Structural, biostratigraphic and petrographic evaluation of the Upper Cretaceous red marlstones and underlying granitoids from the borehole HPJ-1 Jašter near Hlohovec (Považský Inovec Mts., Slovakia)

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AGEOS

Štruktúrne, biostratigrafické a petrografické vyhodnotenie vrchnokriedových červených slieňovcov a podložných granitoidov vo vrte HPJ-1 Jašter pri Hlohovci (Považský Inovec, Slovensko)

Abstract: The article provides the first results of analyses of the core material from the borehole HPJ-1 Jašter, located north of Hlohovec in the southern Považský Inovec Mts. (Western Carpathians, Slovakia). The main aim of the borehole was to determine the thickness and characteristics of sedimentary sequence of the Upper Cretaceous Horné Belice Group in a poorly exposed area and to reach its possible substratum. In the initial interval 0–45.8 m, the borehole penetrated deformed sequence of red and pink pelagic marly limestones and marlstones containing planktonic foraminifera. The drilled sediments are of the Late Cenomanian (45.5–41.5 m) and Middle Turonian – Santonian (41.5–34 m) age in the lower part of the sedimentary sequence. Stronger alteration and tectonic overprint of the uppermost interval (34–0 m) prevented a successful biostratigraphic age determination. The lower part of the borehole profile between 45.8–75.5 m is formed by pre-Alpine biotite granodiorites, which are separated from the overlying sedimentary sequence by a normal fault. Several possible interpretations of the tectonic position of the Upper Cretaceous complexes are discussed.
Key words: Western Carpathians, Tatricum, Horné Belice Group, Late Cretaceous, biostratigraphy, Cretaceous oceanic red beds, granitoids

1. INTRODUCTION

Scientific borehole HPJ-1 Jašter was realized in frame of the project APVV-0465-06 "Tectogenesis of zones with extensive shortening along the External/Central Carpathian boundary", known under the acronym TECTOGEN, as the first of a series of five boreholes (4 of which were located in the Pieniny Klippen Belt, see Plašienka et al., 2012). The core material and technical documentation of the HPJ-1 borehole are stored and available for further investigation at the Department of Geology and Palaeontology, Faculty of Natural Sciences, Comenius University in Bratislava.

The borehole is located northwest of town Hlohovec, at the locality Staré hory close to the road II/507, approximately 100 m east of the roadhouse Jašter, in the area of former vineyards, at present (2013–2015) at the edge of them. The exact location in S-JTSK coordinate system is x = -518356.899; y = -1252025.783; z = 190 (Figs. 1–3); N 48.44981°, E17.81329° in WGS 84 system, respectively. The borehole is named after the nearby roadhouse Jašter.

The Považský Inovec Mts. is a N–S oriented horst situated in the northwestern part of the Central Western Carpathians of Slovakia (Fig. 1). The horst is surrounded by the Miocene depressions of the northern Danube Basin and is built up by the Palaeozoic crystalline basement and the autochthonous Upper Palaeozoic and Mesozoic sedimentary cover of the Tatricum, which is overlain by two thin-skinned Mesozoic nappes of Fatricum (lower) and Hronicum (upper). Occurrences of the Late Cretaceous rocks of unclear tectonic position are locally present (e.g., Ivanička et al., 2007, 2011).

The Mesozoic sequences at the southern tip of the Považský Inovec Mts. were formerly considered to be portion of the autochthonous Mesozoic sedimentary cover of the Tatricum – so called Inovec Unit (Buday et al., 1961). Already at that time, an unusual metamorphic overprint for the Tatricum Triassic members was stated, however. Variegated, mostly red marlstones were originally considered to be Carpathian Keuper Formation, and dark grey shales and marlstones were considered to be an unusual development of Jurassic complexes (Mahel' in Buday et al., 1962; Mahel' et al., 1967). Later on,

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during detailed investigations (Havrila & Vaškovský, 1983) it was proven that sediments at the localities of Staré hory and Laurincove hory represent similar Upper Cretaceous rocks as were documented in the northern Považský Inovec Mts. by Kullmanová & Gašparíková (1982). The following investigations brought some more precise data about the stratigraphy of the Upper Cretaceous complexes (Havrila et al., 1998; Havrila in Maglay et al., 2011; Ivanička et al., 2011) and structural and deformation characteristics of the area (Plašienka, 1995, 1999; Putiš et al., 1999).

Nevertheless, the Považský Inovec Mts. is not the only place where the Upper Cretaceous sediments of similar facies and position were observed. Structural borehole SBM-1 Soblahov, situated in the western Strážovské vrchy Mts. near village Soblahov (Trenčín District, Fig. 1), confirmed presence of Upper Cretaceous (possibly up to Palaeogene) rocks in several intervals between 516 to 1801 m (Mahel' & Kullmanová, 1975; Kullmanová, 1978; Gašpariková, 1980; Mahel', 1985), which can be fully correlated with rocks exposed in the Považský Inovec Mts.

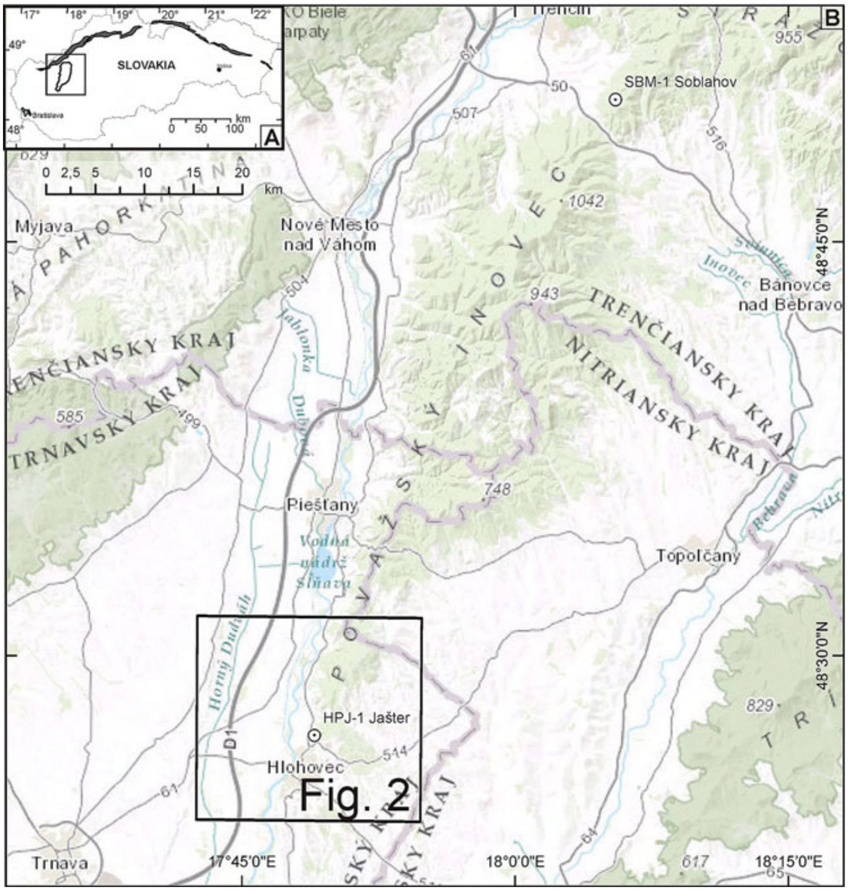


Fig. 1. A – Location of the investigated region in Slovakia. B – Location of the borehole HPJ-1 Jašter, north of Hlohovec.

2. AIMS AND METHODS

The main aim of the borehole HPJ-1 Jašter was to determine the thickness and characteristics of the Upper Cretaceous sedimentary sequence (Horné Belice Group *sensu* Rakús in Ivanička et al., 2011; Belice Unit *sensu* Plašienka et al., 1994) in the Hlohovec region. The borehole was located amidst surface occurrences of eluvial debris of red marls, which position in the regional structure was unclear. The planned depth was 200 m, but the drilling works were terminated after reaching the crystalline basement in depth of 75.5 m.

Drilling was performed using drilling rig ZIF-650 on the chassis of Tatra 148 from September 24 till October 18, 2007. Casing was installed to the depth of 4.5 m. Geophysical logging was not applied.

Standard covered petrographic thin sections were prepared and used for the microscopic analysis. Overall 21 thin sections were analysed. Five of them (33 – 2×, 34, 35, and 37) are particularly rich in microfauna. Additional 5 micropaleonotology samples were processed, but they did not provide positive results. Four thin sections were analysed from the crystalline basement rocks. Limestone microfacies are described by terminology *sensu* Dunham (1962). Stratigraphic ranges of the planktonic foraminifera are based on Caron (1985), Premoli Silva & Verga (2004) and Gonzáles Donzo et al. (2007). Fault rocks in this paper were classified according to classification of Woodlock & Mort (2008).

3. GEOLOGY OF THE INVESTIGATED AREA

The region between the town of Hlohovec and villages of Pastuchov and Koplotovce represents the southern tip of the Považský Inovec Mts. It is composed of the Tatricum basement and cover rocks and the Upper Cretaceous sediments (Horné Belice Group), which are overlain by the Neogene and Quaternary deposits (Ivanička et al., 2007). The Tatricum is composed of granite-dominated crystalline basement and autochthonous Mesozoic sedimentary cover. The granitic rocks are represented generally by the biotite (leuco-) granodiorites to tonalites similar to granites of the nearby Tribeč Mts. (Broska & Uher, 1988; Ivanička et al., 2007). Biotite-amphibole diorite forming mafic enclaves and occasional pegmatites occur in some places. Biotite gneiss with garnet represents only locally preserved remnants of the metamorphic mantle. According to U-Pb dating, the age of granodiorites is between 358 ± 3 and 364 ± 2 Ma (late Devonian–earliest Carboniferous; Broska et al., 2013). Granite body is highly weathered, poorly exposed and covered with surface deposits.

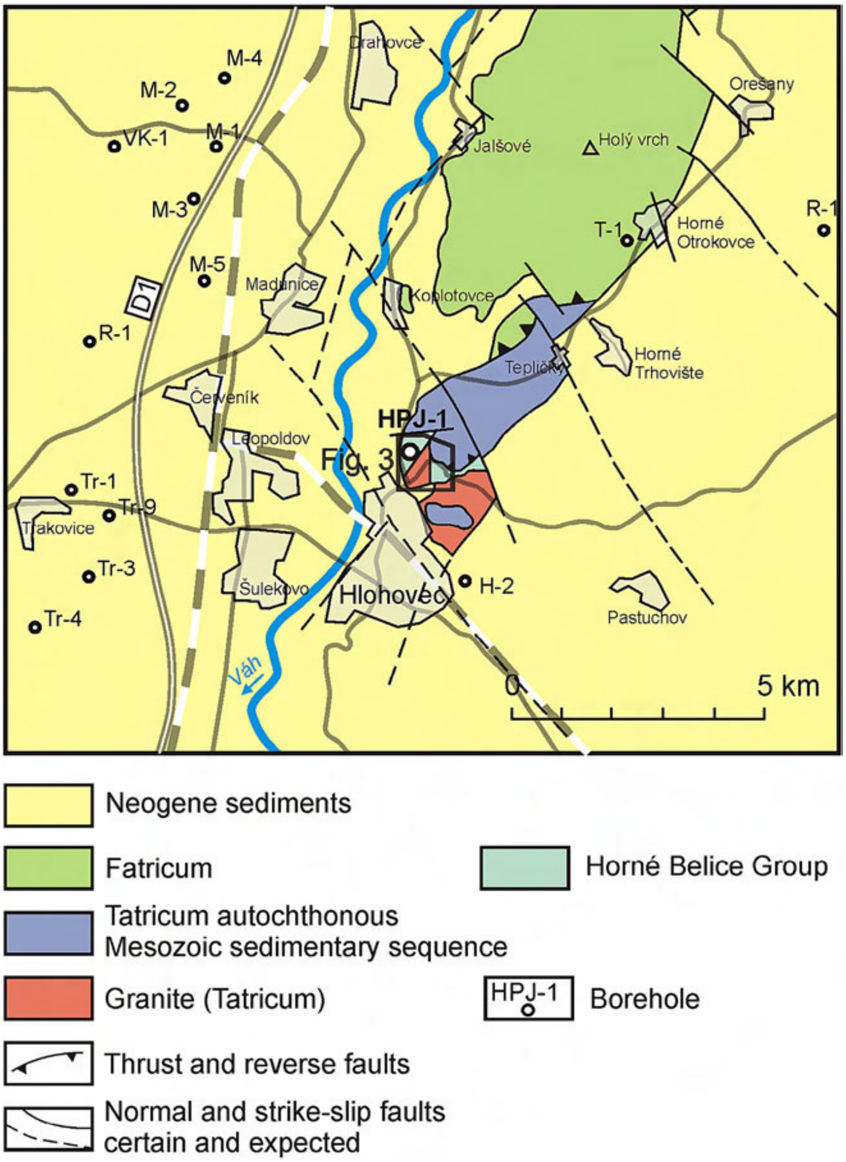


Fig. 2. Simplified tectonic map of southern Považský Inovec Mts. (based on Elečko et al., 2008). For location of the area see Fig. 1.

The crystalline basement rocks are overlain by the Mesozoic sediments of the so-called Tribeč Unit (Ivanička et al., 2007). It is composed of the Lower Triassic quartz sandstones of the Lúžna Formation, Middle and Upper Triassic Gutenstein Limestone, Ramsau Dolomite, and rauhwackes. The younger members include Jurassic sandy crinoidal limestone; siliceous and nodular limestones. Characteristic low grade metamorphosis of the whole Mesozoic sedimentary sequence is manifested by initial recrystallization and development of metamorphic foliation parallel to the bedding. The overlying Upper Cretaceous Horné Belice Group is represented by the red marlstones to pelagic limestones of the Hranty Formation and in a lesser extent by the claystones and shales of the Rázová Formation (Ivanička et al., 2007).

The borehole HPJ-1 Jašter was located in the surface occurrence of the Hranty Formation, close to the unclear boundary with the Rázová Formation and in the relative proximity of the Tatric granitoids (Fig. 3).

4. LITHOLOGICAL AND PETROGRAPHIC DESCRIPTION

4.1. Sedimentary rocks

The borehole penetrated relatively monotonous succession of variegated, brown-grey, pinkish to brick-red marly limestones to marlstones with a very low-grade metamorphic overprint in 0.4 to 45.8 m (Figs. 4 and 5). Microstructures are characterized as mudstone to wackestone (Fig. 6A–C) composed of micrite and clayey admixture. Less recrystallized segments locally contain relatively frequent planktonic foraminifera (Figs. 6A and B, 10A–E). Sedimentary sequence is brecciated near the contact with granitoids due to faulting (Figs. 4 and 5 B). Marlstones with different microfacies were observed in the basal brecciated interval. Some clasts in thin sections from the basal (tectonic) breccias (45.6 m) are represented by foraminiferal packstone (depth 45.2–45.6 m). Marlstone tectonoclasts are cemented by blocky pseudosparite and mixed with material from crushed and mylonitized granites. Few clasts are composed of fine-grained phyllosilicate rocks with metamorphic fabric and without microfossils and rarely also clasts of black chert with a diameter around 1 cm (Fig. 4).

The foraminifera in the thin sections of marlstones, which are affected by various degree of diagenesis, anchizonal or low-grade dynamic metamorphism, are usually flattened and unidentifiable. Phyllosilicate minerals are often developed on the bedding planes of altered rocks usually in the mudstone intervals (depth 8 and 22.5 m). In addition to occasional unidentified foraminifera, scattered quartz sand grains are present in the fine-grained matrix. Fine-grained sand and silt forms laminae and lenses intercalating with marlstones (depths between 8 and 34.8 m; Fig. 6D). The presence of clastic quartz typically indicates lack of any microfauna. Facies of red marly limestones to marlstones from the borehole HPJ-1 represent deep-water marine environment with normal salinity, pelagic fauna and well ventilated floor – highly oxygenated environment, poor in organic matter.

There are two analogues of red to pinkish marly limestones and marlstones, similar to those present in the HPJ-1 borehole

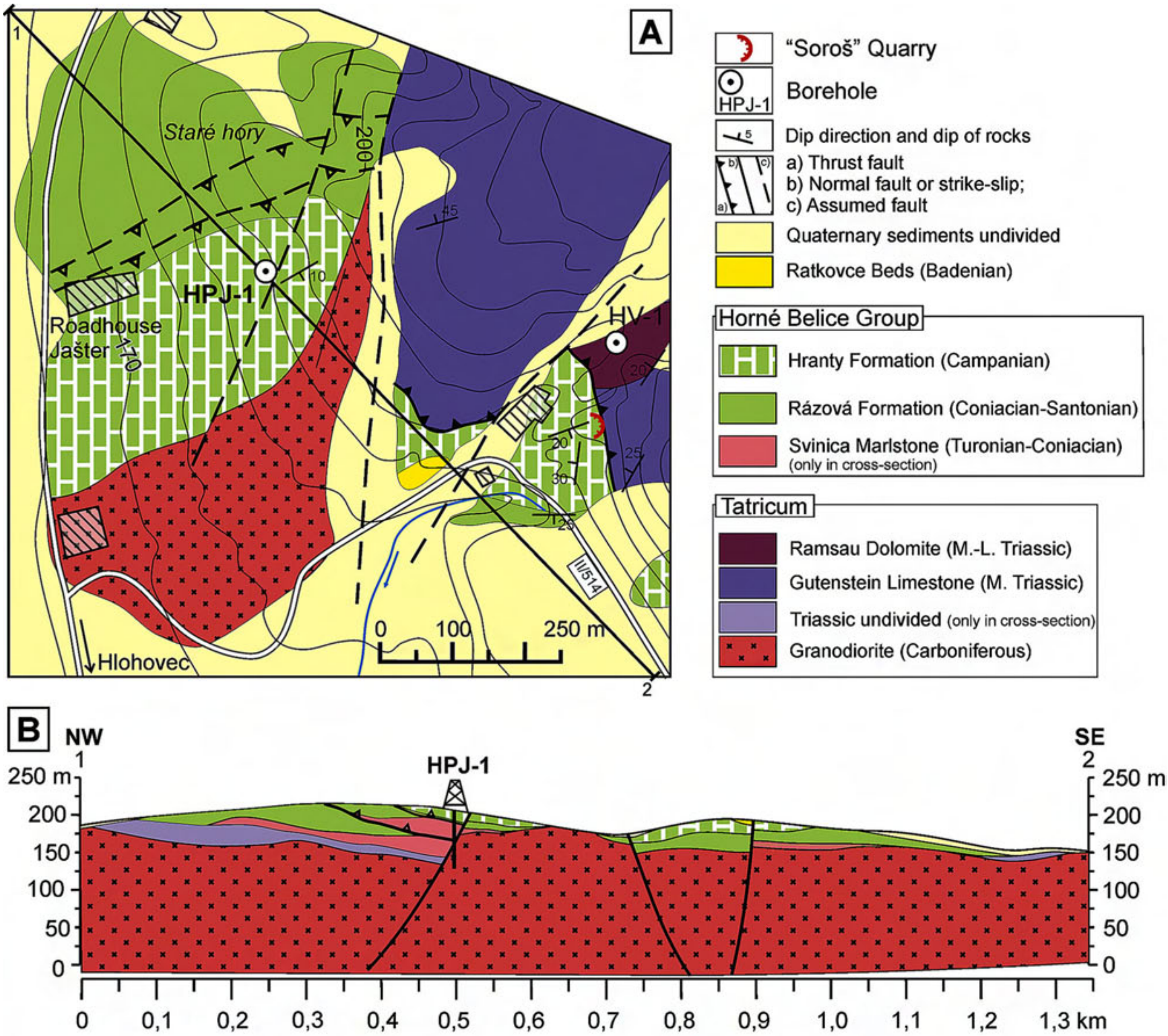


Fig. 3. Geologic map (A) and geological cross-section (B) of the borehole HPJ-1 Jašter area, north of Hlohovec (see location in Fig. 2). Map modified after Havrila in Ivanička et al. (2007).

cores, in the Horné Belice Group in the northern Považský Inovec Mts. The Svinica Marlstone which could occurs in two stratigraphic levels – Turonian (Plašienka et al., 1994) and Santonian (Mišík in Putiš et al., 2006). Younger Hranty Formation (Campanian–Maastrichtian) shows signs of higher proximality due to larger amount of silicilastic admixture (up to coarse breccia) and is therefore less similar (Plašienka et al., 1994). They can be correlated with the Tethyan *Couches Rouges*, *Scaglia Rossa* facies, or Cretaceous Oceanic Red Beds (Hu et al., 2005). In other tectonic units of the Western Carpathians, they are known as the Púchov Marls or Macelowa Member of the Jaworki Formation in the Pieniny Klippen Belt (Birkenmajer, 1977), alternatively as the Košariská Formation in the Brezová Group (Gosau facies, Samuel et al., 1980).

Grey marlstones are present only in one 10 cm thick interval in depth 41.9 m associated with the layer of fault gouge. This is the only occurrence of grey marlstones across the borehole. The rocks are altered and contain only unidentified bioclasts; calcareous nannoplankton or foraminifera were not observed.

4.2. Fault rocks

Tectonic discontinuities in the upper part of the borehole profile, which is composed dominantly of marlstones to pelagic limestones, were filled mostly with brown to dark grey fault gouge (incohesive fault rock with less than 30% of clasts larger than 2 mm in diameter). Thickest body of the fault gouge is present at depth 6.2 to 8 m. Apart of the fault gouge, the less frequent tectonic discontinuities are formed by associated tectonic breccia with signs of hydraulic fracturing with fractures healed by blocky calcite crystals. Tectonic breccias represent cohesive fault rocks composed of more than 30% of clasts with diameter larger than 2 mm. The most important fault penetrated by the borehole, the contact of pink marlstones with granites at depth 45.8 m, belongs

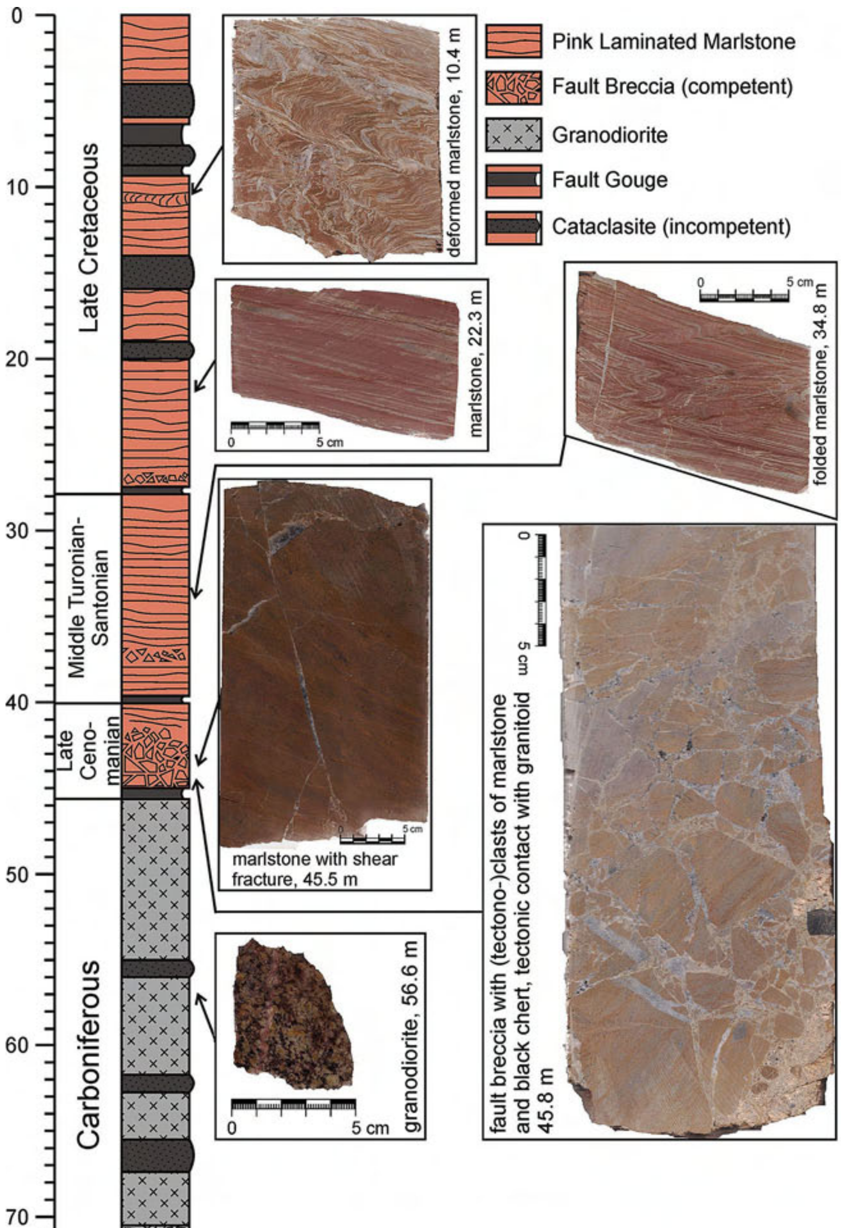


Fig. 4. Simplified log of the borehole HPJ-1 Jašter showing characteristic textures of present rocks and detailed view on contact with the crystalline basement in the core from a depth of 45.8 m.

to the tectonic discontinuities formed by this type of fault rocks. The thickness of hydraulically fractured brecciated marlstones in the tectonic contact with the granites in the borehole reaches more than 4 m. A smaller number of tectonic discontinuities is formed exclusively of tectonic breccia which usually associate with the slickensides (e.g., at depths 27.4 and 35.2 m). Discontinuities resulting from hydraulic fracturing and discontinuities filled with fault gouge were formed by different mechanisms, thus probably represent two distinct deformation phases.

4.3. Granites

Granitic rocks from the borehole are represented by the biotite granodiorites to tonalites, which are strongly weathered, mylonitized and affected by cataclasis. Macroscopically they represent medium- to coarse-grained granitic rocks of grey (brown-purple and grey-green) colour in less weathered samples (Fig. 7A and B). However, in most of cases they are significantly affected by tectonic deformation and weathering, characterized by greyish to white colour of altered plagioclase and ochraceous coatings of Fe-oxides on fracture surfaces (Fig. 7C and D). Usually, they are equigranular with a grain size of 2–6 mm, locally with larger plagioclase phenocrysts of 1 to 1.2 cm in diameter, infrequently disrupted by planar aligned of plagioclase phenocrysts and biotite bands.

Plagioclase (grey-green and purple-grey), quartz (grey-blue, glassy) and biotite (dark grey to black) can be distinguished macroscopically. Isolated plagioclase grains are coated by quartz or quartz with biotite. Phaneritic confining structure with signs of magmatic flow and parallel alignment is usually present. Indistinct porphyric or ocellar structure is found only locally. Deformed granitoids have signs of cataclastic and mylonitic texture. In a microscale, idiomorphic to hypidiomorphic grains of plagioclase, locally with oscillatory zoning, are strongly saussuritized (Plg I – mineral grain cores with basicity An_{28-38}), or sericitized (Plg II – less basic rims with An_{14-26}), as well as overgrown by Plg III – albite on the edges (Fig. 8A and C; 9A, C, and D). Quartz represents elongated aggregates with undulose extinction enclosing plagioclase and biotite grains (Fig. 8A–D). Biotite is represented by the anhedral flakes and oriented bands, often strongly curved and chloritized (Figs. 8 A–D, 9A–D). K-feldspar is less common than plagioclase and quartz, it mostly consists of interstitial grains of perthitic forms, rarely with microcline lamination (Figs. 8A and C, 9A and C). The texture of granitoids is basically typical magmatic, holocrystaline, granitic with signs of flow and subsequent tectono-deformational overprint, locally mylonitic. Accessory minerals are represented by zircon, apatite, magnetite (Fig. 9C), titanite (Fig. 8 C and D), allanite, pyrite, epidote-zoisite (Fig. 9A–C), sporadic ilmenite and monazite.

Biotite granodiorites to tonalites from the borehole HPJ-1 Jašter are according to the accessory minerals association assigned to the Western Carpathian magnetite-allanite series of I-type granites (Broska & Uher, 1988). Zircons from the granitic rocks were dated by U–Pb method which yielded the age between 358 ± 3 and 364 ± 2 Ma (Broska et al., 2013).

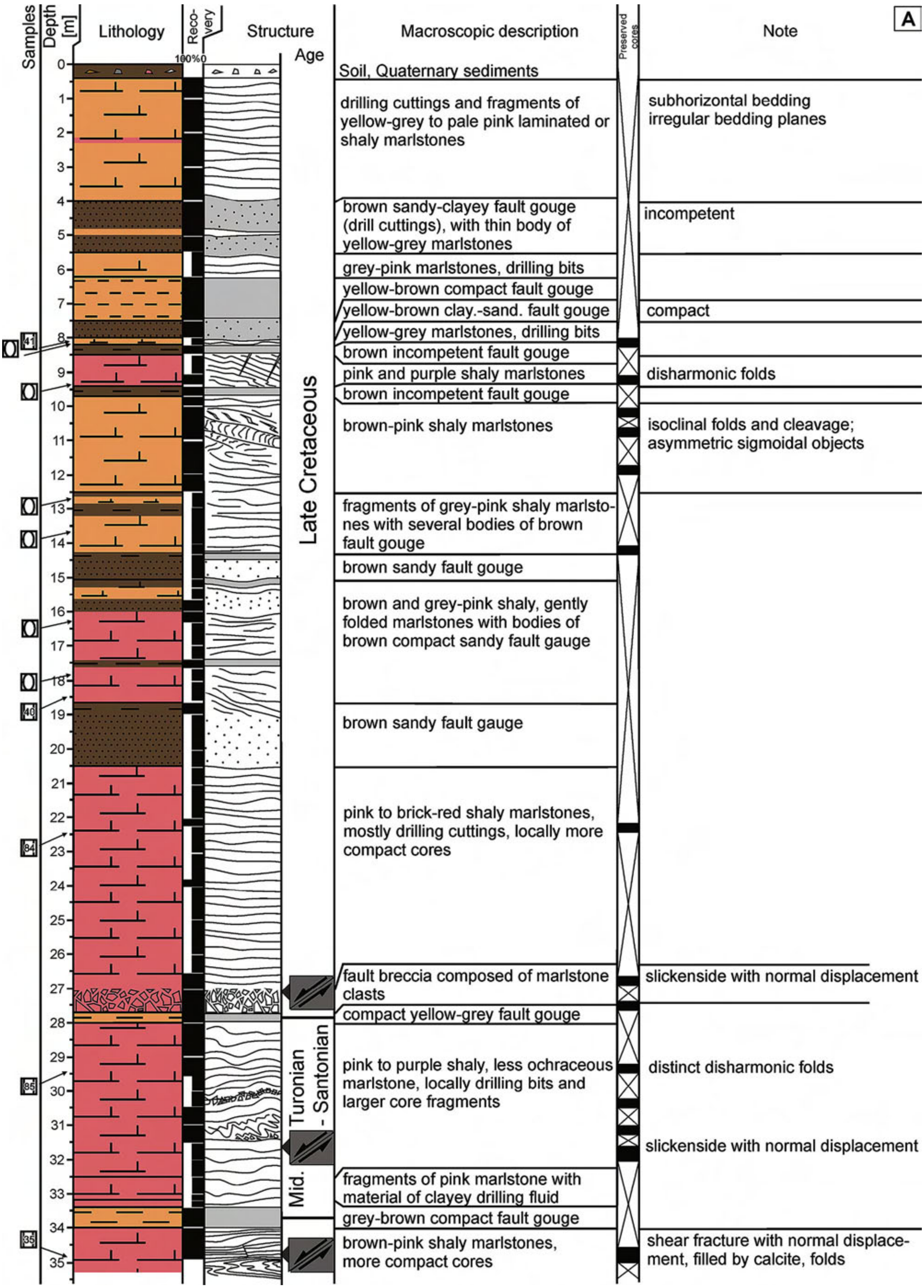


Fig. 5. A–C – Detailed lithological and structural borehole log and description including information about recovery, preserved cores and location of samples.

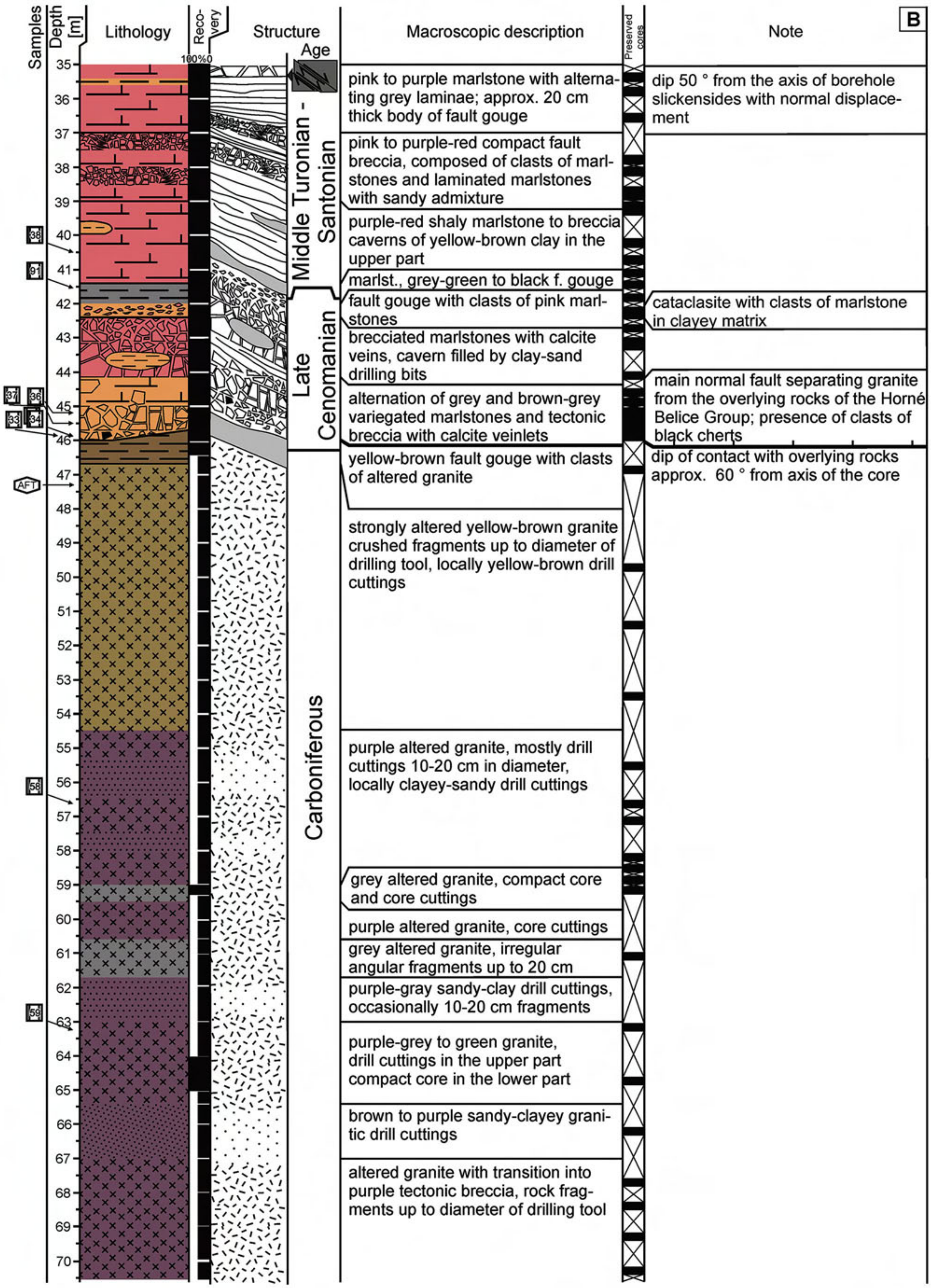
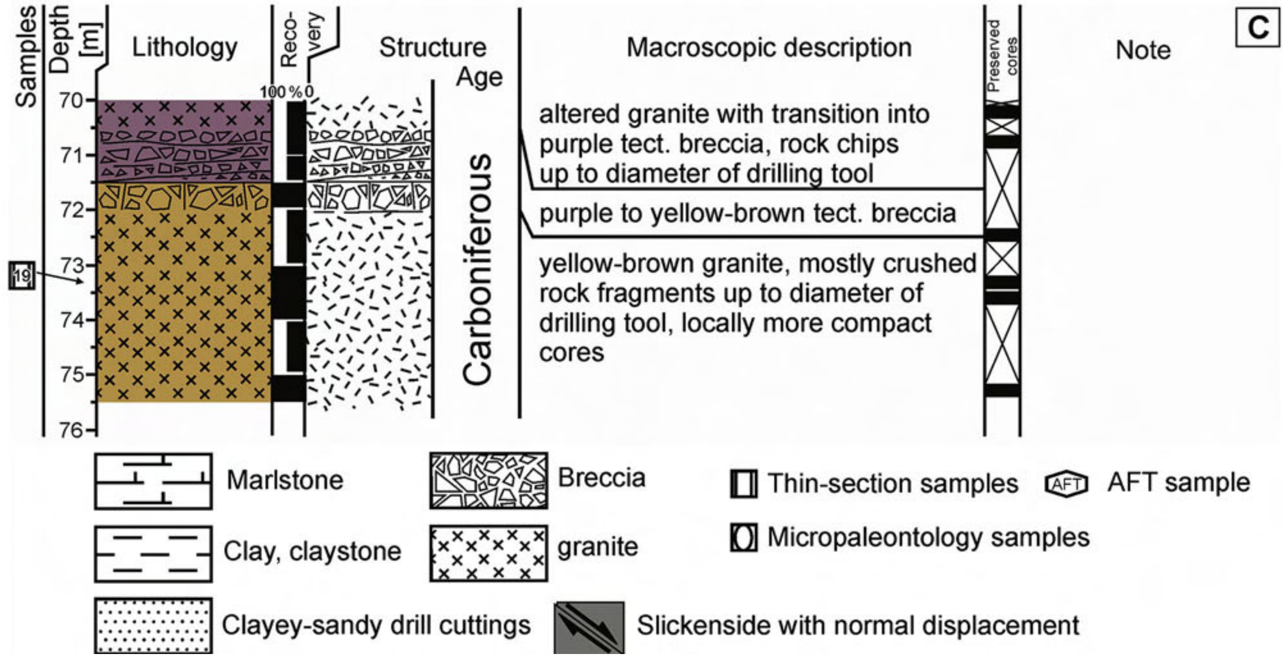


Fig. 5. B – Detailed lithological and structural borehole log and description including information about recovery, preserved cores and location of samples.



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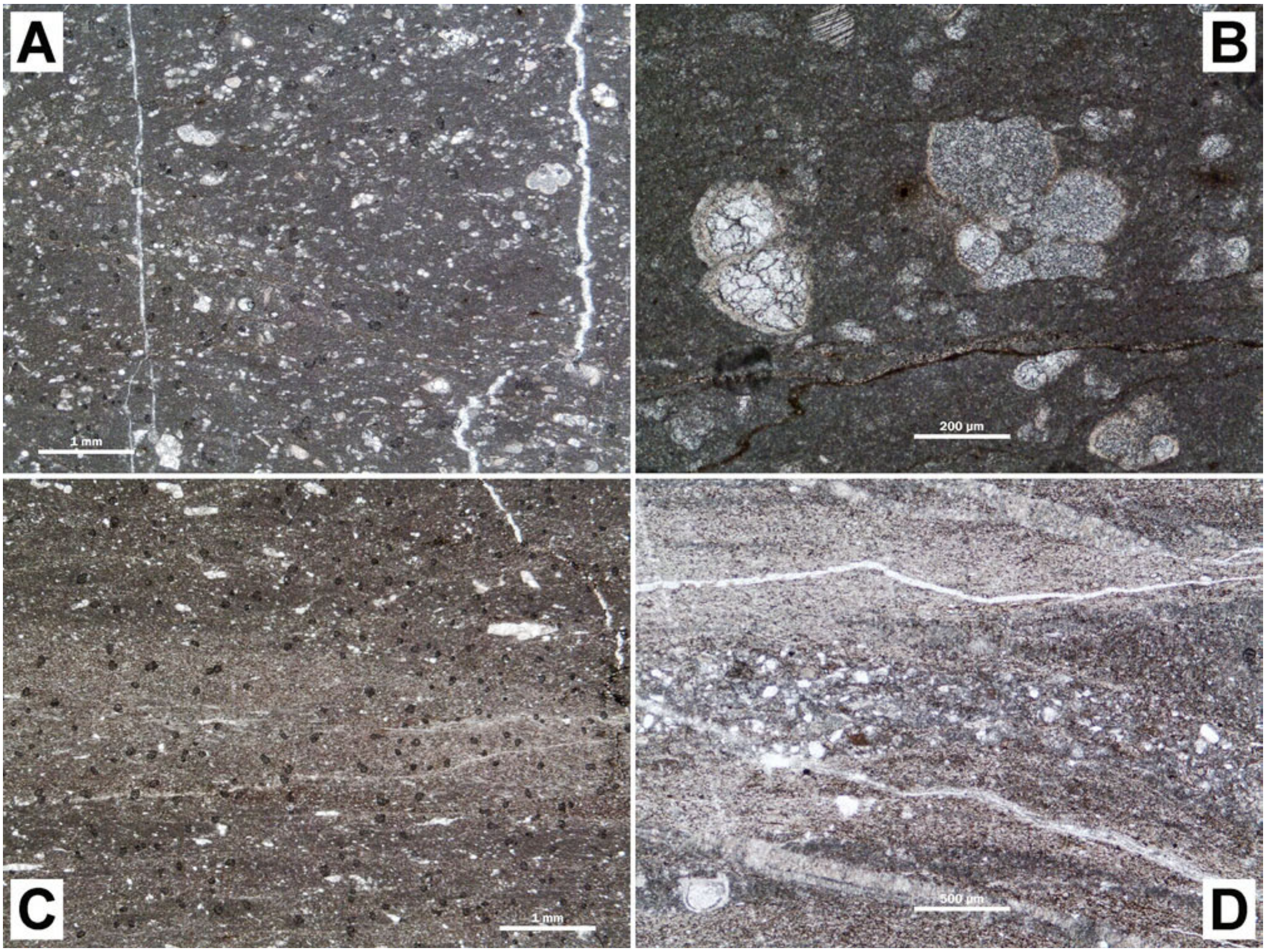

Fig. 6. Photomicrographs of variegated marlstones; A – foraminifera wackestone, thin section 36; B – detailed view of foraminifera wackestone, thin section 36; C – mudstone with scattered fragments of planktonic foraminifera, thin section 35; D – mudstone with sandstone laminae and fragments of foraminifera; thin section 41. Thin section 36 represent clasts from basal tectonic breccia.

A sample for the AFT dating was taken from the upper part of granitic rocks below the contact with the Upper Cretaceous sediments (Králiková, personal communication, Fig. 5B). The results are not included in this paper and will be published in separate paper.

5. BIOSTRATIGRAPHY

During the initial processing of the borehole (2007), the micropaleontology samples from the drilled sedimentary sequence were treated by standard techniques and did not provided well preserved microfossils. Samples were considered as barren due to diagenesis, deformation and low-grade metamorphism which caused the dissolution and destruction of most of calcareous plankton. However, during the structural-geology investigations, relatively well preserved, slightly deformed planktonic foraminifera were observed in the thin sections from several depth intervals.

The biostratigraphic dating of several particular sections of sedimentary profile from the borehole HPJ-1 was not successful. No microfauna was obtained from the depth interval 0–28 m. Its age is considered as Late Cretaceous only due to analogous lithology and structural position.

The basal tectonic breccia (depth 42.4–46.8 m) is composed of marlstone clasts with abundant planktonic foraminifera and sporadic microfacies with small agglutinated foraminifera (Fig. 10E). Sections of foraminifera with a developed keel, similar to the species *Parathalmanninella appenninica* (Gandolfi) with a stratigraphic range from the latest Albian to Late Cenomanian (Fig. 10B), occur among frequent small "hedbergellid" foraminifera (Fig. 10A) in the breccia clasts. Sections similar to *Thalmanninella globotruncanoides* Sigal in the microfacies with echinoid detritus limit the stratigraphic range of some clasts to the Cenomanian (Fig. 10C), while sections similar to the species *Rotalipora cushmani* (Morrow), typical for the Late Cenomanian (Fig. 10D), were observed in the same microfacies of the breccia clasts. Two last-mentioned genera were more frequent. In some isolated clasts, association with species similar to *Muricohedbergella planispira* (Gandolfi), *Parathalmanninella appenninica* (Gandolfi) and *Praeglobotruncana delrioensis* Carsey indicates the possible presence of Upper Albian clasts. However, the overall age of the basal tectonic breccia is determined by the presence of the

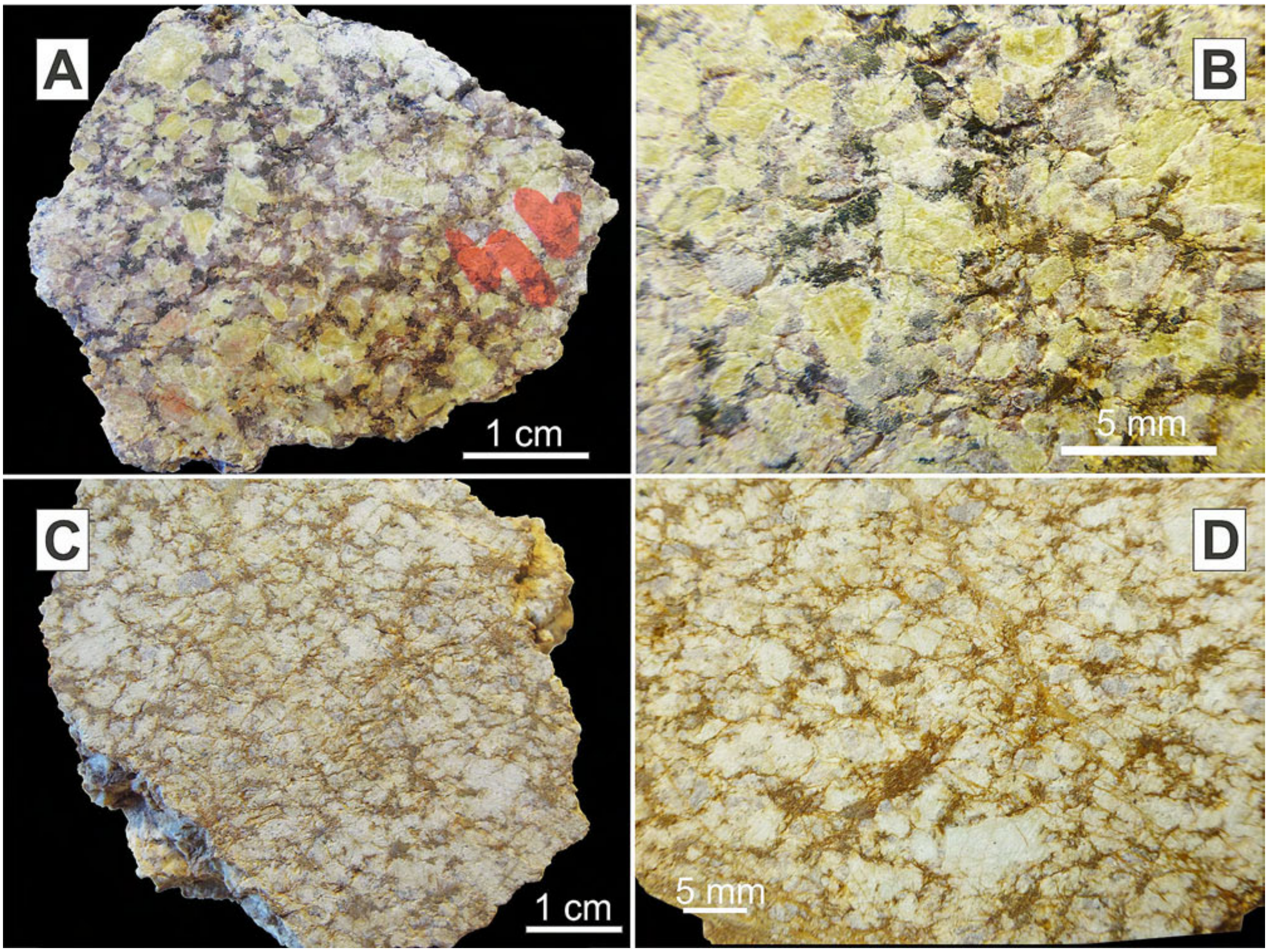

Fig. 7. Phanerocrystalline structures of granitoids from the borehole HPJ-1 Jašter.
A and B – sample from 56.6 m;
C and D – sample from 73.3 m.

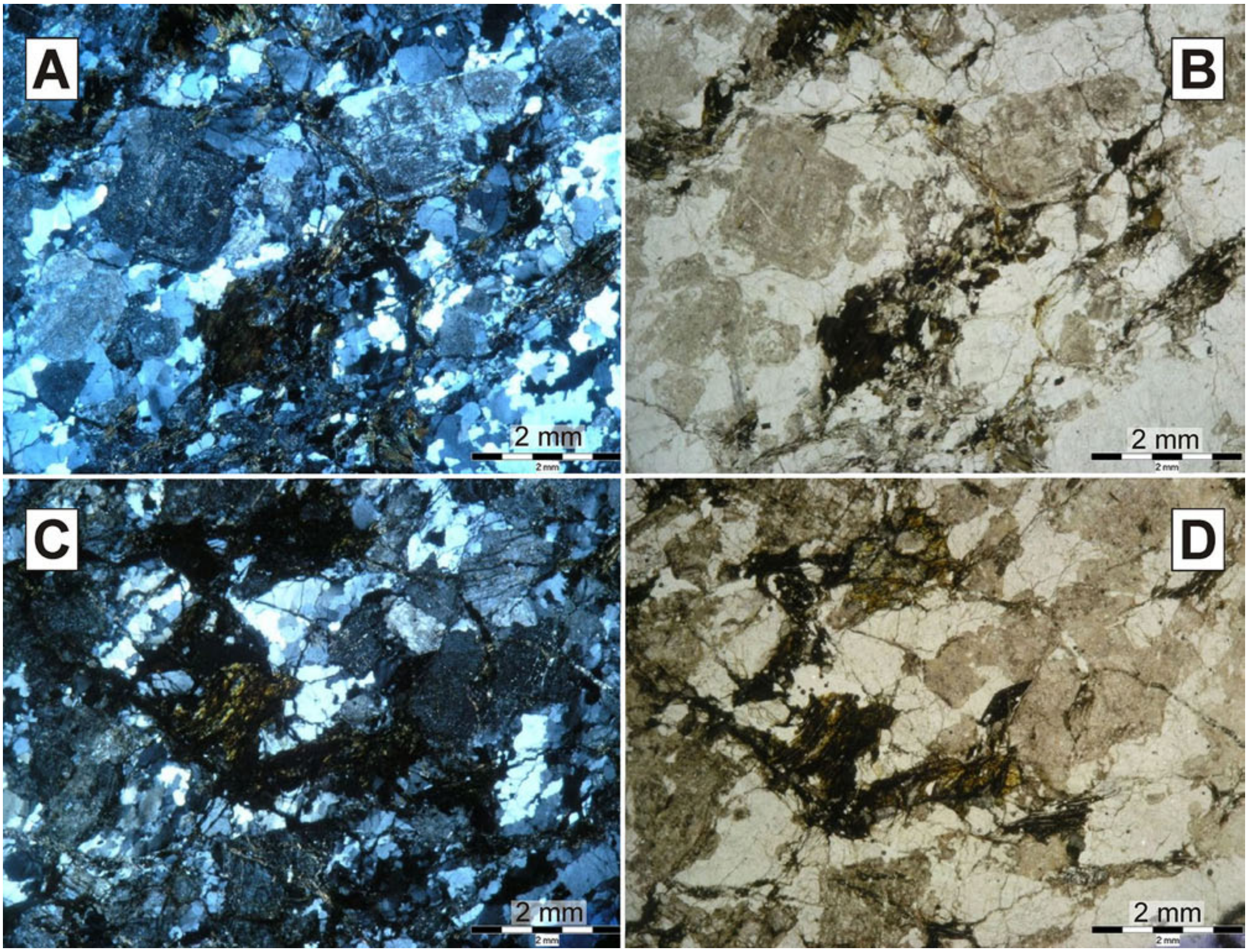

Fig. 8. The textures and the mineral composition of the granitoids from the borehole HPJ- 1 in the petrographic microscope. XPL (A and C), PPL (B and D).

youngest index species *Rotalipora cushmani* (Morrow) which indicates the Late Cenomanian age of both positive samples 34 and 37 (interval between 45.6 and 41.5 m; Fig. 11). The matrix of the tectonic breccia does not contain any determinable microfauna.

The higher part of the borehole profile between 41.5 and 34 m is characterized by low conical foraminifera tests with one or two keels which are similar to the species *Marginotruncana coronata* (Bolli) (Fig. 10F), *M. pseudolinneiana* Pessagno and *M. renzi* (Gandolfi). Compared to the Upper Cenomanian marlstones, this microfauna is monospecific in composition and less rich. However, tests are larger, deformed and sometimes cut on the foliation planes. The age of marlstones with foraminiferal microfauna containing genus *Marginotruncana* ranges from the Middle Turonian to Santonian. Representatives of the genus *Marginotruncana* in the Tethyan Realm rarely occur also in the latest Early Turonian and Early Campanian, but no other stratigraphically important species which could specify stratigraphy of the studied samples were observed (e.g., Bąk, 1998; Cetean et al., 2009). It should be emphasized that no stratigraphically important microfauna was extracted or observed in the matrix of the basal tectonic breccia.

6. STRUCTURAL ELEMENTS OBSERVED IN THE DRILLED ROCKS

Interpretation of the deformation structures in the borehole HPJ-1 is problematic due to the unknown orientation of the drilled rocks and structures observed in particular cores, which allow for only limited tectonic conclusions. However, recently (2013–2015) it has been possible to observe the structures of the Upper Cretaceous sediments in an erosional furrow in the vineyard nearby the drilling site. Strike of the observed structures is generally NE–SW, similar to the occurrences in the northern part of the Považský Inovec Mts. Dip direction is generally to the S to SE (Fig. 3).

According to the investigation of the preserved cores it is possible to interpret the borehole profile as sequence of several, probably thrust sheets of the Upper Cretaceous red marlstones and limestones. Sediments rest in the hanging wall of granites due to a younger, probably Miocene normal faulting that complicates the Eo-Alpine structure.

Bellow the approximately 0.5 m thick Quaternary surface deposits, up to 6.3 m depth, no continuous core was recovered. Only bits and cuttings with smaller diameter than the drilling

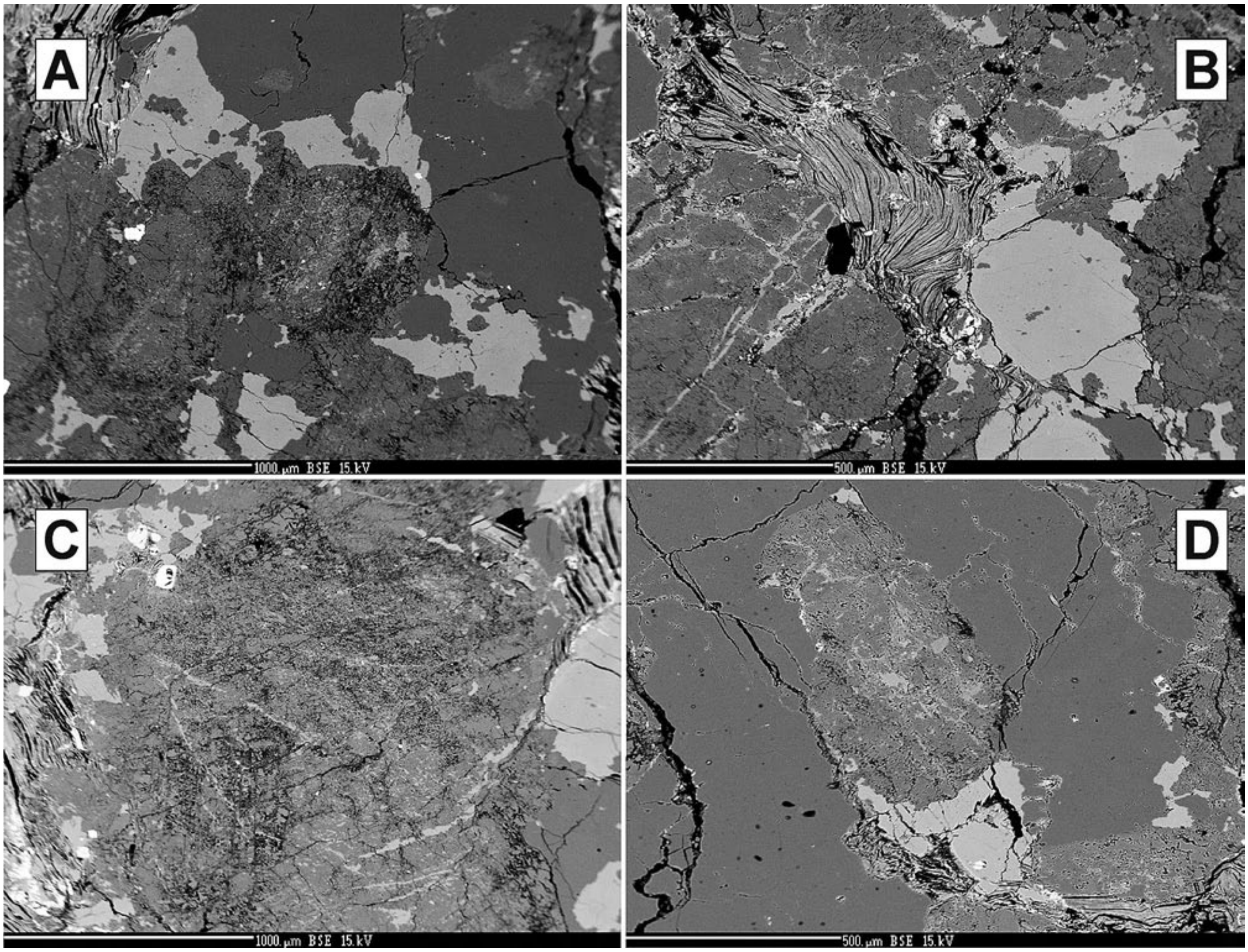

Fig. 9. Mineral composition (plagioclases, quartz, K-feldspar, biotite and accessories) of studied granitic rocks – back scattered electron images in electron microscope (EMP). Textures indicate magmatic fabric with superimposed tectonic deformation signs.

tools were recovered. However, it is possible to assume due to monotonous lithology of recovered core cuttings, that between 0.5 to 6.3 m a weathered and fractured body of marlstones is present with an exception between 4–5.7 m where body of incompetent cataclasite is followed by 0.5 m marlstone layer and 1 m thick fault gouge and sandy cataclasite that continue to the depth of 9.75 m. Analogous bodies of fault gouge and cataclased or ductile deformed rocks could be identified with subhorizontal to inclined shear zones or fault infill.

From the depth of 9.75 m less deformed Upper Cretaceous marlstones occur. More and less deformed segments are alternating several times. Zones of sandy cataclasite and fault gouge are present at depth 14.25–16 m and 18.75–20.5 m (Figs. 4 and 5). At the depth of 27–28 m, a body of tectonic breccia with fault gouge and slickenside indicating normal fault on its base occurs. The same normal fault kinematics could be attributed according to presence of slickenside as well to deformed marlstones and tectonic breccias (34–35.4 m) bellow the body of fault gouge at 33.4–34 m.

The dominant dislocation present in the borehole is represented by a brecciated zone between 41 and 49 m, where the fault contact between marlstones and granites is observed at the depth 45.8 m (Figs. 4 and 5). This zone follows the interval of hydrofractured marlstones, locally with clay caverns at the depth of 42.3–45.8 m. Close to the contact between sediments and granites, black angular chert clasts occur (Fig. 4). The basal part of fault zone is characterized by the 0.3 m thick fault gouge and occurrence of granite clasts. Several breccia clasts are more or less moderately rounded. This phenomenon is probably a result of rotation and abrasion of clasts during the episodes of shear and not a sedimentary contact. Sporadic presence of rounded clasts in the cataclasites and tectonic breccias is commonly observed (Trouw et al., 2010). Crushed granites prevail to the depth of 60.5 m. Lower borehole parts are characterized by better preserved cores, especially in 60–61 m and 73–73.7 m intervals. However, the crystalline rocks are deformed and resemble a tectonic breccia in the interval 70.5–72 m.

Key for the interpretation of the tectonic structure is the contact of marlstones with the crystalline basement at the depth of 45.8 m (Fig. 4). Dip of the contact is steep – about 60 to 70° from the axis of core. According to the dip of this zone it is believed to be a Neogene normal fault.

Apart of younger brittle deformation, ductile to semiductile compressional structures are manifested as folds. In the sample

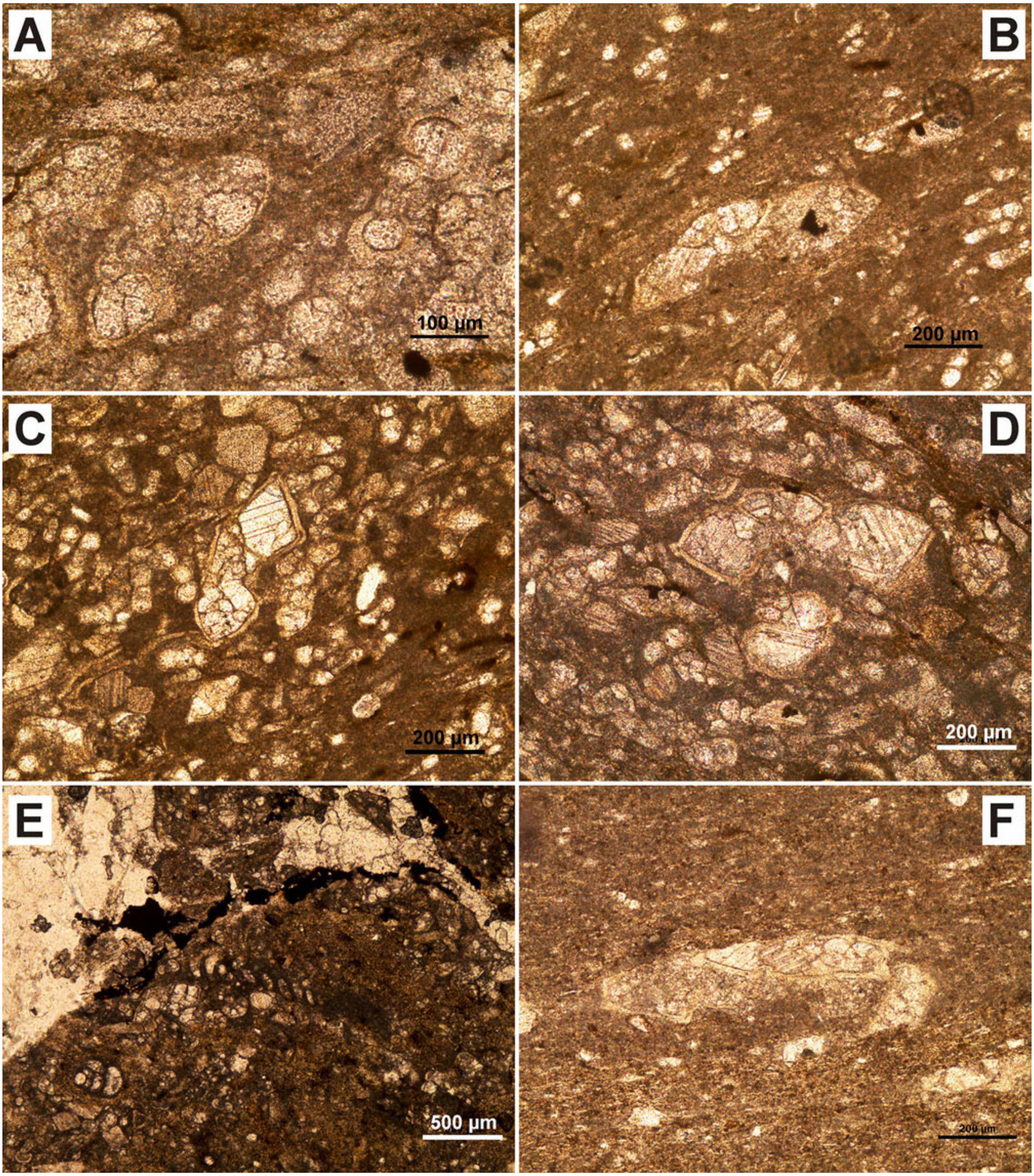

Fig. 10. Foraminifera from red marlstones in the borehole HPJ-1. A – Right *Muricohedbergella* cf. *planispira* (Gandolfi), left *Praeglobotruncana* cf. *delrioensis* Carsey, (thin section 34; depth 42.4–46 m). B – *Parathalmanninella* cf. *appenninica* (Renz) (thin section 37; depth 42.4–46 m). C – *Thalmanninella* cf. *globotruncanoides* Sigal (thin section 37). D – *Rotalipora* cf. *cushmani* (Morrow) (thin section 37 m). E – Microfacies with small agglutinated foraminifera (thin section 34). F – *Marginotruncana* cf. *coronata* (Bolli) (thin section 35; depth 28–40 m). Except of thin section No. 35, all other samples represent fragments from the tectonic breccia in the lowermost part of the sedimentary sequence in the borehole.

from 9.25 m, folds are isoclinal, with subhorizontal fold axis and amplitude between 5–7 cm. Limbs of isoclinal folds are occasionally broken (e.g., 11.8 m), or associated with sigmoidal asymmetric structures with unknown vergence (10.4 m). Intensive disharmonic folding is common at 31.8 m. Asymmetric chevron folds with an amplitude of 2–5 cm occur in 34.8 m depth (Fig. 4).

Microstructures of red marlstones indicate that they were affected by a very low-grade metamorphic recrystallization.

Locally penetrative foliation, which is parallel to bedding in observed cases, is formed by pressure-solution seams enriched in insoluble residuum of clay minerals and iron oxides. Larger objects, such as foraminifera, are sometimes stretched and calcite grains are twinned. Asymmetric sigmoidal objects, indicating simple shearing parallel to the foliation, were observed in places (Fig. 5, depth 10–11 m). Also the folds, described in the previous paragraph, seem to be formed in distinct domains, where the foliation was rotated into the shortening sector of the shear zones governed by noncoaxial shearing. It is probable that cataclastic shear zones filled with fault gouges were formed later in the deformation process, either due to decreasing temperatures, or influx of fluids, or strain hardening. All these processes might have caused a switch from ductile to brittle deformation mechanisms.

In a broader surroundings, a nicely developed shear zone with reliable shear-sense criteria was studied in the abandoned quarry Soroš, about 500 m SE of the borehole location (Plašienka, 1999, pp. 88–89). The several metres thick ductile shear zone accompanies the subhorizontal thrust contact between the underlying red marlstones and overlying calcite mylonites formed from Middle Triassic limestones of a higher Tatricum unit (see Fig. 3). Stretching lineation and asymmetric objects in both the marlstones and in thinly laminated calcite mylonites document the top-to-NW shearing within this overthrust shear zone.

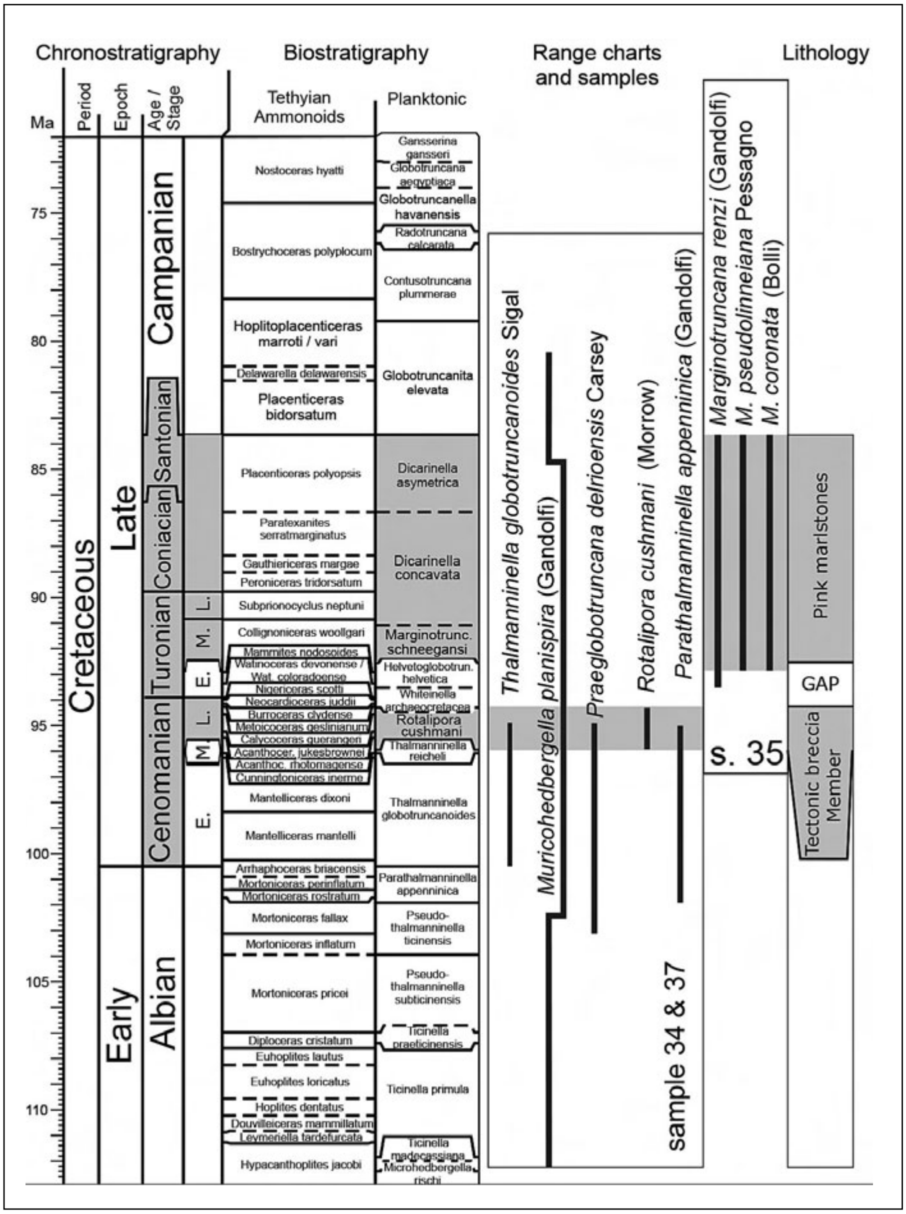

Fig. 11. List of microfossils in the samples 34, 35, and 37 and their stratigraphic classification. Biostratigraphic zonation after Hardenbol et al. (1998). Other analysed samples were negative for stratigraphically significant foraminifera.

7. DISCUSSION

7.1. Age of sediments

Biostratigraphic evaluation of the preserved cores allows determination of the stratigraphic age only of the lower part of the drilled sedimentary sequence. The observed microfauna of the Late Cenomanian (45.5–41.5 m) and Middle Turonian–Santonian (41.5–34 m) age indicates a discontinuous sedimentary sequence (Figs. 4 and 11). Foraminifera of the Albian and Cenomanian age were observed in sediments of the Horné Belice Group already by Kullmanová & Gašpariková (1982), but they were regarded as redeposits due to their co-occurrence with younger forms. During our investigation of the borehole material, no species younger than Late Cenomanian were observed in the basal tectonic breccia. However, the Late Albian and Cenomanian forms redeposited into the younger Middle Turonian – Santonian sediments cannot be excluded also in case of sediments recovered by the borehole HPJ-1. Furthermore, the absence of the Lower Turonian sediments (the Early Turonian "gap" in Fig. 11) between the Late Cenomanian (41.5–45.5 m) and Middle Turonian–Santonian (41.5–34 m) marlstones in the borehole could be avoided, if the redeposition of the Late Cenomanian fauna into the younger Middle Turonian sediments is required. If this interpretation is accepted, the determination of the stratigraphic age of sediment from the borehole would not be in contrast with the existing knowledge. Until now, the lower stratigraphic boundary of the red marlstone complex from the northern part of the Považský Inovec Mts. was considered to be Turonian (Svinica Marlstone – Plašienka et al., 1994; Ivanička et al., 2011). The Upper Cenomanian and Middle Turonian–Santonian pink marlstones could be an analogue of the Svinica Marlstone.

7.2. Position of Upper Cretaceous complexes

Taking into account data gathered from the investigated borehole and interpretation of the poorly detectable structures of its surroundings, as well as various opinions about the origin and position of analogous deposits from the northern part of the Považský Inovec Mts., we can affiliate the present views on the Belice Unit and/or the Horné Belice Group with two basic categories:

1) According to the first group of interpretations, the Belice Unit represents an independent tectonic element of higher order (Vahicum) that occupies the lowermost structural position in the belt of core mountains of western Slovakia, i.e. it is overridden by the (Infra)Tatricum thick-skinned thrust sheet. There are two alternatives of this conception: 1A – the Belice Unit is a succession of detached Jurassic–Cretaceous deep-water sediments related to the Southern Penninicum (Liguria-Piemont-Tauern-Rechnitz-Váh-Iňačovce) oceanic realm (e.g., Plašienka et al., 1994; Plašienka, 1995, 1999, 2012; Froitzheim et al., 2008; Schmid et al., 2008; Méres & Plašienka, 2009); 1B – the Belice Unit corresponds to a unit derived from the distal Austroalpine passive margin facing the Southern Penninic Ocean, later overridden by the lowermost Tatricum (Infratatricum) Inovec basement nappe (Putiš et al., 2006, 2008).

The results presented in this paper allow also for some other considerations. Mainly, the Upper Cretaceous sediments encountered by the borehole Jašter show some significant differences with coeval deposits of the Belice Unit in the northern Považský Inovec Mts. Unlike the latter, the whole borehole succession covers a comparatively wide stratigraphic range and is formed by variegated hemipelagic marlstones almost devoid of a terrigenous admixture, which is in a tectonic contact with underlying basement granitoids. However, any direct comparison with the Belice Unit is hampered by the lack of Jurassic – Lower Cretaceous formations in the study area. In the light of new findings and wide-range correlations we can put forward the third hypothesis: 1C – the investigated sediments can be interpreted as a post-rift sequence onlapping an isolated submarine basement high, possibly "extensional allochthon" on a distal Austroalpine (Adriatic) passive margin formed during Jurassic asymmetric rifting of the Southern Penninic Ocean (magma-poor ocean-continent transition, see e.g., Manatschal, 2004; Mohn et al., 2010, 2011 and references therein). This view partly corresponds to the 1B interpretation. Alternatively, the supposed basement high might be hypothetically regarded as a splinter of the Oravic continental domain (Czorsztyn Ridge, Middle Penninic) underthrust below the frontal Central Western Carpathian units.

2) The second basic group of interpretations considers the Belice Unit as an Upper Cretaceous transgressive sequence of the Klape Unit (Kullmanová & Gašpariková, 1982) or synclines of autochthonous sediments of Tatricum (Mahel', 1986; Havrila et al., 1998; Bezák et al., 2009; Rakús in Ivanička et al., 2011; Havrila in Maglay et al., 2011). Such structural interpretation was favoured even at the time when the correct age of the sediments was not known (Buday et al., 1962; Mahel' et al., 1967). In accordance with opinions about the transgressive and autochthonous character of the Horné Belice Group, the sequences penetrated by the borehole HPJ-1 could be interpreted in such way, that the Upper Cretaceous sediments near Hlohovec overlie the Hercynian granites usually considered to be a part of the Tatricum (Broska & Uher, 1988; Ivanička et al., 2011). The Upper Cretaceous sequence represents post-stacking deposits laid down in the Gosau-type, wedge-top basins above the Tatricum. Such wedge-top basins (*sensu* DeCelles & Gilles, 1994) were located during the Late Cretaceous period above and between thrust sheets of the Central Western Carpathian units.

The contact with granites in the borehole HPJ-1 is modified by the younger Cenozoic normal fault, which results in partial reduction of Upper Cretaceous rock sequence and excludes possibility that the complexes of the Horné Belice Group could crop out from the footwall of granitoids in the Hlohovec area (*sensu* Plašienka, 1999). However, the original sedimentary (transgressive) contact with a direct substratum of the Upper Cretaceous sediments was not encountered by the borehole and remains unknown.

8. CONCLUSIONS

The borehole HPJ-1 Jašter localized in the southern part of the Považský Inovec Mts., north of Hlohovec town (Figs. 1–3) penetrated 45.8 m thick sequence of the Upper Cretaceous Horné Belice Group, 29.7 m thick body of granites and subsequently reached the final depth 75.5 m (Figs. 4 and 5). The Horné Belice Group (sensu Ivanička et al., 2011) is represented by low grade metamorphosed red to pinkish marly limestone to marlstone with sporadic remains of the Late Cretaceous planktonic foraminifera. The age of interval 45.8–41.5 m was determined as the Late Cenomanian; and the interval of 41.5–28 m as the Middle Turonian–Santonian, based on presence of microfauna (Figs. 10 A–D and F, 11). Interval 0–28 m was not reliably dated by biostratigraphic methods, however, due to the similar lithology it is regarded as the Late Cretaceous in age. The occurrence of Late Cenomanian and Middle Turonian–Santonian pink and red marlstones fits with earlier findings of similar lithofacies in the northern Považský Inovec Mts. (Plašienka et al., 1994, Putiš et al., 2006). It confirms presence of red marlstones in several stratigraphic levels of the Horné Belice Group and indicates their lateral replacement with the Rázová Fm. of Coniacian–Santonian age. The Rázová Fm., as it is known from the northern Považský Inovec Mts., practically does not occur in the profile of the borehole. The whole penetrated sedimentary sequence is intensively affected by ductile and brittle deformation and represents a succession of several fault bounded tectonic slices. The Variscan crystalline basement is represented by deformed grey, brown to purple biotite granodiorite to tonalite. Contact of the Horné Belice Group with granites is represented by a steeply dipping normal fault of presumed Cenozoic age (Fig. 3 A and B).

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