GUIDEBOOK

Transgressive Callovian succession and Oxfordian microbial-sponge carbonate buildups in the Kraków Upland

Guide to field trip A5 • 21–22 June 2015

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Transgressive Callovian succession and Oxfordian microbial-sponge carbonate buildups in the Kraków Upland

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Route (Fig. 1): From Kraków we take road 79 to Krzeszowice, then turn south onto a local road to Zalas. **Zalas quarry (stop A5.1)** is located in the eastern part of the village. From Zalas we take the local road to Krzeszowice, there turn right onto road 79 to Rudawa. At Rudawa, we turn left and follow local roads to NE to Bolechowice. We walk to the rock gate of **Bolechowice valley (stop A5.2)** visible NW of the village centre. From Bolechowice we drive south by local roads to road 79 at Zabierzów and turn right. After ca. 0.5 km a narrow road to the left enters **Zabierzów quarry (stop A5.3)** and a restaurant with a parking lot. The trips returns to Kraków along road 79 for overnight. On the second day, we drive NE by road 94 from Kraków to Modlnica and turn east onto a local road to Giebułtów, then north by road 794 to Skała. From Skała we follow road 773 east to Nowa Wieś, then we turn north onto a local road to Gołcza. At Gołcza we turn west to Wielkanoc village. **Wielkanoc quarry (stop A5.4)** is visible on the left after ca. 1 km. From Wielkanoc we drive SW by local roads to road 94, then passing Jerzmanowice we turn right Biały Kościół to Ujazd. Exposure at **Ujazd (stop A5.5)** is located by a small road along the main stream in the northern part of the village. From Ujazd we return to nearby Kraków.

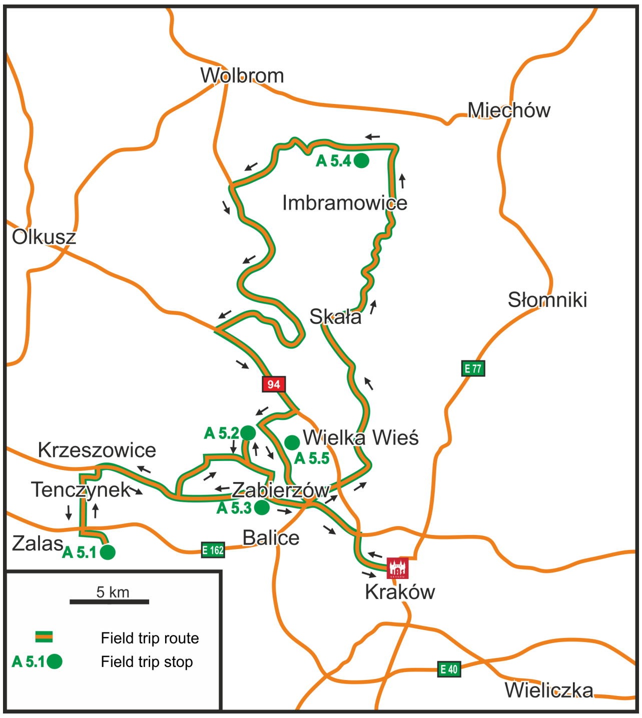

Fig. 1. Route map of field trip A5.

Matyszkiewicz, J., Felisiak, I., Hoffman, M., Kochman, A., Kołodziej, B., Krajewski, M. & Olchowy, P., 2015. Transgressive Callovian succession and Oxfordian microbial-sponge carbonate buildups in the Kraków Upland. In: Haczewski, G. (ed.), *Guidebook for field trips accompanying 31st IAS Meeting of Sedimentology held in Kraków on 22nd–25th of June 2015*, Polish Geological Society, Kraków, pp. 51–73.
Guidebook is available online at www.ing.uj.edu.pl/ims2015

Introduction to the trip

Jacek Matyszkiewicz, Bogusław Kołodziej, Mariusz Hoffmann

The Kraków Upland is situated on the Silesian-Kraków Homocline built up of the Triassic, Jurassic and Cretaceous sedimentary rocks that dip gently to the NE and form a belt ca. 100 km long and 20 km wide on average (Figs 1, 2).

Middle Jurassic

Marine transgression began in the Kraków region in the latest Bathonian or earliest Callovian. The generalized section is characterized by small thickness (several dozen metres) and is clearly bipartite. The lower part consists of carbonate-free siliciclastic rocks passing upward into sandy limestone. Conversely, the upper part is strongly condensed (a dozen centimetres), with stratigraphic gaps in some sections, and it is composed of marls, limestones, ferruginous stromatolites, locally iron-ooidal limestones.

Sedimentary succession of the Callovian in the Kraków Upland documents progressive transgression on an island, or an archipelago of islands. The succession reflects a gradually deepening basin, decreasing supply of terrigenic components and increasing number of nektonic fossils. During the beginning of the transgression, facies distribution and strong variation in thickness resulted from topography of the basement. Conversely, lateral facies variation, variable thickness, presence of non-depositional surfaces, which characterizes the upper part of the succession dated to Middle and Upper Callovian, is interpreted as an effect of synsedimentary tectonic activity. Condensed deposits, with Fe-stromatolites, omission surfaces and traces of submarine erosion, were laid down on local horsts, whereas iron ooids, glaucony-rich marls and clays originated in intervening grabens which acted as submarine depressions. The non-deposition and condensation probably reflects a widespread crisis of the carbonate sedimentation at the turn of Callovian and Oxfordian. In this case, Jurassic of the Kraków region shows many similarities with the Middle Jurassic and Middle Jurassic–Late Jurassic transition successions known from the Peri-Tethys and northern margin of Tethys.

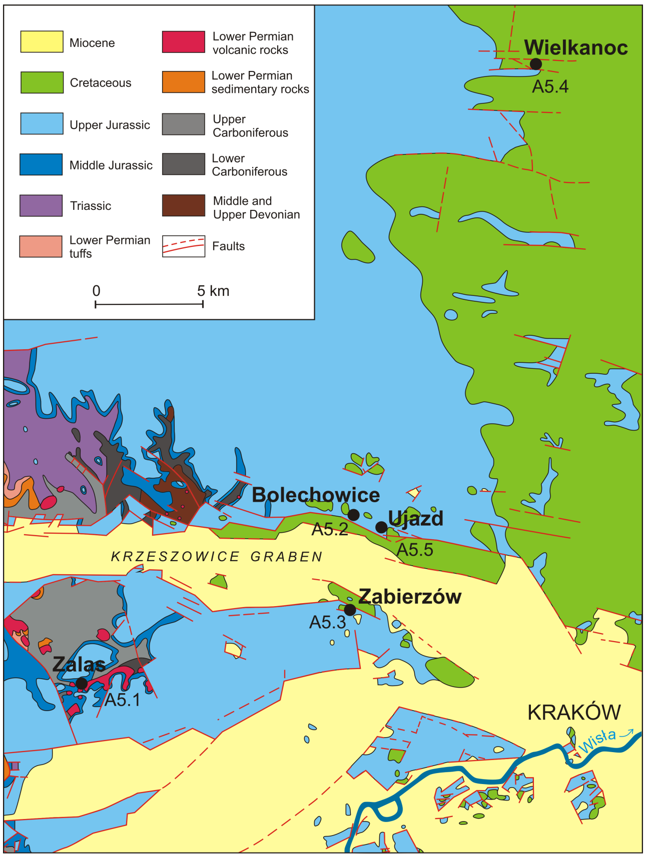

Fig. 2. Simplified geological map of Kraków region (after Gradziński, 2009; Kaziuk and Lewandowski, 1978) and field trip stop locations (A5.1-5)

Upper Jurassic

The Upper Jurassic rocks of the Kraków region are usually underlain by Callovian strata and, locally, by differentiated Palaeozoic substratum. The maximum thickness of the preserved Upper Jurassic strata is ca. 250 m (Fig. 3) in the eastern part of the region and it gradually diminishes to the west.

The Upper Jurassic carbonates of the Kraków Upland are Oxfordian and Kimmeridgian in age and they reveal high facies diversity. The main facies are: bedded facies, massive facies and sediments of lithologically variable gravity flows. The most spectacular landforms typical of the Kraków Upland landscape are built of the massive facies. There occur numerous sponge-microbial, microbial-sponge and microbial carbonate buildups and their complexes. The central parts of vast depressions between the carbonate buildups were presumably the sedimentary environment of a bedded facies. In the Late Jurassic, the area of present Kraków Upland was placed on a shelf of an epicontinental sea that bordered the Tethys Ocean on the north. The shelf contained elevations, the origin of which was related to local differentiation in subsidence between areas underlain and those not underlain by

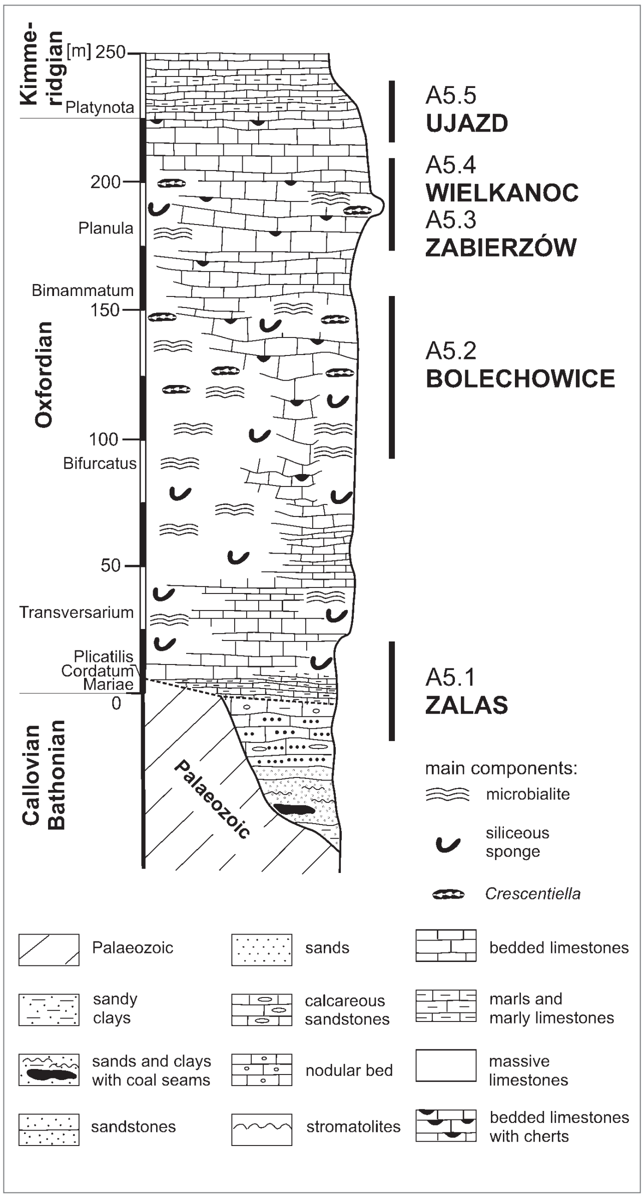

Fig. 3. Sequence of the Middle and Upper Jurassic strata in the Kraków region (after Krajewski *et al.*, 2011; modified)

Permian intrusions in the Palaeozoic basement. These elevations became colonised by microbialites and benthic fauna, mostly siliceous sponges, which initiated aggradational growth of the carbonate buildups, later merged into complexes by lateral growth.

The presence of neptunian dykes cutting through the Jurassic strata indicates activity of Late Jurassic synsedimentary tectonics in the Kraków region. Differentiated relief of the top of the Palaeozoic substratum, intensive Middle and Late Jurassic synsedimentary tectonics and local aggradational growth of carbonate buildups, all contributed to strong local vertical and lateral variability of the Upper Jurassic sediments in the Kraków region. Moreover, this picture became disturbed by differential compaction and subsequent Cretaceous and mostly Cenozoic faulting. As far as lithologic development is concerned, the Upper Jurassic sediments represent: bedded facies, massive facies, and lithologically variable sediment-gravity flows.

Bedded facies

The Upper Jurassic section begins with a series of thin-bedded marls and alternating calcareous-marly strata with abundant benthic fauna of Early and early Middle Oxfordian age (A5.1 Zalas). These strata pass upwards into a strongly differentiated limestone complex. Sediments of the bedded facies of the lower Middle Oxfordian represent thin- to medium-bedded platy-like limestones. Compared to the classical platy limestones of the Sohlnhofen-type, they are typified by a much higher share of detrital components and the lack of lithographic varieties. These strata are locally interbedded with marls and calciturbidites. The upper Middle Oxfordian and Upper Oxfordian section is dominated by thick-bedded limestones with flints, developed as microbial-sponge biostromes. Pelitic and chalky limestones occur locally. The topmost part of the Upper Jurassic section is composed of bedded limestone-marly strata, mostly known from borehole logs.

Massive facies

Deposits of the massive facies in the Kraków region are strongly diversified. These facies are represented by various types of carbonate buildups, as well as by olistoliths derived from the latter and present within gravity flow deposits. Carbonate buildups started to develop at the turn of the Early and Middle Oxfordian. The initial, small-size sponge-microbial low-relief carbonate buildups represent so-called loose bioherms (A5.1 Zalas). Following carbonate sedimentation, intensive aggraded carbonate buildups of laminar and reticulate rigid framework. Small, low-relief carbonate mud mounds turned with time into microbial-sponge segment reefs with laminar framework, filled frame reefs with initial reticulate rigid framework (A5.2 Bolechowice), which, in turn, became later replaced by open-frame reefs with well-developed reticulate rigid framework (A5.3 Zabierzów, A5.4 Wielkanoc). Development of carbonate buildups attained its climax at the turn of the Middle and Late Oxfordian, when intensive growth of such structures was accompanied by development of spectacular open-frame *Crescentiella*-reefs (A5.3

Zabierzów). Owing to lateral growth, carbonate buildups formed large complexes of distinct relief, underlined by locally differentiated subsidence and intensive synsedimentary tectonics. Carbonate buildups started to disappear at the turn of the Oxfordian and Early Kimmeridgian and the sea bottom relief became partly smoothed.

The Upper Jurassic sequence locally includes segment reefs (so called pseudonodular limestones), which reflect either initial stages of development of the rigid framework in carbonate buildups or periods when reticular framework vanished and became replaced by laminar framework. These deposits form nest-bodies within massive limestones and occur locally in marginal parts of carbonate buildups. The present-day features of segment reefs (A5.1 Zalas) are interpreted as a result of complex diagenetic processes, including first of all mechanical and chemical compaction, which proceeded in the inhomogeneous sediment of a delicate rigid skeleton of the laminar framework type (A5.1 Zalas). Stromatactis and stromatactis-like cavities are present in Upper Jurassic filled-frame and open-space reefs (A5.1 Zalas, A5.3 Zabierzów, and A5.4 Wielkanoc), whose origin and age are debatable.

Sediments of gravity flows

Sediments of gravity flows are common in the entire section of the Upper Jurassic, being particularly abundant at the turn of the Oxfordian and Kimmeridgian (A5.5 Ujazd). These are mostly grain-flow and nodular-mudflow sediments, as well as calciturbidites and tempestites. Their occurrence is associated with temporary worsening of the conditions favouring growth of carbonate buildups (initial drowning) and coeval active synsedimentary tectonics.

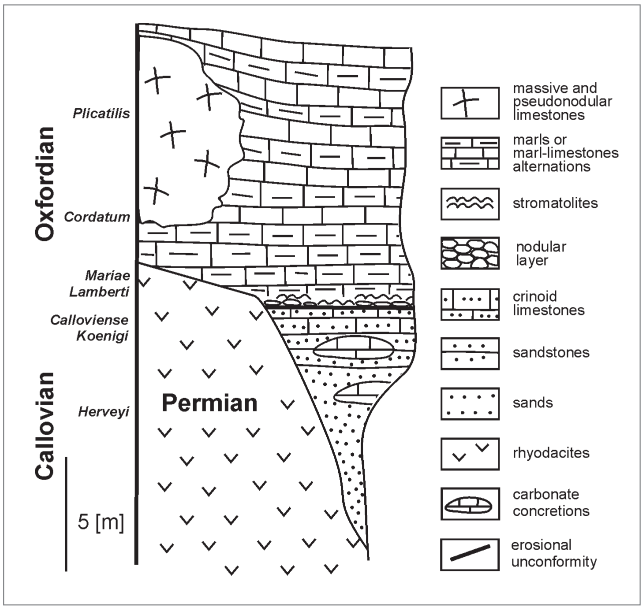

Fig. 4. Simplified section of the Callovian and Lower and Middle Oxfordian at Zalas (after Matyszkiewicz *et al.*, 2007a; modified).

Stop descriptions

A5.1 Zalas. Middle Jurassic transgressive deposits and Upper Jurassic microbial-sponge carbonate buildups in Zalas quarry

A busy active quarry; visits must be arranged with management. (50°05′ N, 19°38′40″ E)

Leaders: Mariusz Hoffmann, Alicja Kochman, Bogusław Kołodziej, Jacek Matyszkiewicz

Zalas quarry is located on the Tęczynek Horst, a complex elevation south of the Krzeszowice Graben (Figs 1, 2). Exploited in the quarry are Early Permian subvolcanic rhyodacitic porphyries intruded into Lower Carboniferous fine-grained siliciclastics. Sedimentary cover shows a succession of Callovian deposits discordantly overlying eroded and uneven Permian substrate. Above, there are Lower and Middle Oxfordian marls and limestones (Figs 3, 4). Stratigraphy of the Callovian and Oxfordian in Zalas is well established by ammonites, studied since the 19th century (Giżejewska and Wieczorek, 1976; Matyja and Tarkowski, 1981; Tarkowski, 1989; Matyja, 2006).

Callovian succession

Lower Callovian siliciclastics (Herveyi Zone). Sands, subordinately sandstones with patchy calcite cement and fine gravel quartz conglomerates (*a* and *b* in Fig. 5A) cover the substrate built of Permian ryodacites. These deposits are up to few meters thick and locally absent. Spheroidal blocks of ryodacites and silicified wood may be observed. Marine macrofauna, relatively common in some horizons, includes mostly bivalves, occasionally gastropods, brachiopods, colonial platy corals, ammonites and nautiloids. Large ammonites of the genus *Macrocephalites* prove the earliest Callovian age. Sands, sandstones, rarely conglomerates from the lower part of the Lower Callovian, were deposited in a near-shore environment. The presence of spheroidal blocks of ryodacites was interpreted earlier as an evidence of high energy at

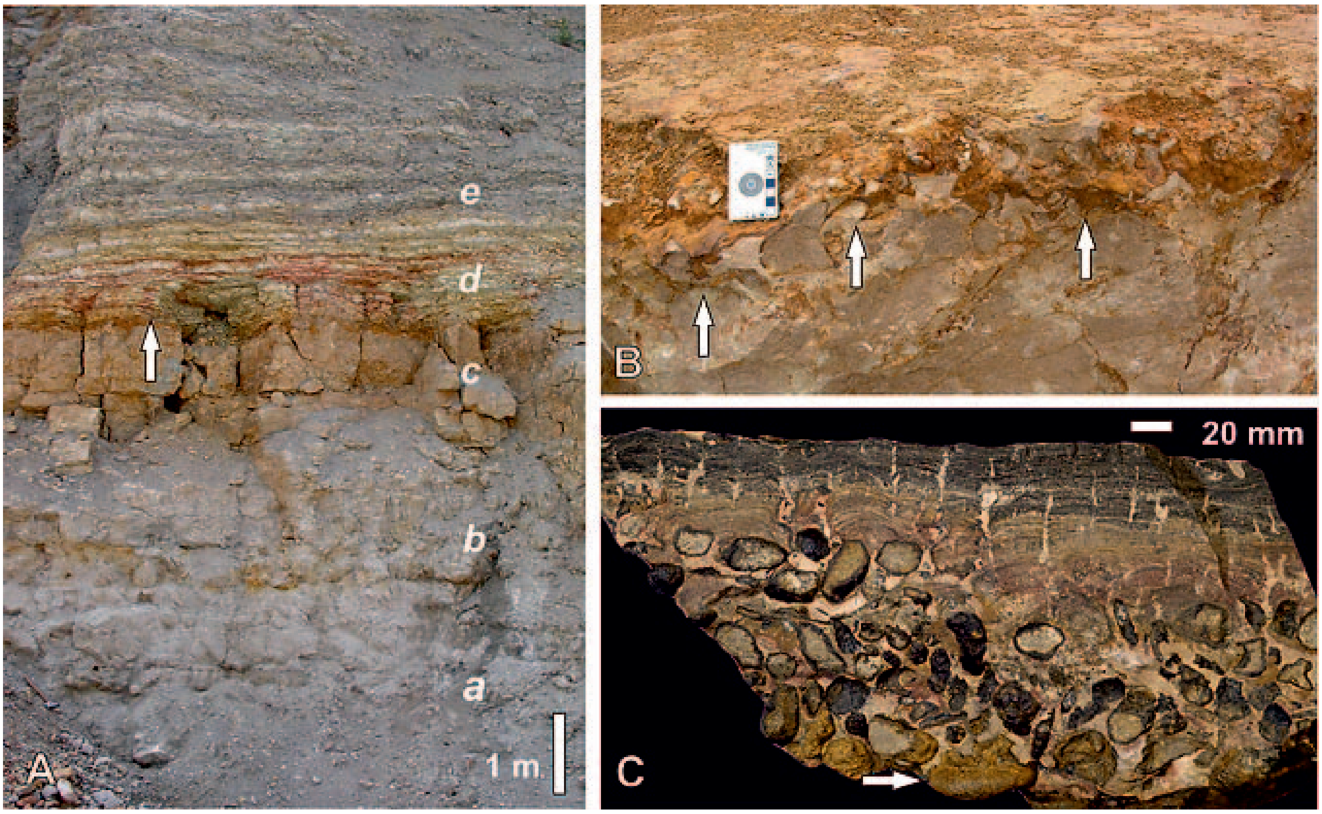

Fig. 5. Callovian and Lower Oxfordian at Zalas. **A.** *a* – Lower Callovian poorly lithified sands; *b* – sandstones; *c* – Lower Callovian sandy crinoid limestones; arrow indicates their truncated surface (a type of hardground); *d* – Upper Callovian condensed deposists (thin Fe-stromatolite, Fe-oncoids), and uppermost Callovian/lowermost Oxfordian pink limestones; *d* – Lower Oxfordian grey marls intercalated with limestones. **B.** Thin Fe-stromatolite covering truncated surface of sandy crinoidal limestones showing nodular structure (arrows). **C.** Fe-stromatolite and Fe-oncoids (clasts of crinoid limestones with thin, black Fe-crust); arrow indicates ammonite shell (coll. J. Wieczorek, Geological Museum, Institute of Geological Sciences, Jagiellonian University).

a near-shore cliff (Dżułyński, 1950), and recently as the result of corestone weathering of the Permian substrate (Matyja, 2006).

Lower Callovian sandy limestones (Koenigi Zone, in places Calloviense Zone). Subsequently, in the Lower Callovian succession, proportion of terrigenous components decreases and sandstones become more calcareous. The upper part of the Lower Callovian is developed as sandy crinoid limestones (the crinoid plates are hardly recognizable with a naked eye) – ca. 1.5 m in thickness – with horizons rich in bivalves, brachiopods, crinoid plates, less commonly echinoids, solitary corals and other benthic fauna (*c* in Fig. 5A, Fig. 5B). Ammonites, belemnites and nautiloids are less common. Sandy crinoid limestones were interpreted by Giżejewska and Wieczorek (1976) as deposited in a shallow, but sublitoral environment. The surprisingly high diversity of encrusters on the large bivalve *Ctenostreon*, higher than in Callovian tropical reefs, is interpreted by Zatoń *et al.* (2011) as the result of a deeper, less turbulent environment, the lack of salinity changes and lower sedimentation rate. The nodular structure at the top of crinoid limestones (Fig. 5B) is possibly related with activity of burrowing organisms, suggesting a low sedimentation rate which favoured early marine lithification (Giżejewska and Wieczorek, 1976; Wieczorek, 1982). The discontinuity surface at the topmost part of nodular limestones is a specific type of hardground (Fig. 4B), which resulted both from early lithification, submarine erosion and corrosion.

Uppermost Callovian condensed deposits. Ammonite studies revealed a stratigraphic gap embracing the Middle Callovian (Jason Zone and bulk of the Coronatum Zone; Giżejewska and Wieczorek, 1976; Matyja, 2006). This evidences prolonged non-deposition, erosion and reworking of underlying crinoid limestones. The truncated surface of crinoid limestones is usually covered by reddish or brownish Fe-stromatolites (but with significant participation of calcium carbonate), locally up to 40 cm thick (Fig. 5C; Giżejewska and Wieczorek, 1976). Inferred environmental factors favouring development

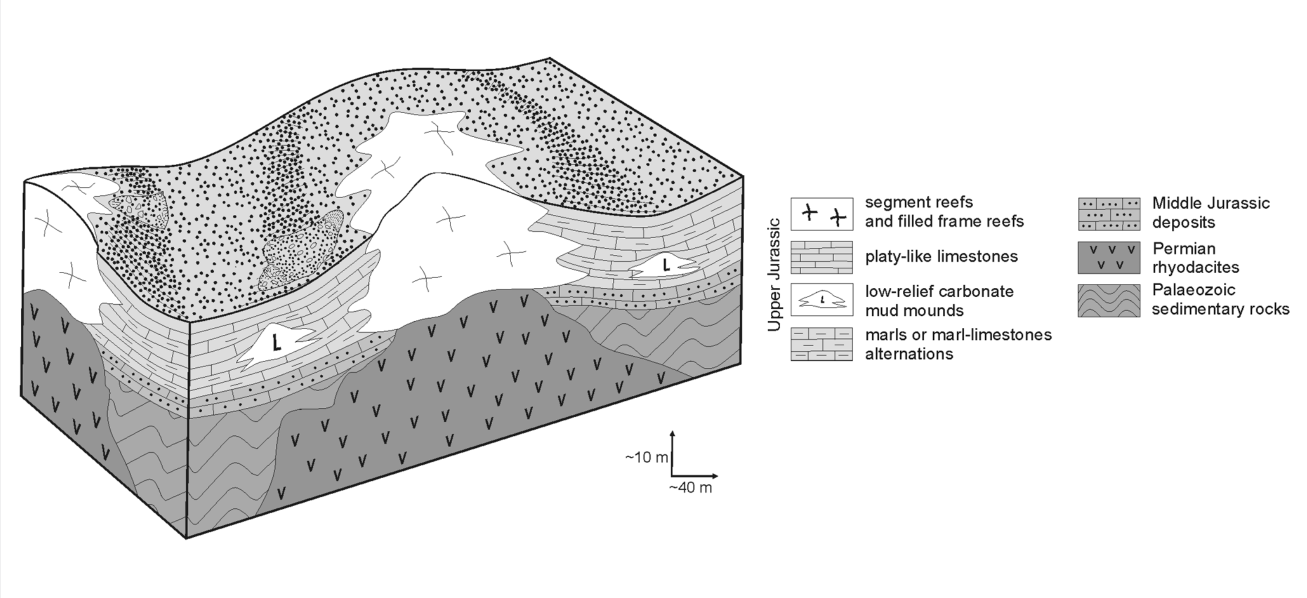

Fig. 6. Carbonate buildups at Zalas at the beginning of the Middle Oxfordian (after Matyszkiewicz *et al*., 2012; modified).

of stromatolites include: hard substrate (hardground), a low sedimentation rate and the lack (or low activity) of burrowing organisms. Stromatolites from Zalas and other sites in the Kraków region formed on submarine swells created by synsedimentary tectonics (Giżejewska and Wieczorek, 1976; Wieczorek, 1982).

Specific oncoids occur below, within and above the stromatolite in pinkish marlstones (Fig. 5B). The oncoids consist of thin Fe, Mn lustrous cortex which coats pebbles of crinoid or pink marlstones and limestones present at the Callovian and the Oxfordian boundary (*d* in Fig. 5A). In the lowermost part of the Oxfordian (Mariae Zone), redeposited ammonites from the uppermost Callovian may be present (Giżejewska and Wieczorek, 1976). Locally, the Oxfordian marls lie directly on Permian ryodacites (Matyszkiewicz *et al*., 2007a).

Oxfordian succession

On a rounded top of Permian rhyodacites, showing height differences of almost 10 metres, with overlapping unconformity lie Middle and Upper Jurassic deposits (Figs 2, 6). Above the stromatolite, which locally covers the rhyodacites top, lie marls and marl-limestone alternations rich in calcified siliceous sponges and other nektonic fauna. These deposits represent Lower Oxfordian and lower Middle Oxfordian (Tarkowski, 1989; Matyja, 2006). They include initial carbonate buildups (so called loose bioherms, cf. Trammer, 1982, 1985) – low-relief carbonate

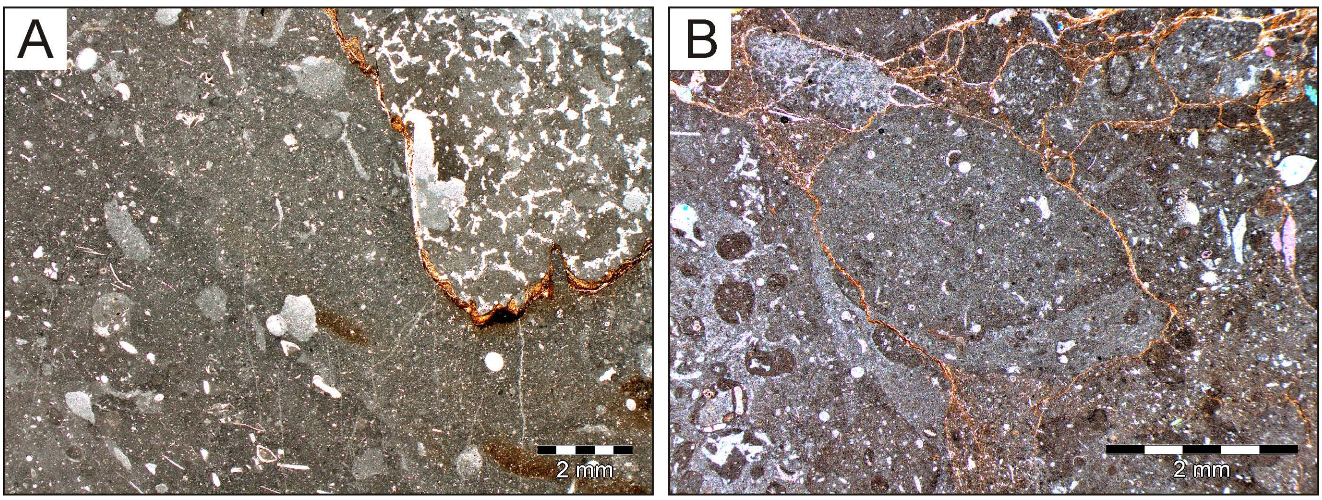

Fig. 7. Microfacies of the low-relief carbonate mud mound and segment reef from Zalas. **A.** Borings within pure leiolite. On the right, calcified siliceous sponge separated from pure leiolites by a stylolite lined by Fe-oxides. Low-relief carbonate mud mound. **B.** Nodules of clotted leiolites separated from fine-grained matrix by a stylolite filled with ferruginous substance. Segment reef.

mud mounds, several metres in diametre. The low-relief carbonate mud mounds are upsection replaced by carbonate buildups more than ten metres high, among which segment reefs and filled-frame reefs can be distinguished (Matyszkiewicz *et al*., 2012; terminology after Riding, 2002). These types of carbonate buildups differ macroscopically and in development of microbialites, which are their main component.

Low-relief carbonate buildups are composed of limestone nodules, a dozen or so centimeters in diameter, residing in marly groundmass. The main macroscopic components of these buildups are dish-shaped calcified siliceous sponges Lithistida (cf. Trammer, 1982, 1985), which appear mainly in life positions. Ammonites, belemnites, brachiopods, bivalves and gastropods are also present. Microbialites observed in limestone nodules are formed as pure, clotted, and sometimes as layered leiolites (Matyszkiewicz *et al*., 2012; terminology after Schmid, 1996). They show numerous penetrations filled with internal sediment (Fig. 7A). Low-relief carbonate buildups were formed in an environment with moderate water energy and low sedimentation rate, but with high nutrient availability (Matyszkiewicz *et al*., 2012), which is confirmed by abundant calcareous nannoplankton dominated by *Watznaueria britanica* in the lowest Oxfordian marl deposits (Kędzierski, 2001).

Towards the top of the section, low-relief carbonate mud mounds turn into segment reefs (so-called pseudonodular limestones; cf. Dżułyński, 1952; Matyszkiewicz, 1994) and more than ten metres-high, complex filled-frame reefs (Matyszkiewicz *et al*., 2012) with abundant fauna consisting of bryozoa, brachiopods, bivalves, echinoderms, ammonites, solitary corals and gastropods. Numerous discontinuities, enhanced by several centimetres thick layers of conglomerates, pink-red or grey-green, can be distinguished in these two types of carbonate buildups.

Segment reefs are composed of rounded nodules (Fig. 7B), which tend to disintegrate into grains with rounded edges (Dżułyński, 1952; Matyszkiewicz, 1994; Matyszkiewicz *et al*., 2012). Their main components are microbialites, dish-shaped siliceous sponges Lithistida and Hexactinellida, but brachiopods, bryozoans, ostracods, polychaetes can also be found.

Filled-frame reefs are formed as tight massive limestones, with microbialites as the main component; secondarily occurs fauna similar to that in segment reefs (Matyszkiewicz *et al*., 2012). In those parts of filled-frame reefs that are formed as very tight massive limestone, stromatactis, stromatactis cavities and stromatactis-like cavities (terminology after Matyszkiewicz, 1997a) are locally observed. Stromatactis form a characteristic sparitic network. Stromatactis cavities and stromatactis-like cavities are filled with internal sediment in their lower part, and in the upper – with several generations of calcite cements (Fig. 8A, B). Isolated stromatactis-like cavities have diameters exceeding 1 cm and uneven, digitate roofs. Internal sediment is formed as micropeloidal

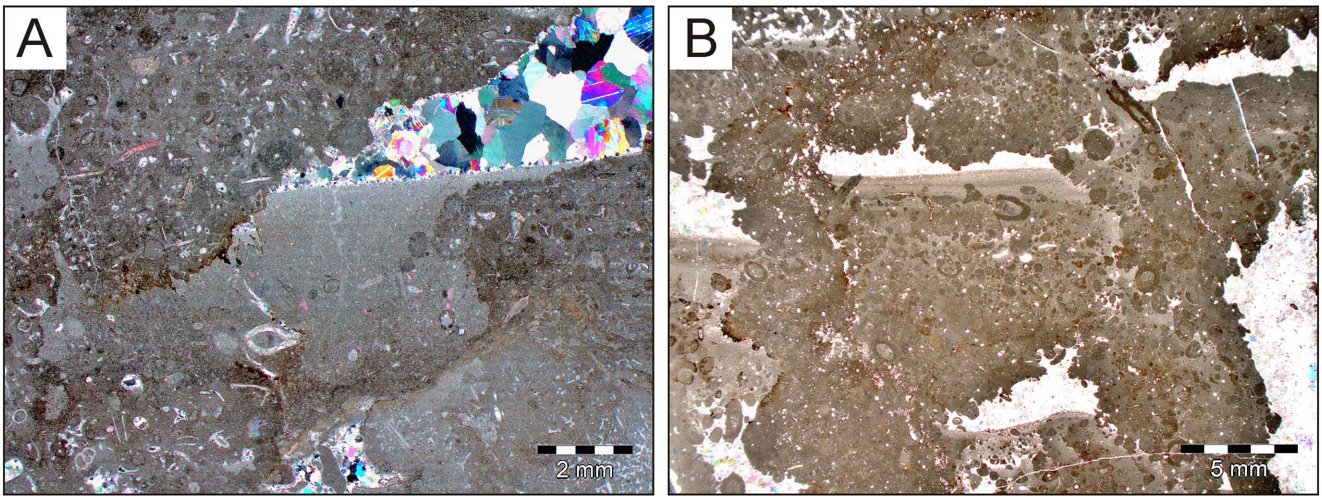

Fig. 8. Microfacies of the filled frame reef from Zalas. **A.** Stromatactis cavity. Internal sediment below the cement represents mudstone with single, rounded grains, and it is separated from the host rock by a stylolite locally lined by Fe-oxides. Layered thrombolite on the right. **B.** Stromatactis cavities filled with internal sediment in their lower part, and in the upper – with several generations of calcite cements. Internal sediment in the upper part, at the contact with cement, is represented by micropeloidal packstone and micropeloidal stromatolite. In the lower part internal sediment is developed as mudstone-wackestone with larger grains.

packstone, micropeloidal stromatolite or fine-grained mudstone-wackestone with fragments of undistinguishable bioclasts or small rounded grains in the upper part, which are in contact with cement. Sometimes the whole internal sediment is separated from host-rock by stylolites (Fig. 8A). Locally, isolated stromatactis-like cavities are filled with granular quartz. Segment reefs and filled-frame reefs were formed in an environment with slightly higher water energy, lower sedimentation rate and nutrient availability than the low-relief carbonate mud mounds (Matyszkiewicz *et al*., 2012).

Various traces of mechanical and chemical compaction of any severity grade are observed in all types of carbonate buildups from the Zalas quarry (Fig. 7A, B). Susceptibility to mechanical compaction of the deposits depends mostly on early-diagenetic cementation and appearance of rigid framework, which can show diverse formations, such as reticulate or laminar rigid framework (cf. Pratt, 1982). In turn, the development of pressure-dissolution connected with chemical compaction depends on clay content in the deposits. During burial diagenesis in limestones with low clay content, stylolites widely develop, whereas in rocks with bigger clay content, pressure-dissolution structures are practically absent. Low-relief carbonate mud mounds with high clay content, in which rigid framework developed only in separated nodules, were subject to significant mechanical compaction, but to a lesser extent than the fine-grained bedded marl-limestone alternations surrounding them. Given the substantial clay content, during burial diagenesis, pressure-dissolution phenomena did not develop in these deposits.

In segment reefs, in which initial laminar rigid framework developed (Matyszkiewicz, 1994, 1997b; Kochman and Matyszkiewicz, 2013), mechanical compaction processes occurred to a lesser extent than in low-relief carbonate mud mounds. Smaller clay content in the deposits allowed early-diagenetic cementation of laminar framework and intense pressure dissolution during burial diagenesis. In filled frame reefs with well-developed reticulate rigid framework, mechanical compaction was minimal due to intensive early-diagenetic cementation (Kochman and Matyszkiewicz, 2013), whereas chemical compaction occurred only occasionally.

In area around Zalas, and in the quarry, many faults are observed. A part of them were probably active during Middle and Late Jurassic, but the main faulting phase took place in Cenozoic. Some faults in the Zalas quarry are mineralised and contain chalcopiryte, piryte, iodargyrite, covelline, galena, native bismuth, malachite, cuprite, Fe- and Mn-oxides, Cu-sulfates and barite (Gołębiowska *et al*., 2010).

Installation of the first low-relief carbonate mud mounds was probably connected with appearance of sea

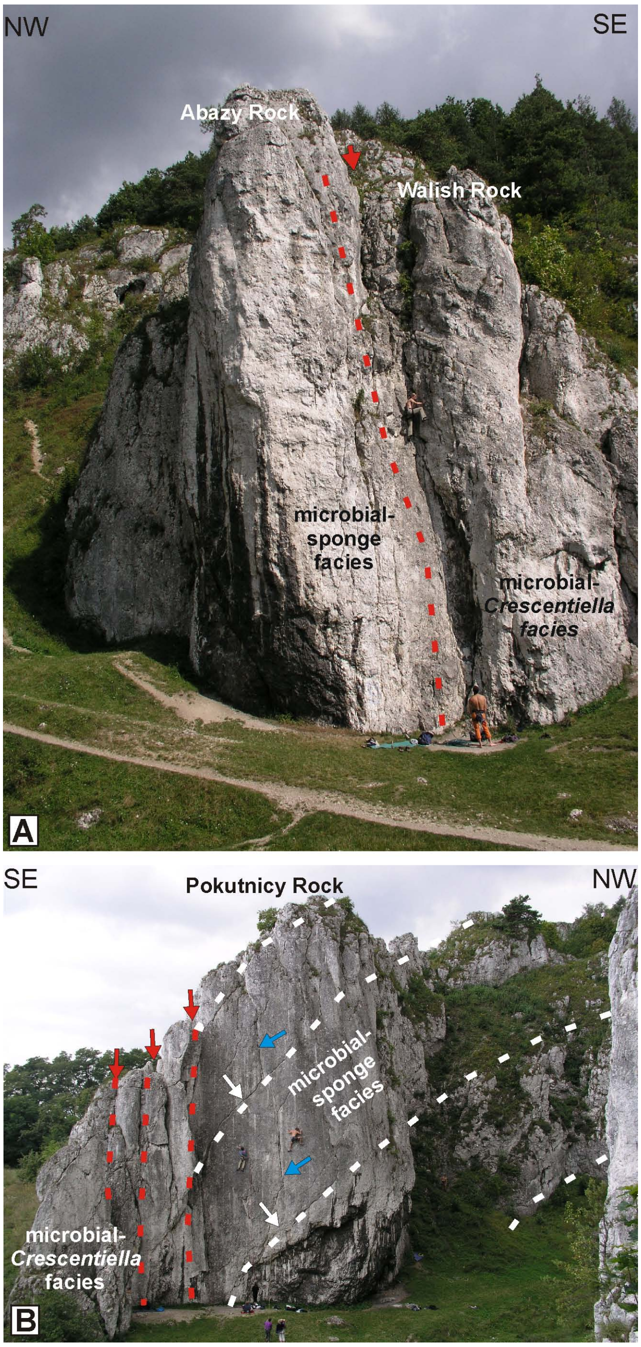

Fig. 9. Facies of Bolechowicka Valley. **A.** Southern part of Bolechowicka Valley, east slope. Abazy and Walish crags separated by a fault surface (red line). The fault surface separates microbial-sponge facies (boundstone) from the microbial-*Crescentiella* facies (grainstone-rudstone). **B.** Southern part of Bolechowicka Valley, west slope. Filar Pokutników located within the near-fault flexure (with line and arrows) that passes southwards into brittle deformation with faults (red lines and arrows). Vertical surfaces are joints (blue arrows).

bottom elevations related to Palaeozoic structures and of active synsedimentary tectonics, also generating submarine gravity flows (Trammer, 1985; Matyszkiewicz *et al*., 2006b; 2012). First initial low-relief carbonate mud mounds became transformed into segment and filled-frame reefs, in which microbialites formed a distinct rigid framework. Layers of conglomerates observed in the segment and filled-frame reefs mirror periods of growth inhibition of these carbonate buildups (so-called incipient drowning; cf. Bice and Stewart, 1990). Geochemical research results, mainly negative Ce anomalies, and distinct enrichment in HREE of microbialites in the Upper Jurassic carbonate buildups from the Kraków region (Matyszkiewicz *et al*., 2012), show that seawater on the whole Late Jurassic shelf in the Kraków region was generally well-oxygenated and corresponded with contemporary seawater in terms of alkalinity (cf. Olivier and Boyet, 2006; Olivier *et al*., 2007). Thus, the formation of microbialites that built the diverse carbonate buildups was affected mainly by local sedimentation environment not related to distinct changes in chemical composition of seawater. Therefore, the development of microbialites as the main component of carbonate buildups was controlled by contents of dissolved or fine-grained nutrients suspended in water, sedimentation rate and energy of sedimentation environment (Matyszkiewicz *et al*., 2012).

A5.2 Bolechowice. Upper Oxfordian facies and microfacies in Bolechowicka Valley and problems with facies relationships in a fault zone

Southern part of Bolechowicka Valley (50°09′09″ N, 19°47′06″ E)

Leader: Marcin Krajewski

Location and geological setting

Bolechowicka Valley is located at the northern margin of the Krzeszowice Graben (Fig. 2). In this area, the faults separate the Ojców Block, the main part of the Kraków Upland, from the Krzeszowice Graben. Numerous exposures of Jurassic rocks can be examined near Bolechowice (Fig. 9). The exposed rocks represent sedimentary sequence located from 100 to 150 m above the bottom surface of the Oxfordian succession (Fig. 3). Several outcrops in and near Bolechowicka Valley were studied in terms of detailed microfacies analysis (Matyszkiewicz and Krajewski, 1996). As a result, numerous microfacies were identified and classified in two groups of facies: microbial-sponge facies, and microbial-*Crescentiella* facies. From stratigraphic point of view, all these facies belong to the Upper Oxfordian (Fig. 3). Precisely, numerous ammonites found in the area indicate that the massive limestones represent the Upper Bifurcatus Zone

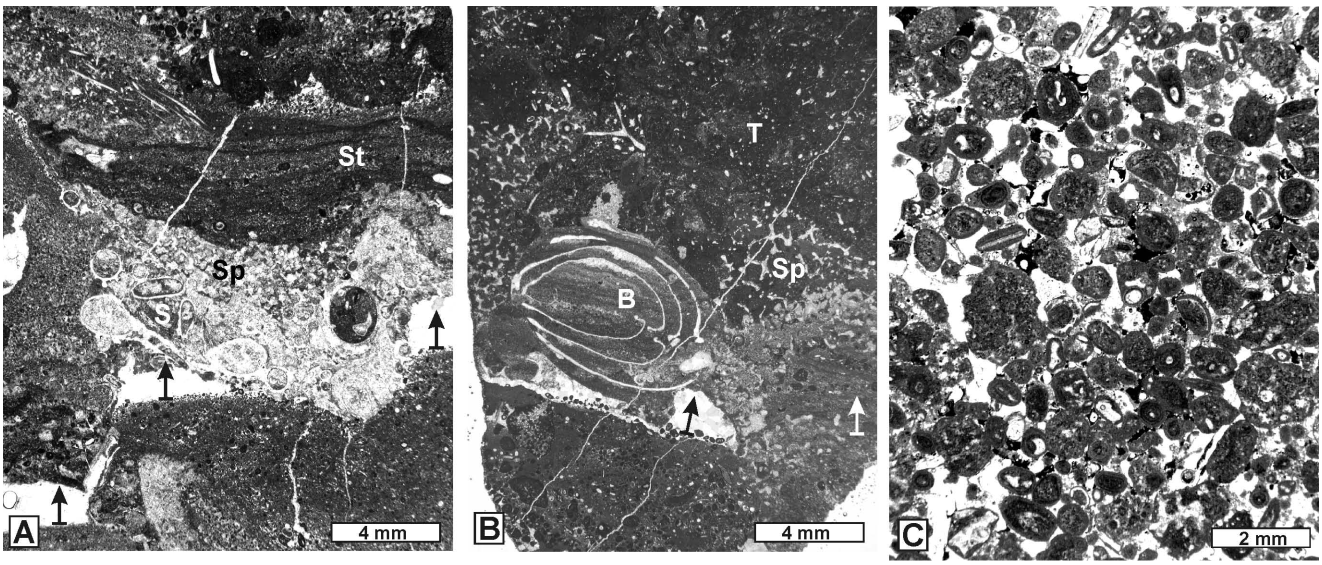

Fig. 10. Microfacies observed in massive limestones of Bolechowicka Valley. **A.** Microbial-sponge boundstone. Calcified seliceous sponge (Sp), stromatolite (St) and serpulids (S) visibele in the central part. The presence of rigid framework is documented by growth cavities with geopetal filling indicating orginal positionof the top. **B.** Microbial-sponge boundstone. Calcified siliceous sponge (Sp) displaying an extensive boring (B) with the shell of the boring organism. Thrombolites are growing on the sponge. Black arrow indicates original top. The present position of the bottom-top direction is indicate by white arrow. **C.** Grainstone with numerous *Crescentiella*, small ooids, oncoids, aggregate grains and bioclast.

(Stenocycloides-Grossouvrei subzones; Krajewski, 2000; Krajewski and Matyszkiewicz, 2004; Ziółkowski, 2007b).

The limestone rocks, particularly that observed in the southern part of the valley, at the margin of the Krzeszowice Graben includes numerous tectonic discontinuities (Fig. 9). Two types were distinguished: vertical joint systems and pene-horizontal surfaces dipping to the east, as evident on the valley western slope. Studies revealed their tectonic origin (Matyszkiewicz and Krajewski, 1996).

Facies description and interpretation

The microbial-sponge facies can be encountered in most rocks of Bolechowicka Valley (Fig. 9). Dominant are microbial-sponge boundstones and bioclastic wackestones, packstones and grainstones (Matyszkiewicz and Krajewski, 1996). In biolithites, numerous growth caverns and borings point out to the presence of a rigid framework typical of reefs (Fig. 10A, B). Many cavities are geopetally filled, which enables us to determine deviation of their roofs from original positions. The framework is formed mainly by siliceous sponges (*Lithistida* and *Hexactinellida*) overgrown by microbialites, dominated by fine crusts of dense micrite, clotted thrombolites and peloidal stromatolites (e.g. Matyszkiewicz, *et al*., 2012; Fig. 10A, B). Commonly observed are brachiopods, echinoids, peloids, tuberoids and abundant fine bioclasts. Frequent are microencrusting organisms, particularly bryozoans, benthic foraminifers (*Nubecularia*, *Bullopora*) and serpulids. In the microbial-sponge facies, distinct transition is observed (cf. Matyszkiewicz, 1997b; Krajewski, 2000): up the sequence, the number of sponges decreases in favour of microbialites (mostly agglutinuating) and peloidal stromatolites. In the upper parts of microbial-sponge facies, large amounts of problematic microencruster *Crescentiella* appear (Matyszkiewicz, 1997b; Krajewski, 2000) and at a short distance the sediment changes to microbial-*Crescentiella* facies.

This facies is representative of most of rock complexes in the Kraków Upland and it records the main stage of reef development in this area (e.g. Matyszkiewicz, 1997b; Krajewski, 2000). The microbial-sponge facies is typical of the Oxfordian in the Kraków Upland and is widely distributed in the northern shelf of the Tethys Ocean (e.g. Leinfelder *et al*., 1996; Matyszkiewicz, 1997b). Most of the results demonstrate that the microbial-sponge facies developed mostly in a low-energy, nutrient-rich environment. Commonly observed microencrusters, mostly benthic microbial communities, serpulids, bryozoans and foraminifers, all indicate low-energy environment, low deposition rates and low terrigenous influx. Environment conditions of this facies are usually interpreted as sea level high-stand mid-ramp, above the storm wave base.

The microbial-*Crescentiella* facies is observed mostly in exposures located in the southern part of the valley (Fig. 9). Two microfacies varieties are observed: microbial-*Crescentiella* boundstones and *Crescentiella*-bioclastic grainstones-rudstones (Fig. 10C). The microproblematica *Crescentiella* (*Tubiphytes* in older literature) build individual or colonial forms in which individual forms are often connected by cyanophycean crusts. Apart from *Crescentiella,* crushed bioclasts: bivalves shells, bryozoans, calcareous sponges, gastropods and echinoderms are common in the coarse grainstones-rudstones. They are accompanied by fine bioclasts, peloids, aggregate grains, intraclasts, oncoids and ooids (Fig. 10C).

The microbial-*Crescentiella* facies represents the mid-ramp setting. The presence of phototrophic *Crescentiella* and detrites indicates paleodephts between normal and storm wave bases (Leinfelder *et al*., 1996; Matyszkiewicz, 1997b; Krajewski, 2000). The limestones rich in microproblematica *Crescentiella,* which illustrate symbiosis between nubecularid foraminifera and cyanophyceans (Senowbari-Daryan *et al*., 2008), were included to the do *Tubiphytes-Terebella* association (e.g., Leinfelder *et al*., 1996). In this facies, common are coarse-grained sediments documenting an intensive reworking of material in the wave base zone (Krajewski, 2000). In grain-dominated sediments, one can observe coated grains pointing out to sedimentary conditions close to normal wave base. Transition from microbial-sponge to microbial-*Crescentiella* facies can be related to progressive shallowing of the basin in the Upper Oxfordian.

Problems with facies interpretation in the fault zone

The exposures examined in the Bolechowicka Valley are located in a tectonic zone, which hampers the observations and interpretation of primary facies architecture and, consequently, may lead to misinterpretations (cf. Koszarski, 1995; Matyszkiewicz and Krajewski, 1996). The primary sedimentary sequence is here disturbed by numerous hinge faults belonging to tectonic megabreccia at the margin of the Krzeszowice Graben (Fig. 11). Fortunately, analogous and contemporaneous sedimentary sequences can be observed in the vicinity, in undisturbed parts of the Ojców Block (Krajewski, 2000), which enables us to reconstruct the primary sedimentary sequences of the Bolechowice area.

In reconstruction of primary facies architecture, particular attention must be paid to numerous tectonic discontinuities (Krokowski, 1984; Matyszkiewicz and Krajewski, 1996; Fig. 9). Basing on the analysis of geopetal infillings found in the rock-tower named ”Filar Pokutników” (Fig. 9B), it was concluded that rocks forming the southern part of Bolechowicka Valley were tilted by 30° from their primary position. The lack of substantial differences in lithology of rocks cut by discontinuities advocates the tectonic origin of these surfaces (Matyszkiewicz and Krajewski, 1996).

The vertical discontinuities cutting through the limestones are joints belonging to several joint systems (Fig. 9; Krokowski, 1984). In the southermost part of the valley, these discontinuities are presumably fault surfaces enlarged by karstic dissolution, genetically related to the broad tectonic zone that separates the Ojców Block from the Krzeszowice Graben. Some of these faults follow pre-existing joints. On the contrary, the discontinuities observed e.g., in Filar Pokutników, gently dip to the south and are genetically linked to shear surfaces in the fault-adjacent flexures developed at the northern margin of the Krzeszowice Graben (Fig. 11; Krokowski, 1984). Complicated facies relationships found in Bolechowicka Valley are, first of all, the effects of hinge faults and megabreccia zones developed in the tectonic zone separating the Ojców Block from the Krzeszowice Graben.

A5.3 Zabierzów Oxfordian microbial bioherm with exceptionally numerous microencruster *Crescentiella* (= "*Tubiphytes*") *morronensis* and common growth cavities and stromatactis-like cavities in Zabierzów

Zabierzów quarry, western part of the Zabierzów village, (50°06′49″ N, 19°47′12″ E)

Leaders: Ireneusz Felisiak, Jacek Matyszkiewicz

The abandoned limestone quarry is located in the western part of the Zabierzów village, 12 km west of Kraków center. Vast, east-west-trending depression north of the quarry is the Krzeszowice Graben (Fig. 12). The quarry was developed in the zone of fault megabreccia visible in the southern wall of the graben, along which it contacts the pre-Badenian horst of the Tenczynek Ridge (Felisiak, 1992). The quarry includes two major excavations: the lower, NE one with a pond and the upper, SW one; each corresponds to one of two small horsts built of the Oxfordian limestones. In the upper, SW part of the quarry, massive limestones predominate, belonging to a core of a buildup (see description below).

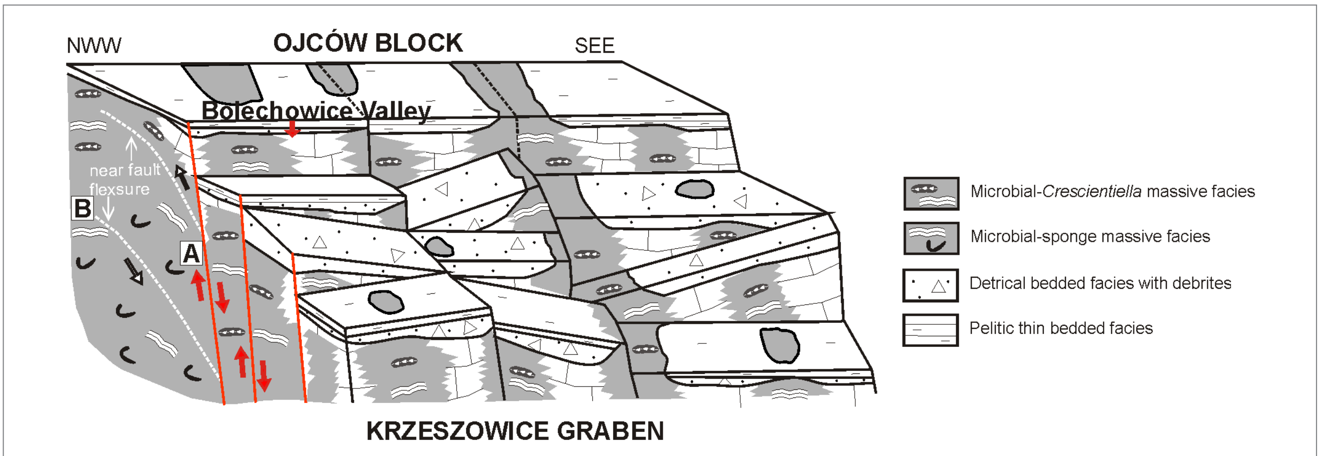

Fig. 11. Position of Bolechowicka Valley in the fault zone that separates the Ojców Block from the Krzeszowice Graben (after Matyszkiewicz and Krajewski, 1996; supplemented). Near-fault flexure passes southward into discontinuous deformations. The total vertical fault's displacement consists of numerous secondary faults, some of which are hinge faults. This caused dipping of sediments in various directions, accompanied by a fault-related megabreccia. A-B. Approximate location of outcrops presented in Fig. 9.

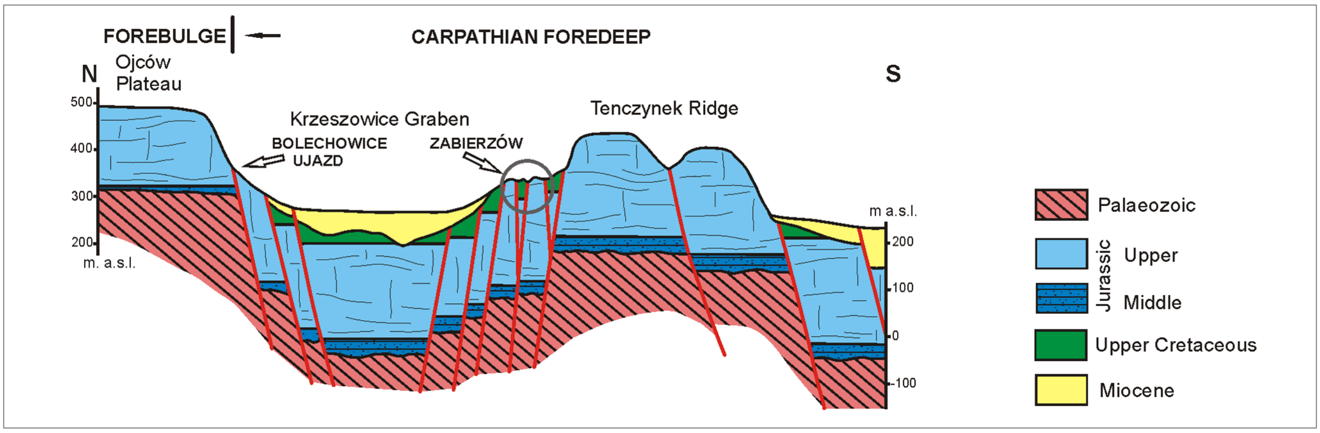

Fig. 12. Diagrammatic cross-section across the Krzeszowice Graben near Zabierzów.

The small graben which separates both horsts is filled with Cretaceous sediments. These rocks have not been quarried and recently form a morphological elevation seen as a NW-SE trending ridge. In the roadcut transversing the ridge we can observe the upper part of the Cretaceous succession – the Senonian marls. Their lowermost portion together with underlying Coniacian and Turonian limestones, as well as the contact surface with the Jurassic sediments are accessible in the upper parts of walls in both quarries.

The Oxfordian limestones are truncated by Cenomanian-Turonian abrasion platform with locally abundant borings (rock ground), which is covered by Upper Cretaceous sediments. Their succession starts with a thin layer of Turonian limestones (foraminifer-calcisphere wackestone/packstone with quartz pebbles, up to 65 cm thick; Jasionowski, 1995). Both layers are separated by a wavy surface of a soft-ground with scarce burrows. Flat, top surface of the Turonian sediments is a hard ground covered by the deep-water, phosphatic stromatolite, up to 4 cm thick (Golonka and Rajchel, 1972; Jasionowski, 1995), which represents the Late Turonian-Coniacian (after E. Machaniec, see Hoffmann *et al*., 2013). It is overlaid by marls grading up into white limestones and gaizes with interbeds of cherts and marls, 15 m thick.

The Upper Oxfordian *Crescentiella* reef with stromatactis-like cavities

The section of Upper Jurassic rocks (?*bimammatum*/*planula* zones; Fig. 3) in Zabierzów region (Fig. 13) is ca. 180 m thick, and the quarry exposes the uppermost part of this section (Matyszkiewicz, 1997a; Matyszkiewicz *et al*., 2012). The Upper Jurassic sediments are represented by massive limestones formed as microbial-

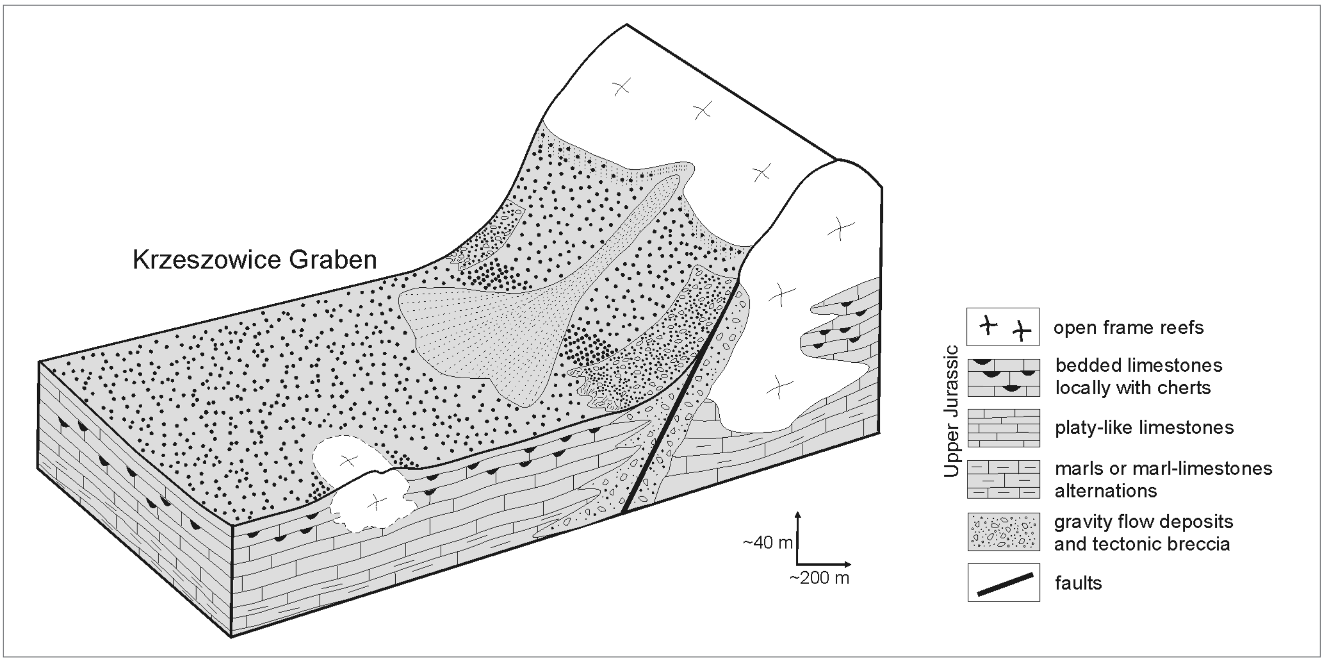

Fig. 13. Position of the open-frame reef at Zabierzów at the end of the Oxfordian (after Matyszkiewicz *et al*., 2012; modified).

sponge boundstone or locally as nest-filling grainstone. The massive limestones contain macroscopically visible abundant and diversified fauna of calcareous and siliceous sponges, serpulids, bivalves, brachiopods, gastropods, echinoids, crabs, and juvenile forms of ammonites. A carbonate buildup formed as an open-frame reef is exposed in the upper level of the quarry, on its SW wall. It represents the most advanced stage of development of the rigid framework (so-called reticulate rigid framework, cf. Pratt, 1982) among different types of microbial-sponge Upper Jurassic carbonate buildups in the Kraków region (Matyszkiewicz, 1997a; Matyszkiewicz *et al.*, 2012).

The most important components of the rigid framework of the microbial-sponge open-frame reef are numerous *Crescentiella morronensis* (cf. Senowbari-Daryan *et al.*, 2008). Microbialites are highly diversified. They are dominated by agglutinating stromatolites, micropeloidal stromatolites, pure leiolites and layered leiolites. Pure leiolites and layered leiolites compose massive, irregular envelopes that bind organisms building the framework of the open-frame reef and comprise abundant benthic fauna of bivalves, brachiopods, crabs, juvenile ammonites, serpulids, *Terebella* sp., bryozoans, siliceous and calcareous sponges and, first of all, *Crescentiella morronensis*.

The rocks bear frequent growth cavities, walls of which are encrusted with polychaetes. Moreover, in the central part of the open frame reef, numerous isolated stromatactis-like cavities about 2 cm high and several centimetres wide are observed (terminology after Matyszkiewicz, 1997a; Fig. 14A). The roofs of the stromatactis-like cavities are usually uneven and digitate, and the bottoms are smooth. In the upper part, stromatactis-like cavities are usually empty and their walls are covered by isopachous granular or dogtooth cement. Sometimes, the upper part contains blocky calcite or poikilotopic cements (Fig. 14B). In the lower part of the stromatactis-like cavities, internal sediment in the form of micropeloidal stromatolite with numerous thin laminae is observed. Some stromatactis-like cavities are filled with light green or yellow clay, which does not contain microfauna.

The open-frame reef from Zabierzów grew at a moderate energy of environment, low sedimentation rate, and moderate nutrient availability. Stromatactis-like cavities could have been formed as a result of: (i) almost synsedimentary internal erosion of weakly lithified parts of soft sediment, which fills spaces between fully lithified parts of rigid framework, caused by water turbulence connected with impact of gravity flows on the bedding (cf. Matyszkiewicz, 1993; Wallace, 1987), (ii) cavitation erosion of primary growth cavities during Late Jurassic regression or Late Cretaceous transgression (cf. Matyszkiewicz, 1997b), (iii) compressional and tensional stress of primary (e.g. growth cavities, shelter porosity) or secondary (e.g. dissolved aragonitic skeletons of corals) voids during early diagenesis, caused by multi-stage activity of faults (cf. Olchowy, 2011), or (iv) local dissolution and mineralization of limestones by hydrothermal solutions migrating along fault zones. The last two possibilities connect the formation of the stromatactis-like cavities with active fault tectonics that took place in the Zabierzów area during a period between at least Late Jurassic and Cenozoic time.

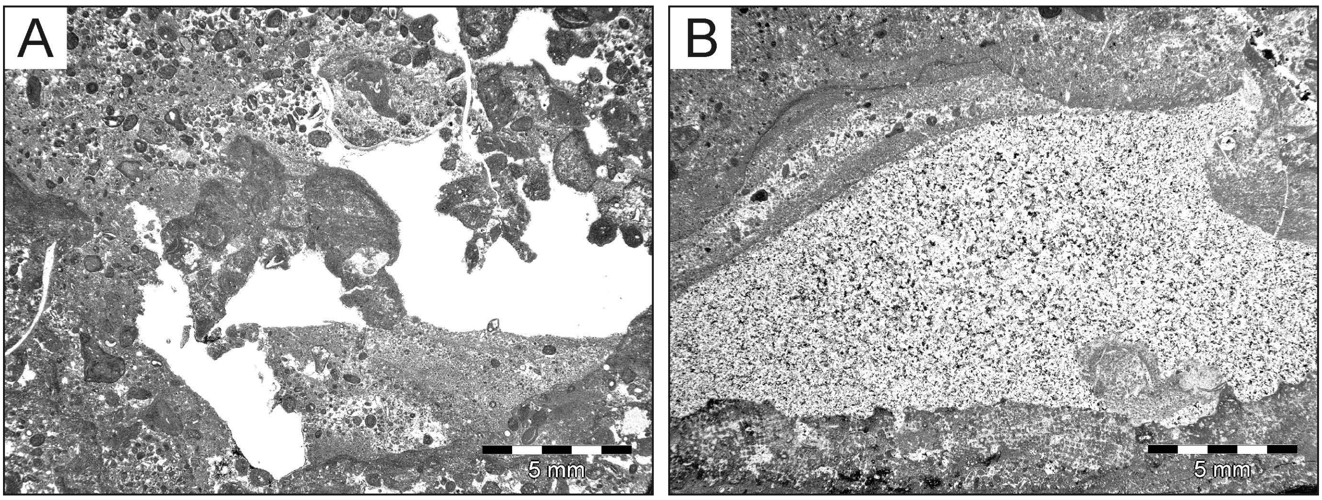

Fig. 14. Microfacies and stromatactis-like cavities in the open-frame reef at Zabierzów **A.** stromatactis-like cavity without internal sediment, partly filled in the uppermost part with greenish clay. **B.** stromatactis-like cavity completely filled with late diagenetic granular cement.

A5.4 Wielkanoc. The Uppermost Oxfordian massive limestones with stromatactis-like cavities; outcrop in Wielkanoc near Miechów

Western part of Wielkanoc village, right bank of the Gołczanka stream (50°20′17″ N, 19°54′31″ E)

Leader: Piotr Olchowy

The Wielkanoc Quarry is located in the eastern part of the Kraków-Częstochowa Upland, about 30 km north of Kraków (Fig. 2). The sub-Mesozoic basement of the Silesian-Kraków Homocline includes folded Paleozoic formations divided by the Kraków-Lubliniec Fault Zone into the Małopolska and the Upper Silesian blocks (Żaba, 1995, 1999; Buła *et al.*, 1997; Buła and Habryn 2008). The Wielkanoc Quarry is located in the western, marginal part of the Małopolska Block, about 7 km east of the Krzeszowice-Charsznica Fault.

The quarry is ca. 300 m long and 100 m wide. In its southeastern wall, we observe an about 15 m-thick succession of Upper Jurassic rocks (Oxfordian, *planula* Zone (Fig. 3), cf. Głazek and Wierzbowski, 1972) followed by an about 16 m-thick Upper Cretaceous sequence (Figs 15, 16). The top surface of the Upper Jurassic succession is an abrasion surface. The Upper Cretaceous sediments include Turonian sandy, sandy-organodetrital, organodetrital and pelitic limestones covered by Coniacian sandy-glauconitic limestones and Late Santonian marly-glauconitic limestones, and glauconitic marls (Olszewska-Nejbert, 2004; Olszewska-Nejbert and Świerczewska-Gładysz, 2009). The Upper Cretaceous strata are overlain by Quaternary loess, about 2 m thick.

Development of limestones in the Wielkanoc Quarry

The Upper Jurassic sediments from the Wielkanoc Quarry were described by Olchowy (2011). These are massive limestones with macroscopically visible, calcified, siliceous sponges up to 1.5 cm thick, serpules of diameters up to 0.5 cm, tuberoids up to 1 cm across, single ammonites and numerous stromatactis-like cavities (*sensu* Matyszkiewicz, 1997a). In the middle and lower parts of the massive limestones sequence, typical are numerous elongated pores, up to 2 cm long. Their transversal sections are commonly rounded and show diameters up to about 0.4 cm. Such pores occur as individuals or as clusters composed of several to a dozen of pores. In some pores, we observe partly dissolved cladophyllid corals. Locally, the massive limestones comprise lenses of granular bioclastic limestones built of irregular grains up to 3 mm across. The lenses of granular bioclastic limestones can be up to several tens of cm long and up to a dozen of cm thick but usually, their dimesions are much lower.

Under the microscope, the massive limestones are dominated by microbialites developed as laminated thrombolites and *Crescentiella*, up to 2 cm in diameter. Common are thrombolite-sponge associations and

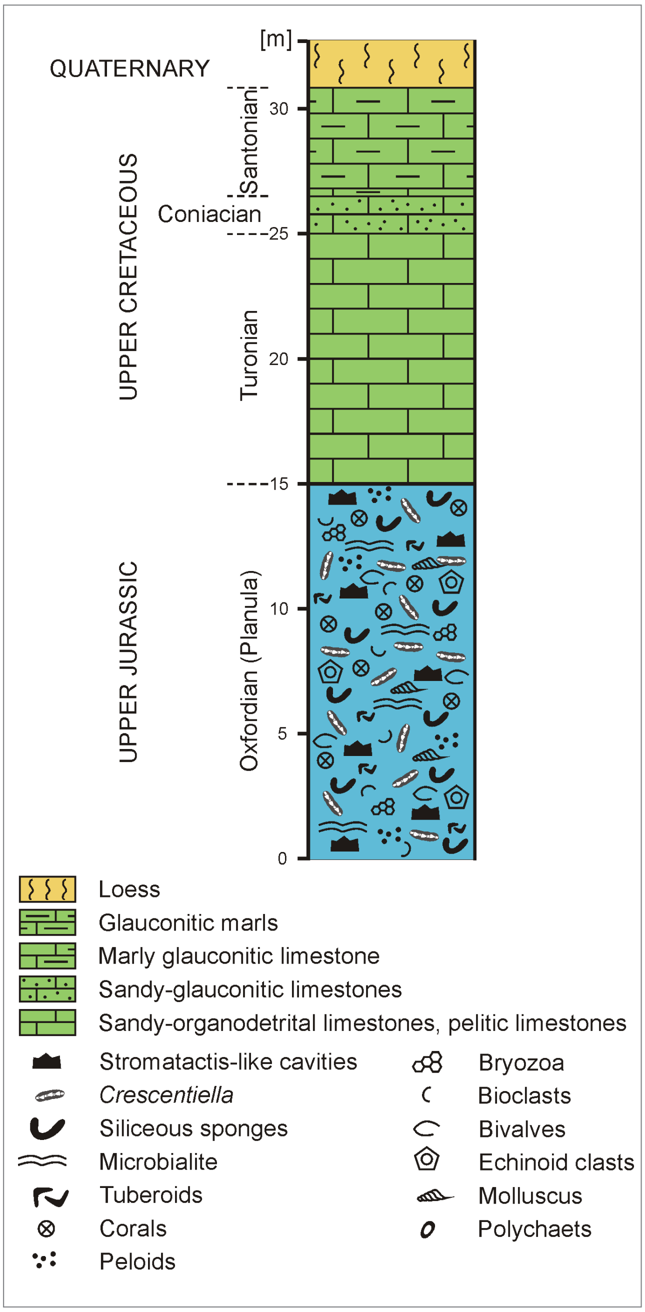

Fig. 15. Lithostratigraphic column of sediments in Wielkanoc Quarry. Upper Jurassic sediments with stromatactis-like cavities and main components.

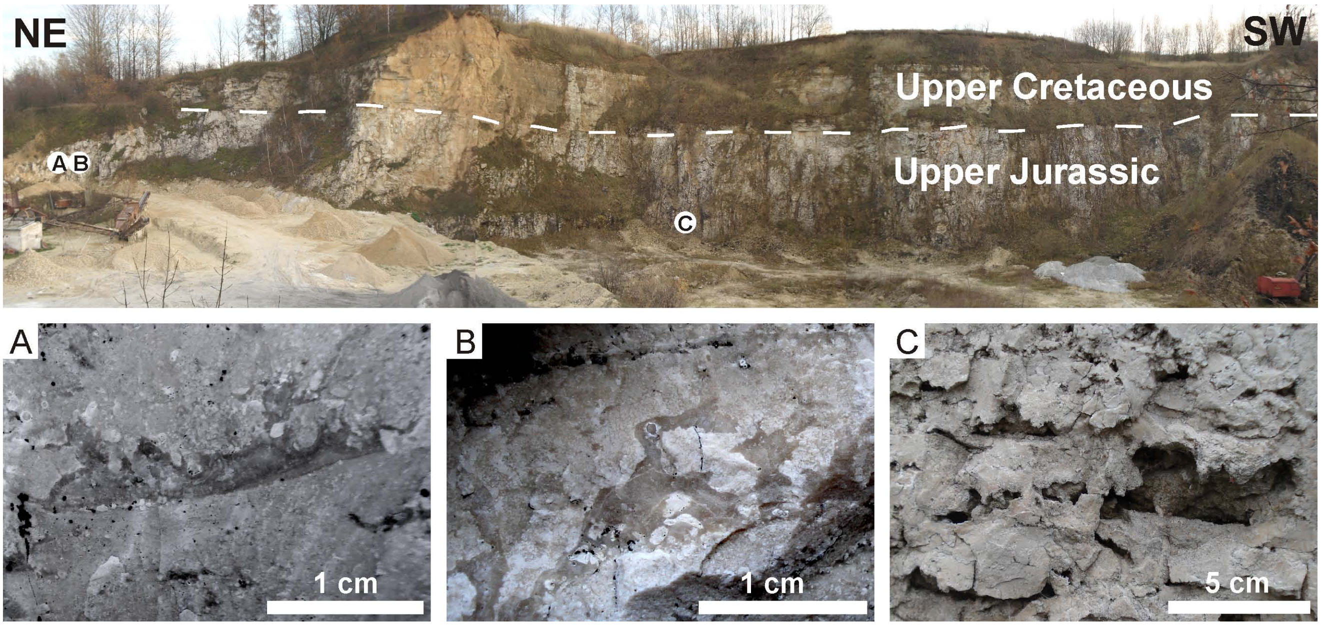

Fig. 16. General view of SE wall of Wielkanoc Quarry with a location of some stromatactis-like cavities. **A–C**. Stromatactis-like cavities at the weathered rock surface.

wackestones with fine peloids, numerous *Crescentiella*, tuberoids, serpules, calcified sponge spicules, echinoderms plates, echinoids spines, bryozoans with microbial rims, fragments of corals up to about 2 cm across, as well as single oncoids, up to 1 mm in diameter, and *Terebella lapilloides*. Abundant are *Stylosmilia* corals with distinct dissolution traces (Fig. 17A). Sometimes, corals have microbial rims, up to 0.6 mm thick. Close to corals, we often observe rounded pores filled with calcite. The lenses of bioclastic limestones consist of packstones/grainstones with *Crescentiella*, fragments of siliceous sponges with microbial crusts, up to 0.2 mm thick, serpules, bivalve shells and echinoderms plates. Most grains are rimmed with isopachous cement, up to 0.4 mm thick, whereas the remaining intergranular spaces are filled with blocky cement. Commonly, bioclastic packstones/grainstones are observed beneath the sponges. Locally, the spaces between the lower surfaces of sponges and bioclastic grainstones are filled with calcite cements.

Description of stromatactis-like cavities

The stromatactis-like cavities occur within the full thickness of the massive limestone succession. When observed on weathered rock surface, they can be up to about 4 cm wide and up to 2 cm high (Fig. 16A–C). These are cavities of rough or smooth, arcuate roofs whereas the

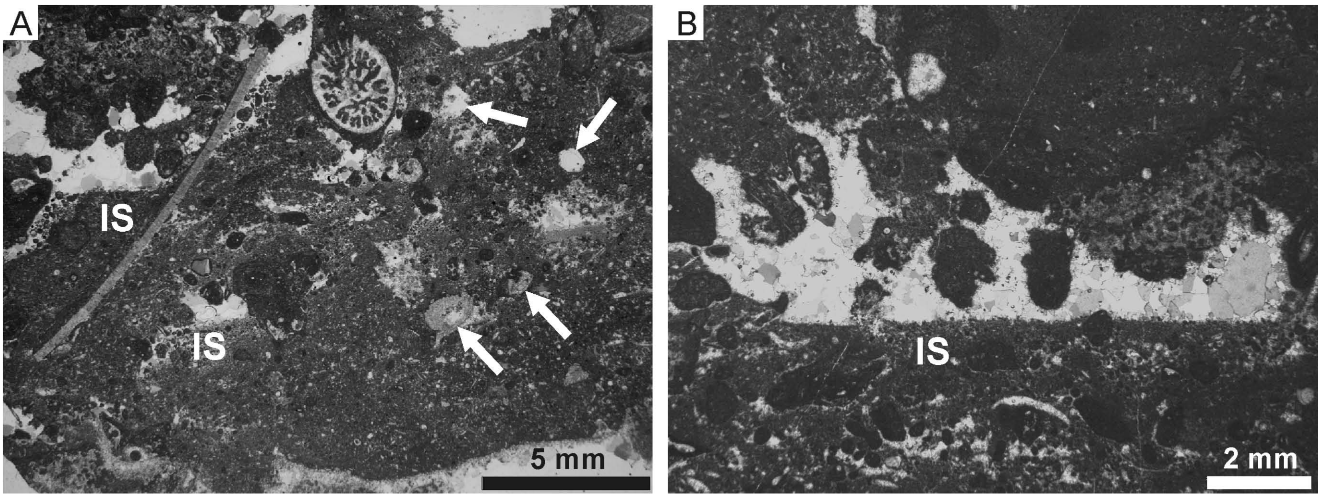

Fig. 17. Stromatactis-like cavities from the Wielkanoc Quarry. **A.** Partly dissolved Stylosmilia coral with microbial coating. Below the coral, stromatactis-like cavities with internal sediments (IS) and numerous voids after the dissolution of coral branches (white arrows). **B.** Stromatactis-like cavity with irregular roof in microbial wackestone. Numerous fragments of enclosing rock embedded within calcite cements. IS – internal sediment.

bottom parts are filled with internal sediments. The top surfaces of internal sediments are flat or slightly rough.

Under a microscope, the stromatactis-like cavities turn out to occur in thrombolite-sponge and *Crescentiella*-peloid wackestones. The roofs of the cavities are usually rough and locally they follow the shapes of large bioclasts or *Crescentiella*, but other cavities have smooth, arcuate roofs. The stromatactis-like cavities are filled with multi-generation calcite cements in their upper parts and with internal sediments in the lower parts. Single, irregular rock fragments composed of particles derived from the enclosing rocks are common in calcite cements (Fig. 17B). Such fragments are embedded within calcite cements or contact each other and/or contact upper surfaces of internal sediments (Figs 16B, 17B). The upper surfaces of the rock fragments embedded within calcite cements often fit well to the contours of the roofs of cavities.

In their lower parts, the stromatactis-like cavities are filled with internal sediments which contain the same components as the enclosing rocks. The internal sediments are wackestones with fine *Crescentiella*, peloids and sponge spicules. Some sediments are packstones with *Crescentiella* or, quite commonly, we observe packstones in the upper parts, then grading downwards into peloidal wackestones.

Proposed genesis of stromatactis-like cavities in the Wielkanoc Quarry

The carbonate buildup from the Wielkanoc Quarry was formed by successively overgrowing microbialites, siliceous sponges and hermatypic cladophyllid corals constituting the framework. The intra-framework spaces were filled with calcareous mudstones, wackestones and bioclastic packstones/grainstones (primary sediments, see Pratt, 1982). In these sediments, numerous rounded or elongated cavities were formed (Fig. 17A). It seems that these cavities have originated (at least partly) during the early diagenesis due to dissolution of corals when the sediment filling the intra-framework spaces has not been entirely lithified.

The formation of open spaces after dissolved corals have disturbed the primary stress field in the close neighbourhood of these spaces. The primary stress field have originated from the load of the overburden exerted on the components of the carbonate buildups (e.g., corals). This vertical load caused lateral compressive stress along the vertical surfaces developed within the corals.

The dissolution of corals led to the disappearance of lateral stress at the contact of sediment and walls of cavities. Simultaneously with the dissolution, the secondary stress field has developed, in which compressive stress has intensified in side walls of cavities acting as supports for their roofs loaded by the overburden. In the cavity roofs, the vertical tensional stress field has appeared due to the lack of support from the sediment. The cavities resulted from dissolution of phaceloidal clusters of coral colonies might have been several centimeters wide and high (see Morycowa and Roniewicz, 1990). Stability of the cavity shapes in time was controlled by the degree of lithification of the enclosing sediment. The shape of cavities developed within the highly lithified rock could not be remodeled later on but if the sediment was poorly lithified, the cavity roofs were susceptible to collapse.

Dissolution of corals was simultaneous with concentration of stress around the cavities. The presence of tensile stress field in the roofs of cavities, combined with low resistivity of sediments to pulling, facilitated separation of single grains from the roofs. Sometimes, compact aggregates of grains were separated, as well (Fig. 17B). Separated grains were then deposited at the bottoms of cavities forming the internal sediments. Hence, the falling of sediment from the cavity roofs and its deposition onto the cavity bottoms caused migration of cavities up the sequence. The presence of compressional stress in side walls of cavities and tensional stress in their roofs determined their stable geometry. If the stromatactis-like cavities formed in a well-sorted and homogenously lithified sediment, the cavities were ellipsoidal. If the sediment was random-grained and inhomogenously lithified, the cavities had irregular, ragged roofs (Figs 16A, B, 17B).

It is possible that the factor responsible for remodelling of the cavities was a dynamic load periodically present in the carbonate buildups with developed framework. The carbonate buildup observed in the Wielkanoc Quarry has grown in a marginal zone of the Małopolska Block, which was subjected to stronger tectonic deformations than the Upper Silesian Block (Żaba, 1999). The tectonic activity along the Kraków-Lubliniec Tectonic Zone and the Krzeszowice-Charsznica Fault documented in the Late Jurassic (Żaba, 1999; Krajewski and Matyszkiewicz, 2004; Matyszkiewicz *et al.* 2006a, b, 2012) might have stimulated the dynamic loads within the carbonate buildups, which affected the stability of sediment over the roofs of cavities and initiated their collapses.

A5.5 Ujazd. Upper Jurassic submarine gravity flows in Ujazd

Entrance part of Kluczwoda Valley, north of the Ujazd village (50°08′48″ N, 19°48′59″ E)

Leader: Jacek Matyszkiewicz

The exposure is situated near the northern edge of the Krzeszowice Graben (Fig. 2), and has been described in several papers (e.g., Matyszkiewicz, 1996, 1997b; Matyszkiewicz and Olszewska, 2007).

The exposure is ca. 50 m long and 10 m high (Fig. 18). Packstone is visible at the bottom of the exposure, in its northern part. It is mostly composed of very well sorted peloids (65%) and fragments of *Saccocoma* sp. (15%) with generally well developed syntaxial calcite cement. Among accessory components, calcified radiolaria, recrystallized planktonic foraminifera, isolated benthic foraminifera, and calcareous dinocysts are observed. The main characteristics of the established microfossil assemblage (Matyszkiewicz and Olszewska, 2007) is a significant amount of planktonic fauna. It consists of foraminifera, calcareous dinocysts, coralline algae, secundibranchia of pelagic crinoids *Saccocoma* sp. (Fig. 19) and radiolaria. The diameter of peloids and fragments of *Saccocoma* sp. gets gradually smaller towards the top of the exposure, and packstone smoothly turns into wackestone and then, closer to the top, into mudstone.

The packstone to mudstone complex is cut by subvertival joints and sometimes by steep listric surfaces. A few horizons of early-diagenetic cherts with diameters up to about 10 cm, decreasing towards the top of the exposure, are present in these deposits. A silicified limestone lens with flat top and bulges in the bottom, 0.4 m thick and several metres long, is present in the northern part of the exposure (Fig. 18). Concentric silica accretions surrounding early-diagenetic cherts are visible on fresh fractures. Crystallinity index values (CI; cf. Murata and Norman, 1976) of quartz from silicified lenses are CI=5.1 (Świerczewska, 1989). Nannoplankton S*chizosphaerella minutissima* and coccolites directly below the silicified limestone lens has been discovered using SEM (Matyszkiewicz, 1996; Matyszkiewicz and Olszewska, 2007; cf.

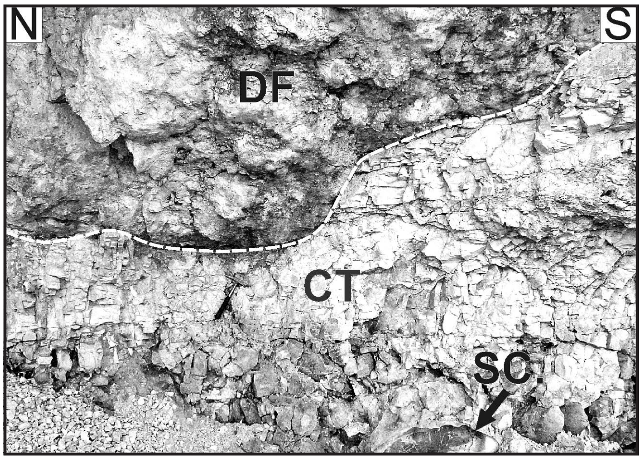

Fig. 18. Northern part of the exposure in Ujazd; DF – debris flow with olistolith of microbial-sponge massive limestone; CT – calciturbidite (packstone-wackestone-mudstone); SC – lens of silicified calciturbidite.

Kälin and Bernoulli, 1984; Bernoulli and Kälin, 1984). A fragment of another silicified limestone lens has been found in a trench situated about 0.1 m below the bottom of the exposure. Locally, oblong 10 cm-thick and several meters long fragmented early-diagenetic cherts are visible at the top of a mudstone layer. This intercalation continues into overlying debrite as a steep listric surface. Such sequnce of the lower part of the sediments can be observed between the northern edge of the exposure and a massive limestone block, which divides the exposure in two. Further to the south, near the bottom of the exposure, bedded limestone is present, represented by packstone-grainstone-boundstone with numerous fragments of benthic echinoderms. Some bedded limestone layers create biostromes formed as boundstone with thrombolites and *Crescentiella morronensis*, *Terebella* sp., echinoid spicules, bryozoans, hexactinellid sponge spicules, tuberoids, and brachiopods. Early-diagenetic cherts are locally present on the bedding planes and near them.

Above the described packstone to mudstone complex, the sediments are variable laterally. In the northernmost part of the exposure, a rounded block of massive limestone of microbial-sponge boundstone microfacies (Fig. 18) lies on the uneven top of limestone representing a packstone to mudstone complex. The massive limestone is locally separated from the underlying complex by a several centimetres-long intercalation of green marls containing breccia of early-diagenetic cherts. In these marls Dr. W. Barwicz discovered foraminifera, radiolaria (Spumellaria), skeletal elements of echinoderms and sclerosponges.

In the northern part of the exposure, limestone representing packstone to mudstone is separated by an intercalation of irregular clasts of massive limestone and early-diagenetic cherts embedded in fine-grained matrix. Clasts of massive limestone consist of microbial-sponge boundstone with thrombolites or of packstone with *Crescentiella morronensis*, fragments of echinoderms, bivalves, brachiopods and hexactinellid sponges, serpules, and benthic foraminifera. A little bit further to the south, on a packstone to mudstone complex with numerous penetrations on top, separated from it by a several centimetres-long layer of green marls, lies debrite containing fractured, irregular bodies of mudstone.

The Ujazd section represents the uppermost part of the Upper Jurassic section preserved in the vicinity of Kraków. It is situated about 200 m above the top of the Middle Jurassic. The presence of numerous fragments of *Saccocoma* sp. (Fig. 19), which appear in much lesser amounts in Upper Oxfordian facies, suggests that these deposits represent Kimmeridgian (cf. Matyszkiewicz, 1996, 1997b; Krajewski, 2001; Krajewski *et al.*, 2011). A discovery of ammonites in an exposure in Giebułtów, several kilometres east of Ujazd, confirms this (Ziółkowski, 2007a, b).

The packstones to mudstones complex at the bottom of the exposure represents at least one calciturbidite sequence. The *Saccocoma*-dominated sediments correspond with characteristics of typical calciturbidites, such as bimodality of grain composition, grading, and secondary silicification bringing out sedimentation structures (cf. Meischner, 1964; Eberli, 1987). In these deposits, T_{abc} and T_e members of Bouma sequence can be distinguished, though the boundaries between them are indistinct. It is possible that these deposits represent several amalgamated calciturbidites, as the bulges in the bottom of siliceous layer may be parallel in shape to erosive structures that may have formed at the base of a subsequent turbidity current. The highly laterally diversified deposits that cover the calciturbidite represent a debris flow. The presence of steep listric surfaces caused by discontinuity in underlying calciturbidites indicate rotational slides (cf. Hansen, 1984; Gawthorpe and Clemmey, 1985) that happened before total litification of the debris flow. It suggests that sedimentation of both types of submarine gravity flows probably took place on leaning fragments of the sea bottom, i.e. on slope and contraslope, where rotational slides usually form. For slightly leaned surfaces translational slides are more typical (cf. Prior and Coleman, 1984). Calciturbidites deposition ended with sedimentary pause documented by penetrations in the topmost part of the packstone to mudstone complex. It preceded another phase of sedimentation related with deposition of debris flows. The unevenness of the top of calciturbidites observed in the northern part of the exposure (Fig. 18), as well as the unevenness of the top of bedded limestone in the southernmost part of the exposure, is probably due to erosional channels, through which the debris flow deposits were transported.

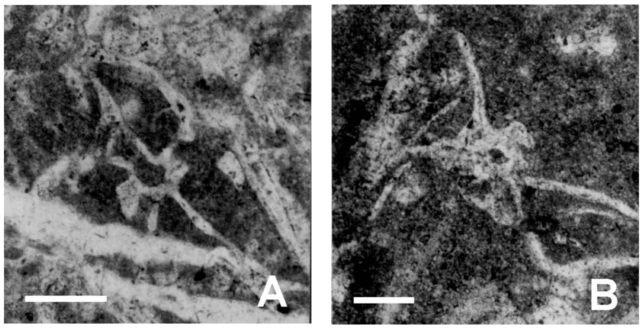

Fig. 19. A-B. Secundibranchia of *Saccocoma* sp. within packstone to mudstone complex. Bar scale 1 mm.

A silicification model presented by Bustillo and Ruiz-Ortiz (1987) explains formation of extensive silicified limestone lenses in calciturbidites. It assumes that the siliceous banks are a result of early diagenetic silicification connected with enrichment of groundwater with silica caused by abrupt burial of sediments. According to Bustillo and Ruiz-Ortiz (1987), radiolarian skeletons and spicules of hexactinellid sponges were the source of silica, but concentric accretions in the silicified limestone lens in the calciturbidite from Ujazd suggest that the process of its formation had several phases, which was probably caused by a significant initial porosity of the silicified T_{ab} divisions of the calciturbidite and by small clay content inhibiting migration of silica (cf. Laschet, 1982). Clay was sieved out during spreading of the turbidity currents. It is indirectly proved by values of CI=5.1 of quartz found in the silicified lens. They are significantly higher than the values typical for Upper Jurassic early-diagenetic cherts (CI<1) and clearly smaller than in epigenetic siliceous deposits (CI>9; Matyszkiewicz, 1987; Matyszkiewicz *et al.*, 2015). Silicification in the calciturbidites was preceded by cementation with calcite, which reduced porosity and permeability of the sediment (cf. Hesse, 1987). The probable source of silica were opal radiolaria skeletons or an unknown external source.

The abundance of the fragments of planktonic *Saccocoma* sp., in calciturbidites, as compared with the predominance of benthic fauna in Oxfordian deposits in the Kraków region, suggests an abrupt change of conditions of sedimentation. The predominance of pelagic material indicates drowning of carbonate buildups complexes that were intensively developing in Middle and early Late Oxfordian times (Matyszkiewicz, 1996, 1997b; Krajewski, 2000, 2001; Matyszkiewicz *et al*., 2012). The predominant benthic fauna was replaced by planktonic fauna, as is shown by the abundance of planktonic crinoids *Saccocoma* sp., planktonic foraminifera, coccoliths, nannoplankton and radiolaria. When the development of microbialites that stabilized the carbonate buildups ceased (cf. Matyszkiewicz *et al*., 2012), loose pelagic sediments, which covered the sea bottom, could be easily moved by turbidity currents.

Local appearance of biostromes in the bedded limestone observed in southern part of the exposure indicates that after the deposition of calciturbidites related to the initial drowning (cf. Bice and Stewart, 1990) of the complexes of microbial-sponge carbonate buildups, again, for a short period, they could benefit from favourable conditions for development, and after that terminal drowning took place (cf. Bice and Stewart, 1990), which is expressed by sedimentation of debris flow deposits containing debris from destruction of upper parts of the microbial-sponge buildups. Debris-flow deposits document the main phase of destruction and smoothing of the sea bottom relief of the Late Jurassic basin in the Kraków region (Matyszkiewicz, 1997b; Krajewski, 2001), which had wide regional extent documented from the southern part of the Kraków Upland, Nida Basin and the foreland of the Carpathian Mountains (cf. Burzewski, 1969; Morycowa and Moryc, 1976).

The sedimentary and tectonic structures in the exposure in Ujazd indicate active Late Jurassic synsedimentary fault tectonics. Examples of material transport, in which synsedimentary faults are a linear source of material, are given - among others - by Schlager and Chermak (1979), Crevello and Schlager (1980) and Eberli (1987). The direction of erosional channels in the calciturbidite sequence (W-E) documents transport by debris-flows parallel to a nearby fault bounding the Krzeszowice Graben, which suggests that the fault was formed in the Late Jurassic (cf. Matyszkiewicz, 1996; Ziółkowski, 2007a, b).

Widely spread sediments of submarine gravity flows in the southern part of the Kraków Upland are probably an effect of Late Jurassic synsedimentary fault tectonics (cf. Koszarski, 1995), which is a reflection of supra-regional phenomena connected with the opening of the Northern Atlantic and the Tethys oceans (Faerseth, 1996; Helm and Schülke, 1998; Allenbach, 2001, 2002). In the Kraków region, these phenomena were accompanied by reactivation of old Palaeozoic structures, mainly the Kraków-Lubliniec and Krzeszowice-Charsznica fault zones (Żaba, 1999; Krajewski and Matyszkiewicz, 2004; Matyszkiewicz *et al*. 2006a, b, 2012, 2015). The presence of Upper Jurassic submarine gravity flows near the edges of the tectonic horsts in the Kraków region suggests a Late Jurassic origin of these structures (Matyszkiewicz, 1996, 1997b; Krajewski and Matyszkiewicz, 2004; Ziółkowski, 2007a, b; Matyszkiewicz *et al*., 2006b, 2007b, 2012), which applies also to the area of Ujazd.

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