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JURASSIC STROMATACTIS MUD-MOUNDS IN THE PIENINY KLIPPEN BELT (WESTERN CARPATHIANS) - PETROGRAPHY AND STRATIGRAPHY

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Abstract
Five occurrences of stromatactis mud-mounds were found in the Czorsztyn Unit of the Pieniny Klippen Belt (Western Carpathians) – in western Slovakia (Slavnické Podhorie, Štepnická skala, Babiná), and in the Transcarpathian Ukraine (Priborzhavskoe and Veliky Kamenets). Their stratigraphic range is from Bajocian to Early Tithonian, i.e. they belong to the latest known true stromatactis mud-mounds. At Štepnická skala, Priborzhavskoe and Veliky Kamenets, flat mound shape of the stromatactis beds is revealed. The wall-rocks are invariably micritic to pelmicritic mudstones, wackestones to packstones with fauna of pelecypods, brachiopods, ammonites, crinoids etc. All the mentioned occurrences contain networks of stromatactis cavities. At Slavnické Podhorie, Priborzhavskoe and Veliky Kamenets, the stromatactis cavities occur as low as in the underlying Bajocian crinoidal limestones. This testifies to their biological origin since the inorganic models of stromatactis origin so far presented are hardly applicable to the wall rock sediment formed by crinoidal skeletal detritus. Occurrence of stromatactis in the crinoidal limestones below the mounds indicates that these sites were already pre-disposed as sites of mud-mounds growth still before the change from skeletal to mudstone deposition. The stromatactis cavities are filled with radiaxial fibrous calcite (RFC), then sometimes by internal sediment and, finally, by clear blocky calcite. Some fillings were incomplete, with empty voids in the centres. In two instances, at Babiná and Slavnické Podhorie localities, tests of the cave-dwelling ostracodes *Pokornyopsis* sp. were found, surrounded by the final stages of the RFC. Presence of cave-dwellers indicates that stromatactis cavities for a certain period of time formed an open-space network through which these ostracodes and their larvae could migrate. In addition to stromatactis cavities, numerous examples of seeming recrystallization were observed in all the samples that were petrographically examined. Radiaxial fibrous calcite encloses patches of matrix and isolated allochems. The RFC crystals are perpendicular to the substrate, hence they could not originate due to recrystallization, because they would not be able to re-orient themselves perpendicular to the allochems they meet on their way. The interconnection of all the "floating"allochems in three dimensions seems very unlikely, as in many cases the "floating"allochems are much smaller than both the surrounding RFC crystals and the average distances between them. The same was observed in perpendicular-made thin-sections of sparry portions of the rocks. There is a conflict between initially empty cavities (internal sediment, cave-dwelling *Pokornyopsis* sp. etc.) and seeming "recrystallization" related to the same RFC filling the stromatactis cavities. The allochems apparently served as nucleation sites on which the RFC crystals started to grow. The patches of micritic host-rocks enveloped by the RFC also had to be different from the surrounding and supporting matrix. The most likely explanation is that the RFC crystals of the "recrystallization" spar grew at the expense of decaying microbial mucilage. The mucus might enclose peloids, allochems or whole mudstone patches which "floated" in the mucus and served as nucleation sites for RFC. The entire mud-mound most probably represented a microbially bound autochthonous micrite; the stromatactis and stromatactoid cavities originated where clearer mucilage patches occurred. Many aspects favour the presence of mucus, as a disorganized assemblage of various protozoans, rather than of sponges and other metazoan organisms.

Key words: mud-mounds, stromatactis, Jurassic, Pieniny Klippen Belt, Western Carpathians

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Introduction

Stromatactis mud-mounds are an enigmatic and still unexplained phenomenon, despite a long period of investigation. The mounds, unsupported by any metazoan framework, form hills or banks that were up to thousand meters in thickness and are believed to have withstood water currents and, possibly, wave motion. A microbial origin, together with in situ formation and early cementation of the carbonate mud of the mounds, is widely accepted. Most workers consider them to be microbial reefs. However, there is still no agreement of opinions concerning the origin of stromatactis cavities. These opinions have been summarized several times in the literature. There are two groups of approaches. The first prefers purely physical or chemical origins, for instance internal erosion and reworking of small cavities (e.g. Kukal, 1971; Wallace, 1987; Bridges & Chapman, 1988; Matyszkiewicz, 1993, 1997), dewatering or fluid escape (Heckel, 1972; Desbordes & Maurin, 1974; Bernet-Rollande et al., 1981), neomorphism or recrystallization of the calcareous mud (Black, 1952; Orme & Brown, 1963; Ross et al., 1975), dynamic metamorphism (Logan & Semeniuk, 1976), slumping (Schwarzacher, 1961), fresh-water leaching (Dunham, 1969) or, recently, presence of clathrate hydrates in the calcareous mud, after which the stromatactis cavities remained (Krause, 1999). The second group of opinions supposes that the cavities originated by decomposition of an unknown soft-bodied organism or by nemorphism of carbonate-secreting organisms, involving a wide scale of representatives from stromatoporoids (Dupont, 1881, 1882; Lowenstam, 1950; Carozzi & Zadnik, 1959), through sponges (Bourque & Gignac, 1986; Bourque & Boulvain, 1993), bryozoans (Textoris & Carozzi, 1964), algae (Philcox, 1963; Textoris, 1966; Coron & Textoris, 1974), stromatolites (Cross & Klosterman, 1981), microbial colonies (Tsien, 1985), to burrowing activity of crustaceans (Shinn, 1968). Some authors suggest that stromatactis originated from a combination of several factors, such as microbial binding of the sediment and excavating of the unbound mud (Bathurst, 1982; Pratt, 1982) or from a succession of sponges and microbial colonies (Flajs & Hüssner, 1993; Flajs et al., 1996). Some stromatactis-like cavities also occur in chemosynthetic mud-mounds, related either to hydrothermal or cold methane seeps (e.g. Belka, 1994, 1998; Kauffman et al., 1996; Mounji et al., 1998; Peckmann et al., 1999).

As stated several times in the literature, stromatactis cavities are time-dependent structures and as such we may suppose that their origin is not related to inorganic processes. Although there are some inorganic factors influencing carbonate precipitation which fluctuate with time (e.g. sea-level change, water chemistry or tempreature), the inorganic processes which were beleived to be responsible for origin of stromatactis cavities, e.g. internal erosion, dewatering, recrystallization, dynamic metamorphism, slumping or fresh-water leaching, are not time-dependent. The first stromatactis cavities were reported from Neoproterozoic (Pratt, 1995) and Cambrian times (James & Gravestock, 1990). They reach their maximum in Devonian and Carboniferous; their latest occurrences were reported from the Late Jurassic (Matyszkiewicz, 1993, 1997; Jansa et al., 1989; Pratt, 1995). Some later occurrences of stromatactis-like cavities were also mentioned in the literature, for instance by Pascal & Przybyla (1989), Pratt (1995, Fig. 49B) and Neuweiler et al. (1999, Fig. 2a) from Aptian-Albian of northern Spain, in Early Albian mud-mounds of Pyrenees (Canerot, 2001); then, some younger stromatactis-like cavities were found in Turonian mud-mounds of Tunisia (Camoin & Maurin, 1988), in Late Cretaceous methane-seep mounds of U.S.A. (Kauffman et al., 1996, p. 801) and in Holocene lithoherms in the Straits of Florida (Neumann et al., 1977). All these younger cavities are not widespread and it is questionable whether they are true stromatactis cavities. The Jurassic period is thus one of the last ones with reported true stromatactis mud-mounds.

Stromatactis mud-mounds in the Jurassic are not common; much more common are sponge mud mounds (Hammes, 1995 and the literature overviewed therein) in which some isolated stromatactis-like cavities may also occur (Leinfelder & Keupp, 1995, p. 19). Mud-mounds with stromatactis structures were also reported from the Early Jurassic of the Eastern Alps (Mathur, 1975), Early Jurassic of Sicily (Jenkyns, 1970), Oxfordian of offshore Nova Scotia (Jansa et al., 1989, Figs. 4B, 6; Pratt, 1995, Fig. 45A), and Oxfordian of epicratonic Poland (Matyszkiewicz, 1993, 1997). Similar cavities were reported from the Late Hettangian Hierlatz Limestone of the Eastern Alps by Mazzulo et al. (1990), but they interpreted them as features caused by karstic dissolution. Stromatactis-like voids, that were mentioned from concretions in Aalenian mudstones of the Swiss fore-Alpine platform (Wetzel & Allia, 2000), may be of different origin. These latter features are similar to those reported by Hovland et al. (1987) from Recent methane-seep pockmarks of the North Sea. Their methane-seep origin is easily detectable by isotopic study, displaying very low $\delta^{13}C$ in most components.

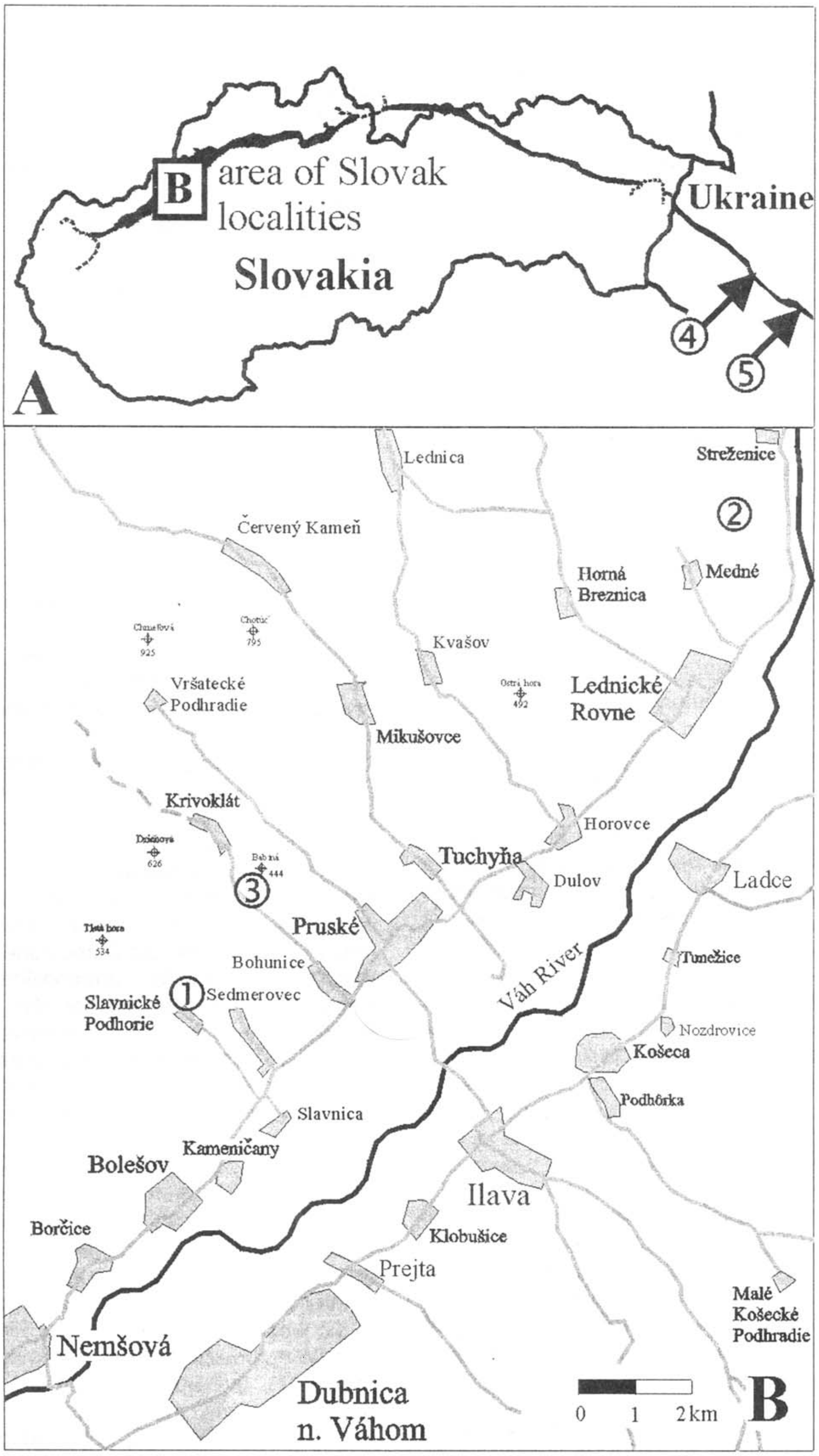

Figure 1: Localities. A – position of the Slovak sites and Ukrainian sites relative to the Pieniny Klippen Belt, B – position of the sites studied within the Váh Valley (Slovakia). 1 - Slavnické Podhorie, 2 - Štepnická skala, 3 - Babiná, 4 - Priborzhavskoe, 5 - Veliky Kamenets.

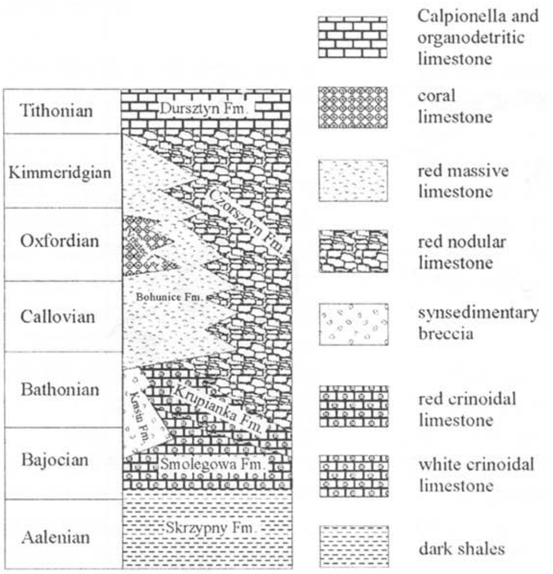

Figure 2: Mid-Late Jurassic lithostratigraphy of the Czorsztyn Unit.

This paper deals with newly found occurrences of Middle to Upper Jurassic (Bajocian to Lower Tithonian) stromatactis mud-mounds in the Western Carpathians in Slovakia and Ukraine (Fig. 1). In this paper, we describe these mounds for the first time: their appearance, petrography and preliminary stratigraphy. Some of the occurrences are still under investigation and the results presented here are preliminary. Nevertheless, all the occurrences mentioned seem to represent true stromatactis mud-mounds, without substantial quantities of sponges, *Shamovella* (*Tubiphytes*), laminated stromatolites or corals. In three of the localities examined, surprising occurrences of stromatactis cavities in skeletal crinoidal limestones may be observed.

Geological setting

The Western Carpathians are a part of the Alpine mountain chain situated between the Eastern Alps and Eastern Carpathians, at the northern margin of the Pannonian Basin. Their principal subdivisions are Inner, Central and Outer Western Carpathians. The Pieniny Klippen Belt represents a boundary zone between the Outer and Central Western Carpathians. It is the most complex of all the Western Carpathian zones as it was affected by at least two major deformation phases: the first, Laramian nappe structures, formed in the latest Cretaceous and earliest Paleogene, the second one, which disturbed the previous structure, was an Oligocene-Early Miocene orogenic phase, dominated by lateral movement and transpressional deformation in a large shear-zone. This process created recent unique klippen structure, where limestone successions (mostly Jurassic to Early Cretaceous) form blocks and tectonic lenses enveloped in softer marlstones and claystones (predominantly Late Cretaceous). Crystalline basement of these sedimentary units is not known; it was most probably consumed by underthrusting beneath the Central Carpathian block. Despite this extensive tectonic deformation, the Pieniny Klippen Belt has almost no metamorphic or thermal overprint and its units contain perfectly preserved fossils and sedimentary structures.

All the localities examined herein belong to the Czorsztyn Unit (Fig. 2) (including the Ukrainian Kamenets Zone) which occurred in subtidal to neritic environments on a relatively shallow-water shelf on the hypothetic Czorsztyn Swell (sensu Mišík, 1994; = Ridge – sensu Birkenmajer, 1986, 1988). In the Aalenian, the sedimentary area lacked contrast due to the dominant deposition of marlstones and claystones in that time (Harcygrund Shale and Skrzypny Shale formations - see Birkenmajer, 1977). In the Bajocian, uplift of the Czorsztyn Swell was strongly accentuated and resulted in deposition of white crinoidal limestone (Smolegowa Limestone Fm.) followed by red crinoidal limestone (Krupianka Limestone Fm.). In more shallow parts of the Czorsztyn sedimentary area, these crinoidal limestones were mostly undifferentiated (Aubrecht et al., 1997). After gradual sea-level rise during the latest Bajocian and Bathonian to Oxfordian, the deposition of the crinoidal limestone gave way to pelagic red nodular ammonitico rosso-type limestones of the Czorsztyn Limestone Formation which was widespread in the Czorsztyn Unit between the Callovian and Late Tithonian. However, some not-nodular equivalents of the Czorsztyn Limestone Formation were found locally by Andrusov (1945, p. 17). This variety was also later found at other places and was named Bohunice Limestone Formation by Mišík et al. (1994). The mutual relationship between the two varieties is mostly unknown, as their lateral transitions are usually not preserved in the individual klippen, except for a few klippen in the western Polish part of the Pieniny Klippen Belt (Wierzbowski, 1994). Following Aubrecht et al. (1997), the Bohunice Limestone Formation represents mud mounds or mud banks with stromatactis structures, surrounded by nodular limestones.

Methods

The field study involved section measurement and sampling, followed by detailed petrographic

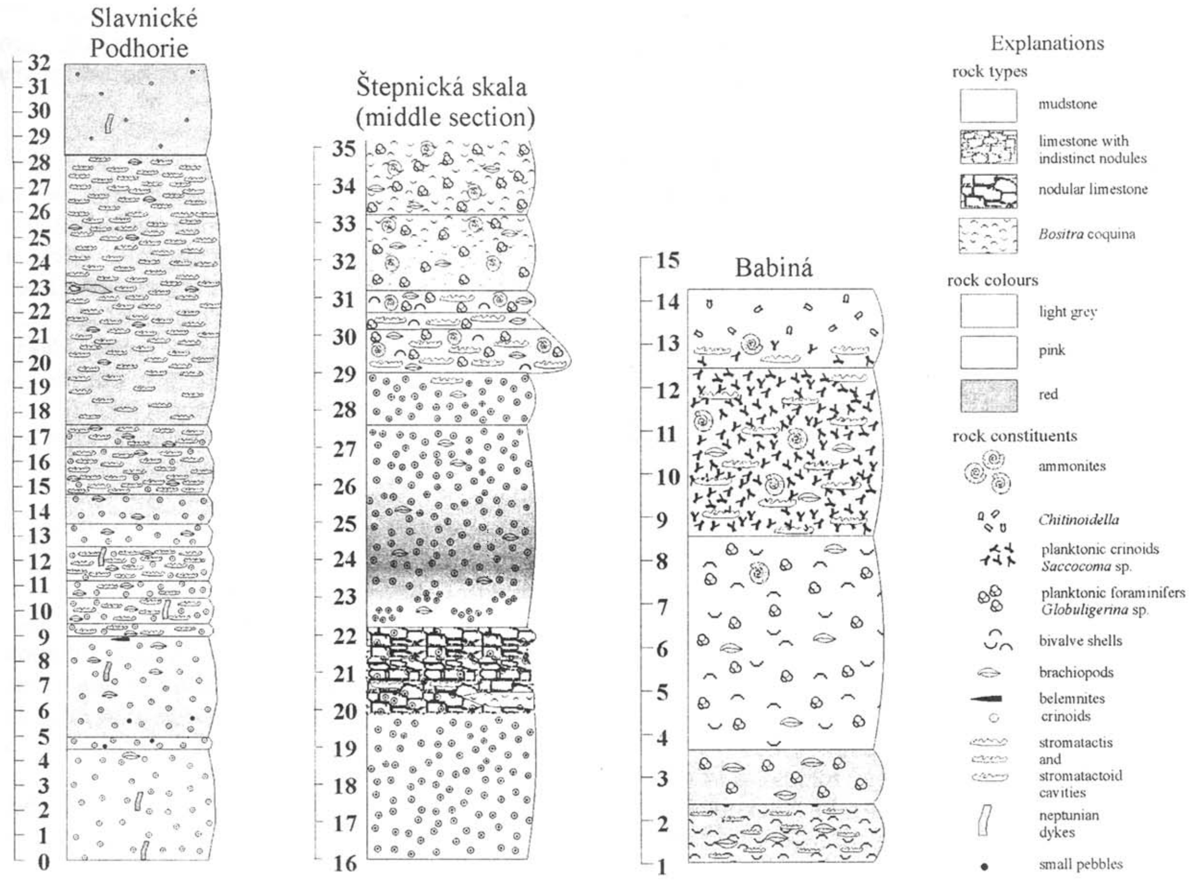

Figure 3: Lithological profiles of the sites examined in Slovakia.

and microfacies study. Stratigraphic analysis is just at the beginning, therefore only preliminary stratigraphic dating has been made, mostly based on microfacies. About 100 thin-sections and slabs were studied petrographically, and some polished thin sections also under CL. Slabs with stromatactis cavities were also examined by staining methods, mainly by potassium ferricyanide (Friedman in Carver, 1971, p. 515) to reveal zonation on the basis of bivalent ferroan content (bivalent Fe in the calcite produces blue colour). Small polished slabs of the cement-rich parts were etched with dilute acetic acid and studied under SEM.

Description of localities

Slavnické Podhorie

The site examined is in the middle part of Váh River valley, near the village Slavnické Podhorie, at the foot of the Biele Karpaty Mts (Fig. 1). It represents a tectonically overturned klippe cut by an abandoned quarry (Pl. I, Fig. 1). A 32 m thick section was investigated in the southern part of the quarry where a core of stromatactis mud-mound is exposed (Fig. 3).

The major part of the quarry reveals the crinoidal limestones. The lower part of the measured section is formed by crinoidal limestone, about 13 meters in thickness, which yielded, approximately in 12 m level, a fragment of the ammonite *Parkinsonia* sp. indicating uppermost Bajocian or lowermost Bathonian. The overlying pink to red micritic limestones (mudstones) are dominated by "filamentous" microfacies which is usually of latest Bajocian to Callovian age in the Czorsztyn Unit, and does not range into Oxfordian (cf. Wierzbowski et al., 1999). Stromatactis cavities appear already in the crinoidal limestone (9-13 m), but they reach their maximum development in the micritic limestones (15-28 m) (Pl. I, Fig. 2-4). At 28 m from the base of the section, the stromatactis cavities disappear. Since the stromatactis cavities are approximately parallel to stratification, the section studied is probably situated in the core of the mound. As the klippe represents just a large tectonic block, there is no transition preserved to the offmound facies.

Štepnická skala

This locality is a small abandoned quarry just below the top of Štepnická skala Hill, SSW of

Púchov town (western Slovakia), about 500 m SE from the small settlement of Štepnice (part of the village Streženice, Fig. 1). The site was firstly mentioned by Andrusov (1945, p. 17) who recognized here the "not-nodular" analog of the Czorsztyn Limestone Formation and called it "ammonite breccia". The klippe is tectonically overturned. Three sections through the klippe (southern, middle and northern parts) were studied, showing relatively high lateral facies variability. A flat stromatactis mud mound is situated in the middle section (Fig. 3; Pl. II, Fig. 1-2).

Massive pale to pink crinoidal limestone occurs at the base of the succession. Its overall thickness could not be measured as the contact with underlying formation is nowhere visible. The crinoidal limestone gradually passes up into red nodular limestone (Czorsztyn Limestone Formation, ammonitico rosso-type facies). The thickness and development of this formation is variable in the individual sections. In the northern part of the klippe the deposits attain 8 m in thickness, and show intercalation of *Bositra* limestone (1 m thick), which is a well-sorted *Bositra* coquina. However, the nodular limestones attenuate in the middle part of the klippe, reaching only 2 m in thickness. The mudstone with nests of crinoids overlies the nodular limestone and reaches about 7 m in thickness; in the southern section it is only about 1-2 m thick. Still higher, in all three sections, pink to yellowish limestone (mudstone) appear, with considerable amounts of brachiopods and ammonites. These faunal elements are also present in the previously mentioned facies but they do not occur so abundantly.

In the middle section, two layers with stromatactis cavities occur at the base of the mudstones (Pl. II, Fig. 1-3). Their maximum thickness is about 2 m and they laterally wedge out over about 10 m distance in both directions, i.e. the stromatactis beds form a flattened mound shape. They may represent either a central cross-section through a flat mound, or a marginal cross-section through a more elevated mound. The microfacies is characterized by small gastropods and mass occurrences of *Globuligerina* sp. which is typical of the Oxfordian in the Czorsztyn Unit. Although the facies development is similar to that of the overlying mudstones, stromatactis cavities are not recognized higher in these beds, except for some isolated cavities which were found in the beds just overlying and underlying the mound. Some stromatactis-like cavities were also found in nodules of Ammonitico Rosso facies in the middle section (Pl. II, Fig.4). In this horizon, the ammonite *Morphoceras* sp. was found, indicating the lowermost Bathonian. The mudstones are about 4 m thick in the southern section; the other two sections do not reach the stratigraphic top of the mudstones. These deposits are followed by *Saccocoma* limestones occuring only in the southern section.

Babiná

This locality is a quarry located at the foot of Babiná Hill, on the road between Bohunice and Krivoklát villages in the Middle Váh Valley in western Slovakia (Fig. 1). The locality has been described in details by Mišík et al. (1994). An overturned Czorsztyn sequence from the Middle Jurassic to the Neocomian crops out in the quarry (Pl. III, Fig. 1). White and pink crinoidal limestones are exposed in the main SE part of the quarry. The crinoidal limestones are cut by numerous neptunian dykes filled with red mudstones of "filamentous" microfacies (Mišík et al., 1994, Aubrecht & Túnyi, 2001). The rest of the quarry shows red to pink micritic limestones (mudstones) of the Bohunice Limestone Formation which gradually pass upwards into Tithonian-Neocomian limestones. The best section showing the lowermost part of the mudstones begins 5 m above the floor of the quarry (Pl. III, Fig.2).

Stromatactis cavities of small size already occur in the basal bed of mudstones which is about 80 cm thick (Pl. III, Fig. 4) (Mišík et al., 1994). This bed is dominated by "filamentous" microfacies which indicates latest Bajocian to Callovian age (cf. Wierzbowski et al., 1999). The same microfacies also represents the infillings of the neptunian dykes cutting the underlying crinoidal limestones. At the top of the mudstone bed a black manganese crust representing a non-deposition surface occurs. Above this crust, pink micritic limestones (mudstones) appear again, with mass occurrence of *Globuligerina* planktonic foraminifers, typical of the Oxfordian in the Czorsztyn Unit (Wierzbowski et al., 1999). These micritic limestones, however, are free of stromatactis cavities. The cavities reappear higher in the section (Pl. III, Fig. 3, 5-6), in limestones (mudstones) containing numerous ossicles of the planktonic crinoid *Saccocoma*, which is typical for the Kimmeridgian and Lower Tithonian (cf. Myczyński & Wierzbowski, 1994; Wierzbowski, 1994). These youngest Jurassic mudstones are erosionally cut by Neocomian breccias.

Priborzhavskoe

This section occurs in an extensive active quarry located at the SW margin of the Priborzhavskoe village on the left side of the Borzhava River in the Transcarpathian Ukraine. The quarry is in a huge klippe of Lower Jurassic to Lower Cretaceous rocks (see Kruglov, 1971, 1986), surrounded by soft Upper Cretaceous marls. The klippe consists of several tectonic slices, and the lowermost of them, corresponding to the most area of the quarry, is tectonically overturned.

White, white-greenish and white-pinkish crinoidal limestones of the Smolegowa Limestone Formation are of Bajocian age (Kalenitschenko et al., 1965). These are the youngest deposits of the lowermost part of the quarry, being represented by crinoidal grainstones, typical of the formation. Their thickness is unknown but the outcrop shows about 15-20 meters. In the central part of eastern face of the quarry, the stromatactis-bearing zone occurs, and it may be traced over a distance of 20-30 meters. The stromatactis structures appear about 10 meters above the base of the Smolegowa Limestone Formation. The largest (max. 1.2 m high, and 20 m long) flat lens-shaped mud-mounds occur within the stratigraphically lower part of this zone. Several small mounds occur higher and the size of individual structures does not here exceed 1-2 m laterally and about 0.15-0.50 m vertically. They have flat bases, but very irregular upper surfaces. The first stromatactis cavities filled with radiaxal fibrous calcite appear about 1-5 cm above the base of such mounds; they are the largest and join laterally. Generally, size of stromatactis cavities diminishes upwards, where they also become isolated. The stromatactis levels are intercalated with thin (10-30 cm thick) crinoidal debris levels, and the contacts between them are very sharp. Brachiopods occur abundantly within some mud-mounds, and probably represent autochthonous assemblages as indicated by their taphonomic analysis. It should be noted that the geopetal structures found in brachiopod shells are concordant with stratification as indicated by orientation of stromatactis cavities.

Veliky (Bolshoy) Kamenets

This quarry, worked for ammonitico rosso and so-called Neresnitsa "marbles", lies on a top of a hill between the Vulkhovchik and Luzhanka rivers near Novoselica village. It was described by Andrusov (1945), Slavin (1966) and Rakús (1990) and mentioned also by Lomize (1968) and Mišík (1992), and it exposes about 40 meters of Middle Jurassic to lowermost Cretaceous limestones. The beds are inclined steeply toward the south (62° S). The lowest strata exposed are crinoidal limestones with abundant micritic matrix up to 4.3 m in thickness. The upper boundary of the crinoidal limestone unit is an omission surface coated with ferro-manganese crusts. Overlying deposits are red nodular limestones about 7 m in thickness.

The stromatactis structures are recognized within the whole crinoidal limestone unit, and in the lowermost part of the overlying nodular limestones. In the latter, the stromatactis structures occur within a flat very large mud-mound traced over a distance of 40 meters, and up to 1.80 m in thickness. This mud-mound shows several flat lateral offshoots, and interfingers with typical red nodular limestones. Some smaller mud-mounds from 2 - 5 m in length, and up to 0.3 m in thickness are recognized in slightly younger strata, directly above the large mud-mound. The stromatactis cavities show the presence of radiaxal fibrous calcite and/or are filled with internal sediment.

In thin-section, lowermost part of the nodular limestones shows dominant occurrence of filaments, and thus it represents the „filamentous" microfacies. Still younger nodular limestones in the Veliky Kamenets section are devoid of stromatactis mud-mounds but are rich in the planktonic foraminifer *Globuligerina*. The part of the Veliky Kamenets succession with stromatactis mud-mounds, i.e. the crinoidal limestones and the lowermost part of the nodular limestones, yielded ammonites of Bajocian-Bathonian age (cf. also Rakús, 1990).

Petrography of the stromatactis cavities and their relationship to the host rocks

So far, some petrographic data are available only from the Slavnické Podhorie, Štepnická skala, Babiná localities, and from the Veliky Kamenets.

The wall-rocks are mostly micritic to pel-micritic mudstones, wackestones to packstones with a fauna of pelecypods, brachiopods, ammonites, crinoids etc. The microfacies is strongly dependent on the age, i.e. the Bajocian-Bathonian skeletal limestones at Slavnické Podhorie locality are formed by crinoid ossicles, the Bathonian-Callovian mudstones of Slavnické Podhorie and Babiná contain "filamentous" microfacies which consists of the thin-shelled bivalve *Bositra buchi*, the Oxfordian mudstones of Štepnická skala are dominated by the planktonic foraminifer *Globuligerina* sp. and tiny gastropods and the Kimmeridgian to Lower Tithonian micritic limestones of Babiná contain numerous ossicles of the planktonic crinoid *Saccocoma* sp. All the mentioned occurrences contain networks of stromatactis cavities. At Slavnické Podhorie, Priborzhavskoe and Veliky Kamenets they occur as low as the underlying Bajocian crinoidal limestones. These sites were thus pre-disposed to be the sites of mud-mound growth even before the change from skeletal to mudstone deposition. At Štepnická skala, the isolated stromatactis cavities occur as low as the Bathonian nodular limestones. The stromatactis cavities with flat bottoms and digitate roofs are common but they form only a part of the cavities; the rest is represented by irregular anastomosing cavities which are, nonetheless, undoubtedly genetically related to the true stromatactis voids. The cavities are invariably filled by radiaxial fibrous calcite (RFC), then sometimes by internal sediment (mostly sterile micrite) and, finally, by clear blocky calcite. The latter is most probably of fresh-water meteoric origin as some microstalactitic growth forms were observed under CL. Some fillings were even incomplete, with empty voids in the centres. In two instances, at the Babiná and Slavnické Podhorie localities, tests of the ostracode Pokornyopsis sp. were found (Pl. I, Fig. 8), surrounded by the last stages of the RFC. These ostracodes were cave-dwellers, indicating that stromatactis cavities at least for a time, formed open-space networks, through which these ostracodes and their larvae could migrate. Except for stromatactis cavities, in all the petrographically examined sites, there are numerous examples of apparent recrystallization. Although there are numerous examples of the RFC filling being separated from the host rock by microstylolites or by shell fragments (shelter porosity), more common are cases where RFC penetration to the host rock occured via small short-bladed initial stages which locally evolved into the long bladed ones. Penetrating into the host rock, the RFC encloses patches of matrix and isolated allochems (Pl. I, Fig.5-8; Pl. II, Fig. 7-8). This penetration typically gives the stromatactis voids their characteristic irregularly digitate roofs (Pl. II, Fig. 6; Pl. III, Fig. 7) but in our petrographically examined material this penetration was commonly very strong and resulted even in larger spar-supported portions of the rocks. However, this penetration is only apparent, because the RFC crystals are invariably oriented perpendicular to the substrate (Pl. I, Fig. 6). In some rare instances, the allochems also seem to be affected by recrystallization (e.g. etched crinoidal ossicles overgrown by RFC). Some allochems apparently formed barriers to RFC growth. All these facts show that not all the allochems served as nucleation sites for the seeming "recrystallization". In Štepnická skala samples, some cavities display molds of aragonite shells of various organisms that were initially coated with Fe-Mn oxides, then dissolved and filled with micrite. Afterwards, they were enclosed in the RFC-filling of the stromatactis cavity (Pl. II, Fig. 7-8). Micrite fill of the molds may serve as an indicator of the former precursor of the RFC.

Discussion

These newly discovered stromatactis mud-mound sites can contribute to the long disputed origin of stromatactis cavities. The unexpected occurrences of these cavities in the crinoidal limestones support a biological, rather than a purely physical or chemical origin. Any of the inorganic models of stromatactis origin so far presented is hardly applicable to the wall rock sediment formed by crinoidal skeletal detritus. Most of those models rely on some internal erosion or excavation of unbound muddy sediment. However, it is difficult to remove the sediment and form the cavities in deposits consisting of skeletal particles (crinoidal ossicles).

There is a major problem of the projection of the allochems into the stromatactis voids and even enclosure of the allochems in the spar ("floating" allochems). The RFC crystals are invariably oriented perpendicular to the substrate whether it is a cavity wall or an enclosed allochem. Therefore, the spar crystals could not grow from the centre of the cavity outward, as proposed by Black (1952) and Ross et al. (1975), because later they would not be able to re-orient themselves perpendicular to the allochems they meet on their way (Bathurst, 1977). In the samples we have studied, the explanation of Bathurst (l.c.) that the "floating"allochems are interconnected in three dimensions not visible in a single thin-section, seems unlikely. In many cases the "floating"allochems are smaller than the surrounding RFC crystals and also than the average distances between the allochems. The same was observed in perpendicular-made thin-sections in sparry portions of the samples studied. There was very little possibility of any allochems being supported by being attached to other allochems. There is a conflict between empty cavities in the rock (internal sediment, cave-dwelling ostracodes *Pokornyopsis* sp. etc.) and seeming "recrystallization" evidently related to the same RFC filling the cavities. An alternative explanation of the "recrystallization" may be that the allochems served as nucleation sites on which the crystals started to grow.

A dispute may arise about the nature of the matter that initially supported the "floating" alllochems. The instances where the RFC encloses the molds of former aragonite shells filled with micrite (Pl. II, Fig. 7-8) indicate that in some cases the RFC might originate via true recrystallization of the mud. However, in most cases, the patches of micritic host-rocks enveloped by the RFC had to be different from the surrounding and supporting matrix. There is no obvious reason why the RFC crystals would start their growth perpendicular on some micrite patches if they were surrounded by the same mud. The most likely origin of "recrystallization" is that the radiaxial fibrous calcite must have replaced some other substance which may be of organic origin. Most likely, the RFC crystals (either short- or long-bladed) of the "recrystallization" spar grew at the expense of decaying microbial mucilage. The mucus might enclose peloids, allochems or whole mudstone patches which, in this sense, really "floated" in the cavity space and served as nucleation sites for RFC. The entire mud-mound most probably represents a microbially bound autochthonous micrite and the stromatactis and stromatactoid cavities originated where only mucilage occurred, relatively free of sediment. The morphological variability of stromatactis, penetration of the sparry calcite into narrow spaces, and enclosing of the "floating" allochems and mudstone matrix patches by sparry calcite, are the common features that are in favour of the presence of mucus produced by a disorganized assemblage of various protozoans, rather than by sponges and other well organized metazoan organisms which by filtering would prevent allochems from entering their growth cavities. Moreover, sponge spicules and skeletons only represent subordinate elements of these mud-mounds.

Conclusions

1. Five new occurrences of Mid - Late Jurassic stromatactis mud-mounds have been discovered in the Czorsztyn Unit of the Pieniny Klippen Belt (Western Carpathians): Slavnické Podhorie, Štepnická skala, Babiná, Priborzhavskoe and Veliky Kamenets. These are among the youngest examples of stromatactis mounds.

2. In addition to mudstones, the stromatactis cavities also occur in crinoidal limestones. This suggests a biological origin of them.

3. Many cases of apparent recrystallization are observed. Rather than being replacements of carbonate mud, they are interpreted as spar growing at the expense of decaying microbial mucilage.

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PLATES

Plate I

Slavnické Podhorie

Fig. 1 - Overall view of the Slavnické Podhorie klippe. Section studied marked by arrow.

Fig. 2 - Spar-filled stromatactis cavities revealed by weathering (40 cm stick for scale).

Fig. 3 - Detail of Fig. 2.

Fig. 4 - Polished slab of mudstone with interconnected stromatactis cavities. Scale in centimetres.

Fig. 5 - Negative photo of thin section showing a cavity filled with radiaxial fibrous calcite (RFC, pale grey) and blocky calcite (dark grey). The RFC penetrates the wall rock and encloses allochems and micrite patches (both white).

Fig. 6 - SEM photo of etched slab, showing perpendicular spar blades growing on a small allochem.

Fig. 7 - Small cluster of peloids enclosed in RFC. Plane polarized light.

Fig. 8 - Test of cave-dwelling ostracode *Pokornyopsis* sp. (top center), quartz grain (top left), together with some micritized allochems, all enclosed in RFC. Plane polarized light.

Plate II

Štepnická skala

Fig. 1 - South facing photo of the quarry wall, showing the margins of flat stromatactis mud-mounds. Note the wedging-out bedding planes (arrows).

Fig. 2 - View to north of the same flat mound. Arrows indicate wedging-out bedding planes.

Fig. 3 - Stromatactis cavities in outcrop (tectonically overturned position). Photographed when wet.

Fig. 4 - Hand specimen from the Ammonitico Rosso-type limestone (lowermost Bathonian) with stromatactis-like cavity. Number of the sample indicates the meter-level in the section.

Fig. 5 - Polished slab of the stromatactis cavity filled with multiphase RFC (white) and internal sediment (dark grey).

Fig. 6 - Microphoto showing a digitate promontory of spar-filled stromatactis cavity roofed by mudstone.

Fig. 7 - Molds of aragonite shells of various organisms, coated with Fe-Mn oxides, dissolved and filled with micrite. Afterwards, they were enclosed in the RFC filling of the stromatactis cavity. Micrite fill of the molds indicate that in this case, carbonate mud might have surrounded the allochems instead of microbial mucus. RFC then originated by a true mud replacement. Plane polarized light.

Fig. 8 - Similar to Fig. 7. Ammonite shell in the middle. Plane polarized light.

Plate III

Babiná

Fig. 1 - Overall view of the Babiná Quarry.

Fig. 2 - Right (SE) part of the quarry. The dashed lines indicate the Bathonian-Lower Tithonian section with stromatactis cavities.

Fig. 3 - Field photo of stromatactis cavities in Kimmeridgian mudstone (tectonically overturned).

Fig. 4 - Polished slab from the base of the section (Bathonian-Callovian) showing small-scale anastomosing stromatactis-like cavities. Centimeter scale below.

Fig. 5 - Polished slab of the mudstone with isolated small-scale stromatactis from the Kimmeridgian-Lower Tithonian part of the section.

Fig. 6 - Polished slab from the highest level with stromatactis-like cavities (Lower Tithonian).

Fig. 7 - Digitate protrusion of the stromatactis cavity roof into the mudstone. Note the *Saccoccoma* ossicles in the micrite, indicating Kimmeridgian-Lower Tithonian age.

Plate IV

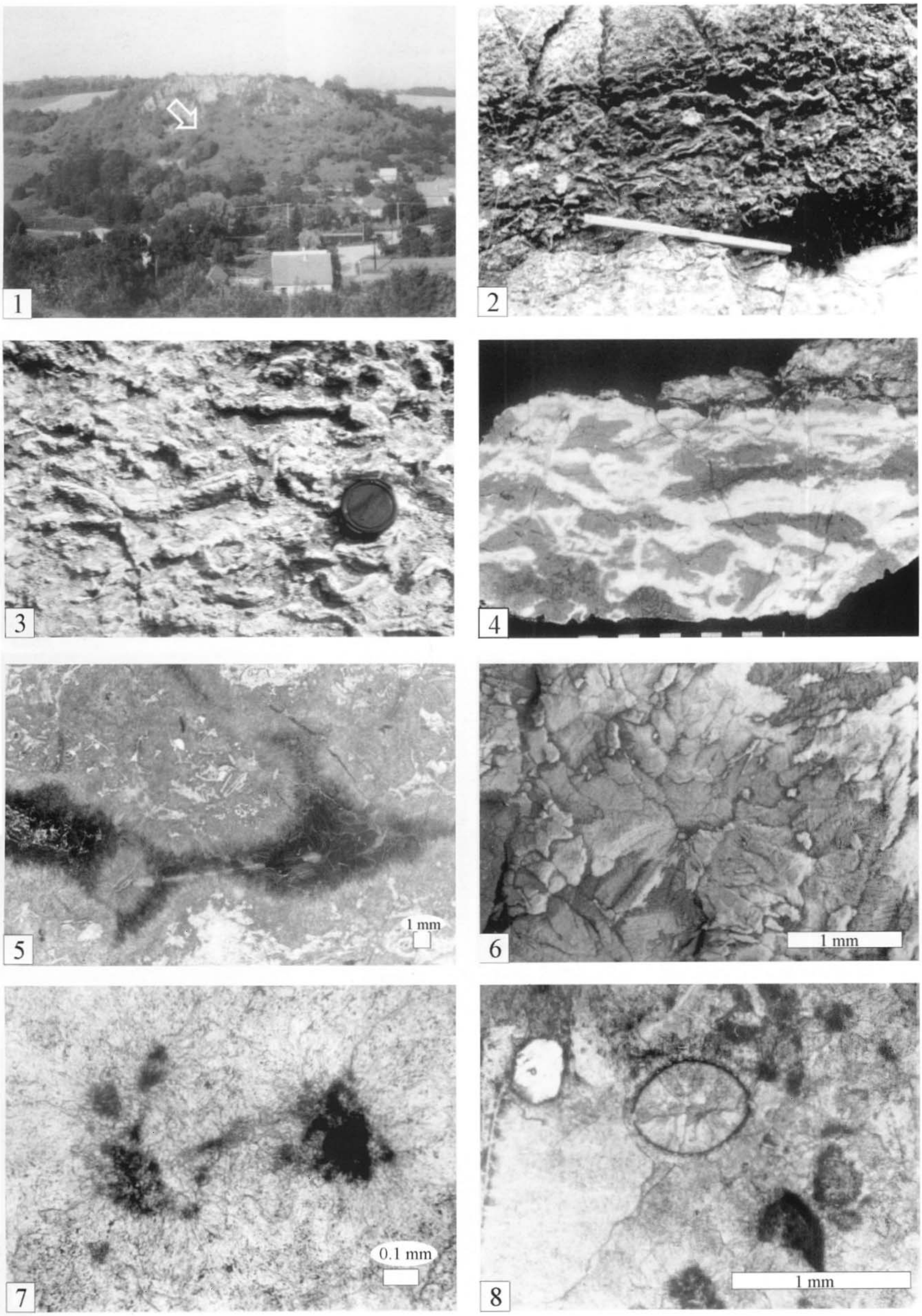
Veliky Kamenets and Priborzhavskoe

Fig. 1 - Small mud-mound in the Ammonitico Rosso limestone at Veliky Kamenets.

Fig. 2 - Detail of the mud-mound showing numerous stromatactis cavities at Veliky Kamenets.

Fig. 3 - Fragment of mud-mound in crinoidal limestone of the Smolegowa Limestone Fm. at Priborzhavskoe.

Fig. 4 - Detail of the mud-mound showing numerous stromatactis cavities filled with fibrous calcite and internal sediment at Priborzhavskoe.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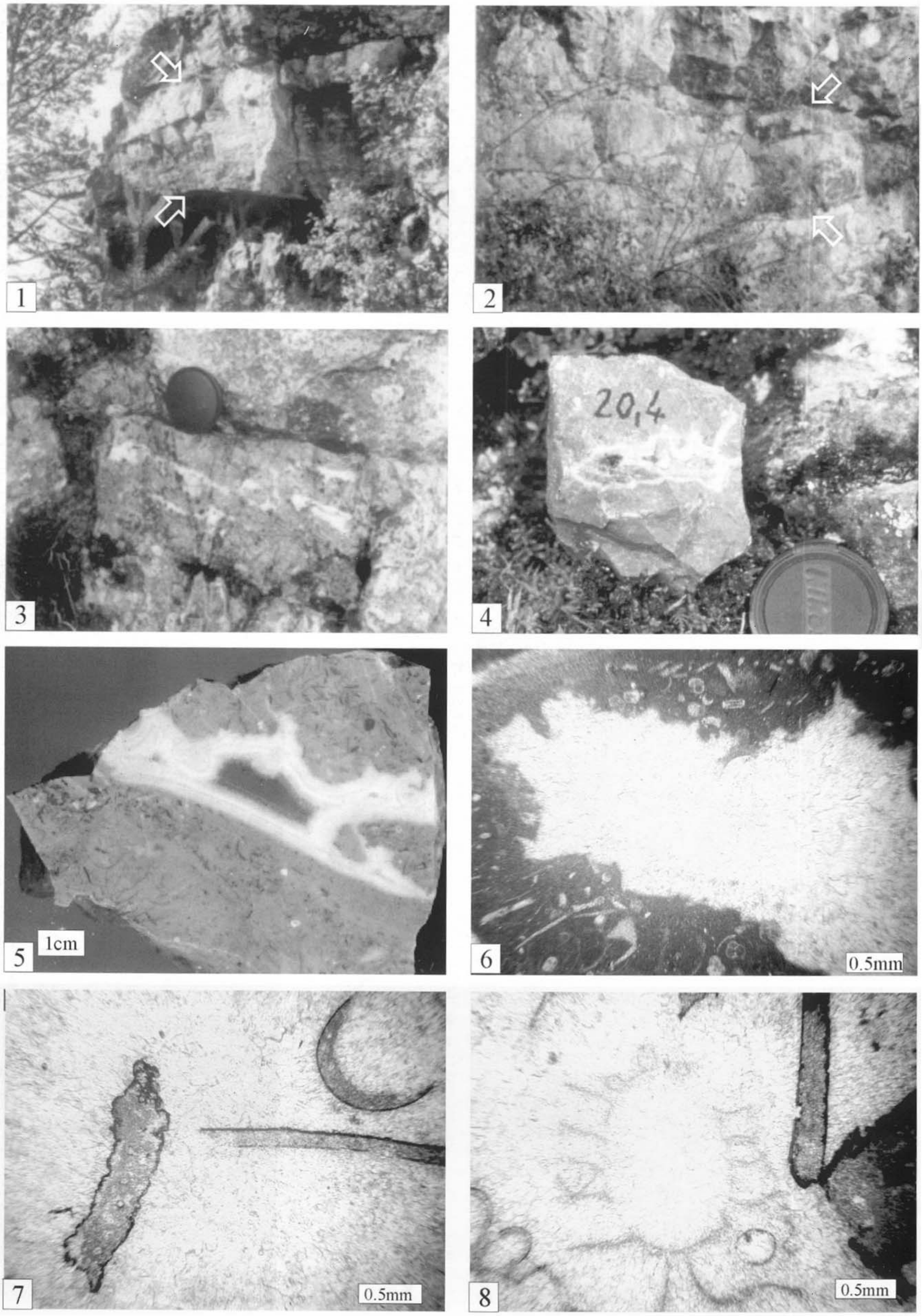
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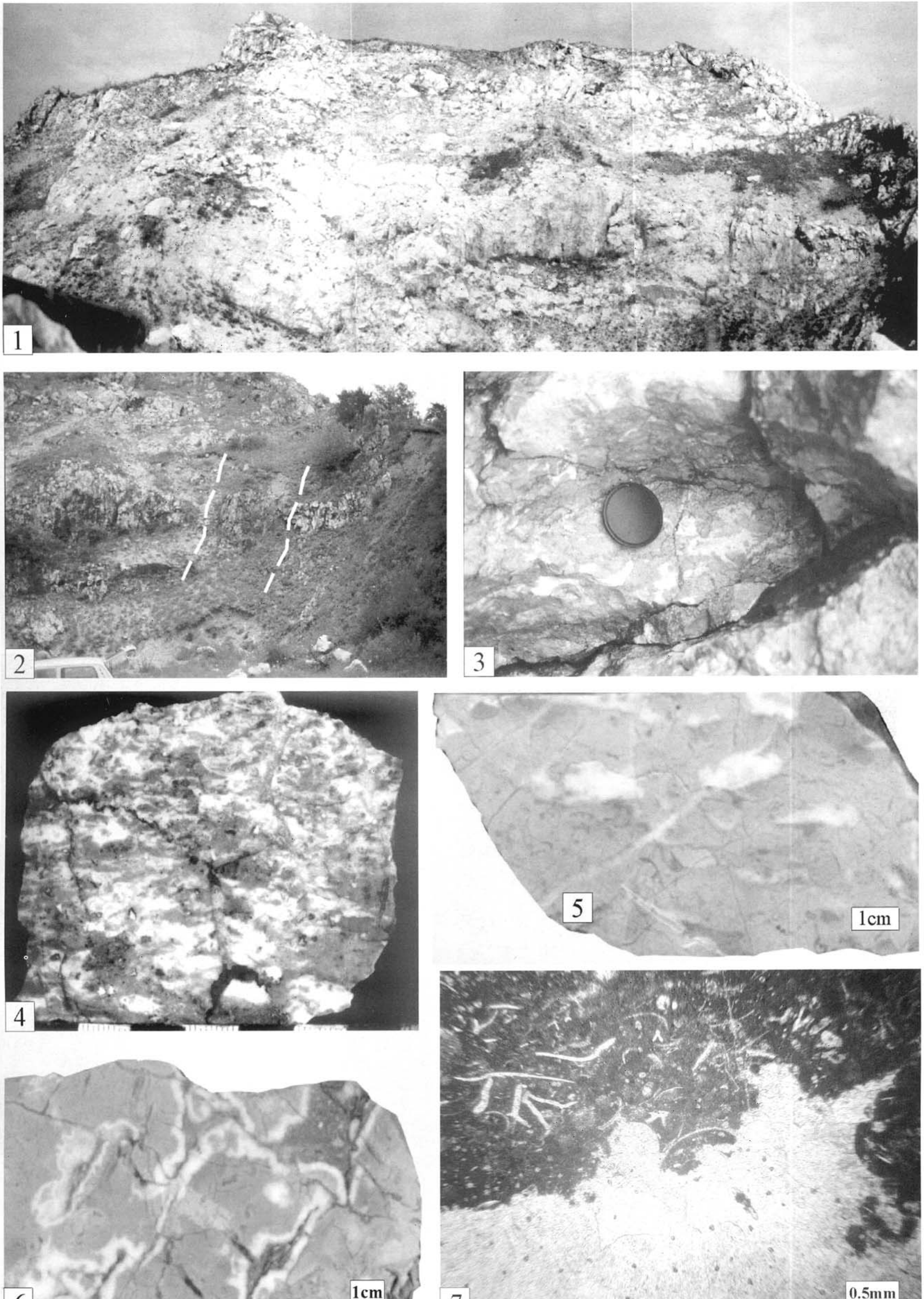
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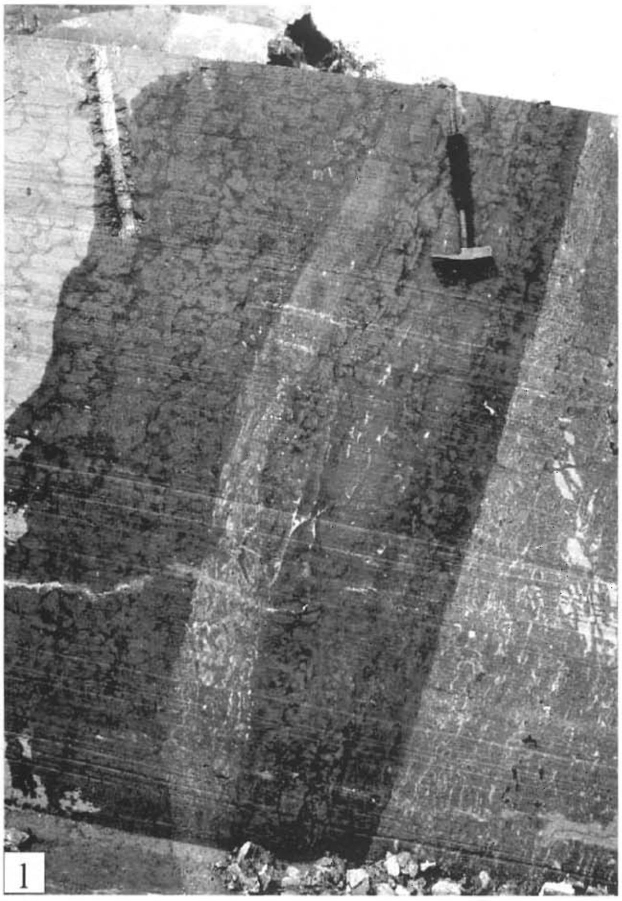
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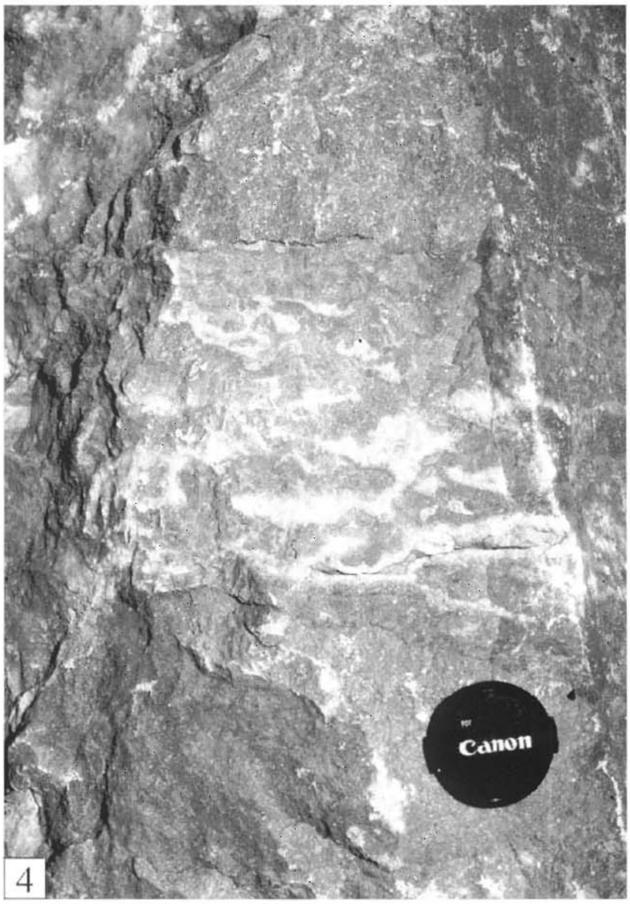

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