Interpretation of the geological structure of an atypical klippe in the Orava sector of the Pieniny Klippen Belt near Revišné (Western Carpathians, Slovakia)

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Abstract: Pieniny Klippen Belt is a mélange zone situated between the internides and externides of the Western Carpathians. This complex zone consists of blocks of sedimentary rocks of various provenance. Most of them belonged to a crustal segment called Oravicum, which was surrounded by branches of Ligurian-Penninic-Vahic Ocean (Pieniny and Magura basins). The Pieniny Klippen Belt underwent several compressional and transpressional phases that caused expressive crustal shortening and mixing of blocks belonging to different tectonic units. At Revišné, in Orava sector of the Pieniny Klippen Belt, a klippe including Bajocian crinoidal limestones (Smolegowa and Krupianka limestone formations), accompanied with synsedimentary Krasín Breccia was found. These formations belong to the Czorsztyn Unit which was the shallowest of all the Oravic units. Occurrences of this unit are rare in the Orava territory and the occurrence of Krasín Breccia is the first outside the middle Váh Valley. The lower part of the klippe is formed by tectonically overturned succession ranging from Kimmeridgian red nodular limestone (Czorsztyn Limestone Formation), Lower Tithonian greenish-grey nodular limestone (Revišné Limestone), through Upper Tithonian to Hauterivian marly white *Calpionella-Nannoconus* limestone (Pieniny Limestone Formation) and Barremian-Aptian grey spotted marls (Kapuśnica Formation) up to Lower Albian marly shales (Wronine Formation). This succession does not fit to the Czorsztyn Unit which characteristically lacks Hauterivian to Aptian strata due to emersion and karstification. Lithology of this part of the klippe, together with strong condensation of the succession indicates that it may belong to the externmost, deep-water Grajcarek Unit which was deposited north of the Czorsztyn Unit. Contact of these two units is most likely tectonic. The Czorsztyn Unit is thrust onto the Grajcarek Unit providing two possible ways of interpretation: 1) Grajcarek Unit was thrust onto the Czorsztyn Unit and later both were overturned, 2) Czorsztyn Unit was thrust over the overturned Grajcarek Unit.

Key words: Pieniny Klippen Belt, Jurassic, Cretaceous, stratigraphy, tectonics, microfacies analysis, calcareous nannoplankton, foraminifers.

1. INTRODUCTION

The Pieniny Klippen Belt (PKB) is a long complex zone situated along the boundary between the Inner and Outer Western Carpathians. It is a mélange zone, formed by rocks of the sedimentary cover of a former terrain called Oravicum and partly also by rocks belonging to the units derived from the Central Western Carpathians. The Oravic units consist of deep-marine (Kysuca-Pieniny Unit) to shallow-marine (Czorsztyn Unit) environments that underwent long-term polyphase tectonic history which resulted in their present ´block in matrix´ structure. Blocks (or klippen) of harder Middle Jurassic to Lower Cretaceous limestones are embedded in softer shales, marls and flysch formations, mostly of the Late Cretaceous age. The PKB sedimentary units exhibit very variable lithology and complex internal structure and the paleogeographical reconstruction of the evolution of the Czorsztyn, Kysuca and all transitional units is difficult.

The Czorsztyn Unit is characterized by deposition of crinoidal limestones, namely Smolegowa and Krupianka limestones during Bajocian. The rising Czorsztyn Swell also incited synsedimentary faults which led to forming of the cliff breccias (Krasín Breccia – Mišík et al., 1994; Aubrecht, 1997; Aubrecht, 2001; Aubrecht & Szulc, 2006) and clefts which later turned to neptunian dykes (Aubrecht & Túnyi, 2001). Late Bajocian to Callovian deposition changed to deeper neritic Ammonitico Rosso (Czorsztyn Limestone Formation - Birkenmajer, 1977) during the global sea level rise reflected also in the Oravic domain.

Another characteristic feature of the Czorsztyn Unit is a period of emersion, with sedimentary break encompassing almost the whole Hauterivian, Barremian and Aptian. It was caused by an emersion of the entire ridge with signs of erosion and karstification (Aubrecht et al., 2006). Local subaerial exposition proved by paleokarst surfaces was documented by Aubrecht et al. (2006). Next, the Chmielowa and Pomiedznik formations of Albian to Cenomanian age were deposited in deep water, suggesting a rapid relative sea-level rise. Klippen of the Czorsztyn Unit occur commonly all along the PKB, except of the Kysuce and Orava sectors, where they are relatively rare (Mišík, 1997).

Recently, a new, undescribed klippe of the Czorsztyn Unit has been studied near the village Revišné in the Orava sector of the PKB (Fig. 1). The klippe is remarkable due to: 1) it is the first

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klippe containing Krasín Breccia found in the Orava territory and outside the middle Váh Valley; and 2) there is no apparent sedimentary break in the Barremian-Aptian stratigraphic interval which was so far found at all Czorsztyn Unit klippen.

2. GEOLOGICAL SETTING (DESCRIPTION OF THE REVIŠNÉ KLIPPE)

The Revišné klippe is situated in the village of Revišné (N 49°12.861´ E 19°14.858´), near the town of Dolný Kubín and forms a distinctive feature visible from all parts of the village (Fig. 2). The klippe consists of several lithostratigraphic units. In the middle part of the hill crest, Krasín Breccia outcrops, however owing to vast cover of vegetation of the klippe, it is poorly visible. It is a synsedimentary breccia to megabreccia (Fig. 3) consisting of clasts and blocks of red to pinkish crinoidal limestones penetrated by neptunian dykes filled with fine pink micrite. The uppermost part of the breccia is more marly. The top and the upper part of the hill consist of massive white crinoidal limestones of Smolegowa Limestone Formation with no visible brecciation (Bajocian); only one neptunian dyke was observed. Red to orange crinoidal limestones outcrop below. They belong to the Krupianka Limestone Formation still of Bajocian age. All

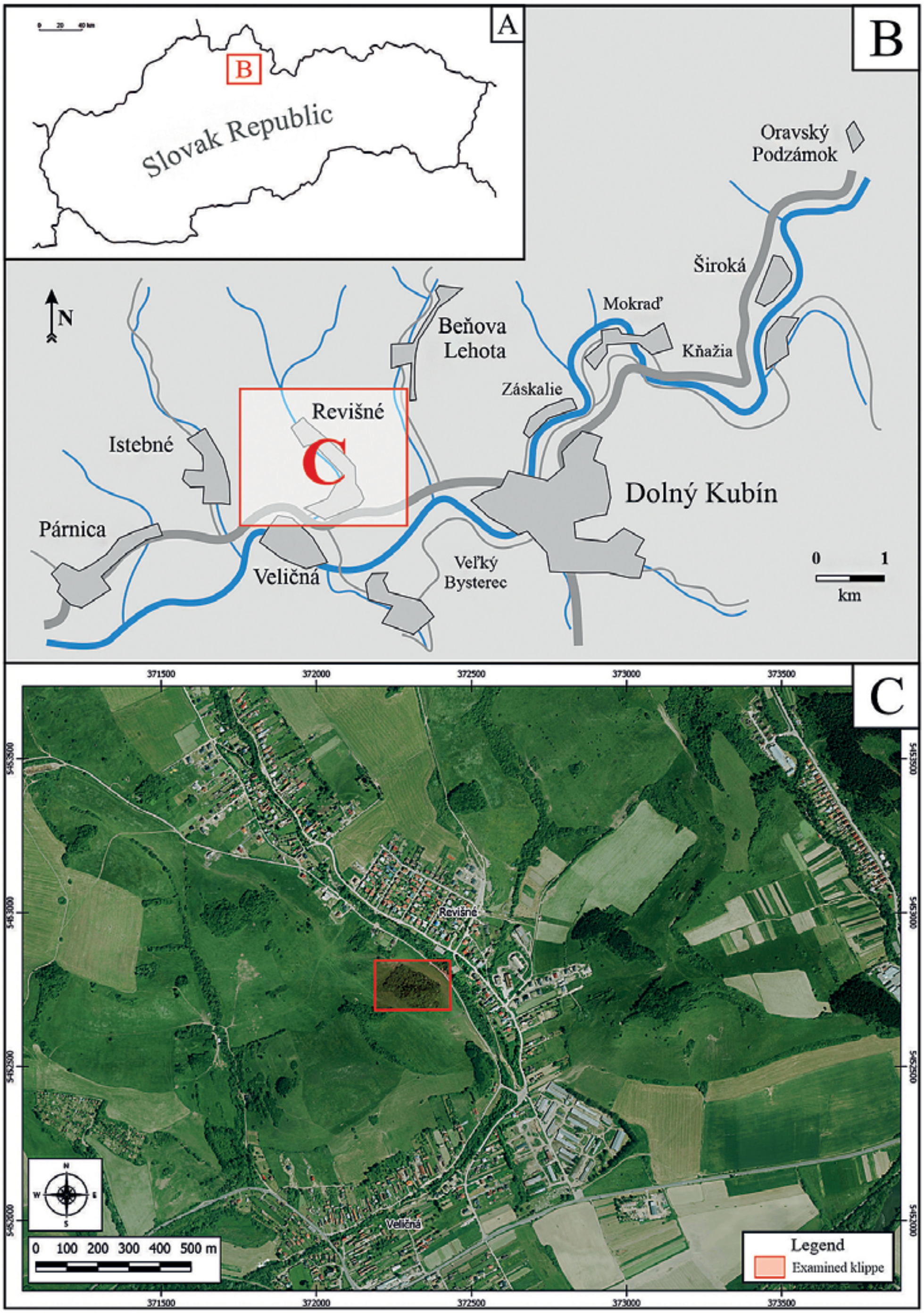

Fig. 1. Position of the examined locality. Source of the photo: Geodetic and Cartographic Institute, Bratislava, National Forrest Centre, 2017.

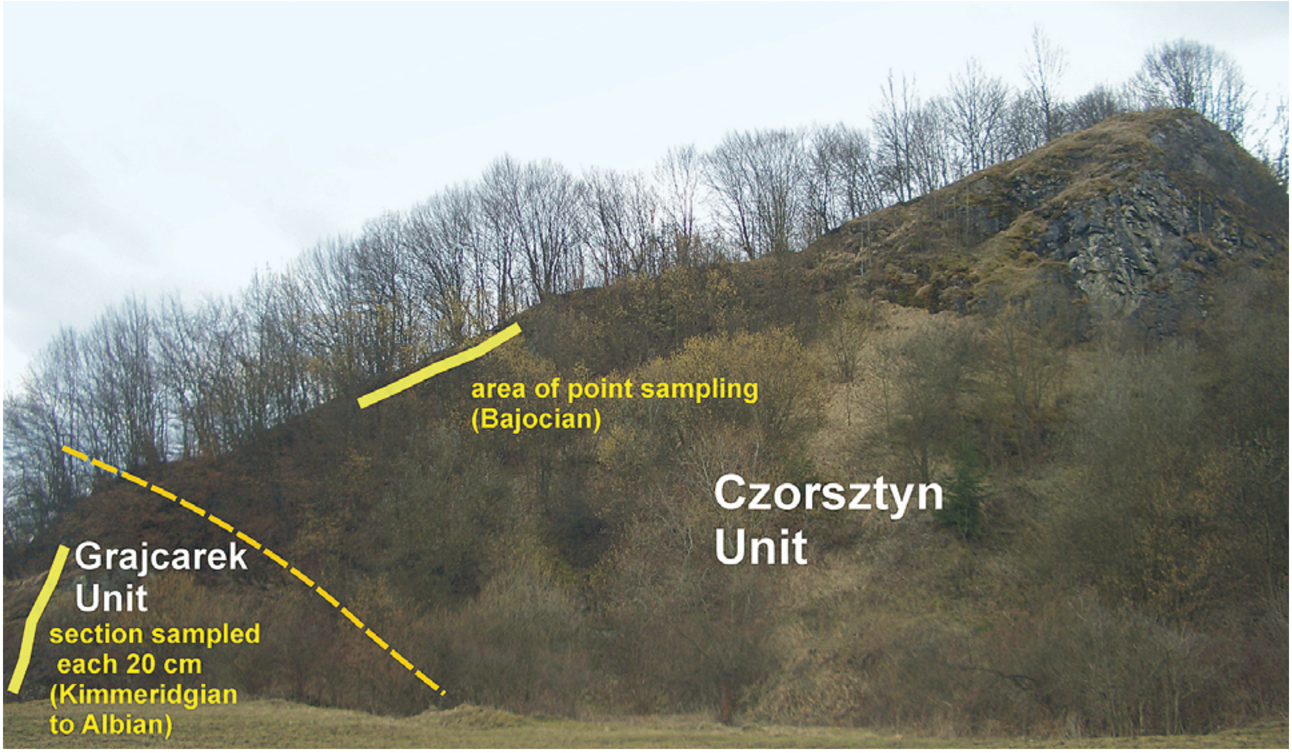

Fig. 2. View on the examined klippe from the NE, with marked sampled parts and tectonic interpretation.

of these formations belong to the Czorsztyn Unit of the Pieniny Klippen Belt (Krobicki & Wierzbowski, 2004).

After several meters of covered sequence, the lowermost part on the eastern edge of the hill consists of beds of Kimmeridgian to Albian in age (Fig. 4). The succession starts with red nodular to pseudonodular limestone (Czorsztyn Limestone Formation), passing to greenish-grey nodular limestone (named as Revišné Limestone – Aubrecht, 1994; Mišík et al., 1996) with overall thickness of 1.2 m and these gradually pass to white micritic limestone of Biancone facies (Pieniny Limestone Formation, 2.9 m) which becomes spotty after the first 0.7 m. Stratigraphically higher, this thin-bedded formation with uneven bedding planes becomes more marly and passes to grey spotted marlstones (Kapuśnica and Wronine formations, visible thickness of 1.4 m).

3. MATERIAL AND METHODS

Due to the sedimentary cover, upper part of the klippe was sampled only by point sampling, whereas the rest of the section was sampled with the step of approx. 20 cm (Figs. 2, 4). Six thin-sections from the Krasín breccia and 25 thin-sections from other formations were studied and photodocumented using the polarizing microscope. 11 samples from the marly intercalations of the upper part of the Pieniny Formation and from the marlstones of the Kapuśnica and the Wronine formations were evaluated for calcareous nannofossils. All rock samples, thin-sections and calcareous nannoplankton samples are stored at the Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University in Bratislava.

4. RESULTS

Crinoidal limestones (Smolegowa and Krupianka limestone formations) and Krasín Breccia

Crinoidal limestones of the Smolegowa and Krupianka limestone formations, differ mainly in the red mud content which is responsible for their colour (white or grey vs. pink or red). Therefore, the Smolegowa Formation is represented mostly by crinoidal biosparites (grainstone sensu Dunham, 1962) and the Krupianka Formation consists of biomicritic limestones (packstones to wackestones). Beside the crinoidal ossicles (Fig. 5A), echinoid spines, fragments of brachiopods and bivalves (Fig. 5B) and foraminifers *Lenticulina* sp. are common. More seldom are sessile nubecularid foraminifers and bryozoans. The crinoidal limestones of both formations contain quite rich clastic admixture, dominated by quartz sand grains, less by dolomite grains. Quartz is commonly polycrystalline, with undulatory extinguishing. The quartz grains are often corroded and broken (Fig. 5C). Feldspar grains are less common. They are mostly sericitized K-feldspars; microcline grains were observed, too. Authigenic glauconite is quite common, mostly filling pores, locally also small borings inside the allochems (Fig. 5D), or just rimming detritic quartz grains. Detritic admixture locally strongly prevails and the rock turns to laminated siltstone. Heavy minerals, dominated by zircon are concentrated in some laminae.

Crinoidal limestone clasts in the Krasín Breccia are commonly separated from the interstitial sedimentary filling by blocky calcite, with relatively clear crystals, but often strongly twinned. Locally it passes to fibrous calcite. At the contact with void filling, stromatolitic laminae with trapped allochems are locally developed (Fig. 5E).

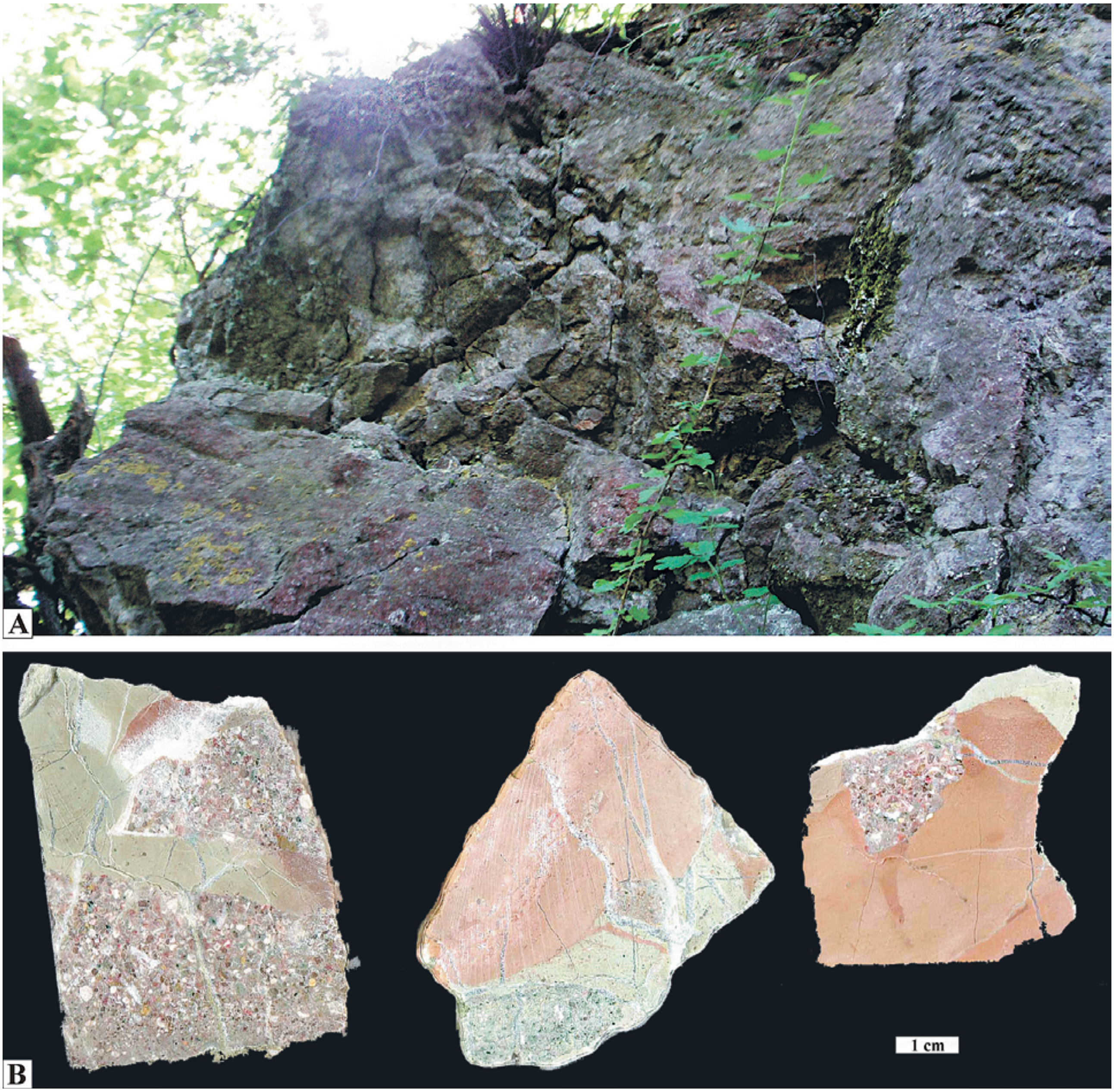

Fig. 3. A – Field view on the Krasín Breccia. Hammer head as a scale. B – Slabs of the Krasín Breccia showing clasts of crinoidal limestones and various phases of micritic interstitial filling with different colours.

The sedimentary filling of the interstitial voids of the breccia consists almost exclusively of nearly sterile reddish mudstone, with dispersed rare allochems, like small echinoderm particles (including ophiurid ossicles and echinoid spines), fragments of brachiopod and bivalve shells (including rare "filaments", i.e. *Bositra* shells), *Lenticulina* sp., nodosariid foraminifers, gastropods, sponge spicules, and quartz grains. Ostracods are mostly thin- and smooth-shelled, but locally ornamented shells of the cave dwellers *Pokornyopsis* (Fig. 5F) were also found. Phosphatic grains, like fish bones and scales are locally present. At some places, the allochems are arranged more densely, forming laminae of wackestones to packstones.

The allochem content of the void filling is similar to that of the crinoidal limestone wall-rock, which indicates that the deposition of the Krasín Breccia took place still before the main deepening phase and turn to the "filament" microfacies that occurred since Late Bajocian, although some rare *Bositra* shells were already present in the filling.

Red and greenish-grey nodular limestones (Czorsztyn and Revišné limestone formations)

The stratigraphically oldest formation in the lower part of the klippe is red to green biodetritic limestone with *Saccocoma*-spiculitic and spiculitic microfacies (samples x20-x17, Figs. 4, 6). Echinoderm particles, including *Saccocoma* ossicles (Fig. 7A), ostracods, globochaets, aptychi, radiolarians, foraminifers, bivalves with microborings and rare gastropods were documented in thin-sections. Calcareous dinoflagellate cysts are represented

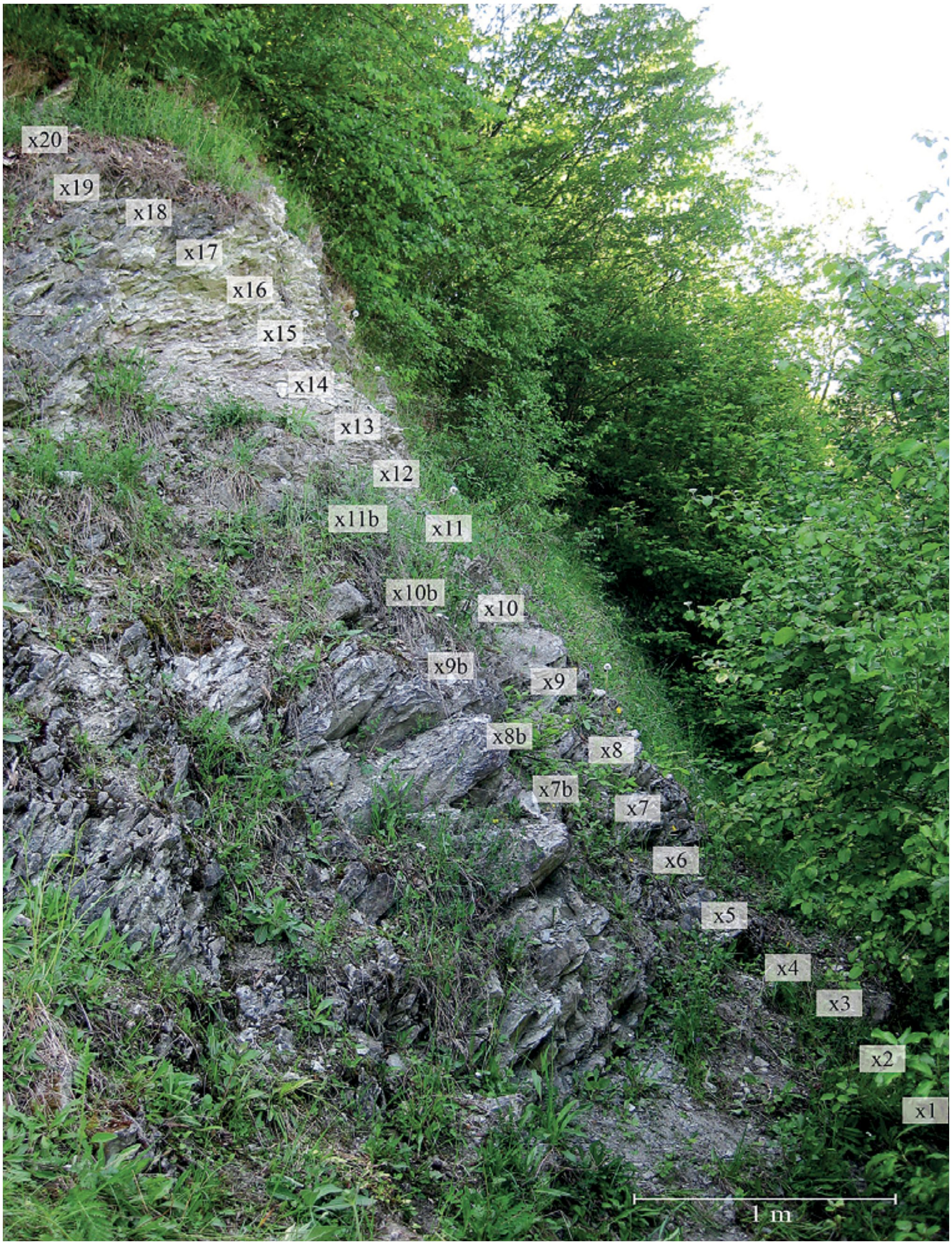

Fig. 4. Lower part of the klippe (Kimmeridgian to Albian) with sampling points.

by *Schizosphaerella minutissima* (Colom) (Fig. 7B), *Cadosina semiradiata semiradiata* (Wanner) (Fig. 7C), *Cadosina semiradiata fusca* (Wanner) (Fig. 7D), *Colomisphaera pulla* (Borza) and *Carpistomiosphaera tithonica* Nowak, which point to the Kimmeridgian - Early Tithonian age. The microfossils are often replaced by pyrite (Fig. 7E) and silicified.

Marly, pale calpionellid and nannoconid limestone (Pieniny Limestone Formation).

The succession continues with light grey limestones with *Saccocoma*-radiolarian microfacies with numerous radiolarians, *Saccocoma*, aptychi, bivalves, juvenile ammonites, echinoderm particles, *Globochaete alpina*, *Lenticulina* sp. (Fig. 7F), agglutinated foraminifers and sponge spicules (sample x16). Calcareous dinoflagellate cysts *Schizosphaerella minutissima* (Colom), *Colomisphaera nagyi* (Borza), *Colomisphaera pieniniensis* (Borza), *Cadosina semiradiata semiradiata* (Wanner) and few poorly preserved calpionellids *Chitinoidella boneti* Doben (Fig. 7G) and *Praetintinopsella andrusovi* Borza are present, indicating the Late Tithonian Andrusovi Subzone of the Praetintinopsella Zone. Layers of grey mudstones with calpionellid microfacies continue onwards (samples x15 – x12). In the microfacies of sample x14, there are abundant radiolarians, ostracods, echinoderm particles, thin-shelled bivalves, perforated foraminifers, *Saccocoma*, *Leavaptychus* and sponge spicules. Limestones are disrupted by numerous calcite veins and contain quartz grains. Calpionellids are represented by *Tintinnopsella carpathica* (Murgeanu & Filipescu), *Crassicollaria parvula* Remane (Fig. 7H), *Crassicollaria*

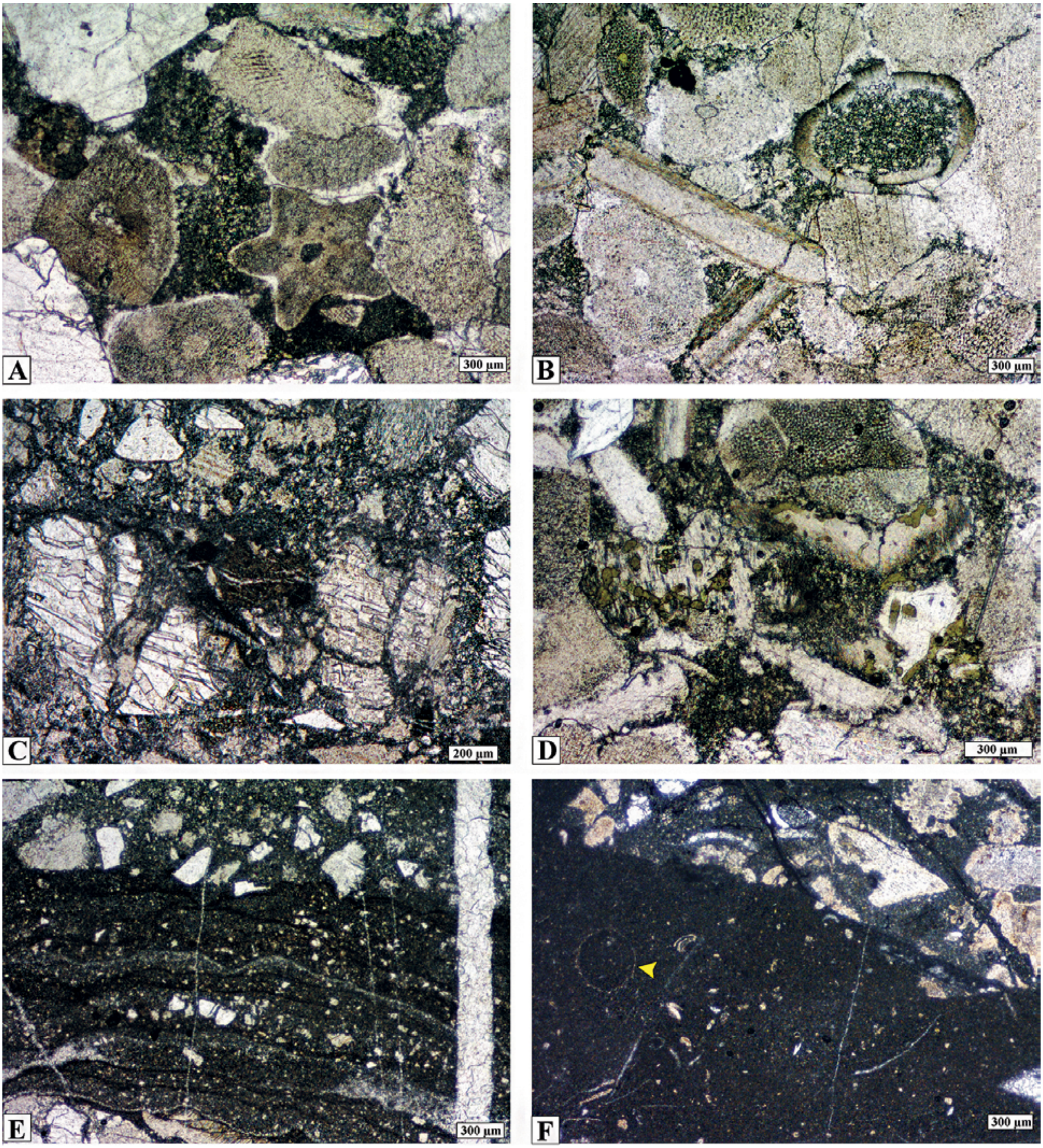

Fig. 5. **Microfacies of the crinoidal limestones and Krasín Breccia. A – Crinoidal packstone showing crinoidal ossicles and quartz sand grains. The ossicles are overgrown by initial syntaxial calcite rims; rest of the pores is filled with micrite. B – Crinoidal packstone showing strong compaction and pressure dissolution. Along with crinoidal ossicles, fragments of brachiopod shells and broken serpulid tube are present. C – Strongly broken quartz sand grains in the crinoidal limestone. The cracks are filled with newly formed calcite. D – Authigenic glauconite (green) filling borings in calcitic allochems in the crinoidal limestone. E – Stromatolitic laminae with trapped sand and silt grains, separating a crinoidal limestone clast in the Krasín Breccia from interstitial micrite filling. F – Contact of the crinoidal packstone clast with mudstone interstitial filling of the Krasín Breccia. The filling is poor in allochems; only cross-sections of thin *Bositra* shells and a tangential cross-section of the cave-dwelling ostracod *Pokornyopsis* sp. (yellow arrow) are visible.**

massutiniana (Colom) (Fig. 7I), *Tintinnopsella remanei* Borza, *Tintinnopsella doliphormis* (Colom) and *Crassicollaria intermedia* (Durand Delga) (Fig. 7J) which indicate the Remanei Subzone of the Crassicollaria Zone (Late Tithonian). Calcareous dinoflagellates include *Stomiosphaera proxima* and *Colomisphaera lapidosa*. Light-grey/greenish calpionellid mudstone (sample x14) contains abundant calpionellids *Calpionellopsis oblonga* (Cadisch) (Fig. 7K), *Tintinnopsella carpathica* (Murgeanu

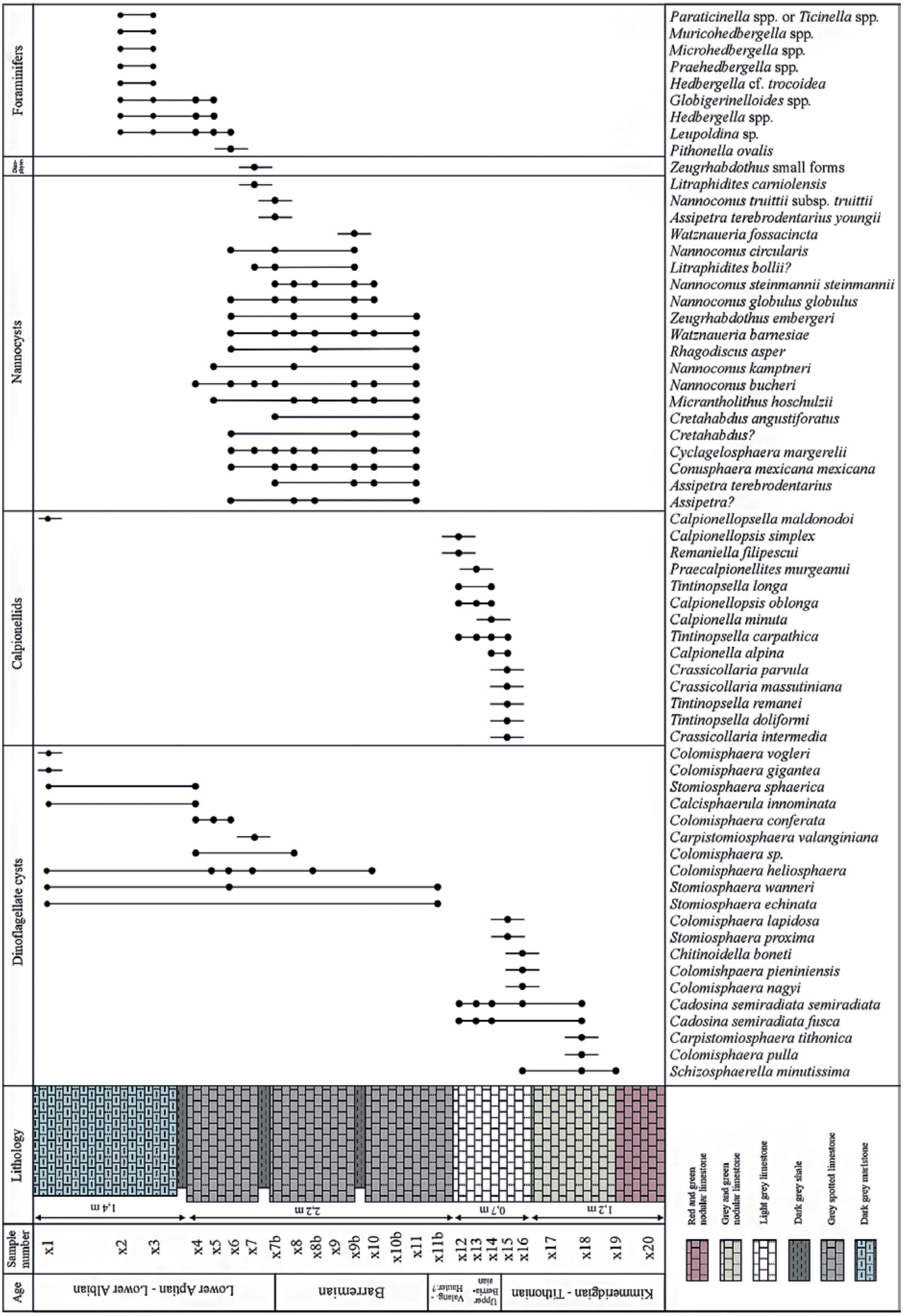

Fig. 6. Ranges of stratigraphically important micro- and nannofossils in the succession of the lower part of the klippe.

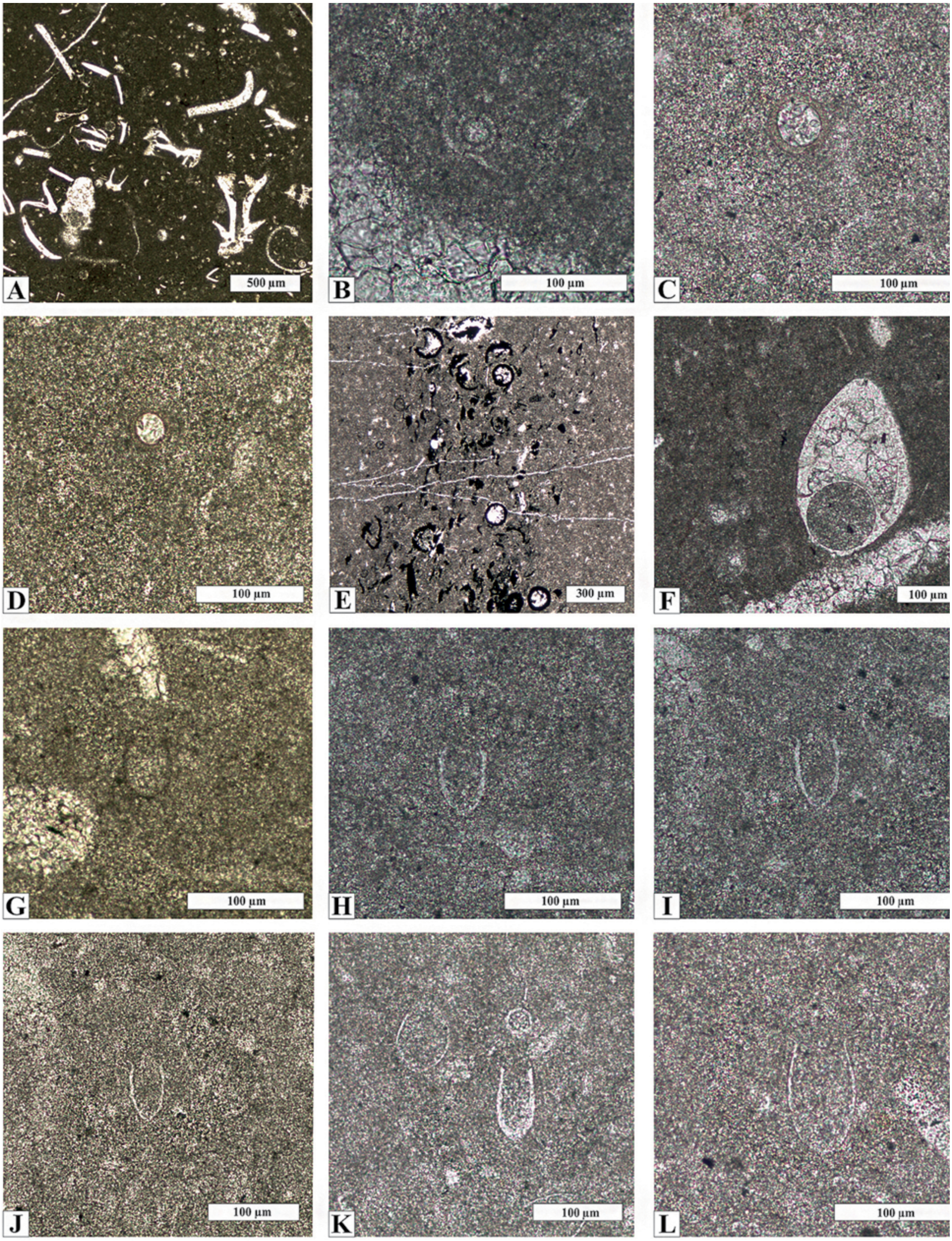

Fig. 7. Microfossils of the Czorsztyn, Revišné and Pieniny formations. A – *Saccocoma* **microfacies in the Revišné Limestone (sample x19). B –** *Schizosphaerella minutissima* (Colom) (x16). **C –** *Cadosina semiradiata semiradiata* (Wanner) (x18). **D –** *Cadosina semiradiata fusca* (Wanner) (x18). **E – Pyrite replacing fossils in the Revišné Limestone (x11b). F –** *Lenticulina* **sp. (x6) G –** *Chitinoidella boneti* Doben (x16). **H –** *Crassicollaria parvula* Remane (x15). **I –** *Crassicollaria massutiniana* (Colom) (x15). **J –** *Crassicollaria intermedia* (Durand Delga) (x15). **K –** *Calpionellopsis oblonga* (Cadisch) (x12). **L –** *Tintinopsella carpathica* (Murgeanu & Filipescu) (x12).

& FILIPESCU) (Fig. 7L), *Tintinopsella longa* (COLOM) (Fig. 8A), *Calpionella alpina* LORENZ and *Calpionella minuta* HOUŠA, which are accompanied by small ostracods, sporadic filaments, echinoderm particles, small foraminifers (*Spirillina* sp. and *Patellina* sp.), sponge spicules and cysts *Cadosina semiradiata semiradiata* (WANNER) and *Cadosina semiradiata fusca* (WANNER). Calpionellids indicate the Oblonga Subzone of the Calpionellopsis Zone (latest Berriasian). Sample x12 contains numerous calcareous dinoflagellate cysts and calpionellids, scattered radiolarians, foraminifers and filaments. Calcareous dinoflagellates *Cadosina semiradiata semiradiata* (WANNER), *Cadosina semiradiata fusca* (WANNER) and calpionellids *Tintinopsella longa* (COLOM), *Calpionellopsis oblonga* (CADISCH), *Tintinnopsella carpathica* (MURGEANU & FILIPESCU), *Remaniella filipescui* POP (Fig. 8B), *Calpionellopsis simplex* (COLOM) and possible *Praecalpionellites murgeanui* POP (Fig. 8C) indicate the Murgeanui Subzone of the Praecalpionellites Zone. The succession then passes to radiolarian microfacies, free of calpionellids, containing calcareous dinoflagellates *Stomiosphaera echinata* NOWAK (Fig. 8D) and *Stomiosphaera wanneri* BORZA (sample x11b, Fig. 8E) indicating the dinoflagellate Echinata Zone of the Late Valanginian. Stratigraphically higher layers of light grey spotted limestones are almost sterile in determinable calcareous dinoflagellate cysts (samples x11-x7b). The only determinable species is *Colomisphaera heliosphaera* (VOGLER) (FIG. 8F). Limestones contain sporadic radiolarians, filaments, sponge spicules, foraminifers (*Involutina* sp., *Lenticulina* sp., silicified *Spirillina* sp.), aptychi and echinoderm particles (occasionally replaced by chalcedony). Sparsely occurs framboidal pyrite creating nests and replacing fossils, along with rare glauconite grains. The sample x11 is the first from the section studied for calcareous nannoplankton in which the following species were registered: *Assipetra terebrodentarius* (APPLEGATE et al. in COVINGTON & WISE) RUTLEDGE & BERGEN (Fig. 9N), *Conusphaera mexicana mexicana* BOWN & COOPER, *Cyclagelosphaera margerelii* NOËL (Fig. 9C), *Micrantolithus hoschulzii* (REINHARDT) THIERSTEIN (Fig. 9P), *Nannoconus bucheri* BRÖNNIMANN (Fig. 9H-I), *Nannoconus steinmannii steinmannii* KAMPTNER (Fig. 9E), *Rhagodiscus asper* (STRADNER) REINHARDT, *Watznaueria barnesiae* (BLACK) PERCH-NIELSEN (Fig. 9B) and *Zeugrhabdothus embergeri* (NOËL) PERCH-NIELSEN. After a barren sample x10b, *Nannoconus* species - *N. bucheri* BRÖNNIMANN, *N. kamptneri kamptneri* BRÖNNIMANN (Fig. 9F), *N. globulus globulus* BRÖNNIMANN (Fig. 9J) and *N. steinmannii steinmannii* occurred, together with *Conusphaera mexicana mexicana* BOWN & COOPER, *Cyclagelosphaera margerelii* NOËL, *Retecapsa angustiforata* BLACK (Fig. 9D), *Micrantolithus hoschulzii* REINHARDT) THIERSTEIN and *Watznaueria barnesiae* (BLACK) PERCH-NIELSEN. Grey spotted limestones continue, and are rich in the previously mentioned species, especially *Micrantolithus hoschulzii* (REINHARDT) THIERSTEIN and *Nannoconus steinmannii steinmannii* KAMPTNER. Further (samples x9b – x8), an onset of *Nannoconus circularis* DERES & ACHÉRITÉQUY (Fig. 9G) and rare specimens of *Lithraphidites bolli?* (THIERSTEIN) THIERSTEIN and *Watznaueria fossacincta* BLACK were observed. In sample x7b FAD (first appearance datum) of *Assipetra terebrodentarius youngii* TREMOLADA & ERBA (Fig. 9O), *Nannoconus truittii truittii* BRÖNNIMANN (Fig. 9K) and dominance of wide-canal nannoconids over narrow-canal forms were recorded, indicating the uppermost Barremian or Barremian/Aptian boundary interval respectively (Tremolada et al., 2006). In further strata (sample x7), the grey spotted limestone is still very poor in microfossils, but presence of cyst *Carpistomiosphaera valanginiana* BORZA (FIG. 8G), nannofossil species *Litraphidites carniolensis* DEFLANDRE and small forms of *Zeugrhabdothus* sp. were documented. The section (sample x6) continues with spiculitic mudstone with dark fine-grained matrix with glauconite grains and sporadic "filaments", foraminifera phantoms (*Lenticulina sp.*) and fragments of small aptychi. Some microfossils were replaced by pyrite. The identified microfossils include *Pithonella ovalis* (KAUFMAN) (Fig. 8H), calcareous dinoflagellates *Colomisphaera heliosphaera* (VOGLER), *Colomisphaera conferata* ŘEHÁNEK (FIG. 8I), *Stomiosphaera wanneri* BORZA and calcareous nannofossils *Conusphaera mexicana mexicana* BOWN & COOPER (Fig. 9M), *Cyclagelosphaera margerelii* NOËL, *Watznaueria manivitiae* BUKRY (Fig. 9A), *Nannoconus bucheri* BRÖNNIMANN, *N. circularis* DERES & ACHÉRITÉQUY, *N. globulus globulus* BRÖNNIMANN, *N. kamptneri kamptneri* BRÖNNIMANN, *N.* sp. wide canal form (Fig. 9L), *Rhagodiscus asper* (STRADNER) REINHARDT, *Watznaueria barnesiae* (BLACK) PERCH-NIELSEN and *Zeugrhabdothus embergeri* (NOËL) PERCH-NIELSEN. The following layers are represented by radiolarian-spiculitic mudstone (samples x5 - x4). They contain numerous filaments and radiolarians, many of which are replaced by pyrite, abundant foraminifers (*Lenticulina* sp.), sponge spicules and few cysts *Stomiosphaera sphaerica* (KAUFMAN) (Fig. 8J), *Colomisphaera* sp., *Calcisphaerula innominata* BONET (Fig. 8J) and *Colomisphaera conferata* ŘEHÁNEK. These layers were also the last ones analysed for calcareous nannoplankton, with *Micrantolithus hoschulzii* (REINHARDT), *Nannoconus bucheri* BRÖNNIMANN and *Nannoconus kamptneri* BRÖNNIMANN. Scarce impoverished planktonic foraminifera are represented by smaller few-chambered representatives of *Hedbergella* spp., *Globigerinelloides* spp. and *Leupoldina* sp. (Fig. 10A).

Grey spotted marlstones (Kapuśnica and Wronine formations)

The section continues with marlstone beds (samples x3 - x2) with planktonic foraminiferal microfacies, with scattered radiolarians, bivalves, rare echinoderm plates and ostracods. The rock also contains glauconite, quartz grains and microfossils replaced by pyrite. The microfacies is packed with planktonic foraminifera with scarce fragments of larger benthic foraminifera. The planktonic assemblage contains exclusively globular-chambered foraminifera, with abundant few-chambered smaller trochospiral planktonic foraminifera similar to *Praehedbergella* spp., *Hedbergella* spp., *Microhedbergella* spp. or *Muricohedbergella* spp. and common larger many-chambered trochospiral types similar to *Hedbergella* cf. *trocoidea* (GANDOLFI) and *Paraticinella* spp. or *Ticinella* spp. (Fig. 10B). The last outcropping and sampled bed of the section (sample x1) is a radiolarian mudstone. It locally contains micro-cavities filled with quartz. Pyrite is abundant. The assemblage of calcareous dinoflagellate cysts contains large specimens of *Calcisphaerula*, *Calcisphaerula innominata* BONET, *Stomiosphaera echinata* NOWAK, *Stomiosphaera sphaerica* (KAUFMAN), *Stomiosphaera wanneri* BORZA, *Colomisphaera heliosphaera*

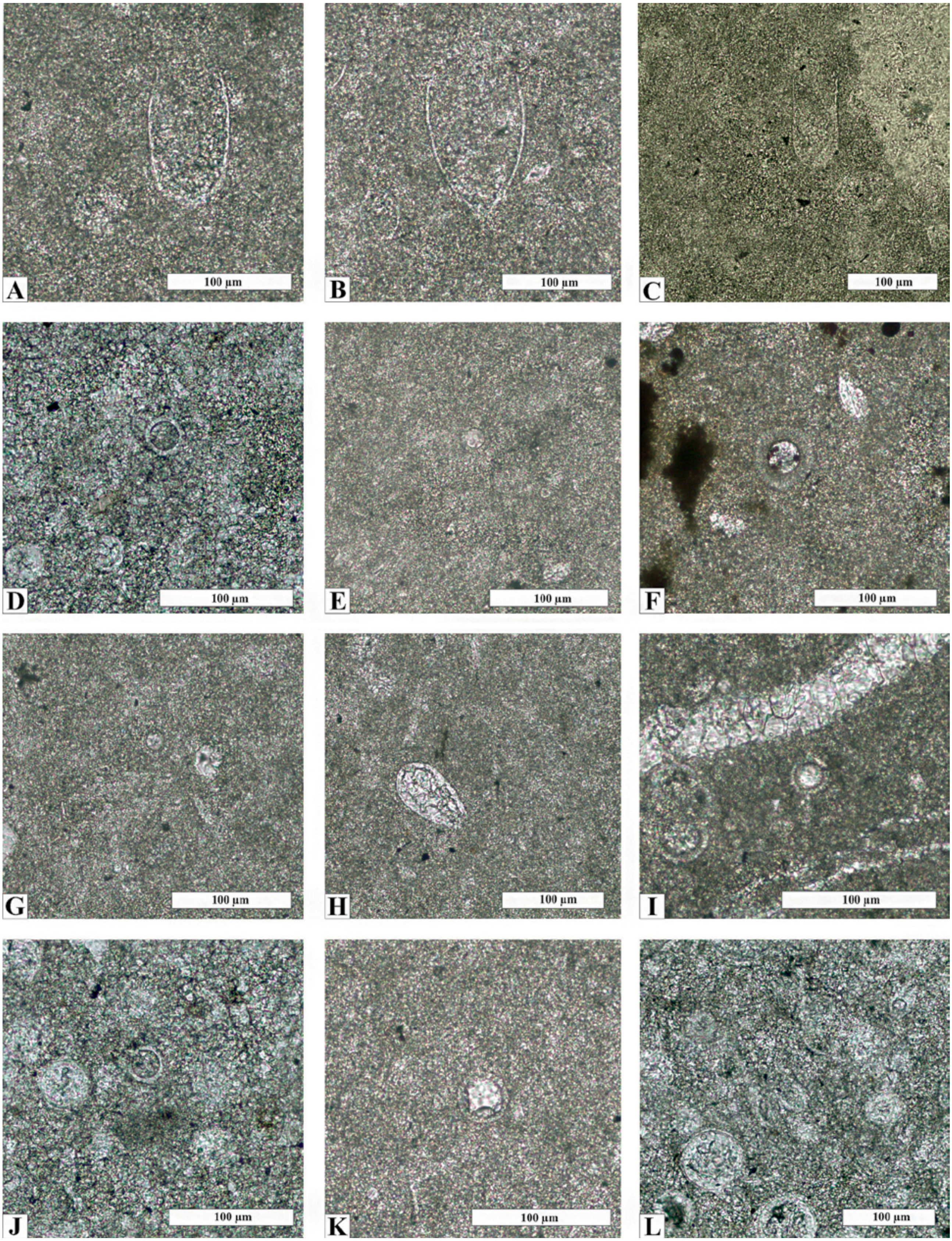

Fig. 8. Microfossils of the Pieniny, Kapuśnica and Wronine formations. A - *Tintinopsella longa* (Colom) (sample x12). **B** – *Remaniella filipescui* Pop (x12). **C** – *Praecalpionellites murgeanui* Pop (x12). **D** – *Stomiosphaera echinata* Nowak (x1). **E** – *Stomiosphaera wanneri* Borza (x11b). **F** - *Colomisphaera heliosphaera* (Vogler) (x7). **G** – *Carpistomiosphaera valanginiana* Borza (x7). **H** – *Pithonella ovalis* (Kaufman) (x6). **I** – *Colomisphaera conferata* Řehánek (x4). **J** – *Stomiosphaera sphaerica* (Kaufman) and *Calcisphaerula innominata* Bonet (x1). **K** – *Colomisphaera vogleri* (Borza) (x9b). **L** – *Calpionellopsella maldonodoi* Trejo (x1).

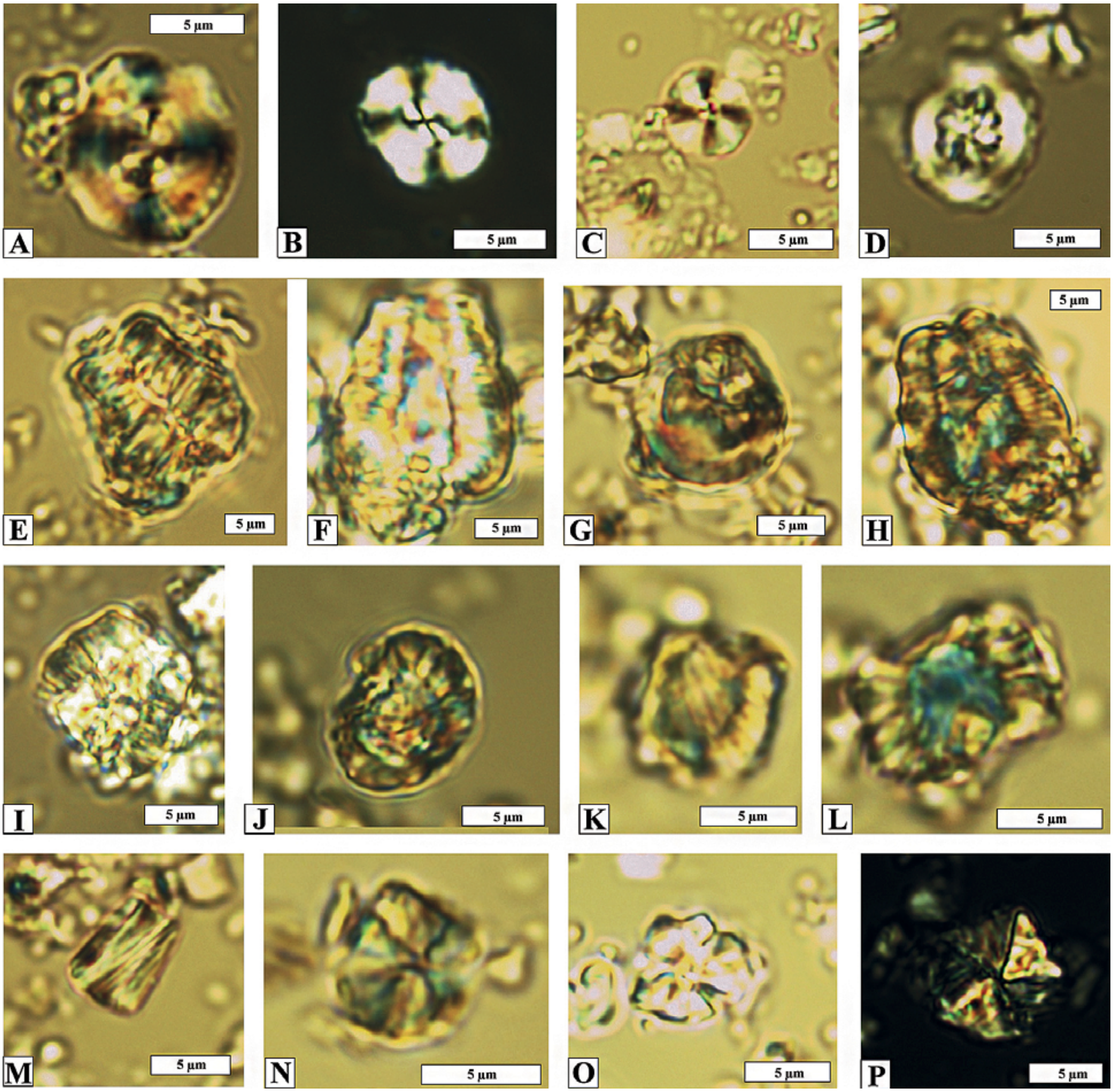

Fig. 9. Calcareous nannofossils from the Pieniny Limestone Formation. A – *Watznaueria manivitiae* Bukry. **B** – *Watznaueria barnesiae* (Black) Perch-Nielsen. **C** – *Cyclagelosphaera margerelii* Noël. **D** – *Retecapsa angustiforata* Black. **E** – *Nannoconus steinmannii steinmannii* Kamptner. **F** – *Nannoconus kamptneri kamptneri* Brönnimann. **G** – *Nannoconus circularis* Deres & Achéritéquy. **H-I** – *Nannoconus bucheri* Brönnimann. **J** – *Nannoconus globulus globulus* Brönnimann. **K** – *Nannoconus truittii truittii* Brönnimann. **L** – *Nannoconus* sp., wide canal form. **M** – *Conusphaera mexicana mexicana* Bown & Cooper. **N** – *Assipetra terebrodentarius* (Applegate et al. in Covington & Wise) Rutledge & Bergen. **O** – *Assipetra terebrodentarius youngii* Tremolada & Erba. **P** – *Micrantolithus hoschulzii* (Reinhardt) Thierstein.

(Vogler), *Colomisphaera gigantea* (Borza), *Colomisphaera vogleri* (Borza) (Fig. 8K) and calpionellid *Calpionellopsella maldonodoi* Trejo. (Fig. 8L). This assemblage indicates Albian age.

5. DISCUSSION

Stratigraphy

Analysis of the Revišné section showed that the upper and middle parts of the klippe consist of crinoidal limestones and Krasín Breccia, which are typical for the Czorsztyn Unit, but the lowermost eastern part of the klippe displays continuous stratigraphic succession from the Kimmeridgian to Albian.

By analogy, the crinoidal limestones (Smolegowa and Krupianka limestone formations) can be dated to Bajocian (Krobicki & Wierzbowski, 2004). Filling of the interstitial spaces of the Krasín Breccia is red mudstone; therefore, we suppose it originated later, since the uppermost Bajocian onward, during the relative sea-level rise and the change of the crinoidal facies to the Ammonitico Rosso facies (Rakús, 1990; Wierzbowski et al., 1999; Schlögl et al., 2005). Occurrences of the Czorsztyn Unit in the

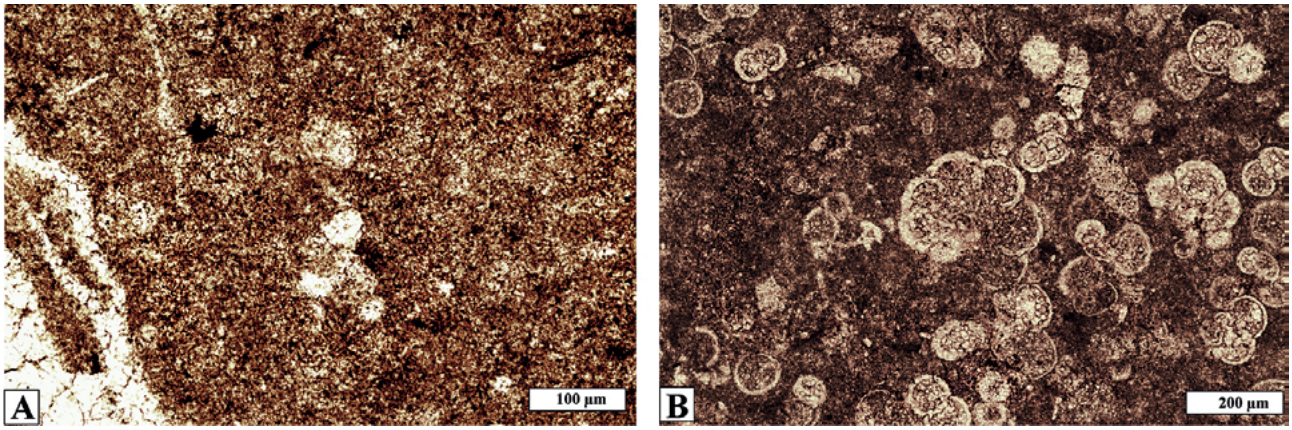

Fig. 10. Foraminifers from the Pieniny Limestone Formation (A), Kapuśnica and Wronine formations (B). A –*Leupoldina* sp. (Barremian-Lower Aptian). B – Microfacies with abundant globular chambered planktonic foraminifera, with larger many chambered representatives similar to *Hedbergella* cf. *trocoidea* (Gandolfi), *Paraticinella* spp. or *Ticinella* spp. (Upper Aptian-Lower Albian).

Orava territory are rare and this is its first record including the crinoidal limestones with neptunian dykes and Krasín Breccia.

Lowermost part of the hill represents a different klippen succession. This section seems to be continuous, however we were not able to document several late Early Tithonian, latest Tithonian - Upper Berriasian calpionellid zones or subzones, and also some Valanginian calpionellid zones. This can be caused by a condensed nature of the section, which appears to be primary, i.e. of sedimentary origin, rather than tectonic, and the 20 cm sampling step is apparently too large to control the completeness of the calpionellid record here. On the other hand the key part of the Barremian-Aptian sediments seems to be better preserved, documented by calcareous nannoplankton and by foraminifers. The stratigraphy is based mainly on calcareous nannoplankton, because the foraminifers were analysed in thin-sections and their determination is thus only approximative.

In the samples x11b to x4, the observed microfauna is impoverished and exhibits poor to moderate preservation (except for the sample x7b). The low number of specimens may be caused by selective dissolution, because calcareous nannofossil assemblages mainly contain dissolution-resistant cosmopolitan and Tethyan genera *Watznaueria* sp., *Nannoconus* sp., *Conusphaera* sp., *Micrantholithus* sp., *Lithraphidites* sp., *Rhagodiscus* sp., *Assipetra* sp. and *Zeugrhabdotus* spp. Even though the determined taxa of calcareous nannofossils can be present also in Hauterivian sediments, Hauterivian index taxa (e.g. *Cruciellipsis cuvillieri, Speetonia colligate, Calcicalathina oblongata*) are missing, except for *Lithraphidites bollii*. However, it is present just as a single specimen in various samples, which could be also an evidence of redeposition. This fact leads us to an interpretation that the part of the section from sample x11b to x8 is Barremian in age. The part of the section with samples x7, x6, x5 and x4 is already of earliest Aptian age.

Nannoconus steinmannii steinmannii, as a representative of narrow-canal nannoconids, was documented from sample x11 up to sample x7b. Starting from sample x7b, dominance of wide-canal nannoconids (*N. bucheri, N. circularis, N. globulus globulus, N. truittii truittii*) over narrow-canal forms was identified. The nannoconid event of outnumbering the wide-canal forms over the narrow-canal forms in Tethyan and Pacific oceans was suggested as an event marking the uppermost Barremian and Barremian/Aptian boundary interval within magnetic chron M0 (Erba et al., 1999; Larson & Erba, 1999; Premoli Silva et al., 1999; Tremolada et al., 2006). FAD of *Assipetra terebrodentarius youngii* (observed only in the sample x7b) corresponds also with the magnetic chron M0 and Barremian/Aptian boundary interval (Tremolada & Erba, 2002).

The thin-sections from samples x5 and x4 contain common smaller few-chambered species of trochospiral and planispiral representatives of globular-chambered planktonic foraminifera (*Hedbergella* spp. and *Globigerinelloides* spp.). The first occurrence of these taxa is reported from the uppermost Valanginian (Verga & Premoli Silva, 2003b; Premoli Silva & Verga, 2004; Coccioni et al., 2007). These few globular-chambered taxa are becoming frequent after the Faraoni event in the Upper Hauterivian (Coccioni et al., 1998). Their exact appearance in the West-Carpathian basins remains yet unresolved. A single occurrence of *Leupoldina* sp. was also noted below the previous samples (sample x6). The first occurrence of leupoldinids according to Verga & Premoli Silva (2002) occurred during the Late Barremian. This datum correlates well with the event of occurrence of wide-canal nannoconids.

The stratigraphically overlying strata (samples x3 – x2) yielded abundant *Praehedbergella* spp., *Hedbergella* spp., *Microhedbergella* spp. or *Muricohedbergella* spp., *Hedbergella* cf. *trocoidea* and *Paraticinella* spp. or *Ticinella* spp. Such an assemblage excludes the Late Aptian foraminiferal zones preceding the last occurrence of *Globigerinelloides algerianus* (Cushman & TenDam) with the presence of common large many-chambered representatives of the genus *Globigerinelloides* (Verga & Premoli Silva, 2003a; Moullade et al., 2005; Józsa & Aubrecht, 2008; Józsa et al., 2016). Thus, the part of the section represented by samples x3 to x2 probably belong to the Late Aptian H. trocoidea - P. bejaouaensis zones and the Early Albian T. primula Zone, or possibly to the Middle Albian (B. breggiensis Zone) preceding the first occurrence of the single keeled *Pseudothalmaninella subticinensis* (Gandolfi) (Caron, 1985; Premoli Silva & Verga, 2004; Lukeneder et al., 2016). Similar deposits with abundant planktonic foraminifera packed in reddish matrix and frequent echinoderm detritus are reported from the Orava sector of the Pieniny Klippen Belt near Krivá above the planktonic foraminiferal packstones of the G. algerianus Zone (Józsa & Aubrecht, 2008).

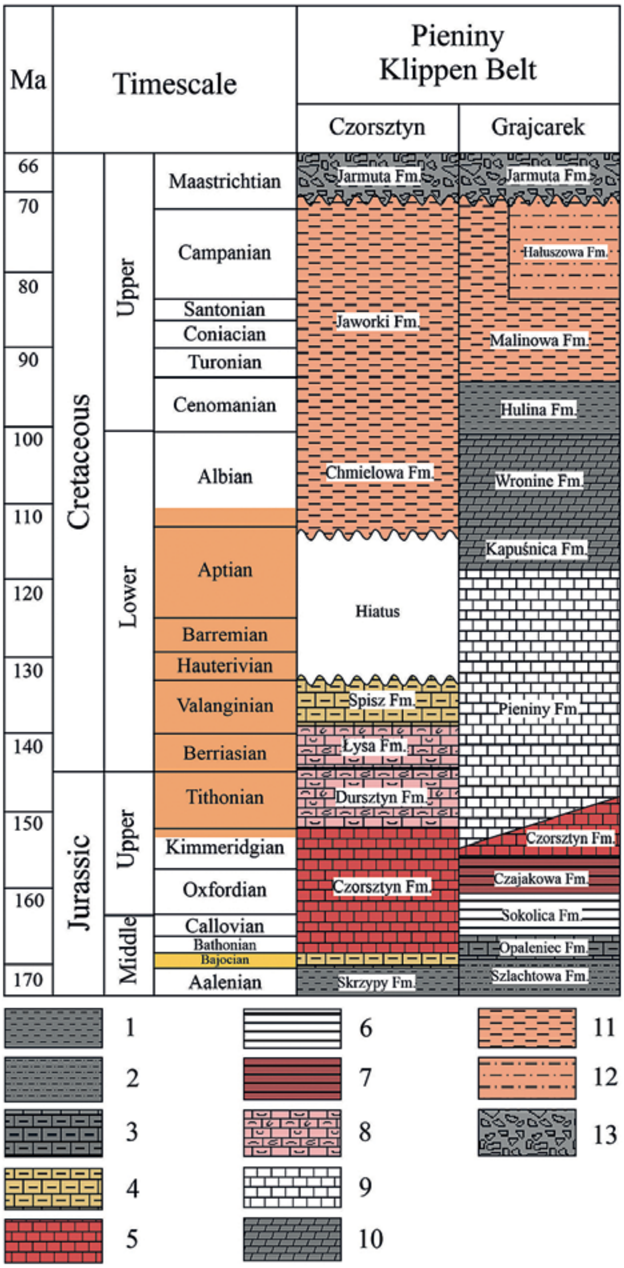

Fig. 11. Comparison of lithostratigraphy of the Czorsztyn and Grajcarek units (Grajcarek Unit after Birkenmajer & Gedl, 2017). 1 – blacks shales, 2 – black flysch, 3 – spotted limestone, 4 – crinoidal limestone, 5 – red nodular limestone (Ammonitico Rosso facies), 6 – greyish to greenish radiolarite, 7 – red radiolarite, 8 – red micritic and bioclastic limestone, 9 – white, marly calpionellid and nannoconid limestone (Maiolica/Biancone facies), 10 – dark, partly spotted marlstone, 11 – variegated *Globotruncana* marlstones (Couches Rouges facies), 12 – variegated marlstones with turbiditic intercalations, 13 – post-tectonic transgressive clastics. Yellow rectangle – stratigraphic range of the Czorsztyn elements in the examined klippe. Orange rectangle – stratigraphic range of the Grajcarek elements in the examined klippe.

In the highest sampled layer (x1) the calcareous dinoflagellate cyst *Calcisphaerula innominata* Bonet was noted together with larger forms of *Colomisphaera vogleri* (Borza). The *Calcisphaerula innominata* Bonet is reported in the Late Albian (Reháková, 2000; Bąk et al., 2016) although it might appear earlier, already in the Early Albian (Borza, 1969). Associated planktonic foraminifera however do not show the presence of any representatives of the Late Albian single-keeled taxa such as *Pseudothalmaninnella* spp. or *Parathalmaninnella* spp. The planktonic foraminifers are composed of common small trochospiral specimens. Similar assemblage is reported after the Aptian/Albian boundary biotic turnover which is marked with the extinction of *Hedbergella* spp., *Globigerinelloides* spp. and *Paraticinella* spp. The persisting successors in the earliest Albian are composed of small *Microhedbergella* spp. (Huber & Leckie, 2011; Petrizzo et al., 2012; Lukeneder et al., 2016).

Interpretation of the klippe structure

The key part of the section which would expose Callovian-Oxfordian strata is covered at the examined locality. However, it is obvious that the lower part of the section displays succession which is by no means typical of the Czorsztyn Unit. Hauterivian to Albian sediments are preserved, whereas in the Czorsztyn Unit they are usually entirely missing due to emersion and karstification (Birkenmajer, 1958; Andrusov et al., 1959; Aubrecht et al., 2006). Moreover, the character of the Tithonian-Lower Cretaceous limestones is different from those which are typical of the Czorsztyn Unit. They are marly, thin-bedded and belong rather to the Pieniny Limestone Formation than to more massive and more organodetritic Sobótka Limestone Formation (Birkenmajer, 1977). Despite of incompleteness, the marly character and the condensed succession indicate that the lower part of the section may belong to the Grajcarek Unit (Šariš Unit sensu Plašienka & Mikuš, 2010), which is considered to be the externmost of all the Oravic units, depositional area of which was originally situated north of the emerged Czorsztyn Swell, i.e. north of the Czorsztyn Unit (Birkenmajer, 1977; Birkenmajer & Gedl, 2017). Correlation of lithostratigraphy of both units is presented on Fig. 11. The whole section then represents a contact of two klippen units which can be interpreted as tectonic, i.e. overthrust (Fig. 2). Sedimentary contact is very unlikely. Admitting a theoretical possibility of falling blocks of crinoidal limestones from the Czorsztyn Ridge to the neighboring Grajcarek sedimentation area on the north, the first phase of interstitial filling would be represented by grey spotted carbonate muds (equivalent to the Podzamcze Limestone Formation) and the second one by radiolarite (equivalent to the Sokolica and Czajakowa radiolarite formations). Instead, the filling is represented by red micritic limestone, with filamentous microfacies and cave dwelling fauna of ostracods typical of the Czorsztyn Unit (Aubrecht, 1997; Aubrecht & Szulc, 2006).

Considering tectonic contact, we have to note that the bedding of the upper and middle parts of the klippe (Czorsztyn Unit) is not visible and its present tectonic position is thus unclear. The succession belonging to the Grajcarek Unit is tectonically overturned. Therefore, there are two alternatives how their present thrust position originated: 1) Grajcarek Unit was thrust onto the Czorsztyn Unit and later both were overturned; 2) Czorsztyn Unit was thrust over the already overturned Grajcarek Unit.

6. CONCLUSIONS

1. At Revišné, in Orava sector of the Pieniny Klippen Belt, a klippe built of Bajocian crinoidal limestones (Smolegowa and Krupianka limestone formations), accompanied with synsedimentary Krasín Breccia was found. These formations belong to the Czorsztyn Unit which is rare in the Orava territory and the occurrence of Krasín Breccia is the first outside the middle Váh Valley.

2. Lower part of the klippe is formed by tectonically overturned succession of red Kimmeridgian nodular limestone (Czorsztyn Limestone Formation), Lower Tithonian greenish-grey nodular limestone (Revišné Limestone), through Upper Tithonian to Hauterivian marly white *Calpionella-Nannoconus*-radiolarian limestone (Pieniny Limestone Formation), Barremian-Aptian grey spotted planktonic-foraminiferal marlstones (Kapuśnica Formation) to Lower Albian grey marlstones (Wronine Formation).

3. The latter succession does not fit to the Czorsztyn Unit which lacks Hauterivian to Aptian strata due to emersion and karstification. Lithology of the lower part of the klippe, together with strong condensation of the succession indicates that it may belong to the externmost Grajcarek Unit which sedimented north of the Czorsztyn Swell.

4. Contact of these two units is most likely tectonic. The Czorsztyn Unit is thrust onto the Grajcarek Unit providing two possible ways of interpretation: 1) Grajcarek Unit was thrust onto the Czorsztyn Unit and later both were overturned; 2) Czorsztyn Unit was thrust over the overturned Grajcarek Unit.

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