid elements and ostracods. Rarely calcified radiolarians and pyritized planktonic diatoms occur. Newly studied calcareous nannofossils enable us to distinguish three stratigraphic levels:

1) upper Campanian UC15e^{TP} zone with *Eiffellithus eximius* and *Zeugrhabdothus diplogrammus* (sample MB001Z1);

2) upper Campanian UC16a–b^{BP} zone with *Broinsonia parca constricta* and *Monomarginatus quaternarius* (sample MB026B5);

3) lower Maastrichtian UC17–18 *Reinhardtites levis* and *Biscutum magnum* (samples MB026B4 and MB001Z3).

The oldest level contains low-latitude taxa *Uniplanarius* spp., *Ceratolithoides* spp. (Fig. 6) and *Prediscosphaera grandis* together with high-latitude *Prediscosphaera stoveri* and *Monomarginatus quaternarius.* In the uppermost Campanian low-latitude taxa disappear (species of genus *Uniplanarius*) or occur scarcely (*Ceratolithoides aculeus*) while high-latitude taxa increase in quantity (*Micula staurophora, Kamptnerius magnificus*).

Heavy mineral assemblage

In the heavy-mineral fraction from sandstones opaque minerals prevail over the translucent. The fine-grained sandstone from the MB001 section contained garnet-zircon-rutile assemblage with minor tourmaline and staurolite, while the MB026 contained garnet-tourmaline-zircon assemblage with minor rutile, apatite and staurolite (Table 2). The ZTR maturity index shows medium values between 46 and 53 %. Similar assemblages were also recorded in the Frýdek Formation west of the type area.

Geochemical proxies

The typical brown grey pelitic rock from the Frýdek MB001 section shows rather low total organic carbon (TOC) of 0.53 % (Table 3), sulphur (TS) of 0.25 % and increased

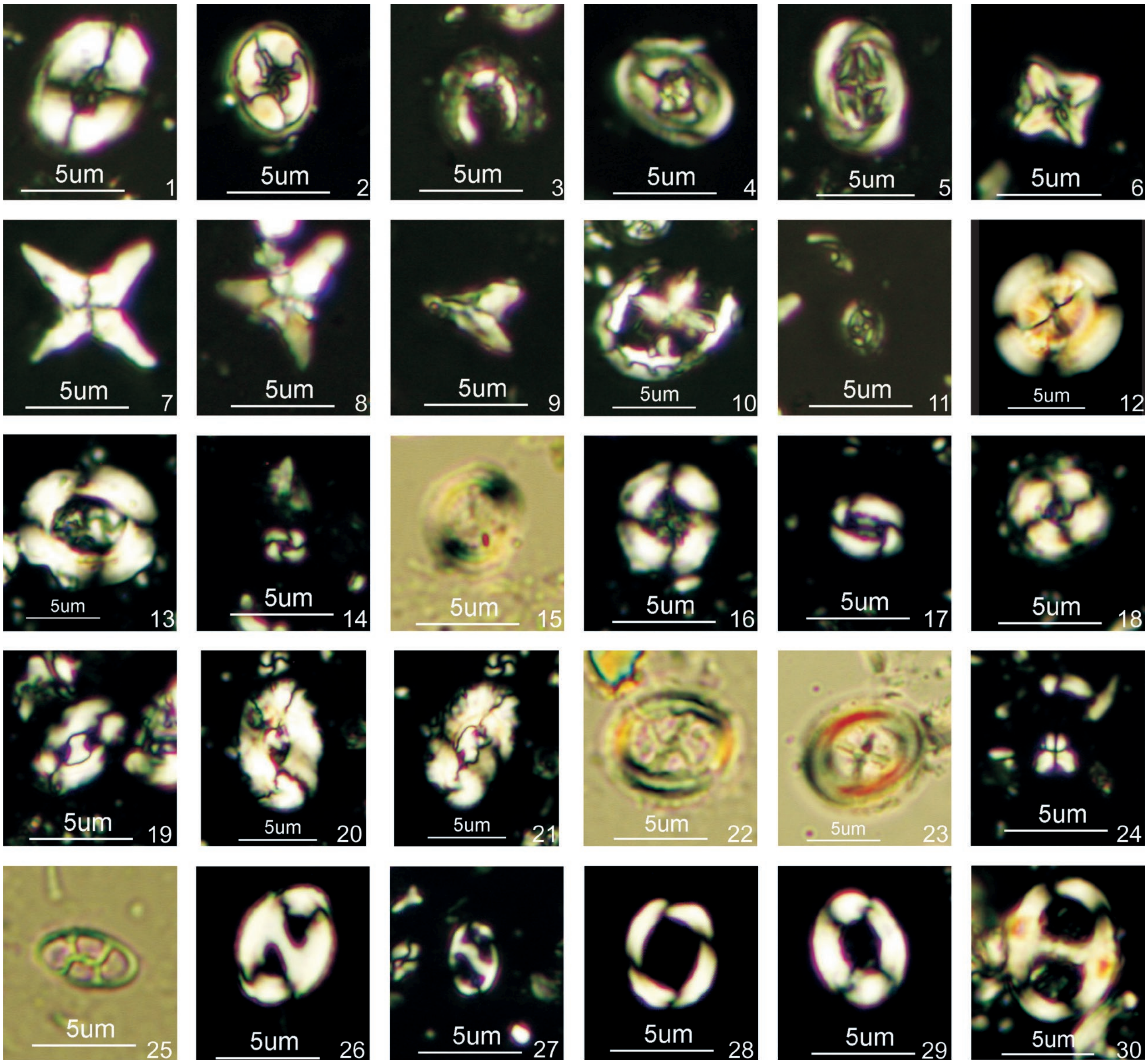

Fig. 6. Marker nannofossils from the Subsilesian Unit. **1** — *Broinsonia parca constricta*, Frýdek MB026B5; **2** — *Eiffellithus eximius*, Frýdek MB001Z1; **3** — *Biscutum magnum*, Frýdek MB026B4; **4** — *Reinhardtites levis*, Frýdek MB026B4; **5** — *Monomarginatus quaternarius*, Frýdek MB026B5; **6** — *Micula staurophora*, Frýdek MB026B4; **7** — *Uniplanarius sissinghii*, Frýdek MB001Z1; **8** — *Uniplanarius trifidus*, Frýdek MB0001Z1; **9** — *Ceratolithoides aculeus*, Frýdek MB001Z1; **10** — *Prediscosphaera grandis*, Frýdek MB001Z1; **11** — *Prediscosphaera stoveri*, Frýdek MB026B4; **12** — *Dictyococcites bisectus*, Frýdlant MB009; **13** — *Reticulofenestra umbilicus*, Frýdlant MB007; **14** — *Reticulofenestra minuta*, Paršovice MB041D; **15, 16** — *Reticulofenestra ornata,* Rakov MB036A; **17** — *Reticulofenestra lockeri*, Dolní Těšice MB032; **18** — *Coccolithus formosus,* Frýdlant MB008; **19** — *Helicosphaera bramlettei*, Frýdlant MB009; **20, 21** — *Helicosphaera intermedia*, Frýdlant MB008; **22** — *Chiasmolithus solitus*, Frýdlant MB009; **23** — *Chiasmolithus altus*, Paršovice MB041D; **24** — *Sphenolithus spiniger*, Frýdlant MB009; **25** — *Neococcolithus dubius*, Frýdlant MB009; **26** — *Pontosphaera obliquipons*, MB041D; **27** — *Pontosphaera sigmoidalis*, Frýdlant MB009; **28** — *Pontosphaera latoculata–magna*, Rakov MB036A; **29** — *Pontosphaera latelliptica*, Rakov MB036A; **30** — *Pontosphaera pax*, Dolní Těšice MB032. 1–14, 16–21, 24, 26–30 — cross-polarized light, 15, 22, 23 and 25 — plane-polarized light.

inorganic carbon (TIC) that corresponds to marl ($CaCO_3$ of 34 %). The exposed rocks in the Frýdek type area are partly weathered and the analytical data may be thus affected.

Remarks

The original type outcrop below the Frýdek castle was very probably destroyed during the construction of a railway finished in 1871. The slope directly below the castle seems to be artificially reshaped because of landslide risk and no outcrops can be seen there. The location of Hanzlíková's test trenches is unknown and no map or coordinates were given (Hanzlíková 1969 and Hanzlíková et al. 1982).

Reworked microfossils and the disturbed stratigraphic order of strata make the type area inappropriate for biostratigraphical study and the local zones of Hanzlíková (1969) can hardly be accepted. Hanzlíková et al. (1982) admitted a dis-

Table 2: Quantitative analysis of the translucent heavy minerals in psammites. Values express the relative number of grains in %. ZTR — maturity index (see Methods for details).

locality sample	Frýdek MB001Z4	Frýdek MB026	Sibudov MB011	Rakov MB037	Ženklava MB046	Ženklava MB050
garnet total	41.42	43.02	0.00	12.22	96.14	92.69
zircon idi.	5.02	4.88	20.00	2.89	0.08	0.14
zircon ov.	21.76	7.54	68.00	41.11	0.08	0.14
apatite	1.26	5.10	1.50	1.11	1.48	2.90
rutile	21.34	8.43	8.50	22.78	1.07	1.79
tourmaline	5.65	25.06	0.00	3.11	0.49	1.93
epidote	0.00	0.00	0.00	0.33	0.08	0.00
staurolite	2.30	3.99	0.00	6.22	0.08	0.00
amphibole	0.00	0.00	0.00	1.11	0.00	0.00
titanite	0.00	0.44	0.50	0.11	0.08	0.00
kyanite	0.00	0.00	0.00	7.33	0.00	0.28
monazite	0.42	0.22	0.00	0.11	0.16	0.00
chromspinel	0.21	0.00	0.50	0.11	0.16	0.00
glaucophane	0.00	0.00	0.00	0.33	0.08	0.00
brookite	0.63	0.44	0.50	0.00	0.00	0.00
sillimanite	0.00	0.00	0.00	0.89	0.00	0.00
anatase	0.00	0.22	0.50	0.00	0.00	0.00
other	0.00	0.66	0.00	0.22	0.00	0.14
grain count	484	451	200	901	1217	729
ZTR (%)	53.1	45.9	96.5	69.8	1.7	4.0

Table 3: Total inorganic carbon (TIC), organic carbon (TOC) and sulphur (TS) in typical lithotypes from the type localities.

locality	sample	lithology	TIC	TOC	TS	formation
Frýdek	MB001Z3	claystone	4.06	0.53	0.25	Frýdek Fm.
Frýdlant n. O.	MB007	marlstone	6.33	<0.05	0.40	Frýdlant Fm.
	MB010	marlstone	5.98	0.18	0.62	
	MB021	claystone	<0.05	1.39	1.31	
Rakov	MB036	chert	3.28	1.34	0.19	Menilite Fm.
Horní Těšice	MB043Š4	chert	<0.05	0.87	0.21	
	MB043Š6	claystone	<0.05	3.03	0.23	
	MB044E	marl	4.46	4.35	0.13	
Dolní Těšice	MB032A	marlstone	7.89	1.73	<0.05	
	MB032B	claystone	4.99	1.95	<0.05	
Ženklava	MB047A	claystone	<0.05	2.39	1.95	Ženklava Fm.
	MB047B	claystone*	0.55	3.2	2.34	
	MB050	claystone	0.44	1.47	<0.05	
	MB051	clay	1.10	1.14	0.24	

* concretion

turbance by faults (tectonic slices). Newly observed gravity folds apparently caused the overturned position of some intervals of the section (Fig. S2 in the Supplementary Material file and Fig. 4). Some marls contained reworked shallow-water fauna of bryozoans, cidarids and serpulids (sample MB026A). A single specimen of Maastrichtian *Abathomphalus intermedius* was found together with a late Campanian nannofossil assemblage in the sample MB001Z2. The sample MB026B5 contained late Campanian nannofossils and sample MB026B4 early Maastrichtian although they came from two limbs of a single fold. All these observations may mean that the strata at the type area are to a smaller or larger extent part of a slump body.

Frýdlant Formation

History of studies

Eliáš (1993) defined the Frýdlant Formation as a replacement for the terminologically inappropriate name "Submenilitic Formation" sensu Menčík et al. (1983). He did not designate explicitly the type section but just mentioned "environs of Frýdlant nad Ostravicí, in particular, Ostravice riverbed" which should be accepted as the type area. Müllerová (1961) published the first biostratigraphic evaluation of the outcrops in this area based on foraminifers. She assigned the strata to the Late Eocene of the Subsilesian Unit. Unfortunately, she did not specify the position of studied samples along the river. Some outcrops in the Ostravice riverbed were assigned by mistake to the Menilite Formation on geological maps (Roth 1964, Menčík and Tyráček 1985, Menčík 1987). Menčík et al. (1983) speculated about the presence of the Šitbořice Member (Menilite Fm.) in Frýdlant referring to an unpublished report by Eva Hanzlíková on the biostratigraphy of the Menilite Formation. Nevertheless, Hanzlíková wrote about claystones underlying the menilite cherts (no longer exposed).

Description of outcrops

In the Ostravice valley at Frýdlant nad Ostravicí light grey mottled marlstones and brown grey mudstones are exposed in a series of outcrops. Varicoloured clays/claystones in Sibudov creek and a facies of dark grey claystones south of its tributary are also a part of the same area (Fig. S3 in the Supplementary Material file).

MB006. Dark grey brown calcareous mudstone with poorly preserved bivalve fauna is exposed in the high riverbank of the Ostravice.

MB007. Light brown grey marlstone outcrops along the right riverside (Fig. 7C).

MB008. Low outcrops in the riverbed near the right bank consist of grey brown calcareous claystone.

MB009. Extensive outcrops in the riverbed consist of bioturbated light brown grey marlstones (Fig. 7A).

MB010. Extensive outcrops in the riverbed and high right bank consist of the same marlstones as at MB009. The bioturbated marlstones (Fig. 7B) are interbedded with dark brown grey mudstones several metres thick.

MB011. Small, disturbed outcrops of green grey, brown grey and grey non-calcareous clays are situated in the bed of Sibudov creek. The clays include a lens-like turbidite layer up to 4 cm thick of grey calcareous glauconitic sandstone with ripple marks.

MB012. Green grey, brown grey and grey non-calcareous clays with hairy laminae of silty sandstone are exposed in meanders of Sibudov creek.

MB013. Green brown non-calcareous silty claystone exposed in a small right stream cut.

MB014. Brown grey non-calcareous silty clay exposed in a left stream cut includes 20 cm thick lens-like concretion of grey non-calcareous pelocarbonate (Fig. 8).

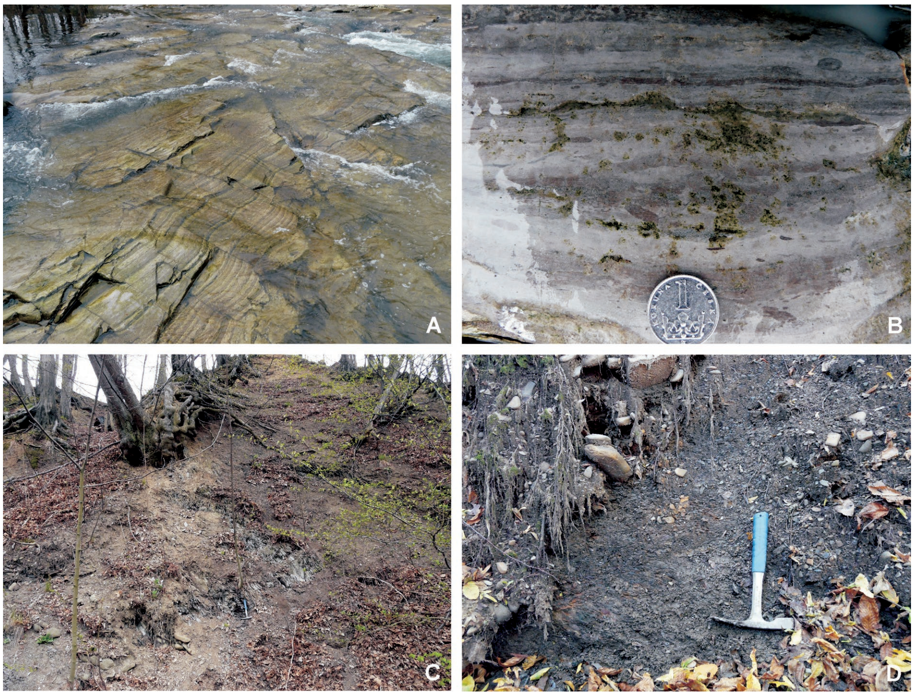

Fig. 7. Frýdlant Formation at Frýdlant nad Ostravicí: **A** — bedded bioturbated marlstones (MB009); **B** — *Chondrites–Planolites* ichnofabric in the marlstone (MB010); **C** — platy brown grey calcareous mudstones (MB007); **D** — dark grey non-calcareous claystones (MB021). Photographs: M. Bubík, 2012–2014.

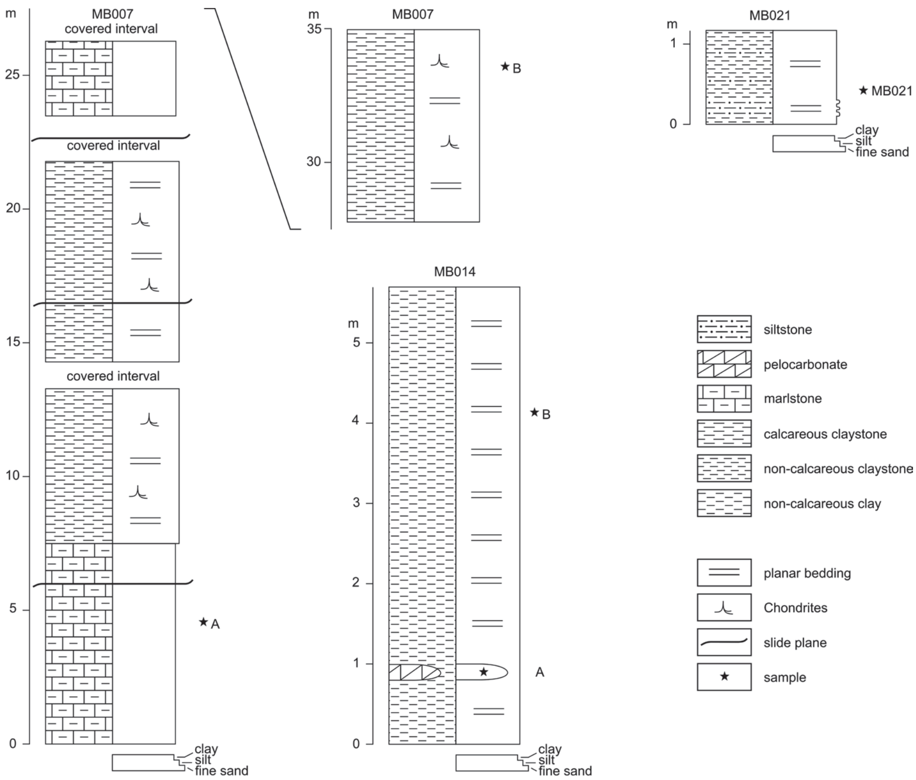

Fig. 8. Lithology and sedimentology of the Frýdlant Formation at selected sections in Frýdlant nad Ostravicí; samples indicated by asterisk.

MB021. Small cut along a right tributary to the Ostravice river exposed dark grey non-calcareous silty claystone intercalated with 2 mm thick siltstones (Fig. 7D).

MB022. Small outcrop of grey non-calcareous silty claystone among the roots of an old tree.

MB023. Small exposure of mottled (bioturbated) pale brown marlstone.

MB024. High right riverbank of the Ostravice with brown grey and grey brown calcareous mudstones with light *Chondrites* burrows.

Lithology and sedimentology

Generally the Frýdlant Formation in the type area consists of three lithofacies:

1) Whitish weathered, light brown grey mottled marlstones intercalated with brown grey calcareous mudstones — silty claystones (MB006–MB010, MB023, MB024). Locally intensively bioturbated horizons were observed. Rare slump layers consisting of brown grey mudstone matrix with intraclasts of marlstone occur.

2) Dark grey non-calcareous silty claystones (MB021).

3) Grey, brown grey and green grey non-calcareous clays with hairy-thin laminae of siltstone and sandstone (MB011–MB014).

A thin section of the light grey marlstone (sample MB010) shows prevailing matrix composed of clay minerals and carbonate. Silty admixture is composed of subangular to angular quartz about 0.05 mm in diameter (dominant), K-feldspar and plagioclase (minor), and phyllosilicates: muscovite, biotite, chlorite and glauconite (5–10 mod. %). Bioclasts (mainly foraminifer tests) form about 40 mod. % of the clastic component.

Sandstones are very rare and usually form laminae up to 10 mm. The only sandstone sample useful for microscopic study

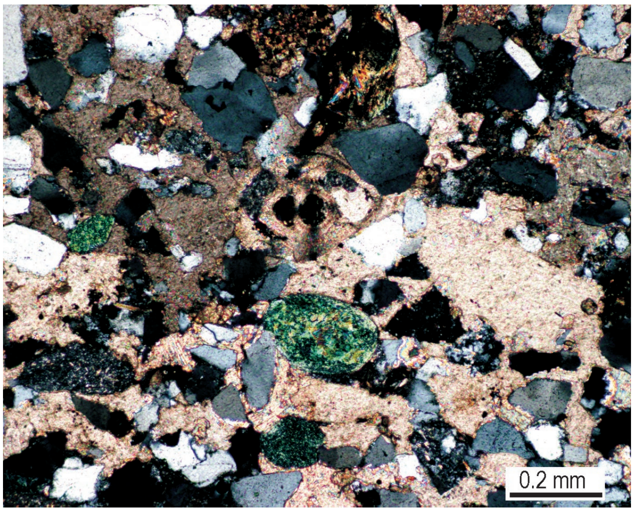

Fig. 9. Thin section of calcareous sandstone with glauconite and foraminifer *Lenticulina*, XPL, sample Sibudov MB011.

was medium-grained calcareous sandstone from Sibudov Creek (MB011; Fig. 9). The rock is poorly sorted and texturally immature. Basal-type cement is composed of carbonate, which corrodes clastic grains. Psammitic clasts comprise about 0.3 mm (exceptionally 0.9 mm) angular quartz grains (dominant), glauconite (about 5 mod. %), feldspars (up to 5 mod. %), chlorite (2–3 mod. %), micas (up to 2 mod. %), bioclasts (foraminifers, bryozoans; about 1 mod. %) and rarely sub-oval to oval lithoclasts of gneisses and basic volcanites. Monocrystallic quartz prevails over aggregate quartz. K-feldspar prevails over plagioclase.

Fossil record and biostratigraphy

The Frýdlant Formation is poor in macrofauna. Unidentified bivalves found in grey brown silty marlstones are probably reworked from shallower habitats (MB006). Intensive but monotonous *Chondrites–Thalassinoides* ichnofabric in mottled marlstones indicate a low-diversity burrowing infaunal community (MB010). In the intercalations of much-less bioturbated grey brown mudstones light-coloured *Chondrites intricatus* is common (MB010, MB024).

Middle to Late Eocene marlstones contain abundant foraminifers. Benthic taxa prevail over planktonics. Calcareous benthics *Homalohedra apiopleura, Siphonodosaria gracillima, Biapertorbis alteconicus, Svratkina perlata, Cibicidoides grimsdalei, Cibicides amphisyliensis, Nuttallides truempyi, Bolivina* spp., *Angulogerina* spp., *Globocassidulina* spp., *Reussella* sp. prevails over agglutinated forms *Rhabdammina* spp., *Bathysiphon robusta, Dolgenia lata, Reticulophragmium gerochi, R. amplectens, Spiroplectammina navarroana, Karrerulina coniformis* etc. Foraminifer microfauna is accompanied by sponge spicules, echinoid spines and pyritized diatoms "*Coscinodiscus*". Brown grey calcareous mudstones also contain frequent prasinophyte cysts *Tasmanites* sp.

Non-calcareous dark grey and varicoloured claystones contain a flysch-type agglutinated foraminifer assemblage with *Saccorhiza* sp., *Hyperammina nuda, Bathysiphon gerochi, Nothia* sp., *Lagenammina* sp., *Ammosphaeroidina pseudopauciloculata, Spiroplectammina navarroana, Karrerulina* spp. etc. Silicified cores of radiolarians (Spumellaria) and pyritized planktonic diatoms are common.

The following stratigraphic levels were recognized based upon planktonic foraminifers and calcareous nannofossils:

1) lowermost Eocene with solely agglutinated foraminifer assemblages containing *Pseudonodosinella elongata* (Fig. 10.1) , *Rzehakina minima* (Fig. 10.2) and *Plectorecurvoides parvus* (dark grey non-calcareous mudstones MB022, varicoloured non-calcareous clays MB011, MB013 and MB014);

2) Lutetian–Bartonian transition: calcareous nannofossils of the NP16 zone with *Sphenolithus spiniger, Chiasmolithus solitus,* and rare *Reticulofenestra umbilicus* — Fig. 6; planktonic foraminifera of the E10–E11 biochron with *Acarinina medizzai, A. bullbrooki* and *Jenkinsina columbiana* — Fig. 10 (MB007, MB009);

3) Bartonian–Priabonian transition: calcareous nannofossils of the NNTe11B zone (lower part of NP18) with *Helicosphaera bramlettei, Neococcolithus dubius* and *Dictyococcites bisectus* — Fig. 6; planktonic foraminifers younger than mid E13 zone with *Turborotalia increbescens* — Fig. 10 (MB006).

4) Eocene–Oligocene transition: calcareous nannofossils of the NP21 zone with *Coccolithus formosus, Helicosphaera* cf. *intermedia, H. euphratis* and *Pontosphaera obliquipons* — Fig. 6 (MB008).

H***eavy mineral assemblage***

The only available sandstone sample for heavy mineral analysis was medium-grained calcareous sandstone (Sibudov MB011). The heavy mineral fraction was strongly dominated by opaque minerals. The zircon-rutile assemblage of translucent heavy minerals has a very high content of zircons, especially oval shaped (Table 2). The ZTR maturity index is therefore high (96.5 %) and indicates a chemically mature source area and mechanical destruction of mesostable and unstable minerals.

Geochemical proxies

The TOC and TS values (Table 3) in mottled marlstones from Ostravice riverbed (MB007, MB010) are relative low and indicate oxic bottom conditions during the deposition. Dark grey claystone from the Frýdlant MB021 outcrop differs by elevated TOC and TS and very low carbonate content that illustrate dysoxic bottom conditions and negligible carbonate content.

Remarks

Eliáš (1993) characterized the environs of Frýdlant nad Ostravicí as an area with „illuminative sections of four fundamental facies of the formation", this means facies of mottled claystones, black grey claystones, variegated claystones and Stráž-type sandstones (Menčík et al. 1983), but does not mention the fifth facies of submarine slumps (Eliáš 1998). In fact just two of these facies were confirmed during detailed field observations in the type area: mottled claystones and black grey claystones. The first mentioned facies comprises

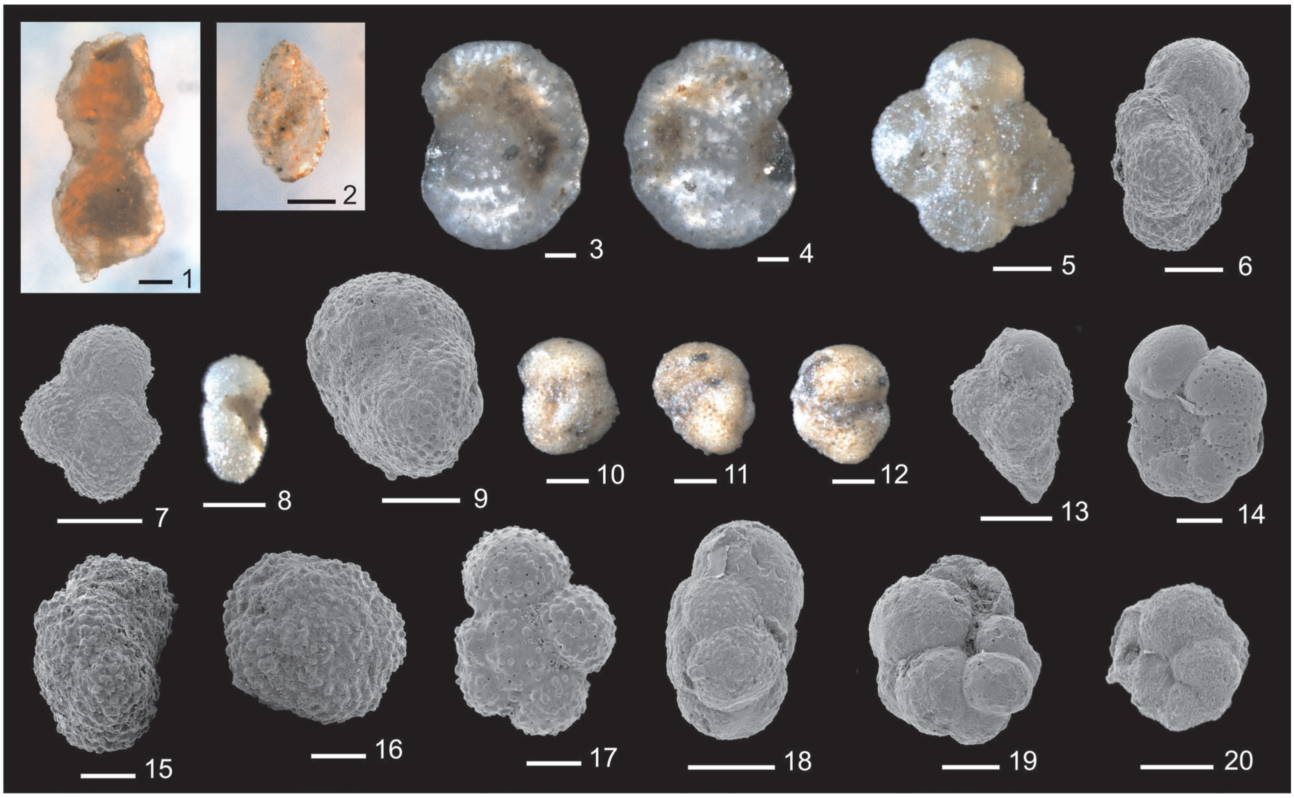

Fig. 10. Selected marker foraminifers from the Maastrichtian to lowermost Miocene of the Subsilesian Unit. **1** — *Pseudonodosinella elongata,* Frýdlant MB022; **2** — *Rzehakina minima*, Frýdlant MB022; **3, 4** — *Reticulophragmium gerochi,* Frýdlant MB008; **5–8** — *Rugoglobigerina rugosa,* Frýdek MB001Z3; **9–12** — *Turborotalia increbescens,* Frýdlant MB006; **13** — *Jenkinsina columbiana,* Frýdlant MB009A; **14** — *Pseudohastigerina naguewichiensis,* Paršovice MB041F; **15, 16** — *Acarinina medizzai,* Frýdlant MB009B; **17** — *Acarinina* cf. *medizzai,* Paršovice MB041F; **18** — *Turborotalita quinqueloba,* Ženklava MB051; **19–20** — *Cassigerinella chipolensis,* Ženklava MB051. 1–5, 8, 10–12 — optical microscope; 6–7, 9, 13–20 — SEM microscope. Scale bars: 1–12 — 100 μm, 13–20 — 40 μm.

light-weathering marlstones (MB009, MB010). These marlstones at first sight recall the Dynów Marlstones of the Menilite Formation which confused various authors of geological maps (Menčík et al. 1983, Menčík & Tyráček 1985, Menčík 1987). Brown grey mudstones were also used in the past as a diagnostic rock type for the Menilite Formation. From this point of view the type area is inappropriate. The environs of Třinec, where all five mentioned facies are exposed in numerous natural outcrops, would be a better choice for the type area. Revision of the Frýdlant Formation should be considered.

Menilite Formation

History of studies

The Menilite Formation is an important lithostratigraphic marker in Carpathian lithostratigraphy. It was first described in Moravia and its type section/area should be accepted only here. Glocker (1844) introduced the Menilite Formation based on outcrops in the area roughly between Kelč and Bystřice pod Hostýnem. His initial find of the diagnostic rock type — laminated menilite chert — was situated in the small village of Mrlínek about 2 km north of Bystřice pod Hostýnem. Subsequently he found menilite cherts and other associated rock types further to the west near Sovadina, near Lhotsko and at Horní Těšice, Dolní Těšice, Rakov and Paršovice near Kelč. Glocker did not designate the type section because in his times the concept of the type section still did not exist. Incidentally, the area of Glocker's field observations covers outcrops of the Menilite Formation in three different tectonic units: Ždánice, Subsilesian and Silesian nappes. This was a very happy choice, because the type area allows comparison of common features and differences between facies of the Menilite Formation in various tectonic units. In the 170 years since Glocker's times, no attempt has been undertaken to find and describe the original historical localities in detail. Jurášová (1974) described calcareous nannofossils as well as reporting the planktonic-foraminifer assemblage of the Subchert Member from Horní Těšice. Nothing more was published about the stratigraphy or palaeontology of these localities.

Description of outcrops

Among the historical localities of Glocker (1844) Horní and Dolní Těšice belong to the Subsilesian Unit. Rakov, Paršovice, Lhotsko and Sovadina belong to the Ždánice Unit. No outcrop of the Menilite Formation and even no rock debris were newly observed in ploughed fields near Lhotsko. The small quarry in Mrlínek, where Glocker (1844) discovered menilite cherts, does not exist any more and its location is forgotten. Newly observed outcrops at Mrlínek will be described in another paper dealing with type sections of the Silesian Unit.

Dolní and Horní Těšice area (Fig. S4 in the Supplementary Material file):

MB032 Dolní Těšice. In an entry of a badger burrow on a side of a small hill, pale brown laminated marlstone with a 3 cm intercalation of brown marl was observed. The marlstone debris on the slope contains the remains of sharks and fish including articulated fish skeletons. (Dynów Mb.)

MB033 Dolní Těšice. Debris of the pale brown marlstone and menilite chert covers the surface of the ploughed field. Isolated fish and shark remains are common. (Dynów Mb.)

MB043 Horní Těšice. Light brown silicified claystones with few menilite chert intercalations were newly excavated beneath loam in a series of 6 test pits along an old road over a distance of 18 m. (Chert Mb.)

MB044 Horní Těšice. The right cut of a small stream exposed slices and buddines of clays and marls of various levels of the Eocene within a strongly tectonically disturbed zone. A block of grey brown silty marl/marlstone to siltstone of the Subchert Member was found in this zone (Fig. 11).

MB046 Horní Těšice. Pale brown marlstone crops out in the steep landslide scarp. (Dynów Mb.)

Rakov area (Fig. S5 in the Supplementary Material file):

MB034 Rakov. Debris of brown grey laminated menilite cherts on the ploughed field. (Chert Mb.)

MB035 Rakov. Eluvial clay with debris of grey non-calcareous siltstones and few brown grey menilite cherts on the ploughed field (Chert Mb.+Němčice Fm.?).

MB036 Rakov. Small abandoned quarry opened on a small hill exposes pale grey brown marlstone intercalated with dark brown grey non-calcareous mudstone and banks of brown laminated menilite chert (Fig. 11). (Dynów Mb.)

MB037 Rakov. Debris of grey brown laminated and brecciated menilite cherts on a ploughed field. The cherts contained rare lenses of fine-grained glauconitic sandstone. (Chert Mb.)

MB038 Rakov. Small outcrop of menilite chert on the margin of a ploughed field. (Chert Mb.)

MB039 Rakov. Abandoned quarry(?) exposes pale brown grey siliceous "shale". (Chert Mb.)

MB040 Rakov. Debris of siliceous "shale", menilite cherts and Dynów-type marlstone (in proportion 10:7:3) on the ploughed field. (Chert Mb.+Dynów Mb.)

Paršovice area (Fig. S6 in the Supplementary Material file):

MB041 Paršovice. Cut around house foundations exposed green calcareous and non-calcareous clays and light brown grey sandy marl (Němčice Fm. with Sheshory Mb.) and overlying laminated light grey brown marl intercalated with dark brown clay (Subchert Mb.).

G041 Paršovice. Dark brown menilite chert on ploughed field. (Chert Mb.)

G042 Paršovice. Menilite cherts on ploughed field. (Chert Mb.)

O099 Paršovice. Pale beige marlstone in a road cut near a cemetery. (Dynów Mb.)

Sovadina area (Fig. S7 in the Supplementary Material file):

MB001 Sovadina. Abundant debris of various types of brown and grey menilite cherts covers a ploughed field. (Chert Mb.)

MB002 Sovadina. Debris of light grey brown marl and claystone were found in a pile dug from a water well. (Dynów Mb.)

Lithology and sedimentology

Generally, the Menilite Formation consists mainly of pelitic, carbonate and siliceous sedimentary rocks of pelagic origin and rich in organic matter (Fig. 12). The Formation can be divided into four formal members in all tectonic units based on characteristic rock types (Stráník 1981). The basal Subchert Member is characterized by brown marls. The overlying Chert Member contains "menilite cherts", which may be more precisely classified as opal silicites. The overlying Dynów Member consists mainly of Dynów-type marlstone, which can also be classified as nannofossil clayey limestone. A thin section of the marlstone (sample MB032) shows sporadic phosphatic fish remains and very rare sub-angular quartz in highly prevailing fine matrix. Intercalated thin laminae of graded siltstone contain 0.005–0.01 mm sub-angular to angular quartz grains and rarely small chips of muscovite and aggregates of glauconite. The Šitbořice Member in the upper part of the Formation consists mainly of brown and light grey claystones.

Small lithological differences between different units reflect different original positions within the Silesian Basin. The Subchert Member in the Subsilesian Unit consists of dark grey-brown silty marls and siltstones, while in the Ždánice Unit we find pale grey brown laminated marls intercalated with dark brown claystones. The Chert Member in the Subsilesian Unit consists predominantly of claystones intercalated with laminated menilite cherts, while in the Ždánice Unit menilite cherts dominate over silicified claystones. The Dynów-type marlstone is nearly identical in both units. In the Ždánice Unit it includes up to 55 cm thick layers of laminated menilite chert and thin intercalations of silty claystone. Exact comparison is, anyway, limited by fragmentary sections. At present time the Šitbořice Member is not exposed in the type area. Slightly calcareous grey, brown and dark grey clays of this member were encountered in a shallow borehole between Býškovice and Opatovice nearby.

While the Subchert and Šitbořice members comprise hemipelagites, the menilite cherts were deposited originally as diatom oozes and the Dynów-type marlstones as coccolith oozes. Turbidites are a subordinate component of all four members and usually form several mm thick graded laminae of siltstone or very fine sandstone, less frequently with ripples. Gravity folds of mm to m scale were frequently observed in the laminated menilite cherts and marls of the Dynów Member (Fig. 11B).

Fig. 11. Menilite Formation in the type area: **A** — grey brown platy claystone of the Subchert Member (Horní Těšice MB044); **B** — Dynów Marlstones interbedded with menilite cherts with synsedimentary fold (Rakov MB036). Photograph: M. Bubík, 2014.

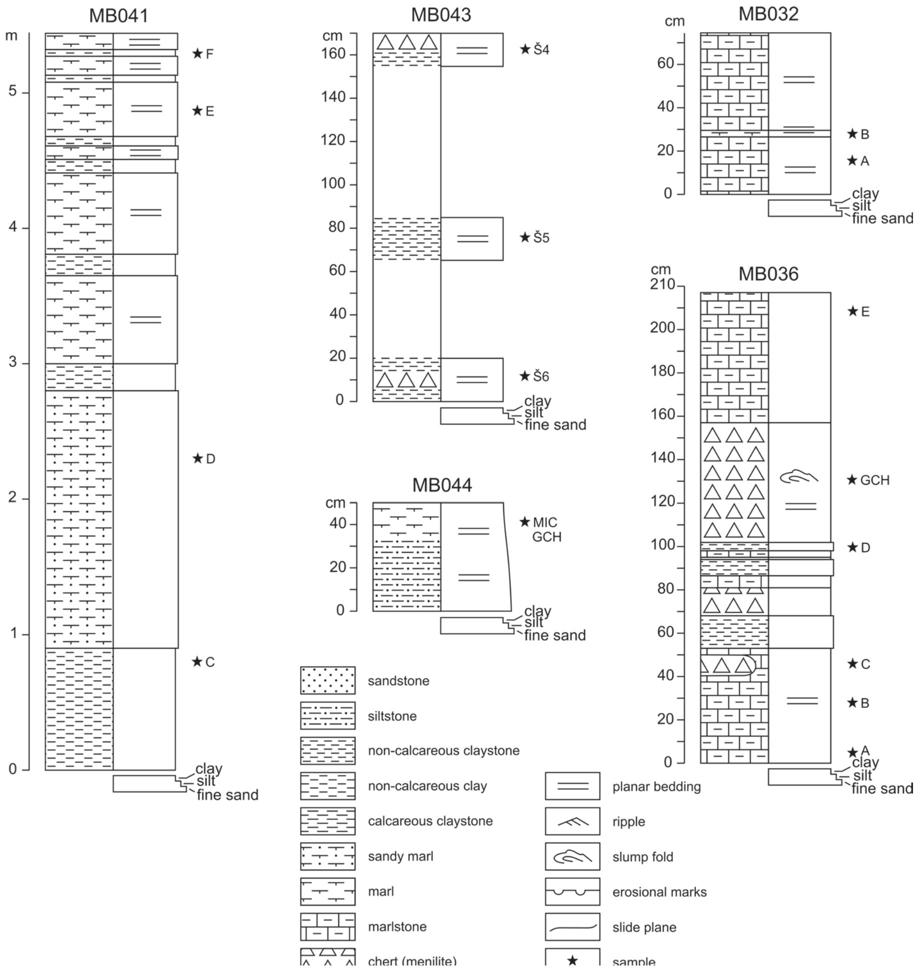

Fig. 12. Lithology and sedimentology of the Menilite Formation in the type area; samples indicated by asterisk.

Fossil record and biostratigraphy

Abundant fish remains are a characteristic feature of the Menilite Formation. The Chert Member in Horní Těšice (MB043) contained fish scales identified as (?)*Sardinella sardinites*, *Palimphyes*? sp. and an unidentified representative of *Myctophidae*. In the Dynów Member near Dolní Těšice (MB032 and MB033) the following isolated fish remains were found: (?) *Sardinella sardinites* (Heckel), *Gadidae* indet., *Zaenopsis*? sp., *Oligophus moravicus* (Pauca), articulated specimens of *Scopeloides glarissianus* (Agassiz) and gill rakers of shark *Keasius parvus* Leriche. Fish otoliths were recovered from the Subchert member at Paršovice (MB041).

The Sheshory Marl directly underlying the Menilite Formation at Paršovice (sample MB041D) contained the planktonic foraminifera *Chiloguembelina ototara, Pseudohastigerina naguewichiensis, Tenuitella* spp., *Subbotina eocaena, S. angiporoides, S. utilisindex, Globigerina officinalis, Dentoglobigerina galavisi, D. tripartita, Globoturborotalita ouachitaensis* etc. and benthic foraminifera *Dolgenia lata,* “*Rhizammina*” sp., *Bolivina* spp., *Lobatula lobatula, Svratkina perlata, Gyroidinoides, Melonis, Cibicidoides, Biapertorbis, Valvulineria, Oridorsalis* etc. The abundant and diversified calcareous-nannofossil assemblage (30 taxa) is dominated by the genus *Reticulofenestra* (mainly *R. minuta*) and contains representatives of *Helicosphaera, Pontosphaera, Zygrhablithus* and *Lanternithus* indicative for shallower habitats. The assemblage can be assigned to the upper part of the NP22 zone (Kiscellian) with *Reticulofenestra umbilicus* and *Chiasmolithus altus.*

The Menilite Formation has characteristic assemblages of foraminifers and calcareous nannofossils specific for each member of the formation. The assemblages are more or less of low diversity. The Subchert Member at Paršovice (samples MB041E and F) contained a planktonic foraminifer assemblage with *Globigerina officinalis, G. praebulloides, Pseudohastigerina naguewichiensis, Tenuitella gemma* and *Chiloguembelina ototara* of the Eocene-Oligocene transition (biochron E16–O1). Benthic foraminifer assemblage comprises representatives of *Cibicidoides, Bolivina* and *Angulogerina* prevailing over *Globocassidulina subglobosa,* *Biapertorbis biaperturatus, Reussella* sp. and the last elements of flysch-type agglutinated fauna: *Hyperammina*? sp., *Ammodiscus* sp., *Paratrochamminoides* sp. in less calcareous horizons (sample F). Compared with the underlying Sheshory Marl, the calcareous nannofossil assemblage with 19 taxa contains more *Coccolithus* spp. but less shallow-water elements like *Pontosphaera* spp., *Helicosphaera* spp. and *Chiasmolithus altus* (MB041F). It can be assigned to the upper part of the NP22 zone with *Reticulofenestra umbilicus.* The laminated marl has abundant pteropods *Spiratella*? sp. on bedding planes (sample E). Marlstone of the Subchert Member from Horní Těšice (MB044E) contained poor planktonic foraminifer fauna with *Globigerina officinalis* and *Tenuitella brevispira*. The benthic assemblage comprises *Bolivina vaceki, Globocassidulina subglobosa, Cibicidoides* sp. and *Biapertorbis* sp. Calcareous nannofossils from Horní Těšice were described by Jurášová (1974).

The soft claystones of the Chert Member from Horní Těšice (MB043Š5) contained just scarce and fragmentary sponge spicules. Foraminifers are primarily missing and a single find of a pyrite cast of an unidentified benthic foraminifer may be redeposited.

Relatively abundant microfauna was recovered from pale brown marls of the Dynów Member from Sovadina (MB002A) and Rakov (MB036A). It comprises fish bones, sponge spicules, foraminifers and ostracods. The ostracods are smooth-shelled forms recalling fresh/brackish-water taxa. Together with fish remains they may be autochthonous while the foraminifer fauna is very probably completely reworked. The plankton comprise Palaeogene *Globigerina praebulloides, G. officinalis, Dipsidripella danvillensis*, and Cretaceous *Macroglobigerinelloides bollii, Muricohedbergella delrioensis, M. planispira* and *Heterohelix planata*. Benthic foraminifera comprise long-ranging taxa: "*Rhizammina*" sp., *Kalamopsis*? sp., *Ammodiscus* cf. *cretaceus*, *Globocassidulina subglobosa, Bolivina vaceki, Cibicides amphisyliensis, Trifarina* sp., *Osangularia* sp., *Cibicidoides* spp., *Escornebovina* sp., *Gavelinella* sp. etc. Low-diversity calcareous nannoplankton comprises *Reticulofenestra lockeri*, *R.* cf. *ornata* and *Pontosphaera pax* (Dolní Těšice MB032) or, more typically, bloom of *Reticulofenestra ornata* accompanied by scarce *Pontosphaera pax, P. latelliptica* and *P. magna* (Rakov MB036A). Reworked nannofossils from older Palaeogene and Upper Cretaceous strata were also recorded. *Reticulofenestra ornata* may have adapted to hyposaline waters and *Pontosphaera pax* to lagoonal habitats (Aubry 1990). Blooms of *Reticulofenestra ornata* were recorded within the NP23–NP24 zone interval of the Western Carpathians (Švábenická et al. 2007).

Heavy mineral assemblage

Psammitic rocks in the type area of the Menilite Formation are practically missing. Rare thin lenses of fine-grained glauconitic sandstone from laminated menilite cherts from Rakov (MB037) were used for the heavy mineral analysis. The quantity of opaque and translucent heavy minerals is nearly equal. The assemblage of translucent heavy minerals was surprisingly rich and may be classified as zircon-rutile-garnet, with relatively important admixture of metamorphogenous minerals: kyanite, staurolite and tourmaline. Accessoric presence of glaucophane indicates a high-pressure metamorphic source. Good preservation of mesostable and even unstable minerals may be explained by the sealing ability of cherts against dissolution and leaching. The ZTR maturity index is relatively high and strongly contrasts with very low values in the overlying Ženklava Formation.

Geochemical proxies

A marlstone of the Subchert member has the highest TOC among the analysed set from the Subsilesian Unit (4.35 %, Table 3) indicating the anoxic conditions during the deposition. The siliceous claystone of the chert member showed TOC of 3 %. The menilite chert from the Chert Member and Dynow Member showed lower TOC which may be affected by partial oxidation of the organic matter. Marlstone and marl from the Dynów Member (Dolní Těšice MB032) have TOC as high as 1.7–2 % which indicates the anoxic conditions confirmed by taphonomic features (articulated fish skeletons). Another interesting finding suggests that some menilite cherts included in the Dynów Member possess TIC indicating a carbonate content of about 27 % and may be classified rather as siliceous marlstones (Rakov MB036).

Remarks

The outcrops of the Menilite Formation at original localities of Glocker (1844) represent just small fragments of its total thickness that may be estimated at about 50 m. None of the newly studied outcrops exceeds the thickness of two metres and can hardly be proposed as the type section of the formation. None of the studied outcrops exposes the boundary between any of the four members of the formation. For now it seems to be reasonable just to accept the type area between Paršovice and Bystřice pod Hostýnem.

Ženklava Formation

History of studies

The Ženklava Formation was introduced by Eliáš (1998). In the English summary of the monograph he specified the type locality as a creek 150 m southwest of a chapel in Ženklava. In the type description of the formation Eliáš (l.c.) did not provide any petrographical, sedimentological or micropalaeontological data pointing to badly weathered rocks. In previously published geological maps the Ženklava Formation in Ženklava is assigned partly to the Frýdlant Fm., partly to the Menilite Fm. (Menčík & Tyráček 1985; Roth 1989).

Description of outcrops

The type locality is situated on the western border of the Ženklava Tectonic Window. Besides the place designated by Eliáš (1998), isolated outcrops of the Formation continue upstream along the creek (Fig. S8 in the Supplementary Material file).

MB046 Ženklava. Brown grey non-calcareous silty claystones with subordinate laminated siltstones and fine-grained calcareous sandstones in a few banks up to 20 cm thick are exposed in several small isolated outcrops in the creek.

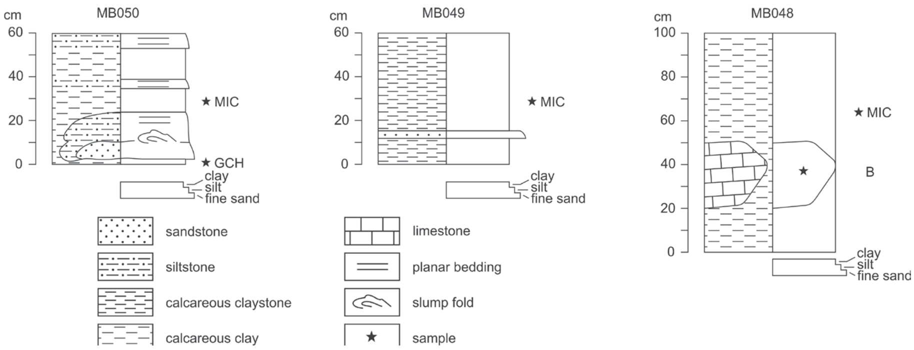

Fig. 13. Lithology and sedimentology of the Ženklava Formation at selected isolated outcrops at the type area; samples indicated by asterisk (MIC — micropaleontology, GCH — geochemistry).

Fig. 14. Type locality of the Ženklava Formation at small creek in Ženklava. Tower of the Ženklava chapel visible at the mid top of picture. Photograph: M. Bubík, 2014.

MB047 Ženklava. Black grey platy non-calcareous claystones crop out in the left cut of the stream.

MB048 Ženklava. Dark grey calcareous clays with fragments of clayey limestone bank (block?) crop out in the left bank of the creek (Fig. 13).

MB049 Ženklava. Brown grey silty calcareous claystone is exposed in the right bank of the creek (Fig. 13).

MB050 Ženklava. Dark grey non-calcareous silty clay to clayey siltstone in the left bank of the creek contains gravity fold consisting of grey fine-grained calcareous sandstone (Fig. 13).

MB051 Ženklava. Weathered soft grey slightly calcareous clay with silty layers crops out in the creek bed (Fig. 14). This outcrop corresponds to the type section according to Eliáš (1998).

Lithology and sedimentology: Brown grey silty non-calcareous claystones and siltstones are the dominant lithology. Locally platy black grey non-calcareous claystones stained on surfaces by limonite may recall claystones of the Menilite Formation. Calcareous claystones and clays occur along the eastern part of the creek (MB048, MB049, and MB051). Fine-grained calcareous sandstones are subordinate in banks up to 20 cm thick. In thin section the calcareous sandstone (sample MB046) reveals poorly sorted structure. Carbonate cement can be classified as pore-type or basal in places and corrodes some clastic grains. Sub-angular to sub-oval sand grains range in size between 0.2–0.3 mm. The quartz grains (both monocrystallic and aggregate) dominate over K-feldspar and plagioclase (10–15 mod. %), muscovite, biotite, chloritized biotite, chlorite and rarely glauconite. Plagioclase prevails over K-feldspar. Psefitic admixture comprises pebbles of gneisses, mica schists and volcanites (volcanic glass?).

Claystones, siltstones and sandstones of the Ženklava Formation are mostly muddy turbidites deposited in bathyal. The sandstones possess usually planar lamination (Tb) and some siltstones showed ripples (Tc–d). Gravity fold observed at MB050 is evidence of rapid deposition and slope failure (Fig. 26). Micropalaeontological analysis of rocks from MB048 proved presence of mudflow containing microfossils from older formations of the Subsilesian Unit and exotic block of Upper Jurassic limestone.

Fossil record and biostratigraphy

The prevailing silty non-calcareous claystones contain a pseudoassociation of calcareous and agglutinated foraminifers, sponge spicules and fish bones with abundant reworked component. The reworked species *Praemurica inconstans, Subbotina triloculinoides, Muricohedbergella planispira, Macroglobigerinelloides bollii, Haplophragmoides decussatus, Paratrochamminoides olszewskii* and *Cibicidoides* spp. came from various levels of the Upper Cretaceous to Eocene (sample MB046A). More reworked fauna was recovered from clayey matrix of mudflow (sample MB048A). The planktonic foraminifera *Rotalipora appenninica, Whiteinella baltica, Pseudotextularia elegans, Globotruncanella petaloidea, Globotruncana arca, Muricohedbergella monmouthensis, Globanomalina compressa, Catapsydrax unicavus* and benthic *Rzehakina lata–fissistomata* trans., *Spiroplectammina navarroana, S. dentata, Dorothia bulletta, Ramulina* sp., *Bolivinoides draco, Nonion troostae, Eouvigerina* gr. *elongata* come from various levels of the Albian–Eocene interval and most of them are common taxa of the Frýdek and Frýdlant formations. A block of exotic limestone contained the foraminifers *Trocholina nodulosa, Paalzowella feifeli, Spirillina concava, S. kuebleri,* holothurian sclerites, *Tasmanites* cysts and may be assigned to the Upper Jurassic.

The highest proportion of autochthonous foraminifer fauna was recorded in the eastern part of the creek — at points MB049, MB050 and MB051. Sample MB051 contained planktonic foraminifera *Cassigerinella chipolensis, Tenuitella brevispira, Tenuitellinata angustiumbilicata,* and *Turboro-*

talita quinqueloba indicating the late Egerian (Eggenburgian?), accompanied by reworked *Heterohelix planata, Muricohedbergella planispira, Pseudohastigerina micra, Acarinina bullbrooki, A. medizzai* and *A. pseudotopilensis*. The benthic component consists of *Glomospira charoides, "Rhizammina"* sp., *Spiroplectammina navarroana, Globocassidulina subglobosa, Bolivina dilatata, Angulogerina* sp., *Biapertorbis biaperturatus, Escornebovina* cf. *binominata, Epistominella* sp., *Valvulineria* sp., *Cibicidoides lopjanicus, Cibicides amphisyliensis* etc. The taphocoenosis also contained frequent pyritized planktonic diatoms "*Coscinodiscus*" sp. Calcareous nannofossils from the same sample are completely reworked from the Maastrichtian, Palaeocene, Upper Eocene and Lower Oligocene. The following species were identified: *Coccolithus eopelagicus, C. pelagicus, Cyclicargolithus* sp., *Dictyococcites bisectus, Discoaster* cf. *multiradiatus, Ellipsolithus distichus, Coccolithus formosus, R. lockeri, R. minuta, R. ornata, R. umbilicus, Micula staurophora, M. murus* and *Watznaueria barnesiae.*

Heavy mineral assemblage

Two samples of fine-grained calcareous sandstone from Ženklava were analysed for heavy minerals (MB046 and MB050). The ratio of opaque to translucent heavy minerals varies. The assemblage of translucent heavy minerals is clearly garnet type, with high dominance of the index mineral (96 and 92 %). Very low ZTR maturity indicates enhanced erosion of fresh metamorphic rocks in the source area. Generally garnet rich assemblages are typical for proximal flysch turbidites.

Geochemical proxies

The elevated TOC values in the partly weathered pelitic rocks of the Ženklava Formation indicate hypoxic conditions and in the case of black grey platy claystone (MB047A) even anoxic conditions, which is supported by high sulphur content and presence of abundant isolated fish bones. According to the TIC values the $CaCO_3$ content ranges from 0 % to 9 %. The upper value allows us to classify the rock as calcareous clay (MB051).

Remarks

Abundance of reworked microfossils and garnet association of the translucent heavy minerals is a characteristic feature of the Ženklava Formation at the type locality. At the same time it is typical for the Krosno Formation that is an analogue of the Ženklava Fm. in each mean. Small and fragmentary outcrops in Ženklava sufficiently illustrate the lithological variability of the formation only as a whole. It is therefore reasonable to extend the type section to the whole 500 m long section of the creek where Egerian strata are exposed.

Conclusions

In the Subsilesian Unit two original type sections (Frýdek and Ženklava) and two type areas (Frýdlant nad Ostravicí and Kelč area) were studied. These localities form the basis for definition of the four formal formations (Upper Cretaceous–lowermost Miocene) that form the sedimentary succession of the Subsilesian Unit.

A section near the destroyed historical locality below the Frýdek castle/chateau is newly proposed as a type locality of the Frýdek Formation.

The particular type section of the Frýdlant Formation was not specified by the original author. Due to fragmentary outcrops the type area is newly specified in an area where facies of dark-grey claystones and mottled marlstones were newly recorded. Three other fundamental lithofacies of the formation: variegated beds, Stráž-type sandstones and pebbly mudstones were not observed at Frýdlant. The hypotype localities for these three facies should be selected and studied.

As the original type area of the Menilite Formation between Paršovice and Bystřice pod Hostýnem has only small isolated outcrops not exceeding 2 m in thickness, the particular type section for the formation cannot be proposed at the present moment.

Based on the field observations and study of the Ženklava Formation at Ženklava, the extension of the type locality to the whole 500 m long creek section is proposed.

None of the discussed type localities or sections in the type areas are protected by law, and the stratotype status of the outcrops is not subject to protection at the present time. The protection is urgently needed and should be managed soon for the sake of Carpathian stratigraphy and preservation of the geological heritage for the future.

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Appendix 1.

The full names of species mentioned in the text

Planktonic Foraminifera

Abathomphalus mayaroensis (Bolli, 1951) ex *Globotruncana*
Abathomphalus intermedius (Bolli, 1951) ex *Globotruncana*
Acarinina bullbrooki (Bolli, 1957) ex *Globorotalia*
Acarinina medizzai (Toumarkine et Bolli, 1975) ex *Globigerina*
Acarinina pseudotopilensis Subbotina, 1953
Cassigerinella chipolensis (Cushman et Ponton, 1932) ex *Cassidulina*
Catapsydrax unicavus Bolli, Loeblich et Tappan, 1957
Chiloguembelina ototara (Finlay, 1940) ex *Guembelina*
Dentoglobigerina galavisi (Bermúdez, 1961) ex *Globigerina*
Dentoglobigerina tripartita (Koch, 1926) ex *Globigerina*
Dipsidripella danvillensis (Howe et Wallace, 1932) ex *Globorotalia*
Globanomalina compressa (Plummer, 1926) ex *Globigerina*
Globigerina officinalis Subbotina, 1953
Globigerina praebulloides Blow, 1959
Globotruncana arca (Cushman, 1926) ex *Pulvinulina*
Globotruncanella petaloidea (Gandolfi, 1955) ex *Globotruncana (Rugoglobigerina)*
Globoturborotalita ouachitaensis (Howe et Wallace, 1932) ex *Globigerina*
Heterohelix planata (Cushman, 1938) ex *Guembelina*
Jenkinsina columbiana (Howe, 1939) ex *Guembelitria*
Macroglobigerinelloides bollii (Pessagno, 1967) ex *Globigerinelloides*
Muricohedbergella delrioensis (Carsey, 1926) ex *Globigerina*
Muricohedbergella monmouthensis (Olsson, 1960) ex *Globorotalia*
Muricohedbergella planispira (Tappan, 1940) ex *Globigerina*
Praemurica inconstans (Subbotina, 1953) ex *Globigerina*
Pseudohastigerina micra (Cole, 1927) ex *Nonion*
Pseudohastigerina naguewichiensis (Myatliuk, 1950) ex *Globigerinella*
Pseudotextularia elegans (Rzehak, 1891) ex *Cuneolina*
Rotalipora appenninica (Renz, 1936) ex *Globotruncana*
Rugoglobigerina rugosa (Plummer, 1926) ex *Globigerina*
Subbotina angiporoides (Hornibrook, 1965) ex *Globigerina*
Subbotina eocaena (Guembel, 1868) ex *Globigerina*
Subbotina triloculinoides (Plummer, 1926) ex *Globigerina*
Subbotina utilisindex (Jenkins et Orr, 1973)
Tenuitella brevispira (Subbotina, 1960) ex *Globigerina*
Tenuitella gemma (Jenkins, 1966) ex *Globorotalia*
Tenuitella praegemma (Li, 1987) ex *Praetenuitella*
Tenuitellinata angustiumbilicata (Bolli, 1957) ex *Globigerina*
Turborotalia increbescens (Bandy, 1949) ex *Globigerina*
Turborotalita quinqueloba (Natland, 1938) ex *Globigerina*
Whiteinella baltica Douglas et Rankin, 1969

Benthic Foraminifera

Alabamina dorsoplana (Brotzen, 1940) ex *Eponides*
Allomorphina obliqua Reuss, 1851
Ammodiscus cretaceus (Reuss, 1845) ex *Operculina*
Ammosphaeroidina pseudopauciloculata (Mjatliuk, 1966) ex *Cystamminella*
Bathysiphon gerochi Mjatliuk, 1966
Bathysiphon robusta (Grzybowski, 1898) ex *Dendrophrya*
Biapertorbis alteconicus Pokorný, 1956
Biapertorbis biaperturatus Pokorný, 1956
Bolivina dilatata Reuss, 1850
Bolivina vaceki Schubert, 1902
Bolivinoides draco (Marsson, 1878) ex *Bolivina*
Cibicides amphisyliensis (Andreae, 1884) ex *Truncatulina*
Cibicidoides grimsdalei (Nuttall, 1930) ex *Cibicides*
Cibicidoides lopjanicus (Mjatliuk, 1950)
Dolgenia lata (Grzybowski, 1898) ex *Ammodiscus*
Dorothia bulletta (Carsey, 1926) ex *Gaudryina*
Eouvigerina elongata (Cole, 1927) ex *Uvigerina*
Eouvigerina serrata (Chapmann, 1892) ex *Textularia*
Escornebovina binominata (Subbotina, 1960) ex *Eponides*
Globocassidulina subglobosa (Brady, 1881) ex *Cassidulina*
Glomospira charoides (Jones et Parker, 1860) ex *Trochammina*
Haplophragmoides decussatus Krasheninnikov, 1973
Hemirobulina hamuloides (Brotzen, 1936) ex *Marginulina*
Homalohedra apiopleura (Loeblich et Tappan, 1953) ex *Lagena*
Hyperammina nuda Subbotina, 1950
Karrerulina coniformis (Grzybowski, 1898) ex *Gaudryina*
Lenticulina discrepans (Reuss, 1863) ex *Cristellaria (Robulina)*
Lobatula lobatula (Walker et Jacob, 1798) ex *Nautilus*
Nonion troostae Visser, 1951
Nuttallides truempyi (Nuttall, 1930) ex *Eponides*
Nuttallinella florealis (White, 1928) ex *Gyroidina*
Paalzowella feifeli (Paalzow, 1932) ex *Trocholina*
Pararotalia bandyi (Martin, 1964) ex *Rotalia*
Paratrochamminoides olszewskii (Grzybowski, 1898) ex *Trochammina*
Plectorecurvoides parvus Krasheninnikov, 1973
Praebulimina petroleana (Cushman et Hedberg, 1941) ex *Bulimina*
Praebulimina reussi (Morrow, 1934) ex *Bulimina*
Praebulimina triangularis (Marie, 1941) ex *Buliminella*
Pseudonodosinella elongata (Grzybowski, 1898) ex *Reophax*
Pullenia marssoni Cushman et Todd, 1943
Pyramidina cimbrica (Troelsen, 1945) ex *Pseudouvigerina*
Remesella varians (Glaessner, 1937) ex *Textulariella*
Reticulophragmium amplectens (Grzybowski, 1898) ex *Cyclammina*
Reticulophragmium gerochi Neagu et al., 2011
Rotorbinella supracretacea (Schijfsma, 1946) ex *Discorbis*
Rzehakina minima Cushman et Renz, 1948
Rzehakina lata Cushman et Jarvis, 1928
Rzehakina fissistomata (Grzybowski, 1901) ex *Spiroloculina*
Siphonodosaria gracillima (Cushman et Jarvis, 1934) ex *Ellipsonodosaria*
Spirillina concava (Terquem, 1870) ex *Cornuspira*
Spirillina kuebleri Mjatliuk, 1953
Spiroplectammina dentata (Alth, 1850) ex *Textularia*
Spiroplectammina navarroana Cushman, 1932
Svratkina perlata (Andreae, 1884) ex *Pulvinulina*
Trocholina nodulosa Seibold et Seibold, 1960

Calcareous nannofossils

Biscutum magnum Wind et Wise in Wise et Wind 1977
Broinsonia parca constricta Hattner et al. 1980
Cassigerinella chipolensis (Cushman et Ponton, 1932) ex *Cassidulina*
Ceratolithoides aculeus (Stradner 1961) Prins et Sissingh in Sissingh 1977
Chiasmolithus altus Bukry et Percival , 1971
Chiasmolithus solitus (Bramlette et Sullivan 1961) Locker 1968
Coccolithus eopelagicus (Bramlette et Riedel, 1954) Bramlette et Sullivan, 1961
Coccolithus formosus (Kamptner 1963) Wise 1973

Coccolithus pelagicus (Wallich, 1871) Schiller, 1930
Dictyococcites bisectus (Hay et al. 1966) Bukry et Percival 1971
Discoaster multiradiatus Bramlette et Riedel 1964
Eiffellithus eximus (Stover 1966) Perch-Nielsen 1968
Ellipsolithus distichus (Bramette et Sullivan 1961) Sullivan 1964
Helicosphaera bramlettei Müller 1970
Helicosphaera euphratis Haq 1966
Helicosphaera intermedia Martini 1965
Kamptnerius magnificus Deflandre 1959
Micula murus (Martini 1961) Bukry 1973
Micula staurophora (Gardet 1955) Stradner 1963
Monomarginatus quaternarius Wind et Wise in Wise and Wind 1977
Neococcolithus dubius (Deflandre in Deflandre et Fert 1954) Black 1967
Pontosphaera latelliptica (Báldi-Beke 1974) Perch-Nielsen 1984
Pontosphaera magna Haq 1971
Pontosphaera obliquipons (Deflandre 1954) Romein 1979
Pontosphaera pax (Stradner et Seifert 1980) Aubry 1986
Pontosphaera sigmoidalis (Locker 1967) Aubry 1986
Prediscospaera grandis Perch-Nielsen 1979
Prediscosphaera stoveri (Perch-Nielsen 1968) Shafik et Stradner 1971
Reinhardites levis Prins et Sissingh in Sissingh 1977
Reticulofenestra lockeri Müller 1970
Reticulofenestra minuta Roth 1970
Reticulofenestra ornata Müller 1970
Reticulofenestra umbilicus (Levin 1965) Martini et Ritzkowski 1968
Sphenolithus spiniger Bukry 1971
Uniplanarius sissinghii Perch-Nielsen 1986
Uniplanarius trifidus (Stradner in Stradner et Papp 1961) Hattner et Wise 1980.
Watznaueria barnesiae (Black 1959) Perch-Nielsen 1968
Zeugrhabdothus diplogrammus (Deflandre in Deflandre et Fert 1954) Burnett in Gale et al. 1996

Supplementary Material File

Situations of outcrops and sample localizations

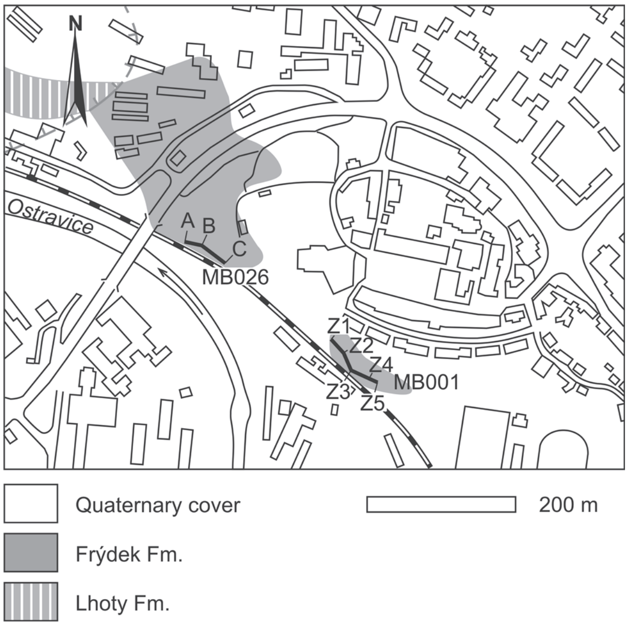

Fig. S1. Situation of sections MB001 and MB026 at Frýdek with indicated sampling points.

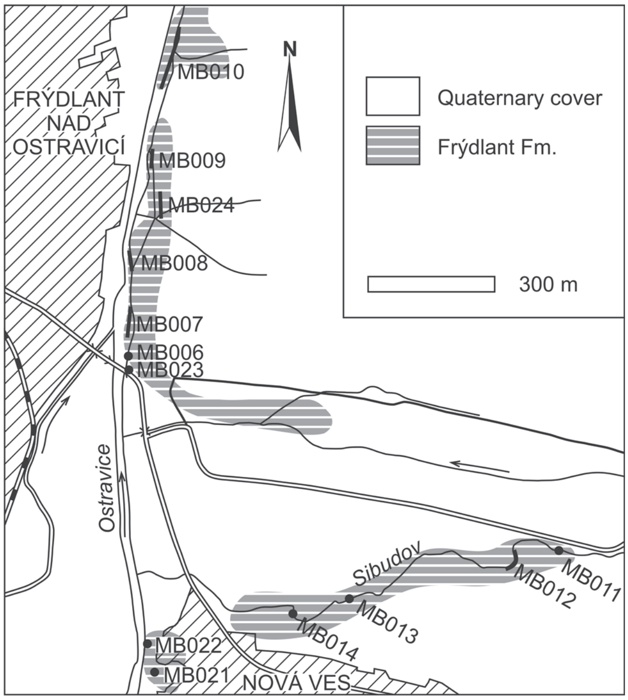

Fig. S3. Outcrops of the Frýdlant Formation at Frýdlant nad Ostravicí.

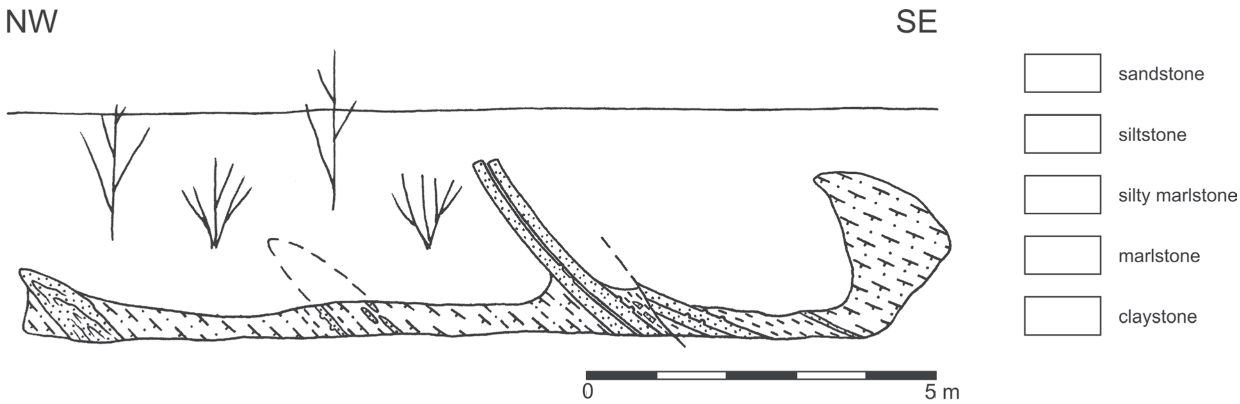

Fig. S2. Outcrop MB026 at Frýdek below an orchard.

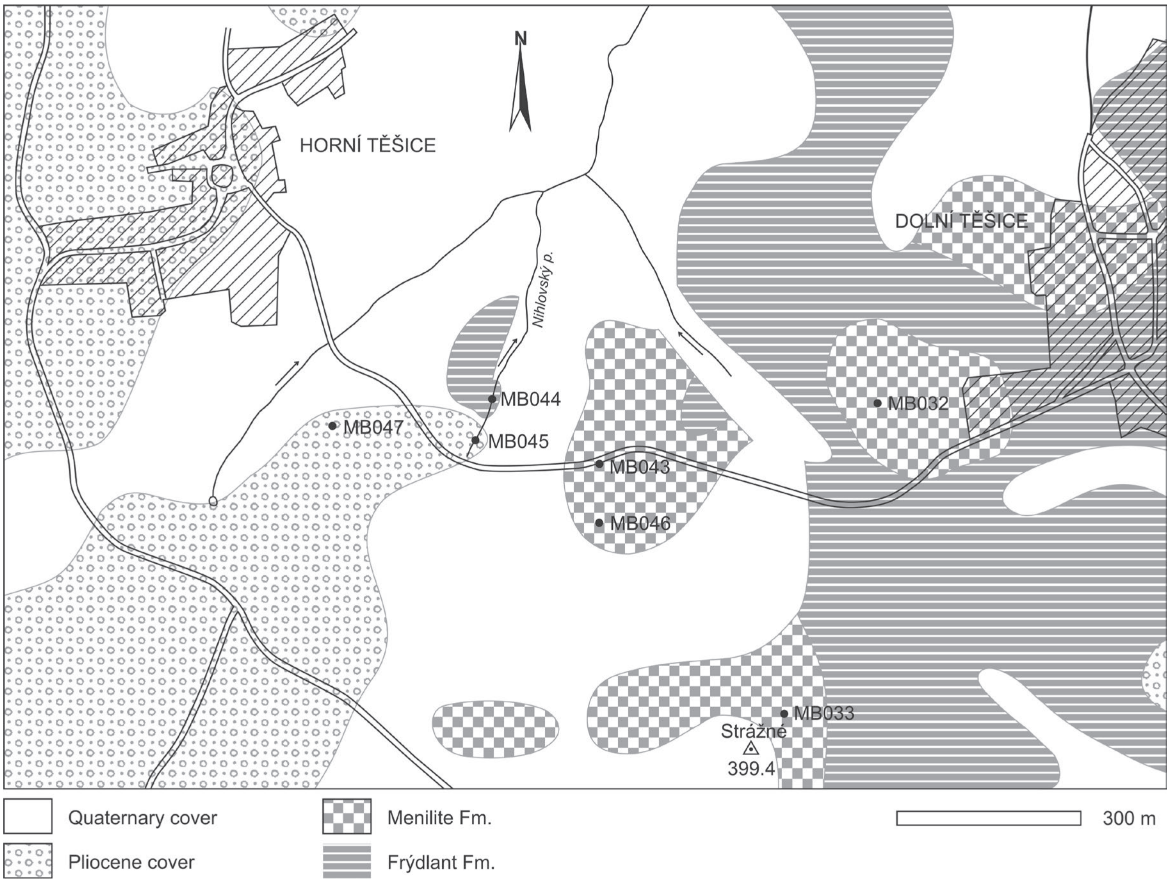

Fig. S4. Situation of outcrops of the Menilite Formation between Horní and Dolní Těšice.

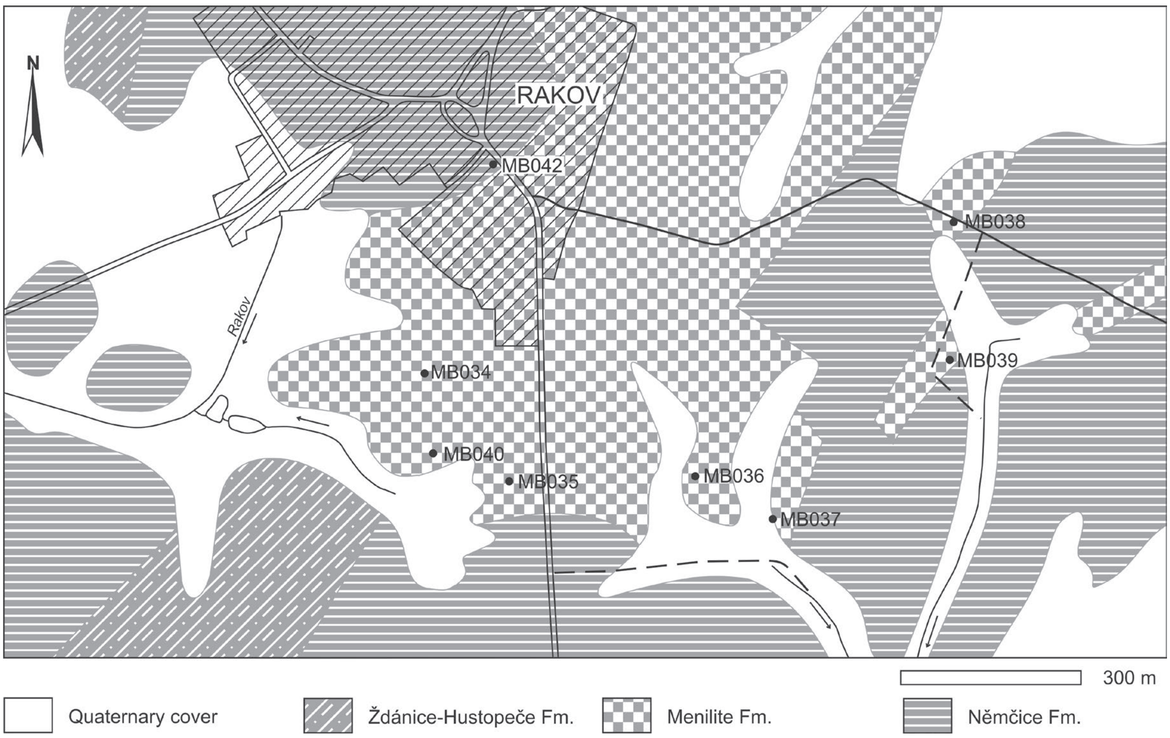

Fig. S5. Situation of outcrops of the Menilite Formation near Rakov.

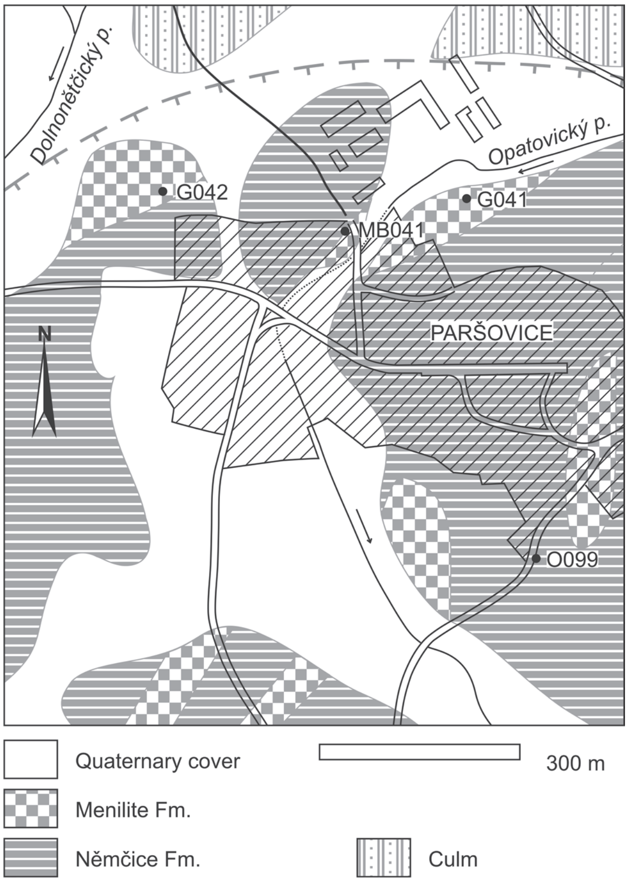

Fig. S6. Situation of outcrops of the Menilite Formation near Paršovice.

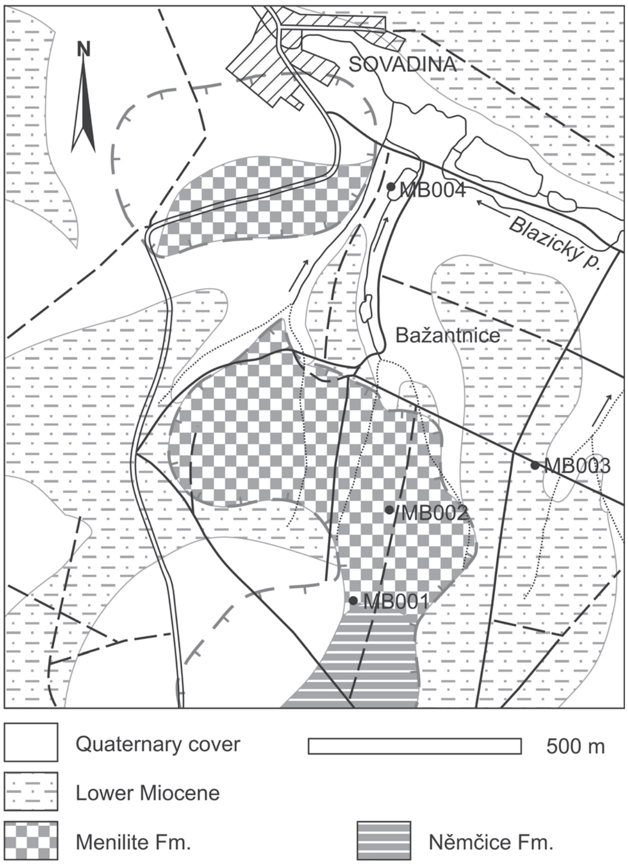

Fig. S7. Situation of outcrops of the Menilite Formation near Sovadina.

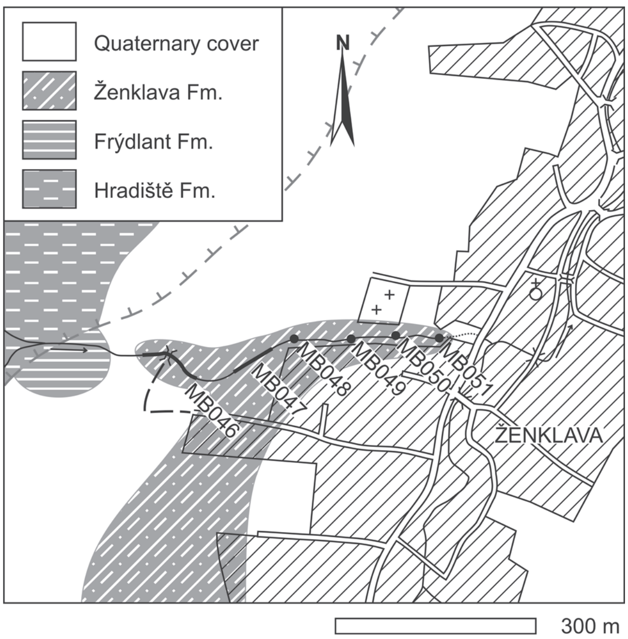

Fig. S8. Situation of outcrops of the Ženklava Formation at Ženklava type area.