Palaeoenvironmental signal from the microfossils record in the Mikuszowice Cherts of the Silesian Nappe, Polish Outer Carpathians

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ABSTRACT

The Mikuszowice Cherts are thick-bedded, fine-grained turbidities consisting of detrital material mixed with biogenic particles which are predominantly siliceous spicules of lithistids. These deposits formed in the Silesian basin (Outer Carpathians) during the middle to late Cenomanian. It is possible that sponge spicules are the relic of mud-mounds formed by sponges and accompanied by other benthic organisms like crinoids, calcareous benthic foraminifers, and encrusting coralline algae. Iron-fixing bacteria occurring within the microfossil communities are the remnants of microbial activity, important for mud-mound formation. Sponge communities were situated on the middle to outer shelf in the marginal part of the North European Platform. Disintegrated material from the mounds was redeposited into the deep basin, as confirmed by the occurrence of hemipelagic, non-calcareous clays within the Mikuszowice Cherts, including radiolarians and deep-water agglutinated foraminifers. The delivery of siliceous and calcareous bioclasts from a shallower part of the basin, was controlled by two groups of factors: (1) environmental parameters such as nutrient availability, water temperature, and salinity, which enabled the growth of benthic and planktonic communities, and (2) a hydrodynamic regime activating the transport of biogenic particles onto the basin floor.

Key words: Spiculite, sponges, turbidite, Outer Carpathians, Cenomanian

INTRODUCTION

The Cenomanian was a period of accumulation of spicule-bearing deposits in the Outer Carpathian basin of the Western Tethyan domain, that extended along the southern edge of the North European Platform. Locally, spicules from sponge buildups were redeposited into deep-water environments due to gravitational flows. These spicules could be one of the main components of turbidites in such regions, forming the gaize and chert layers. The middle–upper Cenomanian deposits in the Silesian and Subsilesian nappes of the Outer Carpathians, named the Mikuszowice Chert (MCh), is an example of such a facies. The siliceous sponge spicules with calcareous benthic foraminifers, radiolarians, and siliciclastic material created a series of fine-grained turbidities intercalated with deep-water, hemipelagic, non-calcareous clays.

In this paper, we present the analysis of microfossils from the MCh in the context of their palaeoenvironmental interpretation of the Silesian Basin during the middle–late Cenomanian.

Figure 1. A – Location of the studied section on the sketch tectono-facies map of the Outer Carpathians. B – Detailed geological map of the studied area including the Barnasiówka-Jasienecka quarry (map after Burtan, 1964, and Burtan and Szymakowska, 1964; simplified)

GEOLOGICAL SETTING AND LITHOSTRATIGRAPHY

The spicule-rich facies (Mikuszowice Cherts) lies in the central part of the Silesian Nappe of the Polish Outer Carpathians, within the Lanckorona – Żegocina tectonic zone (Fig. 1), built of Cretaceous deposits (Książkiewicz, 1962; Książkiewicz & Liszkowa, 1978). The MCh belong to the uppermost part of the Lgota Beds (middle–upper Cenomanian, Bąk et al., 2005), and are overlain by the Barnasiówka Radiolarian Shale Formation (upper Cenomanian–Lower Turonian; Bąk et al., 2001; Fig. 2). The characteristic feature of these sediments are bluish cherts occurring within the middle and upper parts of medium- to thick-bedded, fine-grained turbidites (Fig. 3). Most of the turbidite layers are parallel-laminated and have a gaize character. The cherts represent laminated spongoliolites including numerous radiolarian skeletons.

The MCh do not create a continuous level in the Western Carpathians (Koszarski et al., 1962). It occurs mostly in the northwestern part of the Silesian Nappe. Their average thickness varies between 20 and 30 m.

The presented data of the MCh came from a quarry on the Barnasiówka Ridge within the Pogórze Wielickie Foothills; ca 25 km south of Kraków. This area is located on the SW slope of one of tributaries of the Bysina stream, at an altitude of ca. 520 m (Fig. 1B). The section represents here the upper divisions of the Lgota Beds, including the MCh and their contact with the overlying Barnasiówka Radiolarian Shale Formation (Fig. 2).
METHODS

Samples for micropalaeontological analyses were collected from eight medium- to thick-bedded layers including bluish cherts and a limestone layer within the MCh and from five layers of sandstones of the underlying Middle Lgota Beds (Fig. 3). Microfossils (spicules, radiolarians, and foraminifers) were extracted from every type of deposits as siliciclastics and carbonates.

Fine-grained turbidites were analysed millimeter by millimeter to identify the microfacies and lithology. SEM photographs of the microfauna and photographs of microfacies were made using the scanning microscope HITACHI S-4700 and a Nikon SMZ1500 stereoscopic microscope with a digital camera.

Microfaunal slides with Radiolaria and Foraminifera are housed in the Institute of Geological Sciences, Jagiellonian University (collection Nr LG-1), and in the Institute of Geography, Pedagogical University (collection Nr 11Sl) respectively.

LITHOLOGY

The Mikuszowice Cherts are composed of turbidites, which are siliciclastic sediments such as greywackes, mudstones, siltstones, limestones, and also calcarenites to calcisiltites, usually silicified. The distinguishing feature is the high content of spicules of siliceous sponges (Fig. 4A, B). Other biogenic particles include planktonic and benthic foraminifers (Fig. 4C), radiolarians (Fig. 4D), and sporadic fragmented echinoid spines. Tube-like trace fossils occur on the tops of some layers. Flute casts locally occur on the soles of thick beds.

Occurrence and petrography of cherts

Cherts occur in the lower and middle parts of thick-bedded, sand-sized deposits represented the Ta–Td intervals of Bouma’s turbidite sequence. Locally, they make up nearly the whole thickness of a bed (Fig. 3). The chert layers are 2 to 20 cm thick, with the longer dimension parallel to the bedding. Horizontal contacts are sharp. Relicts of the host rock are common. The cherts are parallel-laminated, similarly as the host-sediment.

The morphology of the chert layer is controlled by primary sedimentary structures and porosity of the turbidite. The cherts are mostly present within greywackes, gaizes, and spiculites, sporadically in calcarenites and calcisiltites. Most of the silica is in the form of cryptocrystalline quartz, microquartz, megaquartz, length-fast chalcedony, and rare microspheres. Microquartz usually replaced carbonate sediment, bioclasts, and is the first cement generation to fill primary intraparticle porosity. Megaquartz
**Figure 3.** Stratigraphic log of the Mikuszowice Cherts and the Middle Lgota Beds at the Barnasiówka-Jasienica section, with position of the studied samples, occurrences of microfossils and photographs of the most characteristic chert beds.
is characterized by mosaics of crystals up to 300 micrometers in diameter. It always occurs as a late cement, after the microquartz and LF-chalcedony generations, as primary and secondary filling of radiolarian and foraminiferal chambers. It is also present as a secondary generation of pseudomorphs after rhombohedral calcite-like crystals. The fibrous variety of quartz is less common.

Length-fast chalcedony is present locally as a cement phase, mostly botryoidal, which infilled axial canals of sponge spicules, radiolarian and foraminiferal chambers. Sometimes it replaces the walls of sponge spicules and forms pseudomorphs after rhombohedral calcite crystals.

The chert also contains spherical structures that are usually rare and dispersed, associated with spicule-bearing rocks (greywacke, geize, spiculite). These microspheres have a regular size, with a diameter of 30-40 μm. Their interior consists of two parts, a central part of microcrystalline quartz, 20-30 μm in diameter, and a cortex, 10-20 μm thick, composed also of microcrystalline quartz but fibrous, radially arranged. Similar microspheres were described by Gimenez-Montsant et al. (1999) from chert related with shallow-water platform carbonates that contains sponge spicules. Thin sections of microspheres display internal structure similar to cross-sections of non-calcitized siliceous sponge spicules, suggesting their biogenic origin.
MICROFOSSILS
Microfossils in the MCh occur in green, hemipelagic shales, sand fraction deposits, limestone, and cherts. Shales are enriched in deep-water agglutinated foraminifera and radiolarians. The sand fraction includes mainly sponge spicules, less common are radiolarians, planktonic and calcareous benthic foraminifera, inoceramid prisms, echinoderm oscicles, and fragments of coralline red algae. Cherts display a similar composition of microfossils, however, they differ from the sand fraction deposits in the much better preservation of siliceous microfossils.

Sponge spicules
Loose spicules have been obtained by dissolving rocks in a weak hydrochloric or hydrofluoric solution (Plate 1). They are present in samples from the uppermost part of the middle Lgota Beds and the whole section of the MCh. The number of spicules exceeds 12 thousand individuals per gram of rock sample. Spicules are present only in redeposited sediments representing Bouma’s Ta–Td sequences, except for the uppermost interval of pelagic sediments, in which spicules are absent.

Lithistid spicules prevail in the assemblages. The most common are desmas, especially dicranoclones. Less common are prodichotriaenes and phyllotriaenes. Various oxeas and microxeas are also very common. Hexactinellid spicules are very rare. These are loose hexactines and hexasters.

Spicules in thin sections of different lithologies represent three types of preservation: (1) recrystalized, (2) replaced by blocky calcite, and (3) replaced by isopachous, bladed calcite. Spicules recrystalized from primordial amorphous opal-A into more stable silica phase are present predominantly in spiculite and gaize. In most of the cross-sections, the spicule interior consists of two parts: a central part (remnants of central canal) infilled by microcrystalline quartz, and an internal part, composed of microcrystalline, fibrous, radially-arranged quartz.

Spicules replaced by blocky calcite are the prevailing type of preservation of spicules in the greywackes. They consist of 20–30 percent of spicules in the gaize layers; they are rare in the spiculites and absent in the limestone layers. Different cross-sections show that calcite very faithfully replaced the whole spicule. The central canal of spicules is usually present, and infilled by the same type of sediment or cement as surrounding the spicule. These calcitized spicules possess micro-borings filled in by micrite or bacterial coatings. In silicified rocks, they are partly dissolved due to changing in pH conditions during diagenesis. The same type of replacement may suggest that this process took place very early, before the spicules were delivered into the turbidite beds. It would suggest that early dissolution of silica, previously forming the spicules, took place during initial decay and early burial of the sponges. The surrounding carbonate mud may be the source of calcite which shortly thereafter precipitated, reducing porosity after spicules.

Former descriptions of sponge spicules from the cherts of the Lgota Beds came from the Beskid Śląski Mountains (Lipnik, Straconka, Brennica; Romer, 1870; Szajnocha, 1884; Sujkowski, 1933, Alexandrowicz, 1973). The described sponge assemblages were dominated by forms of the order Tetractinellida, with accompanying forms from the orders Lithistida and Monactinellida, and sporadic spicules of the order Hexactinellida. Sujkowski (1933) noted also silicified spicules of the order Calcispongia.

Radiolaria
The radiolarians are generally poorly and moderately preserved. Only 15 percent of skeletons may be identified; the best preserved radiolarians come from the cherts. Most of the radiolarian skeletons, especially from the shales have been recrystalized, replaced by pyrite or Fe-oxides, resulting in the destruction of external and internal wall structures.
Radiolarian assemblages are moderately diverse in the middle and upper division of the Lgota Beds. Nassellarians dominate there quantitatively, comprising 50–80 percent of the total assemblage.


Most frequent are representatives of the family Williriedellidae, which prefer eutrophic water conditions (e.g., *Holocryptocanium barbui* Dumitrica and *Cryptamphorella conara* (Foreman)). Generally, skeletons of the family Williriedellidae consist of 98 percent of the whole radiolarian assemblages in the studied series. Other nassellarians belong to families such as: Amphipyndacidae, Archaeodictyomitridae, Eucyrtidae, Stichcyrtidae and Syringocapsidae, of which the total number of specimens does not exceed 10 percent of the whole assemblage.
Spumellaria are less frequent than Nassellaria, consisting 20 to 50 percent of the total number of radiolarian specimens. Species belonging to two families: the Actinommidae and Hagiastridae prevail.

The number of radiolarians skeletons varies along the studied succession, depending on the type and derivation of the host-sediment. In the whole section, green hemipelagic shales include a low number of radiolarians. Only 20 specimens in 100 g of the rock-sample occur within the deposits around the boundary between the middle Lgota Beds and the MCh. Dark-grey and black shales are devoid of radiolarians. On the contrary, radiolarian skeletons, however, as destroyed redeposited particles, are numerous in the sand fraction deposits within both studied divisions of the Lgota Beds. The most abundant radiolarian skeletons have been observed in the beds of the Ta–Td intervals of the upper division. Their number even exceeds 10,000 individuals per 100 g of rock sample. However, there are significant fluctuations in their number within this type of sediment, with an increasing trend that occurs upward in the section.

**Foraminifera**

The study of planktonic and benthic foraminifera was made on the basis of observations in thin sections of the rocks and from their residue in fraction >64 microns. The foraminifers have been determined from green and olive non-calcareous shales, some of them came from the chert layers. The taxonomic list of foraminifers from the middle Lgota Beds and the MCh was published by Bąk et al. (2005).

Non-calcareous shales from the MCh contain mostly deep-water agglutinated foraminifera (DWAF), dominated by opportunistic forms of *Recurvoides* sp., *Thalmannammina neocomiensis* Geroch and *Trochammina* sp. Some shales, especially in the upper part of the MCh, include also numerous infaunal forms such as *Gerochammina* spp. These DWAF assemblages are typical of sediments from the Cretaceous flysch basins of the Western Tethys and the North Atlantic (e.g., Kuhnt & Kaminski, 1990; Kuhnt et al., 1992; Bąk, 2004).

Sandstones, cherts, and limestone layers of the MCh are characterized by different assemblages. More than ten species of planktonic and calcareous benthic foraminifera have been identified in residuum from the dissolved cherts. Small hedbergellids (mainly *Hedbergella delrioensis*) associated with *Globigerinelloides ultramica*, *Heteroehelix moremani* and *Guembelitria cenomanana* are the most frequent along the planktonic foraminifera (10-50 specimens per 1 cm²; Bąk et al., 2005). Calcareous benthic foraminifera are represented mostly by gavelinellids and the genus *Gyroidinoides*, with rare specimens belonging to *Cibicides*, *Præbulimina*, *Quinqueloculina* and *Dentalina*. They are less frequent than planktonic forms, ranging from a few to 30 specimens in 1 cm² (Bąk et al., 2005).

The DWAF are sporadic in the chert layers. Most probably they represent redeposited specimens, which are typical of hemipelagic assemblages, including tube-shaped forms (*Rhabdammina* sp., *Hyperammina* sp., *Bathyphosph* sp. and *Hippocrepina* sp.), and occasionally “flysch-type” forms.

An interesting fact is that large, “keeled” planktonic foraminifera (præglobootruncanids and rotaliporoids) are extremely rare in redeposited, foraminiferal assemblages. Consequently, taking into account the taxonomic composition of the benthic calcareous foraminifera in these sediments, when it is compared with the “complete” assemblages of the same age from the platform environments (cf., Gawor-Biedowa, 1972; Hart, 1980; Leckie, 1987; Hradecka, 1993), it seems that the depth of the sea floor from which the biocomponents have been redeposited was rather shallow, probably between some tens and hundreds of metres.

**Iron-fixing bacteria**

Iron is present and occurs as amorphous iron oxides or hydroxides in skeletal fossil fragments, primary pore space and as encrustations on skeletal walls and some intraclast surfaces. Some benthic foraminifera in thin section views of biomicrites, appear to have their original test replaced by iron.
oxides. On some specimens it is visible that the replacement started with the micro-boring process toward the inside the test wall. In the others, foraminiferal tests are completely replaced and covered inside by Fe-oxides. Fe oxides formed the densest layers in test cavities, which make the remnants of the wall appear much thicker than the original. Thin filaments attached to these iron coatings externally resemble iron-fixing bacteria of the Sphaerotilus – Leptothrix group. In some places, iron oxides are present in elongate structures, approximately less than 10 micrometer in width, and vary in length. These structures resemble Leptothrix discophora which are of similar size and form. Further evidence of iron-fixing bacteria are the circular forms, which may represent cross-section of bacterial sheaths, and fuzzy brown disk-like forms resembling bacterial holdfasts, surrounded usually by defibre, proliz brown flocs and aggregates. Pyrite microcrystals were associated with bacterial coccus filaments and holdfasts. The presence of the bacterial felts is not restricted only to the foraminiferal tests. They encrust echinoderm fragments and spicules of demosponges, primary siliceous, now replaced by calcite. They are present also inside the pores between grains, or partly encrust their surface. Further porosity reduction is by blocky or isopachous bladed calcite cement. The endobiotic forms were developed before cementation by calcite. These delicate structures might be preserved due to early cementation. During the early stages of calcification, micrite crystals aggregated to form plate-like clusters around the biofilm components (Perry, 1999).

PALAEOENVIRONMENTAL INTERPRETATION

The petrography of Ta–Td intervals in the thick beds of the MCh is related more or less to facies distribution in the shallower part of the basin, while the hemipelagites reflect exclusively deep-water pelagic sedimentation. In spite of turbiditic mixing and diagenetic changes, different proportions of sponge spicules, calcareous benthic foraminifers, planktonic foraminifers, radiolarians, glauconite grains, and carbonates is related to facies migration during transgressive-regressive cycles.

The spicule-bearing turbidites possess several types of sedimentary structures, developed on the soles of thick beds, indicating the north–west direction from which the spiculitic material was derived. The source of this material might have been situated on the southern ridge of the North European Platform.

The presence of sponge-rich communities within the shallower part of the basin was related to ecological factors such as sedimentation rate, bathymetry, water energy, temperature, the quantity and quality of food, and water chemistry. The lithistid dominance is the most striking feature in the frequency of sponges in the MCh. Relatively diverse lithistid sponge faunas are also known from the Early Cretaceous platform facies of Poland, Spain, southern France, England, and southern Germany (Reid, 1962; Wiedenmayer, 1980; Kaufmann et al., 2000). The main controlling factor in the lithistid vs hexactinellid sponge distribution was the predominant type of food available, as noted in geological records and present-day communities (e.g., Pisera, 1997; Krautter, 1997; Duarte et al., 2001). It is possible that sponge spicules replaced by blocky calcite are the relic of mud-mounds formed by sponges, accompanied by other benthic organisms like crinoids, calcareous foraminifers, and encrusting coralline algae, which are also present in the spicule-bearing beds (Fig. 3). In modern counterparts (Reitner, 1993), hard automicrites, which are important in the formation of mud-mounds precipitates within organic films or mats, largely produced by microbial activity. The remnants of such biofilms in our material might be the presence of iron-fixing bacteria developed mostly on carbonate grains. Pyrite microcrystals are also present in association with iron-fixing bacteria, near their sheaths and remnants of bacterial biofilms in the studied deposits. These might be a result of phases of oxygen depletion in mud-mounds, which appears also occasionally in modern counterparts, preventing the growth of macro-organisms.
The sponge spicules are diagenetically transformed into calcite. According to Reitner et al. (1995), many of the Upper Jurassic build-ups represent siliceous sponge–microbial crust mud-mounds. The majority of them (without corals – like in case of the MCh) grew in mid to upper outer ramp settings.

The occurrence of radiolarians in redeposited material signify that their source was located in the deeper part of the basin. The same concerned beds with abundant planktic foraminifers. The presence of glauconite grains, though sporadical, marks the formation of condensed facies before or simultaneously with the formation of the turbidite sequence.

The presence of radiolarians marks high productivity and thus high nutrient concentrations. The co-occurrence of radiolarian and siliceous sponges would suggest that sponges communities were situated on the middle to outer shelf, which was influenced by upwelling, also making nutrients available for the growth of sponges.

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