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SEDIMENTATION AND DIAGENESIS OF THE NIEDZICA SUCCESSION RADIOLARITES IN THE PIENINY KLIPPEN-BELT, POLAND

(Pl. I—IV and Figs 3)

Sedymentacja i diageneza radiolarytów serii niedzickiej w Pienińskim Pasie Skałkowym

(Pl. I—IV i 3 fig.)

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Abstract: The sedimentary structures of the Niedzica Succession radiolarites suggest deposition by currents resulting in chert, carbonate or carbonate-chert beds separated by shales. In the early diagenesis the silica and carbonate matter in particular beds was separated, which was controlled by the distribution of clay. The parts of beds with high clay content are carbonate, the parts without clay are siliceous. The separation of silica and carbonate in the particular beds was interrupted in different stages by lithification.

Key words: radiolarites, sedimentation, current, diagenesis, clay content, Upper Jurassic, Pieniny Klippenbelt.

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Treść: Struktury stwierdzone w radiolarytach serii niedzickiej (uziarnienie frakcjonalne, laminacja pozioma i przekątna, obecność intraklastów) wskazują na sedymentację prądami dennymi. W czasie wczesnej diagenezy następowało rozdzielenie w obrębie poszczególnych ławic substancji krzemionkowej i węglanowej — krzemionkowa gromadziła się z reguły w środkowych, mniej zailonych częściach ławic, a węglanowa w częściach dolnych i górnych, silniej zailonych. Czynnikiem kontrolującym rozmieszczenie w ławicy, w czasie diagnozy, obu tych substancji było rozmieszczenie substancji ilastej. Proces rozdzielania substancji krzemionkowej i węglanowej był przerywany w różnych stadiach w różnych ławicach przez lityfikację.

INTRODUCTION

The sedimentation of radiolarites, particularly of the Tethyan Jurassic has been discussed for more than a hundred years, but has by no means been satisfactory explained. In a synthetic paper Grunau (1965) stated that the genesis, paleogeography and stratigraphy of radiolarites was still poorly understood. Since then, there has been a great progress in the study of radiolarites. The results of the Deep-Sea Drilling Project provided important data elucidating some aspects of the origin of the deep sea siliceous deposits. Many papers based on these results, excellently summarized by Calvert (1977), refer mainly to the mineralogical changes of silica in the deposit from opal A, through opal CT, to quartz. This, however, hardly concerns the Jurassic radiolarites, which are now composed mostly of quartz and calcite. The electron microscopy of the siliceous rocks (Folk and Weaver 1952 and many followers) opened new possibilities for the radiolarite study. The principal questions of the radiolarite sedimentation: depth of deposition, significance of volcanism, mechanism of deposition, origin of colour — are still controversial.

The Jurassic radiolarites of the Pieniny Klippenbelt are a good object for sedimentological research. They are relatively well outcropped and

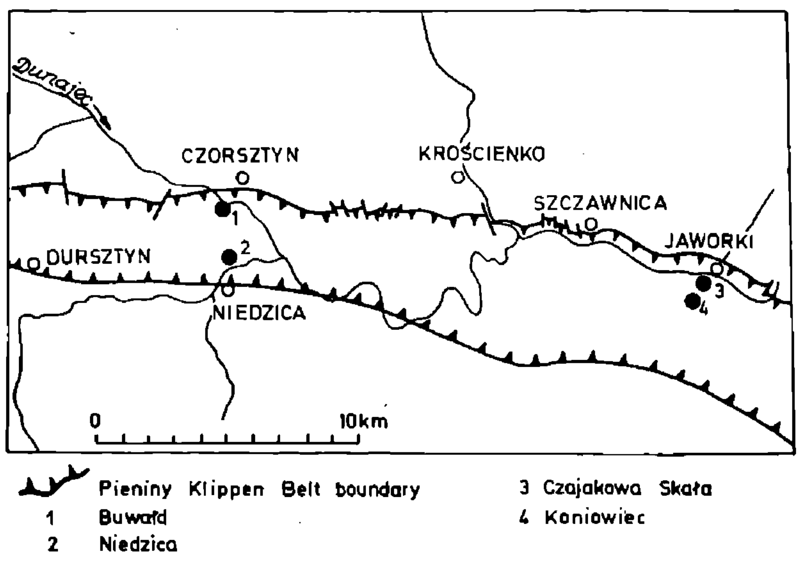

Fig. 1. Position of the section
Fig. 1. Lokalizacja profili

the dating is exceptionally good. The feature hampering the research is the locally strong tectonic deformation.

Studies on the radiolarites have in Poland a long tradition. The papers by Sujkowski (1932, 1933, 1958) are in part still relevant. Birkenmajer (i.a. 1953, 1958, 1977) described the radiolarite outcrops, their geological position, lithology and palaeogeography. Gąsiorowski (1962) dated the Pieniny radiolarites on Aptichi. In two common papers (Birkenmajer and Gąsiorowski 1960, 1961) these authors dealt with the sedimentation of the Pieniny radiolarites, the source of material, the depth and mechanism of deposition etc.

The present paper is based on five sections of the Niedzica Succession radiolarites (Fig. 1). Two hundred polished surfaces and one hundred thirty five thin sections were studied. Some research was done using skanning electron microscope, the spectrophotometer infrared UNICAM SP 1200 and, for the clay minerals, the diffractometer DRON-2.

I should like to thank dr S. Gąsiorowski for showing the outcrops, my wife Ewa for the help in the field work and microscopic investigations, dr A. Łaptaś, dr J. Środoń, mgr E. Kłyś and mgr J. Pawełczyk, which carried out the spectrophotometer and diffractometer analyses and P. Szewczyk who accomplished photographs.

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GEOLOGICAL SETTING

The radiolarites of the Niedzica Succession (Czajakowa Radiolarite Formation — Birkenmajer 1977) were studied at Buwałd, in two klippes at Niedzica, at Czajakowa Skała and at Koniowiec (Fig. 1).

Czajakowa Radiolarite Formation is of an Oxfordian age and is divided into 3 members (Birkenmajer 1977):

1) Kamionka Radiolarite Member (= Lower Red Radiolarites) corresponding to the Aptychus Horizons II_2 and II_3 (Mariae and Cordatum zones — Gąsiorowski 1962).
2) Podmajerz Radiolarite Member (= Green Radiolarites) corresponding to the Aptychus Zone III (Transversarium zone — Gąsiorowski 1962).
3) Buwałd Radiolarite Member (= Upper Red Radiolarites) corresponding to the Aptychus Zone IV (Bimmamatum zone — Gąsiorowski 1962), (Fig. 2).

The Niedzica Succession radiolarites are underlain by the Niedzica Limestone Formation (= Lower Nodular Limestone — Birkenmajer 1977). Their lower boundary is placed at the bottom of the first radiolarian chert bed. The Niedzica Succession radiolarites are overlain by the Czorsztyn Limestone Formation (= Upper Nodular Limestone — Birkenmajer 1977). Their upper boundary is placed at the bottom of the first nodular limestone bed.

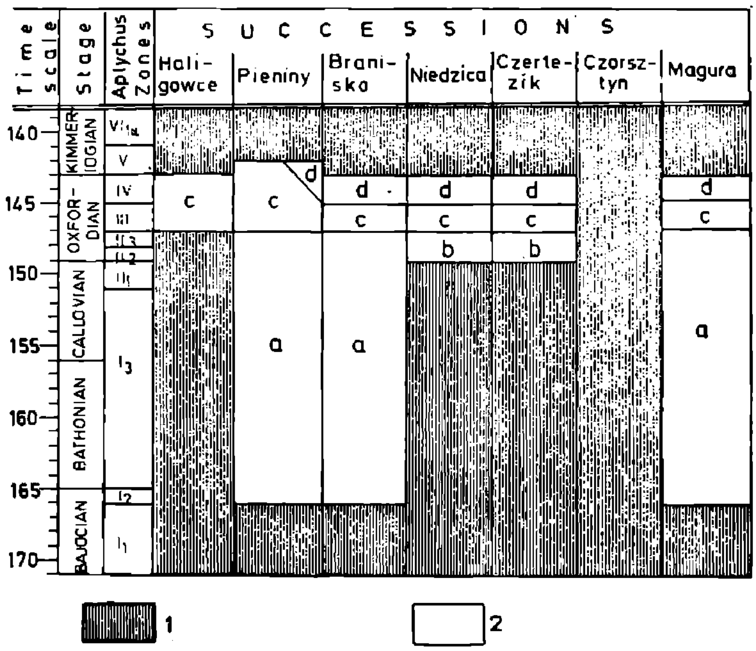


Fig. 2. Radiolarites in lithostratigraphic units of the Pieniny Klippen Belt of Poland, after Birkenmajer 1977. Time scale in milion years after Van Hinte 1976. 1 — limestone formations; 2 — radiolarite formations; a — Sokolica Radiolarite Formation. b — Kamionka Radiolarite Member; c — Podmajerz Radiolarite Member; d — Buwałd Radiolarite Member; b+c+d — Czajakowa Radiolarite Formation

Fig. 2. Radiolaryty w jednostkach litostratygraficznych pienińskiego pasa skałkowego, wg Birkenmajera 1977. Skala czasu w milionach lat wg Van Hinta 1976. 1 — formacje wapienne; 2 — formacje radiolarytowe; a — formacja radiolarytów z Sokolicy; b — ogniwo radiolarytów z Kamionki; c — ogniwo radiolarytów z Podmajerza; d — ogniwo radiolarytów z Buwałdu; b + c + d — formacja radiolarytów z Czajakowej

In the present study one more unit is added, namely the transition beds between the Upper Red Radiolarites and the Upper Nodular Limestone (Birkenmajer 1958, Gąsiorowski 1962). They correspond to the lower part of the Czorsztyn Limestone Formation (upper part of the Bimmamatum zone). Their lower boundary is placed at the bottom of the first nodular limestone bed, and their upper boundary at the top of the uppermost radiolarite bed.

There are gradual transitions between radiolarites and nodular limestones (Upper and Lower) and also between the particular members of the radiolarite formation. There are no distinct gaps in the sequence of the Niedzica Succession radiolarites.

In the Jurassic, the Niedzica Succcession was situated together with Czertezik Succession between the central part of the basin (Pieniny and Branisko Successions) and its outer shallower part (Czorsztyn Succession) (Fig. 2).

ROCK DESCRIPTION

The Czajakowa Formation consists of radiolarites and shales. The term "radiolarite" means here a rock formed from a sediment which consisted mostly of radiolarian skeletons.

The Niedzica Succession radiolarites are formed by cherts, limestones and carbonate-siliceous rocks. Cherts and limestones form separate beds or often occur together in particular beds. The carbonate-siliceous rocks are less abundant than chert and limestone. They appear between cherts and limestones and do not form separate beds (Pl. I, fig. 1).

These three petrographic forms of the radiolarites have many features in common and are described together.

In the beds where the cherts appear together with the limestones, the former usually form the central part of the bed, the latter its upper and lower parts. The ratio of the limestone to the chert is different in different beds — from beds consisting almost exclusively of chert with thin limestone layer at the top of bed to beds of limestone with thin lenses of chert in the central part. The contact between chert and limestone is commonly sharp and horizontal, sometimes inclined, irregular or serrate. The contact of some chert bodies with limestone is partly indistinct, partly sharp, set off by fissures. The contacts of carbonate-siliceous rocks with limestone and chert are usually indistinct, one rock passing gradually into the other.

Some structures appear locally on the top surface of the radiolarite beds: longitudinal ridges, some millimeter high and wide and a few centimeters long, often with concave slopes; larger ridges, up to 70 mm wide and 22 mm high, and round bowl-shaped pits, 5—15 mm in diameter. On the bottom surfaces there appear similar pits and also some rectangular pits 1 mm in diameter. The mounds, 5 mm wide, occur inside the beds in the Green Radiolarites at Koniowiec.

The radiolarites are of various colours: pink, red, green, green with red spots, light gray, dark gray, ashy, yellowish, brown, violet, cream and white. Red, green and gray colours prevail. In non-calcareous cherts cream colour dominates. Such noncalcareous, cream, mat cherts at Bu-wałd contain in the central parts of beds lenses of vitrous, ashy chert.

There is some relation between the colour and the carbonate content of the chert. In the Lower Red Radiolarites of Niedzica the cherts with the lowest carbonate content are pink, and these with the greatest carbonate content are green. Some fissures in these rocks are surrounded by 1—2 mm thick zone of green, calcareous rock.

There is also some relation between the colour of the chert and that of the surrounding limestone. In the Green Radiolarites at Koniowiec, the chert lenses in the green limestone are dark gray and in the red limestone — bright red. Similarly in the Lower Red Radiolarites of Koniowiec the chert lenses in the red limestone are intense orange-red. In the Upper Red Radiolarites at Niedzica the red cherts differ from surrounding limestone by darker or lighter tint.

The study of 20 samples in the infrared spectrophotometer showed that the only form of silica is quartz and the only form of carbonate is calcite.

Microscopic investigation showed that the chert is mostly composed of micro- and cryptocrystalline quartz, the limestone mostly of micrite, and the carbonate-siliceous rock of microcrystalline quartz and micrite. In the chert there occur also: chalcedony, particularly in radiolarian tests and other skeletal remains, dispersed calcareous micrite, calcitic skeletal remains, carbonate intraclasts and locally calcite and siderite crystals. In the limestone there is an admixture of microcrystalline quartz. Some of the skeletal remains, particularly radiolarians, are preserved in chalcedony. Locally appear aggregates of calcite crystals. In the Upper Red Radiolarites at Niedzica there occurs in places, at the boundary between chert and limestone, a sparritic limestone. In the transition beds at Koniowiec there appear single beds of coarsely recrystallized limestone.

The clay content is different in the different petrographic types. It is small or very small in chert. The non-calcareous chert in the Green Radiolarites at Buwałd is an exception. The argillaceous matter forms here a net between aggregates of quartz crystals. The limestone is commonly argillaceous or very argillaceous. The carbonate-siliceous rock is usually more argillaceous than the chert and less so than the limestone. In all the petrographic types the argillaceous matter is dispersed and locally concentrated in horizontal bands.

The ferruginous matter, brown or red, is dispersed in all the types of rock. It forms also bands and lenses (Pl. II, fig. 2), and locally it concentrates in fissures and in skeletal remains. In the carbonate-siliceous rock in the Upper Red Radiolarites at Niedzica a vertical calcite vein divides the rock into two parts: one strongly coloured with ferrum oxides and another non-coloured (Pl. I, fig. 2). In the cherts of the Green Radiolarites at Koniowiec there appear locally pyrite crystals and non-transparent rhombic crystals of an unrecognized mineral. In the transition beds at Buwałd and Koniowiec some skeletal remains are preserved in calcium phosphate.

In the Niedzica Succession radiolarites there appears (in 38% samples) normal or reverse fine graded bedding, expressed by size and/or amount of radiolarians (Pl. I, fig. 2, Pl. II, fig. 1). Commonly there are several sets of graded bedding in one bed. In some cases the graded bedding passes up in the horizontal lamination (Pl. II, fig. 2).

In 93% of the samples there appears a horizontal alignment of the constituents. This alignment passes usually into a weak and irregular lamination represented by bands and lenses of argillaceous or ferruginous matter and by bands with abundant radiolarians or other skeletal remains, separated by bands poor in radiolarians or other skeletal remains (Pl. III, fig. 1 and 2). The thickness of bands varies from 0.1 mm to some centimeters. In 9% of the samples there appears an indistinct cross lamination (Pl. IV, fig. 1). In the transition beds at Koniowiec the lamination expressed by the bands of argillaceous matter is distinct in the uppermost and lowermost parts of bed and indistinct in the middle parts.

The chert and limestone intraclasts are rather rare (Pl. IV, fig. 2). No structures attributable to slumping were observed.

Radiolarians (Spumellina) occur commonly, and in places abundantly. They are preserved in chalcedony, more rarely in microcrystalline quartz or calcite. In some cases the ferruginous matter is concentrated in the radiolarian tests. Their state of preservation varies strongly and the well-preserved tests occur together with the poorly preserved ones. Generally, they are better preserved in chalcedony and calcite than in microcrystalline quartz, and better preserved in the limestone than in the chert.

Other skeletal remains are locally abundant or rare, usually more numerous in the limestone than in the chert. They are calcitic or, mostly in the chert, silicified in various degree. These remains are represented by rhyncholites, aptychi, thin shelled pelecypods, foraminifers, crinoids, sponge spicules, echinid spines, echinoderm plates, ostracods, brachiopods, and (?) bryozoans. In the transition beds at Koniowiec and Buwałd there occur abundantly *Saccocoma*.

The radiolarites are commonly strongly fissured and the fissures are filled by calcite veins (Pl. III, fig. 1) and more seldom by chalcedony or coarse-crystalline quartz veins. In the non-calcareous chert all the veins are chalcedonic. In some cases the chalcedony crystals cover the fissure walls and the calcite crystals fill the center of the fissure. Sometimes a part of the fissure is filled by chalcedony and another part by calcite. In the beds composed of limestone and chert, the veins, some mm thick and always vertical, cut through the chert and the limestone; differently, the numerous fine veinlets running in all directions are limited to the chert. The thick calcite veins are locally disturbed, with brocken calcite crystals and new quartz crystals inside. In the chert of the Green and Upper Red Radiolarites in Niedzica, there occur fissures with the calcite crystals growing into the walls of the fissure. These crystals are widely spaced, forming a "pearl-string" structure of Mišik (1971).

One fissure in the chert of the Lower Red Radiolarites at Koniowiec is gaping open and is filled by micritic limestone. Similarly, in the Upper Red Radiolarites and in the transition beds in Niedzica, some chert layers are cracked and pushed apart and the gaps between the chert fragments are filled by the limestone.

The stylolites are developed locally within the limestone, particularly in the transition beds. Unquestionable stylolites have not been observed within the chert. In places cracks rectilinear in the chert become stylolitic in the limestone.

The shale intercalations between the radiolarite beds are usually 1—2 mm thick, exceptionally amount to 15 cm. Their colour usually corresponds to the predominating colour of the radiolarite. They are red in the Lower and Upper Red Radiolarites and in the transition beds. In the Green Radiolarites the shales are green. The diffractometer study of the shales from a thick intercalation in the Upper Red Radiolarites in Buwałd demonstrated that the only clay mineral here is illite.

DISCUSSION

Sedimentation

The most important question for the radiolarite sedimentation is the origin of rhythmic disposition: radiolarite — shale. For the Tethyan radiolarites there are four theories (Fig. 3).

1) According to Sujkowski (1932) the Jurassic radiolarites were deposited by a "rain" of radiolarians, carbonate skeletal remains and clay particles. The alternation of the radiolarite and clay beds was formed later in the diagenesis.

2) In the opinion of Birkenmajer and Gąsiorowski (1960, 1961) the rhythmic radiolarite deposit is the result of two processes: a continuous falling of radiolarian tests on the bottom and a periodical deposition of clouds of a clay suspension. This hypothesis was based on the following:

— In the same periods, in different Pieniny successions, there are the same numbers of the clay layers.

— Fossils are scarcer in the shales than in the radiolarite beds.

— Absence of benthos in the shales and its presence in the radiolarites.

— Occurence of graded sandstone intercalations in the radiolarian limestones of the Eastern Alps.

3) According to Garrison and Fischer (1969) the Jurassic radiolarite sedimentation consisted of two processes: a continuous falling of clay particles and a periodical radiolarians deposition.

4) Recently the possibility of radiolarite deposition by currents was considered. Imoto and Saito (1973) found graded bedding and cross

lamination in the Permian and Mesozoic radiolarites of Japan and concluded that these radiolarites are a current deposit.

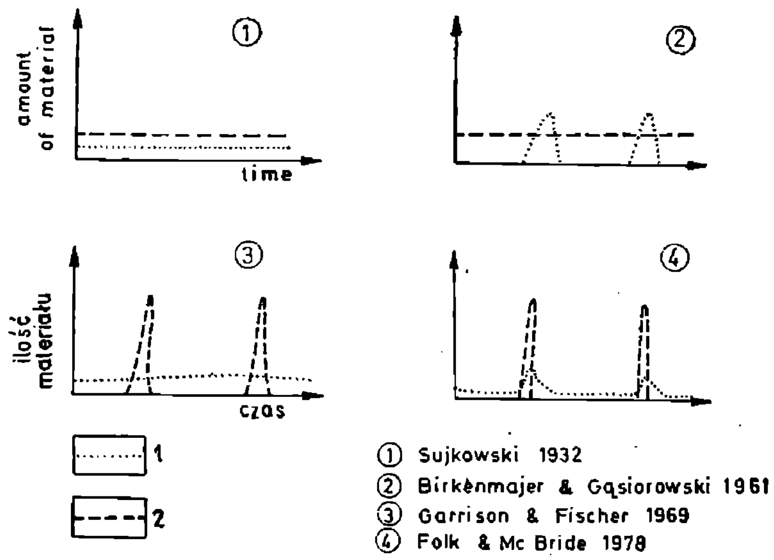


Fig. 3. Pattern of radiolarite deposition according to different authors. 1 — clay; 2 — limestone and chert

Fig. 3. Model sedymentacji serii radiolarytowych wg różnych autorów. 1 — iły; 2 — wapienie i czerty

Garrison (1974) found structures indicating redeposition and sorting by bottom currents (load casts, cross-lamination, graded bedding) in the Jurassic radiolarites of Liguria.

In the Jurassic radiolarites of Greece, composed from alternating radiolarite and shale beds, Nisbet and Price (1974) found similar structures and considered these radiolarites as deposited by currents and mostly by turbidity currents.

According to Folk and McBride (1978), the Jurassic radiolarites of Liguria were deposited mostly by bottom currents, probably turbidity currents. The clay intercalations in these radiolarites are due to tails of turbidity currents plus normal hemipelagic sediment. This opinion is presented in Fig. 3.

Structures indicating deposition by currents are common in the Niedzica Succession radiolarites: fine graded bedding, horizontal and cross-lamination, intraclasts. There are also transitions from graded bedded to laminated deposit — A and B members of the Bouma sequence (Pl. II, fig. 2). It seems very probable that the Niedzica Succession radiolarites are mostly current deposits. Repeated changes in one bed of normal and reverse graded bedding would indicate various energy of the current [1].

[1] Dr S. Gąsiorowski suggested to me that the cross-stratification might be connected with ripple marks of internal waves, and the graded bedding and lamination with stirring up of unconsolidated deposit by internal waves; or that some of these structures might be interpreted as bacterial stromatolites.

Clay, in the radiolarite beds, is most commonly distributed in the following successions:

1) clay — chert with some clay — clay

2) clay — limestone with high clay content — chert with low clay content — limestone with high clay content — clay

3) clay — limestone with high clay content — carbonate-siliceous rock with medium clay content — chert with low or no clay content — carbonate-siliceous rock with medium clay content — limestone with high clay content — clay.

The distribution of clay in the radiolarite beds is a primary feature, unchanged or very little changed by diagenesis. Silica and calcium carbonate can migrate in solution within one bed, but clay can be only displaced by growing crystals. In this last case, at the boundary between argillaceous limestone and non-argillaceous chert, a clayey coating ought to be formed, but this was not observed. So it seems, that each radiolarite bed representing one of the above mentioned successions corresponds to a single sedimentary rhythm, beginning and closing with a high clay contribution, but depositing silica and carbonate without clay in between.

The lack of visible erosion phenomena on the top surfaces of the radiolarite beds indicates that currents were too weak for significant bottom erosion. This conclusion is confirmed by setting of majority of rhyncholites with the lower surface upwards (Gąsiorowski 1973). An exception occurs in the Upper Red Radiolarites at Koniowiec, where only 30% rhyncholites have their lower surfaces upwards. Gąsiorowski (1973) interpreted this as being due to collisions of rhyncholites with crinoid skeletal fragments, abundant in these beds. More probable explanation seems to be a stronger water movement in this place and time.

The Niedzica Succession radiolarites, representing the whole Oxfordian (after Van Hinte 1976 — 6—6.5 million years), contain on the average 65 rhythms. Thus, a rhythm corresponds on the average to about 100 000 years. The major part of a rhythm (chert, carbonate, part of clay) was deposited in a very short time and the rest of clay in a very long period separating one sedimentary current from another. A study of the cosmic dust content in clays and radiolarites (Garrison and Fischer 1969) might help to test this suggestion.

The present study gives no new data on the radiolarite sedimentation depth. The benthonic fauna in the radiolarites is redeposited and cannot be used to determine the depth of sedimentation.

The mounds, pits and ridges on the top and bottom of the radiolarite beds are interpreted (Folk and McBride 1978) as trace fossils. Determination of these forms, which are characteristic for radiolarites, requires a detailed study.

The very variable preservation of the radiolarian tests is the result of many agents. Probably the majority of radiolarian tests were eaten in the superficial layers of the sea water. Later these tests were sinking in the fecal pellets, which protected them against dissolution in the sea water. These fecal pellets could have been eaten again and the tests could have sink in the new fecal pellets; the total of these processes decided about the preservation of the tests (Smayda 1971).

Table 1

Facies

Member	Lithology, thickness of member in cm, range of radiolarite beds thickness in cm		
	Buwałd	Niedzica	Koniowiec
Transition beds	LIMESTONE*, chert 150 3—17	LIMESTONE, chert 100 2—20	LIMESTONE, chert 130 2—19
Upper Red Radiolarites	CHERT 70 3—15	LIMESTONE+CHERT, carbonate-siliceous rock 220 5—29	LIMESTONE, chert 130 2—22
Green Radiolarites	CHERT non calcareous 100 4—12	CHERT, limestone 100 2—12	LIMESTONE with chert lenses 85 2—9
Lower Red Radiolarites		CHERT, limestone 200 3—10	LIMESTONE with chert lenses 20 1—4,5

* the name of prevailing rock is written in capitals

Moore (1969) stated that various Cenozoic species of Radiolaria differed in their resistance to solution. Probably the Jurassic radiolarian species differed similarly in this respect.

According to Thurston (1972) the radiolarians in the chert with a high clay content are better preserved than in pure chert due to the movement of pore solutions easier in the pure, than in clayey chert. This probably explains the better preservation of the radiolarian tests in the argillaceous limestones than in the non-argillaceous chert in the Niedzica Succession radiolarites.

The vertical and horizontal differences in lithology and thickness in the sections seen are presented in table 1. There follows:

1) From the west (Buwałd) to the east (Koniowiec) the limestone amount increases in all the members of the formation.
2) In the western part of the area (Buwałd, Niedzica) the limestone amount increases upwards from the Green Radiolarites to the top of the formation.
3) The thickness of the radiolarite beds increases upwards from the Lower Red to the Upper Red Radiolarites.
4) The thicknesses of the particular members are similar in different sections, excepted the Upper Red Radiolarites.

Probably the radiolarites of Buwałd were deposited at a greater depth than those of Koniowiec. In the upper Oxfordian there was a slow shallowing of the basin or the lowering of the Carbonate Compensation Depth.

Early diagenesis

Silica in cherts was derived by dissolution of radiolarian tests, which are very abundant and commonly show traces of dissolution. The quantity of sponge spicules in the radiolarites is insignificant. No volcanic Jurassic rocks are known in the Pieniny area with only one exception. The montmorillonite found by Sikora and Wieser (1979) in the shale underlying the Red Radiolarites of the Branisko Succession in Stare Bystre seems to be insignificant for the radiolarite sedimentation. Such small amounts of volcanic tuffs could not have been the important source of silica for the radiolarite formation. The diffractometer study of clay minerals from Niedzica Succession shales revealed only the presence of illite.

The common occurrence of the carbonate fragments and skeletal remains in chert proves that these cherts were formed by dissolution of carbonate and precipitation of silica, probably in form of opal CT, which later passed into microcrystalline quartz and chalcedony.

The silicification took place in early diagenesis before the lithification. Cherts were lithified before the lithification of limestones. This is indicated by fissures in chert filled by micritic limestone.

The characteristic and common feature of the cherts is an insignificant content of argillaceous matter, particularly in comparison with a high clay content in the limestones. Distribution of the argillaceous matter in the radiolarite bed is usually regular. Its amount increases up and down from the middle of the bed. Sometimes, this is disturbed by irregular argillaceous bands or lenses. In these cases the non-argillaceous parts are occupied by chert, and the argillaceous ones by limestone. The conclusion is that the silicification developed in the non-argillaceous parts of the deposit and avoided the argillaceous ones.

The clay content is very important for diagenesis of the carbonate and siliceous deposits. According to Bausch (1968), the clay content in the cement of carbonate rocks controls the size of the calcite crystals. Recrystallization is possible only where the insoluble residue is less than 2%. According to Zankl (1969) early lithification of lime mud depends on the purity of sediment. Less than 2% of insoluble residue (especially clay minerals) favours cementation and recrystallization before further sediment accumulation causes compaction.

In the siliceous rocks, clay inhibits diagenesis processes. Sujkowski (1958) thought that the occurrence of argillaceous matter in silico-carbonate deposits delays the silica nodules formation. According to Robertson (1977) the clay admixture in the deposit inhibits the passage of cristobalite (opal CT) into quartz. After Folk and McBride (1978) clay and probably haematite inhibit the growth of the microquartz crystals.

In the Niedzica Succession radiolarites, there was not a delay but a complete absence of silicification in the argillaceous parts of the deposit. It seems, that the inhibition of silicification in these parts was sufficient for all the available silica to concentrate in the non-argillaceous parts of the deposit. Where there was no carbonate, as in the Green Radiolarites of Buwałd, the dissolution of the radiolarian tests and the precipitation of silica occurred within the whole bed, argillaceous or non-argillaceous, because the quantity of silica was sufficient.

Probably silicification and calcitization in particular beds, isolated by clay intercalations occurred independently. Each bed in this respect was a closed system. In some beds, the separation of the carbonate and the silica is almost complete — the chert contains a few carbonate remains and the limestone a few siliceous radiolarians. In other beds, the separation is little advanced and there occur carbonate-siliceous rocks. It seems that the separation of carbonate and silica was stopped in different beds not simultaneously, when lithification inhibited the movement of pore solutions in the deposit.

Late diagenesis

The fissures with calcite or chalcedony veins passing through the cherts and the limestones are probably of tectonic origin. Other fissures are limited to the cherts. Some of them were formed before the lithification of limestone as indicated by filling with carbonate micrite. Some cracks were formed probably later and were due to tectonic stress and competence difference between chert and limestone.

Colouration by ferrum oxides of part of the rock separated from another non-coloured part by a calcite vein indicates the late diagenetic migration of the ferruginous matter.

The occurrence of green and calcareous zones, some mm thick, along the cracks in the red cherts indicates that solution reduced the ferrum oxides and precipitated calcium carbonate.

Authigenic crystals of calcite in the chert and authigenic crystals of quartz in the limestone are referred to late diagenetic calcitization and silicification. These processes do not seem to have been important.

CONCLUSIONS

The Niedzica Succession radiolarites were formed by:

1) Bottom currents which deposited alternating radiolarite and clay beds.

2) Early diagenetic separation of the carbonate and siliceous matter, independent in particular beds, controlled by the argillaceous matter distribution, favouring silicification of non-argillaceous parts of the deposit.

translated by S. Gąsiorowski

REFERENCES — WYKAZ LITERATURY

Bausch W. M. (1968), Clay content and calcite crystal size of limestones. *Sedimentology,* 10: 71—75, Oxford.

Birkenmajer K. (1953), Preliminary Revision of the Stratigraphy of the Pieniny Klippen Belt Series in Poland. *Bull. Acad. Pol. Sci.,* Cl. III, 1/6: 271—274, Warszawa.

Birkenmajer K. (1958), Przewodnik geologiczny po Pienińskim Pasie Skałkowym. Warszawa.

Birkenmajer K. (1977), Jurassic and Cretaceous Lithostratigraphic Units of the Pieniny Klippen Belt, Carpathians, Poland, *Studia Geol. Pol.,* 45, 160 p. Warszawa.

Birkenmajer K., Gąsiorowski S. M. (1960), Badania sedymentologiczne kompleksu radiolarytowego pienińskiego pasa skałkowego. *Spraw. z Posiedz. Kom. Oddz. PAN w Krakowie,* stycz.—czerw. 1960: 1—3, Kraków.

Birkenmajer K., Gąsiorowski S. M. (1961), Sedimentary character of radiolarites in the Pieniny Klippen Belt, Carpathians. *Bull. Acad. Pol. Sci., Ser. sci. geol. geogr.,* 9/3: 171—176. Warszawa.

Calvert S. E. (1977), Mineralogy of silica phases in deep sea cherts and porcelanites. *Philos. Trans. Roy. Soc. London*, A, 286, 1336: 239—252, London.

Folk R. L., Mc Bride E. F. (1978), Radiolarites and their relation to subjacent "oceanic crust" in Liguria, Italy. *J. Sediment. Petrol.*, 48: 1069—1102, Tulsa.

Folk R. L., Weaver C. E. (1952), A study of the texture and composition of chert. *Am. J. Sci.*, 250: 498—510, New Haven.

Garrison R. E. (1974), Radiolarian cherts, pelagic limestones and igneous rocks in eugeosynclinal assemblages. *Spec. Publs int. Assoc. Sedimentologists*, 1: 367—400, Oxford.

Garrison R. E., Fischer A. G. (1969), Deep-water limestones and radiolarites of the Alpine Jurassic. *Soc. Econ. Pal. and Min. Spec. Publ.*, 14: 20—56, Tulsa.

Gąsiorowski S. M. (1962), Aptychi from the Dogger, Malm and Neocomian in the Western Carpathians and their stratigraphical value. *Studia geol. pol.*, 10, 152 p., Warszawa.

Gąsiorowski S. M. (1973), Les Rhyncholites. *Geobios*, 6/2—3: 127—196, Lyon.

Grunau H. R. (1965), Radiolarian cherts and associated rocks in space and time. *Ecl. Geol. Helv.*, 58: 157—208, Basel.

Imoto N., Saito Y. (1973), Scanning electron microscopy of chert. Bull. Nat. Sci. Museum, Tokyo, 16/2: 397—400 Tokyo.

Mišík M. (1971), Observations concerning calcite veinlets in carbonate rocks. *J. Sediment. Petrol.*, 41: 450—460, Tulsa.

Moore T. C. Jr (1969), Radiolaria: change in skeletal weight and resistance to solution. *Geol. Soc. America Bull.*, 80: 2103—2108, Boulder.

Nisbet E. G., Price I. (1974), Siliceous turbidites: bedded cherts as redeposited ocean ridge-derived sediments. *Spec. Publs int. Assoc. Sedimentologists*, 1: 351—366, Oxford.

Robertson A. H. F. (1977), The origin and diagenesis of cherts from Cyprus. *Sedimentology*, 24: 11—30, Oxford.

Sikora W., Wieser T. (1979), Pochodne zasadowych skał magmowych w formacji radiolarytowej z Sokolicy (pieniński pas skałkowy). *Kwart. Geol.*, 23, p. 495, Warszawa.

Smayda T. J. (1971), Normal and accelerated sinking of phytoplankton in the sea. *Marine Geology*, 11: 105—122, Amsterdam.

Sujkowski Z. (1932), Radiolaryty Polskich Karpat Wschodnich i ich porównanie z radiolarytami tatrzańskimi. (Radiolarites des Karpates Orientales et leur comparaison avec les radiolarites de la Tatra). *Sprawozd. Pol. Inst. Geol.*, 7: 97—168, Warszawa.

Sujkowski Z. (1933), Radiolaryty dolno-karbońskie Gór Świętokrzyskich. (Radiolarites du Carbonifere inferieur du Massif de Ste Croix). *Sprawozd. Pol. Inst. Geol.*, 7: 637—711, Warszawa.

Sujkowski Z. (1958), Diagenesis. *Bull. Am. Assoc. Petr. Geologists*, 42: 2692—2717, Tulsa.

Thurston D. R. (1972), Studies on bedded cherts. *Contrib. Mineralogy, Petrology*, 36: 329—334, Berlin.

Van Hinte J. E. (1976), A Jurassic time scale. *Bull. Am. Assoc. Petr. Geologists*, 60: 489—497, Tulsa.

Zankl H. (1969) Structural and textural evidence of early lithification in fine-grained carbonate rocks. Sedimentology, 12: 241—256, Oxford.

EXPLANATION OF PLATES — OBJAŚNIENIA PLANSZ

PLATE — PLANSZA I

Fig. 1. Rock composed of three petrographic elements: a — chert consisting of microcrystalline quartz, with small admixture of clay, with numerous calcite veinlets; b — limestone with a high argillaceous and ferruginous matter content, with a number of radiolarians (dark points). In upper part graded bedding expressed by size and number of radiolarians, in lower-most part a fine lamination with very small radiolarians; c — carbonate-siliceous rock with clay content higher than in limestone but lower than in chert. Lower Red Radiolarites. Koniowiec. Negative. Plane polarized.

Fig. 1. Skała złożona z trzech elementów petrograficznych: a — rogowiec zbudowany z kwarcu mikrokrystalicznego, nieco zailony z licznymi żyłkami kalcytu; b — wapień silnie zailony i zażelaziony, z licznymi radiolariami (ciemne kropki). W górnej części uziarnienie frakcjonalne wyrażone zmianą wielkości i zagęszczenia radiolarii, w najniższej części delikatna laminacja z b. drobnymi radiolariami; c — skała węglanowo-krzemionkowa zailona silniej niż rogowiec i słabiej niż wapień. Radiolaryty czerwone dolne. Koniowiec. Negatyw. Nikole równoległe.

Fig. 2. Carbonate-Siliceous rock with abundant radiolarians, with thin argillaceous bands. Graded bedding expressed by upward decrease of size and number of radiolarians. Rock on the left side of the great, vertical calcite vein is coloured by ferruginous matter (lighter on photo). Upper Red Radiolarites. Niedzica. Negative. Plane polarized.

Fig. 2. Skała węglanowo-krzemionkowa, z dużą ilością radiolarii, smugowana substancją ilastą. Uziarnienie frakcjonalne wyrażone przez zmniejszenie się ilości i wielkości radiolarii ku górze. Radiolaryty czerwone górne. Niedzica. Negatyw. Nikole równoległe.

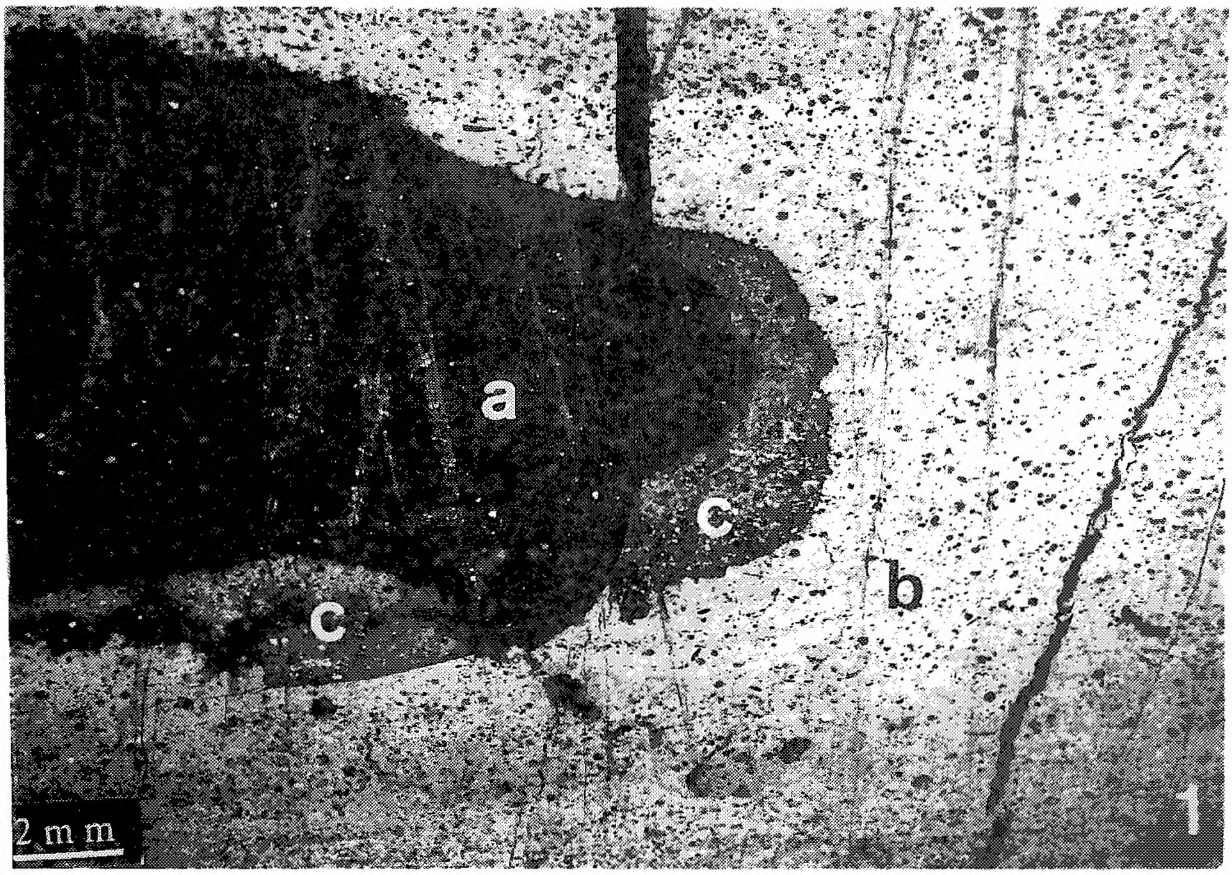
PLATE — PLANSZA II

Fig. 1. Micritic limestone, argillaceous in lower part, ferruginous in upper part, banded, with a number of chalcedonic radiolarians. Reverse graded bedding expressed by upward increase of radiolarians number — in uppermost part the rock composed almost exclusively of radiolarians passes into chert. Green Radiolarites. Koniowiec. Negative. Plane polarized.

Fig. 1. Wapień mikrytowy, w dole zailony, w górze zażelaziony, smugowany, z wielką ilością chalcedonowych radiolarii. Odwrócone uziarnienie frakcjonalne, wyrażone zagęszczeniem się ku górze radiolarii, które w najwyższej części są tak liczne, że skała przechodzi w rogowiec. Radiolaryty zielone. Koniowiec. Negatyw. Nikole równoległe.

Fig. 2. Chert consisting mostly of radiolarians preserved in chalcedony and quartz, with a low clay content. Graded bedding passes upwards into a fine lamination. Little lenses of ferruginous matter (light on photo). Green Radiolarites. Buwałd. Negative. Crossed nicols.

Fig. 2. Rogowiec złożony głównie z radiolarii zachowanych w chalcedonie i kwarcu. Uziarnienie frakcjonalne przechodzi ku górze w delikatną laminację. Małe soczewki substancji żelazistej (białe na zdjęciu). Radiolaryty zielone. Buwałd. Negatyw. Nikole skrzyżowane.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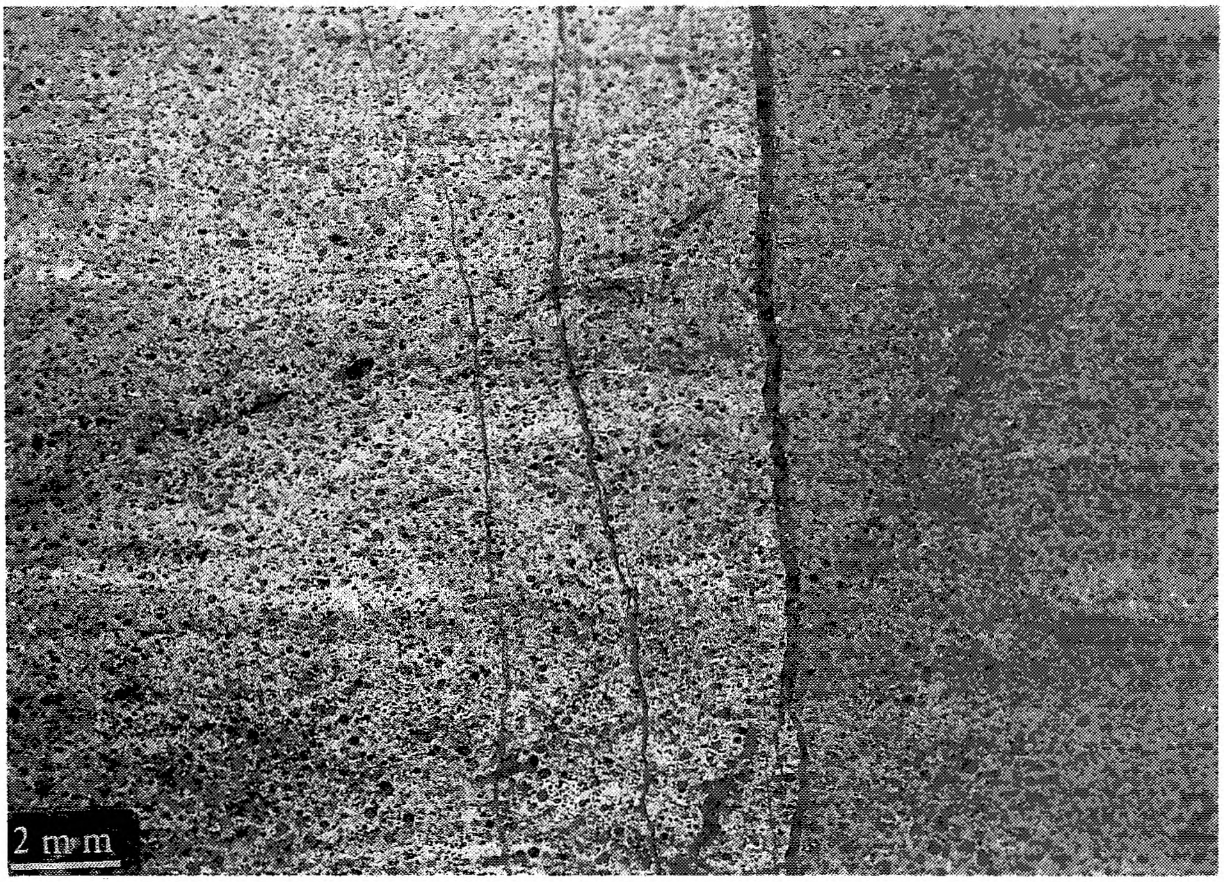
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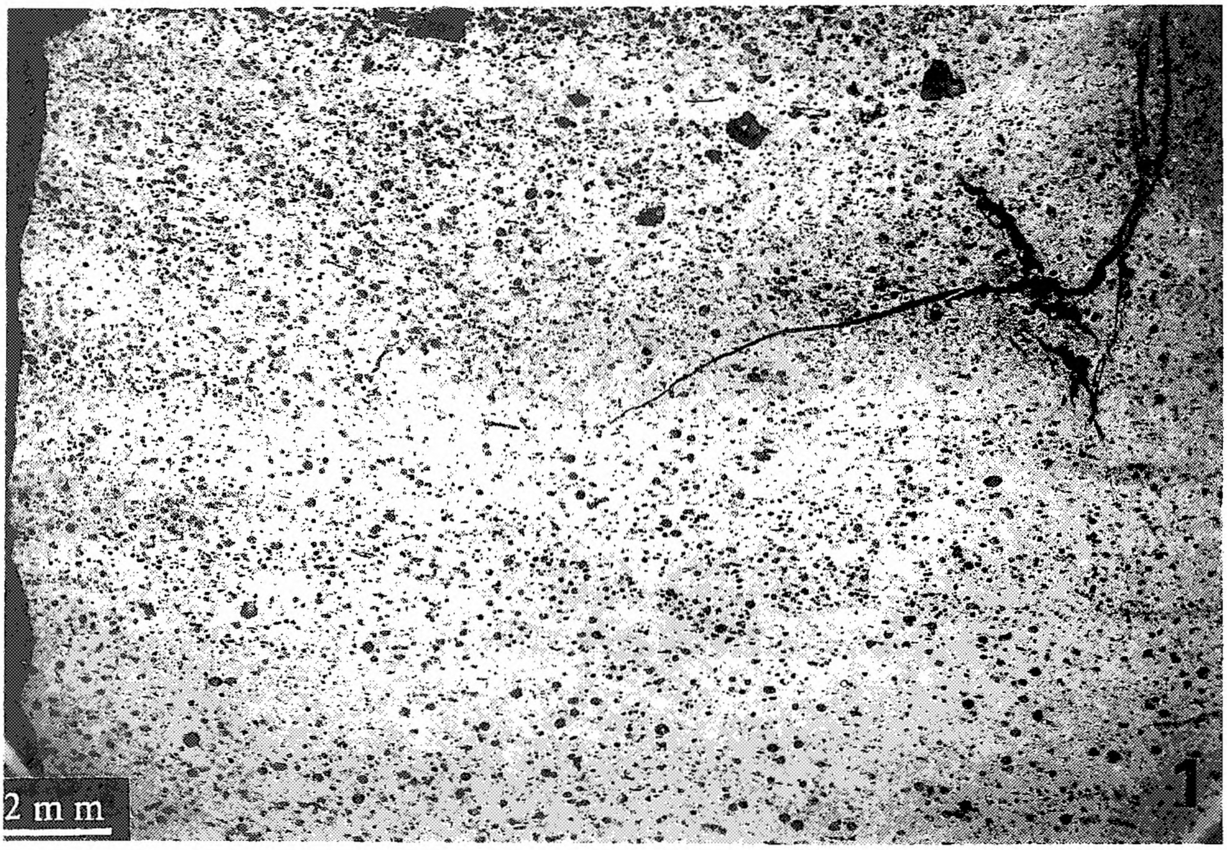
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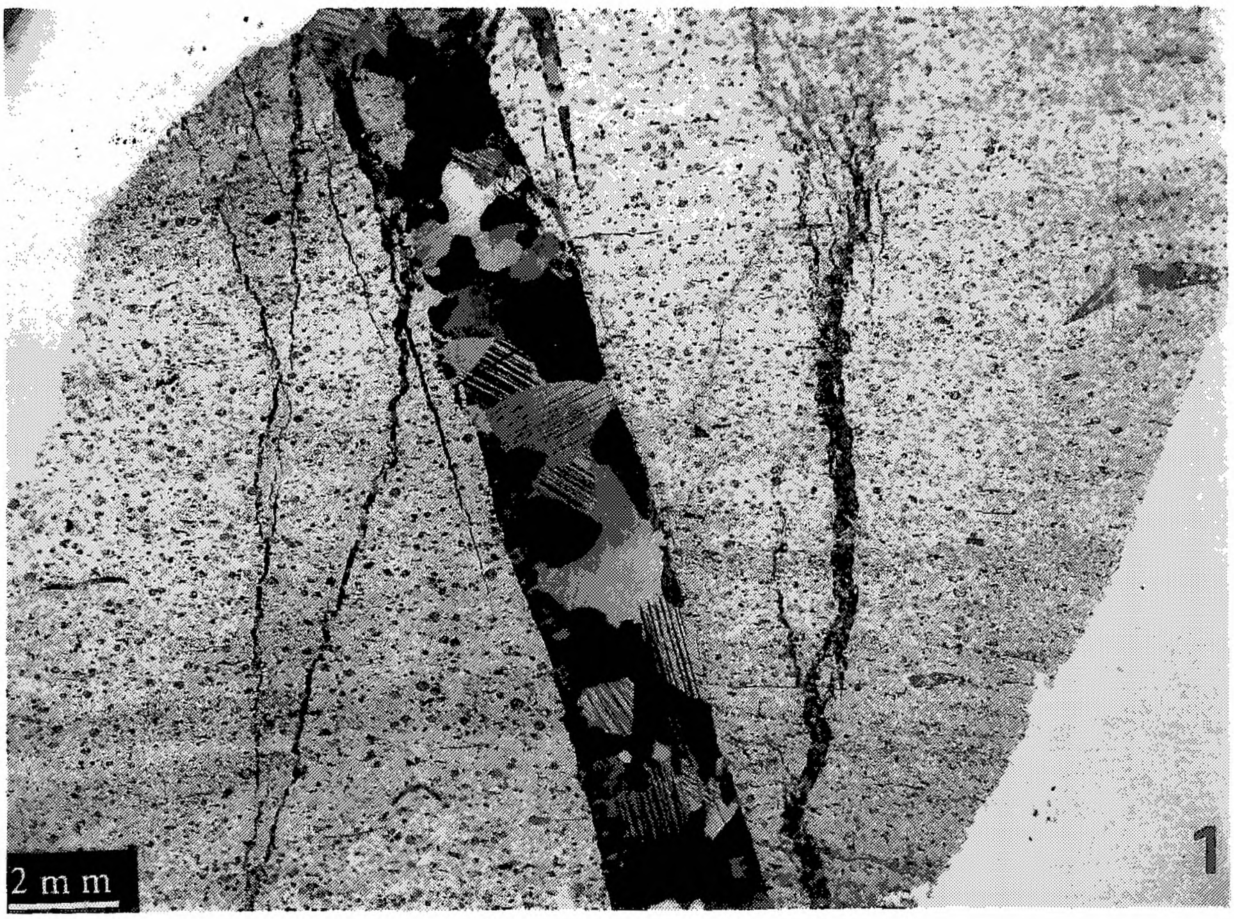
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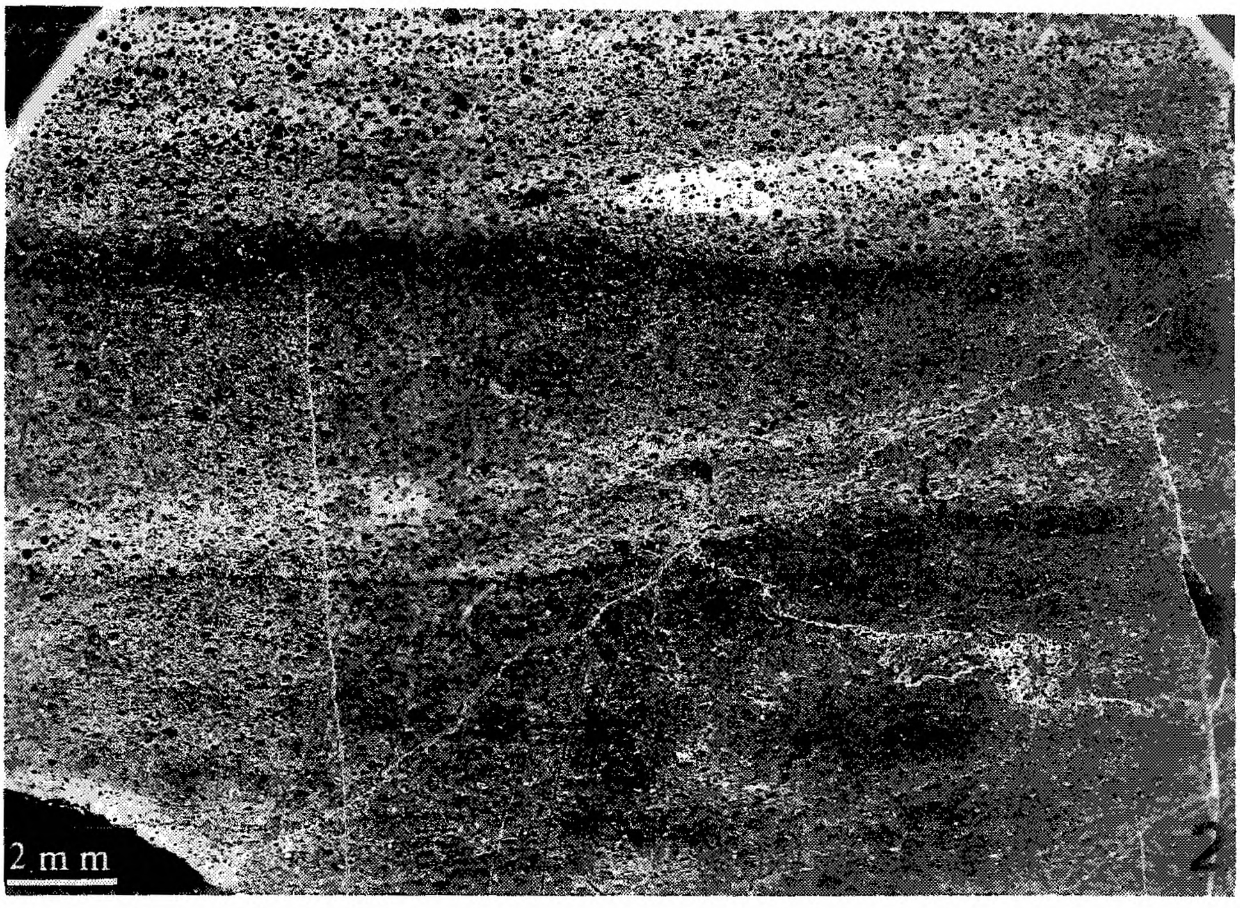
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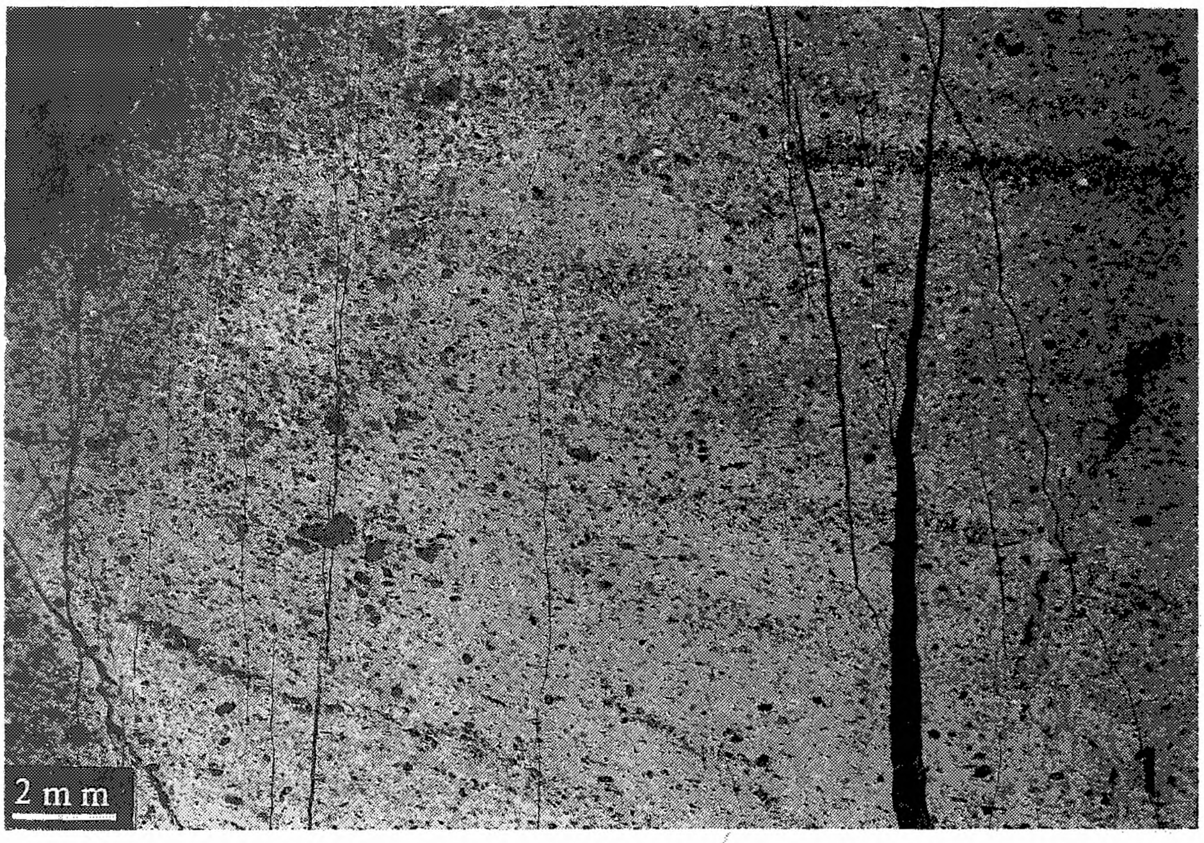
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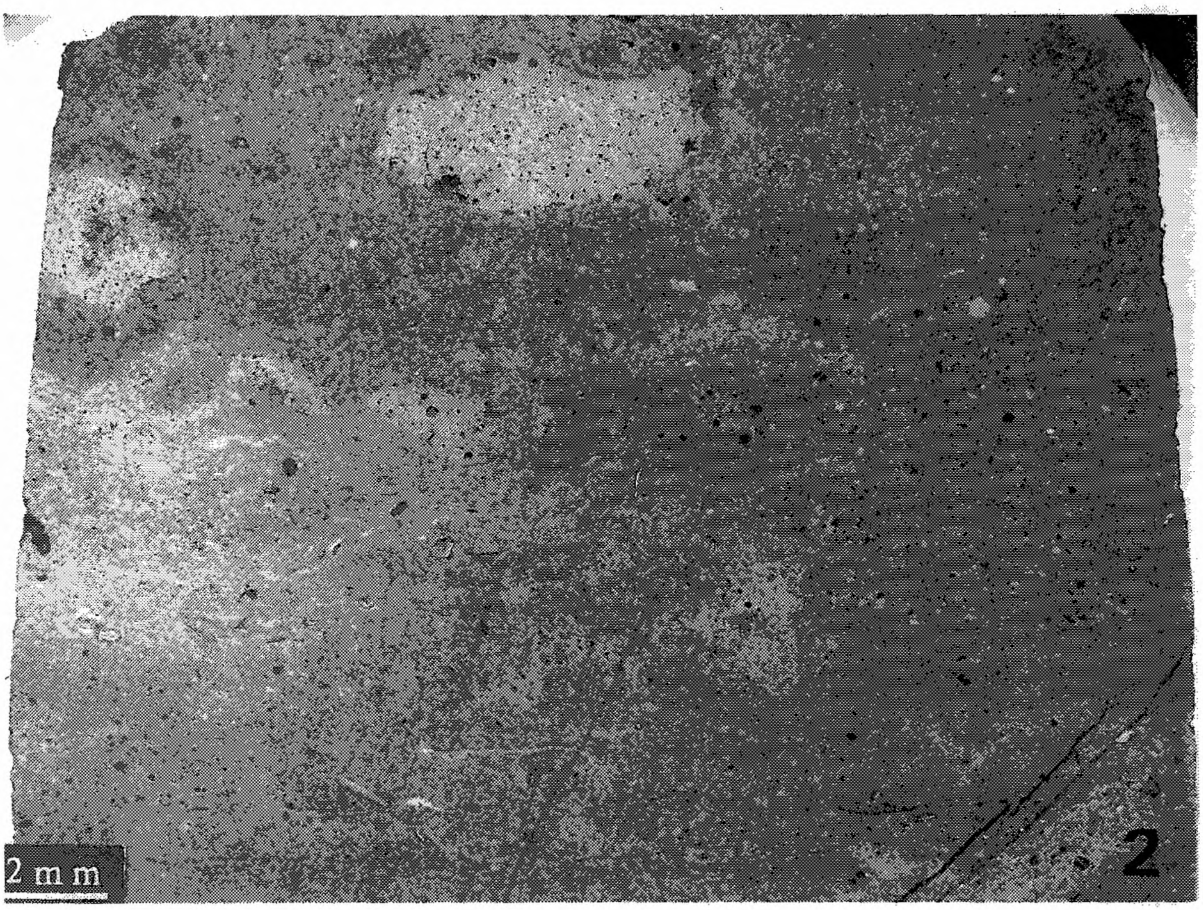
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PLATE — PLANSZA III

Fig. 1. Chert with a clay and carbonate content, with radiolarians and carbonate skeletal remains, arranged horizontally. Irregular banding of ferruginous matter. Calcite veins. Transition beds. Buwałd. Negative. Crossed nicols.

Fig. 1. Rogowiec z domieszką iłu i węglanów, z radiolariami i węglanowymi szczątkami szkieletowymi, ułożonymi poziomo. Nieregularne smugowanie substancją żelazistą. Żyły kalcytu. Warstwy przejściowe. Buwałd. Negatyw. Nikole skrzyżowane.

Fig. 2. Carbonate-siliceous rock with a number of radiolarians, preserved in chalcedony and coarse-crystalline quartz. Lamination with argillaceous and ferruginous bands (light on photo). Greeen Radiolarites. Niedzica. Negative. Plane polarized.

Fig. 2. Skała węglanowo-krzemionkowa, z licznymi radiolariami zachowanymi w chalcedonie i grubokrystalicznym kwarcu. Laminacja smugami substancji ilastej i żelazistej (jasnymi na zdjęciu). Radiolaryty zielone. Niedzicy. Negatyw. Nikole równoległe.

PLATE — PLANSZA IV

Fig. 1. Limestone, strongly argillaceous, with dispersed microquartz, with many carbonate remains and calcitized radiolarians, whose arrangement forms the irregular cross-lamination. Vertical calcite veins. Upper Red Radiolarite. Koniowiec. Negative. Plane polarized.

Fig. 1. Wapień silnie zailony, z rozproszonym mikrokwarcem, z licznymi, węglanowymi szczątkami szkieletowymi i skalcytyzowanymi radiolariami, których ułożenie tworzy nieregularną, przekątną laminację. Pionowe żyły kalcytu. Radiolaryty czerwone górne. Koniowiec. Negatyw. Nikole równoległe.

Fig. 2. Micritic limestone, strongly argillaceous, with dispersed microquartz, with radiolarians and aptychi, with intraclasts of limestone more and less argillaceous. Veins of calcite and quartz. Lower Radiolarites. Koniowiec. Negative. Plane polarized.

Fig. 2. Wapień mikrytowy, silnie zailony, z rozproszonym mikrokwarcem i radiolariami i aptychami, z intraklastami wapienia bardziej i mniej zailonego Żyły kalcytowe i kwarcowe. Radiolaryty czerwone dolne. Koniowiec. Nikole równoległe.