GEOLOGICA CARPATHICA, 48, 2, BRATISLAVA, APRIL 1997
71–84

INDICATIONS OF THE MIDDLE JURASSIC EMERGENCE IN THE CZORSZTYN UNIT (PIENINY KLIPPEN BELT, WESTERN CARPATHIANS)

ROMAN AUBRECHT

Department of Geology and Paleontology, Faculty of Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava, Slovak Republic

(Manuscript received June 12, 1996; accepted in revised form December 12, 1996)

Abstract: A breccia of rounded crinoidal limestone clasts cemented by two generations of stromatolites, then by radiaxial cement with remaining voids filled by marine sediments i.e. crinoidal detritus, micrite with bivalve shells or micrite with *Pokornyopsis* ostracods was found at Horné Sŕnie quarries near Trenčín. This breccia, which can be assigned to the Krasín Breccia Member (Middle to Upper Jurassic of Czorsztyn Unit), bears several signs of freshwater influence. Isotopic data from the first stromatolite generation display a negative $\delta^{13}C$, the clasts in the breccia are rounded and some dissolutional effects have been observed in the voids. The final filling of the cavities with crinoidal detritus and later with filament microfacies suggests that the breccia was formed in the time of the transition between Bathonian and Callovian. It is the first evidence of freshwater diagenesis in the Pieniny Klippen Belt.

Key words: Jurassic, Western Carpathians, Pieniny Klippen Belt, Czorsztyn Unit, carbonate sedimentology, diagenesis, freshwater cements.

Introduction

There is a long-lasting search for evidence of emergence in the area of the former Czorsztyn Ridge. It was provoked by the fact that the foreland and basement of the Czorsztyn Unit as well as of all the Pienidic units are still unknown. The known Jurassic and Cretaceous sedimentary cover was detached from its basement and stacked into nappe structures during the first orogenic phase in the Late Cretaceous and Paleocene. The basement itself has been lost (maybe subducted). Therefore any discovered signs of emergence would shift the investigators "closer" to the unknown shoreline. The emergence is supposed for the time of relative sea-level drop during the Bajocian and Bathonian in this area, which is indicated by the succession of relatively shallow-water facies (mainly crinoidal limestones). The evidence of emergence obtained up to now is restricted to the presence of a clastic admixture of sandy to small pebble size (Birkenmajer 1963, p. 37; Aubrecht 1993; Mišík & Aubrecht 1994 etc.), some dissolutional phenomena caused probably by fresh-water mixing in some neptunian dykes and voids (Mišík & Sýkora 1993, p. 413) and to some eroded strata and rounded clasts in the Krasín Breccia described by Mišík et al. 1994. This paper deals with the first direct evidence of Middle Jurassic freshwater diagenesis in the Czorsztyn Unit.

During the fieldwork on the section of the Pruské Unit at Samášky locality near Horné Sŕnie (Aubrecht & Ožvoldová 1994) a small outcrop with peculiar rocks was found in its immediate neighbourhood following a roadcut (Fig. 1). The rocks resemble the "evinosponge" breccias known from the Oxfordian Vršatec Limestone of Czorsztyn Unit (Mišík 1979). However, it did not include any clasts of Oxfordian coral limestones, but only of the crinoidal limestones and/or so far unknown pink laminated limestone. By its character and stratigraphic position, this breccia is more similar to the Krasín Breccia (see Fig. 2) described by Mišík et al. (1994). The site was largely disturbed by mining and the most interesting samples occurred only in separated blocks. The breccias appear to pass continuously into massive crinoidal limestone penetrated by a network of radiaxial fibrous calcite veinlets. As in situ observation was very difficult and the relationship between various parts of the breccia and the above mentioned transition were poorly observable, the major information has been obtained by laboratory investigations.

Methods of research

The samples were studied petrographically using a polarizing microscope for thin-sections study and a paleontological binocular microscope for direct study of weathered parts of the examined samples. The cathodoluminescence (CL) examinations were made in the Geological Institute, University of Wien (M. Wagreich). The chemical composition of calcite samples was analysed by an electron microanalyser JXA 840 A, with wavelength dispersive spectrometers of JEOL-KEVEX system in the CLEOM department, Faculty of Natural Sciences, Comenius University, Bratislava (J. Krištín). The isotope analyses were made in the Czech Geological Institute, Prague (J. Hladíková).

Petrographical and CL data, trace elements

The breccia is composed of clasts reaching up to several tens of cm in size and, unlike in the typical Krasín Breccia, a complex cement and sedimentary void filling (Fig. 3; Pl. I: Figs. 1, 2). In following text, a detailed description of all

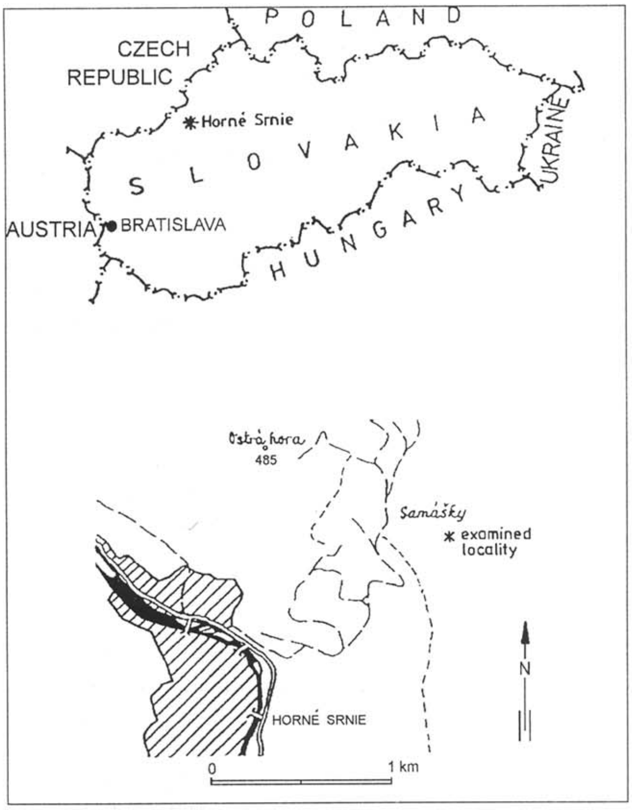


Fig. 1. Position of the locality examined.

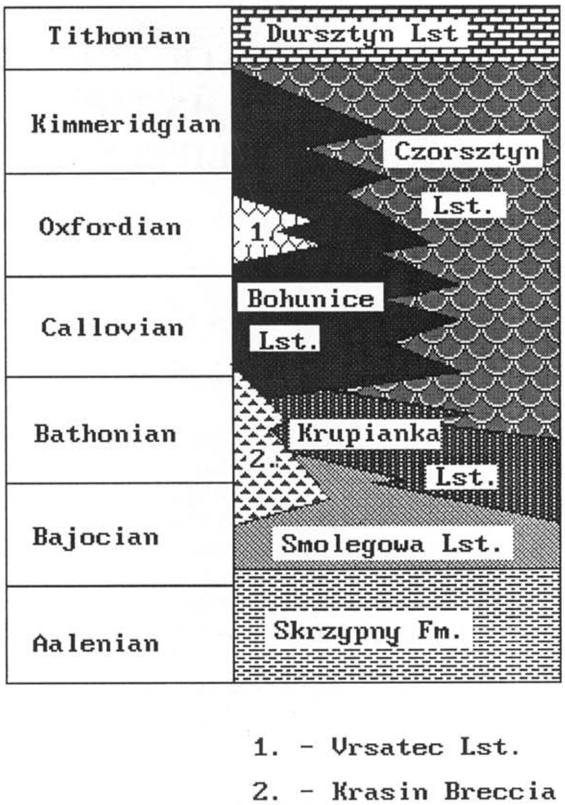


Fig. 2. Schematic lithostratigraphic column of the Czorsztyn Unit, based on the latest data.

components will be given, based on the macro- and microscopic observations under normal and polarized light, CL, completed by some microprobe analyses.

Clasts — 1. The first generation of clasts is represented by crinoidal limestones of subangular to rounded shape, containing a more or less quartz dominated siliciclastic admixture (with rare microclinic feldspars and heavy minerals i.e. garnet, zircon and rutile). They are represented mainly by the crinoidal biosparites to biomicrites with syntaxial calcite overgrowths. In the parts where the micrite is present, frequent teeth-like terminations of the syntaxial overgrowths occur which indicate a prevention of crystal growth by later input of micrite (Bathurst 1971 — p. 430 and the literature cited therein). The inequable distribution of micrite testifies to its local later emplacement. Besides crinoids, the fragments of bryozoans, brachiopods, echinoid spines, bivalve shells (rarely also gastropods), smooth-valved ostracods, serpulids, agglutinated foraminifers, sessile (nubecularid) foraminifers, *Lenticulina* sp., *Ophthalmidium* sp., nodosarid foraminifers, are also present. The surface of skeletal fragments is frequently micritized. All the resulting sediment is full of inclusions which results in an unusual cloudy appearance which has not been observed yet in other localities of crinoidal limestones in the Czorsztyn Unit. Inclusions observed under larger magnification do not appear to be formed of micrite; they mostly resemble black organic matter, many of them have a bubble-like shape hence they represent the fluid inclusions. The possibility, that the cloudy appearance is related to the emergence, weathering and freshwater alteration (mentioned later), is not excluded. Rare small voids filled by clear blocky calcite also occur in the crinoidal limestone (their isotopic character has not been examined).

2. The second generation of clasts is represented by pink laminated limestones often closely related to the previous crinoidal ones (Pl. II: Fig. 3). Many cases of transitions between them have been identified even within a single clast (Pl. III: Fig. 3). They are pelmicrites with laminae of crinoidal detritus up to 1 cm thick. The laminae are often convex and laterally pinching out. They are composed of the same material as the crinoidal limestones mentioned above. The lamination is also observable in the pelmicrites themselves (the pelloids may be of microbial origin — see Reitner & Neuweiler et al. 1995; Monty 1995). They resemble stromatolitic structures in which the pellets were formed by the microbial calcification or they were trapped by algal (or microbial) mats. The latter might also be true for the crinoidal detritus. The described lithofacies was also unknown in the Czorsztyn Unit so far. The absence of filamentous microfacies (containing thin bivalve shells), typical for the Callovian of the Czorsztyn Unit (sometimes already Bathonian — M. Krobicki, pers. comm.), indicates its origin presumably already during Bathonian time. Its character indicates slow continual transition from crinoidal to muddy sedimentation. In many other localities of the Czorsztyn Unit, this change in sedimentation is abrupt with a sharp boundary in the sedimentary record (frequently with Fe-Mn hardgrounds between) due to the rapid sea-level rise, after which the neritic sedimentation followed. However, according to my opinion, the mentioned lithofacies is not related to this process, but it

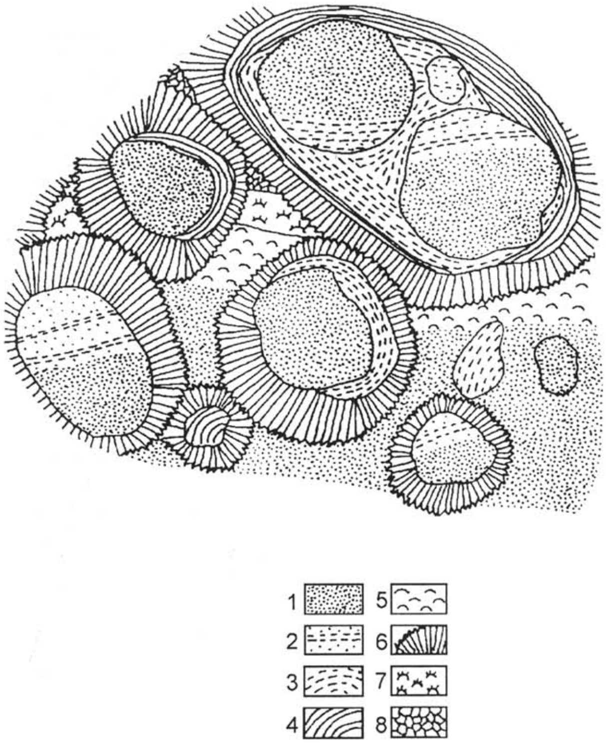


Fig. 3. Schematic outline of the breccia, illustrating the relationship among its various components. Explanations: **1** — crinoidal limestone, **2** — laminated micritic limestone, **3** — faintly laminated freshwater stromatolite, **4** — distinctly laminated marine stromatolite, **5** — void filling with "filamentous" microfacies, **6** — radiaxial fibrous calcite, **7** — void filling with cavity dwelling ostracods *Pokornyopsis feifeli* (Triebel), **8** — blocky calcite.

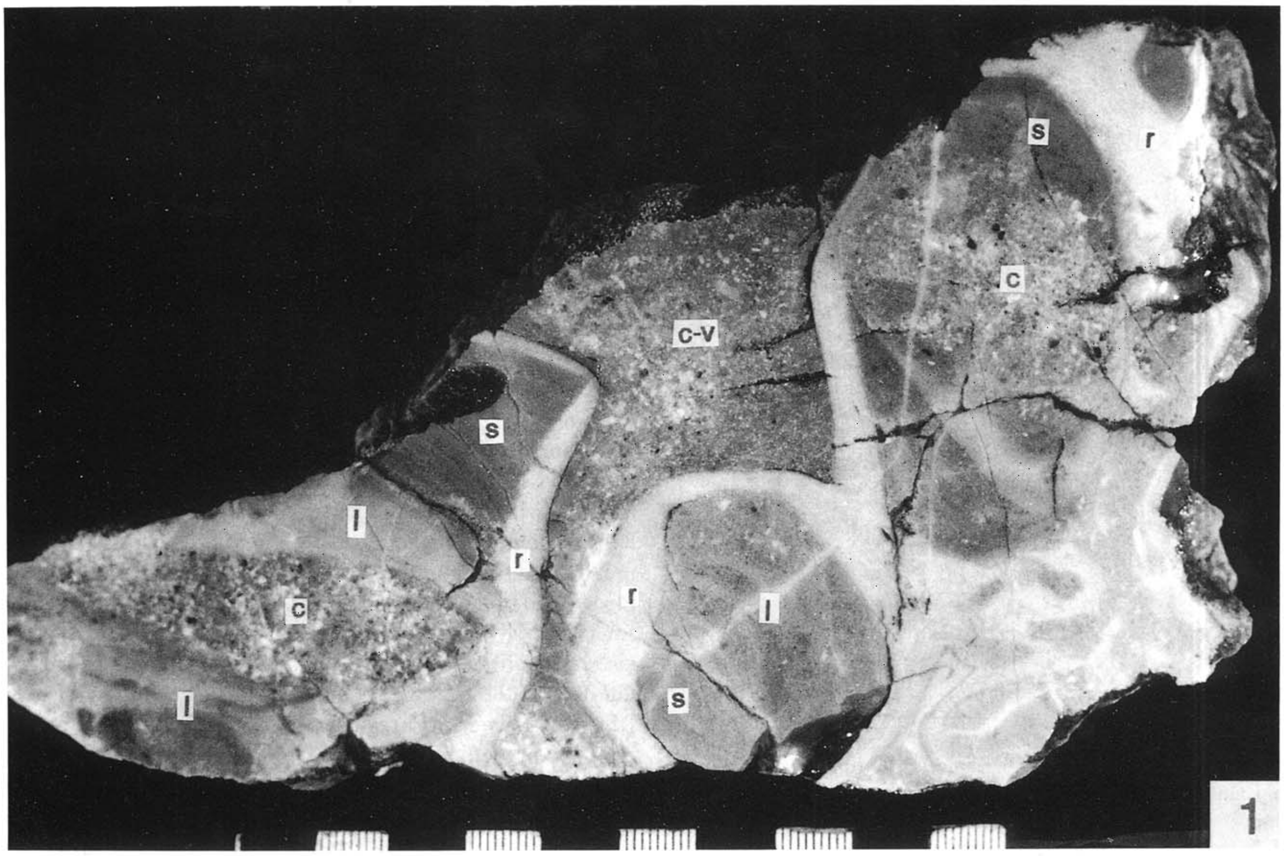
represents sediment deposited in a special environment. As will be mentioned later, its deposition was followed by (or was directly related to) the emergence and repeated submersion all during the continuing sedimentation of crinoidal limestones in the basin. The most probable explanation is that its deposition took place in the restricted sheltered nearshore area or possibly even in a cave environment. This theory was suggested by the irregular lammination and presence of laminae with cavity fauna in some samples (see chapter about the signs of carstification).

Stromatolitic crusts are laminated clotted pelmicrites quite similar to some of the laminated limestones mentioned above if the crinoidal detritus is excluded. Like the previous ones, they may represent either cyanoliths (Pl. II: Fig. 4; Pl. III: Fig. 1) or microbialites (Pl. III: Fig. 2), since most pelloidal structures resemble those defined as being of microbial origin (Reitner & Neuweiler et al. l.c.; Monty l.c.). However, the pelloids are not present all through the stromatolites, hence part of them may also have been formed as a calcified algal mat. The stromatolites with thickness reaching up to 5 cm are developed irregularly on many of the clasts. Their absence may be either primary, due to prevention of the formation by the direct contact of the clasts, or secondary, due to their break-down by the repeated reworking of the sediment (Pl. V: Fig. 2). Thus they frequently form a third generation of debris in the breccia (after crinoidal and pink micritic limestones) (Pl. III: Fig. 4). By petrographic and isotopic investigations, at least two generations of stromatolites may be distinguished. The first appear macroscopically as pink micrite with faint lamination frequently cementing several clasts together (Pl. II: Figs. 1, 2). Such clusters frequently bear signs of reworking after which a second generation of stromatolites onlapped on the new clast. Unlike the older generation of stromatolites, the second one is often macroscopically distinctly laminated (Pl. III: Fig. 1) with brownish, yellowish and greyish colour. However, the variability in stromatolites sometimes precludes the unequivocal identification of their origin; hence the isotopes provide the only reliable source of information.

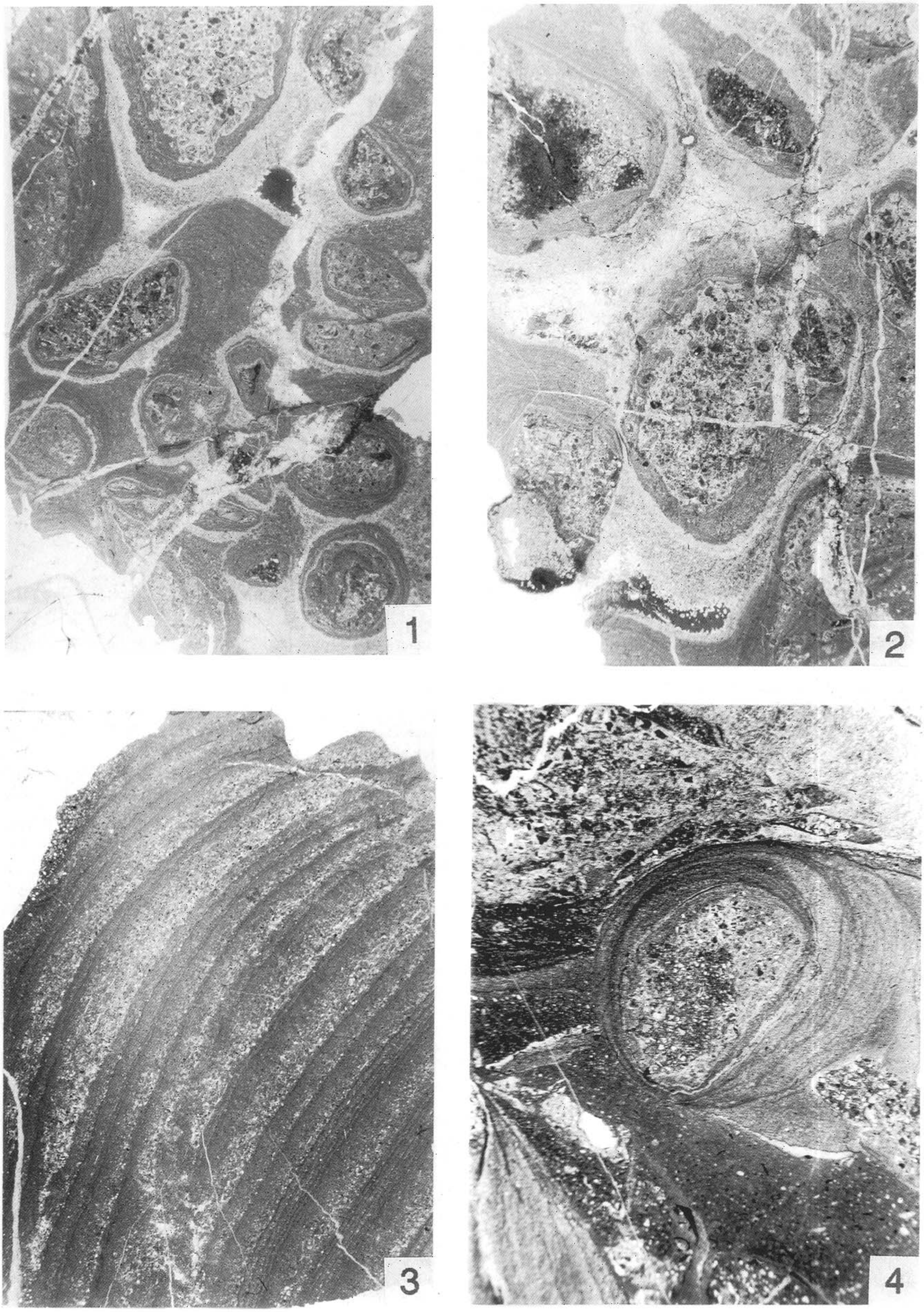
Radiaxial fibrous calcite (RFC) represents an almost ubiquitous cement generation all through the breccia. Its thickness varies from 0.7 cm to almost 2 cm. Some crusts have no constant thickness, which could be caused by the simultaneous filling of the void by internal sediment (thickening upward of the crust). However, such a phenomenon is not found very frequently. Varying thickness of the RFC crusts also results from the filling of depressions and surface irregularities on the clasts (Pl. V: Figs. 3, 4). The density of the RFC vein network is irregular. RFC sometimes fills straight fractures in the limestone but more frequently surrounds the clasts in the breccia. This cement generation overlaps almost all clasts together with their incomplete stromatolite envelopes, being itself disturbed only locally by tiny fractures (Pl. V: Figs. 1, 2). Radiaxial cement is sometimes interlayered with very thin stromatolitic laminae (Pl. IV: Fig. 1; Pl. V: Figs. 1, 2). RFC most probably represents a marine precipitate (see Kendall 1985) which is also supported by its bulk isotopic values (mentioned later) which correspond to the average Jurassic marine cements (Lohmann 1988, Fig. 2.8). However, under cathodoluminescence a relatively brightly luminescent zone has been revealed within the RFC (Pl. IV: Fig. 2) while all other components were non-luminescent or very dully luminescent. This zone is similar to that described from Carboniferous limestones in Belgium by Muchez et al. (1991, Fig. 3C) who attributed it to a neomorphism during later cementation. However, unlike in our luminescent zone, there are signs of alteration also along the intercrystalline boundaries which strongly supports the theory about later

Plate I: Figs. 1, 2 — Parallel slabs from the block of breccia. c — crinoidal limestone (clast), l — laminated stromatolitic limestone with laminae of crinoidal detritus, s — stromatolite, r — radiaxial fibrous calcite, c-v — crinoidal limestone (void filling), m — micrite (void filling), o — void filled by ostracods *Pokornyopsis feifeli* (Triebel). All photos: L. Osvald.

Plate II: Figs. 1, 2 — Small clasts of crinoidal limestones coated and partially cemented together by the freshwater stromatolites, later by radiaxial fibrous calcite with remaining voids filled either by sterile micrite or blocky calcite. Note that some thin layers of RFC are interlayered within the stromatolitic coating. Thin sections. Magn. 4×. **Fig. 3** — Laminated stromatolitic limestone with laminae of the crinoidal detritus. Thin section. Magn. 4×. **Fig. 4** — Clast of crinoidal limestone coated by asymmetrical stromatolitic crust. Thin section. Magn. 4.5×.


s
r
c
c-v
s
l
r
c
r
l
l
s
1


c-v
m
l
c
c
o
l
l
r
r
2


1
2
3
4

neomorphism. Our sample displays only some dispersion of the luminescence around the luminescent zone which is not related to the intercrystalline boundaries. The microprobe investigations displayed an increased content of Mn (main activator of the luminescence), also relatively higher Fe and lower Mg contents if compared with the surroundings (Pl. IV: Fig. 3). The luminescent zone was most probably precipitated under reducing conditions when Mn and Fe^{2+} were apt to be incorporated into the calcite crystal lattice. These conditions could be reached by the restricted water circulation during cementation of the latest porosity or by the freshwater influx and consequent alteration of the precipitating calcite.

The remaining void fillings are related to the size of voids and their mutual interconnections; nevertheless, they are also stratigraphically dependent. In some voids, a successions of several fillings were frequently observed. The following general succession of void filling was summarized from the whole breccia:

1. The initial filling was separated by a thin micritic coating from its surroundings also resembling stylolite. It represents crinoidal biomicrite — packstone (Pl. V: Figs. 3, 4). Crinoidal ossicles (also cirrals) and filaments (thin bivalve shells) are frequent, and stromatolite fragments were also found locally. Some occurrences of *Pokornyopsis feifeli* (Triebel) which are typical for some final fillings have been already enregistered in this zone. Besides these, some smooth shelled ostracods are also present.

2. The sedimentation of crinoidal detritus later gave way to micrite with a filamentous microfacies (Pl. V: Fig. 3). This change in the microfacies observable within the cavities took place during the Callovian in the Czorsztyn Unit (Mišík 1966; Myczynski & Wierzbowski 1994). The filamentous microfacies consists mostly of thin bivalve shells of the genus *Bositra*; also the sculptured shells of ostracods *Pokornyopsis feifeli*, frequent aptychi, gastropods and juvenile ammonoids can be found among the detritus. The micritic matrix is frequently concentrated under vaulted bivalve shells which forms a nice "umbrella" effect (Pl. VI: Fig. 1). This second generation of the final filling is probably already Callovian in age. Bivalve shells are particularly overgrown by "dog tooth" calcite, but some elongated square-terminated crystals resembling acicular fringes of aragonite (Tucker & Wright 1990, Fig. 7.3) may be also found (Pl. VI: Fig. 2). However, the content of strontium, as the diagnostic trace element, is very low near the microprobe detection limit (Table 1), which makes the possibillity of aragonitic precursor unlikely.

3. The final void filling was represented by sterile micrite only with some thin fragments of bivalvian or ostracod shells (filaments). When observed under CL, the micrite possess a dull orange luminescence, which contrasts with nonluminescent surrounding radiaxial fibrous calcite (Pl. VI: Fig. 5). The accumulations of ostracods *Pokornyopsis feifeli* (Triebel) developed in some remaining voids (Pl. VI: Figs. 3, 4). These ostracods were known a long time ago (Mišík 1979) as direct inhabitants of cavities and sea-bottom fractures (neptunian dykes) but their taxonomic determination was done only recently (Aubrecht & Kozur 1995). Many of their recent descendants have also been found to be cave dwellers (Kornicker & Sohn 1976) which is very interesting from the point of view of their evolution and ecology. In such accumulations, many of the closed ostracod shells are packed within the remained interstitial space. The micritic matrix is then emplaced between. Ostracod tests themselves are filled with clear blocky calcite. The stromatolite fragments are sometimes also present in the micritic final filling.

4. Locally, if the pore connections were too small, the voids were cemented by clear drusy sparite. Some voids even remained empty after RFC precipitation.

Table 1: Measured composition of the acicular fringe overgrowths on the bositra shells.

Point	FeO	MnO	SrO	MgO	CaO
1	0.11	0.4	0.03	0.5	56.04
2	0.08	0.04	0	0.26	55.53
3	0.09	0.11	0.02	0.16	54.03
4	0.12	0.06	0.03	0.21	56.34
5	0.11	0.06	0.04	0.21	56.63
6	0.11	0.04	0.04	0.25	56.43
7	0.11	0.04	0.06	0.41	56.12

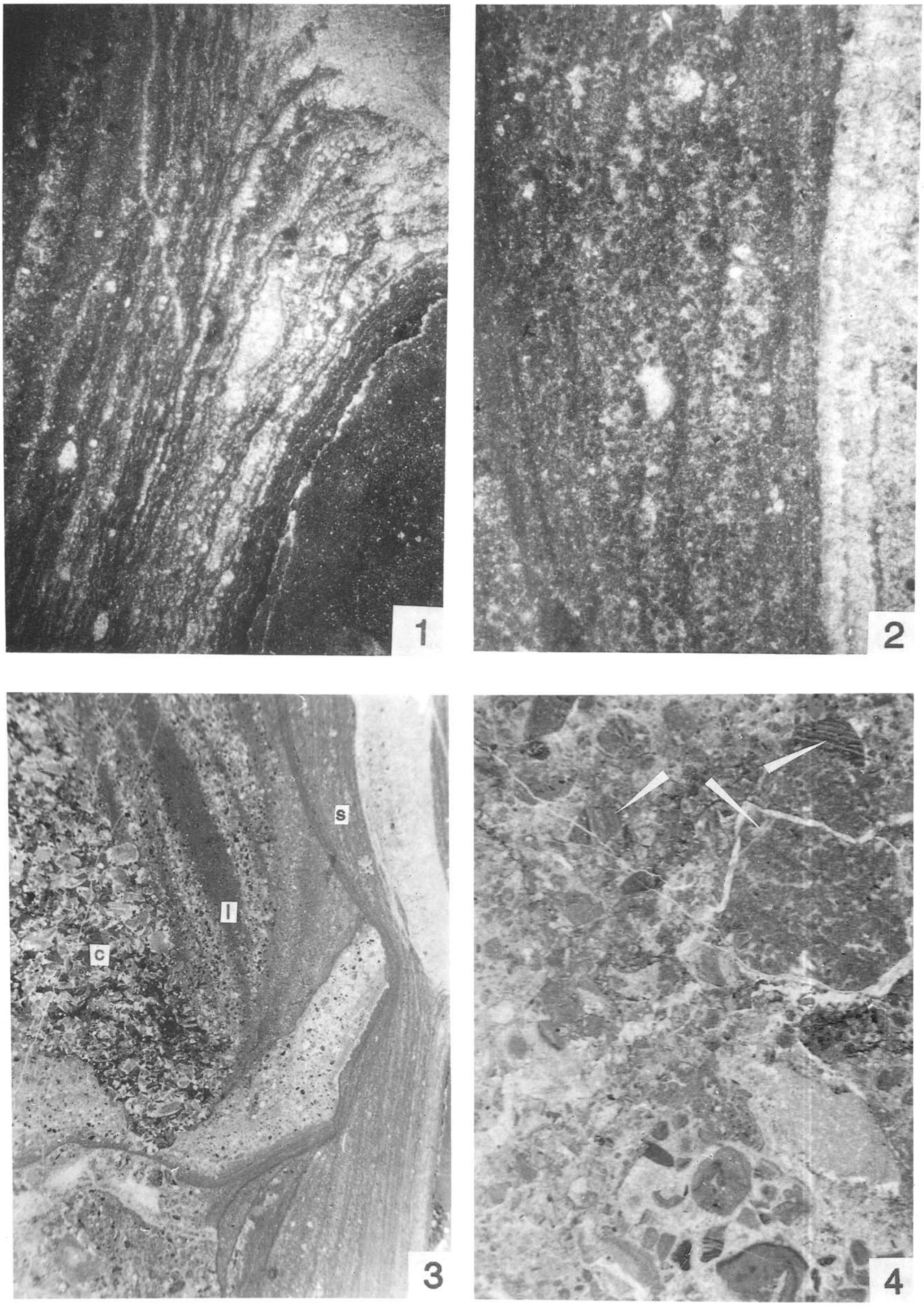
Signs of karstification were observed in three cases:

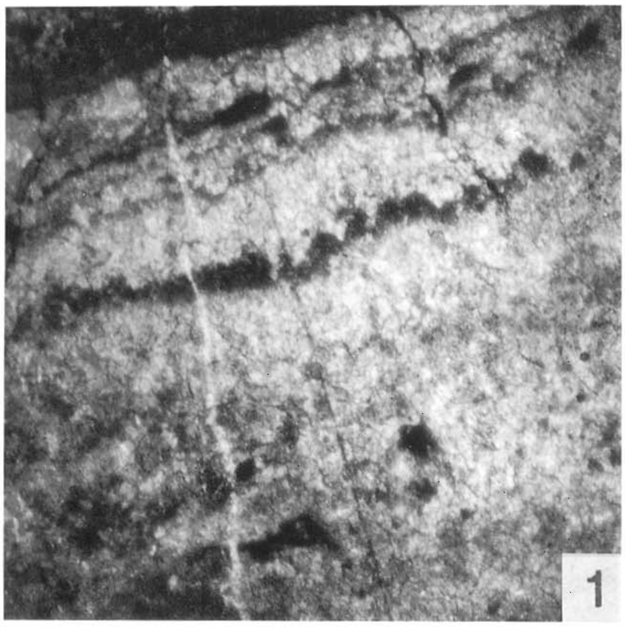
1. The laminated sterile micrite also fills some structures resembling neptunian dykes. The micrite is there in direct contact with crinoidal limestone (the wall-rock). The walls of the dykes bear signs of dissolution. They are curved (karstified) and the opposite walls do not fit together (Pl. VII: Figs. 1, 2). This was most probably caused by the freshwater dissolution. The mixed marine and fresh water might have a similar effect (Smart et al. 1988). Because the sterile micrite represents a relatively late filling a fresh-water interference to the marine environment is supposed. This interference might take place through a network of cavities connect-

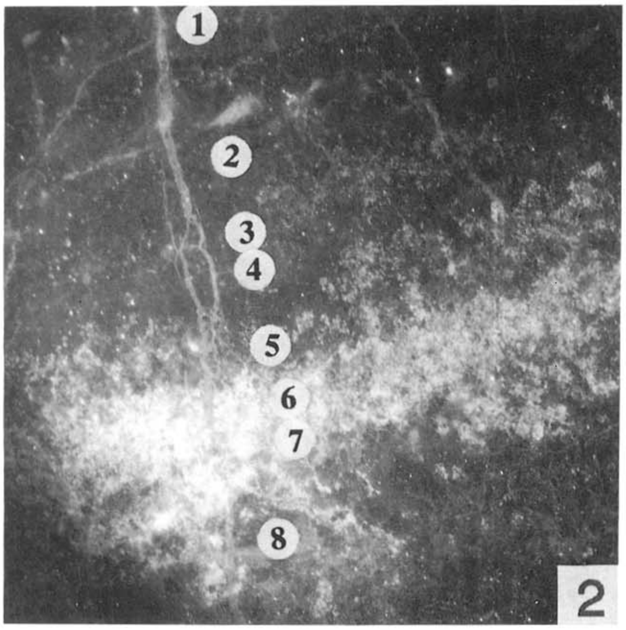
Plate III: Fig. 1 — Distinctly wavy laminated stromatolite covering, faintly laminated to structureless stromatolite (lower right). Thin section. Magn. 27×. **Fig. 2** — Peloids to pseudopeloids probably of microbial origin in the laminated stromatolite. Thin section. Magn. 27× . **Fig. 3** — Mutual overlapping of several stromatolitic generations. Note the transition from the crinoidal limestone (c) through crinoidal laminated limestone (l) to the stromatolite (s). Thin section. Magn. 4.4×. **Fig. 4** — Fine-grained breccia composed of detrital crinoidal limestone (bottom) as well as the stromatolitic and microbialitic detritus (arrows) displaying later sedimentary reworking of all components. Thin section. Magn. 7×.

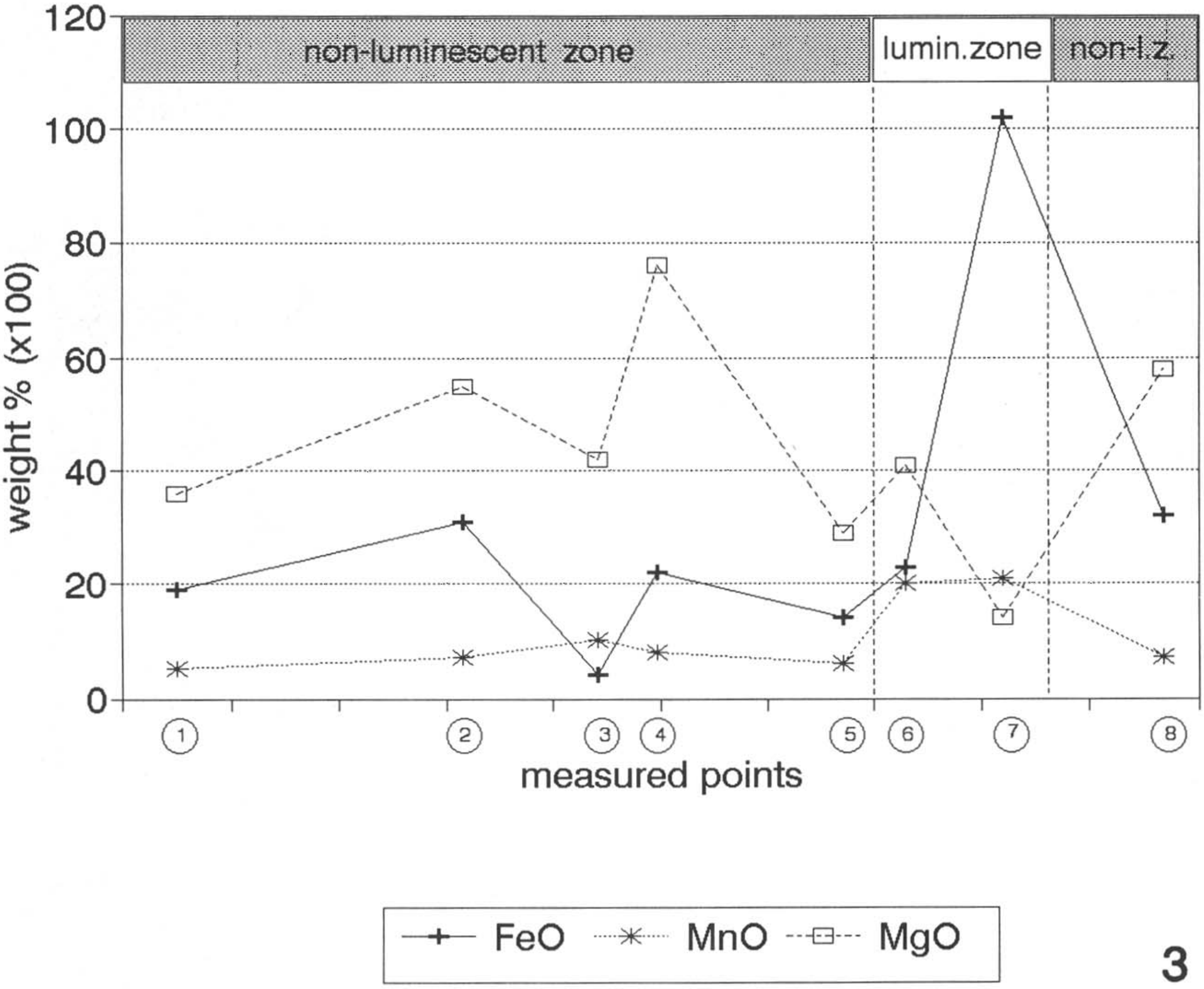
Plate IV: Fig. 1 — Radiaxial fibrous calcite in plain polarized light. Note thin stromatolitic layers. Thin section. Magn. 15.5×. **Fig. 2** — The same under cathodoluminescence. Note the bright luminescent zone caused by increased content of Mn as a result of temporary reducing conditions during precipitation. The numbers point the microprobe analyses plot in Fig. 3. **Fig. 3** — Microprobe traverse across the luminescent zone in RFC (above). Note the relatively increased content of MnO which is the main activator of luminescence.

PLATE III

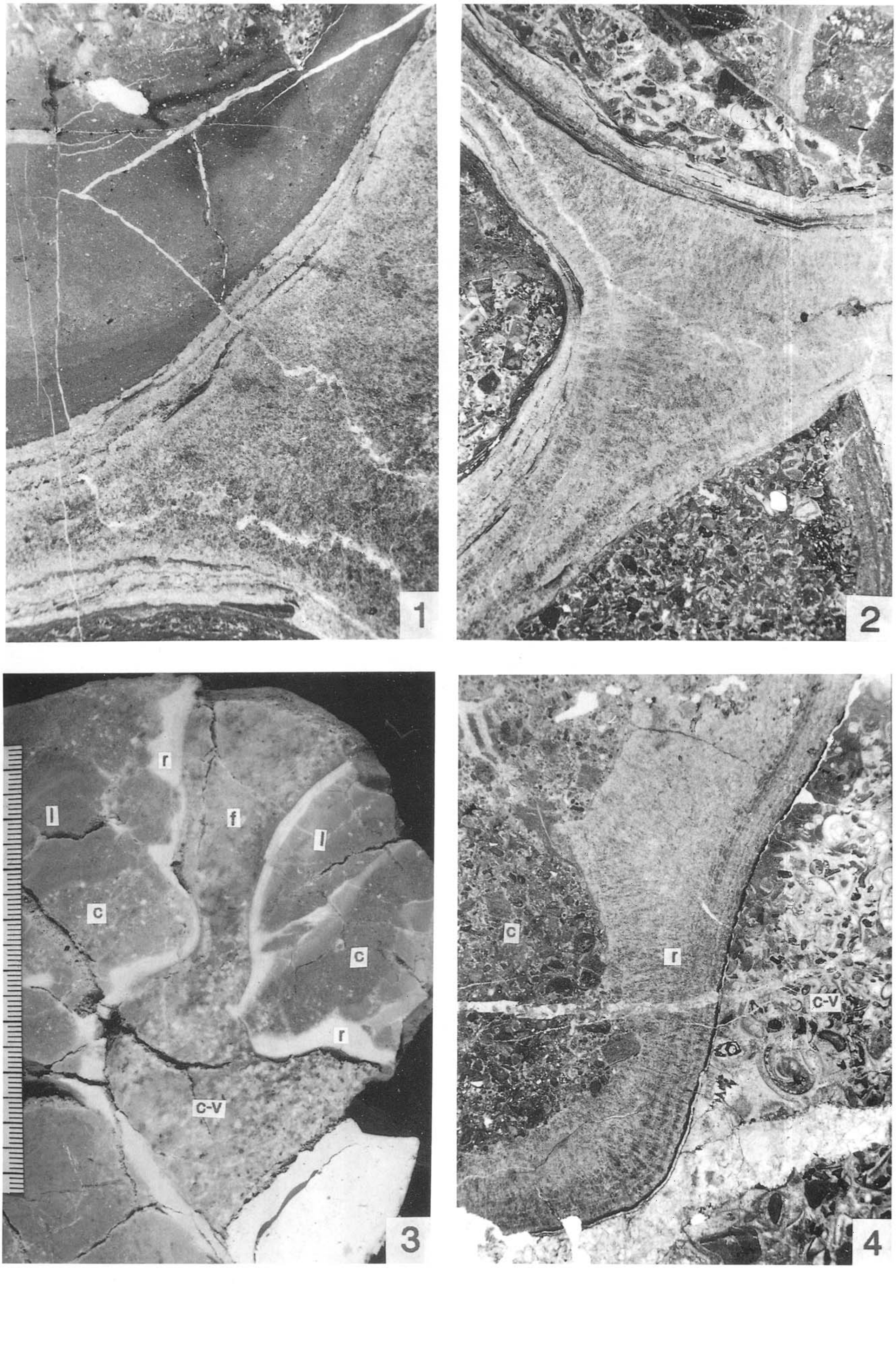


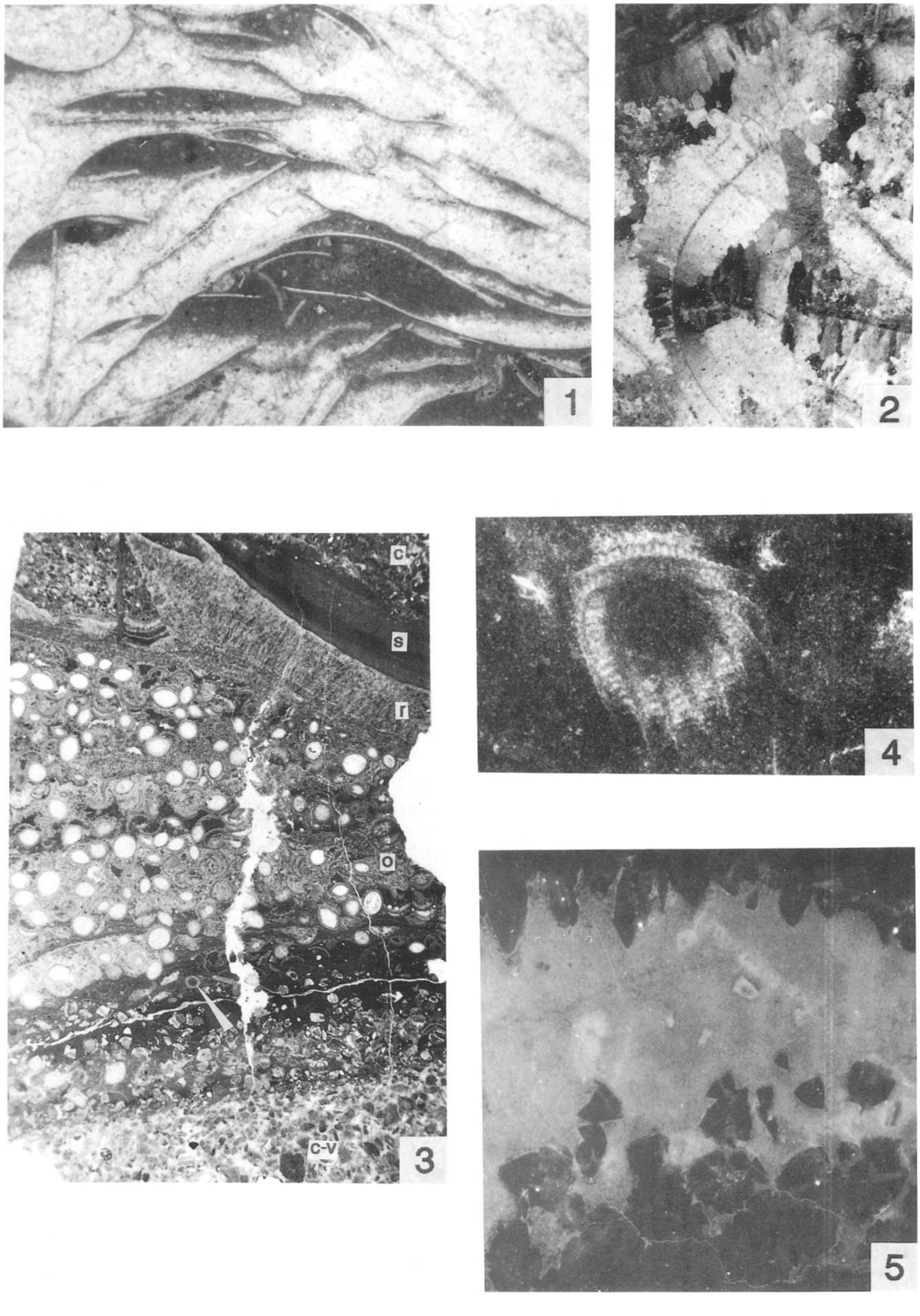

1


1
2
3
4
5
6
7
8
2


120
100
80
60
40
20
0
weight % (x100)
non-luminescent zone
lumin.zone
non-l.z.
1
2
3
4
5
6
7
8
measured points
FeO
MnO
MgO

3


1
2
r
l
f
l
c
c
r
c-V
3
c
r
c-V
4


1
2
c
s
r
o
c-v
3
4
5

ing both marine and fresh-water zones. Modern submarine caves are often formed in such mixing-zones (Smart et al. l.c.).

2. The above mentioned opinion is also supported by the case, where the RFC calcite crystals, surrounding a void filled by sterile micrite, bear signs of gravity-influenced corrosion (Pl. VII: Figs. 3, 4). It is clear, that the RFC calcite, as a marine precipitate, was later corroded by the solutions undersaturated with respect to the $CaCO_3$ (at least to the high-magnesian calcite).

3. An isolated block was found with the appearance of laminated limestone intercalated by irregular RFC calcite veins (Fig. 4). The laminae are frequently formed by the *Pokornyopsis* shells, which indicates sedimentation in a larger-sized cavern. The presence of such blocks supports the theory that a large portion of breccia may represent a cavern collapse breccia, rather than scarp breccia. However, this question requires further investigations, not yet involved in this paper.

Oxygen and carbon isotope data

Most of the data obtained by the oxygen and carbon isotope analysis of all the cements (Table 2), when plotted in the $\delta^{13}C$ versus $\delta^{18}O$ diagram, are concentrated in two groups (Fig. 5).

The first and the most numerous one occurs near the mean value estimated for the carbonates precipitated from normal Jurassic marine water (Lohmann 1988, Fig. 2.8). The variation of $\delta^{13}C$ between 1.8 and 3.3 ‰ PDB is relatively small.

Plate V: Fig. 1 — Clasts of crinoidal limestones (top and bottom) cemented together by the radiaxial fibrous calcite. Note that upper clast is coated with faintly laminated stromatolite. Thin section. Magn. 4.5×. **Fig. 2** — Clasts of crinoidal limestones cemented by radiaxial fibrous calcite. Like in the previous picture, thin stromatolite is developped on one clast (bottom). The stromatolitic coating is sharply discontinuous due to later reworking. Thin section. Magn. 4.5×. **Fig. 3** — Polished slab displaying the void among the clasts filled initially by the crinoidal detritus, later by the filamentous packstone (f). The change of filling is due to the facial change induced by the sea-level rise at the Bathonian-Callovian boundary. Other explanations see Plate I. **Fig. 4** — Detailed view on the contact between clast of crinoidal limestone (c) coated by radiaxial fibrous calcite (r) with crinoidal limestone as a void filling (c-v). Thin section. Magn. 4.5×.

Plate VI: Fig. 1 — "Umbrella" effect — non-recrystallized micrite preserved under vaulted *Bositra* shells. Callovian part of void filling. Thin section. Magn. 27×. **Fig. 2** — Acicular fringes grown on *Bositra* shells, with peculiar square terminations resembling an aragonitic cement. Thin section. Magn. 27×. **Fig. 3** — Transition from the crinoidal initial void filling (c-v) to packstone composed of shells of cavity dwelling ostracods *Pokornyopsis feifeli* (Triebel) (o). The contact with clast of crinoidal limestone (above — c) coated with faintly laminated stromatolite (s) and radiaxial fibrous calcite (r). White arrow shows a tangentially cut shell (Fig. 4 in detail). Thin section. Magn. 4.5×. **Fig. 4** — Detailed view of the tangentially cut shell of *Pokornyopsis feifeli* (see Fig. 3). Thin section. Magn. 45×. **Fig. 5** — CL view on the non-luminescent radiaxial fibrous calcite surrounding a void with dull orange luminescent sterile micrite. Thin section. Magn. 47.5×.

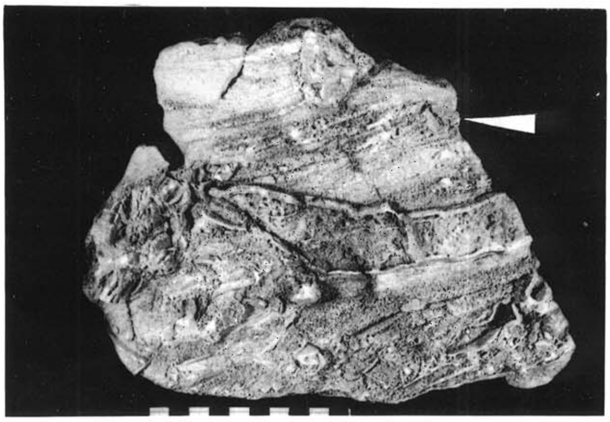


Fig. 4. Block of laminated limestone with laminae (arrow) containing numerous shells of *Pokornyopsis feifeli* (Triebel) indicating sedimentation in a larger cavity. The limestone is penetrated by several RFC veins (positively weathered).

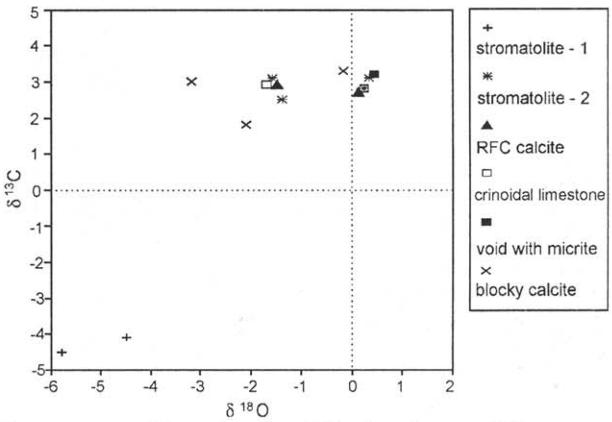
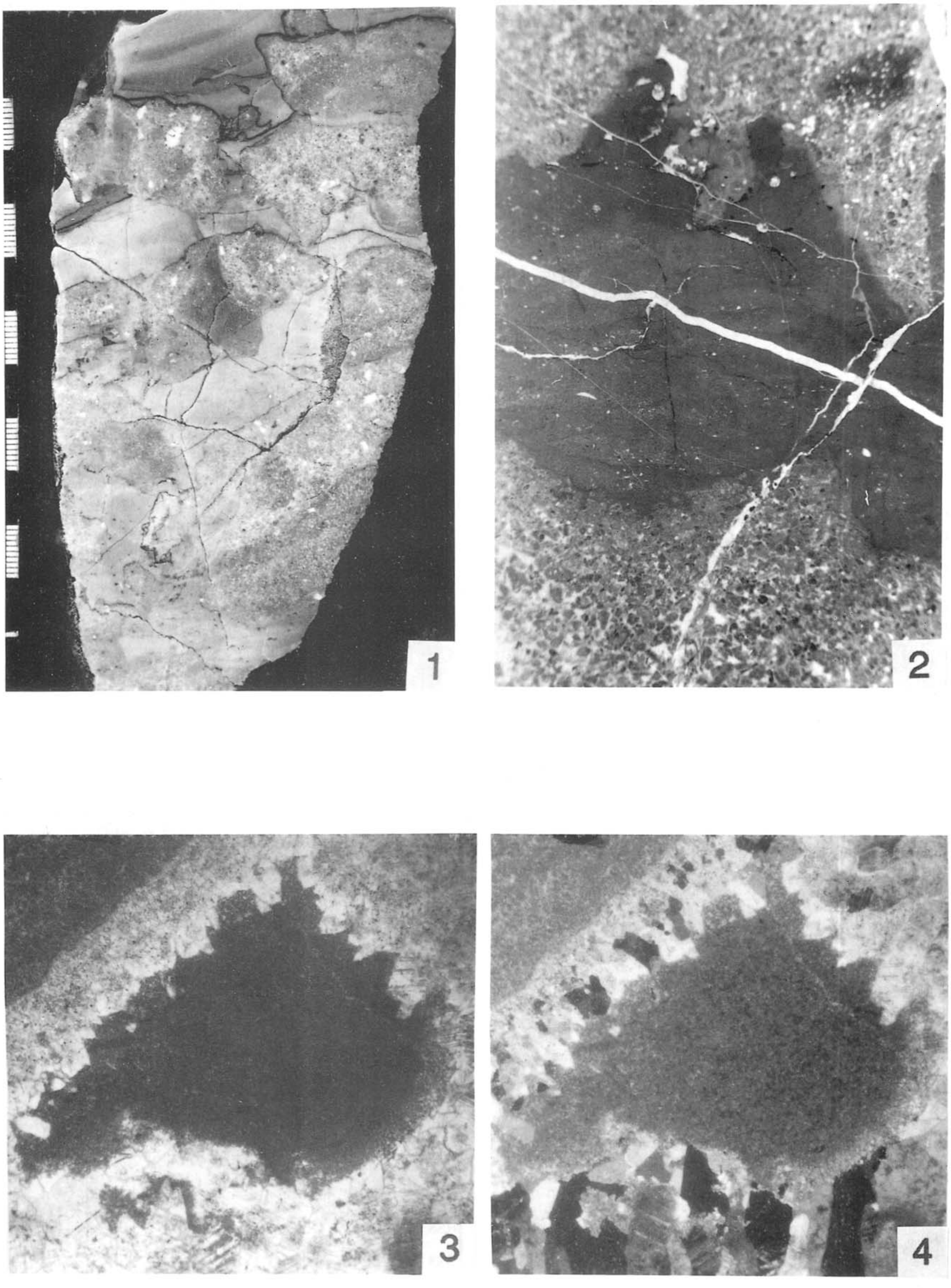


Fig. 5. Measured isotopic values $\delta^{18}O$ plotted versus $\delta^{13}C$.

Table 2: Isotopic composition of the carbonate cements.

Sample	Cement	$\delta^{13}C$ (‰ PDB)	$\delta^{18}O$ (‰ PDB)
HSS I 4	stromatolite - 1st generation	-4.1	-4.5
1/96/2	stromatolite - 1st generation	-4.5	-5.8
HSS I 1	stromatolite - 2nd generation	2.5	-1.4
HSS I 2	stromatolite - 2nd generation	3.1	0.3
HSS I 3	stromatolite - 2nd generation	3.1	-1.6
HSS I 6	stromatolite with crin. detritus	2.8	0.2
HSS I 10	RFC calcite	2.9	-1.5
1/96/1	RFC calcite	2.7	0.1
HSS I 8	crinoidal limestone (clast)	2.9	-1.7
HSS I 9	crinoidal limestone (void)	2.8	0.2
HSS I 5	void with *Pokornyopsis* sp.	3.2	0.4
HSS I 7	blocky calcite	3.0	-3.2
HSS I 11	blocky calcite	3.3	-0.2
1/96/3	blocky calcite	1.8	-2.1


1
2
3
4

The wider range of the $\delta^{18}O$, varying between -5.8 and 0.4 ‰ PDB probably resulted from the temperature variations during the precipitation of individual cements.

The second group consists of only two samples taken from the first generation of stromatolites (the number of measured samples was limited by other factors than the rarity of occurrence; I hope, in spite of this, the results are reliable enough). They display a considerable depletion of ^{13}C and slight depletion of ^{18}O, with $\delta^{13}C$ varying between -4.1 and -4.5, $\delta^{18}O$ from -4.5 to -5.8. Such values are typical for the carbonates precipitated from meteoric waters (enrichment of the light carbon isotopes is mostly due to the pedogenic processes). This result represents the first evidence of Jurassic freshwater precipitated carbonates in the Pieniny Klippen Belt and in the whole Western Carpathians.

Discussion

The described breccia differs from the Krasín Breccia Member in the type locality mainly by the complex cement filling and by the signs of karstification. It bears signs of repeated freshwater influence resulting in dissolution or cementation. However, some freshwater isotopic record could remain unrecognized, particularly in the cases of high rock-water interaction or the total absence of soil cover (the source of lighter carbon isotopes). Nevertheless, the possibility that two generations of stromatolites differing isotopically were formed in different environment, seems likely. The first one was most probably formed during the Bajocian-Bathonian emergence of the relatively rapidly lithified crinoidal limestone. The clasts derived from this limestone were initially cemented by the freshwater stromatolites probably in some stream or spring area. Such Recent stromatolites were dealt with many times in literature (in Western Carpathians for example Mišík 1982, recently also by Szulc & Smyk 1994). However, the examined locality is so far the only one containing Jurassic freshwater stromatolites in the Western Carpathians.

Other registered signs of freshwater influence (dissolutional features) postdate (or are partially synchronous with) the precipitation of radiaxial fibrous calcite and predate micritic void filling. As mentioned earlier, this might be a result of freshwater interference through the network of cavities (karstic or extensional fractures) some of which are represented by the present-day neptunian dykes occurring frequently in the Czorsztyn Unit. This interference ceased completely with submergence of the Czorsztyn Ridge during the Callovian-Oxfordian sea-level rise. The submergence is recorded by the facial changes as well as by the ending of the siliciclastic influx to the basin.

Plate VII: Fig. 1 — Laminated sterile micrite filling neptunian dyke in crinoidal limestone. Irregular walls of the dyke indicate its karstic origin. Polished slab. **Fig. 2** — Detailed view on the irregular walls of the neptunian dyke (see Fig. 1). Thin section. Magn. 4.4×. **Fig. 3** — Void rimmed by the radiaxial fibrous calcite and filled by sterile micrite. Note that in the lower part, the RFC crystals are cut, probably by freshwater etching. Thin section. Plane polarized light. Magn. 27× . **Fig. 4** — The same in crossed polars.

Conclusion

From recently available data, the following evolution can be reconstructed:

1. Crinoidal limestone was locally gradually emerged. The gradual shallowing was recorded in the laminated stromatolites with crinoidal detritus. Emergence and erosion then followed.
2. The clasts were partly coated with stromatolite coatings in the freshwater environment (spring or stream) and then reworked.
3. After placing in marine conditions the second generation of stromatolites was formed.
4. Later, after stabilization of the sediment, the isopachous radiaxial calcite cement precipitated in a marine environment. Even in this stage, the freshwater interference took place probably through the extensional fracture network. This resulted in the formation of small karstification features.
5. The remaining voids of breccia were then filled by crinoidal detritus, later by mudstone containing tiny *Bositra* shells. The final filling was represented by micrite frequently containing cavity dwelling ostracods *Pokornyopsis feifeli* (Triebel). Some relatively closed small pores were cemented by blocky calcite; some of them remained empty.

As the examined problem is not yet exhausted and every new sample brings new data, the future may bring some new discoveries in this locality. However, I hope that the main ones are already comprised herein.

Acknowledgements: The author is grateful to Dr. J. Soták for invaluable help with the arrangement of isotope analyses and for reviewing the paper. My thanks also belong to Prof. M. Mišík, Dr. M. Sýkora, Dr. J. Szulc (Kraków) for many useful consultations. Dr. M. Krobicki (Kraków) is gratefully acknowledged for his very kind hospitality during the excursion in the Polish part of the Pieniny Klippen Belt, as well as for the critical reviewing of this paper. The latter is also true for Dr. J. Michalík. Isotope analyses of Dr. J. Hladíková (Prague), microanalyses of Dr. J. Krištín and CL examinations of Dr. M. Wagreich (Wien) are also gratefully acknowledged. This paper benefitted from the GHD (1/1812/94) grant of the GAV agency as well as from the project "Geodynamic evolution of the Western Carpathians" managed by the Geological Survey of Slovak Republic.

References

Aubrecht R., 1993: Clastic admixture in Dogger crinoidal limestones of Czorsztyn Unit. *Geol. Carpathica*, 44, 2, 105-111.

Aubrecht R. & Kozur H., 1995: *Pokornyopsis* (Ostracoda) from submarine fissure fillings and cavities in the Late Jurassic of Czorsztyn Unit and the possible origin of the Recent anchialine faunas. *Neues Jb. Geol. Paläont. Abh.*, 196, 1, 1-17.

Aubrecht R. & Ožvoldová L., 1994: Middle Jurassic - Lower Cretaceous development of the Pruské Unit in the western part of the Pieniny Klippen Belt. *Geol. Carpathica*, 45, 4, 211-223.

Bathurst R.C.G., 1971: Carbonate sediments and their diagenesis. Developments in sedimentology 12., *Elsevier*, 1-620.

Birkenmajer K., 1963: Stratigrafia i paleogeografia serii Czorsztynskiej pieninskiego pasa skalkowego Polski. *Stud. Geol. Pol.*, 9, 1-380 (in Polish).

Kendall A.C., 1985: Radiaxial fibrous calcite: a reapraisal. In: Schneidermann N. & Harris P.M. (Eds.): *Carbonate Cements. SEPM Spec. Publ.* 36, 59-77.

Kornicker L.F. & Sohn I.G., 1976: Phylogeny, ontogeny, and morphology of living and fossil Thaumatocypridacea (Myodocopa: Ostracoda). *Smithsonian Contr. Zool.*, 219, 1-124.

Lohmann K.C., 1988: Geochemical patterns of meteoric diagenetic systems and their application to studies of paleokarst. In: James N.P. & Choquette P.W. (Eds.): *Paleokarst. Springer Verlag*, 58-80.

Mišík M., 1966: Microfacies of the Mesozoic and Tertiary limestones of the West Carpathians. *Veda*, Bratislava, 1-269.

Mišík M., 1979: Sedimentological a microfacial study in the Jurassic of the Vršatec (castle) klippe (neptunic dykes, Oxfordian bioherm facies). *Západ. Karpaty, Sér. Geol.*, 5, 7-56 (in Slovak, English summary).

Mišík M., 1982: Recent oncolites (algal nodules) from brooks in the Malé Karpaty Mts. *Západ. Karpaty, Sér. Paleont.*, 8, 135-144 (in Slovak, English summary).

Mišík M. & Aubrecht R., 1994: Source of rock fragments in the Jurassic crinoidal limestones of the Pieninicum (Klippen Belt, Western Carpathians). *Geol. Carpathica*, 45, 3, 159-170.

Mišík M. & Sýkora M., 1993: Jurassic submarine scarp breccia and neptunian dykes from the Kyjov-Pusté Pole klippen. *Miner. slovaca*, 25, 6, 411-427.

Mišík M., Sýkora M. & Aubrecht R., 1994: Middle Jurassic scarp breccias with clefts filled by Oxfordian and Valanginian- Hauterivian sediments, Krasín near Dolná Súča (Pieniny Klippen Belt). *Geol. Carpathica*, 45, 6, 343-356.

Monty C.L.V., 1995: The rise and nature of carbonate mud-mounds: an introductory actualistic approach. In: Monty C.L.V. et al. (Eds.): *Carbonate mud-mounds: their origin and evolution. IAS Spec. Publ. No.23, Blackwell*, Oxford, 11-48.

Muchez Ph., Viaene W. & Marshall J.D., 1991: Origin of shallow burial cements in the Late Viséan of the Campine Basin, Belgium. *Sed. Geol.*, 73, 257-271.

Myczynski R. & Wierzbowski A., 1994: The ammonite succession in the Callovian, Oxfordian and Kimmeridgian of the Czorsztyn Limestone Formation, at Halka Klippe, Pieniny Klippen Belt, Carpathians. *Bull. Pol. Acad. Sci., Earth.Sci.*, 42, 3, 156-163.

Reitner J. & Neuweiler F. et al., 1995: Mud Mounds: A polygenetic spectrum of fine-grained carbonate buildups. *Facies*, 32, 1-70.

Smart P.L., Palmer R.J., Whitaker F. & Wright V.P., 1988: Neptunean dykes and fissure fills; an overview and account of some modern examples. In: James N.P. & Choquette P.W. (Eds.): *Paleokarst. Springer Verlag*, 149-162.

Szulc J. & Smyk B., 1994: Bacterially controlled calcification of freshwater *Schizothrix*-stromatolites: an example from the Pieniny Mts., Southern Poland. In: Bertrand-Sarfati J. & Monty C. (Eds.): *Phanerozoic Stromatolites II. Kluwer Acad. Publ.*, 31-51.

Tucker M.E. & Wright V.P., 1990: Carbonate sedimentology. *Blackwell*, Oxford, 1-482.