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Sedimentary environment of the condensed Ordovician limestones from Mójcza section (Holy Cross Mts.)

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The paper deals with sedimentary evolution of the condensed Ordovician sequence outcropping in Mójcza village, near Kielce (Central Poland), basing on microfacies analysis. The occurrence of fossils, their preservation and mineral composition enabled the author to distinguish five microfacies types. The Mójcza section is generally composed of grainstones and packstones which form the Mójcza Limestone Formation, and calcareous claystones intercalated with wackestones assigned to the Zalesie Formation. The deposition of limestones from the Mójcza section took place on the outer part of drowned isolated carbonate platform of temperate water setting in uniform sedimentary conditions with low accumulation rate. This environment, located in the upwelling currents activity area, was favourable for phosphatization of sediment. Abundance of ferruginous ooids in the upper Llanvirn, Llandeilo and upper Caradoc sediments suggests highstand sea-level conditions during Middle and Upper Ordovician.

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Key words: Holy Cross Mts., Ordovician, microfacies, sea-level changes, drowned platform.

INTRODUCTION

The subject of analysis in this paper is the Mójcza limestone section located in a village near Kielce (Fig. 1). This report presents the preliminary results concerning a sedimentary environment during the Middle and Upper Ordovician in the Mójcza area (the western part of the central area of the Holy Cross Mts.).

The detailed field work was supplemented by microscope examination of 30 thin sections. To identify carbonate minerals, staining with alizarin red S and potassium ferricyanide solution, was applied (G. M. Friedman, 1971; Z. Migaszewski, M. Narkiewicz, 1983).

PREVIOUS STUDIES

The Mójcza section was studied in detail by J. Czarnocki and J. Samsonowicz before the World War II. Later investigations of stratigraphy and petrography were carried out by W. Ryka and H. Tomczyk (1959), M. Turnau-Morawska (1961), H. Tomczyk and M. Turnau-Morawska (1964) and W. Bednarczyk (1966, 1971). Microborings in ostracod valves were studied by E. Olempska (1986). The mineralogical characteristics of ferruginous ooids from the section was made by B. Łącka (1990). The limestones outcropping in Mójcza were divided into gray *Asaphus* Limestones, light gray limestones with *Amorphognathus* sp. and red-brown

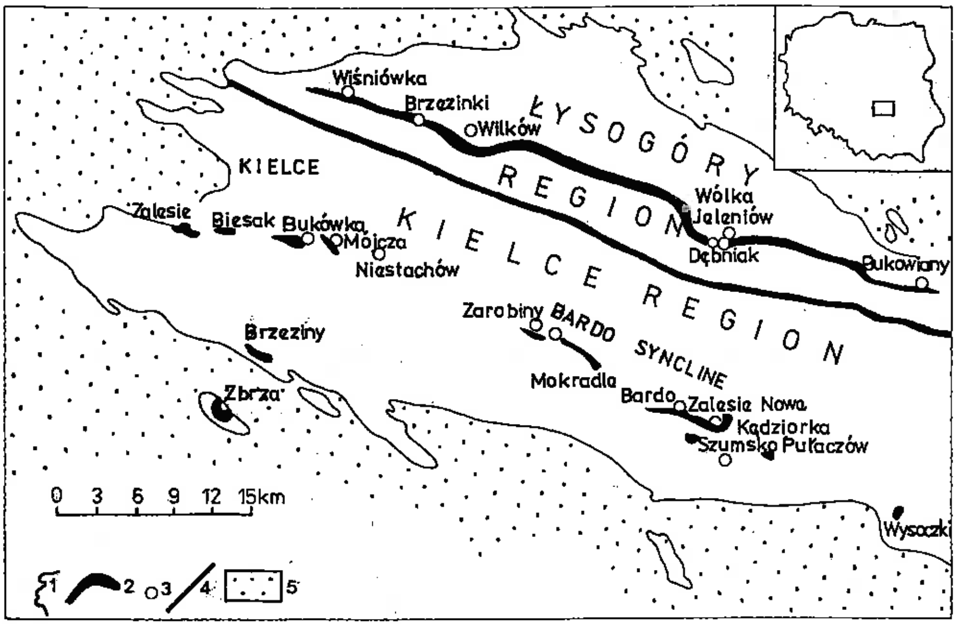

Fig. 1. Location map of the Ordovician outcrops in the Holy Cross Mts. and localization of the investigated section (according to E. Tomczykowa and H. Tomczyk, 1968)
1 — extent of the Palaeozoic core; 2 — Ordovician outcrops; 3 — boreholes; 4 — Holy Cross Fault; 5 — Mesozoic and Cainozoic

Mapa występowania osadów ordowiku w Górach Świętokrzyskich i lokalizacja badanego profilu (według E. Tomczykowej i H. Tomczyka, 1968)
1 — granica trzonu paleozoicznego; 2 — wychodnie ordowiku; 3 — otwory wiertnicze; 4 — uskok świętokrzyski; 5 — mezozoik i kenozoik

limestones (J. Czarnocki, 1919, 1928; J. Samsonowicz, 1920, 1952; W. Ryka, H. Tomczyk, 1959; W. Bednarczyk, 1966). J. Samsonowicz (1952) assigned the first two types to the Llandeilo, and the last one to the Caradoc, but W. Bednarczyk (1971) concluded the Llanvirn and Caradoc age of the whole Mójcza section. J. Dzik *et al.* (1994) concluded the lower Ashgill age of the topmost sediments in the Mójcza section.

J. Dzik and A. Pisera (1994) gave a general description of microfacies types from the Mójcza section, but without detailed analysis. Their studies provided some clues related to sedimentary environment of the limestones. According to them, depositon of limestones from Mójcza took place in an extremely stable environment with a slow sedimentation rate. This conditions favoured a very shallow bioturbation that caused homogenization of the sediment.

GEOLOGICAL SETTING

The Mójcza section is located in the western part of the Kielce (Central) Region in the Holy Cross Mts. (J. Czarnocki, 1928; H. Tomczyk, 1964; H. Tomczyk, M. Turnau-Morawska, 1964; E. Tomczykowa, H. Tomczyk, 1968; W. Bednarczyk, 1971; M. Szulczewski, 1977) (Fig. 1). In the Arenig the Holy Cross Mts. was located at the latitude about 60°S (M. Lewandowski, 1987). During the Ordovician in the Central Region a shallow-water facies belt, probably surrounded by deeper-water environments, was developed. In the Middle and Upper Ordovician this area was favourable for deposition of the condensed carbonate sequence. The best exposed, stratigraphically condensed section deposited during the latest Arenig to the early Ashgill is located in Mójcza (Fig. 2). The section is composed of the Mójcza Limestone Formation (latest Arenig–Caradoc) and Zalesie Formation (Ashgill) (W. Bednarczyk, 1981; J. Dzik, A. Pisera, 1994). The Mójcza Limestone Formation is underlain by the Bukówka Sandstone Formation (Dyminy Orthid Sandstone Member of the Międzygórz Sandstone Formation, according to W. Bednarczyk, 1981) (Fig. 2), composed of calcareous sandstones in the upper part.

Toward the south, in Brzeziny and Zbrza deepening of the basin is observed, and the Middle and Upper Ordovician strata reach thickness of 100–120 m. They are developed as the upper Llanvirn chamosite-siderite rocks overlain by the Llandeilo–Caradoc graptolite shales intercalated with calcareous deposits (H. Tomczyk, M. Turnau-Morawska, 1964; Z. Deczkowski, H. Tomczyk, 1969*b*). Further to the east, in the Bardo Syncline (Fig. 1) the condensed carbonate Ordovician sequence is exposed in Zalesie Nowe near Łagów, where the Upper and Middle Ordovician sediments are about 12 m thick. In the adjacent Szumsko borehole, located further to the south, the coeval deposits reach a total thickness of 30 m.

GENERAL LITHOLOGY OF THE MÓJCZA SECTION

The Mójcza Limestone Formation, composed predominantly of calcarenites, is about 8 m thick. Their basal part is represented by sandy limestones because of a large admixture of quartz grains. This part of the section is medium- to thick-bedded with sharp, erosional contacts between layers. At the top of the section, thin-bedded brown to yellow argillaceous limestones and marls with a sharp, erosional base and calcareous claystones assigned to the Zalesie Formation appear. This unit is about 2 m thick in the studied section.

A sedimentary unconformable surface marked by submarine erosion, burrows and phosphorite pebbles occurs about 1.5 m above the base of the section (J. Dzik, A. Pisera, 1994). In the middle part of the section a thin (about 3 cm thick) bentonite layer occurs. It records volcanic activity in vicinity of the Holy Cross Mts. (Fig. 2) (W. Ryka, H. Tomczyk, 1959; R. Chlebowski, 1971, 1976).

Within the Mójcza Limestone Formation there occur irregular, roughly planar surfaces marked by a microrelief consisting of indurated burrows extending down beneath the surface. The surfaces are impregnated by light brown iron-oxides and hydroxides and may be regarded as omission surfaces. Lithologies and biotic assemblages above and below the surfaces are broadly similar. The surfaces also contain shallow micropits up to 1 mm deep superimposed on the larger scale relief.

COMPONENTS OF LIMESTONES

The major components of the limestones from the Mójcza section are bioclasts, ooids and less commonly peloids. Among bioclasts numerous fragments of ostracods, echinoderms, trilobites and brachiopods are prevalent. The section is characterized by the lack or scarcity of recognizable macrofossils. Numerous remains of trilobite and articulate brachiopod occur in the sandy limestones of the Mójcza Limestone Formation. The absence of macrofossils is a result of destruction during prolonged periods of exposure on the sea bottom (W. Bednarczyk, 1966; J. Dzik, A. Pisera, 1994). The limestone components are described below.

BIOCLASTS

Ostracods are a common component of the limestones. Their calcitic carapaces are resistant enough to diagenetic changes. Size of ostracod carapaces varies from 0.4 to 1.3 mm and larger forms are rare. Microstructure of valves is mainly homogenous. Within some shells the prismatic arrangement of crystallites is visible. In some cases crystallites are perpendicular to the valve wall. The inner part of carapaces is filled up by micrite or phosphates (Pl. I, Fig. 4). Generally, the valves are preserved very well; some of them bear traces of abrasion and breaking. Phosphate envelopes are developed on the inner and outer part of valves. In the Mójcza section only disarticulated valves are present; nevertheless, complete carapaces are preserved as well.

The valves are predominantly chaotically oriented. Some of them lie in convex-up or concave-up position which according to E. Olempska (1994), resulted from a low rate of accumulation. Some valves are inserted one into another (Pl. II, Fig. 4) and larger forms are sometimes filled in by smaller, broken valves. In addition some valves may be oriented perpendicularly to the bedding plane. This orientation results from bioturbation (E. Olempska, 1994). U-shaped tubes and sometimes small patches of borings, iron-oxides filled or phosphate-coated are preserved on the surface of ostracod carapaces (Pl. II, Fig. 2). This is interpreted as a result of a boring activity of endolithic microorganisms (E. Olempska, 1986).

Echinoderms are represented by crinoid ossicles and branches, cystoid stems and plates (Pl. I, Fig. 1) (A. Pisera, 1994). Their calcitic fragments are resistant to diagenetic changes. The size of crinoids ranges from 0.3 to 1.2 mm. Some of echinoderm remains are coated by phosphate envelopes. The echinoderm fragments are commonly syntaxially overgrown by a calcite cement. In a few cases their primary pores are filled by a microspar cement (Pl. I, Fig. 8).

Brachiopods are quite common fossils in the section, particularly in its lower and upper parts. The brachiopod shell consists of two layers (Pl. II, Fig. 5). Originally brachiopod shells were built of calcite, therefore their microfabrics is preserved very well. The outer layer is seldom preserved, and appears as a thin rim of crystallites. The inner layer is built of fibrous calcite crystals commonly oblique to shell surface. Shells are often broken and bear signs of abrasion. The traces of borings sometimes filled by iron-oxides are a common feature of brachiopod shells. No neomorphic changes have been found within the calcitic shells.

Bryozoa. In the investigated section fragments of bryozoan zoaria are a common rock constituent, and occur throughout almost the entire section. The bryozoan colonies are preserved in their initial stages of development (J. Dzik, 1994*a*). They are mostly coated by phosphate envelope. In some cases zoecia are filled up by microspar or phosphates (Pl. I, Fig. 2).

Trilobites usually appear as poorly identified broken fragments of carapaces. In some places cross-sections of carapaces are visible (Pl. I, Fig. 5). The trilobite fragments are a common rock-forming component in the lower and middle part of the section. The carapaces have homogenous microstructure, but sometimes a lamellar pattern is observed. The development of phosphatic envelopes is an important feature of trilobite carapaces.

Molluscs are represented by polyplacophoran, gastropod, bivalve and hyolith lineages (J. Dzik, 1994*b*), and are usually broken. In the Mójcza section they are less common than the particles described above. Hyolith and polyplacophoran shells are easily identified in thin sections because of their cone-like shape (Pl. I, Fig. 3; Pl. II, Fig. 1). Mollusc shells are coated by phosphate envelopes (Pl. I, Fig. 3).

Distribution of mollusc remains is largely chaotic. Some of the shells bear signs of neomorphic changes in the form of an equant-mosaic calcite development. The chambers of ga-

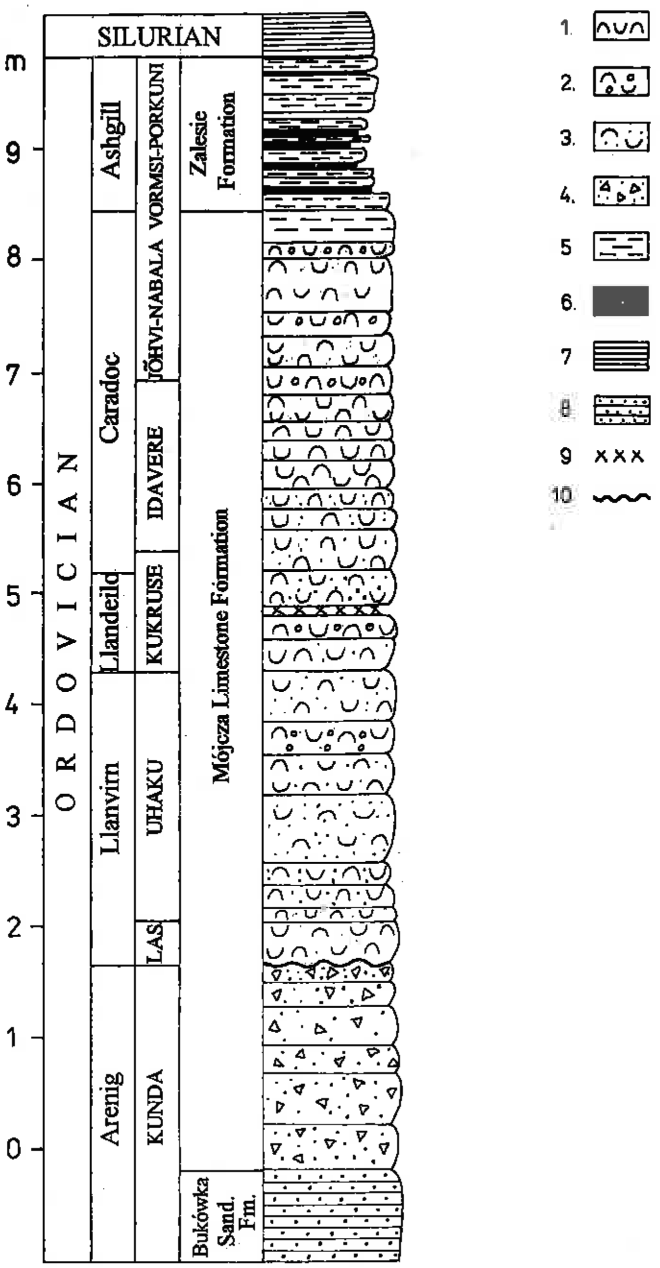

Fig. 2. Lithology and stratigraphy of the investigated Mójcza section (according to J. Dzik and A. Pisera, 1994, modified)

1 — bioclastic grainstones; 2 — ooid-bioclastic grainstones; 3 — bioclastic grainstones to packstones; 4 — sandy-bioclastic grainstones; 5 — ostracod packstones to wackestones; 6 — limy claystones; 7 — shelly claystones and siltstones; 8 — sandstones; 9 — bentonite; 10 — discontinuity surface

Litologia i stratygrafia profilu z Mójczy (według J. Dzika i A. Pisery, 1994, zmieniona)

1 — grainstony bioklastyczne; 2 — grainstony ooidowo-bioklastyczne; 3 — grainstony-pakstony bioklastyczne; 4 — grainstony piaszczysto-bioklastyczne; 5 — pakstony-wakstony małżoraczkowe; 6 — iłowce wapniste; 8 — iłowce i mułowce łupkowate; 8 — piaskowce; 9 — bentonit; 10 — powierzchnie nieciągłości

stropod shells, polyplacophorans and hyoliths are filled in by micrite, phosphates, and in places by microspar (Pl. I, Fig. 3).

Other components like originally siliceous and calcareous sponge spicules as well as calcitic machaeridian sclerites are subordinate (J. Dzik, A. Pisera, 1994; J. Dzik, 1994*b*). They are enveloped by phosphate laminae.

OOIDS

Ooids are important components of the Mójcza section. There occur calcitic and ferruginous ooids.

Calcitic ooids have subordinate importance among limestone components. They are typically spherical (Pl. I, Figs. 8, 9) and reach 1 mm in diameter. Nuclei are formed of bioclasts and fragments of microspar. A high degree of ooid sphericity may suggest their prolonged accretion. The major part of ooid structure is occupied by cortex, up to 50–90% of the grain volume. The ooids exhibit radial microfabrics, suggesting their original calcitic composition (Pl. I, Figs. 8, 9). If the ooids had originally been composed of aragonite then their fabric and structure would have generally been altered during diagenesis (P. A. Sandberg, 1975). Ooids are usually surrounded by syntaxial calcite overgrowths (Pl. I, Figs. 8, 9).

Ferruginous ooids are abundant above the bentonite layer (Fig. 2). In the Caradoc series they are an important component of the sediments. Ferruginous ooids commonly show spherical, ellipsoidal and lens-like shape; in places it is distorted (Pl. I, Figs. 5, 6). These components reach from 0.5 to 2 mm in diameter and are yellowish or brown to pale-green. The ooids are built of goethite, kaolinite, apatite, calcite, illite and sometimes quartz (B. Łącka, 1990). Various fragments of shells, echinoderms, valves and fragments of microsparite form nuclei. These ooids reveal characteristic tangential, concentric microfabrics. Under crossed nicols they are isotropic or show low birefringence. Calcitized parts commonly comprise irregular fragments of the ooids or form discontinuous laminae (B. Łącka, 1990; M. Turnau-Morawska, 1961) (Pl. I, Fig. 5; Pl. II, Fig. 2). Apart from the typical grains with numerous coatings the superficial ooids occur as well.

PELOIDS AND INTRACLASTS

As opposed to bioclasts, peloids and intraclasts are less numerous. Peloids consist of micrite, with an admixture of clay. In thin sections, they are spherical and oval, varying from 0.1 to 0.4 mm in size. Irregular grains bearing some signs of reworking appear as well, including those somewhat larger and containing poorly recognizable skeletons. The grains are mostly unrecognizable and not abraded. The peloids associated with bioturbated deposits are probably coprolites left by burrowing organisms. Much larger and slightly rounded peloids can be regarded as microintraclasts. Some of them are syntaxially overgrown by calcite (Pl. II, Fig. 1). Above the sedimentary unconformable surface overlying the Arenig series, J. Dzik and A. Pisera (1994) recorded phosphorite pebbles which in their opinion represent clasts derived from the underlying lowermost Ordovician or Cambrian deposits.

MICROFACIES TYPES

Basing on the above described spectrum of the Mójcza section components, the following carbonate facies types may be distinguished. The subdivision follows R. J. Dunham (1962) carbonate rock classification:

1. Sandy-bioclastic grainstones.
2. Bioclastic grainstones.
3. Bioclastic grainstones to packstones.
4. Ooid-bioclastic grainstones.
5. Ostracod packstones to wackestones.

The first four facies build up the Mójcza Limestone Formation, while the fifth is present in the Zalesie Formation and the uppermost Mójcza Limestone Formation (Fig. 2).

1. The **sandy-bioclastic grainstones** appear at the base of the section and show a continuous sedimentary transition from the underlying Bukówka Sandstone Formation. These facies are primarily composed of trilobite fragments and brachiopod shells, and less common ostracod valves. The quartz grains are abundant and their size varies from 0.1 to 0.3 mm (Pl. II, Fig. 5). Grains are poorly rounded, well sorted and often coated with phosphatic envelopes. The grainstones framework is mainly grain-supported but in some parts it is matrix-supported. Bioclasts are crushed and bear signs of abrasion and sometimes are coated with phosphate envelopes. The rock components are chaotically arranged. Intergranular voids are filled up with equant calcitic cement.

2. The **bioclastic grainstones** are represented by grain-supported components. The grainstones are mainly composed of trilobite fragments and ostracod valves. The brachiopod and mollusc shells, bryozoa and echinoderm fragments and calcite ooids are less common. The organic remains are often phosphatized and have phosphate envelopes developed on their surface. The sediment particles are cemented by equant sparry calcite cement, sometimes of drusy type (Pl. II, Figs. 4, 6). In the case of large crystals reaching several milimetres in diameter poikilotopic calcite spar developed. On the inner surface of shells and valves calcite prismatic cement in the form of blade-shaped crystals occurs in some places. Most ooids and echinoderm remains have developed syntaxial overgrowths on their surfaces. Bioclasts show a high degree of reworking before deposition and bear signs of abrasion.

3. The **bioclastic grainstones to packstones** occur in the middle part of the Mójcza section. These facies are predominantly composed of trilobite fragments and ostracod valves. The calcite ooids and echinoderm fragments commonly with syntaxial overgrowths are quite common among rock-components. The mollusc and bryozoan remains are less frequent. Bioclasts, especially echinoderm, trilobite and mollusc remains, are abraded and worn. In addition, microintraclasts and peloids occur, but in smaller proportion than the other components. Shells are mostly crushed, chaotically arranged, and densely packed. These facies type contain microspar and spar in various proportions and the framework is grain-supported. Intergranular spaces lacking mud are occupied by equant and rarely drusy calcite spar. The calcite prismatic cement on some shells and valve surfaces is also developed. It occurs as blade-shaped crystals (Pl. II, Fig. 3).

4. The **ooid-bioclastic grainstones** are mainly composed of ferruginous ooids and trilobite fragments. The framework is grain-supported. The ooids are scattered and partly form patches and concentrations. Among the rock particles there occur ostracod valves, some mollusc and bryozoan remains, and sporadically calcite ooids. The bioclasts and ooids are well sorted and chaotically arranged. All grains are cemented by an equant sparry calcite cement.

5. The **ostracod packstones to wackestones** are present at the top of the Mójcza section. They belong to the Zalesie Formation but occur also in the topmost part of the Mójcza Limestone Formation. The main grain components are ostracod valves, trilobite fragments, and scarce brachiopod and mollusc shells. Remains of the brachiopods, trilobites and molluscs are abraded and crushed. Bioclasts are chaotically arranged but some ostracod valves lie in convex-up or concave-up position. These facies are grain-supported to matrix-supported in some parts. The presence of ferruginous cauliflower structures developed on skeletal debris is evidence of calm-water conditions.

CORRELATION WITH GLOBAL SEA-LEVEL CHANGES

The calcareous sequence from Mójcza developed above the Lower Ordovician terrigenous deposits which record the Arenig regression (J. Dzik, A. Pisera, 1994). Gradual decrease of quartz grains proportion in the Mójcza section observed in the uppermost Arenig deposits resulted from increasingly off-shore location and isolation from the clastic source. Decreasing upward terrigenous sediment content related to deepening conditions and isolation from siliciclastic sediment input is usually connected with transgressive system tracts (T. S. Loutit *et al.*, 1988).

According to J. Dzik and A. Pisera (1994) the discontinuity surface between the Arenig and Llanvirn sediments resulted from submarine erosion during low sea-level stand. The time gap corresponds to the late Kunda, Aseri and early Lasnamagi. Above the discontinuity, which is probably a ravinement surface, the condensed limestone sequence is developed.

In the upper Llanvirn, Llandeilo and upper Caradoc deposits there occur layers with numerous ferruginous ooids. According to T. P. Young (1992) ferruginous ooids appear as the initial deposits above a disconformity, separating transgressive systems tracts from early part of the highstand systems tracts, and thus are associated with maximum flooding surfaces. In this position they are correlated with initial periods of a sea-level highstand. A relative rise of sea-level over a carbonate platform may lead to sediment starvation and platform drowning (C. R. Handford, R. G. Loucks, 1993). Presence of the ferruginous ooids in the Llanvirn of the Mójcza section coincides with occurrence of the chamosite-siderite rocks in the upper Llanvirn of Brzeziny and Jeleniów (H. Tomczyk, M. Turnau-Morawska, 1964, 1967). The occurrence of ferruginous ooids in the upper Caradoc corresponds to faunal change in the Mójcza section marked by gradual disappearance of *Amorphognathus* and domination of warm-water *Strachanognathus, Rhodesognathus* and *Icriodella* in conodont assemblage (J. Dzik, 1994*c*, 1996). In this part of the section warm-water molluscs appear in generally cold-water assemblage (J. Dzik, 1994*b*). Presence of ferruginous ooids in the upper Llanvirn, Llandeilo and upper Caradoc sediments of the Mójcza section suggests the maximum flooding and early highstand sea-level conditions during these times in the western area of the Holy Cross Mts., developed above the transgressive systems tracts of the uppermost early Llanvirn and early Caradoc. Additionally the warm-water conodonts and molluscs in the upper Caradoc testify to high sea-level stand after the transgressive event. Comparable, high concentration of the ferruginous ooids connected with high sea-level stand in the late Llanvirn and late Caradoc is known from many places of SW Europe (T. P. Young, 1992). The early Llanvirn subsequent flooding in the western part of the Holy Cross Mts. is marked by rocks bearing graptolites of the *Didymograptus bifidus* and *D. artus* groups known from Brzeziny area, south of Mójcza (H. Tomczyk, M. Turnau-Morawska, 1964). It appears to correspond with the maximum flooding surface (MFS) of the ensuing transgression which correlates with transgressive events from Lake District of northern England, Wales and Gondwanan regions (C. R. Barnes *et al.*, 1996). The global early Caradoc transgression during *Nemagraptus gracilis* Zone (S. C. Finney, S. M. Bergström, 1985) is noted in boreholes Brzeziny, Zbrza, Jeleniów and Bukowiany in the Holy Cross Mts. (Fig. 1) (H. Tomczyk, M. Turnau-Morawska, 1964, 1967; Z. Deczkowski, H. Tomczyk, 1969*b*). In Mójcza it corresponds to rebuilding in conodont assemblage and remarkable increase in productivity of *Amorphognathus* (J. Dzik, 1994*c*, 1996).

There is no evidence for the early Llandeilo transgression in the Holy Cross Mts. It is probable that during this period the highstand sea-level conditions, which started in the upper Llanvirn, were maintained. The occurrence of the ferruginous ooids coincide with domination of warm-water *Complexodus* in conodont assemblage (J. Dzik, 1994*c*, 1996).

Deposition of the lower Ashgill claystones and siltstones is connected with deeper water environment dominated in the Holy Cross Mts. In the late Ashgill there were probably fluctuations in sedimentary conditions recorded by occurrence of shallow-water limestones, dolomites and sandstones in many places of the Holy Cross Mts. including Zalesie Nowe and Bardo–Stawy outcrops, Mokradle borehole, Dębniak and Wilków boreholes (Fig. 1) (W. Bednarczyk *et al.*, 1966; J. Czarnocki, 1950; Z. Deczkowski, H. Tomczyk, 1969*a*). This interval probably corresponds to the Hirnantian glacieustatic shallowing pulse.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

The facies succession above reflects a temporal evolution of the carbonate platform during the late Arenig to lower Ashgill.

Taxonomically the fauna assemblage from the Mójcza section closely resemble modern temperate shelf faunas. Non-skeletal grains represented by calcitic ooids and peloids are less common. In some beds the ferruginous ooids form an important part of the limestones.

Large number of the skeletal grains, mostly ostracod valves are bored, and the tiny borings on the larger shells are usually iron-oxides filled or phosphate-coated. Some of the borings are empty, which in H. R. Young's and C. S. Nelson's (1988) opinion may result from undersaturation of temperate water with respect to carbonate. E. Olempska (1986) postulates that microborings are produced by endolithic algae, though "...they do not show any definite resemblance to recent photosynthetic (algal) endoliths". The boring activity of the endolithic algae occurs within shallow-water photic zone to a depth of 50 m, but it may extend down to 100 m in clear water (R. G. C. Bathurst, 1966; D. R. Kobluk, M. J. Risk, 1977*a, b*; M. E. Tucker, V. P. Wright, 1990). It is possible that some of the borings originated from endolithic fungi boring activity, which would locate depositional environment much deeper, below the photic zone. It is here interpreted that the main source of carbonate mud, represented in the studied section as micrite and microspar, was bioerosion of skeletal grains and the mechanical abrasion combined with chemical dissolution of the $CaCO_3$ (E. T. Alexandersson, 1979; A. W. Tudhope, M. J. Risk, 1985; W. M. Bloom, D. B. Alsop, 1988; H. R. Young, C. S. Nelson, 1988).

Absence of reef-building corals and calcareous algae in skeletal assemblage from the Mójcza section seems to impose important constraints on the water depth. M. E. Brookfield (1988) interpreted the Ordovician *Solenopora* as an equivalent of recent coralline red algae. In temperate regions corallines occur at depths of between 60 and 100 m, and even 120 m (L. B. Collins, 1988; C. S. Nelson *et al.*, 1988). The lack of calcareous algae and reef-building corals in limestones from the Mójcza section suggests deposition below the photic zone. On the basis of the foregoing the bioclastic grainstones and packstones are interpreted as deeper-water sediments. Non-skeletal grains, mostly ooids, were transported from the adjacent wave-dominated shallow shelf during storms and current-action. The peloids are smaller, rounded limestone grains, therefore they can be regarded as microintraclasts. The presence of rounded clasts indicates the erosion of the early cementated sediment. Similar composition of the Mójcza Limestone Formation grainstones and packstones suggests general uniform sedimentary regimes from the late Arenig to late Caradoc.

The modern equivalent of the carbonate platform developed in Mójcza area during the late Arenig to late Caradoc is middle and outer shelf located in temperate climatic zone. This setting is known from the Rottnest Shelf of south-west Australia (L. B. Collins, 1988) and Three Kings Plateau, northern New Zealand (C. S. Nelson *et al.*, 1982). In these environments grainstones and packstones occur at depths of between 50 and 170 m, and even 250 m. The main components of sands and muddy sands are skeletal parts of bryozoans, molluscs, foraminifera, echinoderms, ostracods and brachiopods. An ancient cool-water carbonate successions are described by N. P. James and Y. Bone (1991) from mid-Cainozoic carbonates of the Eucla Platform in southern Australia and by M. E. Brookfield (1988) from Middle Ordovician Trenton Limestone Groups of southern Ontario. The limestones from these places are largely skeletal grainstones composed of bryozoans, brachiopods, gastropods and corals.

The sand or sandy mud deposited on the platform was affected by shallow bioturbation (J. Dzik, A. Pisera, 1994). The traces of burrows are marked by iron-oxides impregnations and form small patches. This is due to early cementation which first affected the burrow fillings containing slightly coarser and more permeable sediment (N. P. James, Y. Bone, 1991). The grains filling the burrows are densely packed, chaotically arranged, and extremely reworked. The burrows are associated with occurrence of iron-stained, irregular surfaces. Scalloped or planar corrosion surfaces with irregular stylolitic solution surfaces and iron-oxides impregnations are described by M. E. Brookfield (1988) from the Ordovician Black River and Trenton Limestone Groups of southern Ontario. On the basis of interpreted marine origin, similar iron-impregnated surfaces were regarded by N. P. James and Y. Bone (1991) as submarine hardgrounds. A limonite-stained surface in the upper Famennian of the eastern Anti-Atlas records a break in sedimentation (J. Wendt, 1988). In Mójcza similar surfaces presumably developed in places of sediment starvation were favourable for early cementation. They appeared just below the sea-floor, where grains were not being moved very frequently or sea-water was pumped through by wave or current action. On modern cool-water shelves relics of Late Pleistocene–Holocene sediments are commonly iron-stained and glauconitized (L. B. Collins, 1988; C. S. Nelson *et al.*, 1988). Much of the impregnations, observed in thin sections, is localized within the matrix between skeletal grains, within micropores in skeletal grains and form iron-stained coatings on grains. According to N. P. James and R. N. Ginsburg (1979) the iron-coating may result from either subaerial or submarine diagenesis.

Location close to the upwelling currents zone (E. Olempska, 1994), and the low sedimentation rate resulted in increase of phosphate-bearing organisms, and phosphatization of sea-floor sediments. Sediment starvation was also favourable for ferruginous ooids formation. Phosphatization, glauconite formation and oxidations develop when unfavourable environmental conditions terminate carbonate production and bioclasts are exposed on the sea-floor (L. Simone, G. Carannante, 1988).

Skeletal fragments formed sandflats of bioclastic sediments affected only by extremely strong storms reworking sediment and removing calcareous mud. Storm-generated swell waves can rework sediments to depths of 60 m, or even 130 m in the case of fine sediment (L. B. Collins, 1988). The ultimate wave abrasion depth on modern cool-water settings is located between 50 and 75 m (N. P. James, Y. Bone, 1991).

On the basis of palaeontological evidence (dominance of nonphototrophic organisms, lack of calcareous algae and coral colonies), lithology and comparison with modern and ancient temperate-water carbonate shelves the Mójcza Limestone Formation sediments are interpreted as deposits accumulated below the zone of active calcareous algae and coral colonies growth. The grainstones and packstones were deposited below fair-weather wave base, and even below storm wave base, in water depths of between 80 and 120 m.

The deposition of the Zalesie Formation took place in deeper water environment than that of Mójcza Limestone Formation due to eustatically controlled gradual deepening of the platform. The ostracod packstones to wackestones intercalated with calcareous claystones were accumulated in low-energy environment below the storm wave base. The sharp bases of layers and chaotic arrangement of rock components suggest single depositional event. These thin-bedded packstones and wackestones resemble T. Aigner's (1984) "distal" deeper water tempestites. These sediments developed in the distal part of the outer shelf or upper slope affected by storm-generated currents. Skeletal wackestones are known from the outer part of the Rottnest Shelf of south-west Australia, as deep as 170 m (L. B. Collins, 1988).

Location in temperate climatic zone and eustatically controlled sea-level rise in the Middle and Upper Ordovician in the Holy Cross Mts. resulted in extremely low accumulation rate. The carbonate production, probably could not keep pace with normal rate of sea-level rise, so that the platform was submerged below the euphotic zone. The low carbonate production is the feature of drowned open temperate carbonate shelves (W. Schlager, 1981; L. Simone, G. Carannante, 1988). In L. B. Collins's (1988) opinion the drowning of temperate shelves is easier when there is "...low bentic growth potential and lack reef". Maximum transgression and highstand sea-level conditions favour drowning of platforms and sediment starvation, and consequently sediment condensation (T. S. Loutit *et al.*, 1988; J. F. Sarg, 1988; J. Wendt, 1988). These conditions, fully developed in vicinity of Mójcza, controlled sedimentation in the whole Central Region area.

Facies arrangement in the Holy Cross Mts. and type of carbonate sediments noted in the Central Region suggest development of drowned, isolated carbonate platform during the Middle and Upper Ordovician

CONCLUSIONS

1. In the Mójcza limestone section five microfacies types were distinguished: sandy-bioclastic grainstones, bioclastic grainstones, bioclastic grainstones to packstones, ooid-bioclastic grainstones and ostracod packstones to wackestones.

2. Deposition took place on the drowned, isolated carbonate platform located in temperate climatic zone, in depths between of 80 and 120 m. This setting was favourable for low sedimentation rate which resulted in extreme sediment condensation.

3. The upper Llanvirn, Llandeilo and upper Caradoc ferruginous ooid horizons developed above the transgressive systems tracts record maximum flooding and early high sea-level stand in the western part of the Holy Cross Mts.

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ŚRODOWISKO SEDYMENTACJI WAPIENI ORDOWICKICH SKONDENSOWANEGO PROFILU Z MÓJCZY (GÓRY ŚWIĘTOKRZYSKIE)

Streszczenie

Skondensowany profil z Mójczy koło Kielc tworzą wapienie ordowickie, należące do formacji wapieni z Mójczy (późny arenig–karadok) i formacji z Zalesia (aszgil). W składzie ziarnowym wapieni dominują bioklasty i ooidy (żelaziste i kalcytowe). W mniejszej ilości (w dolnej części profilu) występują intraklasty, peloidy i kwarc. Zasadnicze znaczenie wśród bioklastów mają małżoraczki, szkarłupnie, trylobity, mniejsze zaś ramienionogi, mszywioły, mięczaki i igły gąbek. Bioklasty w znacznej mierze są zabradowane i często połamane. Charakterystyczną ich cechą jest obecność powłok fosforanowych. Na powierzchni wielu bioklastów często można obserwować ślady drążącej działalności mikroorganizmów.

Na podstawie składników ziarnowych i ich wzajemnych relacji wapienie z profilu mójczańskiego podzielono, według klasyfikacji R. J. Dunhama (1962), na: grainstony piaszczysto-bioklastyczne, grainstony bioklastyczne, grainstony-pakstony bioklastyczne, grainstony ooidowo-bioklastyczne i pakstony-wakstony małżoraczkowe.

Cztery pierwsze grupy tworzą formację wapieni z Mójczy, ostatnia zaś występuje w formacji z Zalesia i w najwyższej części formacji wapieni z Mójczy.

Zespół faunistyczny tworzący wapienie w profilu mójczańskim jest taksonomicznie zbliżony do zespołu współczesnych platform węglanowych umiarkowanej i chłodnej strefy klimatycznej. Sedymentacja wapieni z profilu mójczańskiego odbywała się w dość stabilnym środowisku, w warunkach wolnego tempa akumulacji, co zaznaczyło się znaczną kondensacją osadu. Przypuszczalnie zbyt wolna produkcja węglanu wapnia nie mogła nadążyć za tempem wzrostu poziomu morza, sprzyjając zatopieniu platformy węglanowej. Brak korali rafotwórczych i glonów wapiennych sugeruje sedymentację poniżej strefy fotycznej, na głębokości od 80 do około 120 m, gdzie prądy spowodowane bardzo silnymi sztormami przerabiały zdeponowany osad. Na obszarze współczesnych platform położonych w klimacie umiarkowanym strefa abrazji wywołana falowaniem sztormowym znajduje się na głębokości 50–75 m. Depozycja osadów formacji z Zalesia odbywała się w dystalnej części szelfu zewnętrznego. Do rejonu tego docierały osłabione prądy sztormowe generowane w płytszym morzu.

Rozkład litofacji, charakter sedymentacji węglanowej oraz porównanie ze współczesnymi środowiskami węglanowymi sugerują w środkowym i wyższym ordowiku w regionie kieleckim Gór Świętokrzyskich rozwój zatopionej, izolowanej platformy węglanowej.

W profilu z Mójczy zaznaczone są dwa epizody związane z wysokim poziomem morza, poprzedzone dwoma epizodami transgresywnymi — wczesnolanwirnskim i wczesnokaradockim — korelowane w skali regionalnej i globalnej

EXPLANATIONS OF PLATES

PLATE I

Fig. 1. Echinoderm fragment in bioclastic grainstone to packstone

Fragment szkarłupnia w grainstonie-pakstonie bioklastycznym

Fig. 2. Bryozoa fragment. Intragranular spaces filled up by phosphate

Fragment mszywioła. Przestrzenie intragranularne wypełnione fosforanami

Fig. 3. Cross-section of hyolith shell filled up by phosphate (upper part of photo) and shell of polyplacophoran (lower part of photo). Note concentric phosphate-ferruginous laminae developed on both sides of the hyolith shell (I stage of ooid acretion)

Przekrój poprzeczny muszli hyolita wypełnionego fosforanami (górna część fotografii) i chitona (dolna część fotografii). Koncentryczne laminy fosforanowo-żelaziste po obu stronach muszli hyolita (I etap akrecji ooida)

Fig. 4. Carapace of ostracod filled up by phosphate

Pancerzyk małżoraczka wypełniony fosforanami

Fig. 5. Ooid-bioclastic grainstones with calcitized ferruginous ooids and trilobite fragment

Grainston ooidowo-bioklastyczny ze skalcytyzowanymi ooidami żelazistymi i fragmentami trylobitów

Fig. 6. Ferruginous ooids. Note deformed ooid (lower, larger grain shows signs of deformation)

Ooidy żelaziste. Ślady deformacji

Fig. 7. Phosphate envelope around shell fragment

Obwódka fosforanowa wokół fragmentu muszli

Fig. 8. Calcitic ooid (upper part of photo) and crinoid fragment (lower part of photo). Both the grains encrusted by syntaxial overgrowths

Ooid kalcytowy (wyższa część fotografii) i fragment krynoida (dolna część fotografii). Oba ziarna otoczone obwódkami syntaksjalnymi

Fig. 9. Syntaxial calcite overgrowth on calcite ooid with well preserved radial microfabrics

Cement syntaksjalny wokół ooida kalcytowego z dobrze zachowaną radialną mikrostrukturą

Figs. 1–3, 5, 8, 9 — crossed nicols (nikole skrzyżowane)

PLATE II

Fig. 1. Bioclastic grainstone to packstone with intraclast syntaxially overgrown by calcite cement (central part of photo). Shell of polyplacophoran near the lower edge

Grainston-pakston bioklastyczny z mikrointraklastem otoczonym cementem syntaksjalnym (centralna część fotografii). Muszla chitona przy dolnej krawędzi fotografii

Fig. 2. Ostracod valve with borings on its concave surface. Ferruginous ooids, one (lower left) with well preserved concentritic laminae and the other (upper right) partly calcitized

Skorupka małżoraczka z drążeniami po jej wewnętrznej stronie. Ooidy żelaziste: jeden (lewy dolny) z dobrze zachowanym koncentrycznym układem lamin i drugi (prawy górny) częściowo skalcytyzowany

Fig. 3. Ostracod valve with prismatic cement on its concave surface

Skorupka małżoraczka z cementem pryzmatycznym na jej wewnętrznej stronie

Fig. 4. Equant calcite cement. Note ostracod valves inserted one into another

Cement izometryczny. Skorupki małżoraczków włożone jedna w drugą

Fig. 5. Fragment of brachiopod shell composed of two layers

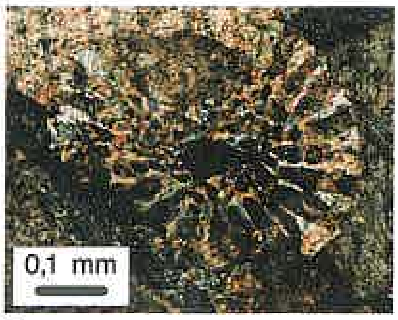
Fragment muszli ramienionoga złożonej z dwóch warstw

Fig. 6. Pore-filling equant calcite cement developed between bioclasts. Ostracod valve (upper part of photo) with prismatic calcite preserved. Fragment of brachiopod shell (lower part of photo)

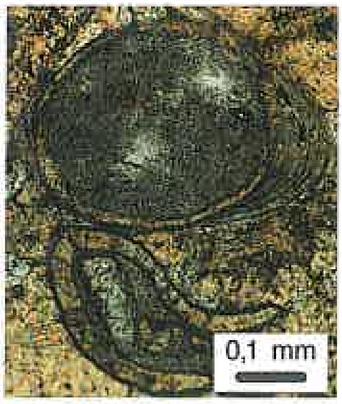
Cement izometryczny wypełniający przestrzenie między bioklastami. Skorupka małżoraczka (górna część fotografii) z cementem pryzmatycznym na jej wewnętrznej stronie. W dolnej części fotografii fragment muszli ramienionoga

Figs. 1, 3–6 — crossed nicols (nikole skrzyżowane)

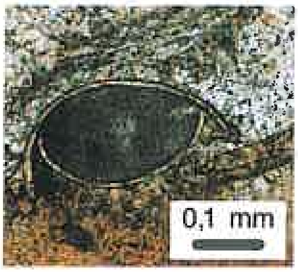
1



2

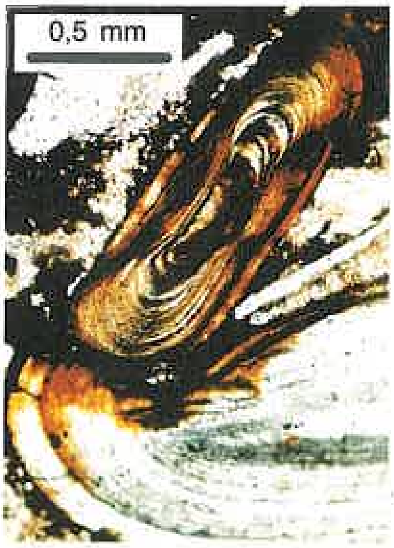


3



4

5



6

7

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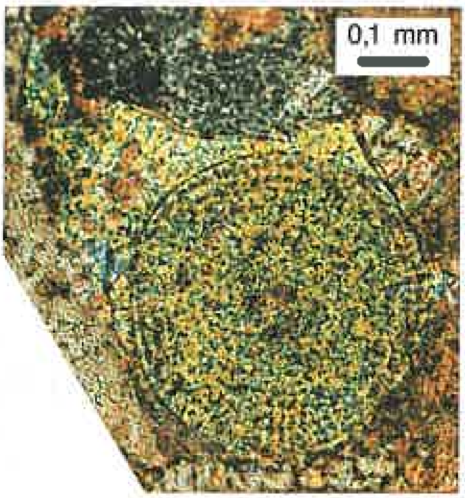
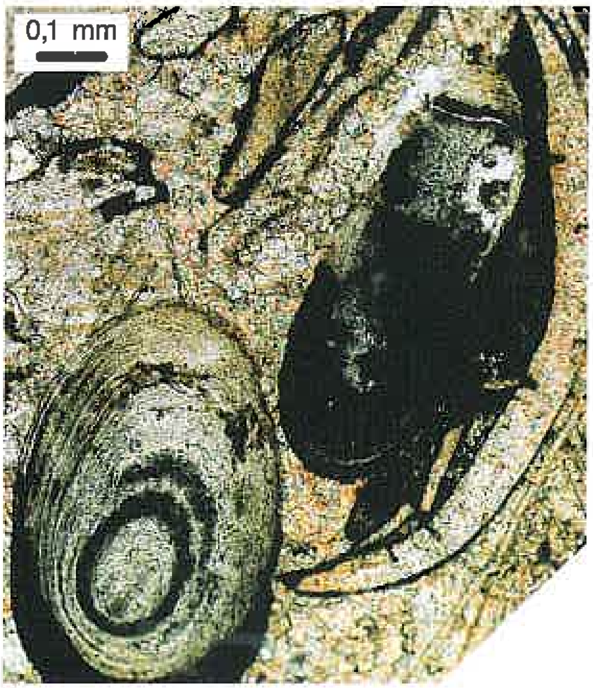


9

Wiesław TRELA — Sedimentary environment of the condensed Ordovician limestones from Mójcza section (Holy Cross Mts.)

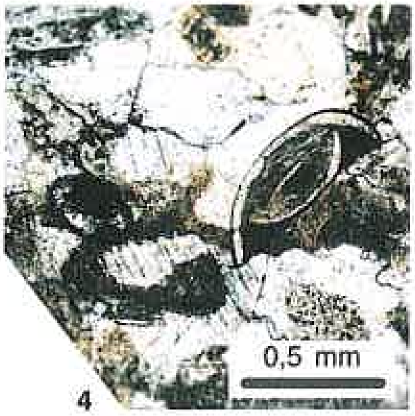
PLATE II

1



2

3



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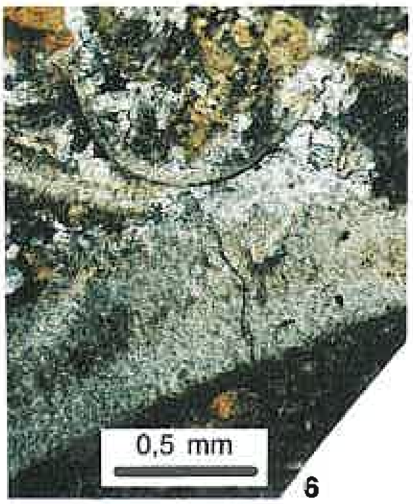

6

Wiesław TRELA — Sedimentary environment of the condensed Ordovician limestones from Mójcza section (Holy Cross Mts.)