NEW OCCURRENCES OF THE KRASÍN BRECCIA (PIENINY KLIPPEN BELT, WEST CARPATHIANS): INDICATION OF MIDDLE JURASSIC SYNSEDIMENTARY TECTONICS

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Key words: *Jurassic, Western Carpathians, Pieniny Klippen Belt, Czorsztyn Unit, sedimentary breccias, limestone diagenesis.*

Abstract: After three sites with Krasín Breccia (syntectonic sedimentary breccia of the Czorsztyn Unit) described in literature, three new occurrences have been found in the Middle Váh Valley in Western Slovak part of the Pieniny Klippen Belt: Babiná Hill, Babiná - quarry and Drieňová. Apart from their partial compositional variability, their genesis was common in stratigraphic range, paleogeographic position and facies development. As at previously described sites, the breccias consist of crinoidal limestone clasts, coated by at least one generation of stromatolite and then cemented by radiaxial fibrous calcite. The stromatolites appear at various levels of the breccia diagenesis. The remaining void filling starts at some localities by the crinoidal detritus which indicates that the breccia was formed due to synsedimentary tectonics still during the deposition of crinoidal limestones. The rest was filled by micritic limestone with "filamentous" microfacies, locally containing also *Globuligerina* sp. and the latest filling is by sterile micrite containing few allochems and fauna of cavity dwelling ostracods *Pokornyopsis* sp. The latest cement is represented by clear blocky calcite filling veinlets cutting the whole rock. Some generations of such veinlets are, however, older. Numerous instances of disturbance, resedimentation and recementation are evident in the breccias. Local etching of the clasts, together with some earlier generations of blocky-calcite veinlets indicates a presence of possible fresh-water diagenesis as was testified earlier at other sites.

1. Introduction

The Pieniny Klippen Belt (PKB), from the tectonic point of view, represents the most complicated zone of the Western Carpathians that underwent multiphase tectonic deformation which resulted in its typical inner structure, where harder rocks, namely Jurassic limestones, form tectonic lenses (klippen) enveloped by softer marlstones and claystones predominantly of Cretaceous age. The original lithostratigraphic composition of the units forming the present PKB and their paleogeographic relationship is still subject of extensive investigations. One of the lithostratigraphic units, that were revealed relatively not long ago, is Krasín Breccia, a reflection of synsedimentary tectonics in the Czorsztyn Unit.

The formation of Czorsztyn Swell in the sedimentary area of the present Pieniny Klippen Belt during the Middle Jurassic (Bajocian) was accompanied by extensive synsedimentary tectonics. It was expressed by neptunian dykes (Birkenmajer, 1958, Mišík, 1979) and Krasín Breccia (Mišík et al., 1994, Aubrecht, 1997). Hitherto, only three occurrences of this breccia were described, occurring only in the western part of the Pieniny Klippen Belt. The first one was found at Krasín quarry near Dolná Súča and became the type locality of the breccia (Mišík et al., 1994). The second occurrence, with more complex interstitial voids filling, was found near Horné Srnie at the local part Samášky. This occurrence was treated in detail by Aubrecht (1997). Other small occurrence was found at a locality at the end of Bolešovská dolina Valley (Aubrecht et al., 1998).

The so far known data have shown that the Krasín Breccia represents a synsedimentary breccia to megabreccia formed exclusively of angular to rounded crinoidal limestone clasts (Bajocian) with more or less commonly developed stromatolitic crusts on them, representing the first cementing medium of the breccia. The interstitial voids are usually still filled by more or less complex filling including isopachous crusts of radiaxial fibrous calcite (not necessarily developed), then by crinoidal detritus indicating still active deposition of crinoidal limestone. This sometimes transits into "filamentous" packstone to wackestone, exhibiting a relative deepening of the sedimentary area. According to the latest research, this facies change in the Czorsztyn Unit, corresponding to change from the deposition of crinoidal limestones to nodular limestones, occurred mostly still in Bathonian (Rakús, 1990, Wierzbowski et al., 1999), though formerly a Callovian age of this onset was supposed to be predominant (Birkenmajer, 1963, 1977). The latest filling of the interstitial voids is commonly represented by relative sterile micrite, with some occurrences of autochthonous cavity-dwelling fauna e.g. ostracods (Aubrecht, Kozur, 1995) indicating gradual closing of communication between voids and open sea. The most isolated remaining voids were finally filled by clear blocky calcite or remained empty.

The detailed field and petrographic description of three newly found occurrences is the aim of this paper. Some of them were treated marginally by Aubrecht et al. (1997) in a summarizing paper.

2. Location of the new occurrences of the Krasín Breccia

The first of the three new sites of occurrences of the Krasín Breccia was found in a klippe on the top of Babiná Hill near Krivoklát Village (fig.1, 2B). The second one is situated in the quarry at the toe of the same hill, near the road between Bohunice and Krivoklát (fig.1, 2A). The locality has been described in detail by Mišík et al. (1994a), however, without mentioning of the Krasín Breccia which was not recognized at that time. The third locality has been revealed on the northern slope of Drieňová Klippe on the opposite side of the Krivoklát Valley (fig.1, 2C). The klippe was investigated by Jurkovičová (1980). She mentioned also the breccious parts with crustification cements but she attributed them mostly to the Oxfordian fore-reef breccias of Vršatec Limestone.

3. Babiná Hill

The breccia, with all of its components, is well observable in form of weathered debris surrounding the northern part of the klippe. It is not easy to see the breccia in the klippe itself for the vegetation cover and poorly discernible clasts and matrix, even after breaking by hammer. There seem to be a continuous transition from the crinoidal limestone to the Krasín breccia through zone containing only the crinoidal limestones and veinlets filled by RFC. Similarly as at Horné Sŕnie - Samášky locality (Aubrecht, 1997), the breccia consists of crinoidal limestone clasts with complex stromatolitic and RFC coatings and void fillings, represented by crinoidal grainstone or, somewhat younger, wackestone.

Clasts are represented by white to light-grey crinoidal limestone (Smolegowa Limestone of Birkenmajer, 1977) and several later components of the breccia. This suggests that the synsedimentary tectonic movements, connected with reworking, were still active even after the initial formation of the breccia. All these different clasts are composed of laminated stromatolites (Pl.II, fig.4), other non-laminated clotted and peloidal microbialites and radiaxial fibrous calcite (RFC) (Pl.IV, fig.4).

Crinoidal limestone is predominantly rich in sandy admixture. Grain size of the limestones is variable, from coarse-grained to micritic (Pl.I, fig.2), sometimes gradually passing into stromatolites and non-laminated microbialites, like at the Horné Sŕnie - Samášky locality. The sandy admixture is formed by medium to coarse quartz grains, up to small pebbles (Pl.I, fig.1). The grains are often angular with signs of corrosion. The quartz is usually polycrystalline with sutured intergranular boundaries (Aubrecht, Sýkora, 1998). Some K-feldspars and garnet, rutile and zircon grains were found also. In one instance, a sandstone clast with carbonate matrix was found. The principal components of the limestone are crinoidal ossicles; bryozoan skeletal remnants and echinoid spines are frequent also. Among the others, the foraminifers *Marssonella* sp., *Ammodiscus* sp., *Lenticulina* sp., sessile nubecularid foraminifers, nodosariid and various agglutinated ones (i.e. *Ophthalmidium* sp.) and rare "microforaminifers" (likely preserved inner Fe coatings of foraminiferal tests) are present in the limestone. Shells of bivalves, gastropods, ostracods and brachiopods are ubiquitous, frequently forming only dissolved molds after aragonite with micritic rim, filled by blocky calcite. Some oyster-like shells were found, bearing traces of boring sponges. Serpulid and Spirorbis tubes are rarity.

Matrix of the limestone is, similarly as the skeletal remnants, full of inclusions. The matrix is formed mainly by microsparite, probably recrystallized micrite. The original brown to red micrite is preserved mainly as fill in the skeletal remnants. The inclusions in the rock might come partially from this micrite. Nevertheless, this cloudy appearance is typical just for the crinoidal limestones in the breccia; unaffected crinoidal limestones are clearer in thin sections. Therefore, we suppose that the inclusions are somewhat related to the diagenetic processes that took place in the breccia. At the contact with voids, the skeletal remnants are not overgrown by syntaxial cements, but instead they are rimmed by radially arranged rhombohedral calcite. Similar layer in some instances directly precedes the RFC calcite.

In some samples, the crinoidal limestone gradually changes to biosparite comprising rarer crinoids but more frequent bivalves, gastropods, brachiopods and juvenile ammonoids (Pl.V, fig.1-2). Such facies may reflect somewhat later (Bathonian to Callovian) microfacies change that is usually present in the Czorsztyn Unit.

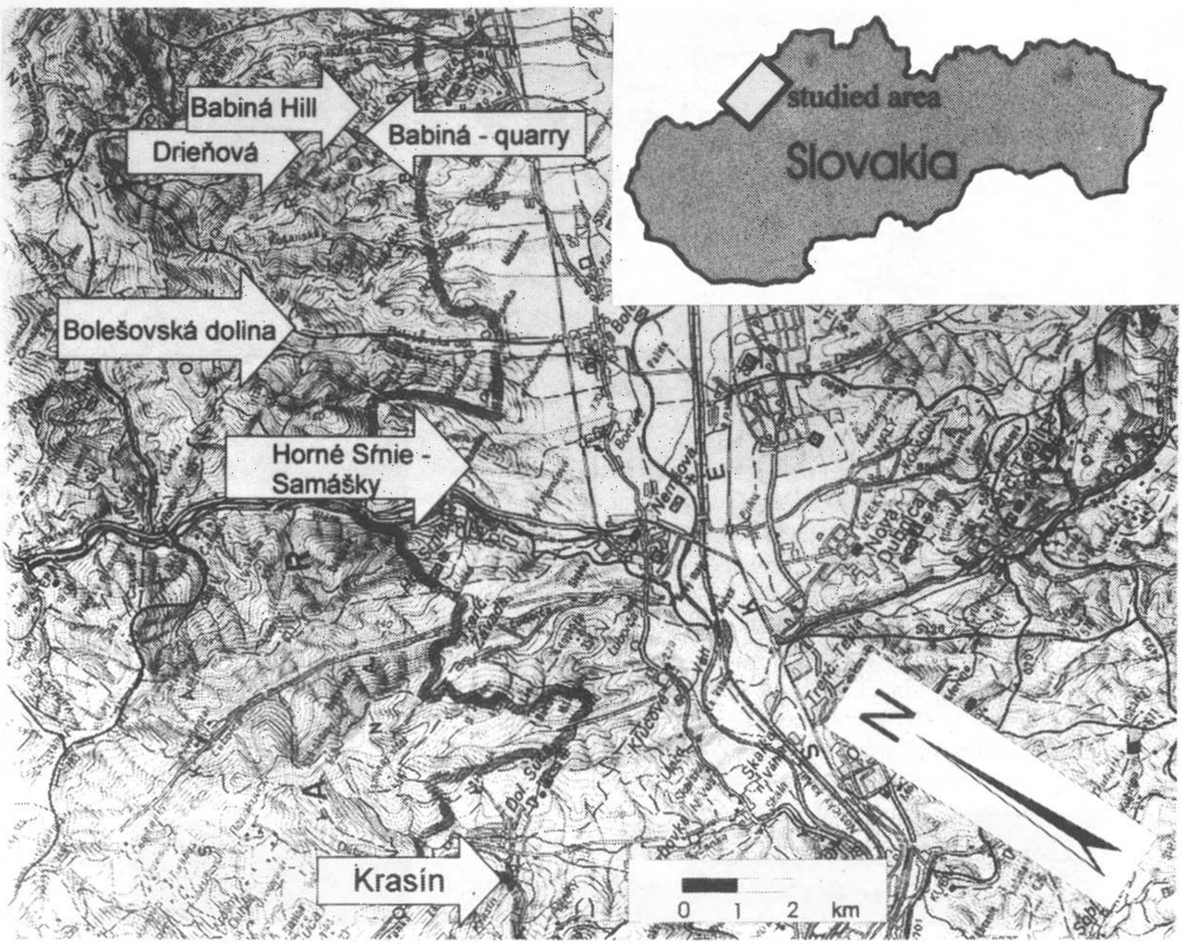

Fig.1 Position of the studied localities

Stromatolites and non-laminated microbialites are not so excellently developed as they were at Horné Sŕnie - Samášky locality. The stromatolites possess laminated structure as a result of seasonal changes during the growth (Pl.I. fig.4), whereas the non-laminated microbialites. originated probably by bacterial activity in an environment free of light, possess pelmicritic to clotted fabrics (Pl.IV. fig.4, Pl.V. fig.3). Because of the lack of proper evidence, the microbial origin is only supposed. However, the other ways of the origin of peloids, i.e. micritization of skeletal remnants and faecal peloids, can be ruled out, as skeletal detritus is usually not present in this stage of development and the faecal pellets tend to be arranged more regularly. Both, stromatolites and non-laminated microbialites. predate, postdate or are generally synchronous with precipitation of the RFC. Their contemporaneous origin is observable in several thin-sections, where the stromatolites and RFC intergrow each other (Pl.I. fig.3-4, Pl.II, fig.3). The stromatolitic laminae are slightly deformed in the places where they are cut by RFC crystals. Possible later neomorphism of RFC after stromatolites can be ruled out for no relics of stromatolitic structures are preserved in the RFC crystals cutting the stromatolite. It is noteworthy that at the places where the RFC crystals penetrate into the stromatolite, the latter possess distinct fine lamination, whereas out of reach of the crystals, the lamination is faint to none. In some instances, this phase was represented also by dense structureless micrite (transiting into pelmicrite), frequently with burrows filled by bladed, later by blocky calcite. Both are full of inclusions. Some burrows possess later pendant micrite to pelmicrite filling. Filling of the burrows indicates that they originated after the sediment was lithified.

Interstitial void fillings are of several generations, being disturbed by active synsedimentary tectonics, which makes the relative dating of individual generations difficult.

Radiaxial fibrous calcite (RFC) represents an undulatory extinguishing type of calcite (converging away from the substrate), bladed in parallel cross-section, usually full of inclusions, frequently with typical convex-down twinning lamellae. If combined with the perpendicular cross-section, however, an actual fibrous to columnar character of its crystals is discernible. RFC coats mainly the calcareous clasts in the breccia. However, one instance of overgrowing of a small quartz pebble was registered also. Sometimes the RFC is zoned, with older zones being more cloudy than the younger ones (Pl.III, fig.1-3). It might be caused by gradual decrease of

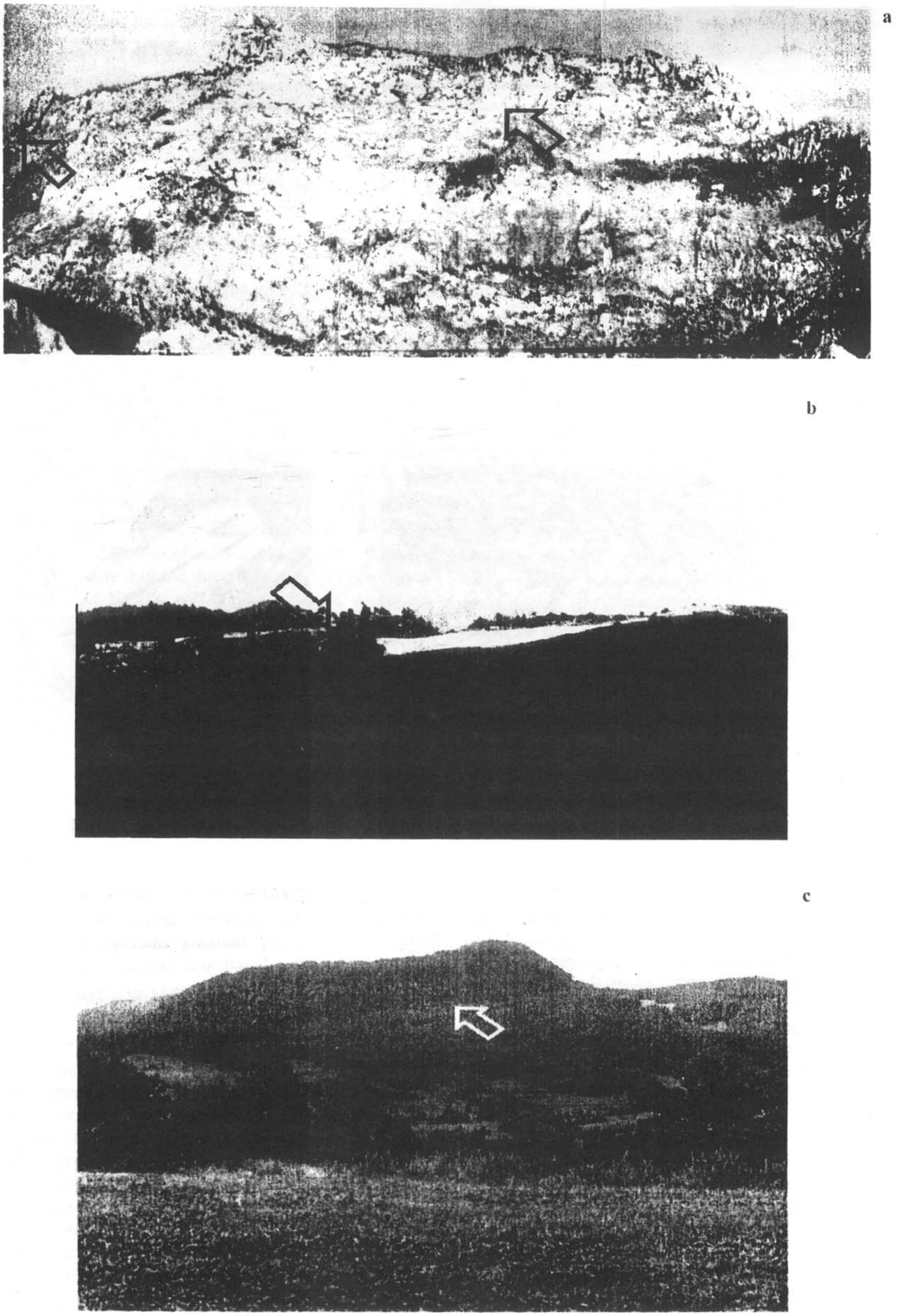

Fig.2 Field views on the studied localities: a) Babiná - quarry, b) Babiná Hill, c) Drieňová - northern slope (arrows show location of the Krasín Breccias).

crystal growth rate (Saller, 1986). RFC growth was locally slowed down by influx of micrite which now forms thin interlayers. In some samples, several generations of RFC are observable (Pl.IV, fig.1-2). Besides coating and connecting the clasts, RFC fills also some later fractures originated due to synsedimentary tectonics (Pl.IV, fig.3). In one instance, the veinlet filled by RFC cuts the clast coated by an older generation of RFC but did not penetrate through the younger sedimentary void filling, which enabled its relative dating. Some samples contained also RFC as clasts in the breccia (Pl.IV, fig.4).

In some samples, however, the RFC is partially missing, which can be explained by good access of the interstitial void space for the surrounding sediment (Pl.VI, fig.1-3). Filling of the voids by sediment prevented growth of the RFC in these parts; only thin equant to bladed calcite layer developed before the final sedimentary filling (Pl.VI, fig.3).

Crinoidal limestone in the voids (Pl.III, fig.1-2) differs from that in the clasts by its higher content of micrite, representing packstone to wackestone. This change is likely related to the gradual deepening of the sedimentary environment and decrease in hydrodynamics. This fact is reflected in the major part of the Czorsztyn Unit by gradual transition from the white crinoidal limestone (Smolegowa Lst.) to the red one (Krupianka Lst.). Besides the components present also in the previous type of crinoidal limestone (in clasts), the limestone filling the voids contains more "filaments" (cross-sections of thin-shelled bivalves *Bositra* sp.), thin-shelled non-sculptured ostracods, much more foraminifers and individual juvenile ammonoid tests. The crinoidal filling often alternates with, or transits to layers of stromatolites (Pl.III, fig.2, 4) or pelmicrites (likely microbialites).

Stromatolites and pelmicrites (non-laminated microbialites) filling the voids are by their character close to those mentioned before. The only difference is presence of "filament" detritus and rare quartz grains trapped in their fabric.

Micrites (wackestones) are present also in some samples, especially in those, where the RFC absents (Pl.VI, fig.1-3). They are very fine red micrites with dispersed tiny crinoidal ossicles, thin bivalve shells ("filaments"), smooth-shelled ostracods, bryozoan fragments, indeterminable foraminifers, "microforaminifers" and scarce quartz grains. The micrites frequently pass into the aforementioned pelmicrites.

Clear blocky calcite fills sometimes the latest unfilled porosity in the rock (Pl.IV, fig.3).

Late calcite veinlets represent the latest cement generation. The veinlets cut the entire rock with clasts, cements and void fillings. As a rule, they are filled by clear blocky calcite (Pl.III, fig.4, Pl.V, fig.4). In one instance, the veinlet was partially geopetally filled by micrite.

4. Babiná - quarry

The breccia occurs mostly within the crinoidal limestones in the higher part of the quarry, where it occurs directly within the crinoidal limestone as probable larger cleft filling, as well as at the left part of the quarry, where it is related to networks of neptunian dykes. Both types contain various fillings of interstitial voids but more complex fillings are in the central part of the quarry (Pl.VII, fig. 1). Nevertheless, some breccia blocks were found with clasts of crinoidal limestones with simple matrix formed also by crinoidal limestone, free of any additional cement crusts (Pl.VII, fig. 2). Moreover, most of such breccias possess the clasts of red, whereas the matrix is of white crinoidal limestone (Pl.VII, fig. 4), i.e. just opposite to division of Birkenmajer (1977) where the red crinoidal limestone (Krupianka Lst.) should be younger than the white crinoidal limestone (Smolegowa Lst.). This contradiction was mentioned already by Mišík et al. (1994a) and Aubrecht et al. (1997).

As at the previous locality, some veinlet networks of RFC are present locally (Pl.VII, fig. 3), also having possible connection with synsedimentary tectonics (RFC indicates still marine cementation).

Both breccias have angular to subangular clasts, more or less developed RFC (mainly in the breccias from the central part of the quarry), stromatolites (pre- or postdating the RFC, mainly in the left part of the quarry) and latest, predominantly micritic filling (red in the left part of the quarry and yellowish in the central part) and blocky calcite filling the veinlets and occluding the remaining porosity.

Clasts - crinoidal limestones. Their all lithological and microfacies characteristics are almost identical with those at the previous locality. The rock is again full of inclusions (namely crinoidal ossicles and syntaxial cement); only in larger interstitial voids between grains, the cement is clearer (Pl.VII, fig. 5). The surface of skeletal remnants is commonly micritized. Unlike at the previous locality, not all crinoidal limestone clasts are sandy. Among the clastic admixture there are also more common yellowish clasts of dolomite (dedolomitized).

As is evident from some allochems that are cut at clast margins, the rock has been well lithified prior of being incorporated into the breccia. However, there are some indications of the synsedimentary tectonics directly in the clasts as they are commonly fractured, with fractures sometimes heeled by a calcite resembling a short-bladed RFC, but originated evidently still before formation of the main breccia body. They represent practically a breccia in breccia. Some limestone clasts even possess an unusual texture. They are penetrated by a framework of thin irregular veinlets lined by laminated micrite which may represent traces after plant roots (rhizocretions) that penetrated the sediment (Pl.VIII, fig. 2). Those crinoidal limestone clasts than achieved an appearance of an initial caliche crust (for overview see Tucker, Wright, 1990, p. 343-346). It indicates a possible exposition of the limestone to pedogenic processes during a short-time emergence of the sedimentary area. Irregular surface of some clasts probably underwent leaching and karstification in fresh-water environment (Pl.IX, fig. 2).

Spongolites - occur as clasts only in several samples. They represent spiculite-crinoidal-organo-detritic limestones (Pl.VIII, fig. 1) containing mainly calcified rhaxa (spherical sponge spicules), seldom monaxone to tetraxone spicules, rare sandy quartz grains, fragments of bryozoans, bivalves (also "filaments"), echinoderm particles (being dominant at some places), tubes of serpulid worms, foraminifers, *Lenticulina* sp., nodosariid and nubecularid foraminifers, various agglutinated foraminifers e.g. *Ophthalmidium* sp., microforaminifers (probable original organic matter lining the juvenile chambers replaced by Fe-oxides; the original tests have been dissolved - see Mišík - Soták, 1998) and single ooid. The matrix of the rock is pelmicritic, probably of microbial origin as indicates its relationship to the spicules. Pelmicrites originate commonly in sponge bodies as a result of calcification of colonies of symbiontic bacteria (Bourque, Gignac, 1983, Reitner et al, 1995 and literature cited therein).

Stromatolites as crusts overgrowing the clasts are developed just rudimentary. They are well or indistinctly laminated, often with peloidal texture. No broken stromatolites forming independent clasts have been found.

Interstitial void filling - radiaxial fibrous calcite (RFC) is developed just locally, mostly in the middle part of the quarry. The RFC locally pass into radial-fibrous calcite which possess uniform extinction and straight twinning lamellae (see Kendall, 1985). The RFC itself is commonly imperfectly developed, often without well-visible shape of crystals, deformed lamellae etc.; typical well-developed RFC occurs locally. Where developed, it use to be also multilayered, with the first layer lighter and the rest darker which is influenced by different amount of inclusions. At some places, the RFC is intergrown with stromatolitic laminae. More commonly, the RFC has grown freely into the void, as indicated by some cave-dwelling ostracods *Pokornyopsis* sp. (Aubrecht, Kozur, 1995) "caught" in the RFC crystals. RFC sometimes fills also thin veinlets in the breccia clasts. The veinlets are sometimes branching and pinching out, further continuing as parallel laminated micrite filling. The RFC also covers some marginal allochems of the clasts or whole pieces of clasts broken off the clast margins. At some places, an apparent leached surfaces of the clasts and their allochems (e.g. crinoidal ossicles) can be seen at the contact with RFC (Pl.VIII, fig. 4). At such corroded contact, tiny peloids are commonly found. As they were found by the author also at other similar instances (e.g. RFC/wall-rock contact in some stromatactoid voids in Bathonian-Callovian mud-mounds recently found in the Czorsztyn Unit, see Aubrecht, Szulc, 2000), the peloids might play some, yet unidentified, role at leaching and corrosion of the limestones.

The RFC was sometimes also subjected to leaching, as indicated by some cases of bizarre cut of RFC crust at contact with later sedimentary void filling (Pl.IX, fig. 3). At some RFC/late blocky calcite contacts, a brown limonitic coat has been developed.

Stromatolites - represent commonly one of the initial void fillings, post-dating the RFC, if present, and predating other generations of sedimentary filling. Like at other void fills, the Pokornyopsis ostracod tests are overgrown by void stromatolites (Pl.VIII, fig. 3). In one instance, numerous allochems have been trapped in void stromatolite, reflecting microfacies change in the Czorsztyn sedimentary area. Echinoderm particles gradually give way to "filaments" (thin-shelled bivalves) in the upper stromatolite laminae (Pl.IX, fig. 4). There was also a single case, when the first sedimentary filling post-dating the stromatolites and predating the micritic filling was a fine-grained crinoidal grainstone (Pl.X, fig. 2). According to the latest data of Rakús (1990) and Wierzbowski et al. (1999), the change from crinoidal grainstone to "filamentous" packstone microfacies in this unit is typical for Late Bajocian-Bathonian, instead of Callovian as thought before by Birkenmajer (1963, 1977). This, together with the breccias with crinoidal limestone matrix mentioned earlier, enables dating of start of the breccia-forming process to Bajocian; its peak, however, has to be placed to Bathonian-Callovian, where there is the maximum development of the "filamentous" microfacies in the Czorsztyn Unit.

Micritic sediment (wackestone to packstone) is represented mainly by "filamentous" microfacies. Pokornyopsis ostracods are also common, together with tiny smooth-shelled ostracods of different genera, other kinds of bivalves (with thicker shells), planispiral foraminifers, foraminifers *Lenticulina* sp.; rare are gastropods and echinoderm particles. Isolated rare occurrences of *Globuligerina* sp. specimens, preceding their mass occurrence in "Protoglobigerina" microfacies (beginning at Callovian/Oxfordian boundary in the Czorsztyn Unit - Wierzbowski et al., 1999), can be found too (Pl.X, fig. 1). The sediment is commonly bioturbated.

The remaining void fillings from the time, when the communication with open-marine environment was already largely restricted, are represented by almost sterile red to yellowish micrite. It contains just local tiny allochems as crinoidal ossicles, broken "filaments" etc. In this phase, however, the cavity-dwelling ostracods Pokornyopsis are more common.

Blocky calcite is usually the latest generation filling the interstitial voids of the breccia. It is clear, locally twinned, with few black inclusions. The crystals are equant; no drusy appearance (increasing of the crystal size towards the centre) has been observed.

The blocky calcite fills also younger veinlets cutting irregularly all the previous generations of cements and sedimentary fillings. Where dense, they make the relative dating of the individual components of the breccia difficult. The veinlets even locally enclose fragments of micritic matrix with filamentous microfacies. Some local recrystallization of the micrite to microsparite has been observed at the contact with the blocky calcite filling.

There had to exist also some earlier generations of veinlets with blocky spar as indicated by a case, where there is the initial sedimentary filling of the interstitial void formed by fine-grained crinoidal limestone (Pl.X, fig. 2). The crinoidal detritus partially fell down to veinlet filled by zoned blocky spar (at that time it had to be at least partially open fracture). This indicates that the veinlets originated still during sedimentation of the crinoidal limestone (Bajocian-Bathonian). Why the rest of the veinlet is filled by blocky and not by fibrous calcite, at that time normal marine cement, is enigmatic. Maybe, some carbon and oxygen isotope analyses will be needed to resolve this problem.

5. Drieňová

The Krasín Breccia was found at northern foot of Drieňová Klippe. Due to extensive vegetation cover, the best samples were found in blocks and debris below the klippe. The relationship between the breccia and the surrounding limestone was not visible on the outcrops. The outcrops were formed exclusively by undisturbed grey crinoidal limestones. The breccias could be found in the debris at various places along the outcrop wall. Therefore, our opinion is that the breccias represent filling of local clefts in the crinoidal limestone, being probably related to synsedimentary extensional tectonics.

The breccia, clasts and cements, is of light-grey colour. The clasts are exclusively crinoidal limestones; the interstitial filling is represented by laminated stromatolites, isopachous crust of fibrous calcite and sterile micrite or blocky calcite, respectively (Pl.X, fig. 3, 4; Pl.XI, fig. 2, 3).

The clasts - crinoidal limestones - are usually angular, though the stromatolitic crusts make them seemingly less angular. Their surface is commonly irregular what may indicate some leaching or even karstification. At some samples it was not for certain whether the complex sedimentary and cement filling rested in an interstitial void or it was just a karstic cavity in the limestone. Crinoidal limestones represent crinoidal biosparitic grainstone to local biomicrite. Syntaxial rims around the ossicles are not developed or they are very thin. The sediment is well sorted as indicated by similar size of all the allochems. The limestones are rich in sandy quartz admixture. Besides the quartz grains, some tiny lithoclasts of micritic and pelsparitic limestones and calcareous siltstones were found. The faunal content is complemented by fragments of bivalves and brachiopods, echinoid spines, bryozoans (also cyclostome forms), numerous micritized indeterminable skeletal fragments. Less common were tubes of serpulid worms, ostracods, gastropods, sessile nubecularid foraminifers, various benthonic agglutinated foraminifers, foraminifers *Lenticulina* sp. and nodosariid foraminifers. The clasts are often penetrated by irregular "microdykes" filled with clotted to peloidal micrite, coming from the enveloping stromatolitic crusts. Similar is the matrix surrounding some crinoidal ossicles or other allochems (Pl.XI, fig. 1), which indicates a microbial cementation of the crinoidal limestones themselves. Such cases have been described also from modern beach carbonate sediments (e.g. Webb, 1999). In some microdykes, a short-bladed fibrous calcite is present, seemingly grown at the expense of clotted matrix micrite.

Except the crinoidal limestones, a single clast with crinoid spiculitic microfacies has been enregistered. It was much less sandy, but with allochems (if not taking into account the sponge spicules) similar to those in the crinoidal limestone.

Stromatolitic crusts - except of grey colour instead of white to creamy, the stromatolitic crusts are similar to those found at other localities. They cover the individual clasts, in some instances they cement several clasts together, mostly still before forming of RFC (Pl.XI, fig. 2, 3). The crusts are from several mm to several cm thick; the thickness is, however, not equal, as the stromatolites fill the irregularities on the clast surfaces and make them smooth. They have thin, usually slightly wavy lamination, but locally the lamination shape is undulose to spherical, forming even oncoidal bodies (Pl.XI, fig. 4). Some tiny smooth-valved ostracods and microforaminifers represent the only fauna trapped in the stromatolites (Pl.XII, fig. 1). Tiny voids left within the stromatolites are filled by fine-crystalline spar. Some faintly laminated stromatolitic varieties with peloids are common too. Calcified filaments of blue algae are visible mainly at the contact with RFC (Pl.XII, fig. 2). Some discontinuous thin stromatolitic layers have grown also within the RFC. As mentioned earlier, the stromatolites form also individual fragments enclosed in the RFC; in other instances, the stromatolite crusts together with covered clasts were broken and later overgrown by the RFC. That indicates that the stromatolites once covered the clasts, were disturbed and cemented again by the RFC or another generation of stromatolite. In this sense, they still represent the clasts and not the interstitial void filling. The stromatolites covered the clasts, which were not always lithified as indicated by stromatolites penetrating to the clasts or even covering individual allochems at the margins of crinoidal limestone clasts (Pl.XII, fig. 3).

Interstitial void filling - radiaxial fibrous calcite (RFC) - represents typical sort of calcite as defined by

Kendall (1985), i.e. with undulatory extinction converging away from the underlying surface, convex-down deformed twinning lamellae and plenty of inclusions (only one clear rhombohedral crystal was found in RFC, which may represent some later stage of alteration). These typical signs are, however, not always fully developed. The RFC crystals are of the same length and thus the RFC forms isopachous cement grown, as a rule, in several layers. Their boundaries are often indistinguishable in thin sections. In some cases, the initial stages of RFC were clearer than those growing towards the centre of the void (also the terminations of RFC crystals use to be clearer). Otherwise, the individual RFC layers are marked by thin stromatolitic or micritic interlayer.

Micritic limestone filling the centres of the interstitial voids is almost sterile (Pl.XII, fig. 4) brownish-grey micrite to pelmicrite, only locally including some tiny crinoidal ossicles, their fragments and other, indeterminable allochems. Locally, the micrite fills the void geopetally, with the rest filled by clear blocky calcite.

Blocky calcite occurs locally in the remaining voids as the latest cement. It fills also the late veinlets cutting the whole rock. The blocky calcite consists of clear anhedral crystals with perfect cleavage, locally with twinning lamellae, in some instances with dark inclusions.

6. Discussion and conclusions

All of the described new occurrences of Krasín Breccia yielded approximately the same genesis pattern and occur in similar stratigraphic and paleogeographic position. They originated by disturbation of early-lithified crinoidal limestones of the Czorsztyn Unit, still during their sedimentation or early after it (late Bajocian to Callovian). Multiple disturbation and reworking indicate longer-time activity of this process. The breccias are mostly closely related to formation of neptunian dykes in this area. They both originated due to synsedimentary tectonics related to opening of Penninic-Vahic Ocean, via crustal extension and tilting of the Oravic crustal block. The clasts of the breccias are mostly crinoidal limestones or, to much lesser extent, coeval calcified spongiolites. Irregular etching of some clasts predating the RFC cementation, possible pedogenic reworking of some limestone clasts and occurrences of some blocky-calcite veinlets clearly predating some later marine cements and fillings (all at Babiná -quarry locality) provide next evidence of partial synsedimentary emergence and weathering of Bajocian-Bathonian crinoidal limestones in the Czorsztyn sedimentary area, except those mentioned previously by Aubrecht (1997).

Apart from similarity in clasts, the proportion of the void filling and cement generations is different at individual localities. There is also interesting difference between filling of the neptunian dykes and the interstitial voids of the breccias despite that they originated due to the same tectono-sedimentary process. The stromatolitic filling of the dykes is much rarer and the RFC lacks completely.

The isotope record at Horné Sŕnie-Samášky locality showed, that there were both fresh-water and marine stromatolites. The first type could reflect erosion and stromatolitic cementation of the crinoidal limestone on land (Aubrecht, 1997), the second type cemented the breccia after deposition in marine environment. The latter type surely includes endostromatolites that grew in cavities (interstitial voids) without access of light and, therefore, representing products of non-photosynthetic organisms (Monty, 1982). Such stromatolites and other types of microbialites are common also in cavities in recent reef environments (Reitner, 1993, Reitner et al, 1995).

The radiaxial fibrous calcite represents typical marine cement of fossil limestones. Apart from discovery of the RFC in Miocene (Saller, 1986) and Pleistocene limestones (Sandberg, 1985), it lacks in Holocene limestones and thus study of its origin is not possible in modern environments (for overview see Tucker, Wright, 1990, p.332). RFC was formerly presented as a result of replacement of acicular aragonitic precursor (Kendall, Tucker, 1973), but later an idea of its primary origin prevailed (Kendall, 1985). Monty (1982a, 1995, p.28-33) pointed to a possible interconnection between calcifying microbes and fibrous calcite cements, which concerns also this study. Monty (l.c.) found some filaments presumably of microbial origin in radiaxial and fascicular-optic mosaics. Another example of neomorphism of fibrous calcite after stromatolites was presented by Cross & Klosterman (1981). In our case, namely at Babiná Hill locality, the RFC and stromatolites are clearly coeval as the RFC penetrates and deforms the stromatolitic laminae. No one may say, however, that the RFC grew due to activity of the bacteria forming the stromatolite mats. Their relationship seems to be rather competitive than stimulative. More commonly, the stromatolites form laminae between different generations of the RFC, which indicates that microbial mats inhibited and interrupted the RFC growth rather than supported it. RFC is, as majority of authors infers, product of marine cementation requiring large amounts of marine water to be pumped through the cavities. Any microbial mat or sediment covering the RFC would cut it from marine water access and then stop (or at least largely restrict) its growth. This is also the reason of ubiquity of RFC in relatively sheltered interstitial cavities of the breccia and its lack in neptunian dykes, where sediment could enter freely.

The micritic filling of the interstitial porosity in the breccia is commonly almost completely sterile (e.g. at Drieňová locality) that indicates good filtration of the entering sediment. As one can hardly imagine such situation occurring among clasts freely resting on the sea floor, such breccias most likely had to form cleft fillings, out of reach of free marine sedimentation.

From the obtained facts we can create two models of origin of the breccias: 1. breccia formed by emergence, erosion, sedimentation and multiple disturbation and recementation on the sea floor, 2. breccias formed by synsedimentary tectonics as cleft fillings (simultaneous with opening of neptunian dykes). This two processes might be (and most probably were) interconnected and combined. Therefore, it is difficult either to strictly discern between these two types of the breccias or to state which one of the both processes prevailed at the individual site. Additional carbon and oxygen isotope analyses of cements which are now in preparation, together with comparison of chemical composition of altered and unaltered crinoidal limestones, can shed more light onto this problem in the near future.

Acknowledgements

My thanks belong to those who helped me in preparation of this paper. Prof. M. Mišík provided critical comments to the earlier versions of this paper, Mgr. J. Schlögl helped me with field sampling, V. Tekula and D. Košťál have made excellent thin-sections and slabs, the photos were made by L. Osvald. This paper is a contribution to project "Tectogenesis of the sedimentary basins of the Western Carpathians" managed by the Geological Survey of Slovak Republic. Additional financial support was provided by grants No. 1/6169/99 and 1/7293/20 of VEGA agency.

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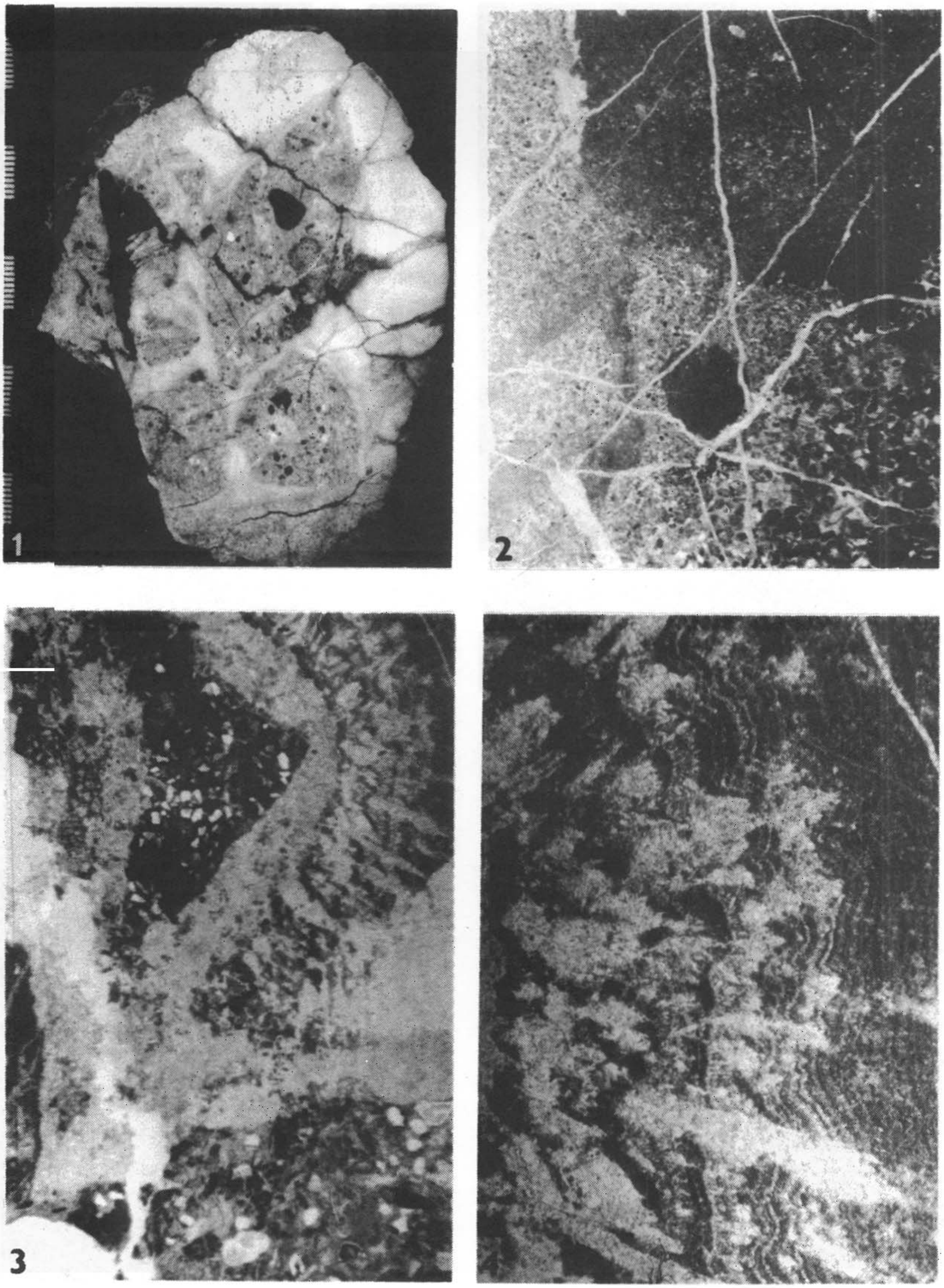

Plate I Microphotos from the Babiná Hill locality

Fig.1 - Krasin Breccia with complex void filling. Note the angular and subangular clasts cemented by radiaxial fibrous calcite. Note also rich sandy to small pebble-size detrital quartz admixture in the limestone clasts. Sample BV1 (all plates photo: L. Osvald)) - polished slab. **Fig.2** - Irregular changes in grain size of the crinoidal limestone (clast in the Krasin Breccia). Sample BV16, thin section No. 24'090, magn. 4x. **Fig.3** - Intergrowing of RFC and stromatolite documenting their nearly synchronous origin. Sample BV1, thin section No. 23'588, magn. 8x. **Fig.4** - Detail from the previous. Note that the stromatolite bands are slightly deformed in the places of RFC penetration. The deformation fades rightward, off the RFC crystals. Magn. 30x.

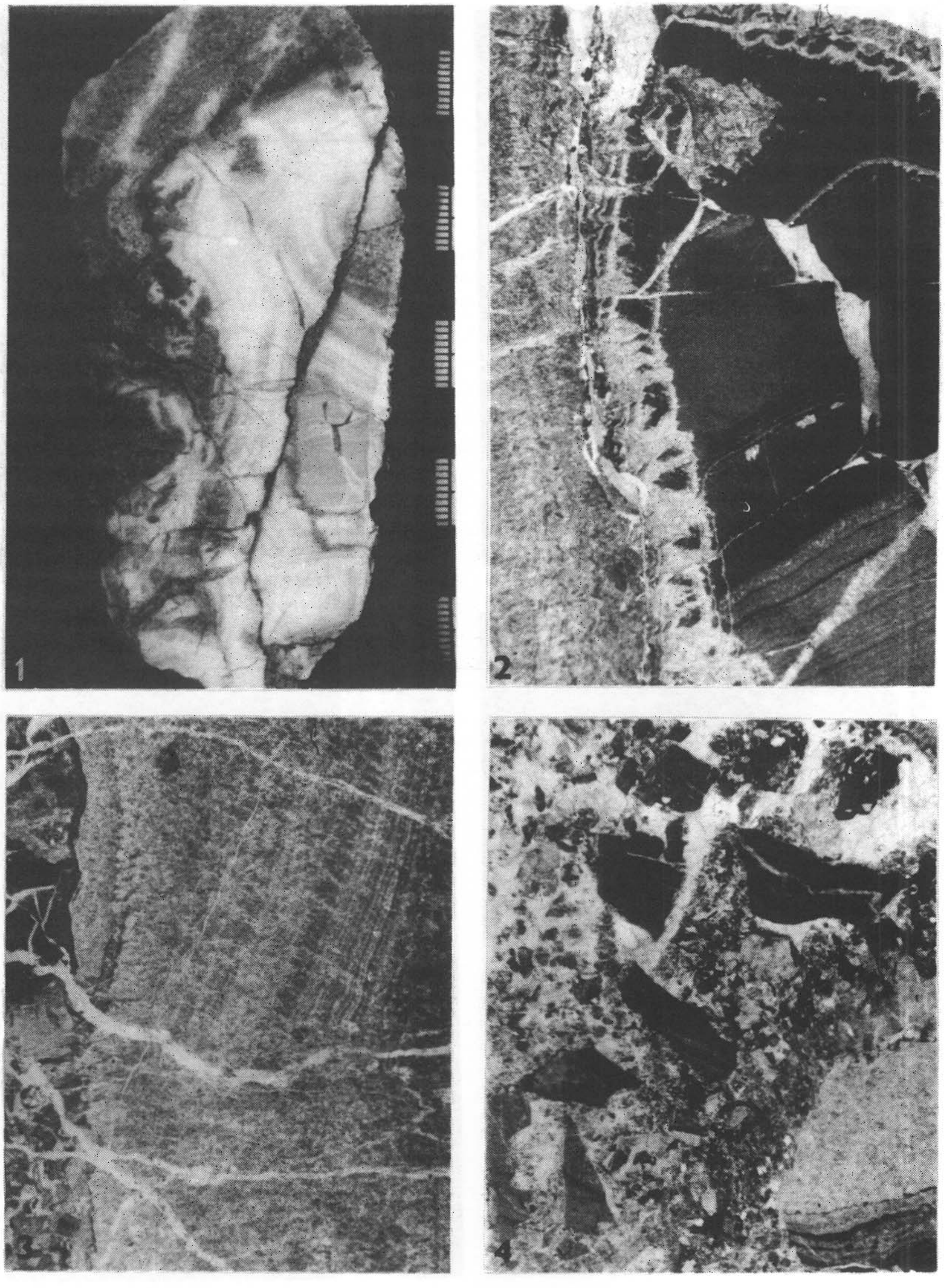

Plate II Microphotos from the Babiná Hill locality

Fig.1 - Krasín breccia with RFC, stromatolitic and micritic void filling. Sample BV3, polished slab. **Fig.2** - Detailed thin section from the previous (approximately right centre). RFC, intergrown with thin stromatolite bands, is followed by laminated micrite to stromatolites, representing the latest void filling. Thin section No. 23´586, magn. 8x. **Fig.3** - RFC intergrown with thin stromatolite bands. Sample - as above, thin section No. 23´586, magn. 8x. **Fig.4** - Clasts of stromatolites in the Krasín Breccia; they document its polyphase origin. Sample BV9, thin section No. 23´579, magn. 8x.

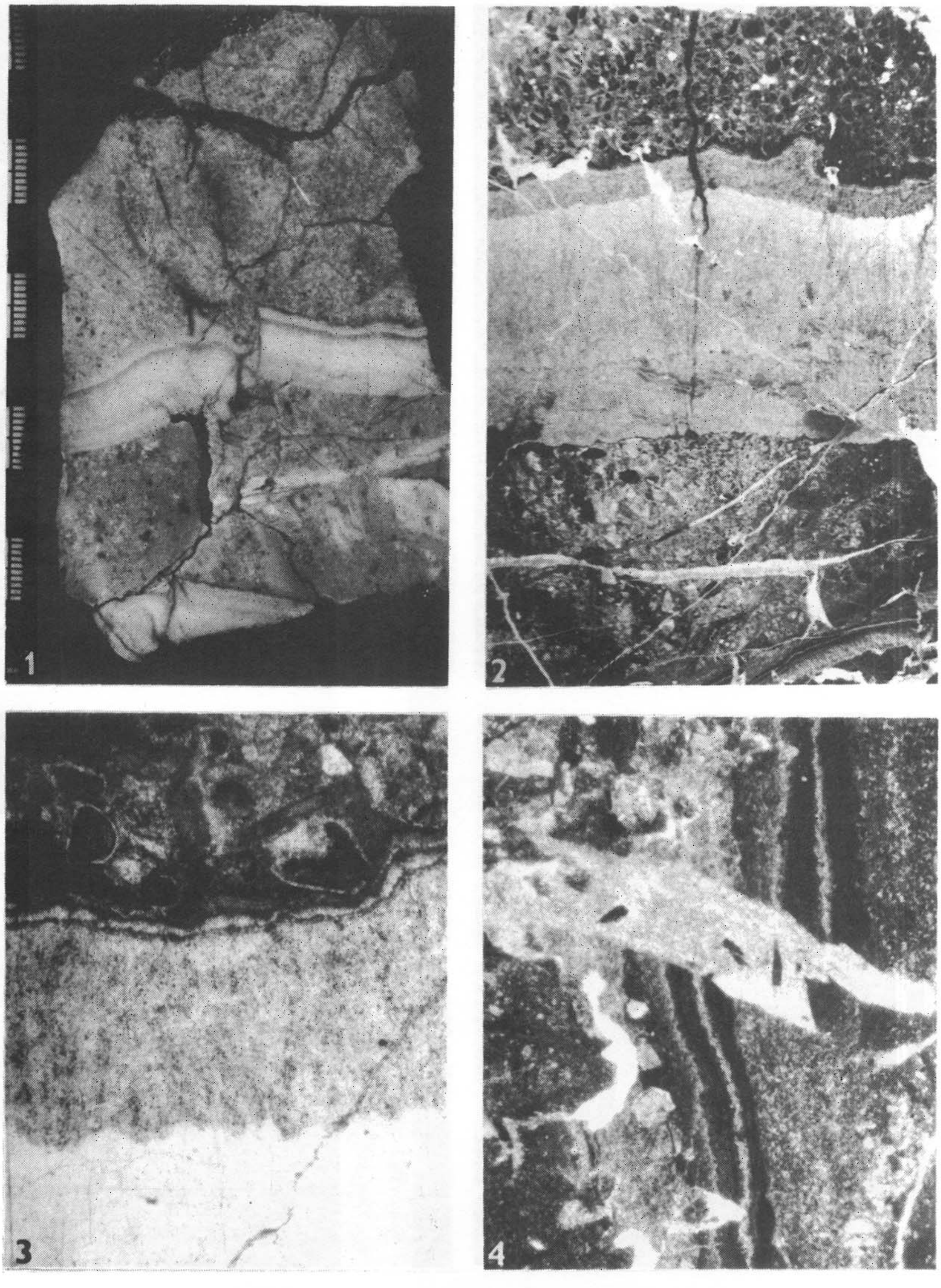

Plate III Microphotos from the Babiná Hill locality

Fig.1 - Slab showing a crinoidal limestone clast (top) and the interstitial void lined with radiaxial fibrous calcite (light) and filled by somewhat younger crinoidal limestone (bottom). Sample BV2. **Fig.2** - Detail from the previous, displaying two phases of the RFC - a thinner, cloudy phase and a thicker, clearer one. Note also some stromatolite layers in the void filling (bottom). Thin section No. 23'587, magn. 4x. **Fig.3** - Closer view to the previous, documenting the relationship between the cloudy and clearer phases of the RFC. Magn. 30x. **Fig.4** - Detail from the bottom of Fig.2, showing the thin stromatolite layer in the void filling, cut by a younger calcite veinlet. Neg. No. 92'520, magn. 30x.

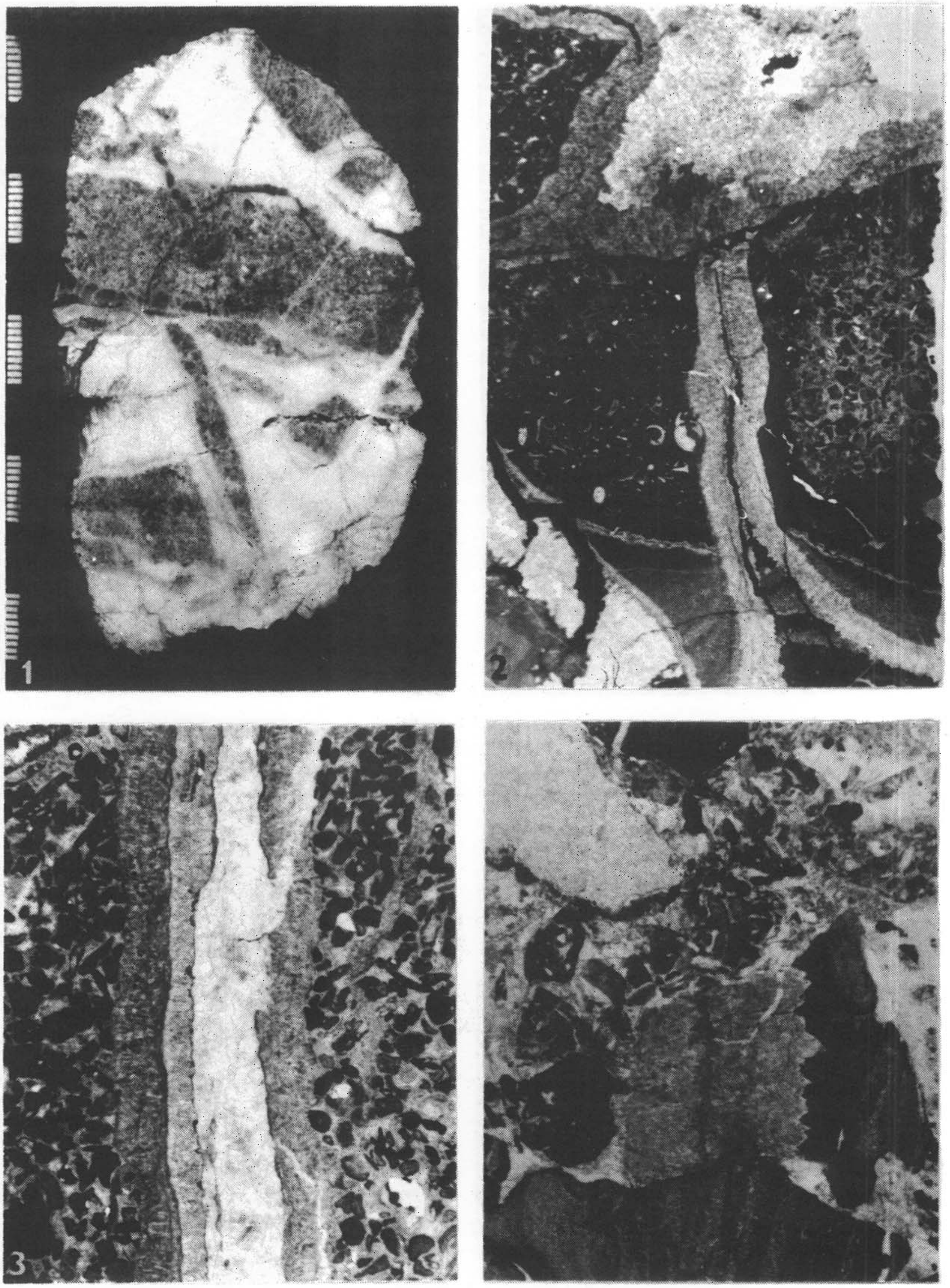

Plate IV Microphotos from the Babiná Hill locality

Fig.1 - Slab of sample BV8. Note the complex intersection of various components of the breccia. **Fig.2** - Thin section of the previous sample. Following reconstruction can be deduced from the picture: crinoidal limestone was covered by poorly laminated micritic sediment (probably microbialite), then cut by cleft filled with RFC and, after reworking, finally cemented by a new multiphase generation of the RFC. Thin section No. 23'583, magn. 4x. **Fig.3** - Crinoidal limestone cut by calcite veinlet, displaying multiphase fill of RFC and a final fill of clear blocky calcite. Sample BV6, thin section No.23'582, magn. 8x. **Fig.4** - Finer-grained breccia with clasts of laminated microbialites (bottom and right) and a clast of RFC (below the centre), all indicating the repeated process of reworking. Sample BV5, thin section No. 25'584, magn. 8x.

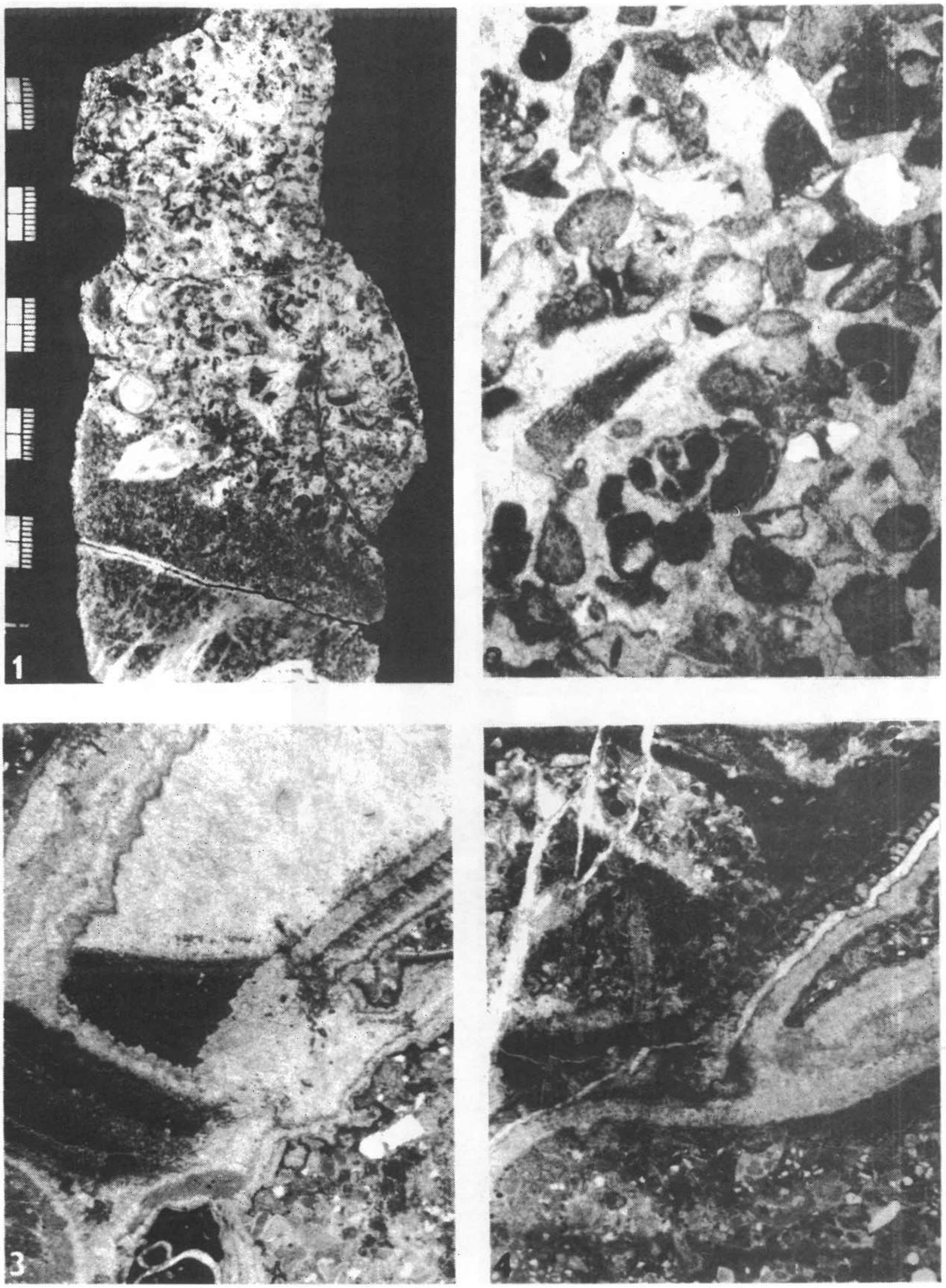

Plate V Microphotos from the Babiná Hill locality

Fig.1 - Transition of the crinoidal limestone to biosparite comprising bivalve, gastropod and brachiopod shells, with rarer crinoids. Sample BV 10, polished slab. **Fig.2** - Thin section from the previous sample. Thin section No. 23'581, magn. 30x. **Fig.3** - Several generations of the RFC and laminated pelmicrites (probably microbialites) filling an interstitial cavity in the Krasin Breccia. Sample BV15, thin section No. 24'100, magn.8x. **Fig.4** - Complex structure of the breccia composed of crinoidal limestone clasts, RFC veinlets, thin stromatolites and blocky calcite veinlets. Sample BV14, thin section No. 24'088, magn. 8x.

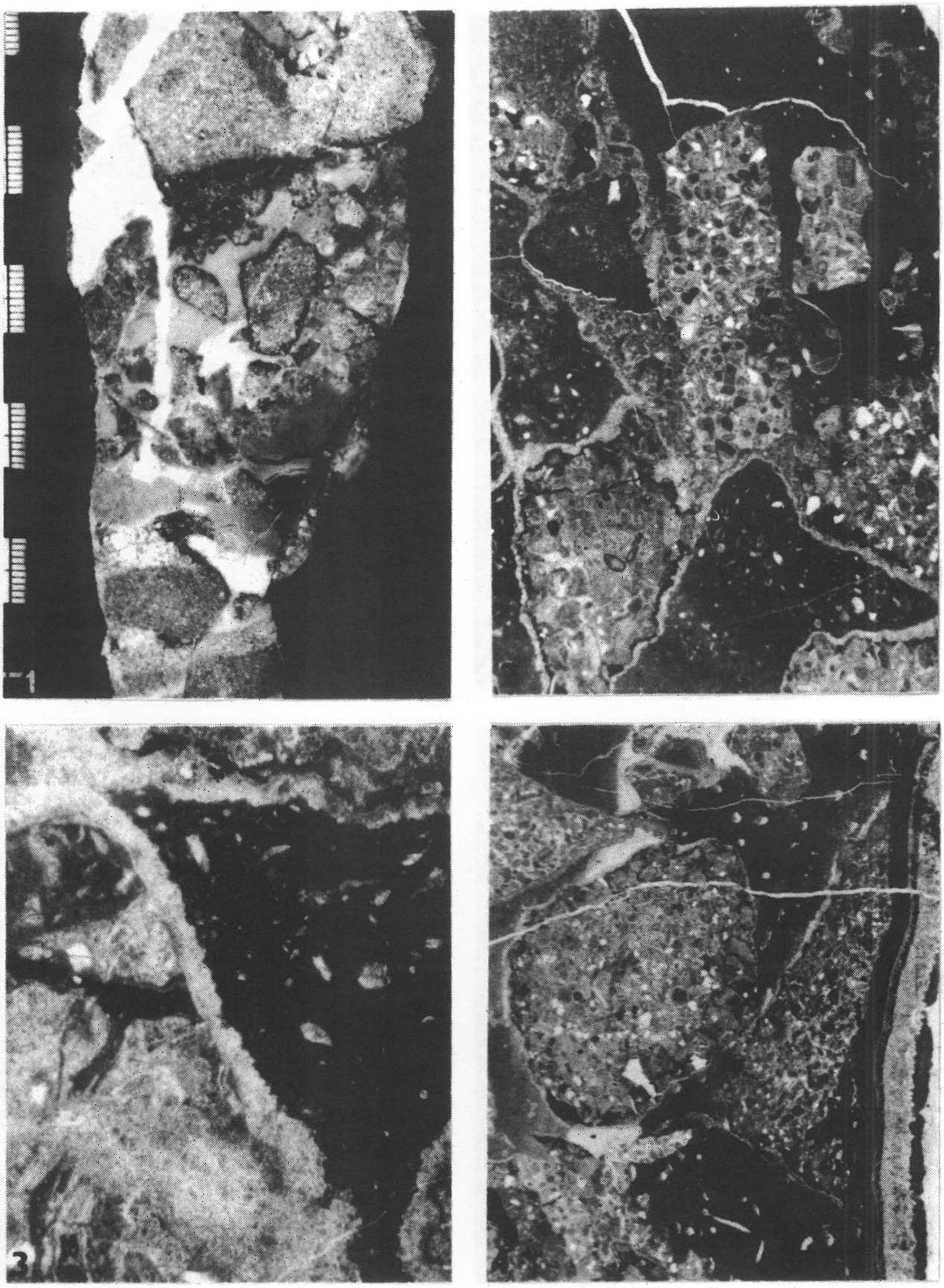

Plate VI Microphotos from the Babiná Hill locality

Fig.1 - Krasin Breccia partially free of RFC. The limestone clasts are in direct contact with red micritic (wackestone) filling of the interstitial cavities. Note some clasts are black coated (probably by Mn minerals) and possess irregular surfaces, likely due to a freshwater dissolution. Sample BV4, polished slab. **Fig.2** - Thin section from the previous sample. Note the thin layer of equant calcite, post-dating the dark coat and pre-dating the wackestone filling. Thin section No. 23'585, magn. 8x. **Fig.3** - Detail from the previous (in continuation of the lower left corner), documenting the relationship of the limestone clast, equant calcite layer and wackestone filling. Magn. 30x. **Fig.4** - Crinoidal limestone clasts (some coated by Mn minerals) cemented by laminated pelmicrite and, after reworking, overgrown by later stromatolite generation, RFC and final micritic void filling (right). Sample BV12, thin section No. 24'089, magn. 4x.

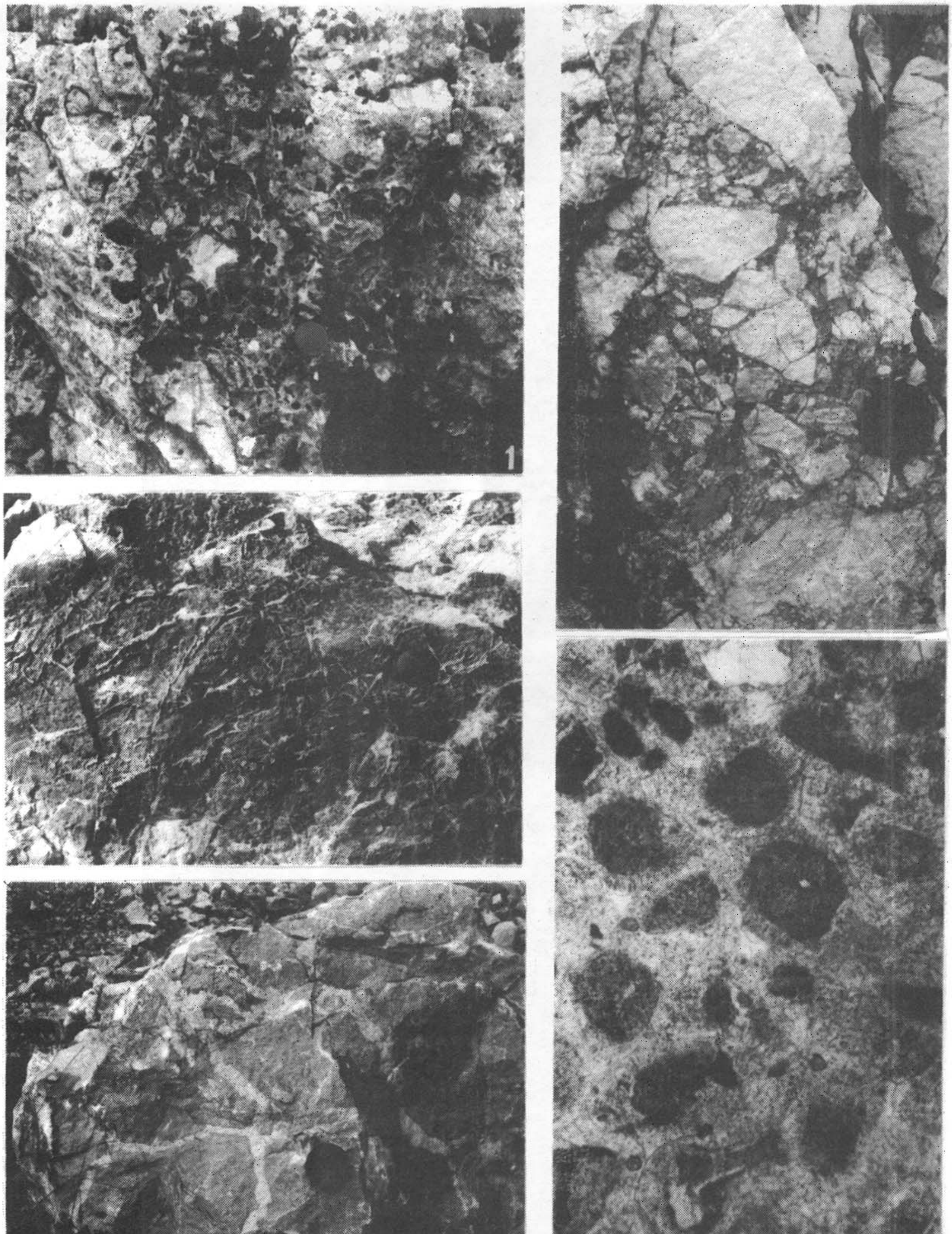

Plate VII Field and microphotos from the Babiná -quarry locality

Fig.1 - Block of Krasin Breccia with radiaxial fibrous calcite coatings, representing a remnant after quarry exploitation. Block came most likely from the middle of the quarry. Scale: lens cap is 5.8 cm across. **Fig.2** - Breccia with clasts of crinoidal and red micritic limestones. Its genesis was related to neptunian dykes in the klippe. Second ridge from the left side of the quarry. Scale: lens cap is 5.8 cm across. **Fig.3** - Crinoidal limestone with dense network of veinlets filled by radiaxial fibrous calcite. Middle part of the quarry. Scale: lens cap is 5.8 cm across. **Fig.4** - Block of breccia with clasts of red and matrix of white crinoidal limestone (inverse coloration of the limestones as in the classic scheme of Birkenmajer, 1977). Middle to left part of the quarry. Scale: lens cap is 5.8 cm across. **Fig.5** - Microscopic view on composition of crinoidal limestone clast with syntaxial rims with densely distributed inclusions (typical namely for the clasts in the Krasin breccias.) Clearer calcite occurs just in centres of larger intergranular pores (centre). Sample B 15/4, thin section No. 25 484, parallel polars, magn. 27x.

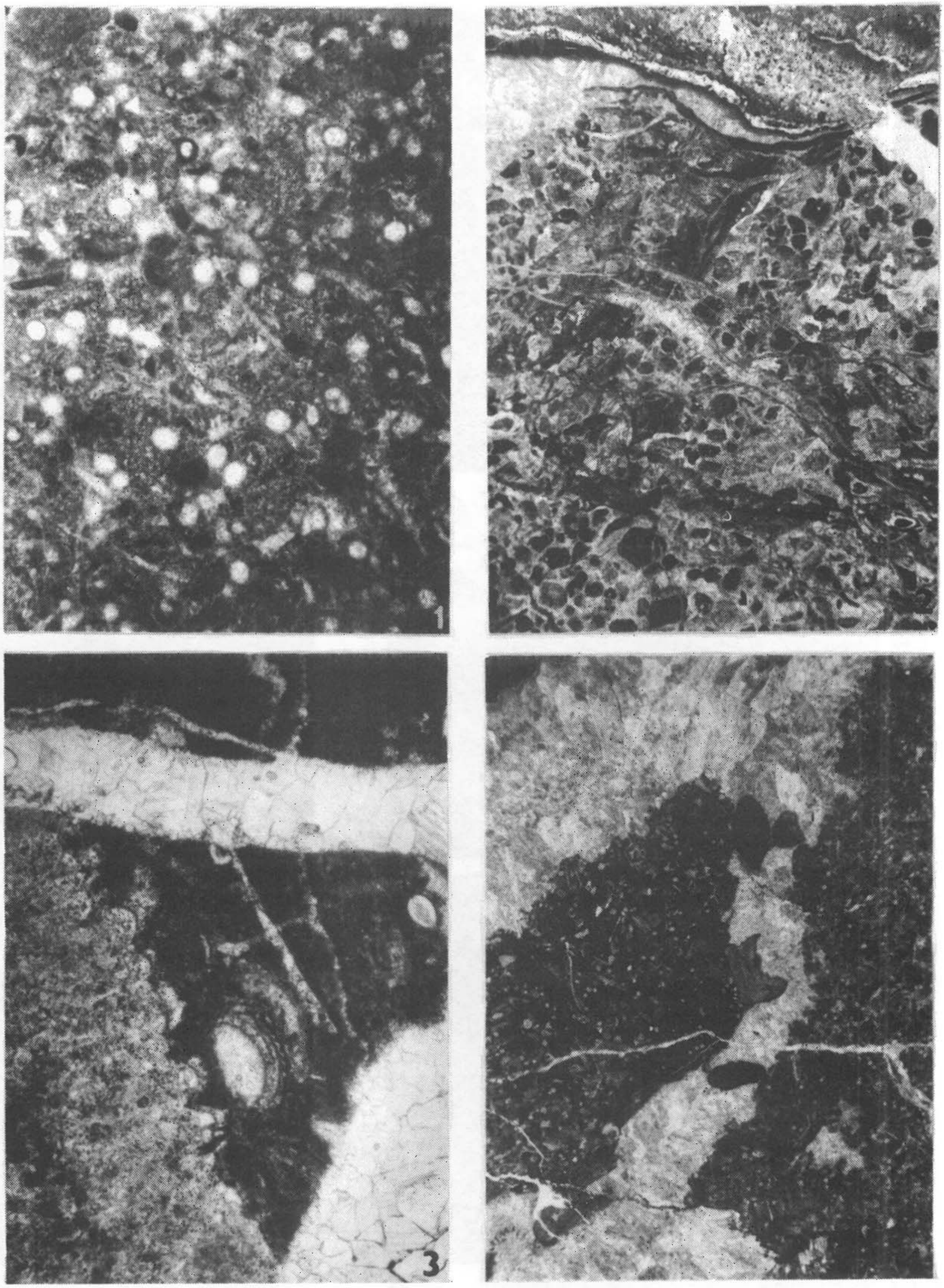

Plate VIII Microphotos from the Babiná -quarry locality

Fig.1 - Clast with thaxa-crinoidal microfacies in the breccia coming from the left part of the quarry. Sample B 4, thin section No. 25 483, plain polarized light, magn. 27x. **Fig.2** - Crinoidal limestone clast with network of branching, laminated micritic veinlets. The clast resembling caliche was possibly partly altered in pedogenic environment. Breccia in the left part of the quarry. Sample B 3, thin section No. 25 473, plain polarized light, magn. 7x. **Fig.3** - Stromatolite with tests of ostracods *Pokornyopsis* sp. as a final sedimentary filling of an interstitial void in the breccia, overlying the radiaxial fibrous calcite. Both, cement and filling are crosscut by blocky calcite veinlet. Breccia from the middle of the quarry. Sample B 15/4, thin section No. 25 484, plain polarized light, magn. 27x. **Fig.4** - Radiaxial fibrous calcite (RFC) penetrating into clasts of the crinoidal limestone, possibly due to etching, as visible also on some crinoidal ossicles (almost surrounded by the RFC). Breccia from the left part of the quarry. Sample B 4, thin section No. 25 482, plain polarized light, magn. 7x.

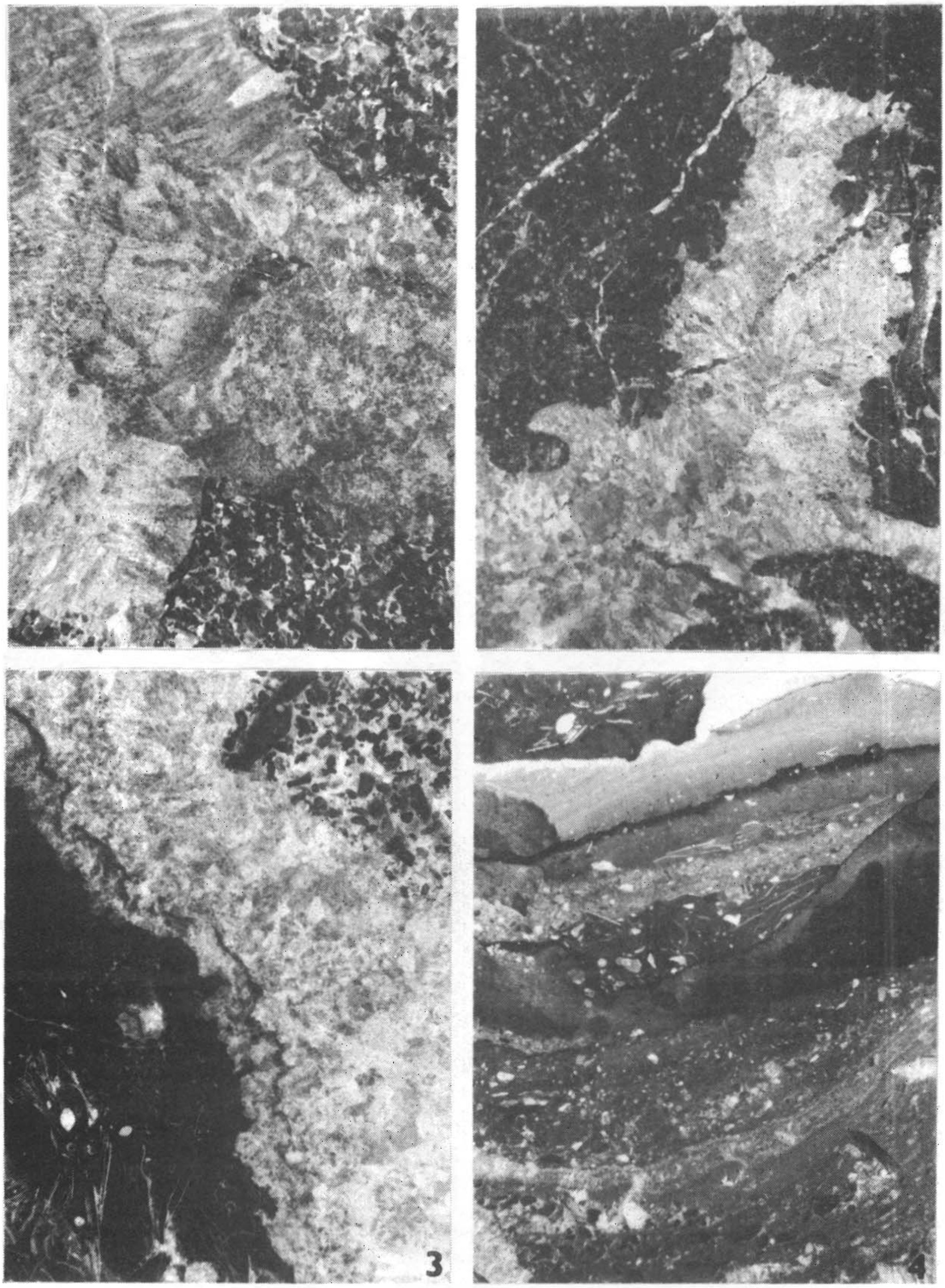

Plate IX

Fig.1 - RFC enclosing fragments of clasts. Breccia from the left part of the quarry. Sample B 7, thin section No. 25 477, parallel polars, magn. 7x. **Fig.2** - Irregular surface of the crinoidal limestone clasts, formed probably by etching, healed by RFC. Breccia from the left part of the quarry. Sample B 4, thin section No. 25 483, parallel polars, magn. 7x. **Fig.3** - Irregular margin of the RFC crust, related most likely to partial leaching. Fallen block of breccia in the left part of the quarry. Sample B 2, thin section No. 25 490, plain polarized light, magn. 7x. **Fig.4** - Stromatolite as a late filling of an interstitial void. The lower portion of stromatolite contains mainly crinoidal ossicles whereas the upper half includes predominantly "filaments" (thin shells of *Bositra* sp.). The stromatolite then originated in the time of change from crinoidal to "filamentous" microfacies, i.e. drowning of the Czorsztyn Ridge and deepening of the sedimentary area (Late Bajocian-Bathonian). Fallen block in the left part of the quarry. Sample B 1, thin section No. 25 480, plain polarized light, magn. 7x.

Plate X Microphotos from the Babiná quarry and slabs from the Drieňová locality

Fig.1 - Late sedimentary filling of an interstitial void (upper part of the figure) representing micrite with "filaments" and rare planktonic foraminifers *Globuligerina* sp. indicating approximately the Callovian/Oxfordian boundary in the Czorsztyn Unit. The sedimentary filling is separated from the crinoidal limestone clast by younger clear blocky calcite veinlet. Breccia from the left part of the quarry. Sample B 9, thin section No. 25 475, plain polarized light, magn. 27x. **Fig.2** - Clast of crinoidal limestone (the same as in Pl. VIII, Fig.2) and sedimentary filling of the interstitial void. The latter is formed by fine-grained crinoidal limestone (centre of the picture), partially entering the veinlet with blocky calcite. The next phase of filling is represented by micrite with "filaments". Relationship and relative dating of the individual filling is complicated by another blocky calcite veinlet separating the crinoidal filling from the "filamentous" micrite. Breccia from the left part of the quarry. Sample B 3, thin section No. 25 473, plain polarized light, magn. 7x. **Fig.3** - Slab of the breccia from the foot of Drieňová hill. The crinoidal limestone clasts are covered just by thin stromatolite coatings (dark grey) and thicker, two-phase RFC crust (older phase is light grey, the younger one is white). Centimetre scale below. **Fig.4** - Cut slab of the Krasin Breccia from the foot of Drieňová Hill. The clasts of crinoidal limestones are cemented by laminated stromatolite (grey) and radiaxial fibrous calcite (white). Some latest voids are filled by sterile micrite. Centimetre scale below.

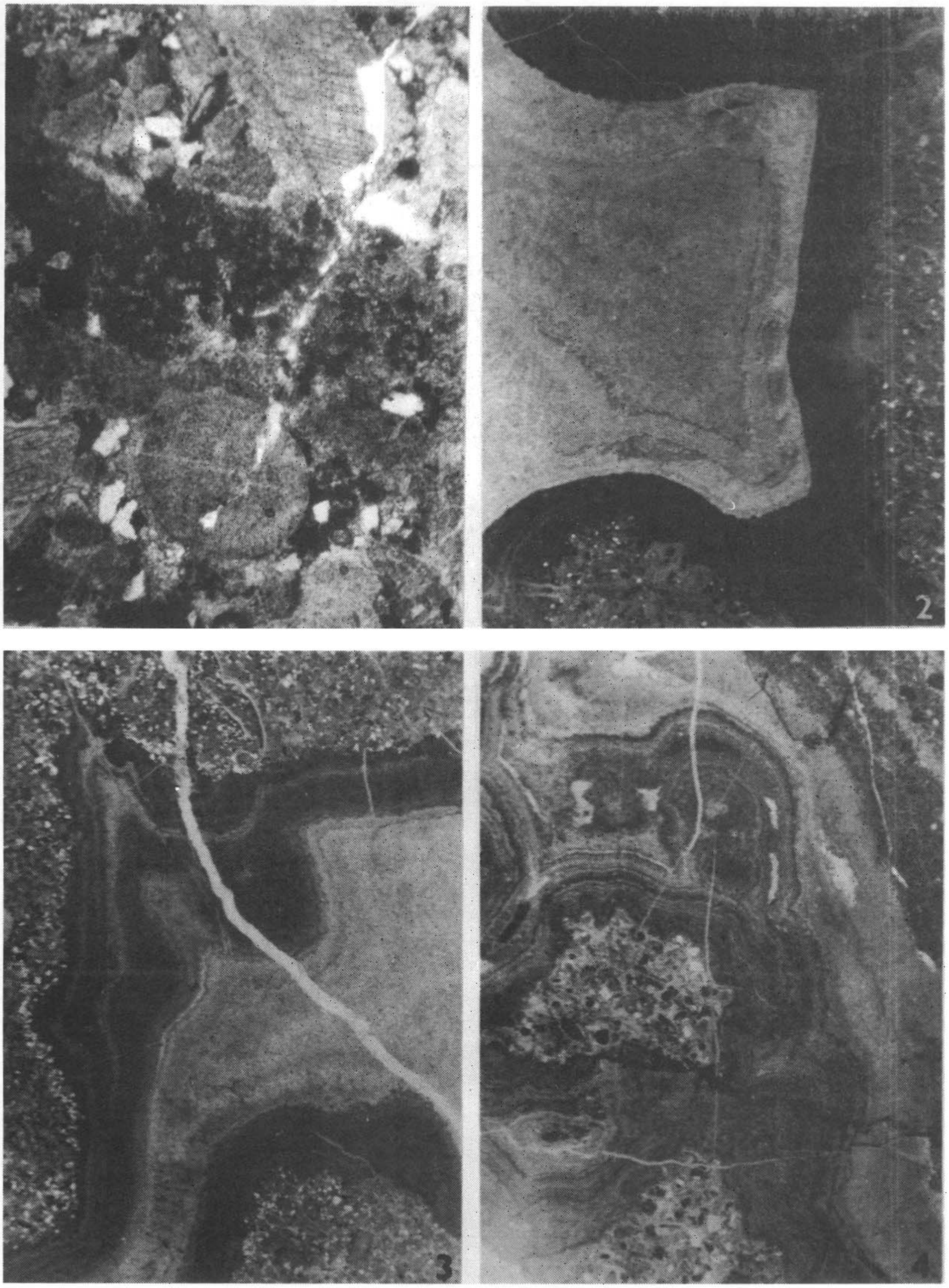

Plate XI Microphotos from the Drieňová locality

Fig.1 - Peloidal matrix (likely of microbial origin) in the crinoidal limestone clast. Thin section No. 25 535, parallel polars, magn. 27x. **Fig.2** - Clasts of crinoidal limestone cemented by laminated stromatolite and later by radiaxial fibrous calcite. Thin section No. 25 592, plain polarized light, magn. 4.3x. **Fig.3** - Crinoidal limestone clasts covered by laminated undulated stromatolite crust and cemented by the RFC. Thin section No. 25'519, plain polarized light, magn. 4.3x. **Fig.4** - Spherical to oncoidal bodies in stromatolitic crust connecting isolated clasts of crinoidal limestones. Thin section No. 25 528, plain polarized light, magn. 5.2x.

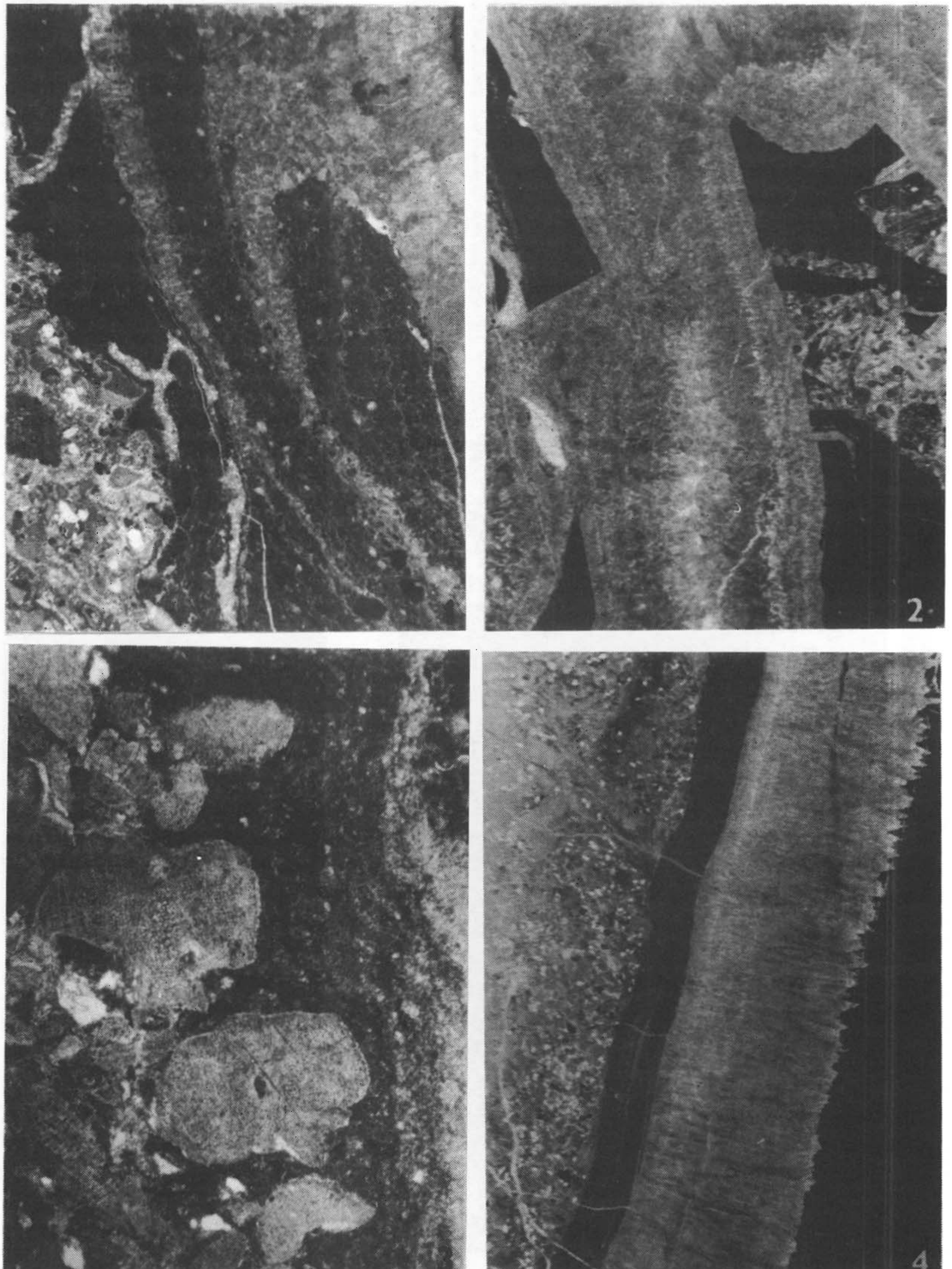

Plate XII Microphotos from the Drieňova locality

Fig.1 - Discontinuous crusts of stromatolite with peloidal laminated texture, forming interlayers in the RFC. The tiny white spots are numerous small smooth-shelled ostracods in the stromatolite. Thin section No. 25 528, parallel polars, magn. 7.7x. **Fig.2** - Broken crinoidal limestone clast with stromatolite crusts. The stromatolite crust fragments form independent clasts surrounded by the RFC. It indicates a tectono-sedimentary reworking of the breccia still after formation of the stromatolitic crusts on clasts. Thin section No. 25 527, parallel polars, magn. 4.3x. **Fig.3** - Crinoid ossicles protruding away from the crinoidal limestone clast. They are covered by laminated stromatolite. Thin section No. 25 529, plain polarized light, magn. 27x. **Fig.4** - Clast of crinoidal limestone (left) covered by thin laminated stromatolite and then by isopachous crust of RFC. The latest filling of the interstitial void represents sterile micrite (dark). Thin section No. 25 535, plain polarized light, magn. 4.3x.