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DISTAL TURBIDITES WITH PYROCLASTIC MATERIAL IN MALMIAN RADIOLARITES OF THE PIENINY KLIPPEN BELT (WESTERN CARPATHIANS)

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Abstract: Acid and intermediary Upper Oxfordian volcanic material transported from distant centres (probably the Eastern Alps) by bottom currents (distal turbidites, or contourites) forms intercalations in radiolarites of the Klippen Belt. The study of radiolarians (U.A. 7-8 and U.A.9) and partly also of calcareous nanoplankton allowed to determine a wider stratigraphic span of red radiolarians (Buwald Member) – minimally Upper Oxfordian–Lower Kimmeridgian. The correlation between the thicknesses of alternating silicite and pelite beds is insignificant (0.266). Fourteen types of radiolarian preservation, various types of veinlets, the presence of spheroids and slide structures allow to reconstruct to a certain extent the processes of sedimentation and diagenesis.

Key wores: radiolarite petrography, turbidites, Malmian, radiolarians, nanoplankton, Western Carpathians.

Introduction

Radiolarite formations are typical sedimentary formations of orogenic belts. Two groups can be distinguished among them (e.g. Grunau 1965): 1 – radiolarites occurring together with basic volcanites; 2 – radiolarites in formations without volcanites. From the viewpoint of plate tectonics, the first type represents deep-sea sediments on newly-formed oceanic crust, the second ones are deep-sea sediments on thinned continental crust. The latter type without accompanying volcanites includes also radiolarites of the Doggerian–Malmian in the Outer and Central Western Carpathians. It is interesting that some authors assume that the source of SiO_2 were also in this case hypothetical submarine volcanic emanations (Khvorova 1968), or from an 1.5 *cm* thick intercalation of benthonized pyroclastics in a claystone bed they assign a decisive role in the formation of Carpathian radiolarite sediments to volcanites (Śikora and Wieser 1979).

Our hitherto sole finding of laminae with clastic material (distal turbidites, or contourites) with pumice fragments and feldspar crystaloclasts is interesting as one of very few traces of Jurassic volcanism on the territory of Outer and Central Western Carpathians. It is necessary to note that in the Inner Carpathians, in Meliaticum, or Bükkicum on the territory of Hungary, basic volcanites occur together with Doggerian radiolarites (Kozur 1984).

We assume that pyroclastic material described by us was transported by currents from a great distance. It originated perhaps in the same rhyolite-dacite centers which formed tuff beds in Oxfordian radiolarites of the Eastern Alps near Salzburg (Diersche 1980). We consider the role of volcanism in the formation of radiolarites of the Pienniny Klippen Belt to have been insignificant.

The discovery of distal turbidites is important from the viewpont of paleogeography. The determination of continuation of these bottom currents could increase the accuracy of our conception of direct relationship between the klippen and it could bring new criteria for their classification with various Klippen Belt units (Magura, Pieniny, Kysuce). Although we investigated all further 12 klippen in the surroundings of Trstená registered in the map of Andrusov (1938, Pl. IX), we did not find laminae with clastic material in any other klippen except the here described occurrence near Trstená-bowling alley. Since we have found in the studied profile at least six such intercalations with thicknesses exceeding 1 *cm*, this absence can hardly be due only to insufficient number of complete exposures. This fact by itself indicates unusually intensive compression-reduction of space in the Klippen Belt, where individual klippen – lenses – represent only an insignificant fraction from the total surface of sediments of the original sea bottom.

In the present contribution we would like to document that detailed study of thin sections and polished sections can yield hitherto insufficiently exploited information on sedimentary conditions and diagenesis of radiolarites.

Data on the studied profile, rhythmicity and bed thicknesses

The studied profile is situated in the woods of Halečková, west of the village Trstená, at a forest road, approx. 300 *m* NNW of the old bowling alley (Fig. 1). There are at least three parallel klippen belts in the region of Trstená: the studied profile is situated in the externmost one.

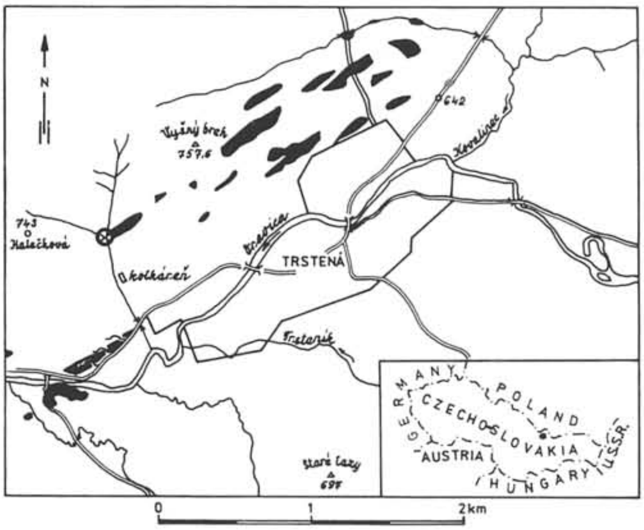

Fig. 1. Klippen (tectonic lenses) of Pieniny succession with Malmian radiolarites (black) and localization of the studied profile Trstená-bowling alley (double circle).

Radiolarites occur here in two scales lying above each other (Fig. 2), they are separated by Cretaceous sandstones (tectonic contacts). The exposed thickness of the radiolarite formation in the lower scale is 7 *m*, it comprises five allodapic intercalations with clastic material, the thickest one reaching 5 *cm*. In the upper scale there are incompletely exposed about 5 *m* of radiolarites, containig two contourite intercalations. The continuation is covered by road timbering, it can be however partly observed in a parallel creek. Gradational bedding in contourites shows that the lower scale has reversed sequence of beds, the upper one normal. This has been confirmed also by micropaleontologic analysis (in the reversed sequence Kimmeridgian radiolarian association was found to be below Oxfordian associations).

The profile contains only so-called red radiolarites, or upper red radiolarites, named by Birkenmajer (1977) the "Buwald Radiolarite Member". They occur usually above green radiolarites. He mentioned the thickness of 4–12 *m* for red radiolarites and according to aptychi they belong to the upper part of the Upper Oxfordian.

L. Ožvoldová determined in the studied profile that the Buwald Radiolarite Member has a wider stratigraphic span that hitherto assumed – from radiolarian U.A. 7-8 (upper part of the Lower Oxfordian–Upper Oxfordian) to U.A. 9 (Kimmeridgian, and perhaps even lowermost Tithonian).

The stratigraphically lower part belonging to the Oxfordian is formed by beds of silicites-radiolarites, usually lustrous (a representative sample contained 86.99% SiO_2). Marly shale intercalations (calcareous claystones) are in this part of the sequence very thin, or they are missing.

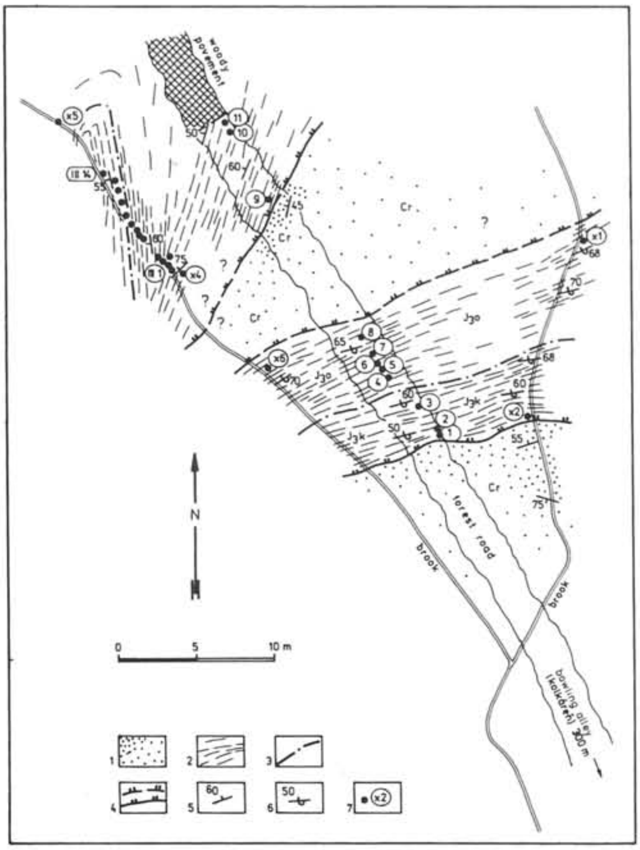

Fig. 2. Geological map representing the complicated structure of the klippe Trstená-bowling alley with the studied profile across Oxfordian–Kimmeridgian radiolarites.

Explanations: 1 – sandstones (Cretaceous); 2 – bedded radiolarites (Oxfordian – Lower Kimmeridgian); 3 – boundary between Oxfordian and Kimmeridgian; 4 – faults; 5 – strike and dip of beds; 6 – inverted position; 7 – samples.

The upper part of the profile belongs to the Kimmeridgian (U.A.9). It consists of matt calcareous radiolarites (a representative sample contained 72.40% SiO_2) with substantially more frequent and thicker intercalations of marly shales (calcareous claystones – their representative sample contained 54.72% SiO_2 and approximately 35% of carbonates), Lower Kimmeridgian nannoplankton has been determined in two shale intercalations.

A slump body occurred in one case (Pl. 2, Fig. 4), slump structures have been documented near the studied profile.

Rhythmical alternation of silicite and pelite layers corresponds to formations called ribbon radiolarites or banded radiolarites (Fig. 3). We calculated the frequency of thicknesses of both rock types (histograms on Fig. 4) on the basis of measured layer thicknesses (accuracy to 1 *cm*). The frequency distribution is markedly asymmetric – thinner layers are predominant.

Maximal layer thickness in pelites is 8 *cm*, layers with a thickness over 1 *cm* are predominant; it is frequently only a thin film separating two radiolarite beds, and even these laterally thin out (amalgamation).

The dispersion of silicite layer thicknesses is greater. Maximal thickness has been reached by a bed with clastic allodapic intercalation – 16 *cm*, maximal thickness without this intercalation would be 13 *cm*. Average radiolarite bed thickness is 5.5 *cm* (for a comparison, Ruiz-Ortiz et al. 1989,

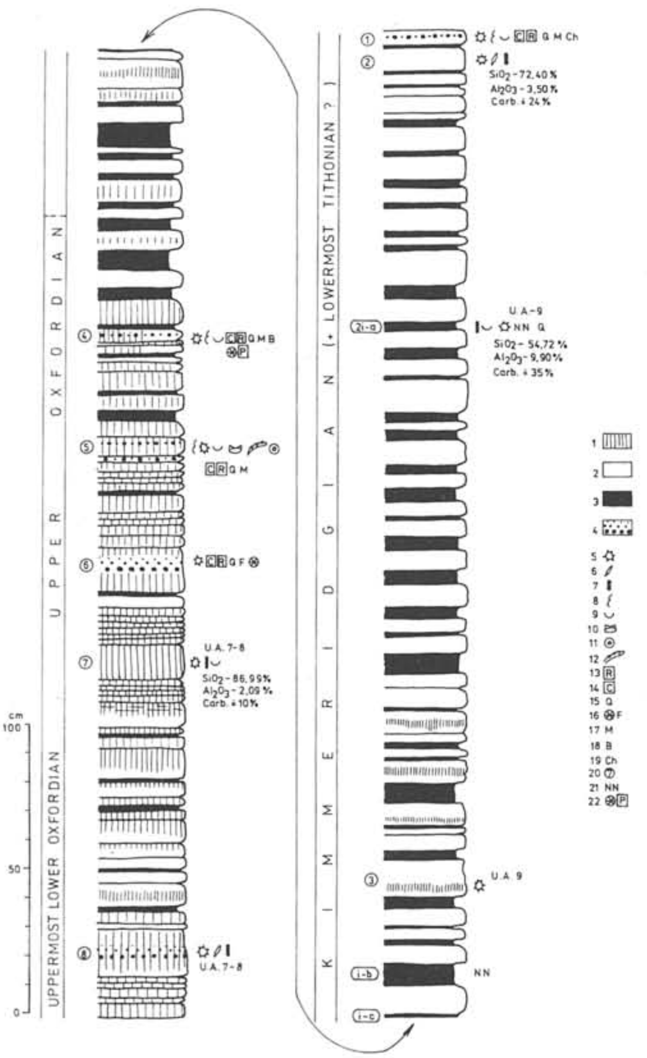

Fig. 3. Profile across red radiolarite formation (banded radiolarites) of the Pieniny Klippen Belt succession, site Trstená-bowling alley. *Explanations:* 1 – radiolarites; 2 – calcareous radiolarites; 3 – marly shales (calcareous claystones); 4 – distal turbidites, or contourites and their gradational bedding; 5 – radiolarians; 6 – silicispongia spicules; 7 – phosphatic fragments (mostly fish scales); 8 – "filaments" (juvenile bivalvians of the type *Bositra*); 9 – ostracods; 10 – bivalvians; 11 – echinoderm segments; 12 – aptichi; 13 – radiolarite intraclasts; 14 – white claystone intraclasts; 15 – clastic quartz; 16 – feldspar crystalloclasts from pyroclastic admixture; 17 – muscovite; 18 – biotite; 19 – chlorite; 20 – sample No.; 21 – reworked nannoplankton; 22 – pumice fragments.

reported 9 *cm*, and Diersche 1980, 8 *cm*). Some statistical parameters of silicite beds (Tab. 1) are similar to data on bed thickness frequencies of Paleogene silicites from Japan (Ijima, Inagaki and Kakuwa 1979).

The correlation between silicite bed thicknesses and overlying pelitic intercalation thicknesses proved to be positive, but very low, in the whole profile (correlation coefficient $r = 0.266$, see also Fig. 5), as well as in its individual sections. Almost the same low values of correlation – 0.22 and 0.26 – have been determined also by Ruiz-Ortiz et al. (1989) in the Subbetic unit of Spain.

We obtained a similar result by the comparison of pelitic layer thicknesses with overlying silicite beds (reversed coupling). This positive, but insignificant correlation indicates that processes that led to the formation of alternating rock types were fundamentally independent from each other, which is after all indicated also by the absence of gradual transitions between both rock types.

Rhythmical radiolarites (ribbon radiolarites) of the Mesozoic do not have any analogues in sediments of the same age found in boreholes in the Atlantic. According to Jenkyns and Winterer (1982) they sedimented in small, embryonal, unusually fertile oceans of the Tethys, with predominant

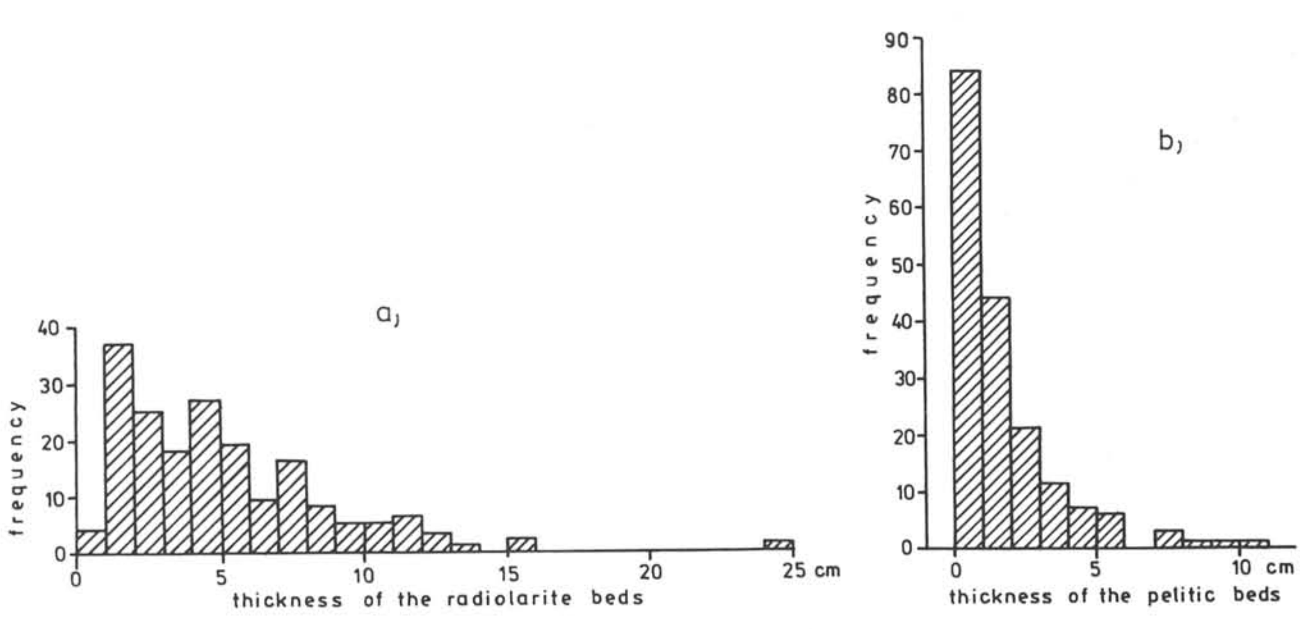

Fig. 4. Frequency histograms of radiolarite (a) and calcareous claystone (b) bed thicknesses on the profile Trstená-bowling alley.

Table 1. Statistic data calculated from the frequency of bed thicknesses of radiolarites and calcareous claystones (Upper Oxfordian–Kimmeridgian) on the profile Trstená-bowling alley. Date in brackets are derived from the cummulative curve.

	Silicites (radiolarites)	pelites
Number of beds (N)	186	179
Range of thicknesses	1–25 *cm*	0.1–10 *cm*
Median (Md)	5 *cm* (4.4 *cm*)	2 *cm* (1.2 *cm*)
Average thickness (M) (arithmetic mean)	5.5 *cm* (4.9 *cm*)	1.3 *cm* (1.7 *cm*)
Standard deviation	3.8 *cm*	1.8 *cm*

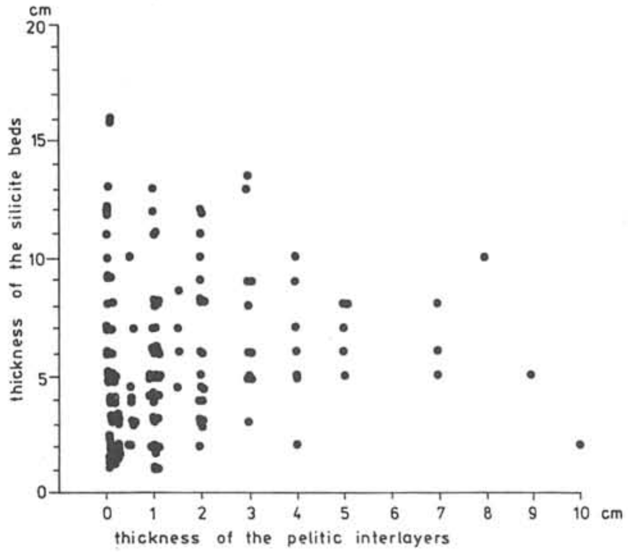

Fig. 5. Variation diagram representing the relationship between bed thicknesses of radiolarites and calcareous claystone intercalations on the profile Trstená-bowling alley (correlation coefficient $r = 0.266$)

transform faults. Their rhythmicity remains an unexplained phenomenon. It used to be explained by four processes:

1. Diagenetic segregation (Sujkowski 1932), today almost has no supporters because of lack of evidence. In submarine slumps it can be seen that differentiation into claystone intercalations and radiolarite beds was present already in the earliest stages.

2. Fertility (radiolarian production) variations due to climatic oscillation, or to regular changes in the circulation of water, upwelling (Jenkyns and Winterer 1982). This genesis would hardly lead to the formation of sharp contacts between pelite and radiolarite beds.

3. Slow autochthonous accumulation of radiolarians in the sediment interrupted by supplies ("clouds") of clay suspension (Birkenmajer and Gąsiorowski 1961; Ijima et al. 1985). In contradiction to this it is necessary to mention that radiolarite beds display abundant traces of current activity and claystone intercalations sedimented more slowly than radiolarian sediments.

4. Slow autochthonous sedimentation of clayey sediment periodically interrupted by radiolarian accumulations brought by bottom currents contourites, or perhas also turbidites (McBride and Folk 1979; Nisbet and Price 1974; Barrett 1982).

Our observations support the fourth variant. Silicite beds often contain laminae of radiolarians sorted by current. Marked beds of distal turbidites (or contourites) described here occurred always only in radiolarite beds, only here a part of cavities after radiolarians is compacted. Sporadic radiolarians occurring in calcareous claystones (more precisely cavities after them filled by calcite) were never deformed by compaction, indicating thus very slow sedimentation similarly as the more abundant occurrence of phosphatic biodetritus than in radiolarite beds. Slow accumulation of claystones is proved by Mutch and Garrison (1967) on the basis of higher content of cosmic spherules in comparison with their content in radiolarites.

Microscopic analysis of radiolarites

The colour of radiolarites from the profile Trstená-bowling alley is red, pink, sporadically brownish red. The radiolarites only rarely have homogeneous structure; thin sections and polished sections usually display well-visible or unclear lamination which occassionally passes into small lenses and slump-flow sructures a few milimeters in size. The lamination is most frequently caused by a difference in the intensity of colouring, in the density of radiolarians or in the quantity of micritic calcite admixture. Lamination in the form of clastic intercalation (distal turbidites or contourites) will be described separately. The preservation of lamination indicates a scarcity of limnivorous animals. In one case we could observe a white elliptic spot – probably a compacted tunnel of a worm filled by differently couloured material.

Organic remnants. In radiolarites without clastic intercalations radiolarians are usually the only components. Sporadically they contain silicisponge spicules (monaxone and rhaxes, only 1–2 specimens in a thin section, with a surface of approx.

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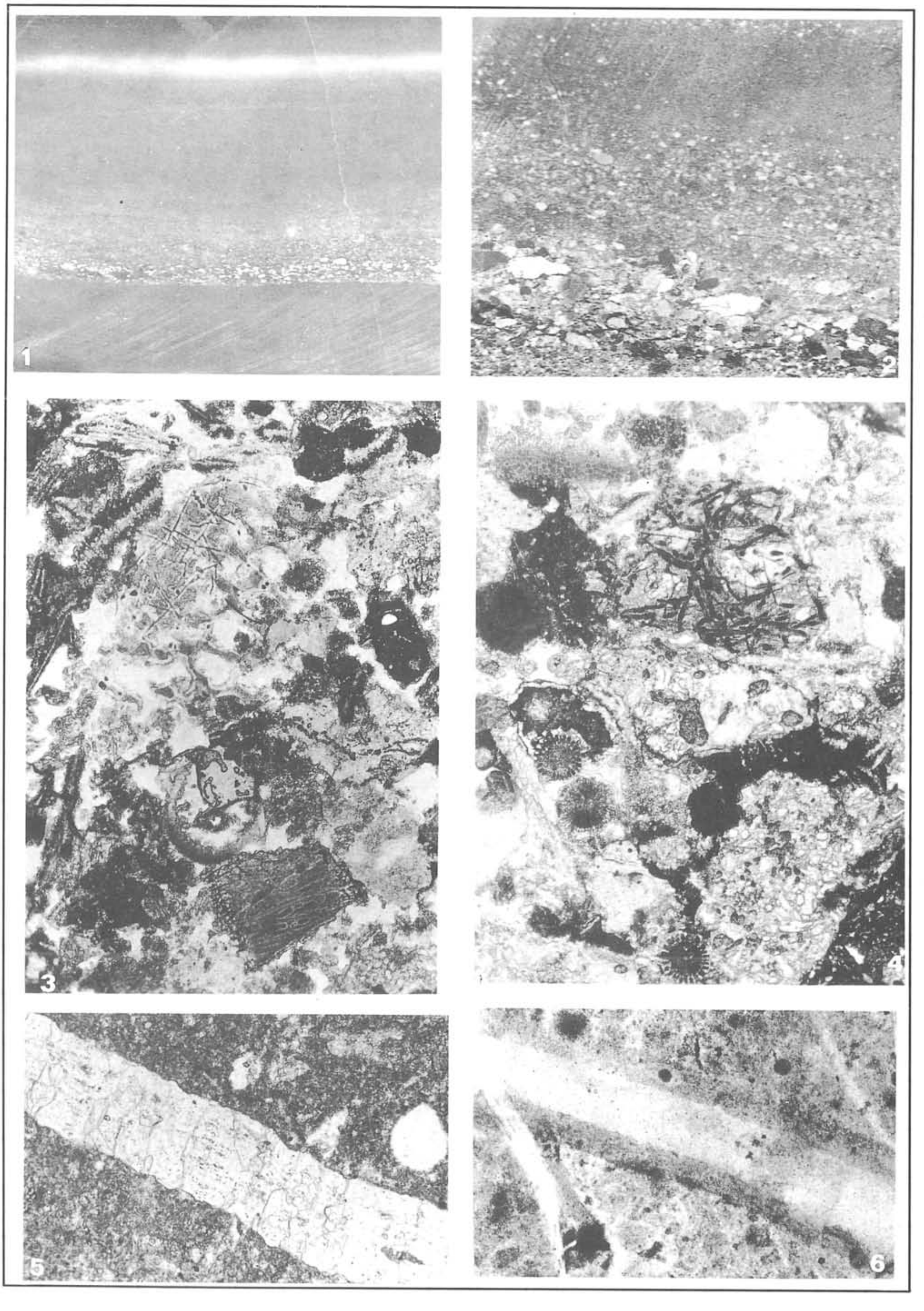
Plate 1: Fig. 1 – Distal turbidite, or contourite lamina with gradational bedding in Kimmeridgian radiolarites of the sucession Pieniny Klippen Belt. Trstená-bowling alley-I. (Apparent „cross-stratification", in the lower part there are artificial grooves). Polished section, magn.1.5x. Fig. 2 – Intercalation of gradationally bedded allodapic material with radiolarite intraclasts and pumice fragments in Upper Oxfordian radiolarites of the Pieniny succession. Trstená-bowling alley-11. Polished section, magn.3x. Fig. 3 – Fragment of silicified bivalvian with channels after boring algae (visible due to their filling by red Fe hydroxids), ostracods, prismatic layer of a bivalvian preserved in the form of calcite, „filaments" – cross-sections of juvenile bivalvians of the type Bositra. Distal turbidite lamina in Upper Oxfordian radiolarite of the Pieniny succession. Trstená-bowling alley-11. Thin section No. 17715. Magn. 48x. Fig. 4 – Sicified fragment of a bivalvian shell with channels after boring algae, radiolarite intraclast and large radiolarian tests. See previous figure. Fig. 5 – Dashed calcite veinlet formed by coalescence of hair-thin parallel shear deformation cracks. Upper Oxfordian radiolarite of the Pieniny succession. Trstená-bowling alley-11. Thin section No. 17715, magn. 30x. Fig. 6 – Chalcedony veinlet (clear filling of empty crack), with calcite margins (metasomatic replacement of radiolarian sediment composed of SiO_2). Oxfordian radiolarite (U.A.7-8) of the Pieniny succession. Trstená-bowling alley-7. Thin section No.17589, magn. 48x.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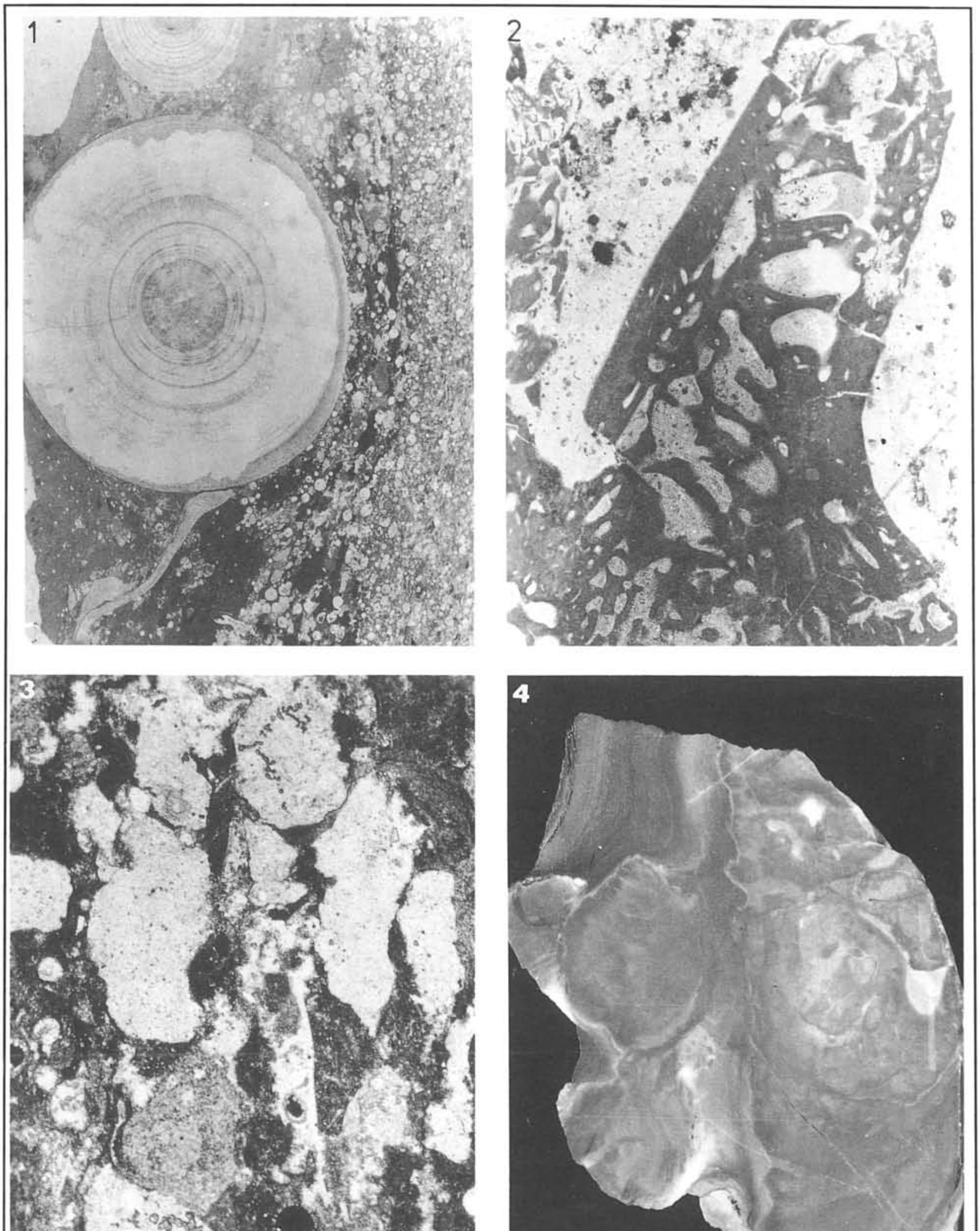
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40 *mm*), phosphatized fish scales (2–3 specimens). A large fish tooth has been found once (its cross-section having a 7 *mm* diameter at the base, with a cavity inside).

Radiolarites with clastic intercalations (distal turbidites or contourites) contain in these laminae also abundant filaments (juvenile bivalvians), sporadic ostracods, echinoderm segments, fragments of oyster bivalvians as well as bivalvians with a prismatic layer in the shell (frequently with traces of boring algae – Pl. 1, Figs. 3, 4), aptychi, foraminifers *Nodosaria* sp. and *Lenticulina* sp., sporadically there were bryozoans, two belemnite rostra (Pl. 2, Fig. 1) and a fragment of a calcareous sponge (Pl. 2, Fig. 2). One intraclast contained *Colomisphaera* sp., which in accordance with other data indicates that the radiolarites cannot be older than Oxfordian.

Forms of preservation of radiolarians. Smaller tests considerably predominate over larger ones (max. 0.3 *mm*); large tests are accumulated in allodapic intercalations (contourite laminae), as a result of sorting by currents. Globular shapes of the tests are strongly predominant. In places there is abundant detritus consisting of fine needles broken from the surface of tests, miniature trident shapes are also frequent, however, they have never been selectively calcified. In the absolute majority of cases there are only cavities after leached radiolarian tests. Traces after the cavities can be usually distinguished by their prevalently clear (white) colour, in contrast to the red-pigmented interstitial matter. In polarized light they can be distinguished by their content of more coarse-grained microcrystalline quartz than the surrounding matter. The following cases of preservation of contours can be distinguished:

1a) The contours of cavities are well preserved, the decoration of the surface of original tests can be observed (indentations, "clock-wheel" shape). **1b)** The contours of cavities are poorly preserved, the circular cross-sections do not show any details. Together with the following type it is the worst form of preservation. **1c)** The contours are poorly preserved, the cavities are deformed due to compaction of sediment (frequent at high contents of red coloids in the lamina and probably at higher contents of clay minerals).

In the filling of the cavities there are the following cases:

2a) Filling of microcrystalline quartz (flaky chalcedony). **2b)** The filling consist of microcrystalline quartz with micritic calcite admixture. **2c)** The filling consists of colloidal material, it is isotropic in polarized light (probably they are Fe_2O_3 colloids). **2d)** The filling is formed by microcrystalline quartz with an admixture of red colloids. **2e)** The central part of the filling is formed by light-brown aggregate of metacolloid fibrous SiO_2 (sheaf-like to spherulitic in polarized light, with a lower refracion index, probably containing less water that the clear peripheral filling micro-grained SiO_2). The light-brown central aggregate has passive semiglobular contours which shows that the older peripheral filling of clear SiO_2 originally had globular shapes (lepispheres?).

When the traces of external test are preserved (and the internal part of the test has been dissolved), the following cases can be distinguished:

3a) The outer part of the test is preserved in the form of clear, radial chalcedony (Pl. 3, Fig. 5), which can be well distinguished from the filling of red colloids (types 2c, 2d), as well as from the red-pigmented matrix of radiolarites. The outer part of the test can be probably well distinguihed in the cases when sediment, with pigmentation and inclusions, penetrated into the test before its total dissolution. The majority of tests was after burial empty, filled by a gas bubble, as it is the case e.g. of fossilization of globigerinas and globotruncans. **3b)** The ghost of the outer test can be distinguished according to the slightly different texture and composition of the microcrystalline quartz filling. **3c)** In sporadic cases the ghost after outer test is separated from the rest of the filling of the cavity by calcite grains along its inner perimeter.

Relatively few radiolarian tests are preserved due to their selective calcification:

4a) Coarse, imperfectly selective calcification – only the outer test is preserved, it is imperfectly substituted by numerous calcite grains which partly continued to grow also towards the center of the cavity. The rest of the cavity is filled by microcrystalline quartz. **4b)** In exceptional cases such from the outer part of test growing aggregate can fill the whole cavity. **4c)** The whole radiolarian test, including the inner part, is perfectly, in detail calcified (Pl. 3, Fig. 6), substituted by a single, or very few optical individuals of calcite. Sometimes only the outer part of the test can be so perfectly calcified (the inner part was dissolved prior to calcification), or only a fragment of the test. This is the best form of preservation. Dissolution in HF can yield well-preserved tests formed by artificial fluorite.

The above-mentioned forms of preservation suggest the following conclusion: partial dissolution of some tests could take place already during their falling down to the bottom. Differences in the grade of preservation could have been caused also by the fact that a part of the tests was enclosed during the subsidence inside fecal grains which protected them from dissolution.

After sedimentation during early-diagenetic processes a large majority of the radiolarian tests was totally dissolved. The cavities were filled by silica, sometimes in two separate phases. Sporadically the cavity functioned as a trap – collector of migrating Fe-colloids.

In some specimens only the inner part of the test (with concentric, globular structure) was dissolved and through the outer, still preserved, but at some part damaged test pigmented sediment penetrated into the central cavity. In other cases SiO_2 solutions, sometimes containing also calcium carbonate, infiltrated only through pores. The outer test is dissolved and substituted by fibrous chalcedony only after the solidification of the filling; the outer part of the test is then preserved in the form of white (clear) ghost. In sporadic cases the whole skeleton of the test or its part is selectively calcified (the original test from SiO_2 is substituted by one or several optical individuals of calcite). It is probably a very early process, since inner elements of the test, which are usually dissolved first and are missing in all other preservation types on this profile, are preserved here as well (from other

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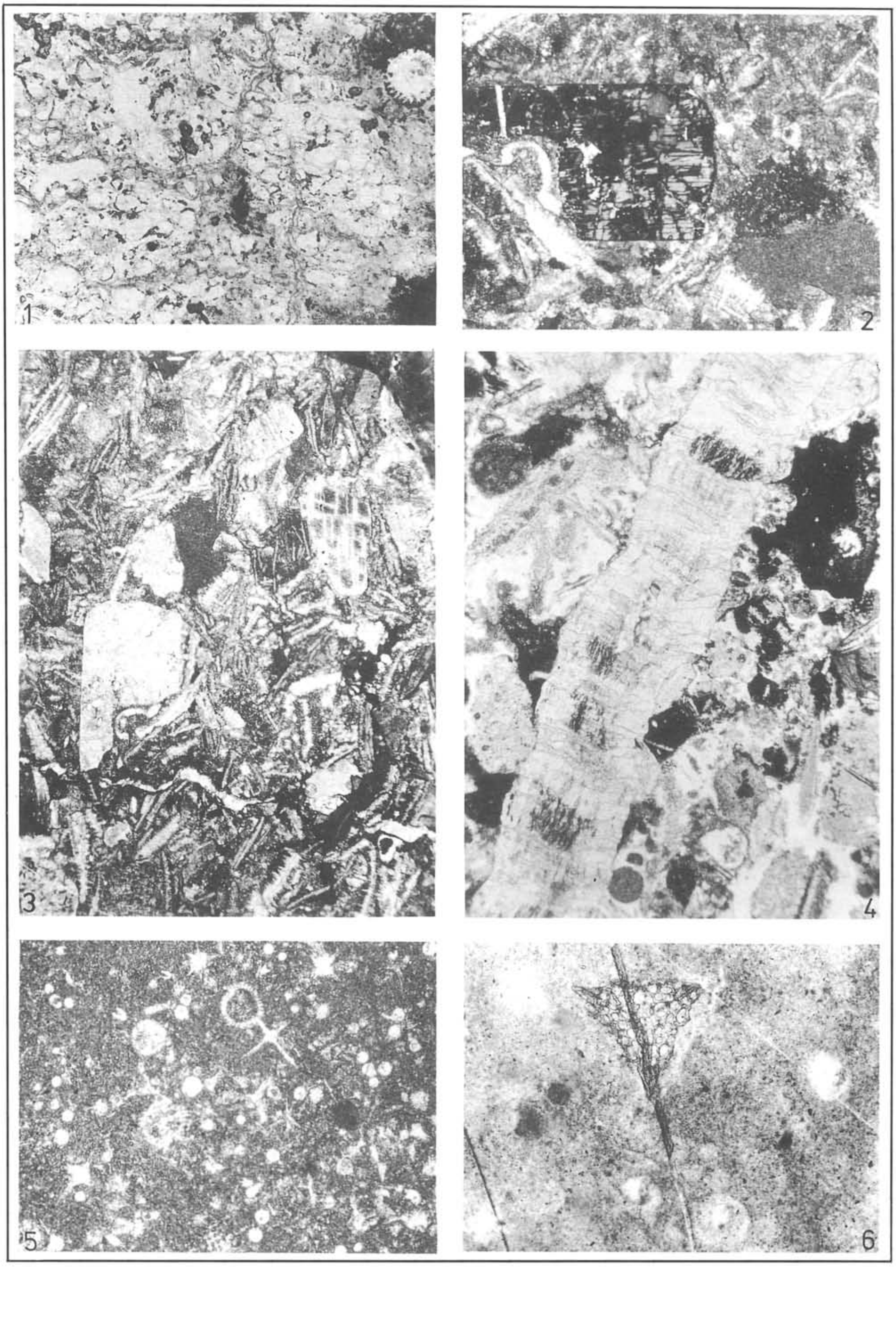
Plate 2: Fig. 1 – Two belemnite rostra, a greater part of them silicified (on the picture white) and a bivalvian of the base of an allodapic lamina in Malmian radiolarite of the Pieniny succession. The picture is rotated by 90 °. Trstená-bowling alley-d. Thin section No. 17873, magn.8.5x. Fig. 2 – Fragment of a calcareous sponge on the base of an allodapic lamina in radiolarite. See previous figure. Thin section No.17311, magn.8.5x. Fig. 3 – Intraplasts (by compaction deformed lithoclasts of white argillites) in distal turbidite or contourite, in a red radiolarian bed. The picture is rotated by 90°. Kimmeridgian of the Pieniny Klippen Belt succession. As above. Thin section No. 17713, magn. 58x. Fig.4 – Slump structure in Malmian radiolarites of the Pieniny succession. The same location. Polished section, slightly magnified.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localities we know also the preservation of inner elements of tests formed by a different SiO_2 aggregate than the surrounding matrix, the difference probably lies in their water contents).

When comparing the forms of preservation of radiolarian tests in radiolarites with their preservation in chert concretions in limestones (Mišík 1973), we do not find the filling in the form of small calcite rhombohedrons with chalcedony, calcite monocrystals of globular shapes, and growth of calcite monocrystals through the peripheral barrier of the test with the formation of a large rhombohedron, in which the ghost of the radiolarian is preserved; these types were present only in concretions from limestones.

Mineralogical composition. Absolutely predominant are fine-grained and fibrous aggregates of SiO_2 minerals classifed as microquartz (only quartz reflexes are present on the X-ray record). Rare fibrous aggregates e.g. from radiolarian fillings are of length-fast chalcedony. The content of clay minerals can be estimated from the content of Al_2O_3 (3.5%); hydromica flakes can be rarely observed in thin sections. Hematite pigment is abundant. Clastic silt quartz occurred rarely, only in thin sections of contourite interacalations, similarly as crystaloclasts of orthoclase, andesine, pumice fragments, sporadic biotite and muscovite flakes. A third of the thin sections contained sporadic chlorite flakes, perhaps of authigenic origin.

Veinlets in radiolarite. They are most frequently cracks filled by calcite or short-fibrous chalcedony. Not infrequent are cracks filled by fluidal SiO_2 aggregate (Pl. 5, Figs. 1, 4, 5) sporadically there are also cracks filled by sediment – we shall deal with them later. In general it holds that chalcedony veinlets are older and calcite veinlets younger. To the oldest ones belong cracks filled by chalcedony in the form of fibrous ("asbestos") aggregate. We could distinguish syngenetic and epigenetic calcite veinlets.

Older (syngenetic) calcite veinlets have corroded margins, they are formed by large calcite individuals clouded by inclusions (probably microquartz) to the point of becoming opaque. Calcite solutions were transported along syneretic hair-thin cracks, they substituted the SiO_2 aggregate which at that time consisted of opal-A or -CT, and oscillation of the conditions led also to a reversal of the process – dissolution of calcite and its substitution by SiO_2. This type of older calcite veinlets has been described before in chert concretions (Mišík 1973, p. 155). Chalcedony veinlets with clouded calcite margins have been found as well. The central part is formed by clear, fine-grained chalcedony which filled the empty crack. The margins are formed by calcite which metasomatically replaced the surrounding sediment of SiO_2 the abundant inclusions of which cause the clouding of both margins of the veinlet (Pl. 1, Fig. 6).

Younger (epigenetic) calcite veinlets have sharp contours, they represent cracks, filled in already completely lithified rock. In the case of repeated movements calcite on veinlet margins was granulated (micritized). Sporadically there are margins around calcite veinlets consisting of brown, colloidal-dispersed minerals (probably authigenic illite).

Dashed veinlets. In two cases we have found dashed calcite veinlets (Pl. 1, Fig. 5; Pl. 3, Fig. 4) known from micritic limestones (Mišík 1971, p. 454). They originated by coalescence of subparallel hair-thin cracks filled by short-fibrous aggregate. Recrystallization of their filling and metasomatic substitution of rock relics which separated them led to the formation of prismatic calcite aggregate: in places there are preserved red relics – an evidence of their formation from hair-thin cracks. Ramsay and Huber (1983, p. 248) described similar veinlets as "stretched crystal fibre veins" formed by "crack-seal mechanism". However, they did not take into consideration the process of recrystallization without which the formation of such textures in veinlets would not have been possible.

Veinlets influencing colour changes in the rock. Some early veinlets are clearly older in relation to diagenetic processes causing colour changes. Red laminated radiolarite contains one olive-green lamina; the same lamina continues after crossing a vertical calcite veinlet – in white colour. Another red lamina continues after a neighboring vertical veinlet, its colour becoming pink. In thin section we can see that this is not only a change of colour, but also of composition – the lamina looses beyond the veinlet the micritic calcite admixture and the filling is pure chalcedony.

Cracks filled by SiO_2 aggregate with fluidal structure. The studied red radiolarites contained in several cases veinlets of pink, very fine SiO_2, up to 3 *mm* thick and 10–20 *mm* long, oriented approximately vertically to bedding. Observed in microscope, they are formed by clear microcrystalline quartz aggregate with thin laminae pink in colour, symmetrical on both sides of veinlets (Pl. 5, Figs. 4, 5). These veinlets do not contain any radiolarians, they formed by filling of empty cracks. The inner part of an incompletely filled crack is sometimes later closed up by calcite grains (Pl. 5, Fig. 1).

Some veinlets with fluidal structure penetrating the contourite, were plastically deformed – undulated in unlithified sediment (Pl. 5, Figs. 4, 5). A measurement of a 2 *cm* section of such veinlet has shown compaction of the contourite component by 18.6%. Since compaction could have taken place already before the formation of the veinlet, we have to count with a minimal compaction of 20%. For a comparison

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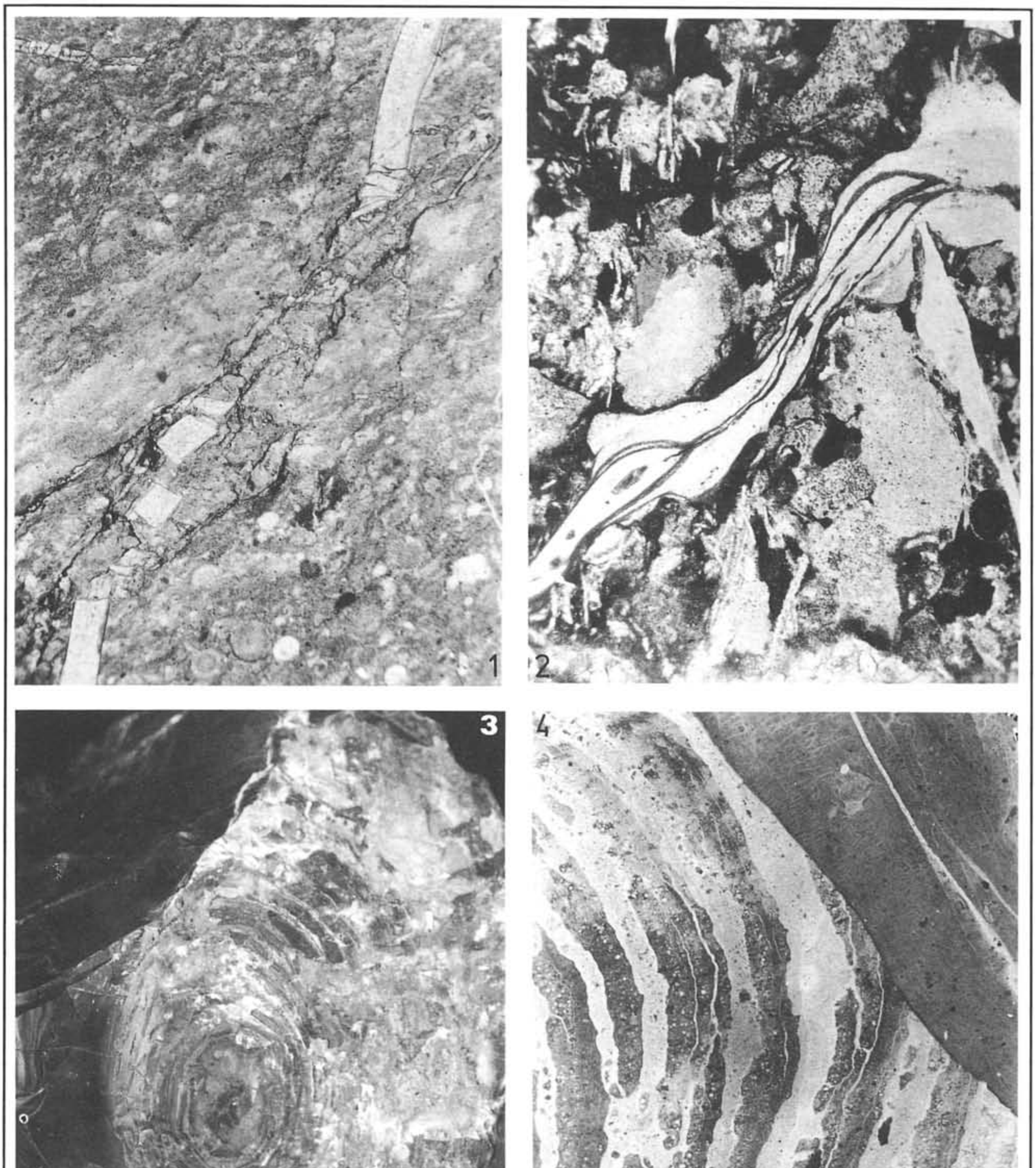
Plate 3: Fig.1 – Pumice fragments in Upper Oxfordian radiolarite (U.A. 7-8) of the Pieniny succession. Trstená-bowling alley-11. Thin section No. 16791, magn. 95x. Fig.2 – Plagioclase (andesine) – crystalloclast. As above. Magn. 48x. Fig.3– Crystalloclasts of volcanic feldspars in distal turbidite or contourite with abundant „filaments" (juvenile bivalvians) – intercalation in Upper Oxfordian radiolarite bed of the Pieniny Klippen Belt succession. As above. Thin section No. 17859, magn.30x. Fig.4– Dashed calcite veinlet formed by coalescence of hair-thin parallel shear-deformation cracks. Upper Oxfordian radiolarite of the Pieniny Klippen Belt. Trstená-bowling alley-11. Thin section No. 18 006. Magn. 95x. Fig.5–Malmian radiolarite, in the middle *Emiluvia* sp. Thin section parallel to bedding. Trstená-bowling alley, as above, magn.30x. Fig.6 – Selectively calcified radiolarian *Perispyridium* sp. – best type of preservation compared with the worst type of preservatioin: a cavity after radiolarian with unsharp contours filled with flaky chalcedony. See previous figure. Thin section No. 17322, magn. 95x.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we should mention that Diersche (1980) estimated the value of compaction flattening of radiolarians in radiolarites at 10–20%.

We have observed also the opposite case – breaking of such rigid veinlet formed by very fine-grained chalcedony (microquartz) in relatively more plastic radiolarite during its tension deformation (Pl. 4, Fig. 1).

Veinlet with filling probably of hydrothermal origin. An approx. 4 *mm* thick veinlet of bluish chalcedony penetrates red laminated radiolarite (Pl. 5, Fig. 3). The filling does not contain any radiolarians. It is composed of several layers parallel to the walls of the crack; its banded structure is similar to that of hydrothermal veins. Radiolarite laminae are bent at contact with the veinlet. We assume that the laminae were bent upwards already in semi-plastic sediment, by escaping gases which accompanied hydrothermal activity.

Syneretic concentric cracks – contraction spheroid. A loaf-like body of shiny "jewellery" radiolarite approx. 30 *cm* in diameter, with concentric bands, has been found outside the profile in debris; its colour was in contrast to other samples light brown. Since it was decorative stone suitable for the manufacture of jewellery, the Geological Survey (Žilina) made a test trench at the location, however, analogous rock has not been found any more.

The study of thin sections has shown rings of brown bands (1–2 *mm*) alternating with thinner bands – veinlets (up to 0.3 *mm*). The white bands represent the filling of concentric dehydration cracks (Pl. 4, Fig. 4). The central part of the loaf-like body displays in cross-section concentric rings (Pl. 4, Fig. 3) resembling so-called wood-grained cherts described by DeCelles and Gutschick (1983); they explained this phenomenon by the Ostwald-Prager theory of Liesegang band formation (an analogous example from the Western Carpathian has been reported by Mišík 1972, Pl. LIII). However, they are most closely related to so-called spheroids described by Taliaferro (1934) in Tertiary silicites and Jurassic radiolarites. According to the cited author they are structures originating as a result of the formation of dehydrating SiO_2 gels. Rare structures of this type have been mentioned also by McBride and Folk (1979) to occur in Jurassic radiolarites of Italy.

The above described "jewellery" radiolarite (spheroid) is very shiny in spite of its almost one-third content of calcite. According to the analysis of Prof. Ing. J. Plško, DrSc. and Ing. E. Kubová (Geological Institute of the Faculty of Sciences, Comenius University), the content of insoluble residue in hot HCl was 65.45% (from this 61.29% SiO_2). The bulk content of Al_2O_3 was 1.79% (from this 0.30% in the soluble part), indicating an insignificant admixture of clay minerals.

The loaf-like body formed in a light-brown sediment of the first generation filled by small radiolarian tests (Pl. 4, Fig. 4). These are almost exclusively cavities after dissolved radiolarians with imperfectly preserved contours. Selective calcification of radiolarians did not occur here. Perhaps hydrothermal solutions caused concentric dehydration cracks leading to the formation of spheroid in the sense of Taliaferro (1934). Into the cracks penetrated silicite sediment of second generation (internal sediment) containing angular clasts broken from the walls of the cracks. It is a fine-flaked "chalcedony" (micro-grained quartz) aggregate. It encloses crystals of baryte, sometimes of lobate habit (Pl. 5, Fig. 2). This filling contains considerably less reddish pigment concentrated only in sporadic radiolarian ghosts. In the lower part of the spheroid the concentric cracks were filled completely, in the upper part of the spheroid the filling has geopetal texture. The upper part of the cracks remained here empty and this space was during diagenesis filled by the third generation – an aggregate of sheaf-like fibrous chalcedony with reddish globules 0.01–0.03 *mm* in size. This third generation sporadically fills rare short, concentrically oriented dehydration cracks formed at the consolidation of the second-generation filling. In exceptional cases its central part contains the youngest (fourth-generation) filling consisting of calcite aggregate.

In one case we have observed a microdyke with red sediment cutting the ring structure (Pl. 4, Fig. 4). The formation of such regular concentric dehydration cracks in the described spheroid (in average six white veinlets separating the same number of brown radiolarite bands in an 1 *cm* section) is difficult to explain. Drying cracks usually form during the emergence of a sediment, however, these concentric syneretic cracks formed in deep-sea conditions, immediatelly under the sea-floor. The described spheroid contains in the core an inraclast around which it formed; the formation of the spheroid was perhaps caused by hydrothermal solutions. An evidence of the hydrothermal origin could be the occurrence of baryte grains, up to 0.4 *mm* in size, partly crystallographically confined (Pl. 5, Fig. 2), in the second generation filling (determined with the help of the apparatus EDAX). We have observed an analogous phenomenon on a considerably smaller scale (five concentric cracks about an undifferentiated core) in unlaminated greenish Malmian siliceous limestones at a nearby location Halečková, in the largest of the three quarries.

Diagenesis of radiolarites. The succession of various types of radiolarian fossilization as well as various veinlet types indicate frequent mutual substitution of silica minerals and calcite during the early, "highly reactive" stage of diagenesis of radiolarian sediment. This stage is controlled by considerable porosity, high water contents with successive dehydration processes, the presence of opal-A and -CT. It lasts probably several million years and its upper boundary is the substitution of all opal-A and -CT by microquartz. Resch and von Rad (1979) estimated the minimal duration of this alteration in oceanic conditions at 40 million years. Mizutani (1983) calculated on the basis of a $^{86}Rb/^{87}Sr$ isochrone for three Mesozoic radiolarites that their diagenetic changes were complete 35 m.y. ago.

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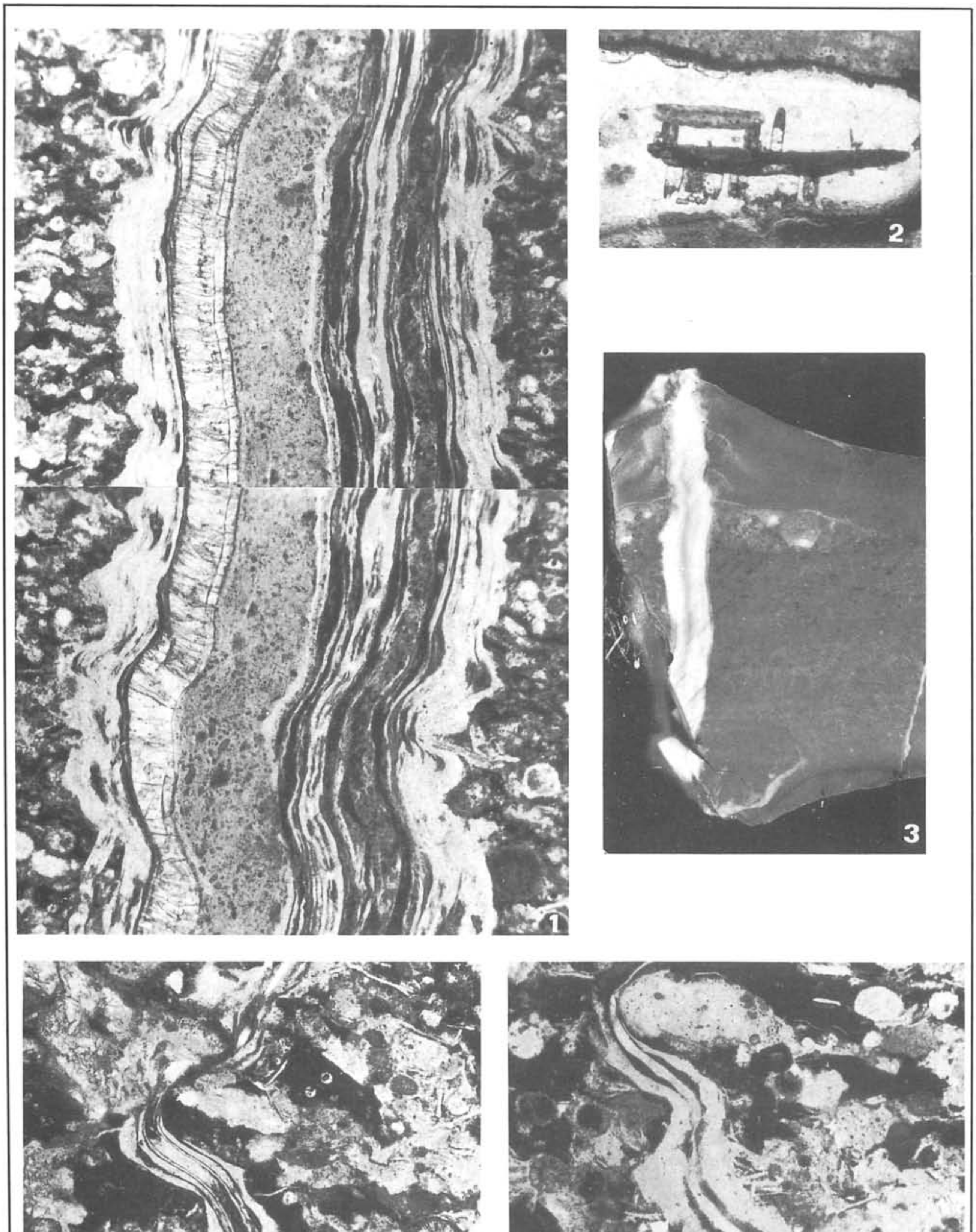
Plate 4: Fig.1 – Rigid veinlet composed of fine-grained chalcedony broken during tension deformation in more plastic radiolarite. Upper Oxfordian of the Pieniny succession. Trstená-bowling alley-7. Thin section No. 17590, mang.30x. Fig. 2 – Compacted veinlet in radiolarite. Thin section No.16793, magn.30x. Fig. 3 – Central part of a spheroid in Malmian radiolarites of the Pieniny Klippen Belt succession. Trstená-bowling alley. Fracture surface, natural size. Fig. 4 – Concentric contraction cracks (white filling) in a spheroid („jewellery radiolarite"), disturbed by a crack filled by different, partly fine-brecciated radiolarian sediment (microdyke). See previous figure. Thin section No. 17554, magn.8x.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Evaluation of radiolarian associations extracted from the radiolarites

Oxfordian associations (Pl. 6, Figs. 1–13; Pl. 7, Figs. 3–13). The samples No. 7, 8, 9, 10, A-1, III/2, III/8, III/9 had approximately the same contents of species. Spiny thin-walled tests and rayed tests strongly dominated over conical ones, which occurred in negligible amounts. The most characteristic composition of the association was in the sample III/2, where the following 44 species have been identified:

Acaeniotyle diaphorogona Foreman, *Acanthocircus amissus* (Squinabol), *Acanthocircus variabilis* (Squinabol), *Andromeda podbielensis* (Ožvoldová), *Angulobracchia cava* Ožvoldová, *Angulobracchia biordinale* Ožvoldová, *Archaeospongoprunum imlayi* Pessagno, *Gingulot urris carpatica* Dumitrica, *Emiluvia chica* Foreman, *Emiluvia orea* Baumgartner, *Emiluvia ordinaria* Ožvoldová, *Emiluvia pessagnoi* Foreman, *Emiluvia premyogii* Baumgartner, *Emiluvia sedecimporata elegans* (Wiśniowski), *Emiluvia sedecimporata salensis* Pessagno, *Haliodictya hojnosti* Riedel et Sanfilippo, *Homoeparonaella argolidensis* Baumgartner, *Homoeoparonaella* sp. A, *Hsuum brevicostatum* (Ožvoldová), *Mirifusus mediodilatatus baileyi* Pessagno, *Napora deweveri* Baumgartner, *Orbiculiforma* sp., *Paronaella kotura* Baumgartner, *Paronaella* aff. *kotura* Baumgartner, *Pantanellium lanceola* (Parona), *Paronaella mulleri* Pessagno, *Paronaella* sp., *Perispyridium ordinarium* (Pessagno), *Perispyridium tamanense* Pessagno et Blome, *Podobursa spinosa* (Ožvoldová), *Podobursa triacantha* (Fischli), *Ristola altissima* (Rüst), *Spongocapsula perampla* (Rüst), *Spongocapsula* cf. *perampla* (Rüst), *Staurosphaera antiqua* Rüst, *Tetratrabs bulbosa* Baumgartner, *Tetratrabs zealis* (Ožvoldová), *Tetraditryma pseudoplena* Baumgartner, *Triactoma blakei* (Pessagno), *Triactoma jonesi* (Pessagno), *Tritrabs* aff. *casmaliaensis* (Pessagno), *Tritrabs ewingi* (Pessagno), *Tritrabs exotica* (Pessagno), *Tritrabs worzeli* (Pessagno).

The presence of *Emiluvia orea* Baumgartner in all associations indicates that the communities are not older than U.A.7., which corresponds stratigraphically to the upper part of the Lower Oxfordian. The presence of *Tritrabs exotica* (Pessagno), *Andromeda podbielensis* (Ožvoldová). *Cingulotırris carpatica* Dumitrica, *Emiluvia premyogii* Baumgartner or *Napora deweveri* Baumgartner, the occurrences of which end in U.A.8, determine the upper boundary of the stratigraphic span of the Upper Oxfordian.

The composition of the associations can be thus correlated with U.A.7 and U.A.8, which corresponds to the stratigraphic span upper part of the Lower Oxfordian–Upper Oxfordian.

Kimmeridgian–Lowermost Tithonian associations (characteristic species – Pl. 7, Figs. 1, 2). A positive sample from claystones (2a) contained cores or imperfectly preserved radiolarian tests from which the species *Sethocapsa cetia* Foreman could be identified, the occurrence of which begins in U.A.9 – in the Lower Kimmeridgian.

The associations in the radiolarite samples No. 3, III/1, III/11, III/12, III/14 contained approximately the same proportions of species. The characteristics of the associations were also the same. Two types of test were found in them: 1 – matt, opaque, impregnated by Fe pigment, fragile, their spherical shapes being frequently deformed; 2 – glassy, more resistant forms. The following 18 species have been identified: *Acanthocircus amissus* (Squinabol), *Acaeniotyle diaphorogona* Foreman, *Emiluvia ordinaria* Ožvoldová, *Emiluvia sedecimporata elegans* (Wiśniowski), *Emiluvia sedecimporata salensis* Pessagno, *Homoeoparonaella* sp. A, *Mirifusus mediodilatatus baileyi* Pessagno, *Obesacapsula morroensis* Pessagno, *Obesacapsula* aff. *rotunda* (Hinde), *Parvicingula boesii* (Parona), *Podobursa triacantha* (Fischli), *Podocapsa amphitreptera* Foreman, *Ristola altissima* (Rüst), *Sethocapsa cetia* Foreman, *Triactoma blakei* (Pessagno), *Triactoma jonesi* (Pessagno), *Triactoma tithonianum* Rüst, *Tripocyclia trigonum* Rüst.

The presence of *Sethocapsa cetia* Foreman the occurrence of which starts in U.A.9, indicates that the associations are not older than the Lower Kimmeridgian.

The first occurrence of *Podocapsa amphitreptera* Foreman has been reported (Baumgartner 1984) from U.A.8 (upper part of the Upper Oxfordian). However, in the Western Carpathians this species has never been found in associations older than the Lower Kimmeridgian and it was almost always accompanied by *Sethocapsa cetia* Foreman.

The absence of species characteristic for U.A.10 and U.A.11 allow to correlate the analyzed associations with U.A.9, having a stratigraphic span of Kimmeridgian–lowermost Tithonian.

The index of refraction has shown that the extracted and depicted tests are composed of newly-formed fluorite.

Stratigraphic conclusions resulting from the evaluation of the associations are based on the biostratigraphic zoning after Baumgartner (1984, 1987).

The determination and evaluation of radiolarians was carried out by L. Ožvoldová.

Red marly shales (calcareous claystones)

Marly shale intercalations have been analysed chemically and by X-rays. Thin sections were made from them after their impregantion by canadian balm; nannoplankton was studied in pulverised rocks.

The content of insoluble residue (in hot HCl) in the sample N-a was 65.88% (thus, about a third of the rock is composed of calcite). In the insoluble residue 54.72% was SiO_2, 5.10% Al_2O_3, the rest was Fe_2O_3 (hematite pigment) and other components. It is surprising that the

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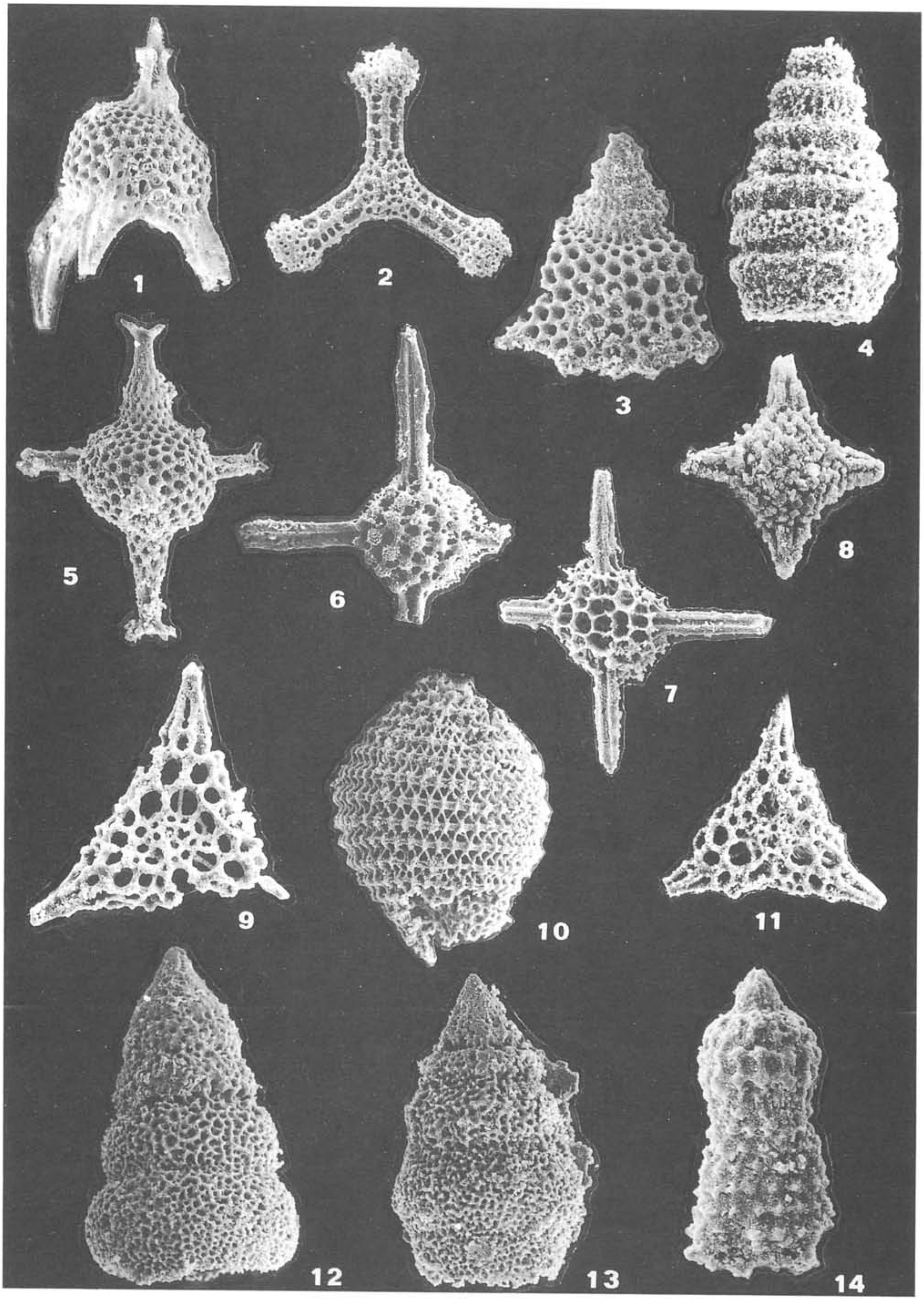
Plate 5: Fig.1 – Undulated vertical veinlet with complicated filling, mostly of clear fine-grained chalcedony (fluidality enhanced by red pigment), in the middle a mixture of chalcedony and small calcite grains (grey), on the left filling of prismatic calcite. Malmian radiolarite. Trstená-bowling alley. Thin section No.18005, magn.30x. Fig. 2 – Lobate baryte crystal from the spheroid (Pl. 4, Figs. 3, 4). Thin section No.17554, magn.32x. Fig.3 – Laminated red radiolarian disturbed by vertical veinlet of bluish chalcedony with fluidal structure. In the upper part the laminae were roof-like elevated, probably due to to the movement of fluids upwards along the crack. Trstená-bowling alley. Polished section, magn.1.7x. Figs.4 and 5 – Vertical chalcedony veinlet indicating at least 20 % compaction of contourite intercalation in Malmian radiolarite. Trstená-bowling alley. Thin section No.16793, magn. 30x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soluble part of the rock (34.12% of the sample) contained as much as 4.89% Al_2O_3 from the bulk content of 9.9% Al_2O_3 in the sample. The chemical analysis was carried out by Ing. E. Kubová and Prof. Ing. J. Plško, DrSc., from the Geological Institute of the Faculty of Sciences, Comenius University, Bratislava.

X-ray analysis carried out by Dr. E. Šamajová, CSc. (GI Fac. Sci.) showed only the presence of quartz, calcite, illite (9.82 *nm*) and chlorite (14.73 *nm*). Saturation by glycol did not result in shifting of the lines, smectites are thus not present. For a comparison we would like to mention that Kwiatkowski (1981) as well determined in claystone intercalations in radiolarites of the Klippen Belt only illite, smectites were not present.

Thin sections display clearly higher contents of clay mineral flakes – illite – in comparison with surrounding radiolarite beds. Sporadically we have found chlorite, silt grains of quartz and tiny columnar greenish tourmaline.

The scarcity of radiolarians is surprising (3–10 specimens in a thin section, in contrast to hundreds of specimens in radiolarite thin sections). It is always only calcite filling of cavities after radiolarians which is found here. In one of five samples (i-a) there were cross-sections of globular bodies with a smooth surface, 0.03 *mm* in diameter, clearly smaller that the smallest radiolarians (they are probably of chitine-phosphatic composition, the central cavity is filled by calcite). Tiny phosphatic fragments of unidentified organisms (partly fish scales) are clearly more frequent than in the surrounding radiolarites. Three ostracods, a fragment of a bivalvian and one specimen of *Colomisphaera minutissima* (Colom) were found in the sample i-d (this species appears for the first time in the Upper Oxfordian). Calcareous nannoplankton will be described later. Miospores are probably also present.

Since calcareous claystones contain as much as one-third of $CaCO_3$ we cannot assume the sedimentation to have taken place below CCD level. Depths near to this level are however indicated by strong dissolution of calcareous nannoplankton. Traces of compaction have not been observed on radiolarians. The surprising scarcity of radiolarians in marly claystone intercalations supports the theory explaining the formation of radiolarite beds by rapid accumulation of radiolarians due to bottom currents.

Associations of calcareous nannoplankton from red shale intercalations

Four samples have been studied in optical microscope as well as with the help of SEM. The samples i-a, i-b contain relatively abundant nannoplankton (at an enlargement of 1600 × 10 specimens in the field of vision), it is however a monotonous placolith association with a small number of species. *Cyclagelosphaera deflandrei* is strongly predominant. The following species (Pl. 8, Figs. 1–8) having the below given stratigraphic spans have been found in both samples collected on a section with determined radiolarian association U.A.9 (Kimmeridgian):

x *Cyclagelosphaera deflandrei* (Mainivit) Roth – Callovian–Hauterivian
x *Cyclagelosphaera margelii* Noel – Bathonian–Campanian
x *Ellipsagelosphaera britannica* (Stradner) Perch–Nielsen – Toarcian–Campanian
Watznaueria barnesae (Black) Perch–Nielsen – Bathonian – Maastrichtian
x *Watznaueria biporta* Bukry – Bathonian–Campanian
\+ *Ellipsagelosphaera fossacincta* Black – Middle Bajocian –Barremian
\+ *Ellipsagelosphaera ovata* (Bukry) Black – Callovian–Santonian
\+ *Lotharingius crucicentralis* (Medd) Grün–Zweilli – Bathonian–Oxfordian

(Species marked by + have been identified with the help of SEM, species marked by x were present in both samples, the rest only in the sample i-a).

Dominant are representatives of the family *Ellipsagelosphaeraceae* – an indication of Upper Jurassic communities. The stratigraphic classification of the association can be based on *Lotharingius crucicentralis* with the span of Bathonian–Oxfordian (Medd 1971, reported that he found one form of the species *L. crucicentralis* also in the Lower Kimmeridge Clay, England), as well as on the absence of *Zeughrabdotus embergeri,* the first appearance of which is assigned to the Upper Kimmeridgian (*Z. embergeri* is a marked member of Upper Jurassic communities, very resistant to dissolution processes). It can be thus concluded that the association is older that the Upper Kimmeridgian. Since the radiolarian association U.A.9 points to the Kimmeridgian stage, it is most probable that the interval containig both samples belongs to the Lower Kimmeridgian and that the span of *Lotharingius crucicentralis* has to be extended to Bathonian–Lower Kimmeridgian.

The samples i-c, i-d were poor in organic remnants (approximately 3 specimens in the field of vision at an enlargement of 1600 x). Less than a half of the above mentioned species have been identified in the first of the samples; i-d contained only placoliths with one disc, which is the highest grade of destruction indicating sedimentation in deep, strongly undersaturated marine water.

The described thanatocenoses are completely free of abundant species with a short time span, which allowed detailed zoning in epicontinental sediments of England and France (Barnard and Hay 1974). We also could not rely on the zoning suggested for deep-sea sediments from the northern Atlantic by Roth (1983), since the studied thanatocenoses were strongly depleted due to dissolution of less resistant forms.

The nannoplankton was determined and evaluated by E. Halásová.

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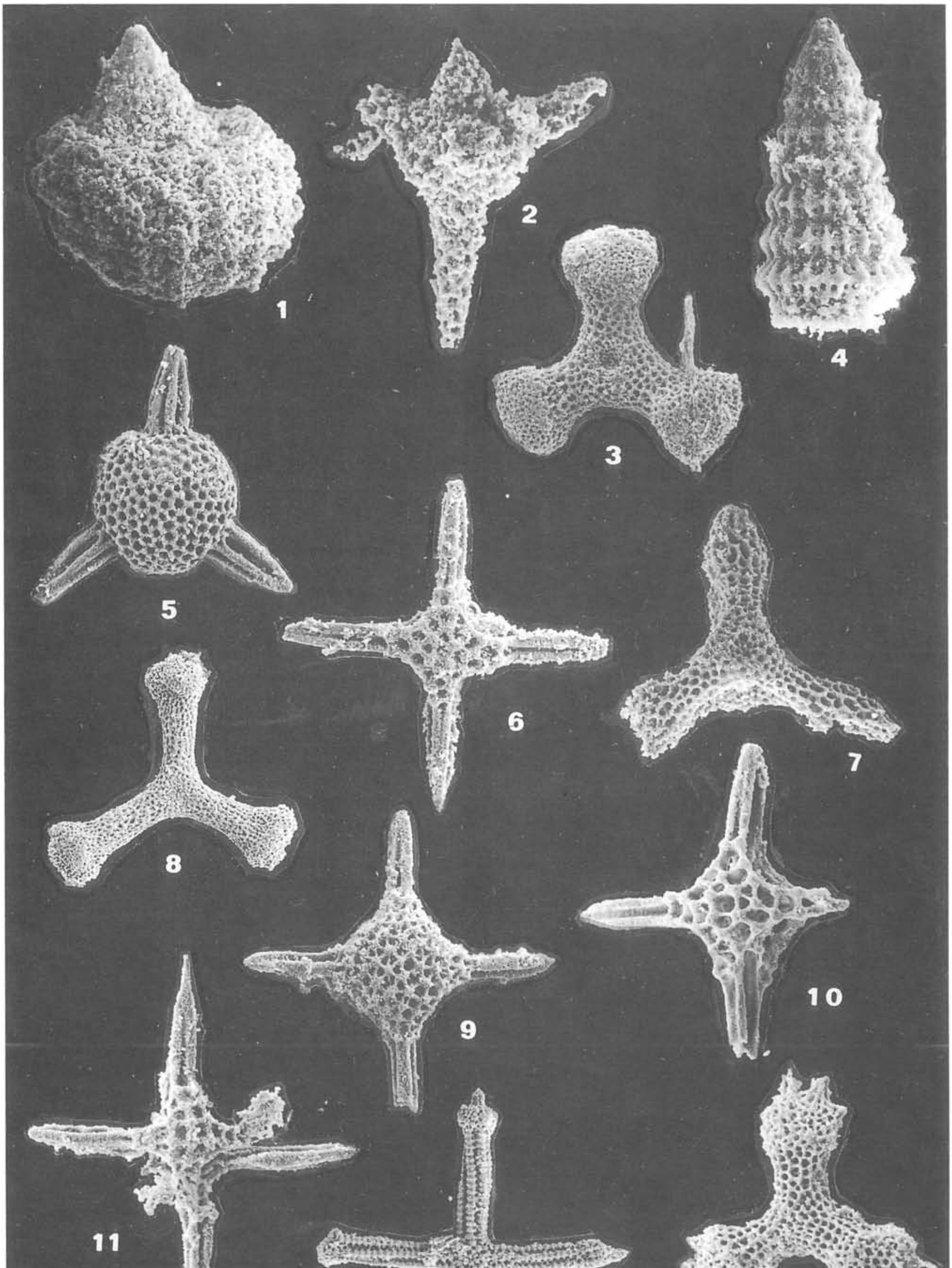
Plate 6: Fig. 1 – *Napora deweveri* Baumgartner – 10,4647,190 x magn.; Fig. 2 – *Tritrabs exotica* (Pessagno) – III/2,6070,120 x magn.; Fig. 3 – *Andromeda podbielensis* (Ožvoldová) – III/2,6067,155 x magn.; Fig. 4 – *Cinguloturris carpatica* Dumitrica – 10,4232,220 x magn .; Fig. 5 – *Podobursa spinosa* (Ožvoldová) – III/2,6078,120 x magn.; Fig 6 – *Emiluvia orea* Baumgartner – 9,3245,115 x magn.; Fig. 7 – *Staurosphaera antiqua* Rüst – III/2,6095,100 x magn.; Fig. 8 – *Haliodictya hojnosi* Riedel and Sanfilippo – A–1,4212,235 x magn.; Fig. 9 – *Perispyridium ordinarium* (Pessagno) – 10, 4242,170 x magn.; Fig. 10 – *Mirifusus mediodilatatus baileyi* Pessagno – III/2,6077,110 x magn.; Fig. 11 – *Perispyridium tamanense* Pessagno and Blome – 10,4240,205 x magn.; Fig. 12 – *Spongocapsula* cf. *perampla* (Rüst) – III/2,6083,195 x magn.; Fig. 13 – *Spongocapsula perampla* (Rüst) – III/2,6082,125 x magn.; Fig. 14 – *Ristola altissima* (Rüst) – 3,5017,120 x magn.;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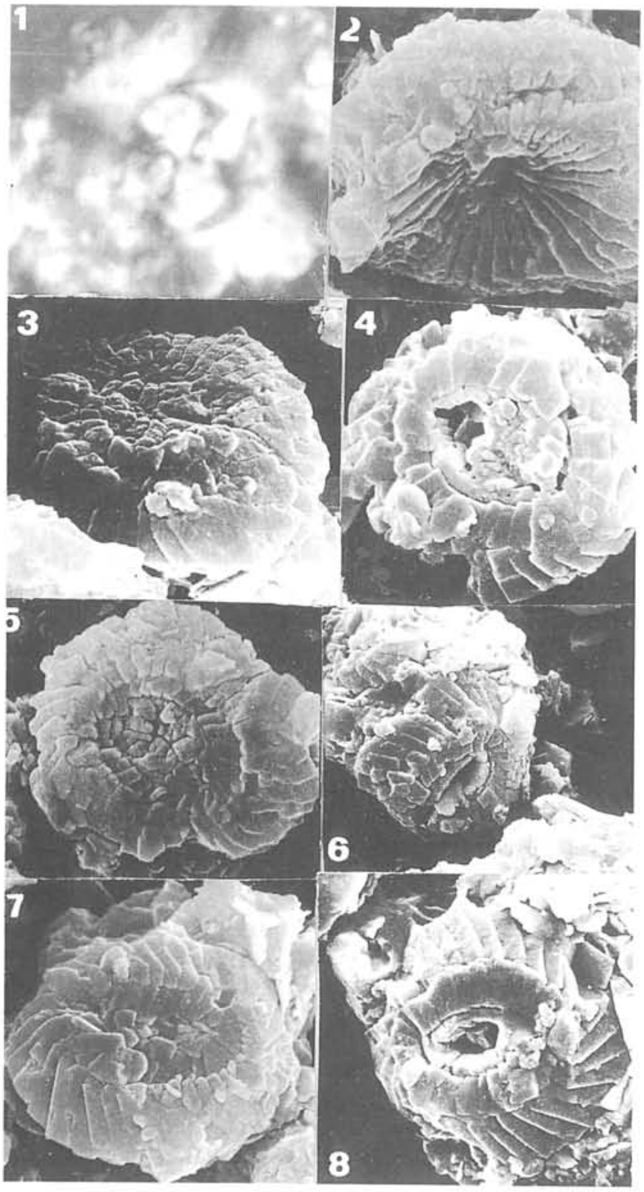

Plate 8: Fig. 1 – *Cyclagelosphaera deflandrei* (Manivit) Roth – i-a, 5 000 x magn.; cross-polarized light; Fig. 2 – *Cyclagelosphaera deflandrei* (Manivit) Roth – i-a, 4 500 x magn.; Fig. 3 – *Lotharingius crucicentralis* (Medd) Grün et Zweilli – i-a, 5 300 x magn.; Fig. 4 – *Ellipsagelosphaera ovata* (Bukry) Black – i-a, 6 000 x magn.; Fig. 5 – *Watznaueria barnesae* (Black) Perch-Nielsen – i-a, 4 000 x magn.; Fig. 6 – *Ellipsagelosphaera fossactinata* Black – i-a, 3 600 x magn.; Fig. 7 – *Watznaueria biporta* Bukry – i-a, 4 000 x magn.; Fig. 8 – *Ellipsagelosphaera fossactinata* Black – i-a, 5 500 x magn. *Photographed* by SEM, Geological Inst. of D. Štúr, Bratislava Fig. 1 by LM.

Distal turbidites – clastic intercalations in radiolarite beds

They attain the maximal thickness of 5 *cm*. A part of them is gradationally bedded (Pl. 1, Figs. 1, 2). The thickest allodapic intercalation contained clasts with a maximum size of 9 *mm*.

The predominant component of organic remnants are here radiolarians, however, in contrast to the radiolarites they contain more frequenty large (as much as 0.32 *mm* in diameter) thick-tested types as a result of sorting by currents. Radiolarians, bioclasts and lithoclasts are thickly packed ("packstone"), sometimes they are even pushed one into another (pressure solution). A frequent phenomenon is selective calcification of radiolarians. Thicker allodapic intercalations contain abundant filaments (juvenile bivalvians of the Bositra type – Pl. 3, Fig. 3), usually subparallelly oriented. Ostracods are rare (2–5 specimens in a thin section – Pl. 1, Fig. 3); mostly with thicker, partly silicified shells. Further there are silicisponge spicules (Monactinellida, Hexactinellida and rhaxa – only about 1–3 specimens in a thin section), rarely fragments of bivalvians with prismatic structure (Pl. 1, Fig. 3), sporadically also of oyster bivalvians (4 *mm* large fragments, silicified, with ghosts of boring algae – Pl. 1, Figs 3, 4). Infrequent components are echinoderm segments from calcite, aptychi, partly silicified lagenid foraminifers, a sole fragment of silicified bryozoan, two belemnite rostra on the basement of the allodapic intercalation (Pl. 2, Fig. 1) and a 3 *cm* large fragment of a calcareous sponge (Pl. 2, Fig. 2).

Rock fragments are visibly rounded by transport. Most frequently there are clasts of red radiolarites, light-coloured to white claystones (probably argillized tuffites), sporadically silt claystones, micrites (in one case containing *Colomisphaera* sp.) and rare pumice fragments with preserved relics of vesicular texture (Pl. 3, Fig. 1) and feldspar crystalloclasts (Pl. 3, Figs. 2, 3). Lithoclasts are usually oriented subparallelly to the bottom. Fragments of white claystones are sometimes clearly flattened by compaction, adopting s-like forms (Pl. 2, Fig. 3). Barrett (1982, Fig. 96) figured very similar picture. This indicates that deformations took place in unconsolidated state (intraplasts). Sporadically clastic quartz grains of silt size can be found as well as flakes of muscovite, chlorite and biotite. There is very little interstitial matter between the clasts and skelets of organisms, due to washing out; it is usually densely coloured due to Fe oxides.

Clastic allodapic intercalations represent distal turbidites. However, we cannot exclude that the material was reworked into so-called contourites by traction currents following bathymetric contours of the basin (Heezen, Hollister and Ruddimann 1966). They contain predominanly material generated in a deep basin. Those containing detritus of shallow-water organisms of psammitic grain-size could have originated by reworking of distal calciturbidites, as suggested by Stow and Lowell (1979). An evidence against direct deposition from suspension currents is the rounding of

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Plate 7: Fig. 1 – *Sethocapsa cetia* Foreman – 3,6062,140 x magn.; Fig. 2 – *Podocapsa amphitreptera* Foreman – 3,4996,155 x magn.; Fig. 3 – *Paronaella* aff. *kotura* Baumgartner – III/2,6080,120 x magn.; Fig. 4 – *Hsuum brevicostatum* (Ožvoldová) – 10,4226,230 x magn.; Fig. 5 – *Triactoma blakei* (Pessagno) – III/2,606,135 x magn.; Fig. 6 – *Emiluvia sedecimporata elegans* (Wisniowski) – III/2,60987,140 x magn.; Fig. 7 – ? *Angulobracchia cava* Ožvoldová – III/2,6063,140 x magn.; Fig. 8 – *Paronaella kotura* Baumgartner – 10,4215,75 x magn.; Fig. 9 – *Emiluvia chica* Foreman – III/2,6081,120 x magn.; Fig. 10 – *Emiluvia sedecimporata salensis* Pessagno – III/2,6092, 170 x magn.; Fig. 11 – *Emiluvia ordinaria* Ožvoldová – III/2,5081,140 x magn.; Fig. 12 – *Tetratrabs bulbosa* Baumgartner – III/2, 6088,60 x magn.; Fig. 13 – *Homoeoparonaella* sp. A – III/2,6122,140 x magn.

lithoclasts and the absence or exceptional scarcity of the most typical groups (foraminifers, algae, crinoid fragments) which usually form the most abundant component in calciturbidites within pelagic limestones (e.g. Barmstein limestones of the Malmian – Mišík and Sýkora 1982). The predominance of short filaments indicates a spatial relationship with the sedimentation environment of red nodular limestones with filament microfacies (sediments of deeper shelf, or submarine elevations). Vertical facial transitions from radiolarites to red nodular limestones must have had, according to Walther's rule, also lateral equivalents in the form of transitions into these facies. We can observe this quite frequently in the Western Carpathians and it has been documented in great detail by Diersche (1980) in the Eastern Alps.

The most probable source of material of the here described distal turbidites or contourites was a submarine elevation, with a volcanic island producing acid pyroclastics. Frequent preservation of calcite biodetritus in thin laminae is together with calcareous claystone intercalations an evidence of the sedimentation having taken place above CCL.

Except macroscopically visible distal turbidites or contourites the activity of weak bottom currents is indicated also by frequent laminae (1–5 *mm*) consisting of large, tightly packed radiolarians, sometimes displaying signs of gradational bedding, in contrast to the surrounding radiolarite where considerably less packed smaller tests are predominant.

Miall (1984, p. 356) suggested that turbidites and contourites are more abundant in periods with lower level of the world ocean. The detailed curve of eustatic movements (Haq et al. 1986) displays three minima which could perhaps be related to six contourite horizons (from material of distal turbidites) in our profile: 148.9 m.y. (the lowermost horizon), 146.5 m.y. (four closely above each other lying horizons) and 144 m.y. (the uppermost horizon).

It is surprising that allodapic intercalations occurred several times on that locality in such a long time span. It indicates that the bathymetric conditions and topography of the sea floor did not change in about 4 milion years (or 1.3–6.5 m.y.). The second estimation was based on the minimal interval of 6.5 *m* between the lowermost and uppermost contourite horizon, on the total duration of the Upper Oxfordian and Lower Kimmeridgian of about 5 m.y., on the minimal sedimentation rate of 1 *mm*/m.y. and maximal sedimentation rate of 5 *mm*, assumed for Alpine radiolarites by Diersche (1975).

Volcanic admixture in radiolarites

We have found sligt admixture of pyroclastic material only in allodapic intercalations (contourites), represented by pumice fragments with relics of vesicular texture, max. 4 *mm* in size (Pl. 3, Fig. 1), feldspar crystalloclasts (orthoclase and andesine, max. 1.10 *mm*, Pl. 3, Figs. 2, 3); probably also white claystone intraplasts representing argillized tuffites (Pl. 2, Fig. 3).

Pyroclastic material has been observed in sample No. 11, in which the radiolarian association of the Upper Oxfordian (U.A. 7–8) has been determined, No. 6 occurring 30 *cm* and No. 4 1 *m* above proved Upper Oxfordian and 1.5 *m* below proved Lower Kimmeridgian (U.A. 9). Material of this Upper Oxfordian volcanism was brought by contourite currents from a distant region. Let us try to determine this source on the basis of sporadic notes on Oxfordian volcanism related to radiolarites of the Alpine–Carpathian region.

There are no known volcanic intercalations in Doggerian–Malmian radiolarites of the Western Carpathians. Only indirect traces of volcanic activity in Jurassic radiolarite of the Polish part of the Pieniny Klippen Belt have been mentioned in a short report by Šikora and Wieser (1979), on a locality near Staré Bystré. It is a half-meter thick bed of clayei shales in so-called manganese radiolarites (Sokolica Formation), consisting to a large extent of montmorillonite. The cited authors assumed that it formed by submarine weathering of hyaloclastic tuff of basaltic composition. They found in beds lying under red radiolarites (which are discussed in this paper), among clay shales, a 1.5 *cm* thick layer of bentonite composed of Ca-montmorillonite, microcrystalline quartz, zircon and angular garnet. The authors interpreted this intercalation as pyroclastic material, an evidence of subaqueous extrusions of basalt lavas. Sokolowski (1985) reports radiolarite intercalations with intraclasts of pumice and seladonized volcanic glass from the Doggerian–Malmian of the Subtatric (Krížna) Nappe in the drillhole Banska IG-1, from a depth of 4090 *m*.

The rest of the traces and manifestation of Oxfordian volcanism are related to the Eastern Carpathians. Bombiţă and Savu (1985) reported an occurrence of basalt andesite tuffs up to 9 *m* thick, to occur among variegated Callovian–Oxfordian radiolarites and claystones at the end of the Klippen Belt near Poiana Botizii in Romania. Birkenmajer (1986) attributed this locality to the Magura Klippen of the Grejcarek unit.

Lomize (1968) mentioned an occurrence of a sequence of amygdaloidal porphyrites and volcanic breccias about 200 *m* thick in the Rachovo unit, situated externally of the Ukrainian Carpathian Klippen Belt; Oxfordian ammonites have been found in tuffitic intercalations.

We have found a pebble of Callovian–Oxfordian radiolarite with *Higumastra imbricata*, penetrated by quartz-albite veinlets (an indication of post-volcanic activity) in Eocene Strihov conglomerates of the Magura Belt – the Krynica subzone, lying immediately next to the Eastern Slovak section of the Klippen Belt (Mišík et al. 1991a).

A marked pyroclastic admixture consisting of basic volcanites has been determined in a pebble of Callovian–Oxfordian limestone from Proč conglomerates of the Eastern Slovak section of the Klippen Belt (Mišík et al., 1991b).

We can thus conclude that practically all mentioned occurrences concerned basic volcanites, the pumice fragments found by us were however related to acid and intermediary volcanism.

Marked presence of syngenetic acid (rhyolite-dacite) volcanism in Oxfordian radiolarites is known in the Eastern Alps, in the broader surroundings of Salzburg, on an about 100 *km* section. They have been lately described in detail by Diersche (1980). He mentioned about 30 locations (map – l.c., p. 142). In Tirolicum there are also 2 *m* thick layers of silicified crystalline tuffs with rhyolite fragments, zonal plagioclases etc. In contrast to our occurrences, the cited author does not mention pumice fragments. He assumes the source region to have been situated south of Tirolicum. Material was mostly transported by water, however, he suggests that acid tuff intercalations in Tirolicum formed from tropospheric ashfall. He related this acid and intermediary volcanism with subduction on the northern margin of Unterostalpine, which could perhaps have started already in the Oxfordian. We assume that volcanic sources were situated at the northern margin of Tirolicum from where pyroclastic material could have been

Fig. 6. Localization of acid and intermediary Oxfordian volcanic material in the Eastern Alps – surroundings of Salzburg and in the Western Carpathians – Trstená-bowling alley (top), and schematic representation of the possible transportation (bottom). Differences in the width of facial zones and lateral shift on the boundary of the Outer and Central Carpathians are not taken into consideration.

Explanations: 1 – volcanic sources; 2 – assumed directions of aerial transport of pyroclastic material; 3 – assumed direction of water transport by contour currents; 4 – area of pyroclastic material occurrences in Eastern Alpine radiolarites (Diersche 1980); 5 – occurrences of clastic material in radiolarites of the Pieniny Klippen Belt.

transported by winds also to the other side, to the sedimentation basin of Penninicum, and it could have been brought by longitudal currents to the area of the Pieniny Klippen Belt in Orava (Fig. 6).

Conclusions

For the first time, acid and intermediary volcanic material has been found in the Western Carpathians in Upper Oxfordian radiolarites of the Pieniny Klippen Belt. It is a component of clastic intercalations of psammitic type, containing in inferior amounts also bioclasts of shallow-water organisms transported by bottom currents (distal calciturbidites eventually reworked into contourites). Continuous layers of acid and intermediary pyroclastics are known to occur in Malmian radiolarites of the Eastern Alps, in an extensive region near Salzburg (Diersche 1980); the here decribed occurrences in the Western Carpathians can be related probably to the same volcanic source.

Allodapic intercalations indicate surprisingly constant sedimentation conditions during a 4 milion year interval. Red radiolarites of the Pieniny succession (Buwald Member) have a wider stratigraphic span than believed up to now (Birkenmajer 1977) – minimally Upper Oxfordian–Lower Kimmeridgian. 44 radiolarian species have been determined in the association U.A. 7–8 (defined by Baumgartner 1987), in U.A. 9 there were in all 18 species.

In the extremely complicated structure of the Klippen Belt, normal and reverse succession of beds in tectonic lenses – klippen can be distinguished with the help of radiolarian zones and graded bedding.

The banded radiolarite formation sedimented immediately above CCD. Calcareous claystone intercalations contain depleted associations of calcareous nannoplankton. The correlation between the bed thicknesses of radiolarites and calcareous claystones is insignificant (0.266), they thus formed in two independent processes. We assume that calcareous claystone intercalations are "autochthonous" sediments and radiolarian accumulations were brought by bottom currents, even weaker ones than those which gave rise to contourite layers.

At least 14 types of fossilization, or ghosts of radiolarians have been determined; the earliest one from them, resulting in the most perfect preservation, is selective calcification of tests. Deformations of early vertical veinlets allowed to estimate the minimal value of compaction at 20%. Submarine slump structures occurred sporadically as well as spheroids with concentric contraction cracks (their formation was prehaps affected by low-temperture hydrotherms). The succession of radiolarian fossilization, the succesion of various veinlets, mutual substitution of calcite and SiO_2 allow to infer that the early diagenetic stage was "highly reactive", with a duration of as much as several million years.

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