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EARLY CRETACEOUS HIATUS IN THE CZORSZTYN SUCCESSION (PIENINY KLIPPEN BELT, WESTERN CARPATHIANS): SUBMARINE EROSION OR EMERSION?

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Abstract: The Czorsztyn Succession is the shallowest Pienidic unit of the West Carpathian Pieniny Klippen Belt. After the Valanginian, a hiatus encompassing almost the whole Hauterivian, Barremian and Aptian occurred in this unit. The Tithonian–Lower Cretaceous limestones are overlain by pelagic Albian–Cenomanian marlstones, marly limestones and cherts (Chmielowa and Pomiedznik Formations). The nature of this hiatus was so far unclear, either representing a submarine non-deposition and erosion, or subaerial exposure.

The paper brings provides a summary of data collected from the literature and new data from 5 re-examined sites and 5 new sites: Dolný Mlyn, Vršatec (3 sites), Horné Sŕnie, Lednica, Jarabina, Kamenica (all Slovakia), Czerwona Skała Klippe (Poland) and Vilki Dil (Ukraine). At two sites, the Albian marlstones and limestones overlie rocks older than Tithonian or Neocomian. In Jarabina, the Barremian–Aptian erosion reached the level of Kimmeridgian red micritic limestones, though clasts of limestones with “filamentous” microfacies indicate that Bathonian–Callovian limestones were also exposed and eroded. At Horné Sŕnie, the Albian deposits overlie Bajocian crinoidal limestones. The Bathonian to Hauterivian sediments are missing, which indicates that this part of the Czorsztyn sedimentary area experienced the deepest erosion. Unequivocal indicators of subaerial exposure and karstification, e.g. karren landform with vertical drainage grooves, small cavities in the bottom rock filled with younger sediment, bizarre fractures and veinlets filled with calcite, were revealed mainly at Horné Sŕnie and Lednica sites. The emersion was followed by pelagic of pelagic Albian marlstones and limestones. At this time, the palaeokarst surface was bored by bivalves and encrusted by deep-water Fe-Mn to phosphatic stromatolites. This suggests a very rapid relative sea-level rise, causing marine ingression. There were two transgression pulses in the Late Aptian and Albian, separated by a temporary emersion and karstification. The Upper Aptian sediments are still organodetrital with crinoids and other benthic fauna, whereas those of the Albian contain exclusively pelagic planktonic fauna.

Key words: palaeokarst, Early Cretaceous, Carpathians, Pieniny Klippen Belt.

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INTRODUCTION

The Pieniny Klippen Belt represents a narrow zone separating the Outer and the Central Western Carpathians. It is one of the most complex zones of the Western Carpathians. After at least two deformation phases, the zone gained its typical klippen structure, where harder rocks (mostly Jurassic to Lower Cretaceous limestones) form tectonic slices and blocks (klippen), whereas softer rocks (mainly Cretaceous marls) form their envelope. The Pieniny Klippen Belt thus represents a mélange in which numerous paleogeographically different units are mixed. One of them is Czorsztyn Succession which is the most shallow-water Pienidic unit of the Pieniny Klippen Belt. Sediments of this unit were deposited on an elevation called the Czorsztyn Ridge. The Hauterivian to Aptian sediments are completely missing in this unit; the Tithonian–Lower Cretaceous limestones are overlain by pelagic Albian marlstones and marly limestones with stromatolitic crusts at their base. The nature of this hiatus was often discussed in the literature. Some authors favoured a submarine non-deposition and erosion (e.g., Birkenmajer, 1958b, 1975), whereas others proposed an emersion and subsequent flooding of the Czorsztyn Ridge (Andrusov *et al.*, 1959; Mišík, 1994). One of the aims of this paper is to provide new data that may be clues to resolve this problem. The new data were obtained by field observations and petrographic-microfacies analysis. Special emphasis is placed on the Aptian–Cenomanian sequences that were deposited after the hiatus.

Another aim is to provide a complete summary of the localities and previous literature, dealing with the Albian–Cenomanian of the Czorsztyn Succession, so that the readers could have all the necessary data accessible in one paper.

GEOLOGICAL AND GENERAL STRATIGRAPHIC SETTING

Ten localities with the preserved contact between the Albian and the underlying formations in the Czorsztyn Succession were studied in detail; five formerly known and five new found. The re-examined sites are: Dolný Mlyn, Jarabina, Kamenica and Czerwona Skała Klippe; the new localities are: Vršatec (3 sites), Horné Sŕnie, Lednica and Vilki Dil (Fig. 1). These locations are crucial for investigation of the contact zones of the Albian with pre-Albian basement.

The Albian sediments of the Czorsztyn Succession are referred to the Chmielowa Formation (Middle–Upper Albian) (Fig. 2) and the Pomiedznik Formation (Middle Albian–Lower Cenomanian) (Birkenmajer, 1963, 1977; Alexandrowicz, 1966, 1979; Birkenmajer & Jednorowska, 1987; Gasiński, 1988; K. Bąk *et al.*, 1995). The former consists of red or greenish marly limestones with abundant planktonic foraminifers (*Hedbergella* microfacies), rare belemnites (*Neohibolites*), and inoceramid shell fragments (Birkenmajer, 1977). The Chmielowa Formation is usually very condensed, with thickness reduced to some tens of centimetres, and sometimes down to 1.5 cm. The Pomiedznik Formation is dominated by green and black, often spotty marly limestones, sometimes silicified, with rare belemnites (*Neohibolites*) and bivalves (*Aucellina*, *Pycnodonta*).

Both formations have good stratigraphical documentation based on foraminifers (e.g., Alexandrowicz, 1966, 1979; Alexandrowicz *et al.*, 1968; Gasiński, 1988). Micropalaeontological studies indicate the Middle-Late Albian age for the Chmielowa Formation and the Middle Albian–Early Cenomanian age for the Pomiedznik Formation.

Between Chmielowa Formation and its substratum, some non-depositional features can be observed, including erosional base, irregular (patchy) distribution of the basal deposits of the formation, Fe-Mn crusts at its base (being up to several centimetres thick) or accumulation of belemnite guards (e.g., Birkenmajer, 1963; Alexandrowicz & Tarkowski, 1979). Sometimes the basal bed contains angular fragments of older rocks or crinoid segments derived from the underlying Spisz Limestone Formation.

Only Jendrejáková and Salaj (1962) mentioned continuous transition from the Neocomian to the Albian in the Czorsztyn Succession, from the borehole near Mikušovce. However, this interpretation is most probably erroneous. Most likely, the borehole penetrated Kysuca Succession because the Neocomian rocks are represented by dark-grey marly shales, and the Aptian by dark-grey to black marls. These authors suggested a deep-water sedimentation in this part of the Czorsztyn Succession.

The Chmielowa Formation overlies erosional surface of different age, predominantly represented by the red crinoidal limestones of the Valanginian Spisz Limestone Formation (Krobicki & Wierzbowski, 1996). At several locations (see below) the substratum is built by older rocks, like various parts of Berriasian *Calpionella* limestones, Tithonian red nodular *ammonitico rosso*–type limestones and even Bajocian crinoidal limestones. The erosion lasted from the Hauterivian to the Albian.

The Pomiedznik Formation, varies in thickness from about 10 to 35 m. The contact with the underlying Chmielowa Formation is sedimentary, and is marked by colour change from red (Chmielowa Formation) to green and black (Pomiedznik Formation) (Birkenmajer, 1977). The Pomiedznik Formation often covers directly the pre-Albian sequences, and therefore it can be considered as facies equivalent of the Chmielowa Formation (Birkenmajer, 1963, 1977; Alexandrowicz, 1966; Alexandrowicz *et al.*, 1968).

MATERIALS AND METHODS

Five sites were re-examined and 5 new sites, recently discovered, were studied. Field observations focused on the contact between the Albian–Cenomanian sediments and their substratum. The features like erosion, borings, stromatolitic encrusting, older calcite veinlets and character and generations of basal sediments were noted; age and lithology of the substratum were also examined. The localities were sampled for petrographic, microfacies and XRD analyses. The samples were taken from the underlying rocks, from the lowermost sediments and from the overlying sediments up to 2 m above the base. Oriented samples were studied microscopically.

Mineralogical composition of stromatolites and oncoids from Vršatec, Horné Sŕnie and Jarabina were studied by means of powder X-ray diffraction analysis (XRD). The analysis was done on DRON-3 analyser, using $Co_{K\alpha}$ of the wavelength λ: 1.79021 Å, filter Fe, voltage 30 kV, intensity 15 mA, diaphargms 1;1;0.1, or $Cu_{K\alpha}$ of the wavelength 1.54178 Å, filter Ni, voltage 40 kV, intensity 20 mA, diaphragms 1;1;0.5. The obtained diffraction data were compared with the etalon data from the database JCPDS (1974) – fluorapatite JCPDS 15-876; calcite JCPDS 5-586; pyrolusite JCPDS 12-716. Rusty and brown colouration of some stromatolites and oncoids is caused by goethite, with the reflections 4.18 Å, 3.86 Å (or the RTG-amorphous Fe-oxides). The reflections 4.28 and 3.35 Å belong to quartz.

Review of all localities mentioned in the literature is given in the Appendix.

FIELD OBSERVATIONS, PETROGRAPHIC AND PALEONTOLOGICAL DATA

Dolný Mlyn

The Valanginian limestones are penetrated by thin (mm-size) neptunian dykes and small caverns filled with dark-red limestone with tiny hedbergellid foraminifers. The absence of *Ticinella roberti* may indicate the Barremian–Aptian age of the sediment. However, a size-sorting in narrow spaces cannot be ruled out (*Ticinella* is larger than the hedbergellids in the neptunian dykes). Contact between the Neocomian limestones and Albian marlstones crops out in the northern part of the quarry (Fig. 3A, B), where also a ba-

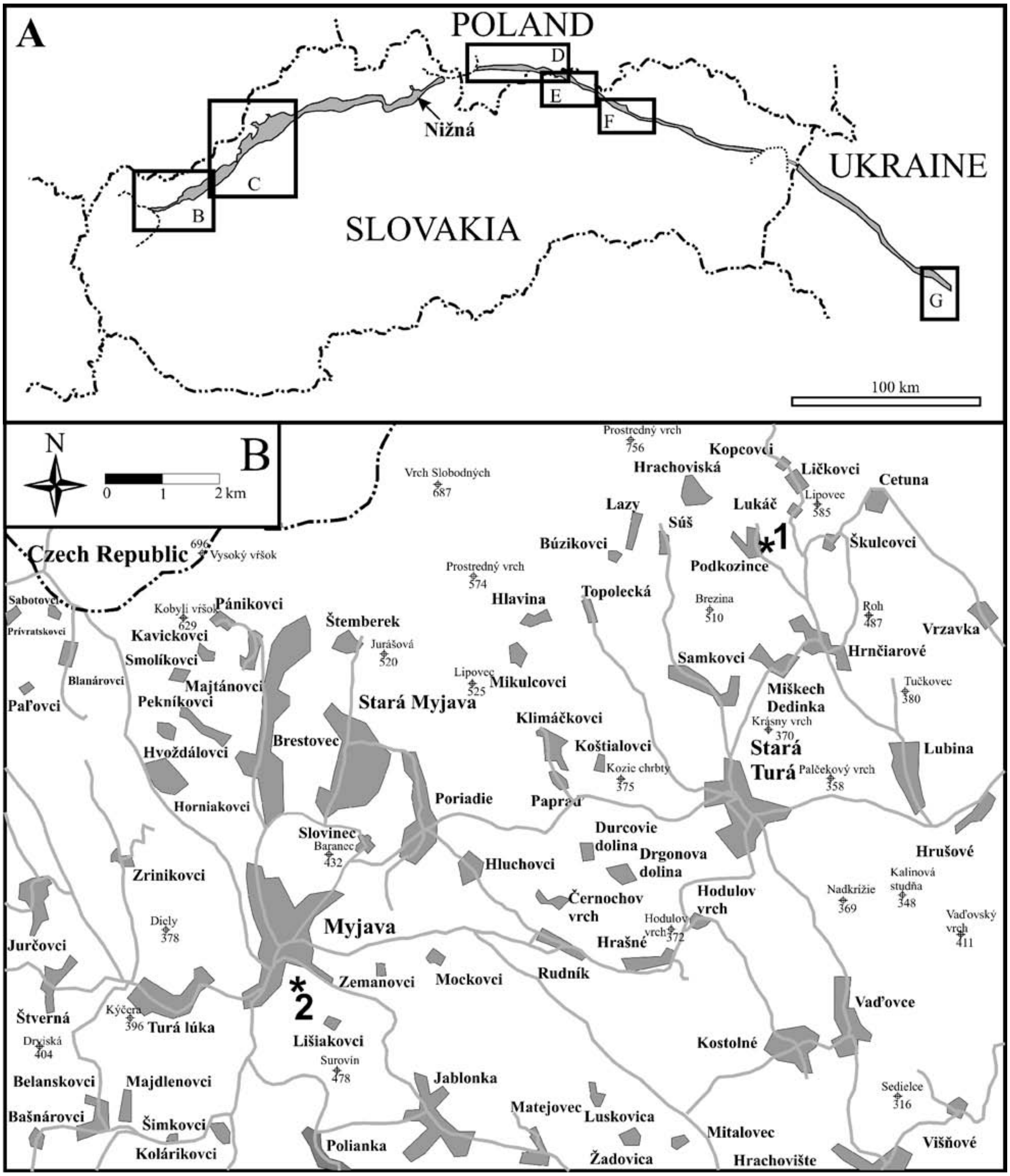


Fig. 1. **A** – Sketch map of the Pieniny Klippen Belt with marked location of detailed maps with occurrences of the Albian–Cenomanian sediments in the Czorsztyn Succession. **B** – Myjava sections of the Pieniny Klippen Belt with Albian/Cenomanian localities (localities studied in detail and described in the text – in bold) (**1 – Dolný Mlyn**, 2 – Myjava)

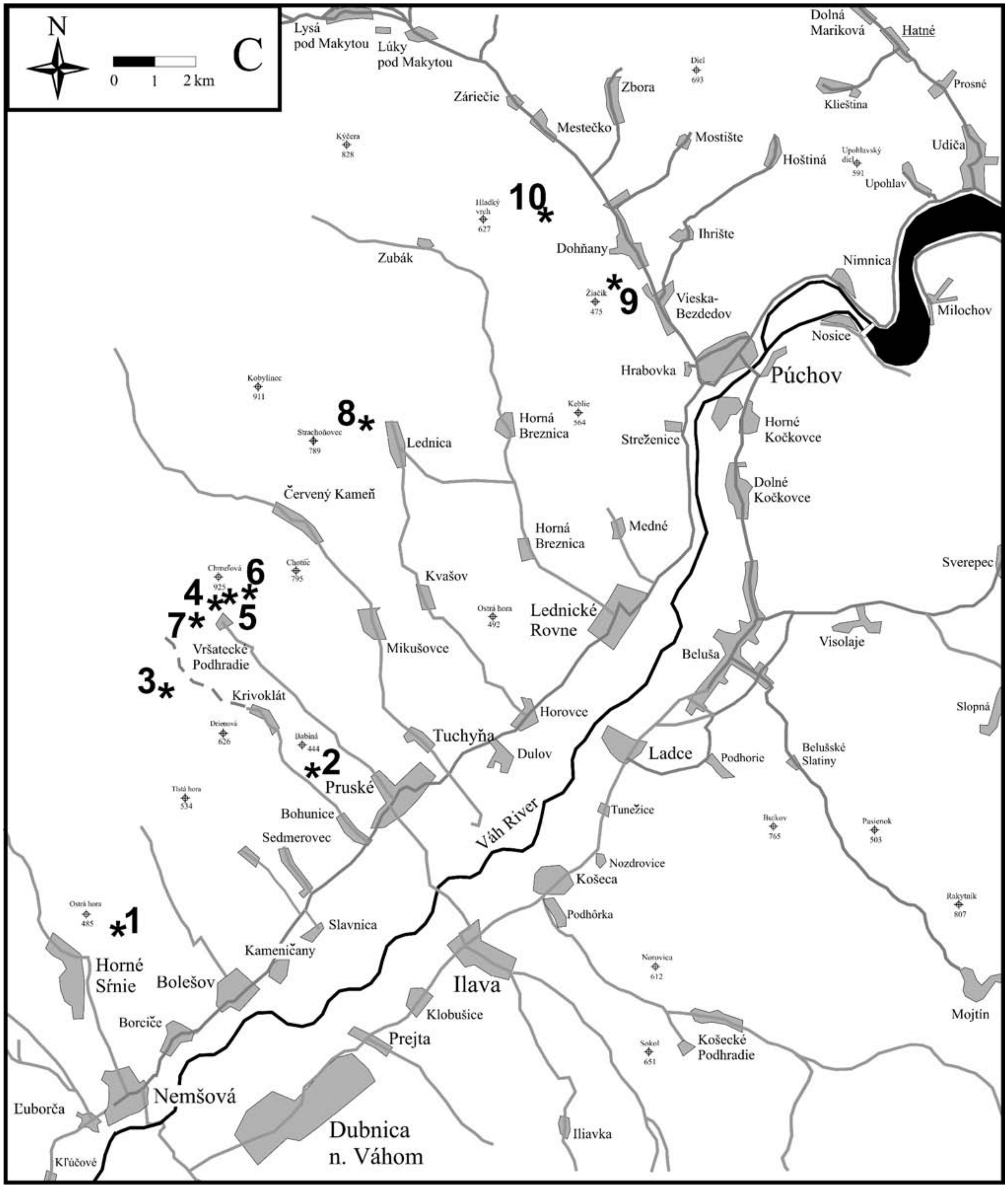


Fig. 1. **Continued. C** – Váh Valle sections of the Pieniny Klippen Belt with Albian/Cenomanian localities (**1 – Horné Sŕnie,** 2 – Babiná, 3 – Chrastková, 4 – Vršatec (loc. 1, 1a, 5, 6, 34, 43c), **5 – Vršatec (loc. 47)**, **6 – Vršatec** (beneath the profile II), **7 – Vršatec** (the southernmost coulisse), **8 – Lednica**, 9 – Žiačik, 10 – Dohňany).

sal breccia is preserved with some clasts bored by bivalves (Fig. 3C). The locality provides a rare example of the Albian basal breccia in the Czorsztyn Succession. At most other localities (see the Appendix) pelagic to hemipelagic sediments rest directly upon the substratum, with only small amount of detritic admixture.

Vršatec (loc. 47)

The locality was previously mentioned by Mišík (1979) (Fig. 4). Re-examination of this locality showed that contains a complex manganese hardground involving a very large stratigraphic interval probably from the Bathonian to the Lower Tithonian. Specific for this locality is presence of

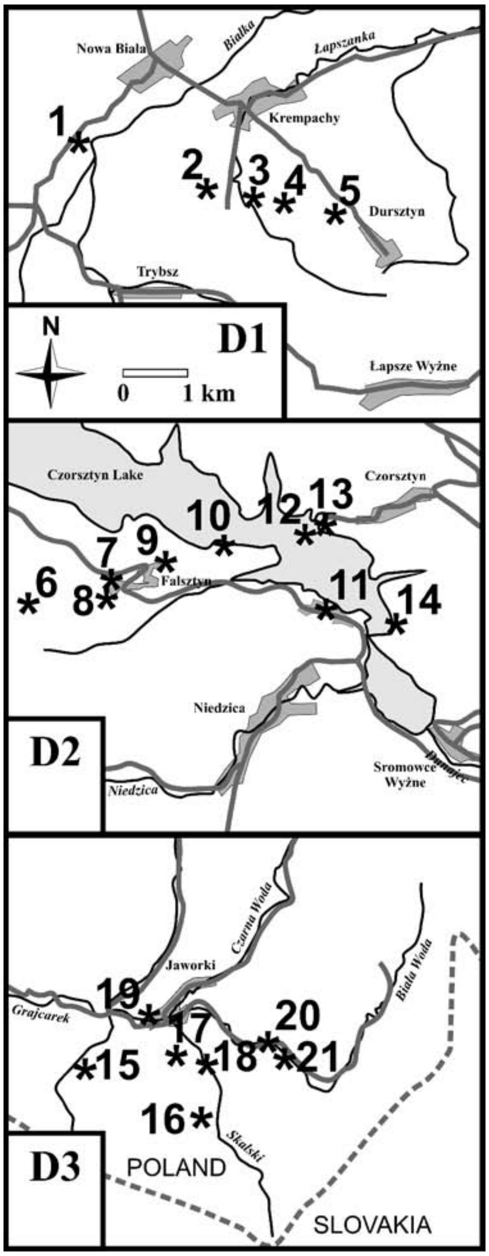


Fig. 1. Continued. **D** – Polish section of the Pieniny Klippen Belt with Albian/Cenomanian sediments; **D1**: 1 – Obłazowa Klippe; 2 – Korowa Klippe; 3 – Lorencowe and Gęśle Klippen; 4 – Borsukowa Klippe; 5 – Czerwona Skała Klippe; **D2**: 6 – Łysa Skała Klippe; 7 – Falsztyn-Pomiedznik Klippe; 8 – Chmielowa and Kosorki klippen; 9 – Brynczkowa Klippe; 10 – Zielone Skałki Klippen; 11 – Niedzica Castle; 12 – Halka Klippe (submerged now); 13 – Sobótka Klippe; 14 – Kapuśnica; **D3**: 15 – Krupianka stream; 16 – Szczepanówka Klippe; 17 – Szczobiny; 18 – Czajakowa Skała Klippe; 19 – Jaworki, church; 20 – Biała Woda, waterfall; 21 – Biała Woda Valley.

serpulid bioconstructions developed on a very irregular substrate. During the Cenomanian, this condensed layer was cut by many thin microdykes, followed with red marls. The marls also filled some empty parts of the bioconstructions (Fig. 5A, B). The marls contain planktonic foraminifers *Thalmanninella brotzeni* (Sigal), *Th. micheli* (Sacal et Debourle), *Th. ticinensis ticinensis* (Gandolfi), *Praeglobotruncana delrioensis* (Plummer) and *Hedbergella planispira* (Tappan) indicating the Cenomanian (probably Early Cenomanian) age. Some wider dykes were filled by microbreccias with the same marly matrix, including various carbonate clasts: fine-grained crinoidal wackestone, crinoidal grainstone, *Globochaete-Saccocoma* wackestone, *Calpionella* mudstone to wackestone.

Vršatec (new localities)

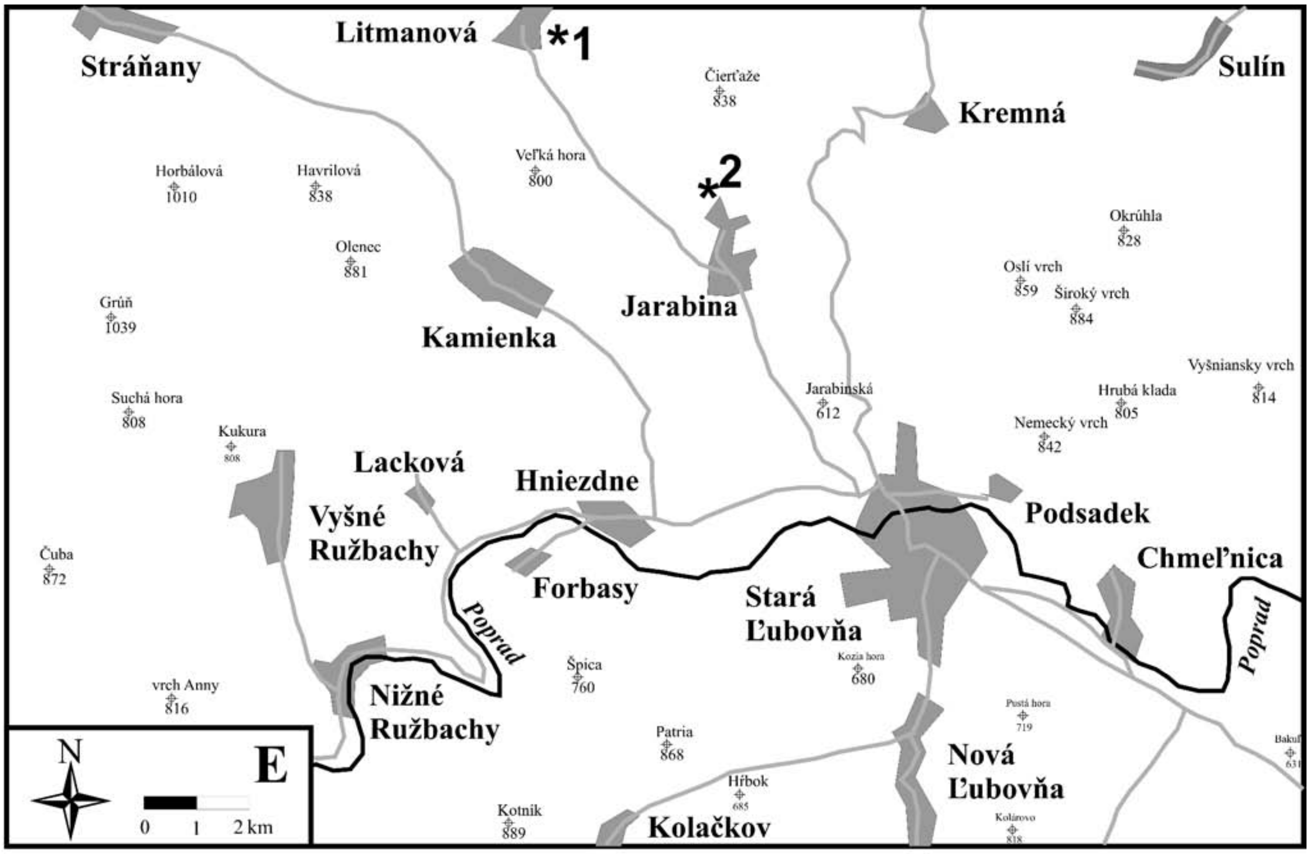
Two new sites with contact betwen the Albian marlsones and the underlying Neocomian limestones were found. The first locality was named “Vršatec – the southernmost coulisse”. It is situated at the southern end of the ridge of Vršatec Castle Klippe, NW of the town Ilava. Cenomanian cherts (Pomiedznik Formation) and partly the Albian sediments from this site were studied by Sýkora *et al.* (1997). The second locality was named Vršatec – “Profile II". It is situated at the forest path (blue tourist trail) from Vršatské Podhradie to Červený Kameň at the SE foot of the highest Vršatec Klippen. The contact between the Albian marlstones and Neocomian limestones is situated just beneath Profile II of Mišík (1979).

The contact sequence (Fig. 6A) consists of the underlying rocks, the overlying Upper Aptian–Albian sediments, and locally P-Fe-Mn stromatolites (up to 3 cm thick), occurring either directly at the basement or within the Albian sediment. The stromatolites may even form several thin horizons.

The underlying rocks are represented by crinoidal wackestone of Neocomian age. The rock is mostly grey and contains echinoderm ossicles, foraminifers *Lenticulina* sp., *Globuligerina* sp., nodosariid and various agglutinated foraminifers (e.g. *Dorothia* sp.), fragments of bivalves, brachiopods (pygopids), bryozoans, rare shells of juvenile ammonites, aptychi, echinoid spines, ostracods, gastropods, and single sclerite of theeliid holothurians. Locally, also intraclasts with Berriasian to Valanginian calpionellids were found. The skeletal debris are frequently bored; the aragonitic shells were commonly dissolved and the moulds were filled by younger, Albian sediment.

The Neocomian rocks are locally penetrated by veinlets filled with blocky calcite that, however, terminate at the base of the overlying Albian sediment (Fig. 6B). Therefore, the pre-Albian age is inferred for the veinlets. A fresh-water origin of the blocky clacite cannot be excluded. Similar blocky calcite, probably also pre-Albian, sometimes fills voids in the Neocomian limestone that originated either due to boring, or karstification, or as molds of aragonitic bivalves. Some veinlets, however, obviously originated due to recrystallization as they still contain ghosts of allochems from the surrounding matrix.

P-Fe-Mn stromatolites formed during break in deposition. As a rule, the stromatolites are finely laminated but locally, the lamination is less pronounced. The laminae are irregularly undulated even to form spherical oncoid-like bodies. The laminae are of yellow-brown, brown to black colour. As inferred from the X-ray analyses, the colours mark different dominant minerals: the yellow-brown parts contain mostly fluorapatite, the brown parts are dominated by



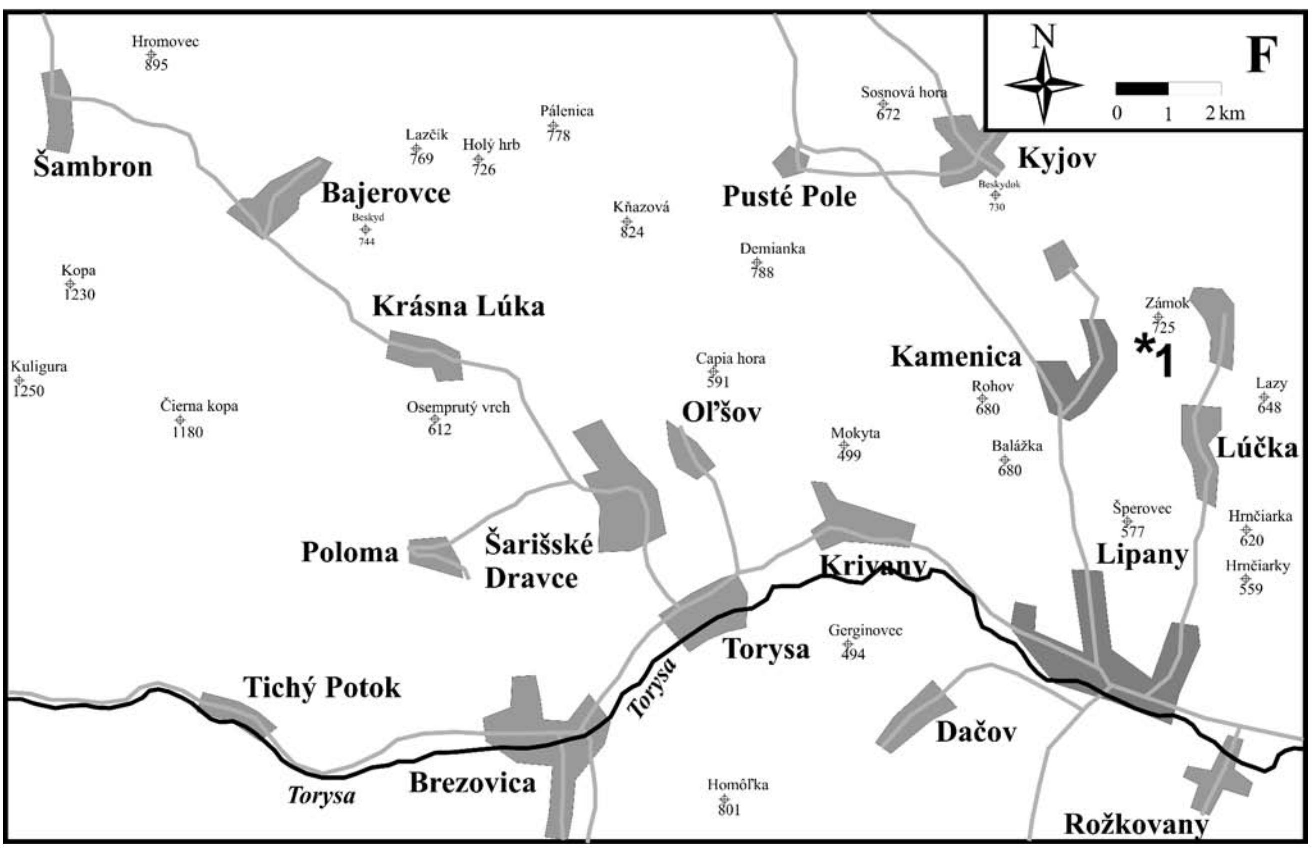


Fig. 1. Continued. **E** – Stará Lubovňa sections of the Pieniny Klippen Belt with Albian–Cenomanian sediments (1 – Litmanová, **2 – Jarabina**). **F** – Lipany section of the Pieniny Klippen Belt with Albian–Cenomanian sediments (**1 – Kamenica**).

goethite and black portions contain pyrolusite. Between some individual laminae, deformed calcitic veinlets occur (Fig. 6C), imprinting the lamination of the stromatolite. In some other cases, the stromatolites are perpendicularly scut by systems of subparallel thin veinlets. The veinlets are filled with blocky calcite, with crystals in some veinlets rimmed by black manganese minerals. In some cases, the Mn minerals rim the whole veinlets which indicates that the veinlets represented conduits for migrating Mn fluids. Both cases testify that the mineralization of the hardground continued still after dissection of the stromatolite by the veinlets.

The stromatolites commonly contain one- or multiple-chambered sessile foraminifers that occur between the laminae. These were a part of the hardground ecosystem. *Frutexites*-type stromatolites are common in the overlying Albian sediment, forming discontinuous shrub-like forms branching upwards. However, some cases of downward branching stromatolites (towards the Neocomian rocks) were also registered (Fig. 6C). Such structure of stromatolite might be either caused by a diagonal orientation of the thin-section and irregular surface of the underlying limestone or the *Frutexites* grew in a void.

The underlying Neocomian limestones are commonly impregnated by dark Fe-Mn minerals, most probably coming from the overlying Albian stromatolitic hardgrounds. In places, these minerals also replace bioclasts or even the matrix in the Neocomian limestones. Some thin sections show networks of thin borings (most likely fungal) coming from the stromatolite that are filled with opaque Fe-Mn minerals (Fig. 6D). The borings penetrate as deep as several centimetres down the substrate. The stromatolites locally occur in small cavities in Neocomian limestone. In such cases, very dense networks of the borings are concentrated around these voids.

The **Albian sediments** cover the uneven underlying surface. They can also be found in numerous cavities in the Neocomian limestones. Geopetal fillings of these voids are common. Cavity sedimentation was inferred for the samples where there was an obvious contradiction between the position of Neocomian substatum, encrusted by stromatolite and the overlying Albian sediment on one side and the geopetal filling of some tiny voids in the underlying rocks (Fig. 6E, F) on the other. These samples were taken from scree, not allowing reconstruction of their original orientation. Origin of many cavities seems to be tied to leaching. Whether the leaching originated due to karstification after emergence or by dissolution by marine water, was not possible to resolve. Nevertheless, some cavities were found several tens of centimetres below the top of the Neocomian limestones.

The overlying, older sediments are represented by two different lithologies occurring in stratigraphic order: crinoidal wackestone to packstone (Upper/Aptian) and foraminiferal wackestone (Albian).

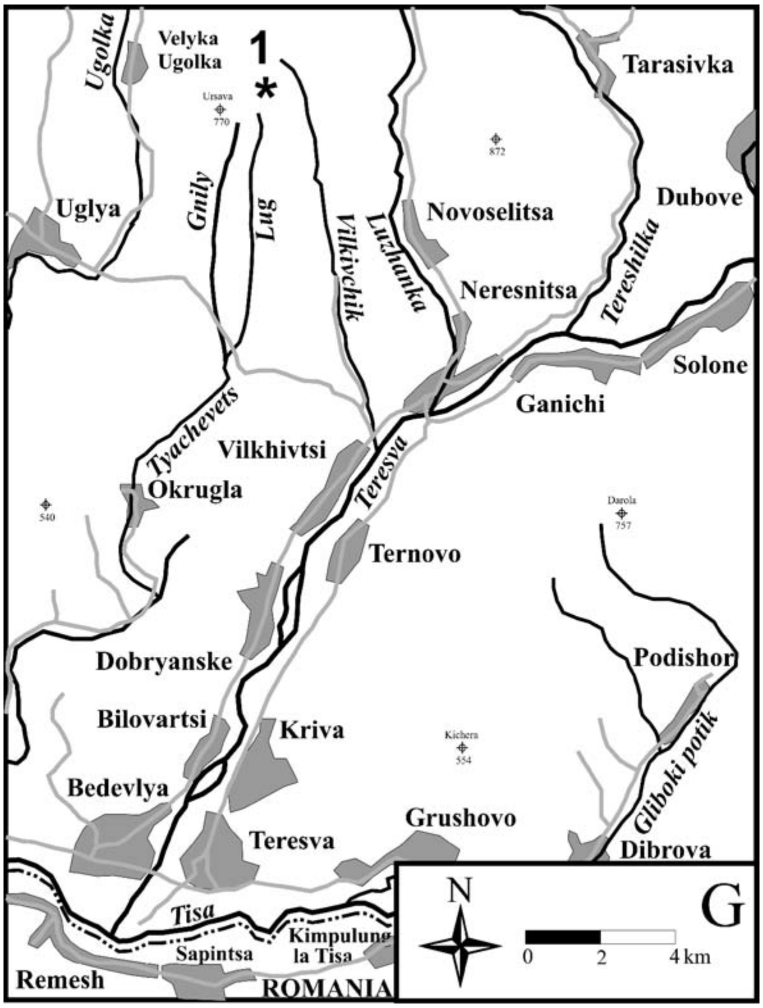


Fig. 1. **Continued**. **G** – Novoselitsa section of the Pieniny Klippen Belt with Albian–Cenomanian sediments (**1 – Vilki Dil -Barakishtche**)

The crinoidal wackestone to packstone contains abundant crinoid ossicles (Fig. 6G). Besides the ossicles, the sediment contains abundant planktonic foraminifers *Hedbergella infracretacea* (Glaessner), less frequent *Ticinella roberti* (Gandolfi), benthic foraminifers *Lenticulina* sp., *Tetrataxis* sp., various planispiral foraminifers and agglutinated ones. Less common are echinoid spines, sponge spicules, ostracod and bivalve shells; very rare are shells of juvenile ammonoids. The skeletal remnants, mainly of benthic organisms show common microborings.

The crinoidal biomicrite contains sandy quartz admixture and uncommon lithoclasts, that are missing in the overlying foraminiferal biomicrite. Most of the clastic admixture is concentrated in depressions of the irregular discontinuity surface of the Neocomian limestones. Some authigenic glaucontic grains were found. Among the lithoclasts, detritus of limestones with *Calpionella alpina* Lorenz, pure micritic or organodetritic limestones and one clast of basic volcanic rock were found. The P-Fe-Mn stromatolites locally form clasts in these sediments which indicate their reworking by currents.

The sediment often contains tiny voids resembling fenestrae, commonly containing geopetal filling of micrite and

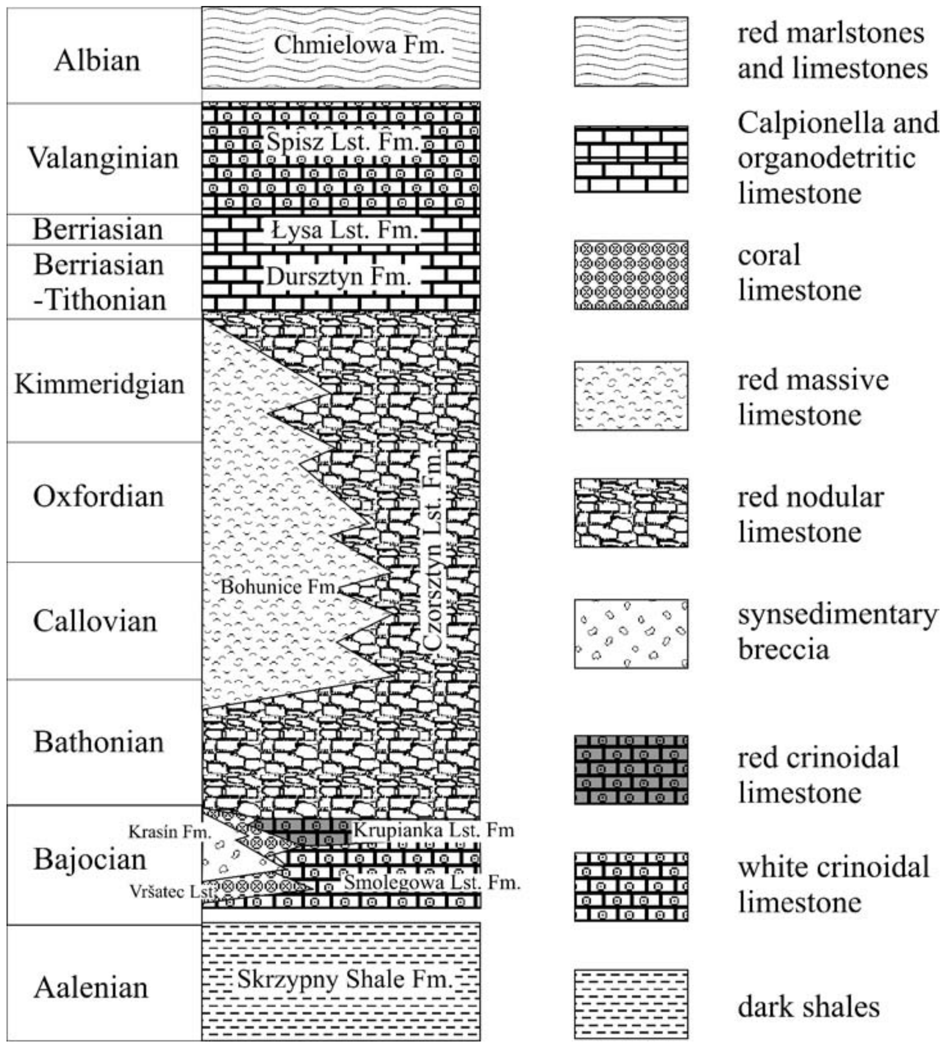


Fig. 2. Lithostratigraphical scheme of the Czorsztyn Succession (after Aubrecht *et al.*, 1997; modified)

blocky sparite. In one case, the crinoidal biomicrite was cut by blocky calcite veinlet which terminated at the boundary with younger foraminiferal biomicrite. The veinlet indicates lithification of the crinoidal biomicrite and its fracturing prior to deposition of the foraminiferal biomicrite.

Foraminiferal wackestone with dominant planktonic organisms like foraminifers with *Ticinella roberti* (Gandolfi), benthic foraminifers (e.g., *Lenticulina* sp., nodosariids), agglutinated foraminifers (e.g., *Marssonella* sp.,), rare planispiral foraminifers, ostracods and fragments of bivalve shells of various genera (thin shells of *Aucellina* sp., prisms of inoceramids etc.) reflect the second phase of the submersion (Albian). The clastic admixture is very rare. The colour of the micrite is patchy which was caused by strong local bioturbation. Micrite filling the voids contains only fine allochems.

Locally, the sediments of the latest Albian (*Planomalina buxtorfi* Zone according to Maamouri *et al.*, 1994) occur. They are dominated by *Planomalina buxtorfi* (Gandolfi) (Fig. 7I), *Thalmanninella* cf. *appeninnica* (Renz), *T. ticinensis ticinensis* (Gandolfi), *T. ticinensis conica* Gašparíková et Salaj (Fig. 7D), *Praeglobotruncana delrioensis* (Plummer), *Biticinella breggiensis* (Gandolfi) (Fig. 7G, H), *Whiteinella gandolfii* Gašparíková et Salaj, *Hedbergella delrioensis* (Carsey), and *H. planispira* (Tappan).

Locally, even younger sediments of the *Thalmanninella brotzeni* Zone (Salaj, 1996) were found near the base, representing the Lower Cenomanian. The fauna of planktonic foraminifers consists of *Thalmanninella brotzeni* Sigal (Fig. 7A, B), *T. appenninica appenninica* (Renz), *T. ticinensis ticinensis* (Gandolfi) (Fig. 7C), *Praeglobotruncana delrioensis* (Plummer), (Fig. 7E), *P. stephani* (Gandolfi) (Fig. 7F), and *Hedbergella planispira* (Tappan). Benthic assemblage includes *Dorothia oxycona* (Reuss) and *Anomalina* sp.

The Albian sediment often fills the voids in the stromatolites. Locally, it is replaced by Fe-Mn-P minerals. Tests of planktonic foraminifers trapped in the stromatolite and filled with opaque Fe-Mn minerals are common. In places, stromatolitic laminae alternate with sediment layers. On the other hand, there were some cases of fractured stromatolites, with fractures filled by micrite with tiny hedbergellid foraminifers, forming thus neptunian microdykes. Outside the stromatolites, the sediment is impregnated by dark Fe-Mn minerals.

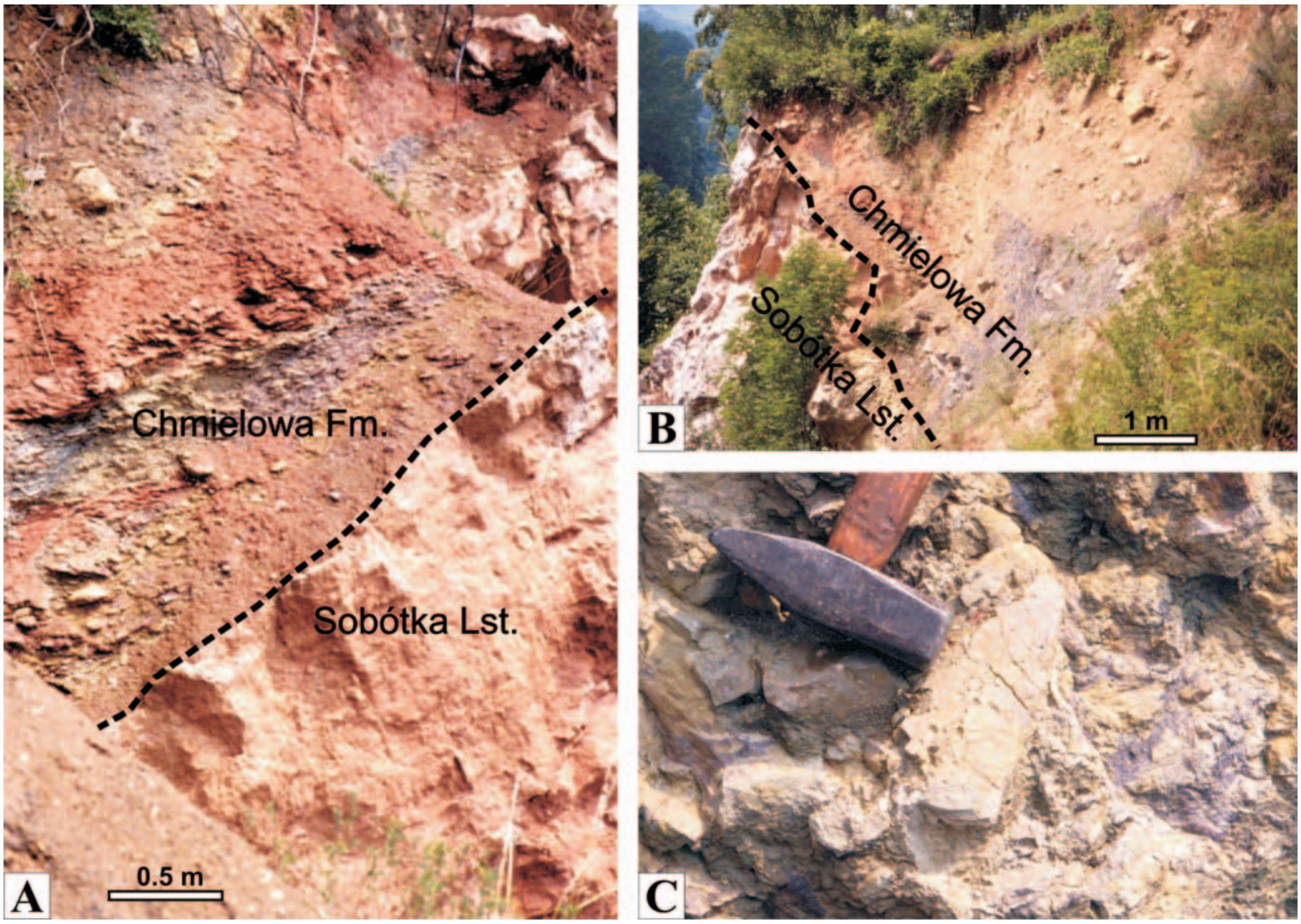


Fig. 3. Chmielowa Formation at Dolný Mlyn: **A**, **B** – Chmielowa Fm. overlying Sobótka Limestone; **C** – Rare occurrence of basal breccia on the base of the Chmielowa Formation. Some clasts are bored by bivalves (at the hammer head)

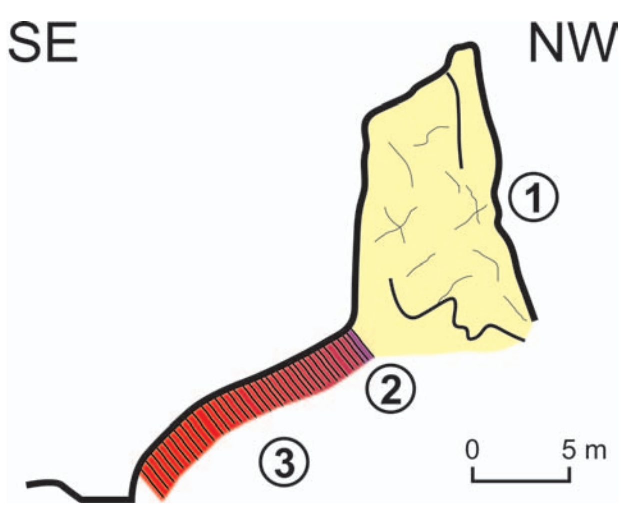


Fig. 4. Vršatec (the southernmost coulisse); fragment of the section studied near the road to castle. 1 – Creamy *Calpionella*-bearing limestones of the Dursztyn Limestone Formation (Berriasian); 2 – Reddish-violet marls of the Chmielowa Formation (Albian); 3 – Red and brittle-red marls of the Pustelnia Marl Member of the Jaworki Formation (Upper Cretaceous)

In some cases younger, Late Albian/Early Cenomanian sediments with *Hedbergella infracretacea* (Glaessner) and *Thalmanninella ticinensis* (Gandolfi) occur in contact with the stromatolites. This indicates that the conditions suitable for stromatolite growth lasted during a long period of time.

Lednica

Although the old outcrop described by Mišík (1979) does not exist anymore, a new exposure was found in the close vicinity, just left to the entrance to ruins of the Lednica Castle. On the rocky wall, represented by steeply inclined top of the Neocomian *Calpionella* limestone (i), several features can be observed. The surface is very uneven with obvious signs of erosion (perhaps karstification), with visible shallow karren surface (Fig. 8A). The karren surface was later densely bored by bivalves (Fig. 8D) and then covered by younger sediments. It is noteworthy that some remnants of Upper Aptian red crinoidal wackestones (ii) (the same as at Vršatec localities) fill the karren surface and are themselves eroded (Fig. 8B). The Neocomian limestones were fractured, with fractures filled with blocky calcite. These calcite veinlets do not cut the overlying Albian marlstones (Fig. 8C), hence, they originated after lithification of the Neocomian and before deposition of the Albian pelagic

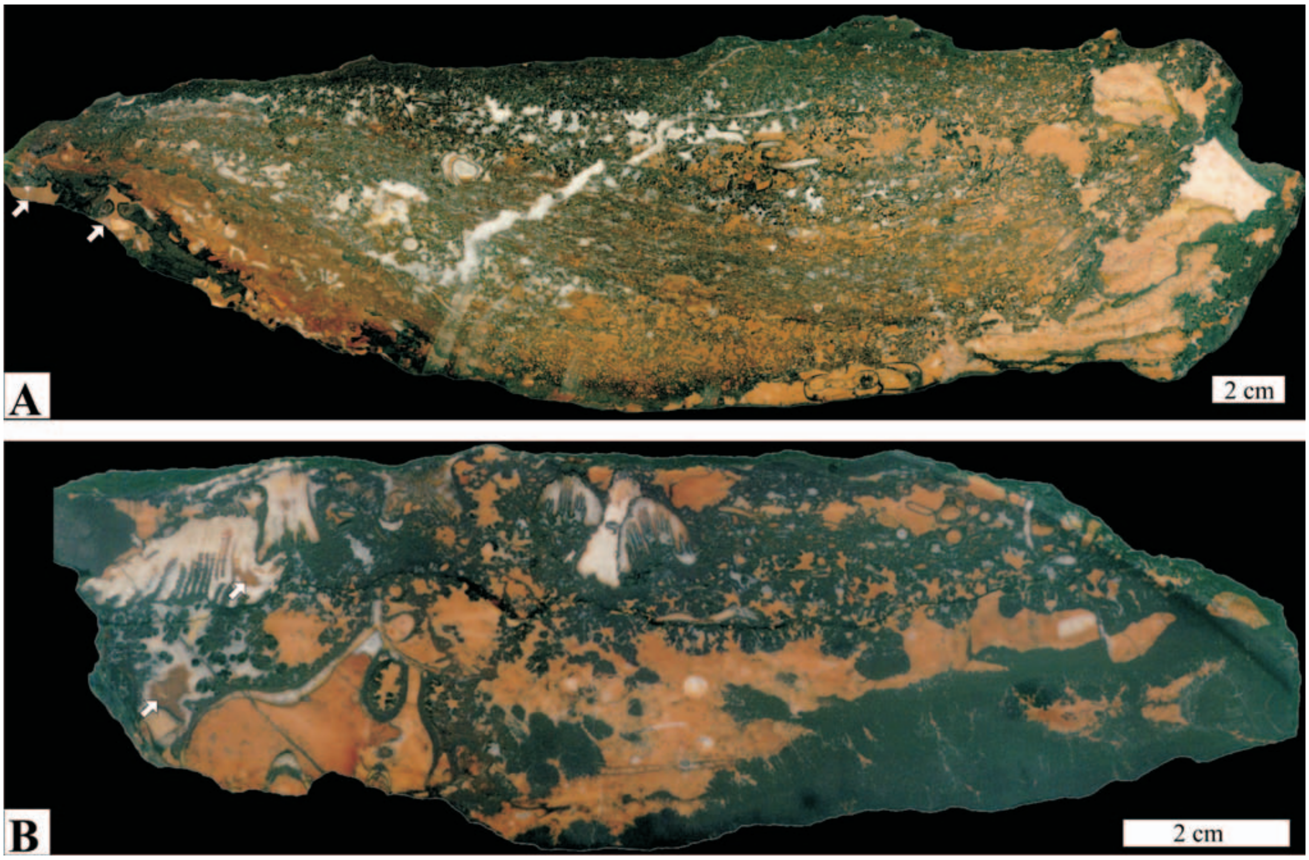


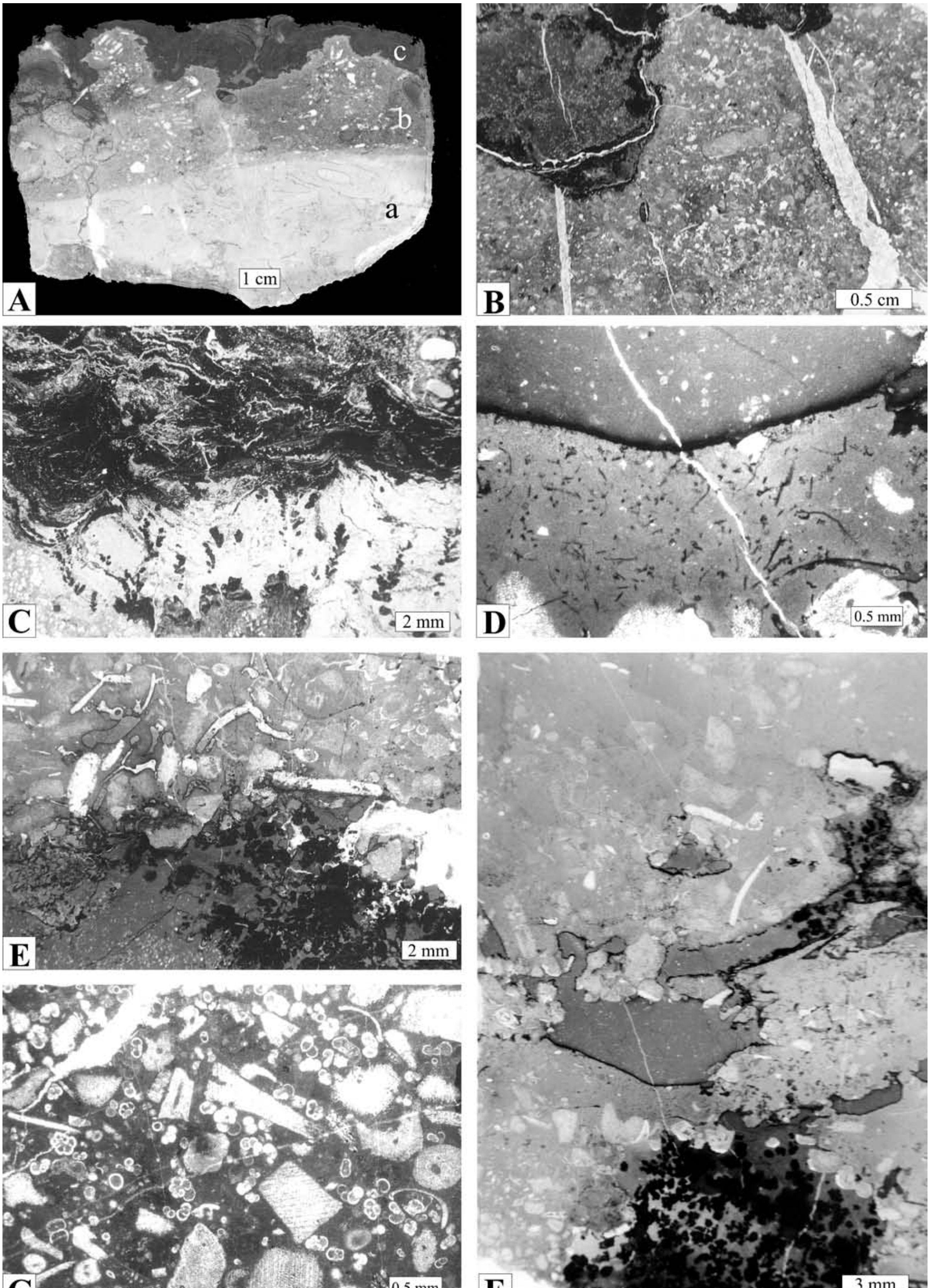
Fig. 5. Slabs of samples from the Vršatec – locality 47: **A** – Tithonian manganese crusts with embedded serpulid microreefs (cavern filling). Relic voids are filled with Cenomanian red micrite (arrows); **B** – Other slab of the filling; the Cenomanian micrite fills remaining growth cavities in solitary corals (arrows)

sediments (iii). The calcite filling the veinlets (iv) was bored by bivalves together with the surrounding limestones (Fig. 8D). Therefore, it may be presumed that the veinlets originated during the second phase of emersion and their filling may be of fresh-water origin.

(i) The *Calpionella* limestone represents wackestone with abundant tintinnids *Crassicollaria intermedia* (Durand Delga) and *Calpionella alpina* Lorenz. Along with them, numerous ghosts after calcified radiolarians, globochaets, ostracods, rare crinoid ossicles, echinoid spines, agglutinated foraminifers and very rare fragments of aptychi are present.

(ii) *Upper Aptian limestone* contains macroscopically visible crinoidal ossicles and bivalve fragments (mainly *Aucellina* sp.), siliciclastic admixture and grenish-yellow oncoids of phosphatic composition. Besides with these components, microscopical investigation shows that the limestone is the packstone to wackestone with hedbergellid foraminifers, rare echinoid spines, sponge spicules, ostracods and very rare bryozoan fragments. The allochems are commonly corroded. Some allochems and intraclasts are coated and impregnated with yellowish phosphate. Similar material also forms the small oncoids and fragments of branching columnal stromatolites. Rarely also some completely

Fig. 6. Slabs and microphotos from Vršatec-the southernmost coulisse and Vršatec-below profile II. **A** – Slab of Neocomian limestone (a), covered by Upper Albian organodetrital limestone (b), with P-Fe stromatolite (c) at the base of pelagic Albian deposit. Note the uneven surface between the Upper Albian limestone and the stromatolite. The surface was most likely shaped by karstic dissolution; **B** – Two pre-Albian veinlets filled with blocky calcite, cutting the Neocomian organodetritic limestone but not continuing to the Albian stromatolitic hardground; **C** – Albian stromatolite (with ptygmatitically folded calcite veinlets – upper part of the photo) and bush-like *Frutexites*-type stromatolites growing in the Albian sediment towards the stromatolite. The latter means that the sediment represents filling of a larger cavity and the stromatolite above grew on its ceiling; **D** – Network of Mn-oxides-filled traces in the Neocomian limestone created by boring organisms, most likely fungi (the traces are locally branching) below the base of the Albian; **E** – Geopetal filling of the leached bivalves in the Neocomian limestone (above) contradicts to the location of the Albian sediment (below). It indicates that the Albian sediment deposited in a cavity (most likely karstic); **F** – Bizarre cavities in the Neocomian limestone filled with Albian micrite. Their geopetal filling enables to orient the photo properly, in spite of the position of the Albian stromatolite and sediment (below). They most probably represent filling of a larger karstic cavity; **G** – Crinoidal-foraminiferal wackestone to packstone of the Late Aptian–Early Albian age, representing sediment of the first phase of flooding after the hiatus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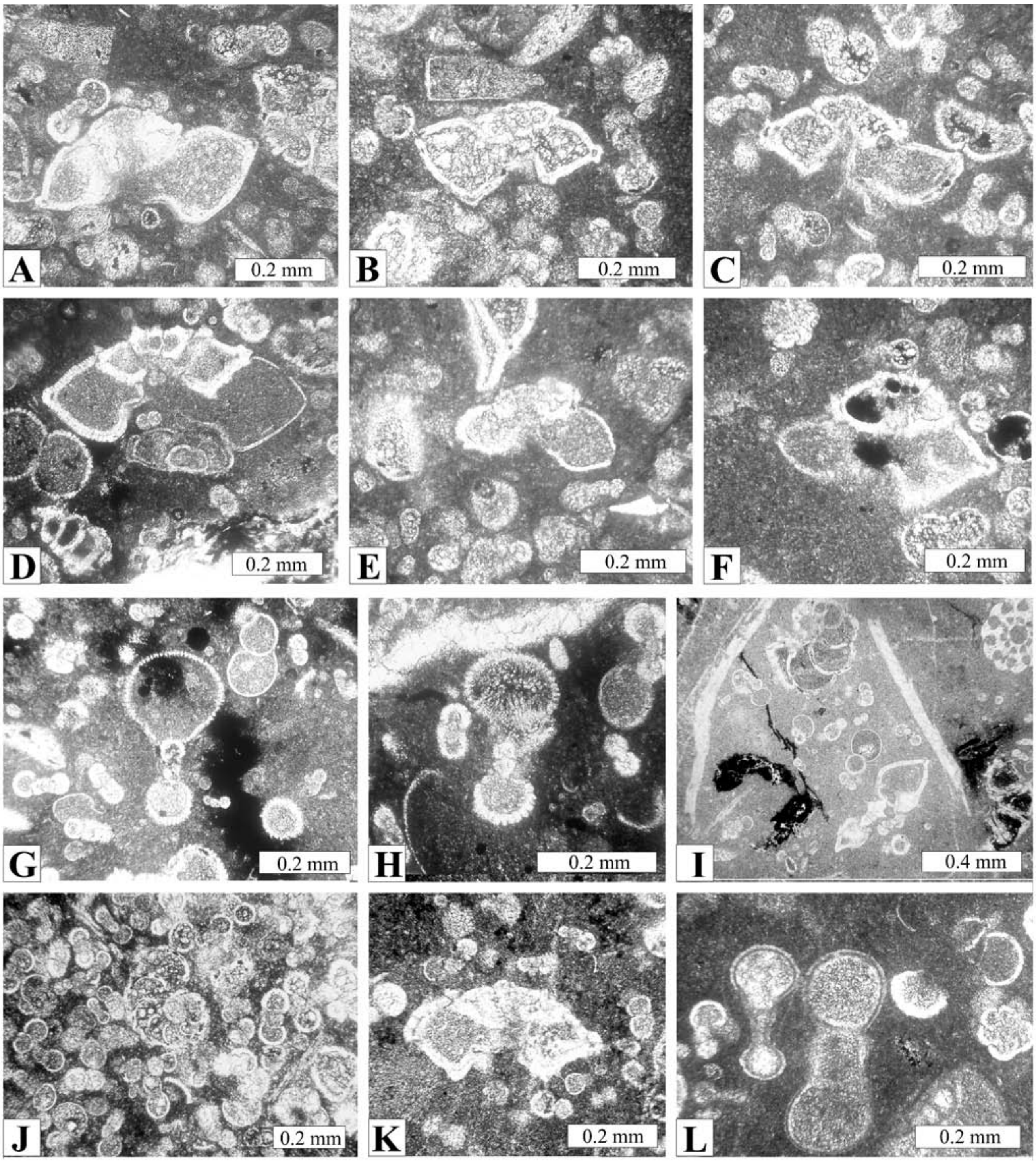


Fig. 7. Stratigraphically important planktonic foraminifers from Vršatec (A–I), Jarabina (J) and Lednica (K, L) localities: **A, B** – *Thalmanninella brotzeni* Sigal, *T. brotzeni* Zone; **C** – *Thalmanninella ticinensis ticinensis* (Gandolfi), *T. brotzeni* Zone; **D** – *Thalmanninella ticinensis conica* Gašpariková et Salaj, *P. buxtorfi* Zone; **E** – *Praeglobotruncana delrioensis* (Plummer), *T. brotzeni* Zone; **F** – *Praeglobotruncana stephani* (Gandolfi), *T. brotzeni* Zone. **G, H** – *Biticinella breggiensis* (Gandolfi), *P. buxtorfi* Zone; **I** – *Planomalina buxtorfi* (Gandolfi), *P. buxtorfi* Zone; **J** – *Planomalina buxtorfi* (Gandolfi), Jarabina, *P. buxtorfi* Zone; **K** – *Thalmanninella ticinensis ticinensis* (Gandolfi), *P. buxtorfi* Zone; **L** – *Globigerinelloides ferreolensis* (Moullade), Upper Aptian

phosphatized limestone intraclasts occur (Fig. 8F). The foraminifers in the limestone are dominated by planktonic genera *Hedbergella* and *Globigerinelloides*. The latter genus is represented by *Globigerinelloides ferreolensis* (Moullade) (Fig. 7L) and *G. algerianus* Cushman et Ten Dam; the hedbergellids are represented by *Hedbergella trocoidea* (Gandolfi) and *Ticinella roberti* (Gandolfi). Other foraminifers are "*Biglobigerinella barri"* (Bolli, Loeblich et Tappan), *Blefuscuiana* cf. *gorbachikae* (Longoria), *B. infracretacea* (Glaessner), *Dorothia* sp., other agglutinated forms, nodosariids, sessile nubecularids and *Lenticulina* sp. The assemblage indicates the Late Aptian age.

(iii) *Pelagic Albian* represents marly limestone with frequent planktonic foraminifers, mainly hedbergellids, but also *Planomalina buxtorfi* (Gandolfi), single-keeled *Thalmanninella ticinensis conica* Gašpariková & Salaj and *T. ticinensis ticinensis* (Gandolfi), *Biticinella breggiensis* (Gandolfi), *Whiteinella gandolfii* Gašpariková et Salaj and *Hedbergella* sp. Benthic foraminifers are subordinate. The foraminiferal assemblage indicates the latest Albian (*Planomalina buxtorfi* Zone *sensu* Maamouri *et al.*, 1994).

Other components are mostly represented by ghosts after calcified radiolarians. The rock does not contain sandy terrigenous admixture, echinoderm ossicles and inoceramid prisms. Locally, the limestone overlies directly the Tithonian–Berriasian limestone. This suggests that a large portion of the earlier, Upper Aptian limestone was removed by erosion.

Locally, structureless phosphatic crusts occur near the base, but stromatolitic phosphate crusts also occur higher up, in the Albian marly limestone (Fig. 8E). The stromatolites consist of parallel reddish haematitic laminae, locally greenish (probably chloritic). In places, the laminae split and the space between them is filled by fibrous calcite. The splitting might originate due to dehydratation of the stromatolite that can occur even in the submarine environment (Donovan & Foster, 1972; Plummer & Gostin, 1981; Pratt, 1998; Mišík & Aubrecht, 2004). Some *Frutexites* were also observed among the stromatolites.

About 60 cm above the base occur red marls, representing packstones with hedbergellid foraminifers, *Thalmanninella reicheli* (Mornod), *T. globotruncanoides* (Sigal) and *Whiteinella gandolfii* Gašpariková et Salaj. This assemblage is of Middle Cenomanian age. In this stratigraphic level, thin-shelled bivalves and inoceramids are present in the sediment, too. The marls are laminated, with the laminae often disturbed by bioturbation.

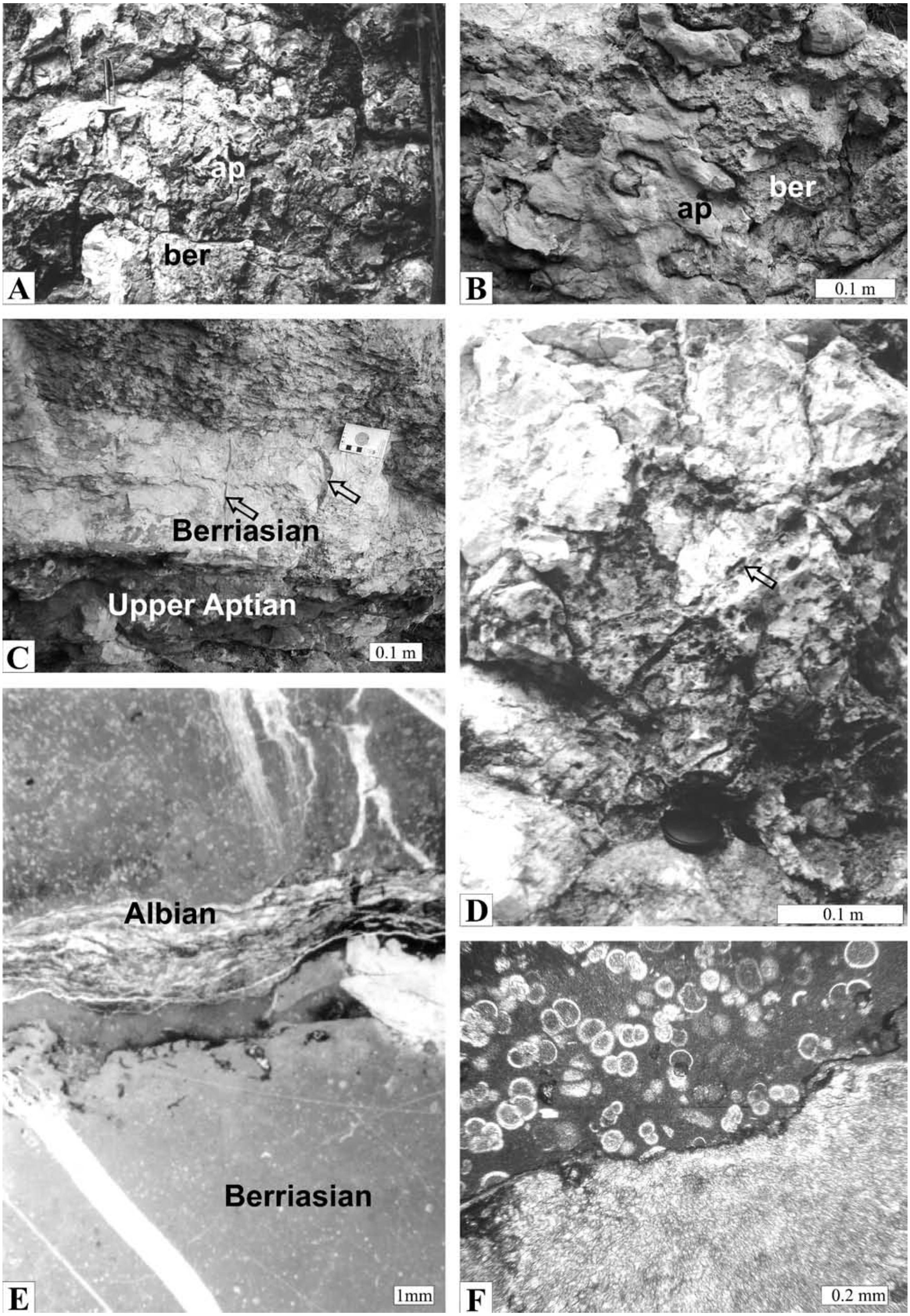
(iv) *The calcite veinlets (earlier than later Albian transgression)* are filled with blocky calcite. The calcite is full of inclusions and commonly twinned. Locally, the middle parts of the veinlets are more clear. They commonly include wall-rock fragments without any signs of corrosion or karstification.

Horné Sŕnie

The locality is sitaued in the uppermost part of the active quarries of a cement factory at the northern margin of the Horné Sŕnie village in the middle Váh Valley. The contact of the Albian sediments with their basement was observed at the SW margin of the highest step of the quarry and its continuation was found in the lower part of the quarry. The locality is unique by the range of the pre-Albian erosion and by preserved palaeokarst phenomena. In the overturned position, the contact of the Bajocian crinoidal limestone (Smolegowa Limestone Formation) and the Albian sediments is visible (Figs 9, 10). The crinoidal limestones yielded Bajocian brachiopods *Septocrurella defluxa* (Oppel) and *Linguithyris curviconcha* (Oppel), and numerous bivalves. Besides the crinoidal limestones, some relics of younger organodetritic limestones with "filamentous" microfacies (Bathonian–Callovian) were found, mainly as filling of fissures in the crinoidal limestones (Fig. 11C). The rest of the Jurassic sediments was eroded. The overlying rocks rocks, as a rule, represent both, the organodetritic limestones (latest Aptian) with crinoids, belemnites, bivalves and siliciclastic admixture (up to size of small pebbles) and somewhat younger, more pelagic red marlstones to marly limestones containing only planktonic fauna (Albian). At the base of these deposits, greenish-yellow, brown to black P-Fe-Mn stromatolites and oncoids occur (Fig. 11A). Locally, white marly limestones fill the karstic depressions (Fig. 10D). The limestones contain Middle Turonian microfauna. This is a further evidence of repeated non-deposition and erosion episodes that took place after the initial Late Aptian flooding.

The lack of the Bathonian to Hauterivian sediments points to a deep-reaching erosion that so far was not found in the Czorsztyn Succession. The field observation showed that there was no difference between inclinations of geopetal fillings in the brachiopod shells in the Albian limestones and those in the underlying crinoiodal limestones. That implies that no large tilting took place between Bathonian and Albian. The deep erosion cannot be therefore explained by a large-scale tilting-induced emergence. The erosional surface is irregular most likely due to karstification (Fig. 10A–C, E) as shown by rainwater grooves perpendicular to the basement (Fig. 10B, C) and karren surface as deep as 1m. The same interpretation was suggested for a very similar palaeokarst in Betic Cordillera (Martín-Algarra & Vera, 1995, 1996). Similarly as in Lednica, pre-Albian calcite veinlets penetrate the substrate to several meters down. However, unlike in Lednica, they are irregular and filled by multiphase fibrous calcite filling that can be supposed to represent a fresh-water sinter (Fig. 10F, G). The veinlets are very irregular to bizarre which points to their possible origin by karstic leaching. Some wider veinlets, however contain remnants of neptunian dyke fillings of beige micritic limestone.

The lithological phenomena mentined above are shortly describe here. The *crinoidal limestone* is biosparite to biomicrite (packstone to grainstone) consisting of crinoidal ossicles, numerous clasts of micritic carbonates (mostly dolomites and recalcified dolomites, some of them were bored) and less numerous fragments of bivalves (in places only ghosts – *i.e.* leached and filled with micrite), brachiopods, echinoid spines, and foraminifers (e.g., *Ophthalmidium* sp., *Tetrataxis* sp., and *Lenticulina* sp.). Thick-shelld ostracods and serpulid worms are quite rare allochems. Besides the micritic carbonates, some clasts of calcarenites were found, too. The crinoidal limestone also contains dis-



A
ap
ber
B
ap
ber
0.1 m
C
Berriasian
Upper Aptian
0.1 m
D
0.1 m
E
Albian
Berriasian
1mm
F
0.2 mm

Fig. 8. Field photos and microphotos from Lednica: **A** – Preserved steeply inclined paleokarstic surface near the entrance to the castle Lednica. The surface was formed by multiphase karstification; **B** – Upper Aptian sediment (organodetritic wackestone – ap) filling a karren depression in the Berriasian limestone (ber); rest of the Upper Aptian sediments was removed by the second phase of erosion and karstification; **C** – Berriasian limestone cut by calcite veinlets (arrows) that do not continue to Upper Aptian limestone; **D** – The karstified Berriassian limestones cut by veinlets filled with blocky calcite (arrow) that is bored by the bivalves, too; the veinlets originated still before or during the karstification; **E** – Onset of the Albian sediment onto uneven surface of the Berriasian *Calpionella* limestone (the Upper Aptian limestone is missing in this sample). Note that the P-Fe-Mn stromatolite does not overgrow directly the base but occurs within the Albian sediment; **F** – Clast of phosphatized limestone (lower right) in the Upper Aptian sediment

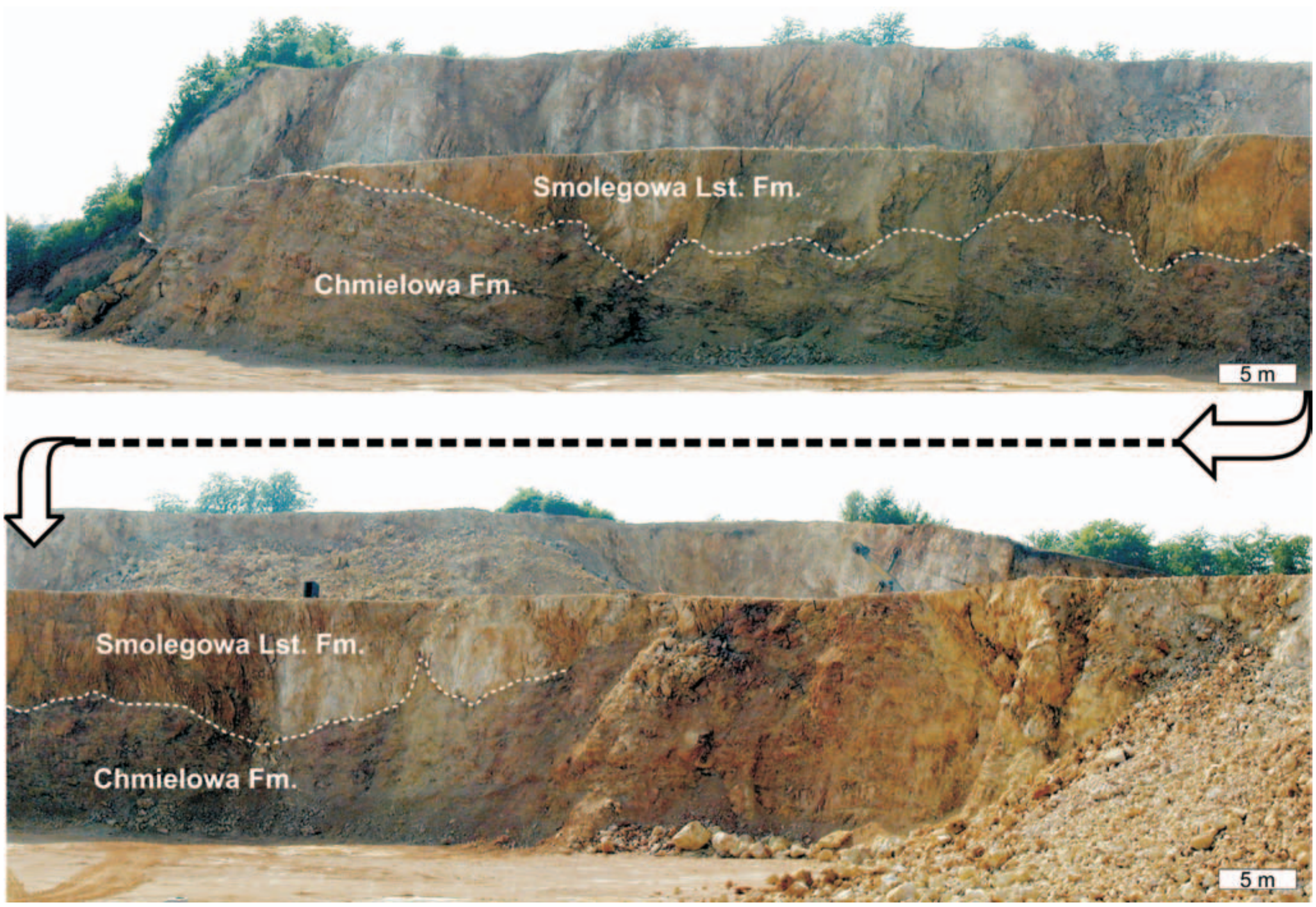


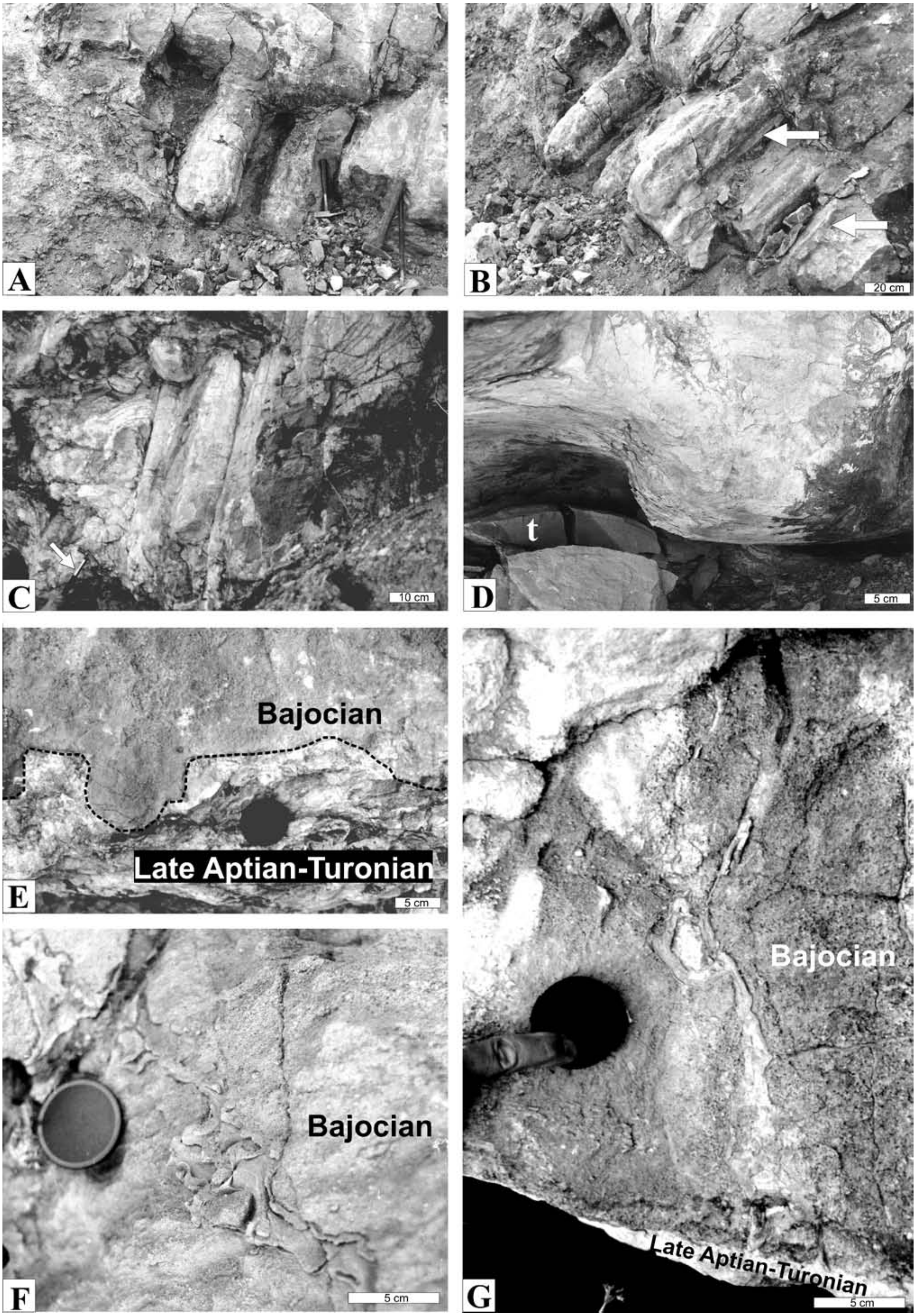
Fig. 9. Field view showing the uppermost steps of the quarries at Horné Sŕnie. Sharp irregular boundary (dotted line) between the Bajocian crinoidal limestone (Smolegowa Limestone Formation) and the Upper Aptian/Albian marly limestones and marls (Chmielowa Formation) originated by deep erosion and karstification that removed all the Bathonian to Hauterivian sediments. The succession is tectonically overturend. State from the year 2003

persed sandy quartz admixture. The crinoidal ossicles are overgrown by clear syntaxial calcitic rims, but at the contact with the overlying Albian sediments they are strongly corroded (Fig. 11D, E).

The *relics of micritic limestone* represent packstones with "filamentous" microfacies (cross-sections of thin-shelled epiplanktonic bivalves *Bositra buchi* (Roemer)) and dispersed bigger crinoidal ossicles. This transitional microfacies represents sediment deposited in the period of change from crinoidal to "filamentous" microfacies that took place in Late Bajocian–Early Bathonian (Wierzbowski *et al.*, 1999). The sediment also contains larger quartz grains, thicker bivalve and brachiopod fragments. Foraminifers *Lenticulina* sp., *Spirillina* sp., *Nodosaria* sp. are also present.

The *pre-Albian veinlets* (Fig. 10G) are filled with well developed multilayered radiaxial fibrous calcite (RFC – cloudy fibrous calcite with convex-down twinning lamellae). Between the individual RFC generations there are some micritic intercalations. The edges of the RFC fibres were partly corroded before the onset of a new generation. Some veinlets display difference in lenght of the RFC fibres in the generations, where the fibres of older generations are shorter than those of the younger generations.

Remnants of the neptunian dykes were found in two cases only. In the first case, the filling represents a sterile laminated pelmicrite (lacking fossils), with laminae parallel to the dyke walls. The peloids may be of microbial origin. In the second case, the filling represents a wackestone with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G
Bajocian
Late Aptian-Turonian
5 cm

"filamentous" microfacies (Fig. 11C), containing also thicker-shelled bivalves, and brachiopods, with less thin-shelld ostracods (including cave-dwelling *Pokornyopsis* sp.), agglutinated foraminifers, nodosariid foraminifers and sparce shells of juvenile ammonites. Some sandy quartz grains were found too. This sediment represents an older, Bathonian–Callovian neptunian dyke filling, preserved in the crinoidal limestone and was not related to the Barremian–Aptian emersion and karstification. However, some Albian neptunian microdykes were found too.

The *Upper Aptian–Lower Albian organodetritic limestone* can be characterized as wackestone with planktonic and agglutinated benthic foraminifers, crinoidal ossicles, echinoid spines, bivalve fragments (mostly *Aucellina* sp.), fish teeth (*Sphenodus* sp., determined by macroscopic study), some tiny gastropods, bryozoan fragments, ostracods and silicisponge spicules. In the rock portions impregnated by Fe-Mn oxides, radiolarian tests were preserved, being otherwise only visible as ghosts. The benthic biodetritus is, as a rule, strongly bored. The foraminiferal assemblages are dominated by planktonic genera as *Hedbergella* and rare *Globigerinelloides*. The most common are *Hedbergella trocoidea* (Gandolfi), *H. delrioensis* (Carsey), *H. planispira* (Tappan), *Blefuscuiana infracretacea* (Glaessner), *Globigerinelloides ferreolensis* (Moullade), *G. algerianus* Cushman et Ten Dam, *Ticinella roberti* (Gandolfi), *T. bejaouaensis* Sigal. The benthic foraminifer assemblage consists of *Lenticulina* sp., *Dorothia oxycona* (Reuss), *D.* cf. *trochus* (D' Orbigny), *Anomalina* sp., *Frondicularia* sp., *Pleurostomella* cf. *reussi* Berthelin, *Discorbis* cf. *wassoewizi* Djaffarov et Agalarova. Nodosariid and sessile nubecularid foraminifers occur, too. The foraminiferal assemblages indicate the Late Aptian–Early Albian age, mainly *Ticinella bejaouaensis* Zone, *sensu* Maamouri *et al.* (1994) or *Hedbergella planispira* Zone, *sensu* Robaszynski & Caron (1995).

At the base of the Upper Aptian sediments, clastic admixture is commonly concentrated, mostly represented by quartz grains up to small pebble size (Fig. 11A). The quartz grains are angular and strongly corroded. Along with them, lithoclasts of Triassic dolomites and dedolomites (recalcified dolomites), as well as tiny lithoclasts of Upper Tithonian micritic limestones with *Crassicollaria* occur. From accessoric minerals, some grains of chromspinelids, rutile, garnet and epidote were found. Authigenic glauconite is sparse but present in all samples.

Stromatolites that locally occur at the base are greenish-yellow (predominantly phosphatic), rarely brown (goethite). They are finely laminated, with lamination being planar or slightly undulated. Some contain sessile foraminifers that give stromatolite a bubble-like appearance in cross-section. Some stromatolites occur only as relics due to strong replacement by phosphatic minerals. *Frutexites*-type stromatolites are common too. Unlike planar stromatolites, these bush-like forms are commonly brownish, *i.e*. formed predominantly by haematite and goethite. Free spaces in stromatolites are filled micritic sediment, containing predominantly tiny forms of hedbergellid foraminifers. Some cross-sections of stromatolites show that they grew against each other. Apart from tangential cross-sections where this is a natural fact, such growth was also observed in perpendicular cross-sections. We interprete these cases as growing in cavities. In some samples, the stromatolites grew in cavities and in neptunian microdykes that cut older generations of stromatolite. Under some stromatolites, dense algal and fungal borings were present. Locally, the underlying micrite was completely replaced by phosphate. The phosphatized limestones also form intraclasts in the sediment.

Besides planar and *Frutexites*-type stromatolites, some oncoids were found too (Fig. 11A). The oncoids are pale-brown (greenish in hand specimen) and reach up to 4 cm in size. Their shapes are ovoidal, with laminae slightly undulated. Two types of oncoids can be distinguished under the microscope: first, consisting of pinkish, fine-grained calcite with several concentric layers and the second, less common type, consists of brownish, low birefringence (almost isotropic) phosphate. In the first type of oncoids, sessile nubecularid foraminifers are common, mostly occurring in depressions of the lamination. Part of these oncoids possess cores consisting of several larger calcite crystals that apparently originated by recrystallization. This coarse-grained mosaic is independent of the original oncoid structure. At the margins of the oncoids, black (probably manganese) spots, patches and microcolumns of stromatolites occur. The second type of phosphatic oncoids is brownish-yellow, passing even to clear, colourless matter towards periphery. Their cores are sometimes broken oncoids, or they may be broken themselves. In this type of oncoids, the sessile foraminifers are almost missing. If present, they apparently belong to other taxa than the sessile foraminifers in the first type of oncoids. Their sphaerical chambers form frequently grape-like bunches.

The *pelagic Albian marly limestone* is similar to the Upper Aptian limestone but, is free of echinoderm ossicles and contains more abundant inoceramid prisms. In one sample *Ticinella primula* Luterbacher, was found indicating a

Fig. 10. Field documentation of the paleokarstic surfaces at the Horné Sŕnie locality: **A, B** – Deep karren landform (all photos are in the recent position, *i.e.* tectonically overturned) artifically exhumed in the year 2000 (recently destroyed by quarrying). Bizarre phalloidal promontories are formed by the Bajocian crinoidal limestone; the depressions contain multiphase filling, involving Upper Aptian up to Turonian sediments. Note the grooves (arrows) perpendicular to the former basement, originated by rain water; **C** – Other instance of the vertical grooves, testifying the subaerial origin of the karstic surface; hammer for scale (arrow); **D** – Paleokarstic surface filled with Middle Turonian white marly limestones (seemingly darker) (t); **E** – Paleokarstic surface on the Bajocian crinoidal limestone, covered by Albian and younger marlstones; **F, G** – Bizarre veinlets filled with fibrous calcite; the veinlets start at the paleokarst surface and penetrate the Bajocian crinoidal limestone. Their irregular shape indicates their origin by dissolution

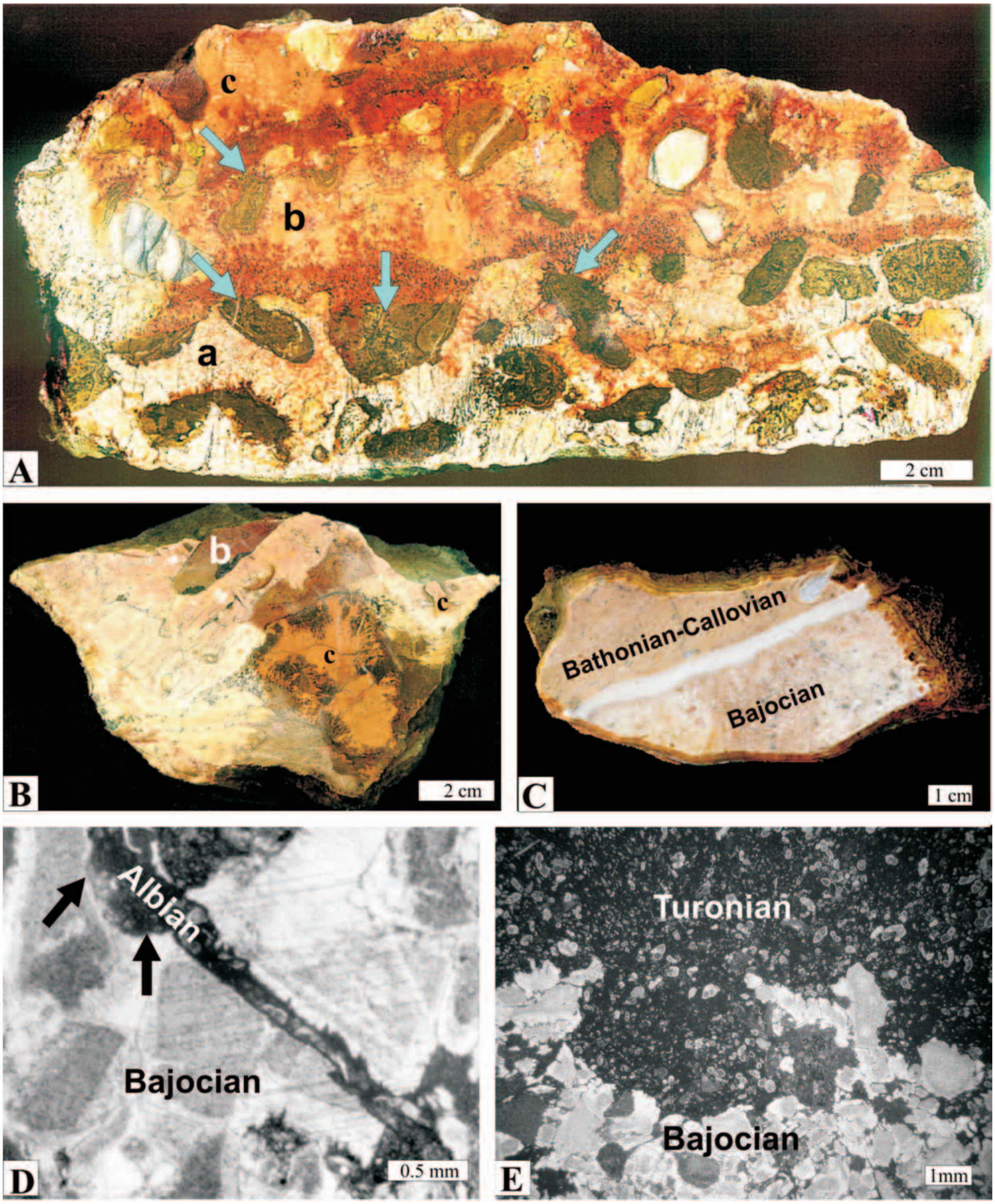

Fig. 11. Slabs and microphotos from the Horné Sŕnie locality: **A** – Upper Aptian limestone found above the karstified surface. The limestone contains rich clastic admixture in form of quartz pebbles (white) and greenish P-Fe oncoids (blue arrows); the slab shows three small units (a, b c), that were separated by phases of nondeposition, connected with dissolution, which affected also the oncoids; **B** – Upper Aptian limestone with borings (b) and karstic dissolutional cavities (c) filled with dark-red Albian sediment; **C** – Bajocian crinoidal limestone with remnant of neptunian dyke filled with "filamentous" microfacies (Bathonian–Callovian). Both lithologies are separated by thin seam of fibrous calcite (white, middle). Limestones with "filamentous" microfacies (composed by shells of bivalves *Bositra buchi* (Roemer)) are preserved almost only in neptunian dykes; **D** – Onset of the Albian–Cenomanian marly limestone on the Bajocian crinoidal limestone. Note the corrosion affecting both, crinoidal ossicles and syntaxial calcite cement (arrows). The Albian–Cenomanian sediment also fills a thin neptunian microdyke. **E** – Onset of the Turonian marly limestone with *Helvetoglobotruncana helvetica* on the irregular, corroded surface of the Bajocian crinoidal limestones

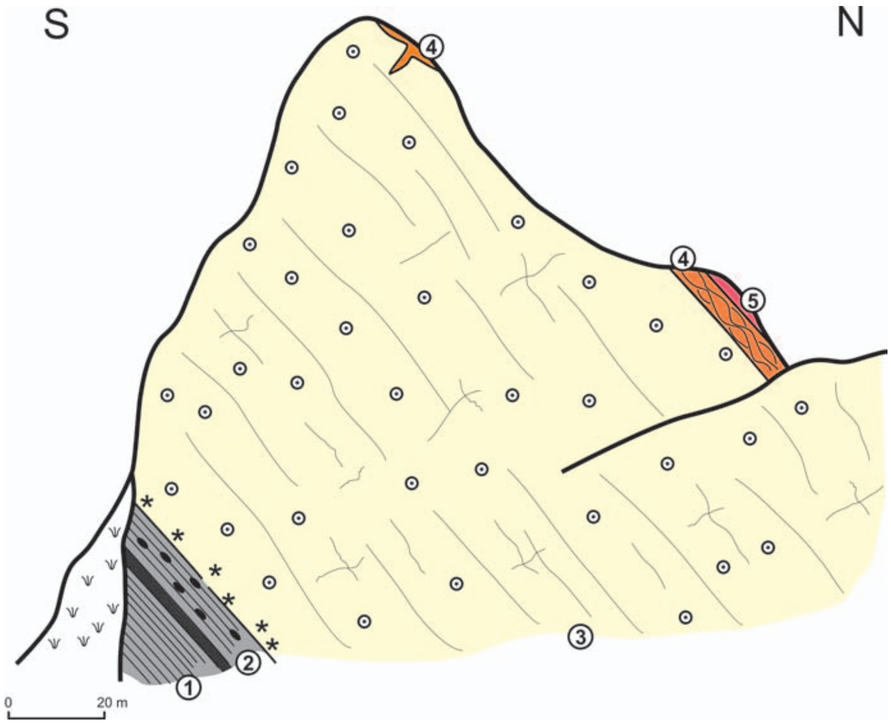

Fig. 12. General cross section of the Jarabina quarry with position of the Albian deposits. 1 – Black shales (probably Skrzypny Shale Formation, Aalenian); 2 – Black shales with spherosiderites of the Skrzypny Shale Formation (Aalenian–lowermost Bajocian); 3 – White-yellowish crinoidal limestones of the Smolegowa Limestone Formation with pyrite framboids at the base (stars) (Bajocian); 4 – Red thick-bedded micritic limestones of the Bohunice Formation (Bathonian–Kimmeridgian); partly they fill the neptunian dykes; 5 – Red marlstones and marly limestones of the Chmielowa Formation (Albian)

zone of the same name (according to Robaszynski & Caron, 1995) corresponding to higher Lower Albian through the Middle Albian.

The *white to creamy marly limestone* (Figs 10D, 11E) occurring locally on the palaeokarst surface contains a rich assemblage of planktonic and less abundant benthic foraminifers: *Dicarinella biconvexa gigantea* (Samuel et Salaj), *D. carpathica* (Scheibnerova), *D. oraviensis oraviensis* (Scheibnerova), *D. hagni* (Scheibnerova), *D. imbricata* (Mornod), *Helvetoglobotruncana helvetica* (Bolli), *Whiteinella gigantea* (Lehmann), *W. inornata* (Bolli), *Falsomarginotruncana renzi* (Gandolfi), *F. schneegansi* (Sigal), *Sigalitruncana turona* (Olbertz), *Praeglobotruncana gibba* Klaus, *Heterohelix* sp. and *Dorothia* sp. This assemblage indicates late Middle Turonian age. Besides the foraminifers, the limestone also contains inoceramid prisms, oyster-like bivalves and fish scales. The allochems are irregularly distributed which points to severe bioturbation of the sediment. Rare phosphatic grains that can be found in the sediment are irregularly penetrated and replaced by calcite. Siliciclastic admixture is missing.

Jarabina

The locality is situated in the southern part of the two uppermost steps of a large quarry (Fig. 12) at the mouth of small Jarabina Canyon, at the northern margin of the Jarabina village, near Stará Ľubovňa in the eastern Slovakia. The main volume of the rocks in the quarry is represented by pale Bajocian crinoidal limestones (Smolegowa Limestone Formation) which are overlain by several metres thick red, thick-bedded Bathonian–Kimmeridgian micritic limestones (Bohunice Formation), which in turn are overlain uncomformably by red marlstones, marly limestones and breccias of the Albian age (Fig. 13A–D). They fill irregular surface (depressions and fissures) in the Bohunice Formation (Fig. 13B). The base is irregular, cutting several beds of the underlying formation (Fig. 13A).

The Albian sediments contain numerous yellow, perfectly sphaerical phosphatic oncoids (Fig. 13C, D); planar stromatolites were not found. Clasts in the basal breccia were mostly derived from the underlying limestones and various phosphatized limestones. Small quartz pebbels also occur. Macroscopically visible fossils are fish teeth (Fig. 13E, F) and some casts of ammonoids.

Clasts of the basal breccia:

1. The limestone with crinoid-"filamentous" microfacies (Fig. 14A) was found only in one instance. This limestone indicates that the deepest level reached by the erosion was Bathonian–Callovian. The limestone contains crinoidal ossicles, thin shells of *Bositra buchi* (Roemer) bivalves, echinoid spines, nodosariid foraminifers and some ghosts after ammonoid shells.

2. The *Saccoccoma* limestones (Fig. 14B) are characterized by presence of ossicles of planktonic *Saccoccoma* crinoids and other, sessile crinoids, as well as bivalve shells, aptychi and foraminifers. Their age is Kimmeridgian to early Tithonian.

3. The Berriasian organodetritic limestone clasts contain calpionellids (*Calpionella alpina* Lorenz), bivalve and brachiopod fragments, crinoid ossicles, ostracods, tiny gas-

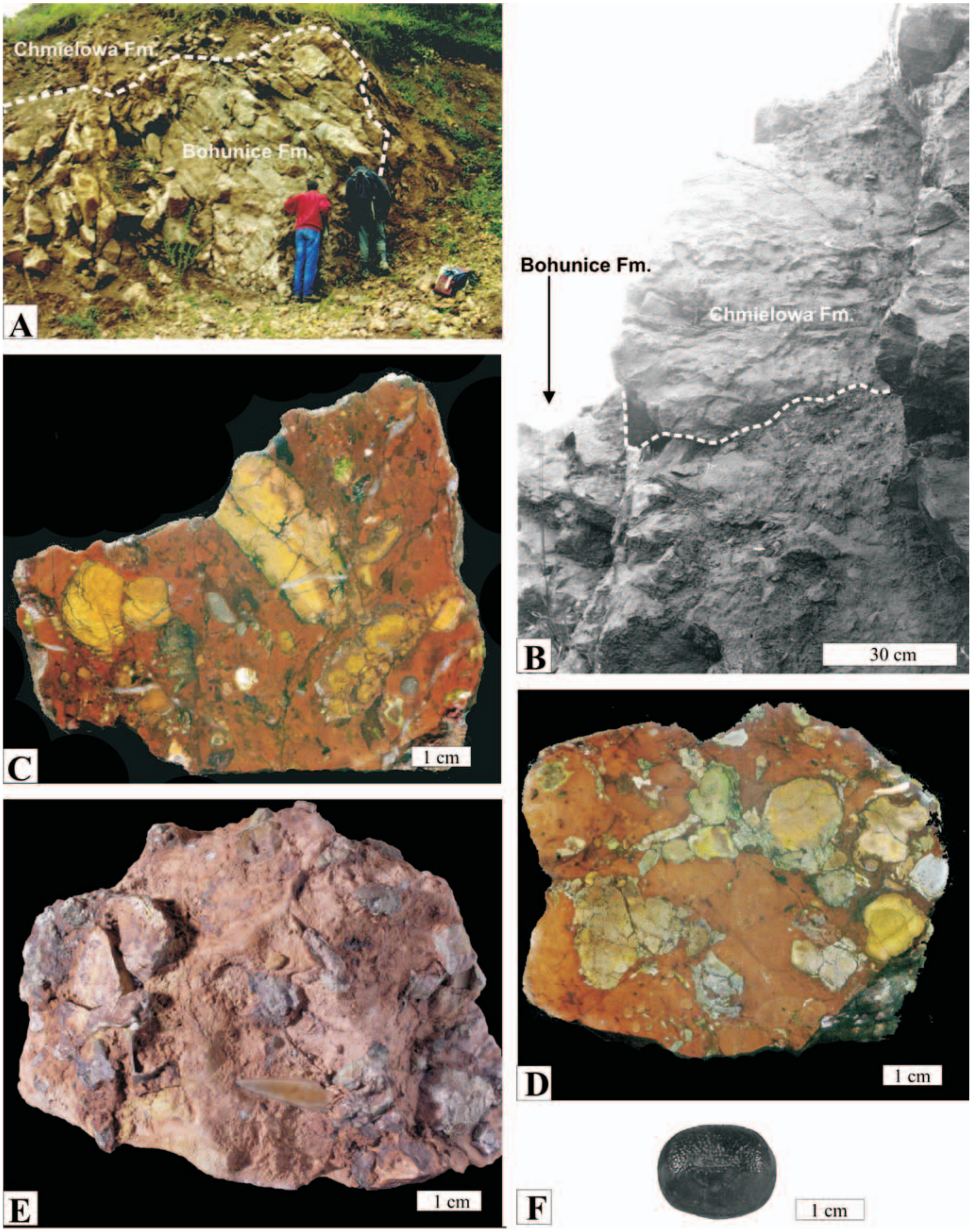

Fig. 13. Field photos, slabs and macrophotos from the Jarabina locality: **A** – Field view on the highest part of the Jarabina quarry; the dashed line separates the Albian marls (Chmielowa Formation) from the red Callovian–Kimmeridgian micritic limestones (Bohunice Formation); the contact is uneven and cuts across several layers; **B** – Pre-Albian erosional surface on the limestones of the Bohunice Formation, covered by the Chmielowa Formation; **C, D** – Red limestone with pebble-sized clasts (white or grey), phosphatic oncoids and phosphatized limestones (both yellow or greenish); **E** – Shark tooth and detritic admixture in the condensed Albian limestone (treated by acetic acid); **F** – Knob-shaped fish-tooth (*Sphenodus* sp.), extracted from the condensed Albian limestones

tropods, juvenile ammonite shells, rare ossicles of *Saccocoma*, *Lenticulina* sp. foraminifers, agglutinated and nodosariid foraminifers, rare calcified radiolarians and bryozoans. One clast was fractured, with fracture filled with clear blocky calcite (Fig. 14G);

4. The organodetrital wackestones with hedbergellid foraminifers (uppermost Aptian–Lower Albian; see the previous section) also contain dispersed echinoderm ossicles, echinoid spines, bivalve shells, fragment of serpulid worms, ostracods, *Lenticulina* sp. foraminifers and various agglutinated foraminifers. The bivalve fragments are frequently bored. In one instance, the limestone clast also contained phosphatic stromatolites.

5. The clasts of phosphatized limestones commonly have their original structure almost completely obliterated by newly-formed phosphate. Some ghosts of bush-form stromatolites (Fig. 14C, D) and hedbergellid foraminifers can be observed. They indicate, that the limestones were of Late Aptian–Albian age. However, some instances of older phosphatized limestones were found too. Their age is Kimmeridgian to Berriasian as they contain ghosts after *Saccocoma* and calpionellids;

6. The clasts of older breccia contain detritus of calpionellid limestones (Berriasian), limestones with hedbergellid foraminifers (Aptian–Albian), glauconite and quartz grains. The clasts of breccia points to multiple reworking of the sediment.

Most of the clasts are strongly corroded (Fig. 14H). At the margins of some of them, yellowish-green patches occur (probably phosphatic). They indicate that some phosphatization might take place still after the formation of the basal breccia.

Presence of the clasts with crinoid-filamentous microfacies (Bathonian–Callovian) indicates relatively deep erosion, similarly as at Horné Sŕnie locality. The thickness of Upper Jurassic (Oxfordian–Kimmeridgian) limestones, underlying the Albian, is also relatively small. The Tithonian limestones were not found *in situ*, only as clasts.

The *Albian to Cenomanian matrix of breccia* represents red micrite with dispersed crinoid ossicles, tiny hedbergellid foraminifers, inoceramid prisms and shell fragments, aptychi, fish teeth, various taxa of agglutinated foraminifers, nodosariid foraminifers, rare ostracods and juvenile ammonites. Sandy quartz admixture and authigenic glauconite are not common. Locally, tiny phosphatic oncoids occur too. The foraminifers are dominated by planktonic forms (benthic are subordinate): *Hedbergella planispira* (Tappan), *H. delrioensis* (Carsey), *H. trocoidea* (Gandolfi), *Planomalina* (*Globigerinelloides*) sp. and *Ticinella primula* Luterbacher. The assemblage points to late Early Albian through the Middle Albian. Some samples contained *Planomalina buxtorfi* (Gandolfi), *Thalmanninella ticinensis ticinensis* (Gandolfi), *Praeglobotruncana delrioensis* (Plummer), *P. stephani* (Gandolfi), *Whiteinella* sp. and *Hedbergella planispira* (Tappan). They represent *Planomalina buxtorfi* Zone (the uppermost Albian) *sensu* Maamouri *et al.* (1994). In some thin sections, Cenomanian foaminifers were found (Fig. 14E, F): *Thalmanninella brotzeni* (Sigal), *Praeglobotruncana* cf. *delrioensis* (Plummer) and *Thalmanninella* sp. The presence of these taxa indicates that filling of the interstices in the basal breccia was finished in the Early Cenomanian.

Kamenica

This locality is situated at the SW foot of a large klippe (Figs 15, 16A), close to the NE margin of the Kamenica village in the eastern Slovakia. The klippe is steeply inclined. Its main portion consists of Bajocian crinoidal limestones (Smolegowa and Krupianka limestone formations), Upper Bajocian–Kimmeridgian red nodular limestone (Czorsztyn Limestone Formation), the Dursztyn Limestone Formation and Łysa Limestone Formation (Tithonian–Neocomian). The uppermost part of the latter is represented by white limestone breccia (Walentowa Breccia Member). This member is overlain by red Albian marlstones (found in relics). They fill depressions, remaining interstitial pores and fractures in the breccia (Fig. 16B–D). The Albian sediment also represent a breccia.

Clasts in the breccia: The clasts are relatively monomictic, almost exclusively represented by micrites with ghosts of calcified radiolarians and calpionellids *Calpionella alpina* Lorenz (Berriasian), fragments of thin-shelled bivalves, sparce sponge spicules, crinoid ossicles, *Lenticulina* sp. and agglutinated foraminifers, tiny gastropods, juvenile ammonoids and very rare *Saccocoma* ossicles.

Matrix of the breccia: There are two types of matrix in the breccia:

1. Older matrix is represented by crinoid grainstone, with blocky calcite, cementing the interstitial pores. Together with crinoids there are thick-shelled bivalves, brachiopods, aptychi (mostly *Laevaptychus*), echinoid spines, agglutinated foraminifers, foraminifers *Lenticulina* sp. and ghosts after radiolarians. Fragments of phosphatic oncoids were found too. This matrix is bored, with borings filled by younger, Albian packstone with hedbergellid foraminifers.

2. The younger (Albian) matrix is red-coloured, in places passing to grey. The rock is a packstone with numerous crinoid ossicles (with initial syntaxial rims), inoceramid prisms, fragments of other bivalves, benthic foraminifers (*Lenticulina* sp. and *Dorothia* sp.). Reworked older allochems (including even calpionellids) occur also in the matrix. The hedbergellid foraminifers mainly occur in more open spaces; they are not so numerous in more closed interstitial spaces. The assemblages consists mostly of: *Hedbergella planispira* (Tappan), *Ticinella roberti* (Gandolfi), *T. primula* Luterbacher and *Planomalina* (*Globigerinelloides*) sp. The walls of the foraminiferal tests are commonly recrystallized. The assemblage points to *Ticinella primula* Zone *sensu* Robaszynski & Caron (1995), that indicates late Early Albian to Middle Albian. According to Maamouri *et al.* (1994), this zone is narrower, with a range from the latest Early Albian early though Middle Albian.

Czerwona Skała Klippe

The locality occurs in the western road-cut beween Dursztyn and Krempachy villages (Spisz region) on the Polish part of Pieniny Klippen Belt (Fig. 1D1). The results obtained show that the oldest part of the Pustelnia Marl Member overlies a small, Lower Cretaceous (Berriasian) klippe of red *Calpionella* limestone, belonging to the Dursztyn

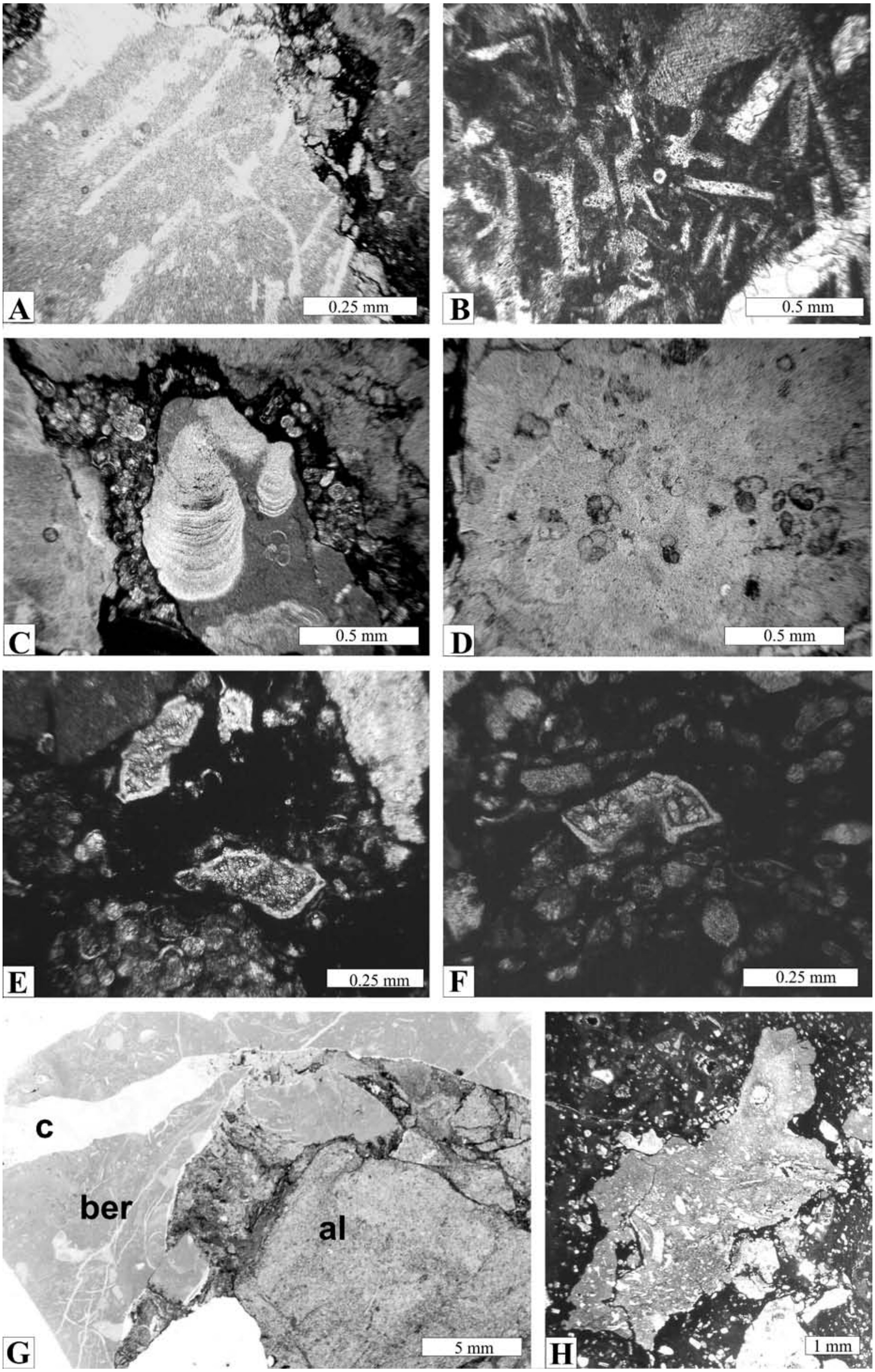
A
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Fig. 14. Microphotos of clasts and foraminifers from Albian–Cenomanian sediments at the Jarabina locality: **A** – Clast of the limestone with "filamentous"-crinoidal microfacies (left). The most probable age of the limestone is Bajocian–Bathonian (it represents the deepest level of erosion at this locality); **B** – Clast of Kimmeridgian limestone with ossicles of planktonic crinoids *Saccoccoma*; **C** – Clast of the Upper Aptian–Lower Albian limestone with collumnal phosphatic stromatolites; **D** – Clast of Upper Aptian–Lower Albian phosphatized foraminiferal limestone; **E** – Cenomanian planktonic foraminifers *Thalmanninella brotzeni* Sigal) (right) and *Praeglobotruncana* cf. *delrioensis* (Plummer) in the matrix of the breccia; **F** – Cenomanian planktonic foraminifer *Thalmanninella* sp.; **G** – Clast of Berriasian *Calpionella* limestone (ber) surrounded by Albian sediment (al). The limestone clast contains pre-Albian blocky calcite veinlet (c); **H** – Strongly corroded clast of *Saccoccoma* limestone in the Albian–Cenomanian sediment

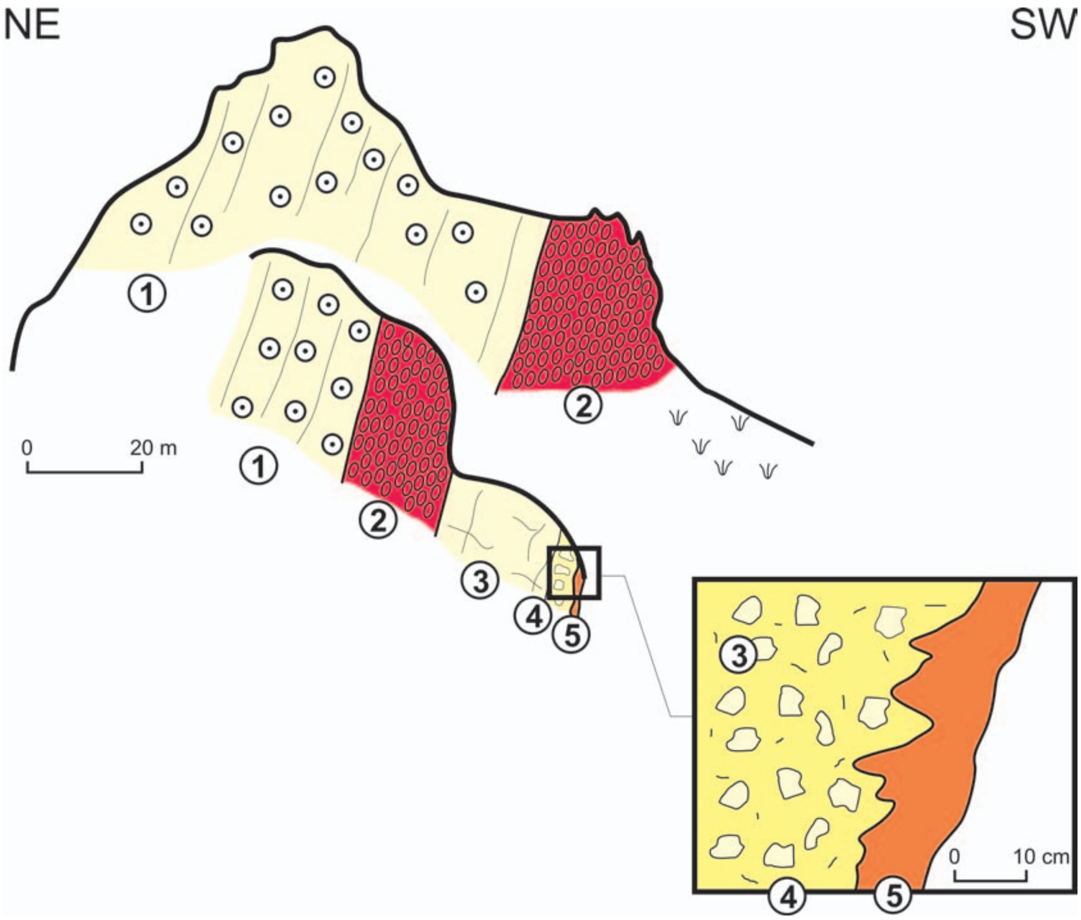

Fig. 15. General cross section of the Kamenica locality with position of the Albian deposits. 1 – White crinoidal limestones of the Smolegowa Limestone Formation (Bajocian); 2 – Red nodular limestones (*ammonitico rosso*-type) of the Czorsztyn Formation (Upper Bajocian–Kimmeridgian); 3 – Creamy *Calpionella* limestones of the Dursztyn Limestone Formation (Tithonian–Berriasian); 4 – Sedimentary breccia of the Walentowa Breccia Member of the Łysa Limestone Formation (Berriasian) with irregular clasts of the underlying limestones of the Dursztyn Limestone Formation; 5 – Red Albian marlstones

Limestone Formation and, as K. Bąk showed (1998, fig. 3), the oldest sample number 10 is about 0.5–1.0 m above this contact. Therefore, it is possible that the lowermost bed of the red marls is of the Lower Cenomanian age (K. Bąk, pers. com.). Moreover, the contact between the pinkish micritic limestones of the klippe and marls is sharp, erosional and irregular. A very thin, only 1mm thick, layer of fine-grained quartz covered immediately this surface, and 1–5 cm thick greenish and brown-greenish phosphatic stromatolite occur on it. The laminae of this stromatolite are multicoloured, depending on the mineralogical composition (revealed by X-ray analysis; e.g.: fluoroapatite – greenish, goethite – dark brown). Microbialites are especially represented by *Frutexites*-like stromatolites with several upward oriented branches. These biostructures are directly overlain by the lowermost beds of the Pustelnia Marl Member of (Early?) Cenomanian age.

Vilki Dil - Barakishtche

The locality occurs in the Ukrainian part of the Pieniny Klippen Belt in the Vulkovchik Valley (Fig. 17). The Barakishtche hill represents almost a whole sequence of an

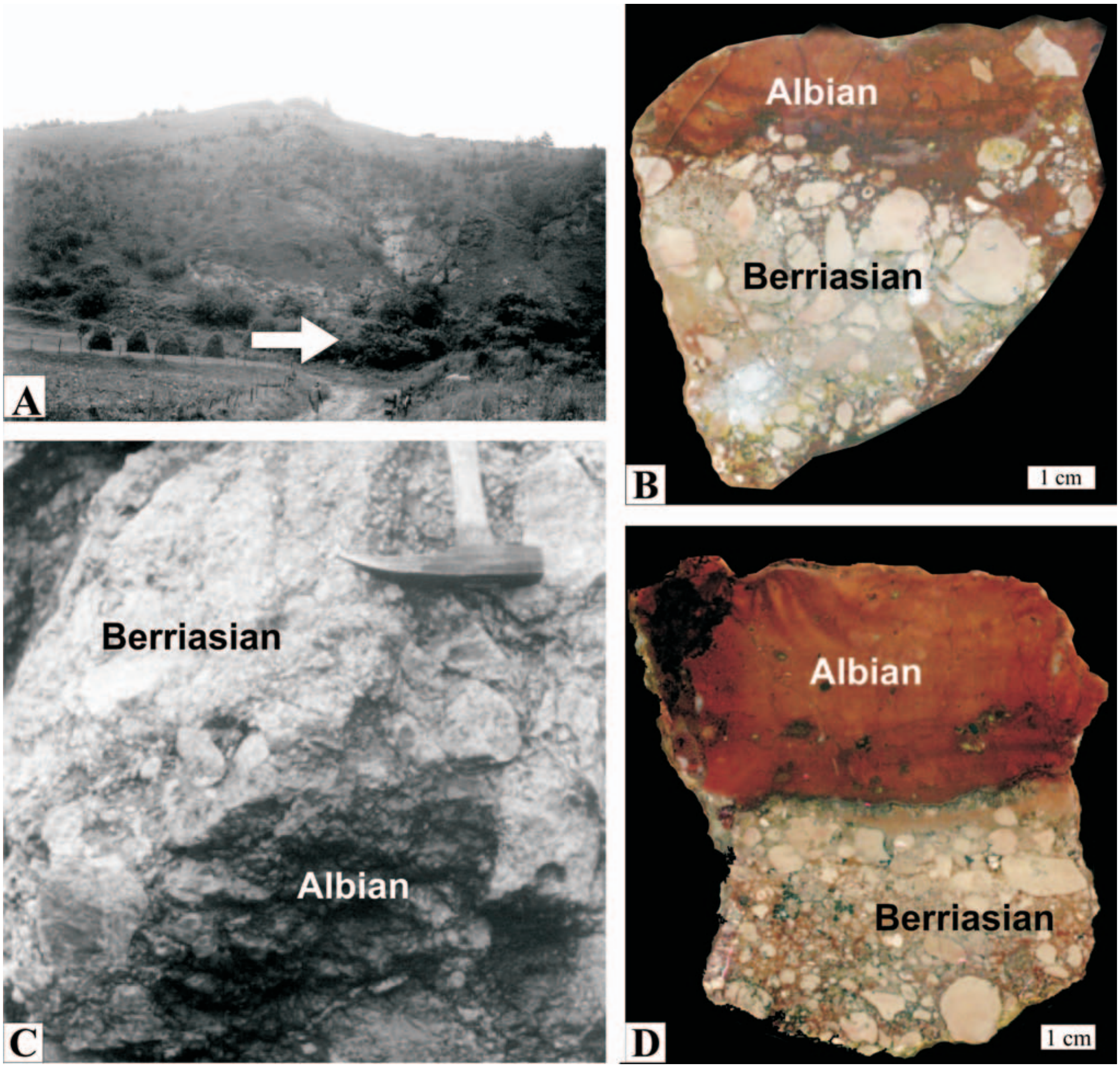

Fig. 16. Field photos and slabs from the Kamenica locality: **A** – View on the Kamenica Klippe; position of the relic Albian sediments indicated by arrow; **B, D** – Walentowa Breccia Member, overlain by red Albian marls; **C** – Onset of the Albian marls onto Walentowa Breccia Member of the Łysa Limestone Formation (Berriasian). The succession is tectonically overturned

atypical Czorsztyn Succession from Bajocian arcosic sandstone at the base up to pelagic mid-Cretaceous, variegated marls on the top. In the upper part of the outcrop, the contact between white-yellowish *Calpionella* limestones and the overlying violet marly limestones (Chmielowa Formation?) is sharp. The surface of topmost *Calpionella* limestone bed is corroded and irregular, with traces of borings (?bivalve-type), covered by P-Fe-Mn crusts (Fig. 18A, B). The thickness of violet marls does not exceed 2–2.5 m and they are overlain by green, spotty marls (Pomiedznik Formation?). The precise age of these marls is unknown because this sequence is still under investigation, but the comparison with another localities within the Pieniny Klippen Belt suggests their Albian age.

X-RAY DIFFRACTION ANALYSIS OF THE ALBIAN DEEP-WATER STROMATOLITES AND ONCOIDS

The XRD analyses were carried out of the stromatolites from Vršatec, Horné Sŕnie and oncoids from Horné Sŕnie and Jarabina localities. At Vršatec locality, the XRD record shows mostly presence of three phases: fluorapatite, goethite and quartz (Fig. 19A). Another sample from Vršatec locality 47 consists of calcite and pyrolusite (Fig. 19C). The stromatolites from Horné Sŕnie have very similar composition to the first samples from Vršatec. This paragenesis was here complemented by calcite; goethite was present but not in all samples.

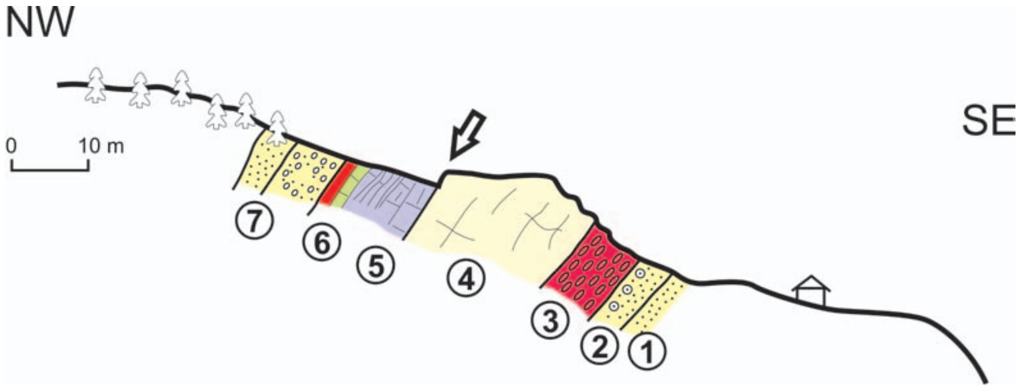

Fig. 17. General cross section of the Vilki Dil-Barakishtche locality with position (arrow) of surface of the Neocomian limestone, covered by the Albian deposits. 1 – White-grayish sandstones (?Bajocian); 2 – Yellow sandy-crinoidal limestones of the Smolegowa Limestone Formation (Bajocian); 3 – Red nodular limestones (*ammonitico rosso*-type) of the Czorsztyn Limestone Formation (Upper Bajocian–Tihonian); 4 – White-yellowish *Calpionella* limestones of the Dursztyn Limestone Formation (Berriasian); 5 – Violet marly limestones of the ?Chmielowa Formation (Albian); 6 – Variegated marls of the Jaworki Formation; 7 – Yellowish conglomerates and sandstones of the Jarmuta Formation (Palaeogene)

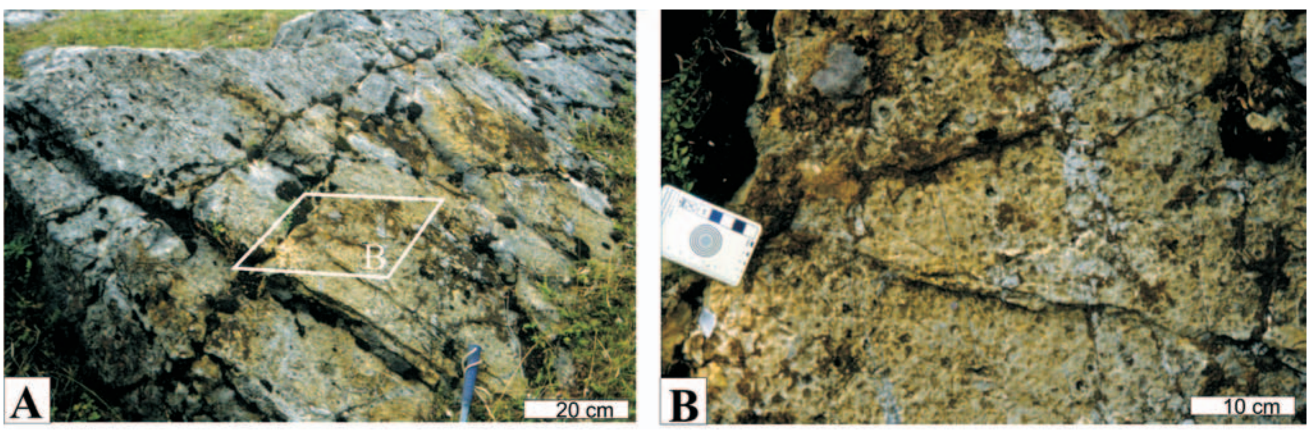

Fig. 18. Field photos from the Vilki Dil-Barakishtche locality. **A** – Neocomian limestones (grey), covered by yellowish phosphatic stromatolites at the base of the Albian sediments; **B** – Surface of the Neocomian limestone bored by bivalves

The XRD analyses of oncoids showed that those from Hrné Sŕnie locality have variable mineralogical composition. There were oncoids with compositions identical to those of the fluorapatite stromatolites (fluorapatite, goethite, quartz ± calcite; Fig. 19B). Besides them there were also goethite and calcitic oncoids, with admixture of quartz. From Jarabina locality, the analysed oncoids were mostly formed by fluorapatite, with low proportion of quartz (Fig. 19D). Along with stromatolites and oncoids, insoluble residuum of the Upper Aptian limestone from Horné Sŕnie (containing stromatolites and oncoids) was also analysed. The diffraction records show that illite and smectite is also present except of the minerals present in the aforementioned stromatolites and oncoids.

The results of XRD analysis show that the dominant mineral of the samples is fluorapatite, which is the most widespread phosphate in nature. It is known, however, that the fluorapatite group phosphates are characteristic by isomorphic replacement of anions and cations which results in transition to other minerals ofthe group. The phosphatic group can be replaced CO_3 and the ratio of F and OH also changes. In this way, carbonate fluorapatite $Ca_5(PO_4\ CO_3)_3$ (F,OH) (francolite) originates, which is the most common marine phosphate. The isomorphic replacement, however, is accompanied by small changes of elementary cell dimensions of the mineral.

Guldbrandsen (1970) proposed a simple indirect method to estimate the CO_2 content of francolite on the basis of XRD analysis. He found the following empirical equation: $CO_2\%=23.6341–14.7369\ x$, where $x = \Delta 2\theta$ (004 – 410) $Cu_{K\alpha}$. Using this equation, the CO_2 amount estimated for our samples (after recalculation $Co_{K\alpha}$ to $Cu_{K\acute{a}}$ radiation values) varies in the range 1.45–1.87% (prior to the XRD analysis, calcite impurities were removed by 10% acetic acid). This method is widely used but the results obtained are systematically higher than those determined chemically (Nathan, 1984).

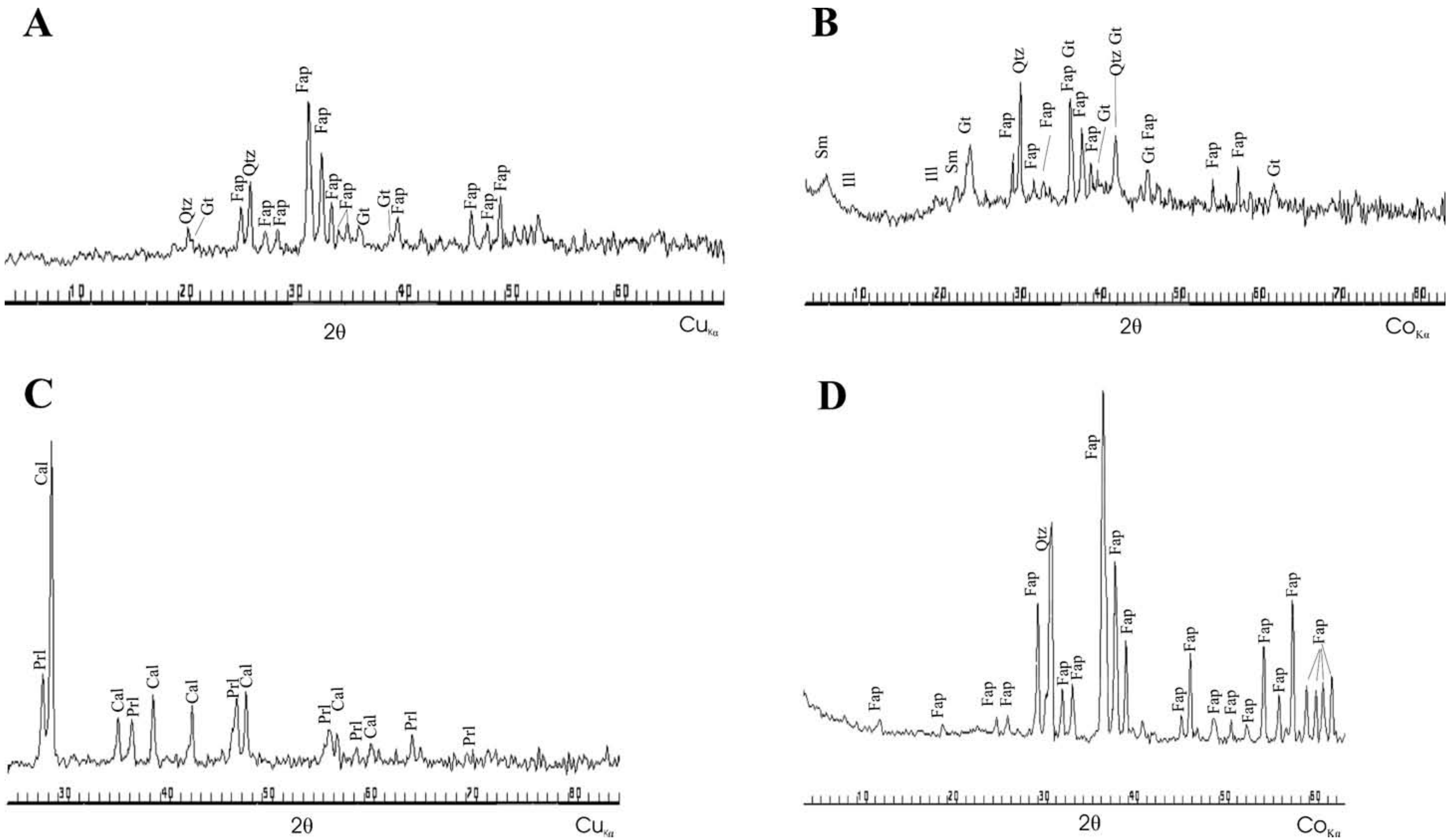

Fig. 19. X-ray diffraction record of the phosphatic stromatolites, oncoids and Mn stromatolites. **A** – Stromatolite from Vršatec locality; **B** – Oncoid from Horné Sŕnie locality; **C** – Mn stromatolite, Vršatec locality (sample 47); **D** – oncoid from the Jarabina locality. Fap – fluorapatite, Cal – calcite, Qtz – quartz, Gt – goethite, Prl – pyroluzite, Ill – illite, Sm – smectite

Minerals can be distinguished either by quantitative chemical analysis or by its refraction index. The latter could not be verified, as the phosphate crystals were submicroscopic. Data about origin of carbonate fluorapatite were summarized by Nathan (1984). Krajewski *et al.* (1994) provided summary about mechanism of precipitation of apatite in sediments. Phosphatic stromatolites are common in Precambrian and Cambrian of the Asian-Pacific province and in the Mesozoic Mediterranean province (Krajewski *et al.*, 1994) to which also Czorsztyn Succession belongs. Many examples of Albian phosphatic stromatolites in the Tethyan realm can be found in the literature, e.g., Krajewski (1981, 1983), Martín-Algarra & Vera (1994) etc. Modern examples appeared to lack, but recently Rao *et al.* (2000, 2002) reported analogs of ancient phosphatic stromatolites from Holocene deposits offshore Southeast India.

Rusty-brown colouration of some samples was caused by goethite or by X-ray amorphous Fe-oxides. These minerals were accompanied with calcite. Minor amounts of quartz and pyrolusite were found too. Among clay minerals, illite and low-crystalline smectite are present.

DISCUSSION

Submarine erosion or emersion?

The absence of the Hauterivian–Aptian sediments in the Czorsztyn Succession has been recognized long ago (Birkenmajer, 1963, 1977; Krobicki & Wierzbowski, 1996). Earlier opinions preferred explanation involving submarine erosion, rather than emersion and subaerial erosion. The main reason was the overall absence of basal clastics and onset of the pelagic Albian deposits directly on the discontinuity surface. The Albian marls of the Chmielowa Formation overlie uneven substratum of different ages, mainly of the red crinoidal limestones of the Valanginian Spisz Limestone Formation (Krobicki & Wierzbowski, 1996). The common occurrence of P-Fe-Mn stromatolites and hardgrounds near the base of the Albian indicates a condensed sedimentation that could help to explain the absence of the Hauterivian–Aptian sediments. Another important fact was the lack of shallow-water Hauterivian–Aptian deposits in the units which were probably situated in the vicinity of the Czorsztyn sedimentary area (mostly Niedzica, Pruské and Czertezik successions). In the case of emersion, expectation of shallow-water deposits (Urgonian-type facies) in the surrounding deeper-water units, together with clastics derived from the emerged area, would be logical.

From the new and revisited localities presented herein, the Horné Sŕnie locality plays a key role. Deep erosion, bizarre karren landforms with vertical grooves, cavities in the underlying limestones etc., alow us to state that the pre-Albian emersion and karstification of the Czorsztyn Swell is evident. Fresh-water algae found in Lednica by Dragastan & Mišík (2001) also support this view.

The time range of the emersion is difficult to estimate but it had to occur during a longer time in the Hauterivian–Aptian period. The erosion reached as deep as the Bajocian crinoidal limestones and formed karstic relief. Most of to-date observations registered mostly overlying of the Albian sediments on Tithonian to Valanginian limestones. So far, there were only two examples of contact between the Albian sediments and the Bajocian crinoidal limestones. The first example was the Szczobiny locality of Jurewicz (1997, see also summary of literature data). Another contact between the Albian and the Bajocian crinoidal limestones at Vršatec was interpreted as penetration of neptunian dykes (Mišík, 1979).

The events that followed the main phase of emersion and karstification are best documented in Lednica, that indicates several repeating events of deposition, emersion and karstification before the final flooding. After the main, Hauterivian–Aptian karstification, the land was submerged and crinoidal wackestones were deposited. After lithification of the limestones, the bottom emerged again and underwent the next phase of karstification Thereafter the area was flooded definitely, the bottom was bored by bivalves and red pelagic marls sedimented subsequently. The evolution resulted in development of so called polyphase karst. The term was introduced by Molina *et al.* (1999) from the Betic Cordillera, Spain. Some of their karstification phases are even coeval with those found in the Czorsztyn Unit.

Paleogeographic consequences

The question of the absence or presence of the Hauterivian–Aptian shallow-water deposits in the Pieninicum can be explained by emersion of larger area than previously thought. From the Pienidic units, Urgonian-type facies occur mostly in the Nižná Succession (provenance of Haligovce Succession, that also contains Urgonian-like limestones, is commonly attributed to the Central Western Carpathians; Birkenmajer, 1959, 1977). Its Jurassic development is, however, similar to the Kysuca Succession, which together with Pieniny Succession belongs to the deepest successions of the Pieniny Klippen Belt. In the transitional Niedzica Succession, the Barremian–Aptian sediments were described by Birkenmajer (1977) as pelagic grey micritic limestones. However, Obermajer (1987) documented a case where the Barremian–Aptian sediments were missing in the Niedzica Succession. The Albian marlstones rested on a bizzare surface of the Neocomian Pieniny Limestone Formation. Although the author interpreted the uneven surface as originated due to submarine dissolution, it is very similar to the palaeokarst surfaces mentioned herein from the Czorsztyn Unit. A similar site was also reported by Began (1969) from the vicinity of Horná Súča village, where the *Calpionella* limestone is overlain there by dark greenish spotted marls containing Albian microfauna. However, no detailed information of this contact is given. As far as the Czertezik Succession is concerned (another transitional unit), its Barremian–Aptian deposits are not known. Moreover, its original position between the Czorsztyn and Niedzica successions, as defined by Birkenmajer (1977) was recently challenged (Wierzbowski *et al.*, 2004). More likely, this unit occurred more seaward, in an area between the Niedzica and Branisko (Kysuca) units. Once admitting emersion as far as the Niedzica sedimentary area, it is also necessary to admit that the Urgonian-type limestones of the

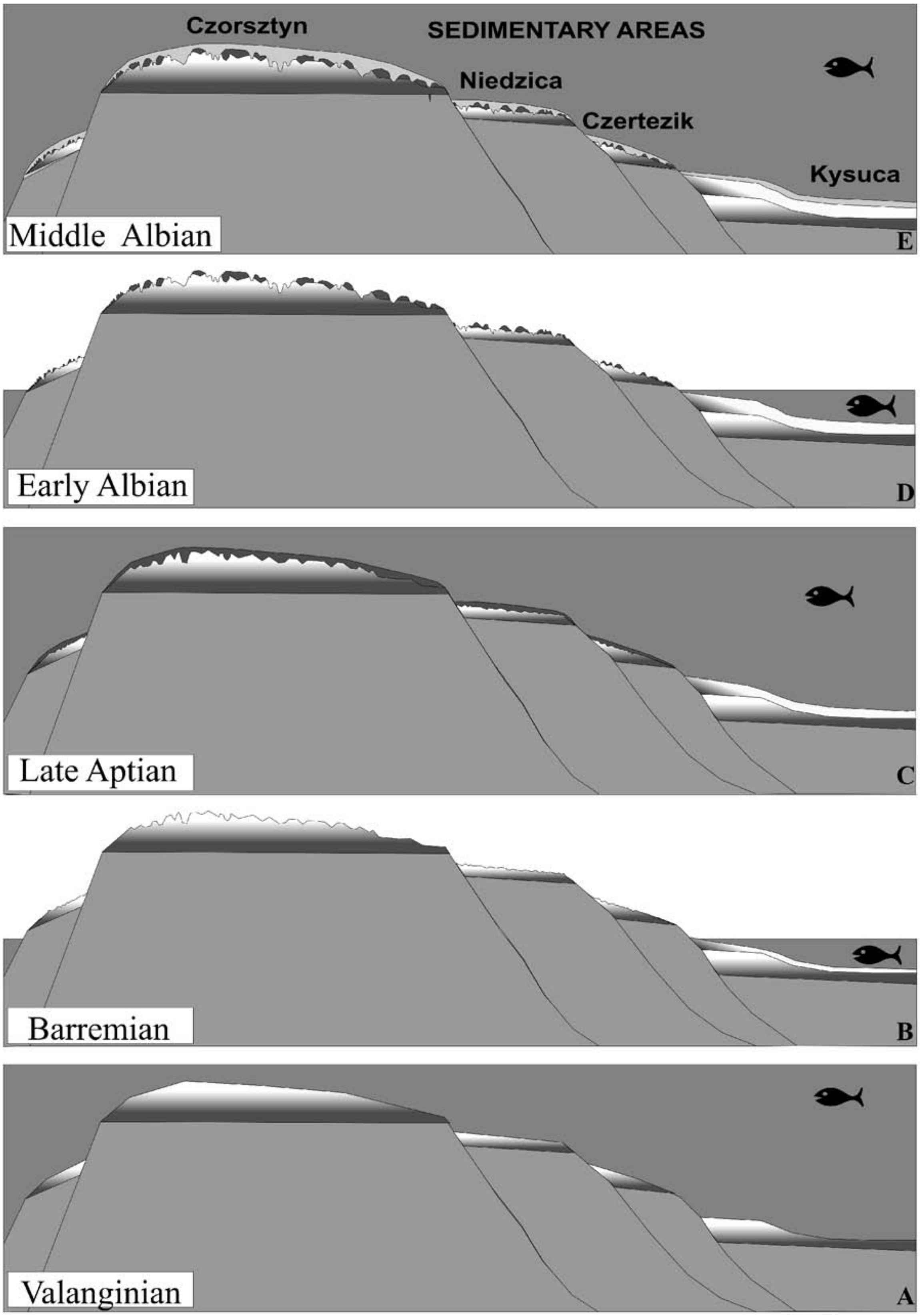

Fig. 20. Model of the Early Cretaceous evolution of the Pienidic area. **A** – Valanginian: the Czorsztyn elevation was flooded and subtidal to neritic sedimentation took place; **B** – Barremian sea-level drop resulted in emersion of the more elevated Pienidic units as far as the margin of the Kysuca-Pieniny Trough (sedimentary area of the Nižná Succession), where a shallow-water deposition of the Urgonian-type facies took place; most of the emerged land was eroded and karstified to various depths; **C** – Late Aptian new flooding occurred with deposition of organodetritic limestones on the Czorsztyn Elevation; **D** – Early Albian a new sea-level drop resulted in new karstification, also involving the new Upper Aptian limestones, forming thus a polyphase karst; **E** – Middle Albian: rapid flooding, with deposition of red pelagic marls that covered the karstified areas

Nižná Succession (Nižná Limestone defined by Scheibner, 1967b) might represent the sought shallow-water deposits that rimmed the emerged area. These limestones also contain clasts (e.g., black cherts and limestone clasts), derived from the Pieniny Limestone (Scheibner, 1967b). Reworking of this Neocomian Maiolica-type limestone to such a degree that free residual chert nodules remained was possible only by subaerial exposure and weathering. The sedimentary area of the Nižná Succession was then also partially emerged.

CONCLUSIONS

From the data presented in this paper, a new model of pre-Albian evolution of the Czorsztyn Ridge (Swell – sensu Mišík, 1994) is introduced. After Valanginian deposition of crinoidal Spisz Limestone Formation (Fig. 20A), an emersion of the Czorsztyn Ridge, with adjacent sedimentary areas of the Niedzica, Czertezik and partly Nižná Succession, took place (Fig. 20B). The emersion resulted in deep, karstification and local fresh-water cementation. In this time, the shallow-water Nižná Limestone was deposited in the Nižná Succession.

The succeeding flooding was multiphase. In the latest Aptian, a rapid, but temporary marine incursion flooded the Czorsztyn Ridge (Fig. 20C) and hardgrounds were formed, covered by P-Fe-Mn stromatolites. Afterwards, red organodetritic limestones were deposited. Contradicting former views, our investigation showed that there were some basal clastics but restricted only to this first phase of flooding. After this marine incursion, a next temporary sea-level drop followed, with subsequent phase of partial erosion and karstification. A polyphase karst, as defined by Molina *et al.* (1999), was formed (Fig. 20D). In the newly emerged part of the ridge, only remnants of the Upper Aptian organodetritic limestones were preserved. The phosphatic stromatolites and phosphatized limestones that originated during the first phase of flooding were partly reworked. In the areas that were not affected by the regression, a continuous deposition between the Late Aptian and Albian occurred. The final flooding came in the form of rapid ingression in the Middle Albian, accompanied with the formation of new hardgrounds and stromatolitic crusts, accompanied by the deposition of pelagic marlstones and limestones (Fig. 20E). This deposition alternated with periods of non-deposition and submarine erosion, because also younger, Cenomanian to Turonian deposits, were found on the base. Some emersion events that can happen at that time also cannot be excluded.

Acknowledgements

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Appendix

ALBIAN–CENOMANIAN OF THE CZORSZTYN UNIT – COMPLETE SUMMARY OF THE LITERATURE DATA

Prior to this publication, more than 40 occurrences of the Albian–Cenomanian sediments of the Czorsztyn Succession, overlying underlying rocks were mentioned in literature (Fig. 1). This appendix provides their brief summary that is necessary to understand their character and variability. Note, the age determinations were taken from the literature and do not necessarily fit to the present knowledge.

Localities in Slovakia

Babiná – quarry. The locality represents an abandoned quarry at the foot of Babiná Hill, close to the road between Bohunice and Krivoklát in the middle Váh Valley (see Mišík *et al.*, 1994; Aubrecht, 2001; Aubrecht & Túnyi, 2001). In its left part, Scheibnerová (1969, p. 26 and 28) described caverns filled with variegated marls containing *Rotalipora ticinensis* (Gandolfi) and *Planomalina buxtorfi* (Gandolfi). She determined the age of the assemblage as Early Cenomanian. These caverns were observed still during quarrying; later they were destroyed.

An inaccurately located Bohunice locality was also mentioned by Kantorová & Andrusov (1958, p. 168). They informed about red and grey Albian marls with *Thalmanninella ticinensis* (Gandolfi) near a klippe of Czorsztyn Succession.

Chrastková near Krivoklát. Jurkovičová (1980, p. 44) mentioned red marlstones (15 m) overlying the *Calpionella* limestones. In the marlstones, Began (1958) found *Rotalipora appeninnica* (Renz) etc., belonging most probably to the Cenomanian. The Albian is also present at the base of the marlstones.

Vieska-Bezdedov - Žiačik Hill. Albian neptunian dyke was found, that was recently investigated by Potfaj *et al.* (2000).

Dolný Mlyn near Lubina. A quarry described by Andrusov *et al.* (1959, p. 319 and fig. 5). On the right part of the quarry, immediately above a fault, red to violet marls (up to 30 cm) overlie Tithonian limestones. The marlstones contain *Rotalipora apenninica* (Renz). Higher up, grey-greenish marls (up to 20 cm) occur, also containing *R. apenninica* (Renz). The foraminifers indicate the Cenomanian age. The Cenomanian marls are overlain by red marls of the Lower Turonian.

A more recent picture of this quarry was given by Scheibner (1967a, p. 64). Other picture and description was published by Scheibnerová (1969, p. 24–26, fig. 2). The corroded surface of Malm limestones is overlain by greenish and violetish marls of Late Albian to Early Cenomanian age. Higher up, they pass into variegated Late Cenomanian *Globotruncana* marls with radiolarians. These are overlain by Turonian to Coniacian purple marls and shales.

Dohňany. The locality is situated 3km south of Mestečko village, east of Hladký vrch Hill. The locality was mentioned as a documentation point No. 173 by Aubrecht (1990, p. 297). Red limestones of Late Albian age were found overlying Tithonian limestones. They contain *Aucellina* sp. bivalves and numearous planktonic foraminifers: *Ticinella roberti* (Gandolfi), *Thalmanninella ticinensis* (Gandolfi), *Whiteinella gandolfii* Salaj et Gašpariková, *Hedbergella* aff. *planispira* (Tappan), *Hedbergella* div. sp., *Marssonella* ex gr. *oxycona* (Reuss), *Clavihedbergella* sp. and *Lenticulina* sp. The species *Whiteinella gandolfii* Salaj et Gašpariková indicates the letest Albian, the zone of the same name *sensu* Salaj & Samuel (1984).

Jarabina. The locality was described by Andrusov *et al.* (1959, p. 318, see also a figure of Scheibner, 1967a, fig. 4). Corroded surface of Kimmeridgian–Lower Tithonian *Saccocoma* limestones, coated by a ferruginous crust, is overlain by red Albian marls and marly limestones with *Ticinella roberti* (Gandolfi) and radiolarians (max. thickness up to tens of centimetres). Higher up, they are overlain by Cenomanian marls.

Brvnište. An inaccurately located site was described by Kantorová and Andrusov (1958, p. 168). They mentioned occurrence of red marls at a Czorsztyn Succession klippe close to Brvnište village, with *Praeglobotruncana stephani* (Plummer), *Rotalipora apenninica* (Renz), *Rotalipora reicheli* Mornod and *Globigerina aequilateralis* (Brady). The age of the marls was determined to be Late Cenomanian. A closer stratigraphical relationship with the klippe occuring nearby is not given.

Kamenica. The locality is an abandoned quarry at the foot of the castle hill at Kamenica village in the eastern Slovakia. An overturned section of the Czorsztyn Succession crops out in the quarry, with two small relics of brick-red marls containing *Ticinella roberti* (Gandolfi). The marls with stromatolites and ferruginous hardground on the base represent transgression of the Albian sediments on Berriasian and Valanginian limestones. In the first occurrence, a brown stromatolite occurs on the base. This stromatolite, as well as the overlying marlstones, contain Albian foraminifers: *Ticinella roberti* (Gandolfi), *Hedbergella* sp. Along with this fauna, numerous shark teeth, rare foraminifers *Marssonella* sp., *Lenticulina* sp., echinoderm ossicles, bored fragments of bivalve shells, glauconite grains and larger quartz grains (missing in the underlying Neocomian limestones) are present. In the Albian sediment, some black *Frutexites*-type columnar stromatolites occur. The second occurrence found by Mišík (1998, pl. 7, fig. G) represents Albian neptunian dyke cutting the Neocomian limestone. The filling is red, microsparitic, with rare Albian foraminifers filled with glauconite. Some lithoclasts of Neocomian and Albian limestones were found in the sediment.

Litmanová. On the creek bank near the village Litmanová, Scheibnerová (1969, p. 28) described transgression of Upper Albian to Lower Cenomanian sediments onto corroded and bored surface of Upper Tithonian/Berriasian limestone with *Calpionella alpina* Lorenz, *C. elliptica* Cadisch and *Tintinnopsella carpathica* (Murgeanu et Filipescu). The borings are filled with red and violet limestone with hedbergellid foraminifers.

Lednica. Mišík (1979, p. 29, pl. 18, fig. 2) mentioned a remnant of Albian marlstones on the corroded and bored surface of uncovered Upper Tithonian limestone. The bivalve borings were initially filled (rimmed) with phosphate, the rest was filled with red marlstone with planktonic foraminifers of Albian: *Thalmanninella ticinensis* (Gandolfi) and *Hedbergella* aff. *infracretacea* (Glaessner). This part examined by Mišík (1979), however, does not exist anymore as it was covered by building an amphiteatre over it. A new, even better preserved part was discovered recently (see present paper). From the remnants of the older occurrence, Dragastan and Mišík (2001) described fresh-water algae from beneath the Albian hardground. This fact complements the evidence of the Hauterivian–Aptian emersion of the Czorsztyn Swell presented in this paper.

Myjava. Scheibnerová (1969, p. 28) provided a short description of a quarry north of the 393.5 m elevation point near the town Myjava. In the left side of the quarry, crinoidal limestone of the Spisz Limestone Formation is overlain by grey marls and shales of Albian age. According to the description, the transition seems to be gradual, contradicting to relatively abrupt change that is usual in the Czorsztyn Succession.

Nižná – Červená Skala. The locality, described by Richter (2002), is situated in Orava section of the Pieniny Klippen Belt, in the vicinity of Nižná Town, west of the elevation point 707 m. In the overturned position, the Czorsztyn Limestone Formation and the Dursztyn Formation crop out in an old abandoned quarry. Stratigraphical top of the latter formation is corroded and overlain by red marls with small clasts at the base. Higher up in the stratigraphic succession, thin radiolarite layers (6 and 30 cm) occur (Pomiedznik Formation), with Turonian radiolarians (Richter, 2002).

Vršatec. In the Vršatec Klippen, several sites with the Albian of the Czorsztyn Succession were found. Most of them were mentioned by Mišík (1979) or in other papers. An interesting information comes from Salaj and Samuel (1966, p. 64) who found an Upper Albian flysch intercalation with exotic material in the Czorsztyn Succession near Vršatské Podhradie village. Two new sites were found recently (see the next chapter). The so far known sites are as follows (original names of the localities of Mišík (1979) are maintained):

Vršatec – loc. 1a. It represents a pressure-deformed filling of a cavity (or neptunian dyke), several tens of centimetres in size, in white crinoidal limestone, found at the summit part of the Vršatec Castle (Mišík, 1979, p. 29 and fig. 4f). On the basis of thin-section study, the Lower Albian age was determined. The cavern is laminated but the Albian planktonic foraminifers are concentrated just in some laminae. A clast with "filamentous" microfacies (Bathonian–Callovian) was found in the cavern.

Vršatec – dyke G at loc.1. The occurrence was described by Mišík (1979, p. 29, fig. 4a, pl. 16, fig. 1). The neptunian dyke penetrates through the white crinoidal limestone and possess twofold filling: Callovian/Oxfordian and Albian. The Albian filling is laminated.

Vršatec – loc. 5. The occurrence represents a cavern of about 1m size, filled with red marlstones (Mišík, 1979, p. 28). The filling contains small bivalves (probably *Aucellina* sp.). The presence of *Thalmanninella ticinensis* (Gandolfi) and *Hedbergella* aff. *infracretacea* (Glaessner) indicates Late Albian age.

Vršatec – loc. 6. It represents a cavern filling in Neocomian limestone (fine-grained limestone breccia). The filling is of Late Albian age. Its substratum was heavily bored by boring algae and sponges. At the base, a crust (probably phosphatic) with local relics of stromatolite was found. In this crust, *Ticinella roberti* (Gandolfi) and *Thalmanninella ticinensis* (Gandolfi) are present, together with abundant prisms of inoceramids. Belemnite guards were also found, from which *Neohibolites minimus* Lister was determined.

Vršatec – loc. 34. The occurrence represents red marlstone filling of a 1m sized cavern in the Upper Tithonian limestones. The marlstones contain foraminifers *Thalmanninella* (*Rotalipora*) *appenninica* (Renz) and *Planomalina buxtorfi* (Gandolfi) that were referred to the Early Cenomanian. It is noteworthy that this was the only locality where clasts of the underlying Tithonian limestones were found. Usually, the Albian sediments do not contain clastic material from the underlying rocks .

Vršatec – loc. 43c. Transgressive Albian sediments on the Neocomian limestones, representing a pocket some tens of centimetres in size were described by Scheibnerová (1969, p. 23, fig. 1). The author mentioned abundant rostra of belemnite *Neohibolites minimus* Lister and bivalves. The base is covered by Fe-Mn oxides and tiny borings. The filling represents red to violet marly limestones, with small red cherts. The author also mentions angular quartz grains and clast of metaquartzite and a clast of probably Aptian limestone. More recently, *Ticinella roberti* (Gandolfi) and *Hedbergella* aff. *infracretacea* (Glaessner) were found, indicating the Early Albian age. In other part of the locality, Cenomanian thalmanninelids were accumulated. The sediment also contains indistinct *Frutexites*-type stromatolites.

Vršatec – loc. 47. The locality mentioned by Mišík (1979) but without closer description was re-examined by the present authors (see above).

Vršatec – a locality above the ski lift. The site was mentioned by Mišík (1979, p. 28, pl. 19, fig. 1). Neocomian limestones are overlain by erosional relic of red marlstones with *Ticinella roberti* (Gandolfi) and *Hedbergella* aff. *infracretacea* (Glaessner), which belong to Early Albian. The substratum is bored by algae and sponges. On the base, a phosphatic stromatolitic crust has developed. The Albian sediments also penetrate to tiny fractures in the underlying limestones, forming neptunian microdykes (Mišík, 1998, pl.8, fig. A). The Albian sediment also fills molds after leached bivalve shells in the underlying limestone.

Localities in Poland

Recently accessible outcrops:

Czerwona Skała Klippe. The locality is situated between Krempachy and Dursztyn villages, at a road cut near Pustelnia (bus-stop place). It represents stratotype section of the Pustelnia Marl Member of the Jaworki Formation and was several times mentioned in literature (Birkenmajer, 1958a, fig. 57; 1963, pls 7, fig. 2; 9, fig. 3; 1977, figs 7n, 37a; 1979, fig. 46; Alexandrowicz, 1966, figs 23, 25; 1975; Dudziak, 1979; fig. 2; 1985; Jednorowska, 1979, fig. 2; K. Bąk, 1995, fig. 1; 1998, figs 2, 3; 2000; M. Bąk, 1996; Szydło, 1997, fig. 4). Micropalaeontological studies documented the age of these marls by means of foraminifers (Alexandrowicz, 1966; Jednorowska, 1979; Szydło, 1997; K. Bąk, 1998, 2000), radiolarians (M. Bąk, 1996) and calcareous nannoplankton (Dudziak, 1979, 1985). The microfossils indicate that the oldest part of brick-red marls is Middle Cenomanian in age (foraminiferal *Rotalipora reicheli* Zone) and, simultaneously, it is the oldest level of the Pustelnia Marl Member in the whole Polish part of the Pieniny Klippen Belt (Alexandrowicz, 1975; K. Bąk, 1998, 2000). In this part of the section, forminifers are dominated by *Globigerinelloides bentonensis* (Morrow), *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Praeglobotruncana delrioensis* (Plummer), *P. stephani* (Gandolfi) and *Rotalipora appenninica* (Renz) (Alexandrowicz, 1975; K. Bąk, 1998 – his sample number 10); radiolarians by *Holocryptocanium barbui* Dumitrica species (M. Bąk, 1996 – the same sample) and calcareous nannoplankton by *Coccolithus actinosus* Stover, *Cyclococcolithus* cf. *rotula* (Kamptner) and *Discolithus* cf. *obliquipons* Deflandre (Dudziak, 1979).

Falsztyn–Pomiedznik Klippe. The outcrop near the "Cisówka" pension, close to the Niedzica–Nowy Targ road at Falsztyn village, belongs to the Pomiedznik klippen (Birkenmajer, 1963, pls 8, fig.1; 16, fig. 3; 1977, figs 7l, 31b; Alexandrowicz, 1966, figs 19, 21; 1979; Gasiński, 1988, figs 1, 3; M. Bąk, 1993a, b; Wierzbowski, 1994, fig. 5; K. Bąk *et al.*, 1995; Krobicki, 1996, fig. 4). About 5.5 m thick complex of well bedded dark-red, cherry-coloured and variegated marly limestones of the Chmielowa Formation cover irregular surface of strongly corroded underlying rocks, which belong to 8.5m thick sequence of red and brown-violet crinoidal limestones of the Spisz Limestone Formation. Poorly preserved calpionellids (Wierzbowski, 1994) and brachiopods (Krobicki, 1996) within these crinoidal limestones indicate their Early Valanginian age.

The Chmielowa Formation in this section yielded foraminiferal fauna, including *Gyroidina infracretacea* Morozova, *Osangularia infracretacea* Bukalova, *Gavelinella schloenbachi* (Reuss), *Globigerinelloides breggiensis* (Gandolfi) and *Rotalipora ticinensis* (Gandolfi) but without precisely indication of the sampling sites (Alexandrowicz, 1966, 1979). This foraminiferal assemblage indicates Middle to Late Albian age. However, within the uppermost part of the formation (see Gasiński, 1988, fig. 3 – his samples 1 and 2) "the occurrence of *B. breggiensis* and the absence of *Rotalipora* suggest a Middle Albian age" (Gasiński, 1988: 238, fig. 8) and therefore this author created informal, *Hedbergella* local assemblage zone (= "*Hedbergella* microfacies" of Alexandrowicz, 1966) which is "older than Late Albian" (op. cit.). Consecutively, either the lower part of the Chmielowa Formation in this outcrop is also Middle Albian in age or the lowermost part of it may belong to the Early Albian. On the other hand, for the whole Pieniny Klippen Belt Alexandrowicz (1979: 169) suggested a lack of microplaeontological evidences of the Early Albian age of the red limestones and marls of the Chmielowa Formation. Therefore, precise stratigraphical position of the lowermost part of this formation needs additional investigations.

The Pomiedznik Formation which overlies the Chmielowa Formation consists of thin beds of green, sometimes spotty limestones, with rare brachiopods (terebratulids) and *Aucellina gryphaeoides* Sowerby bivalves and foraminifers which are dominated by *Hedbergella delrioensis* (Carsey) (whole section) and *Globigerinelloides bentonensis* (Morrow) with *Hedbergella planispira* (Tappan) (lower part of section) and *Planomalina buxtorfi* (Gandolfi) with *Rotalipora appenninica* (Renz) (upper part) (Gasiński, 1988).

In conclusion, the top of the uppermost bed of the Spisz Limestone Formation marks a distinct non-depositional surface and stratigraphical gap between the Spisz and Chmielowa formations ranging from the Late Valanginian to Aptian (or even Early Albian) inclusively.

Niedzica Castle hill. The locality occurring just below the Niedzica Castle was described and illustrated several times by Birkenmajer (1957, fig. 10; 1958a, fig. 76; 1963, pl. 19; 1977, figs 7h, 28b; 1979, figs 62, 63; 1986, fig. 44; 1998, figs 6, 8, pl. 2; 1999, fig. 4; 2001, fig. 51). The Chmielowa Formation is absent in this outcrop and, therefore, thin beds of green, spotty, often silicified marly limestones of the Pomiedznik Formation (1.0 m thick) occur directly on the white or greenish, massive and bedded *Calpionella* limestones of the Sobótka Limestone Member of the Dursztyn Limestone Formation (Lower Berriasian – *Calpionella* Zone (B); Wierzbowski, 1994). Sedimentary contact between these two formations occurs here as suggested Birkenmajer (1998), with big gap between the Middle Berriasian and the Lower Albian inclusively.

Northern klippen above the **Krupianka** stream (E side) at Jaworki village represent Jurassic–lowermost Cretaceous sequence (Birkenmajer, 1958a, fig. 111; 1963, pl. 24, figs 1, 2, 4, 5; 1970; 1977, figs 7a, 30b). The Chmielowa Formation is represented by very condensed (only 1.5 cm in thickness), dark-red, cherry-coloured and haematite-red limestones, occurring as small lenses or infillings of shallow pockets on the irregular surface of the white-cream and yellowish *Calpionella* limestone of the Sobótka Limestone Member of the Dursztyn Limestone Formation (Berriasian). Poor macrofossils were found within the Chmielowa Formation: belemnite, crinoid ossicles, spine of echinoid and some prisms of *Inoceramus* shells (Birkenmajer, 1963: 225). However, the thickness of the Pomiedznik Formation is incomplete due to partial erosion of the outcrop. The formation is developed as green-black or variegated spotty limestones with black-green cherts and poorly preserved belemnites. The stratigraphical gap ranged from Berriasian (Upper?) to Albian.

Szczepanówka Klippe. The locality is situated near the Homole Gorge at Jaworki village and was only mentioned by Birkenmajer (1970: 17). The Chmielowa Formation consists of dark-red and greenish nodular limestones and its thickness does not exceed 30 cm. Crinoidal ossicles are common but belemnites and fragments of bivalves are rare. However, green and black-green spotty marls of the Pomiedznik Formation are about 7–8m in thickness. The basement of these formations is unknown here.

Szczobiny. In the vicinity of the quarry on the western side of the Homole Gorge, Jurewicz (1997, figs 2, 7) described and illustrated a sedimentary contact between white crinoidal limestones of the Bajocian Smolegowa Limestone Formation and green-black shales of the Pomiedznik Formation which sometimes penetrated its basement as neptunian dykes (*op. cit*., fig. 7). On the other hand, green marly limestones of the Chmielowa Formation occur locally as isolated lenses between Smolegowa and Pomiedznik formations, and documented tha lack of Upper Bajocian–Aptian rocks; perhaps they were removed by erosion.

Czajakowa Skała Klippe above Homole Gorge near Jaworki village was well documented in literature (Birkenmajer, 1958a, fig. 115; 1963, pl. 25, fig. 4; 1970, fig. 3a; 1977, figs 7a, 20b; 1979, figs 106, 108; 1986, fig. 67; 2001, fig. 39; Golonka & Krobicki, 2001, fig. 11a). One of the youngest units of the whole Jurassic–Cretaceous sequence of the Czorsztyn Succession in this outcrop is the Pomiedznik Formation represented by green and green-black marls and marly limestones, that are overlain by a higher tectonic unit of the Niedzica Nappe. The Pomiedznik Formation rests upon massive, white *Calpionella* limestone of the Sobótka Limestone Member of the Dursztyn Limestone Formation (Berriasian).

A klippe below the **church at Jaworki village** belongs to the best-known localities documenting the Early Cretaceous hiatus. Variegated and red marls with irregular distribution of thin (maximum to 5 cm thick) variegated and red marly limestones of the Chmielowa Formation (Birkenmajer, 1970, fig. 5b; 1979, fig. 109; 1986, figs 64, 65; 2001, figs 46, 47; Alexandrowicz, 1979; Alexandrowicz & Tarkowski, 1979; Gasiński, 1991, fig. 8; Birkenmajer & Kokoszyńska, 1999) cover strongly erroded hardground-type surface of white or cream-yellow *Calpionella* limestones of the Sobótka Limestone Member of the Dursztyn Limestone Formation (Berriasian) covered with haematite crusts. Numerous small belemnites (*Neohibolites* sp.; Alexandrowicz & Tarkowski, 1979) were found in the Chmielowa Formation, whereas black and green spotty marls and limestones of the overlying Pomiedznik Formation yielded (L. Horwitz's collection) *Ostrea* sp., *Pycnodonta* aff. *vesicularis* (Lamarck), *P.* aff. *vesiculosa* (Sowerby), *Aucellina* cf. *gryphaeoides* Sowerby, *Exogyra* sp., *Neohibolites* sp. (Birkenmajer, 1970; Birkenmajer & Kokoszyńska, 1999). Microfossils are represented by low-diversified foraminiferal assemblage, consisting of *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan) and *Tritaxia gaultina* (Morozova) (Alexandrowicz, 1979). Stratigraphic hiatus between the Sobótka Limestone Member and the Chmielowa Formation shows a gap ranging from Berriasian to Albian.

Biała Woda Valley – waterfall outcrop shows the Chmielowa and Pomiedznik formations (Birkenmajer, 1963, pl. 23, figs 2, 4; 1977, figs 7a, 30a; 1979, figs 115, 116; 1986, fig. 72; Krobicki, 1994, fig. 7l; 1996, fig. 6; Krobicki & Wierzbowski, 1996, figs 1, 2, 5; Birkenmajer & Kokoszyńska, 1999). The Chmielowa Formation is represented by dark red-brown limestones, overlying red and cherry-coloured crinoidal limestones of the Spisz Limestone Formation (Lower Valanginian). The lower boundary of the formation represents an erosional surface (Birkenmajer, 1963) corresponding to the non-deposition and/or erosion that affected sediments ranging from Valanginian/Hauterivian to Albian. The Chmielowa Formation contains very abundant planktonic foraminifers (*Hedbergella* microfacies) of Early to Middle Albian age (Birkenmajer, 1977)

Biała Woda Valley. About 100 m far from the waterfall there is a small outcrop on the right side of Biała Woda stream (Birkenmajer, 1963, pl. 23, fig. 5; Alexandrowicz, 1979, fig. 2; Alexandrowicz & Tarkowski, 1979), where red crinoidal limestones of the Spisz Limestone Formation occur (Valanginian). The erosional surface of the topmost bed is covered by haematite, dark-red and violet marly limestones of the Chmielowa Formation infilling small, corroded cavities where numerous small belemnites were collected by L. Horwitz and determined by Kokoszyńska as *Neohibolites ultimus* (d'Orbigny) (Birkenmajer & Kokoszyńska, 1999, see also Alexandrowicz & Tarkowski, 1979). The foraminiferal assemblage consists of *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Rotalipora ticinensis* (Gadolfi), *Globigerinelloides breggiensis* (Gandolfi), *Osangularia infracretacea* Bukalova, *Gavelinella schloenbachi* (Reuss) and others (Alexandrowicz, 1979). The assemblage indicates Middle and Upper Albian age. By this reason, the stratigraphic gap between the Spisz and Chmielowa formations ranges here from Valanginian to Aptian (or even Lower Albian) inclusively.

Recently inaccessible outcrops (known only from literature):

Obłazowa Klippe near Nowa Biała village at Białka river (Birkenmajer, 1958a, fig. 48; 1963, pls 7, fig. 1; XII, fig. 1; 1977, figs 7p, 20c; 1979, fig. 35). Pomiedznik Formation is represented by greenish spotty marls. The contact with underlying white *Calpionella* limestones of the Sobótka Limestone Member of the Dursztyn Limestone Formation (Berriasian) is not exposed now (covered by Holocene deposits).

Korowa Klippe near Krempachy village (Birkenmajer, 1963, pls 7, fig. 1; 9, fig. 1; 1977, figs 7o, 27c; 1979, figs 39, 41; Alexandrowicz, 1979; Krobicki, 1994, fig. 7g; 1996, fig. 3). The Chmielowa and Pomiedznik formations were exposed by an artificial trench. The former unit was characterized by violet-pink, greenish and variegated limestones with gentle transition to the underlying red and cherry-coloured crinoidal limestones of the Spisz Limestone Formation (see Birkenmajer, 1963: 131) of the late Valanginian age (Krobicki & Wierzbowski, 1996). The foraminiferal assemblage in the Chmielowa Formation consists of numerous specimens of *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Textularia chapmani* Lalicker, *Spiroplectinata annectens* (Jones et Parker), *Tritaxia gaultina* (Morozova), *Saracenaria italica* Defrance (Alexandrowicz, 1979).

The Pomiedznik Formation is represented by variegated, often spotty marly limestones with multicoloured cherts.

Borsukowa Klippe near Krempachy village (Birkenmajer, 1963, pl. 11, fig. 4; Alexandrowicz, 1979; Krobicki, 1994, fig. 7i). The locality is recently covered by Pleistocene and Holocene debris and vegetation. Formerly it was investigated by Birkenmajer (1963) in a shallow artificial trench. The Chmielowa Formation is represented by green and variegated marly limestones and marls with unidentified fragments of macrofossils; the Pomiedznik Formation consists of green spotty limestones with brown and black cherts. Contact with the underlying violet crinoidal limestones of the Spisz Limestone Formation (Valanginian) was tectonicaly disturbed and, therefore, unclear. In the Chmielowa Formation, following foraminifers were deterimned: *Hedbergella delrioensis* (Cersey), *H. planispira* (Tappan), *Spiroplectinata annectens* (Jones et Parker), *Tritaxia gaultina* (Morozova), *Lenticulina planiuscula* (Reuss), *Saracenaria italica* Defrance (Alexandrowicz, 1979).

Lorencowe and Gęśle klippen near Krempachy village (Birkenmajer, 1963, pl. 11, fig. 1; 1977, figs 7o, 29a; 1979, figs 42, 43). Only a small tectonic lense of red limestones of the Pomiedznik Formation was rooted between two slices of the Upper Cretaceous marls. Recently it is completely covered by Quaternary rubble. The basement of the Albian rocks is then unknown.

Łysa Skała Klippe near Falsztyn village (Birkenmajer, 1958a, fig. 89; 1963, pls 8, fig. 1; 18, figs 1, 4; 1977, figs 7l, 28a; Alexandrowicz, 1966, fig. 19; 1979). Cherry-red and partly green limestones of the Chmielowa Formation were discovered within an artificial trench on the southeastern side of the main ridge of the klippe. They yielded a foraminiferal assemblage, containing *Hedbergella delrioensis* (Cersey), *H. planispira* (Tappan), *Rotalipora ticinensis* (Gandolfi), *Globorotalites brotzeni romanus* Neagu, *Textularia chapmani* Lalicker, *Marginulina elongata* d'Orbigny, *Saracenaria bronni* (Roemer) and *Valvulineria gracillima* Ten Dam (Alexandrowicz, 1979). Overlying green and black marls and marly limestones belong to the Pomiedznik Formation. These formations rested upon greenish and pinkish crinoidal limestones of the Spisz Limestone Formation (Valanginian).

Chmielowa and Kosorki klippen at Falsztyn village (Birkenmajer, 1963, pls 8, fig. 1; 17, figs 2, 3; 1977, figs 7l, 30d; Alexandrowicz, 1966, figs 19, 22, 1979). At this locality, the stratotype of the Chmielowa Formation (10 m thick) was located. The formation consists of cherry-coloured, red and green, sometimes spotty limestones. However, it was only studied in a long trench that does not exist anymore. Numerous micropalaeontological samples were collected from the trench, with rich assemblages of foraminifera, consisting of *Hedbergella delrioensis* (Cersey), *H. planispira* (Tappan), *Globigerinelloides breggiensis* (Gandolfi), *Rotalipora ticinensis* (Gandolfi), *Gyroidina infracretacea* Morozova, *Osangularia infracretacea* Bukalova, *Anomalina hostaensis* Morozova, *Gavelinella intermedia* (Berthelin), *G. schloenbachi* (Reuss) and others, described by Alexandrowicz (1979). The above cited assmblage indicates Middle to Late Albian age (see Alexandrowicz's discussion). The top of the underlying white and cream *Calpionella* limestones of the Sobótka Limestone Member of the Dursztyn Limestone Formation (Berriasian) forms uneven hardground-type surface (see Birkenmajer, 1977, fig. 30d). The Pomiedznik Formation is represented by green limestones and green and black marly limestones (often spotty).

Brynczkowa Klippe at Falsztyn village (Birkenmajer, 1963, pls 8, fig.1; 16, figs 1, 2; 1977, figs 7l, 31a; Alexandrowicz, 1966, figs 19, 20; 1979). In this locality, the Chmielowa and Pomiedznik formations were uncovered by shallow trench (Birkenmajer, 1963) and were represented by dark red and greenish, sometimes crinoidal limestones (Chmielowa Formation) and greenish, black-green spotty limestones with cherts (Pomiedznik Formation). Both formations overlie dark–red crinoidal limestone of the Spisz Limestone Formation (Valanginian), but the thickness of the Chmielowa Formation is probably tectonicaly reduced (only 20 cm) without features of sedimentary condensation. Foraminifers assemblage is represented by *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Globigerinelloides breggiensis* (Gandolfi), *Rotalipora ticinensis* (Gadolfi), *Spiroplectammina baudouiniana* (d'Orbigny), *Textularia chapmani* Lalicker, *Gyroidina infracretacea* Morozova, *Gavelinella schloenbachi* (Reuss) and others (Alexandrowicz, 1979).

Zielone Skałki klippen near Falsztyn village (Birkenmajer, 1963, pls 8, fig. 1; 15, fig. 2; 1977, figs 7j, 27b; Alexandrowicz, 1979). Thin beds (0.5 m in total thickness) of green and red limestones of the Chmielowa Formation with rare crinoid ossicles occur just above dark red, green-yellow and violet crinoidal limestones of the Spisz Limestone Formation (Valanginian); the

Pomiedznik Limestone Formation is represented by green and green-black spotty marly limestones with multicoloured cherts. All the mentioned rocks were discovered in a small trench located in the middle part of belt of the klippen. Within the Chmielowa Formation, following foraminifers were determined: *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Rotalipora ticinensis* (Gandolfi) and *Spiroplectinata annectens* (Jones et Parker) (Alexandrowicz, 1979).

Halka Klippe (= "Nad Plosem" Klippe) near the Czorsztyn Castle (Birkenmajer, 1958a, fig. 73; 1963, pls 8, fig. 3; 14, fig. 1; 1977, figs 7i, 22a; 1979, figs 56, 57; Gasiński, 1988, figs 1, 5; M. Bąk, 1993a, b; Myczyński & Wierzbowski, 1994, fig. 1; K. Bąk *et al.*, 1995, figs 1, 3). This locality is now flooded by water of Czorsztyn dam (lake) built during the 90-ies in the last century. The Chmielowa Formation was absent in the klippe; the Pomiedznik Formation was represented by greenish-pinkish and green-blue limestones, often silicified, with belemnites and fragments of bivalves. Birkenmajer (1963, 1977, 1979) suggested occurrence of a tectonic gap between this unit and its basement. The substratuum is represented by dark- and light-red coloured nodular limestones of *ammonitico rosso*–facies of the Czorsztyn Limestone Formation (Kimmeridgian/Tithonian?; cf. Wierzbowski & Remane, 1992; Myczyński & Wierzbowski, 1994). Foraminiferal biostratigraphy was studied by Gasiński (1988) (see also K. Bąk *et al.*, 1995) and dinoflagellate cysts were described by Jamiński (1990). The foraminifers are mainly represented by *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *H. simplex* (Morrow), *Rotalipora appenninica* (Renz) (Gasiński, 1988). Radiolarian fauna was dominated by *Holocryptocanium barbui* Dumitrica (M. Bąk, 1993a) which indicates Late Albian–Early Cenomanian age.

Sobótka Klippe within the Czorsztyn Castle klippen was most often described and illustrated in literature, since this outcrop is the type locality of the Czorsztyn Succession (Birkenmajer, 1958a, fig. 71; 1963, pl. 13, figs 1, 2; 1977, figs 7i, 27a; 1979, figs 53, 54; 1986, fig. 33; 2001, figs 50, 51; Alexandrowicz, 1966, figs 13, 15; 1979; Alexandrowicz & Tarkowski, 1979; Gasiński, 1988, figs 1, 4; M. Bąk, 1993a, b; K. Bąk *et al.*, 1995; Krobicki, 1994, fig. 7k; 1996, fig. 5). Unfortunatelly, the lower part of this section was flooded by the Czorsztyn dam and, therefore, the younger parts of the sequence are recently inaccessible. The Chmielowa Formation was represented by cherry-red and greenish bedded limestones. According to Birkenmajer (1963), they were tectonically reduced. The Pomiedznik Formation consists of black, green and black-green, often spotty limestones with cherts. These formations rest immediately on the red-violet crinoidal limestone of the Spisz Limestone Formation (Lower Valanginian; Wierzbowski, 1994; Krobicki, 1996). Within the Chmielowa Formation, microfossils are very abundant and are represented by foraminifers dominated by planctonic *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Globigerinelloides bentonensis* (Morrow), *G. breggiensis* (Gandolfi) and *Rotalipora appenninica* (Renz) or benthic *Dorothia gradata* (Berthelin), *Arenobulimina preslii* (Reuss) and *Osangularia infracretacea* Bukalova (Alexandrowicz, 1966, 1979; Gasiński, 1988, K. Bąk *et al.*, 1995). Radiolarian fauna was represented by *Holocryptocanium barbui* Dumitrica and *Squinabollum fossilis* (Squinabol) (M. Bąk, 1993a, b); dinoflagellate cysts were mainly represented by *Lithosphaeridium siphoniphorum* (Cookson et Eisenack) (Jamiński, 1990; K. Bąk *et al.*, 1995). From macrofossils, solely small belemnites were found (Alexandrowicz & Tarkowski, 1979). All the fossils indicate Late Albian age and, therefore, the stratigraphical gap at the locality ranges from the Upper Valanginian to the Middle (?) Albian.

Kapuśnica. The section that was exposed on the left side of Dunajec river (opposite to the Niedzica Castle) is recently flooded by the Czorsztyn dam. Only Pomiedznik Formation has been illustrated and its basement was unknown (Birkenmajer, 1958a, fig. 75; 1979, fig. 61).