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Development and chronology of the Late Jurassic shallow-water carbonate deposits of the Holy Cross Mountains area, central Poland

Andrzej WIERZBOWSKI[1]

Key words: history of sedimentation, cyclicity, climatic and tectonic factors, ammonite stratigraphy, Late Oxfordian, Kimmeridgian, Early Tithonian.

Abstract. The Late Jurassic shallow-water carbonates with intervening clayey-marly deeper-water deposits in the Holy Cross Mts. area formed over large bank of the elevated part of the Northern Tethyan Shelf during about 12 myr. They comprise three main successions (I, II and III) deposited partly in different environmental conditions, controlled by tectonic and climatic factors, and still preserved in the north-eastern margin, the north-western margin and the south-western margin of the Holy Cross Mountains. The history of sedimentation is presented according to the concept of the large tectono-stratigraphic units COK, LUK and KVB, which owe their origin to variable rates of tectonic subsidence, as introduced by Kutek (1994) for the area of central Poland. The studied deposits of the COK megasequence corresponding to the Upper Oxfordian and the Lower Kimmeridgian up to the Hypselocyclum Zone consist of coral limestones, various grained (including oolitic) limestones, and micritic limestones formed over the gradually enlarging shallow-water carbonate platform of the Holy Cross Mts. This platform was subsequently subdivided into two elevated areas, separated by a depressed zone in the middle, bounded by the Nowe Miasto–Iłża–Bałtów Fault Zone in the north-east and the Holy Cross Fault System in the south. The younger megasequence LUK with it strongly transgressive character marks the successive stages of the marine transgression which entered the central, lowered part of the area of the Holy Cross Mts. from the west, where it appeared already in the early Hypselocyclum Chron. It successively spread across the Holy Cross Mts. area towards the north-east and south bringing everywhere the deposition of various oyster lumachelles and marls with ammonites at the end of the Hypselocyclum Chron and during the Divisum Chron of the Early Kimmeridgian to the Acanthicum/Mutabilis Chron of the earliest Late Kimmeridgian. The following megasequence KVB is represented by the detrital lumachelles and chalky limestones with nereineids of the Eudoxus Chron of the Late Kimmeridgian marking the development of still younger shallow-water carbonate platform in the uplifted areas in the north-eastern and possibly the south-western margins of the mountains, allegedly subdivided by a deeper area of sedimentation of marly deposits. The youngest Late Jurassic deposits of the Holy Cross Mts., are very fragmentarily preserved, mostly because of Early Cretaceous uplift and erosion. They suggest an initial episode of complete drowning of the carbonate platform which became covered by marly deposits during the Early Tithonian, and the subsequent restoration of shallow-water carbonate sedimentation at the end of the Early Tithonian.

INTRODUCTION

The Upper Jurassic carbonate deposits occurring around the Palaeozoic core of the Holy Cross Mountains (Polish: Góry Świetokrzyskie), and constituting its north-eastern, north-western and south-western margins (Fig. 1), represent remnants of the primary cover of the mountain area partly eroded due to the subsequent tectonic movements: Neo-Cimmerian (latest Jurassic/earliest Cretaceous to pre-Albian) and Laramian (at the end of the Maastrichtian and during the

[1] University of Warsaw, Faculty of Geology, ul. Żwirki i Wigury 93, 02-089 Warszawa, Poland; andrzej.wierzbowski@uw.edu.pl.

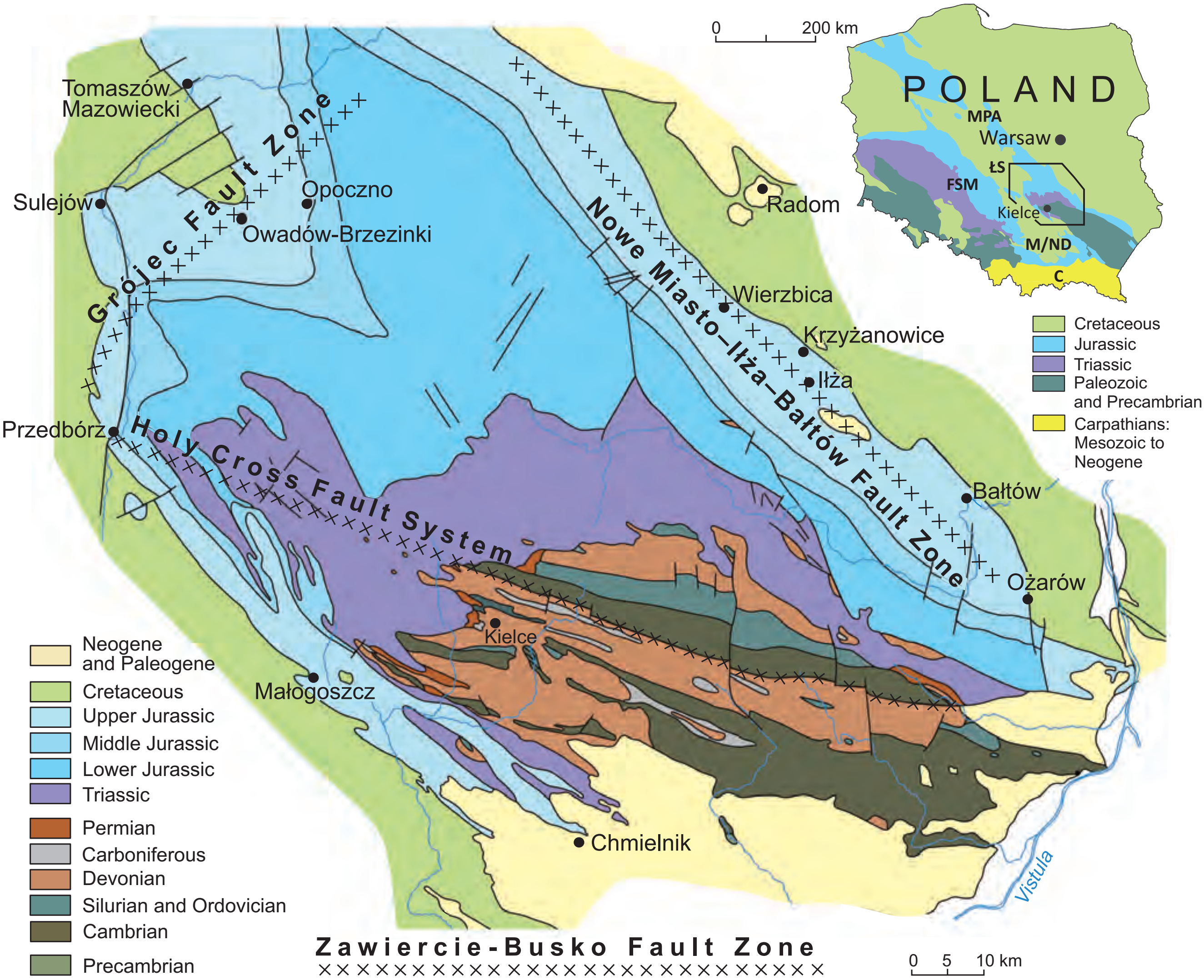

Fig. 1. Geological map of the Holy Cross Mountains (after Samsonowicz in: Książkiewicz, Samsonowicz, 1953, somewhat modified) showing the main tectonic zones active during the Late Jurassic: they are situated in the area of the mountains and in substrate of the Carpathian Foredeep. The inset shows the position of the area of study in the background of geology of Poland

FSM – Fore-Sudetic Monocline, ŁS – Łódź Depression, M/N D – Miechów/Nida Depression, MPA – Mid Polish Anticlinorium, C – Carpathians

Paleocene) onces. The Neo-Cimmerian movements, mainly active in south-western areas of Poland, were responsible for erosion of the youngest Jurassic deposits (mostly Tithonian and uppermost Kimmeridgian) as recognized especially in the north-eastern and south-western margins of the Holy Cross Mts. (*e.g.*, Pożaryski, 1948; Kutek, 1962), whereas the Laramian movements resulted in total erosion of the Upper Jurassic deposits from the elevated central part of the mountains – from the Palaeozoic core and adjacent areas (*e.g.*, Kutek, Głazek, 1972). The character of the Late Jurassic deposits of the Holy Cross Mts. margins allows for neglecting (see Kutek, 1962) older ideas on the elevation of the central part of the area during their sedimentation.

The stratigraphical subdivision of the Upper Jurassic deposits of the Holy Cross Mts. has been markedly modified during the last decades. The first attempts to classify the Upper Jurassic deposits of the area included recognition of stratigraphical "stages" like "Oxfordian", "Argovian", "Rauracian", "Astartian" and "Kimmeridgian", which being in fact characteristic local lithostratigraphical units, enabled detailed local correlations only (*e.g.*, Pożaryski, 1948; Świdziński, 1962; see also Malinowska, 1970; Liszkowski, 1963, 1976, and older papers cited therein). The common usage of the Oxfordian, the Kimmeridgian, and the Tithonian stages as based on well-established ammonite chronozones, was also preceded by stratigraphical discussion on the usage of the Volgian Stage instead of the older "Bononian" (replaced later by Tithonian, see Kutek, 1962; Kutek, Zeiss, 1974, 1997; Matyja, Wierzbowski, 2016a), and the marked modification of position of the Oxfordian/Kimmeridgian boundary finally solved by the recent acceptance of the GSSP of the base of the Kimmeridgian Stage. The latter resulted in the inclusion in the newly re-defined Kimmeridgian Stage of a stratigraphical interval corresponding to the Bimammatum and Planula ammonite zones which previously had been correlated here (but also in other areas of the Submediterranean Province in Europe) with the uppermost Oxfordian (see Wierzbowski *et al.*, 2016, 2023a).

Detailed stratigraphical, palaeontological, and sedimentological investigations have been carried out in particular areas of the occurrence of Late Jurassic carbonate deposits in the margins of the Holy Cross Mountains. These included during the last decades studies of deposits in the north-eastern margin (Dąbrowska, 1968, 1983a; Liszkowski, 1972, 1976; Kutek, 1983, 1994; Gutowski, 1992, 1998, 2006a, b), the north-western margin (Barczyk, 1961, 1980; Kutek, 1961; Wieczorek, 1975; Matyja, Wierzbowski, 2014) and the south-western margin (Kutek, 1968, 1969, 1994; Pszczółkowski, 1970a, b; Matyja, 1977, 2011; Matyja *et al*., 1989). The recently presented detailed interpretations of the stratigraphical successions of the Lower Kimmeridgian of the south-western margin (Wierzbowski, 2020), and the whole Upper Jurassic succession in the north-eastern margin of the Holy Cross Mts. (Wierzbowski, 2023; see also Wierzbowski *et al.*, 2023b) has enabled a more generalized treatment of these subjects herein. The aim of the present study is to summarize the current state of knowledge on the development of the deposits, especially those representing the shallow-water part of the whole succession corresponding generally to the shallow-water carbonate platform facies foremost: (1) to show the stratigraphical correlation between particular areas of their occurrence, (2) to recognize the main lithological sequences important for reconstruction of the history of sedimentation, and (3) to give proposals for the chronostratigraphical subdivision of the summarized lithological column according to climatically and tectonically controlled phenomena, dated also by the collected ammonites.

Collections of ammonites coming from the shallow-water Upper Jurassic deposits of the Holy Cross Mts. have been described in older papers cited above. They are housed mostly in the Museum of the Geological Faculty of the University of Warsaw (collections nos: IGPUW/A/4, IGPUW/27; MWG UW ZI/100), but some also at the Institute of Paleobiology, Polish Academy of Sciences (collection ZPAL V/69). However, some corrections of older palaeontological determinations are given and a few newly determined ammonites which are important for stratigraphical interpretations, are also added herein.

SHALLOW-WATER CARBONATE FACIES ASSOCIATIONS IN THE HOLY CROSS MOUNTAINS AREA: GENERAL SETTING

The transition from shelf deep-neritic sponge megafacies to shallow-water carbonate platform deposits was preceded in the whole area by the random development of coral-buildups founded on the tops of older cyanobacteria-sponge biohermal complexes (Matyja, 1977; Gutowski, 1992; Matyja, Wierzbowski, 1996). The coral reefs/bioherms composed initially of foliaceous hermatypic corals indicated a relatively deeper and quiet-water environment (Roniewicz, Roniewicz, 1971). The areas of coral buildups became successively places of sedimentation of various bioclastic and oncolitic limestones which commonly spread around, as a result of a sudden progradation of shallow-water deposits due to subsequent sea-level fall.

Several major facies associations are conveniently recognized in the shallow-water successions as based on detailed sedimentological and stratigraphical regional studies in various areas of the Holy Cross Mts. (*e.g.*, Kutek, 1969; Gutowski, 1992, 2006b; Matyja, 2011; Wierzbowski, 2020, 2023). These include four main facies associations of the carbonate platform treated as areas of carbonate deposition occurring above, or close to wave base: the chalky limestone association, the oolitic limestone association, the micritic lithographic, locally banded limestone association, and the micritic to varied fine grained limestone association. All of them are representatives of particular sectors of the general morphology of the shallow-water carbonate platform from the external or open platform environment through the oolitic barriers to the more restricted platform environment. The detailed characteristics of these facies associations are as follows:

– chalky limestone association including dominant well-bedded soft and porous ("chalky") limestones composed of various carbonate grains (including especially common here oncoids) with abundant and diversified benthic fossils including hermatypic branching and massive corals and solenoporoids – especially common stratigraphically below (in bedded limestones following or replacing older coral buildups), and bivalves (mostly diceratids and various oysters) and nerineid gastropods – above;

- oolitic limestone association including limestones with predominant occurrences of oolites – both cross-bedded and non-cross-bedded;
- banded and/or lithographic type micritic limestone association showing local bands of micritic and very fine-grained organodetrital-oolite limestones, with a very poor macrofauna, locally with cherts – these deposits are commonly strictly related to the oolite limestone association;
- micritic and marl association consisting of micritic and marly limestones usually with some amount of fine organodetrital material with admixture of other grains (ooids, oncoids, peloids) with a commonly encountered impoverished fauna mostly of burrowing myid bivalves, such as *Pholadomya* and *Pleuromya*.

Additionally there can be distinguished some other associations such as that of oncolitic limestone and another one of oyster lumachelle, yielding some ammonites, both having usually a wider distribution and formed in a more open marine environment during episodes of partial drowning of the carbonate platform (*e.g.*, Matyja *et al*., 2006, see also Kutek, 1994), as well as an association of some widely distributed marly deposits representing siliciclastic sedimentation in a non-fully marine environment developed especially during regressive episodes (Wierzbowski, 2020). The deeper-water deposits developed within the discussed successions of the Holy Cross Mts. when the carbonate platform or its parts was fully drowned are also considered.

The rate and extent of transgressions and regressions very strongly influenced the spatial and temporal distribution of shallow-water carbonate facies, regardless of whether the changes in sea-level were controlled by orbitally-climatic or tectonic phenomena. The transgressive or regressive tendencies shown in the character of the deposits described have been related to orbitally-controlled eccentricity cycles (Boulila *et al*., 2008, 2010; see *e.g*., Wierzbowski, 2020). On the other hand, the facies pattern was also significantly modified by synsedimentary tectonic activity related to local basement tectonics, especially in some zones. One important tectonic zone at the south-eastern margin of the Holy Cross Mountains was the Nowe Miasto–Iłża Fault (and its south-eastern prolongation towards Bałtów and Ożarów), treated as the south-west margin of the East European Craton, and a tectonic zone that bounds the Mid-Polish rift system from the east (Mid-Polish Trough – see *e.g.*, Świdrowska *et al.*, 2008; *cf.* also Pieńkowski, 2006). Another zone of synsedimentary faulting was the Grójec Fault Zone, called also the Tomaszów–Grójec Fault Zone (Dadlez, 1997) in the north-western corner of the north-western margin of the Holy Cross Mts., linking the Częstochowa Upland and the Radomsko Elevation in the south-west (Matyja, Wierzbowski, 2014; see also Barski, 2012; Wierzbowski, 2020). Very important tectonic zones showing synsedimentary activity were also: the Holy Cross Fault System in the south, at the border between the north-western and south-western margins, the synsedimentary activity of which strongly influenced the facies pattern of the Upper Jurassic deposits (Matyja, Wierzbowski, 2014; Matyja, 2015; Wierzbowski, 2020), and the Zawiercie–Busko Fault Zone at the southern border of the south-western margin of the Holy Cross Mts. (Różycki, 1953; Kutek, 1996; Matyja, 2009, 2015; Wierzbowski, 2020).

The general features of the development and distribution of the facies associations, and their time-relations in particular parts of the Holy Cross Mts. as based on ammonite faunas, are presented below. Although the main subject of study corresponds to the shallow-water zone of the Holy Cross Mts., some additional comments refer to the similarly developed deposits of the surrounding areas – especially those placed west of the mountains. These include a part of the Laramian Miechów/Nida Depressions where the coeval shallow-water deposits were encountered in cores (*e.g.*, Jurkiewicz *et al*., 1969; Złonkiewicz, 2009), but also the Radomsko Elevation where similar deposits were studied in quarries (see *e.g.*, Kutek, 1968; Wierzbowski, Głowniak, 2018), and the substrate of the brown-coal field in the Szczerców–Bełchatów area along with adjoining part of the Wieluń Upland, studied in boreholes and outcrops (*e.g.*, Wierzbowski, 2017; see also Olchowy *et al.*, 2019).

SHALLOW-WATER CARBONATE SUCCESSION OF THE NORTH-EASTERN MARGIN OF THE HOLY CROSS MOUNTAINS

LOCATION AND CRITERIA OF STRATIGRAPHICAL SUBDIVISION

The Upper Jurassic deposits of the north-eastern Mesozoic margin of the Holy Cross Mountains stretch along north-eastern limb of the Gielniów Anticline and its south-eastern prolongation, between Dobrut and Śniadków in north-west and Zawichost in south-east. Three main groups of outcrops occur in the following areas: (1) between Dobrut and Wierzbica, (2) the environs of Iłża, (3) at the Kamienna river valley between Bałtów–Skarbka and Przepaść–Podgrodzie to Ożarów (Fig. 1). When studying the succession of these deposits five main intervals subdivided into smaller scale biostratigraphically-controlled units each characterized by a different lithology can be distinguished (Fig. 2). These are correlated with older lithostratigraphical units which have been recognized here (Dąbrowska, 1983a; Kutek, 1983; Gutowski, 1992, 1998).

The stratigraphical intervals recognized in the Upper Jurassic succession (I: 1–5; see Fig. 2) are interpreted as

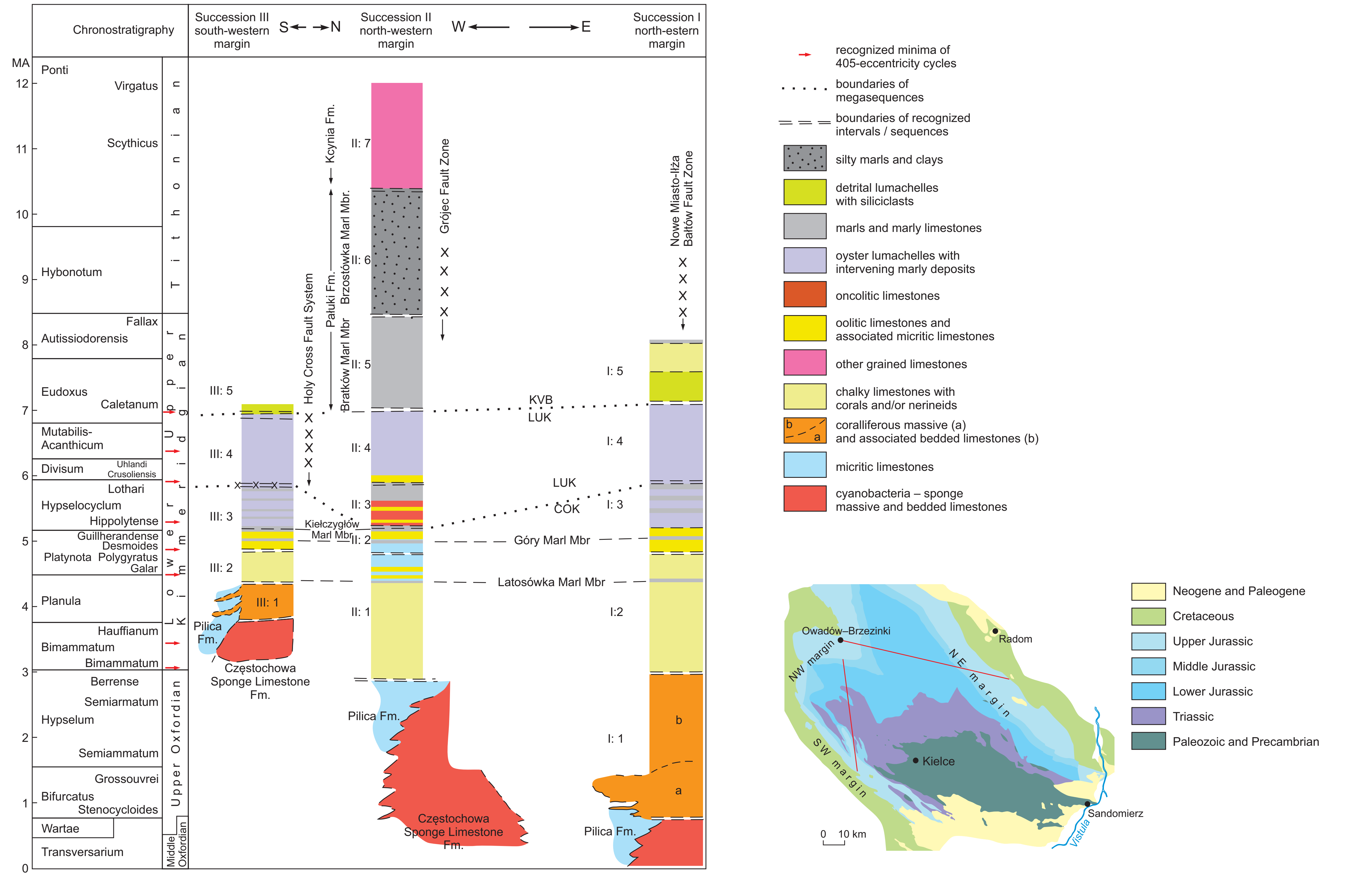

Fig. 2. The main stratigraphical intervals/sequences from the south-western margin, through the north-western margin to the north-eastern margin of the Holy Cross Mountains to show their chronostratigraphical position and correlation with megasequences COK, LUK and KVB of Kutek (1994)

The recognized minima of 405-kyr eccentricity cycles corresponding to high sea-level are indicated as red arrows. The stratigraphical intervals are drawn to scale corresponding to the chronostratigraphical time-scale of Hesselbo *et al.* (2020). The line of section is marked on the generalized structure of the Holy Cross Mts. (inset) major-scale transgressive-regressive sequences. They correspond generally to the megasequences COK (**C**allovian–**O**xfordian–**K**immeridgian), LUK (**L**ower–**U**pper **K**immeridgian) and KVB (**K**immeridgian–**V**olgian–**B**erriasian) as recognized by Kutek (1994) in the south-eastern and central areas of epicratonic Poland as follows: the sequences I: 1–2–3 correspond to the shallowing upward carbonates of the shallow-water carbonate megafacies which developed after the sponge megafacies of the COK megasequence – these span, from the Upper Oxfordian to the Lower Kimmeridgian (Bifurcatus Zone to the upper part of the Hypselocyclum Zone); the sequence I–4 corresponds to the LUK megasequence, spanning from the upper part of the Lower Kimmeridgian to the lowermost part of the Upper Kimmeridgian (uppermost part of the Hypselocyclum Zone to the Acanthicum/Mutabilis Zone); sequence I–5 corresponds to the lowermost part of KVB megasequence, which is located in the middle part of the Upper Kimmeridgian (mostly Eudoxus Zone).

Something of a different classification of the Upper Jurassic deposits in the south-eastern margin of the Holy Cross Mts. was proposed by Gutowski (*e.g.*, Gutowski, 1992, 2006a, b). According to his classification, given in terms of sequence stratigraphy, the recognized sequences were bounded by regional sedimentary unconformities controlled by eustatic changes of sea-level. The sequences distinguished by him generally corresponded in number to the stratigraphical intervals/sequences recognized herein (including some smaller scale sequences denoted herein as subintervals). However, their boundaries have been placed in different positions – allegedly corresponding to an extremely shallow-water environment according to sequence stratigraphy requirements. The general scheme of the distinguished sedimentary sequences has been correlated, however, with the major sequences of Kutek (1994) recognized as megasequences I–III, and treated as resulting from regional tectonic events: “although this mechanism did not have a global effect, its fairly isochronous results can be observed in [those] distant sedimentary basins of epicontinental Europe which were situated close to the Tethyan shelf” (Gutowski *et al.*, 2005).

DESCRIPTION AND INTERPRETATION OF STRATIGRAPHICAL SUCCESSION (I)

Massive coral limestone-dominated interval (Middle to Upper Oxfordian: uppermost Transversarium to Hypselum zones) (I: 1a, b)

These deposits exposed between Olechów and the Wyszmontów–Ożarów railway cut (*cf.* Gutowski, 1992) include a section of remarkable thickness, up to 20 m, of coral buildups that pass laterally into bedded limestones. They are underlain by bedded deep-water micritic limestones. The key-sections showing the beginning of development of shallow-water carbonate sedimentation occur in the Kamienna river valley near Bałtów (see Liszkowski, 1976, fig. 1). There are exposed here massive coral limestones (Bałtów Coral Limestones) forming flat coral-buildups which contain numerous foliaceous and submassive coral colonies occurring in micritic or biomicritic matrices (Roniewicz, Roniewicz, 1971; Gutowski, 1992, 2004a, 2006a). The local depressions between the massive coral buildups are infilled with bedded limestones showing a variable lithology – from mostly pelletal grainstones to limestones more micritic in character (Roniewicz, Roniewicz, 1971, fig. 2). The character of the coral assemblage suggests a calm environment attaining some dozen meters in depth and devoid of stronger-water activity. (Roniewicz, Roniewicz, 1971).

The foundation of coral buildups was limited initially to the topmost parts of older cyanobacteria-sponge bioherms of deep-neritic environment, such as those cropping out in the Podgrodzie-Przepaść area, about 20 km southward from Bałtów. Just in this area the appearance of the first foliaceous *Microsolena* corals was reported in the Wyszmontów–Ożarów railway cut by Gutowski (1992). Then, successively coral facies and associated bedded limestone facies prograded onto the foreland areas which originally had been the place of sedimentation of the deep-water platy micritic limestone with ammonites. Whereas the foundation of coral-buildups took place during the latest Middle Oxfordian (at the end of the Transversarium Chron) as shown by ammonites such as *Perisphinctes* (*Dichotomosphinctes*) ex gr. *wartae* Bukowski, *Proscaphites anar* (Oppel) and others, a strong progradation of coral-facies onto older micritic limestones occurred during the beginning of the Late Oxfordian, in the Bifurcatus Chron as evidenced by an ammonite assemblage of the genera *Perisphinctes* (*Perisphinctes*, *Dichotomoceras*), *Subdiscosphinctes* and *Passendorferia* (Gutowski, 1992, 1998; see also Brochwicz-Lewiński, Liszkowski, 1976; Brochwicz-Lewiński, Różak, 1976).

As the environment became shallower, detrital coralline deposits formed, leading to a change in coral faunas and the development of oncolitic limestones. A characteristic subunit at Bałtów, but also at nearby Lemierze, is an oncolitic limestone subunit, up to about 3 m thick, often containing large oncolites, and foliaceous to massive coral colonies, the latter commonly broken, abraded and covered by cyanobacteria crusts. The limestones clearly mark a phase of shallowing as evidenced by their lithological and faunal character, as well as their progradation over the whole visible areas of the north-eastern margin of the Holy Cross Mts. Moreover, they are affected by early dolomitization and silification at the top, indicating extremely shallow-water to subaerial conditions (Roniewicz, Roniewicz, 1971; Gutowski, 1992). The age of the youngest deposits as proved by ammonites, corresponds to the Late Oxfordian – to the Bifurcatus Chron, but also to the Hypselum Chron, as shown by *Taramelliceras externnodosum* (Dorn) and *Microbiplices* (see Gutowski, 1992, 1998) at Stoki Duże and Bałtów, respectively, near the upper boundary of the discussed deposits. The latter form (see Gutowski, 1998, pl. 1: 2; see also Pl. 1: 1) can be actually referred to as *Microbiplices anglicus vieluniensis* Wierzbowski et Matyja which is the characteristic subspecies occurring in the topmost part of the Hypselum Zone, *i.e.* the topmost part of the Oxfordian (*cf.* Wierzbowski, Matyja, 2014).

A somewhat different development of coeval deposits is recognized in the area between Lipniki, Jelenia Góra and Krzemionki Opatowskie. The old quarry of the iron-works at Lipniki shows a very reduced development of the massive coral limestones (Liszkowski, 1976, p. 116), and the upper boundary of the coral limestone-dominated interval can be possibly placed here at about 4.5 m above the base of the section (see Gutowski, 1992, fig. 16, beds 1, 2). It is the level where thick-bedded organodetrital limestones with solenoporoids, corals and crinoids are overlain by medium- to thin-bedded organodetrital to micritic chalky limestones with oolites, and nerineid gastropods. The latter represent already a younger chalky limestone-dominated interval (see below). Remarkable is the occurrence here in some beds of fairly numerous and well-preserved terrestrial-plant remains and limestone intraclasts (Liszkowski, 1972; Gutowski, 1992). Whereas the older currently non-existing quarries at Lipniki yielded some ammonites indicative of the Bifurcatus Zone of the Upper Oxfordian (see Gutowski, 1998, pl. 2: 5), ammonites coming from the younger deposits at Lipniki discussed above (unfortunately found in the rubble) are poorly diagnostic, indicating a wider stratigraphical interval from the uppermost Oxfordian (Hypselum Zone) to the lowermost Kimmeridgian (Bimammatum to Planula zones) (see Gutowski, 1992).

All these limestones (including the underlying coralliferous ones) yielded an abundant and diversified faunas of corals (Roniewicz, 1966), calcareous sponges, bryozoans (Hara, Taylor, 1996), brachiopods (Barczyk, 1969, 1970), bivalves – including oysters (Pugaczewska, 1971) and rudistids (Karczewski, 1969), nerineid gastropods (Karczewski, 1960; Wieczorek, 1979), echinoids (Radwańska, 2004), crinoids, and others (see also Liszkowski, 1962).

The coral buildups possibly formed in a close relationship with an older cyanobacteria-sponge bioherm complex, the occurrence of which was possibly controlled by the tectonic uplift of the Nowe Miasto–Iłża–Bałtów Fault Zone. This elevation evidently took place at the end of the Middle Oxfordian and the beginning of the Late Oxfordian – at the end of the Transversarium Chron and the beginning of the Bifurcatus Chron. The discussed coral buildups possibly did not range far west beyond the present distribution of the Upper Jurassic deposits. It may be suggested that they passed laterally in that direction into limestones of the sponge megafacies. A few isolated and poorly visible occurrences of bedded sponge limestones, including those at Jasieniec and Wola Lipieniecka in the middle and northern parts of the north-eastern margin of the Holy Cross Mts., yielded poorly recognized ammonite assemblages ("*Perisphinctes*") indicating a Middle to Late Oxfordian age for these deposits (see Różycki, 1950; Dembowska, 1953). This suggests the original occurrence of a zone of deeper water to the west of the centre of the coral buildups.

Chalky limestone (locally with oolites) – dominated interval (lowermost Kimmeridgian: Bimammatum to Planula/Platynota zones) (I: 2a–c)

This stratigraphical interval is sharply marked at its base by specially developed deposits described from the local quarries at Wólka Bałtowska near Bałtów. The succession begins here with conglomerate composed of various limestone pebbles resting on the erosional surface of older biogenic limestones. It is overlain by oolitic limestones, followed by micritic limestones showing lenses of fine-grained oolites. Both deposits contain abundant and varied remains of terrestrial-plants (tree trunks, leaves, conifer cones), but also other fossils, indicating shallow-marine and lagoonal environments (Liszkowski, 1972; Gedl, Ziaja, 2004; Ziaja *et al.*, 2023). These types of deposit correlate possibly with other plant-bearing limestones in this area (*e.g.*, oolitic limestones with limestone intraclasts and abundant plant remains at Lipniki: see above, also Gutowski, 1992), commonly occurring in a narrow stratigraphical interval corresponding generally to the boundary-beds between the lower and middle parts of the "Astartian" (Liszkowski, 1972, fig. 1; see also Pożaryski, 1948). These deposits (denoted as 2a having a character of a smaller transgressive-regressive subinterval) represent the beginning of the new sedimentary cycle and may be interpreted as having formed during a transgression which resulted in flooding of the surrounding forested land areas (islands). This transgression occurred directly after the Hypselum Chron and during the Bimammatum Chron, very near the base of the Kimmeridgian Stage, as indicated by ammonites found by J. Liszkowski in a close neighborhood of the discussed Wólka Bałtowska locality, and in similarly developed deposits, whose detailed interpretation is given herein for the first time, and as well by dinoflagellate cyst assemblages (Gedl, Ziaja, 2004). The ammonites include the amoeboceratid *Plasmatites lineatus* (Quenstedt) (Pl. 1: 2A, B). at Eugeniów, preserved with the original label of Liszkowski: "*Amoeboceras* – upper Rauracian–lower Astartian, Eugeniów, 1964". It should be remembered that the genus *Plasmatites* including the species *P. lineatus* appears at the base of the Kimmeridgian, but it is especially common in central Poland in the lowermost part of the Hauffianum Subzone – in the upper part of the Bimammatum Zone (see Wierzbowski *et al*., 2023a, and earlier papers cited therein, especially Matyja, Wierzbowski, 1997; Wierzbowski, Matyja, 2014). Another ammonite described by Liszkowski as "*Discosphinctes virgulatus* – Wolanka river valley", showing fine oolite in its matrix, is *Vineta* aff. *streichensis* (Oppel) (Pl. 1: 3A, B). This specimen is very close to that recently described from the Bimammatum Zone of the Cracow Upland showing strong, well-spaced bi and triplicate ribs of the aulacostephanid type in the umbilicus (Wierzbowski, 2022, pl. 14: 4A–C). Two further specimens come from "series with land plants at Skarbka Dolna" including a small-sized young specimen referred to as *Orthosphinctes* cf. *tiziani* (Oppel) (Pl. 1: 4) and a juvenile *Vineta* sp.; both these forms are also indicative of the Bimammatum Zone (*e.g.*, Schweigert, Callomon, 1997). These new data indicate for the first time, the approximate position of the base of the newly redefined Kimmeridgian Stage in the Upper Jurassic succession of the north-eastern margin of the Holy Cross Mountains.

Overlying is a thick sequence of deposits representing various types of chalky limestones with an abundant fauna of rudistid bivalves (diceratids), nerineid gastropods (*e.g.*, Karczewski, 1960, 1969, 1983; Wieczorek, 1979, 1983), small colonies of corals, and other invertebrates (brachiopods, bivalves, echinoids, crinoids), and of micritic limestones, commonly occurring in vast areas of the north-eastern margin of the Holy Cross Mts., from the Kamienna river valley in the south to Dobrut and Śniadków in the north. All these deposits reveal locally, especially in their lower part, numerous intercalations of oolitic limestones, reported from both southern and northern areas (Dembowska, 1953; Dąbrowska, 1968; Malinowska, 1970; Gutowski, 1992, 2006a) and recognized sometimes as belonging to separate oolitic units. These oolite subunits are, however, possibly of local character, and represent a set of smaller scale oolitic bodies within the large chalky limestone complex.

The upper boundary of the chalky limestone dominated interval as recognized herein is placed higher, at the spectacular banded chert levels, occurring between the Kamienna river valley in the south and the environs of Iłża (Błaziny) in the north. Such an approach better explains the appearance of larger-scale oolite units above (see next stratigraphical interval). The banded chert nodules occurring generally in a few closely-spaced chert levels within micritic limestones are interpreted as early diagenetic concretions developed along crustacean burrows (Gutowski, Pieńkowski, 2004; Gutowski *et al*., 2006). They originated in extremely shallow-water, near tidal flat environments, thus proving the shallowing or even emersion of the area, and marking the top of the sedimentary sequence (*cf.* Gutowski, 1992; 2006a). In some areas placed more westward the banded chert nodules are, however, missing, and the corresponding deposits are micritic limestones with a poor bivalve fauna and marls, possibly developed in a somewhat deeper environment. Such deposits have been recognized recently at Iłża–Zuchowiec (Wierzbowski, 2023; Wierzbowski *et al.*, 2023b) and the newly opened quarry at Śniadków.

Ammonites are encountered very rarely in the middle to upper parts of the chalky limestone interval. The fragmentarily preserved specimen referred to as *Idoceras* (*Subnebrodites*) sp. by Gutowski from the Błaziny section (see Gutowski, 1992, pl. 3: 2; 1998, pl. 1: 1; see also Pl. 1: 5) differs, however, from representatives of *Subnebrodites* in its extremely evolute coiling, the presence of simple ribs, and much higher position of the secondary ribs on the whorl side. It seems to be closer to the Tethyan genus *Trenerites* (see Sarti, 1993, 2002) which occurs from the upper part of the Planula Zone through the Silenum Zone (corresponding generally to the Platynota Zone) (Sarti, 2002; Enay, Howarth, 2019). Another specimen, coming from the uppermost part of the chalky limestone interval in the old Marylin–Śniadków quarry and referred originally to as "*Rasenia* (*Eurasenia*) cf. *vernacula* (Schneid)" by Gutowski (1992, pl. 5: 4; 1998, pl. 1: 5; see also Kutek, 1983 who mentioned occurrence of *Eurasenia* at this level; see also Pl. 1: 6), belongs to the later established genus *Vielunia* (*cf.* Wierzbowski *et al.*, 2010). It is especially similar to *Vielunia conspicua* (Schneid) known from the upper part of the Planula Zone to the lower/middle parts of the Platynota Zone of the Lower Kimmeridgian (see also Wierzbowski, 2017, 2022). It should be remembered that the celebrated specimens found at a similar level by A. Łuniewski in the old Marylin–Śniadków quarry, and referred to the genus *Ringsteadia* (*e.g.*, Dembowska, 1953), unfortunately not illustrated and lost during the Second World War, most likely belonged also to the genus *Vielunia*. They were considered for a long time as indicative of the Pseudocordata Zone (*e.g.*, Malinowska, 1970, p. 156), and thus giving a misleading correlation with the uppermost Oxfordian (*cf.* also Kutek, 1983).

In the middle/upper levels of the discussed chalky limestone-dominated interval (denoted as 2b), in the marginal area of occurrence of chalky limestones at Błaziny quarry, interbeds of grey marls, attaining about 2–3 m in thickness, are present. The same marly unit, but up to about 7 m thick, has been recognized recently within the coeval micritic limestones, representing an originally somewhat deeper environment at Iłża–Zuchowiec, placed a few kilometers westwards, beyond the range of chalky limestones capped by the banded chert levels (Wierzbowski, 2023; Wierzbowski *et al.*, 2023b). The discussed marly unit, because of its stratigraphical position corresponding possibly to the upper part of the Planula Zone, can be correlated with the Latosówka Marl Member distinguished in the Wieluń Upland, and the Częstochowa Upland within the deeper marine deposits, representing a foreland of the shallow-water carbonate platform. Another marly unit occurs locally at the top of the discussed chalky limestone-dominated interval (denoted as 2c): some marly intercalations are known moreover at the base of the overlying oolites and organodetrital limestones of the younger stratigraphical interval at Iłża Zuchowiec; possibly the same marly level, about 3.5 m thick, is recognized also at the top of the chalky limestones succession in the old Marylin–Śniadków quarry in the northern part of the north-eastern margin of the Holy Cross Mts. (Gutowski, 1992, Marylin–Śniadków, locality 10, bed 6), but the banded chert nodules are missing there. All these younger marly beds can be possibly correlated with the Zapole Marly Bed recognized in the Wieluń Upland and some areas of the Holy Cross Mts. at the top of the lower part (Polygyratus Subzone) of the Platynota Zone (Wierzbowski, 2017, 2020).

The bulk of the chalky limestone-dominated interval, which contains nerineid gastropods and rudistid bivalves, was deposited in a shallow-water, open-marine sedimentary environment of low relief and of rather stable substrate, forming a large carbonate bank located far from the coastline on the north-eastern margin of the Holy Cross Mts. (Wieczorek, 1979, 1983). The small coral colonies and oolitic limestones at Śniadków (*cf.* Dembowska, 1953; Gutowski, 1992) suggest an increase in water turbulence towards the northwest. The prevalence of deposits of a very high calcium carbonate content and of a high primary porosity in the sequence represented by chalky limestones is related to the paucity of marly to silty deposits. The only exceptions are two marly units having a special stratigraphical correlation value, marking tectonically or climatically-controlled phenomena, in a higher part of the sequence.

Oolitic to micritic-marly limestone – dominated interval (Lower Kimmeridgian: Platynota to uppermost Hypselocyclum zones) (I: 3a, b)

This higher interval begins with a distinctive transgressive surface followed by high-energy deposits (oolites, biogenic detrital limestones) which are exposed at Błaziny and Skarbka quarries. The deposits of the lower part of this interval represent two laterally interfingering environments: (1) the high-energy open marine oolite shoals, (2) low-energy lagoons sheltered by ooid shoals. Only two large bodies of oolitic limestones and closely related micritic limestones recognized as subintervals 3a and 3b are seen between Zawichost–Ożarów in the south-east and Wierzbica–Śniadków in the north-west – the lower and the upper ones. Although some segments of them were distinguished in the past under separate names, the similar development, and similar stratigraphical range of the two oolitic limestone bodies as defined herein strongly suggest their lateral continuity over the whole north-eastern margin of the Holy Cross Mountains. These large oolitic units were in the past attributed to the “upper Astartian” and /or to the “Kimmeridgian” according to the interpretation given (*e.g.*, Pożaryski, 1948; Dembowska, 1953; Malinowska, 1970). The large bodies of oolitic limestones commonly show large-scale cross-bedding. However, a more detailed study of transport direction has only been conducted at Wierzbica quarry in a fragment of the oolitic limestone succession (Gutowski, 1992; Wojciechowska, 2007), indicating a generally unidirectional transport of ooid grains towards the east. It seems to correspond well to the suggested NNW–SSE longitudinally-oriented oolite barriers which may have formed over “swell” areas situated over structurally controlled elevations of the seafloor as controlled by the Nowe Miasto–Iłża–Bałtów Fault Zone.

The lower oolite (3a) includes mostly the cross-bedded oolites, almost without fauna, occurring directly above the banded chert levels. It is recognized between Skarbka and Błaziny, corresponding approximately to the Skarbka Oolite Limestones and the Błaziny Oolite Limestones of Gutowski (1992, 1998, 2004b, 2006b). These oolites are a few meters thick (about 6 m at Skarbka quarry), and are overlain by micritic limestones and oolites – attaining also similar thicknesses. Locally, they are partly laterally replaced, and underlain by organodetrital limestones (Wierzbowski, 2023; Wierzbowski *et al.*, 2023b). These deposits, but mostly their upper part, show concentrations of the “chocolate cherts”. They are overlain in the north-western area between Błaziny and Wierzbica by strongly bioturbated limestone with commonly occurring myid bivalves, marked at its base by a regional hard-ground surface. On the other hand, the deposits directly overlying the oolites in the south – at Skarbka quarry – are strongly dolomitized, but the regional hardground surface can be also recognized here (Liszkowski, 1976; Gutowski, 1992, 2004b, 2006b).

Some ammonites found directly below and directly above the discussed lower oolite were interpreted by Gutowski (1992, 1998) as belonging to the genus/subgenus *Eurasenia*, but their critical revision indicates that all of them are in fact late representatives of the later introduced genus *Vielunia*. This interpretation (see also comments given above at the chalky limestone-dominated interval) refers also to the specimen "*Rasenia* (*Eurasenia*) sp." (see Gutowski, 1992, pl. 5: 6; see also Pl. 1: 7), found directly above the lower oolite at Wierzbica. These determinations indicate that the lower oolite, as corresponding to the Błaziny Oolite Limestones (and its lateral equivalent the Skarbka Oolite Limestones, as redefined here), cannot range stratigraphically higher than the middle part of the Platynota Zone of the Lower Kimmeridgian.

Above the lower oolite, as seen in the Wierzbica quarry section only, marly deposits about 7 m thick, follow. These deposits according to the author's observation consist of marls, marly limestones and micritic limestones that contain in their upper part interbedded oolitic limestones and marls. Capping these deposits are bivalve coquinas, about half a meter thick, which consist of the redeposited shells of semi-infaunal forms, mostly *Gervillia* and *Inoperna* occurring in a micritic matrix with loosely spaced small ooids. A single ammonite found here is *Eurasenia frischlini* (Oppel) (Pl. 1: 8) suggesting the presence of the middle to upper parts of the Platynota Zone (*cf.* Geyer, 1961; Wierzbowski, 2022, 2023). The discussed marly unit because of its stratigraphical position can be correlated with the over-regional marly level called the Góry Marl Member, corresponding *int.al.* to the "lowermost marly horizon" of Kutek (1968) from the south-western margin of the Holy Cross Mountains, marking a time of increased supply of siliciclastic-marly deposits during a lower sea-level period (Wierzbowski, 2017, 2020).

The upper oolite (3b) includes the lower parts of the Ożarów Oolite and Platy Limestones and of the Wierzbica Oolite and Platy Limestones (*cf.* Gutowski, 1992, 1998, 2004b, 2006b), and consists mostly of oolites – commonly cross-bedded, with banded and/or lithographic-type micritic limestone being their lateral equivalents. Its upper boundary runs in the middle of unit D as recognized by Gutowski (2004b, 2006a) in the Wierzbica quarry section. These deposits attaining about 15–17 m in thickness are recognized in the Wierzbica and Ożarów quarries. Similarly developed oolitic and micritic limestones are cropping out also at Iłża (see Dąbrowska, 1953).

The upper oolite has yielded the fairly abundant ammonites described both from Wierzbica and Ożarów quarries. They include: *Rasenia* (*Rasenia*) *inconstans* Spath (see Wierzbowski, 2022, pl. 2: 6), *Rasenia* (*Pachypictonia*) *perornatula* (Schneid) (see Wierzbowski, 2022, pl. 6: 1), *Rasenia* (*Pachypictonia*) sp. (Gutowski, 1992, pl. 5: 5; Gutowski, 1998, pl. 2: 2), *Eurasenia trimera* (Oppel) (see Wierzbowski, 2022, pl. 12), *Eurasenia pendula* (Schneid) (see Gutowski, 1992, pl. 5: 1; also pl. 5: 2 referred to as "*Rasenia* (*Eurasenia*) sp." which can be attributed with reservation to the same species). Additionally two ammonites described from coeval deposits at Iłża include: *Eurasenia gothica* (Schneid) and *E. rolandi* (Oppel) (Dąbrowska, 1983b; see also Wierzbowski, 2022, p. 77). These ammonites are very close to those described from similarly developed deposits in the SW margin of the Holy Cross Mts. and can be correlated with the upper Platynota Zone – lowermost Hypselocyclum Zone (Wierzbowski, 2020; see also Kutek, 1968). It is worth noting that both in the area of study as well as in the SW margin of the Holy Cross Mts., a directly overlying marly unit can be considered as having a wider stratigraphical importance, and it is correlated with the Kiełczygłów Marl Member known from the foreland of the shallow-water carbonate platform at the Wieluń Upland (see Wierzbowski, 2017, 2020).

The overlying deposits are represented by a set of beds of micritic and marly limestones and marls with rare fossils. They are well seen at the Ożarów and Wierzbica quarries attaining about 25 to 30 m in thickness (see Gutowski, 1992). The interval includes the deposits from the upper – marly part of unit D to unit F of the "oolite sedimentary cycle" of Gutowski (2004b, fig. 2; 2006a, fig. B2.16) in the Wierzbica quarry section. These deposits contain subordinate intercalations of organodetrital-oolitic limestones, locally with *Nanogyra* shells. The skeletal remains are, however, not very common, and together with rarely encountered levels with trace-fossils, mostly *Thalassinoides*, represent a rather monotonous faunal assemblage composed mostly of oysters and crustaceans, but without cephalopods. The facies pattern in the upper part of the transgressive-regressive major sequence differs markedly from that in the lower part: it is dominated by micritic and marly limestones to marls with monotonous impoverished faunal assemblages of the inner parts of the shallow-water carbonate platform. Subtle changes in the open-marine environment are difficult to recognize in this area, and the occurrence of smaller-scale sequences can be easily overlooked without detailed studies.

The uppermost part of the discussed interval consists of deposits showing a somewhat different lithological development. In the south (Ożarów quarry) it is mostly represented by marly deposits, about 5 m thick, with an erosional surface inside covered with quartz grains, and topped by the hard-ground surface. In the north (Wierzbica quarry) the corresponding deposits show a more diversified facies pattern. They represent here a subtidal channel-fill sequence composed of oolite-organodetrital grainstones with abundant lithoclasts, followed by silty marly mudstones with abundant quartz grains, glauconite grains and mostly oyster shell debris with low-angle cross-lamination. Locally accumulation of flat limestone pebbles, plant detritus, in places even tree-trunks (Gutowski, 1992, 2004b, 2006a; Woźniak, 2007), and pterosaur tracks (Pieńkowski, Niedźwiedzki, 2005) have been encountered, confirming the intertidal formation conditions of these deposits. These highly diversified deposits markedly vary in their thickness from a few centimeters to about 10 m. The overlying discontinuous micritic limestone bed is highly bioturbated – commonly with *Thalassinoides*, and is topped by the hard-ground surface encrusted by oysters and heavily bored by lithophags (Gutowski, 1992, 2004b, 2006a).

A few ammonites, *Eurasenia vernacula* (Schneid) (see Wierzbowski, 2022, pl. 11: 1) and *Prorasenia* sp. found at the top of the discussed stratigraphical interval in the Wierzbica quarry section are indicative of the upper part of the Lower Kimmeridgian (especially of the Hypselocyclum Zone). More precise data, based on ammonites coming from directly younger deposits, however, indicate that the discussed stratigraphical interval ranges through the Hypselocyclum Zone but excluding its uppermost part.

The uppermost part of the discussed interval displays deposits of tidal flats that are dissected by a network of tidal channels, which can be observed at Wierzbica quarry. A decrease in grain size towards the top suggests some progradation of the tidal flat, which was abruptly stopped by the development of an eminent erosional transgressive surface marking the onset of the next major transgressive-regressive sequence. This phenomenon corresponds to the boundary between the megasequences COK and LUK of Kutek (1994), and also signifies the end of the major interval/sequence I: 3 beginning the successive stage in development of the Late Oxfordian to Early Kimmeridgian shallow-water carbonate platform in the Holy Cross Mts.

Oyster lumachelle and micritic limestone to marl – dominated interval (Lower Kimmeridgian: uppermost Hypselocyclum – Divisum zones – to Upper Kimmeridgian: especially Acanthicum/Mutabilis Zone) (I: 4a, b)

The deposits are exposed mostly in Wierzbica quarry in the north, and in Ożarów quarry in the south. Some differences in the development of these deposits has resulted in recognition of two lithostratigraphical units (Gutowski, 1992, 1998, 2006a): the Wierzbica Oyster Lumachelle and the Ożarów Oyster Lumachelle, in a lower part of the interval (distinguished herein as subinterval 4a).

The Wierzbica Oyster Lumachelle is fully exposed at the Wierzbica quarry section, where it attains about 28 m in thickness and consists of several subunits (Gutowski, 1992). The lowermost one, about 3 m thick, consists of densely packed shells – mostly of oysters, especially *Actinostreon* ("*Lopha*", "*Alectryonia*"), associated with other bivalves *Trichites, Isognomon*, *Nanogyra*, *Liostrea*, *Mytilus*, "*Trigonia*", *Pleuromya* and brachiopods – mostly *Epithyris* (Dzik, 1979; Machalski, 1993, 1998). The discussed remarkable lumachelle of crowded oysters (*Actinostreon*) evidently reveals some episodes of reworking of the original deposit indicating the presence of high-energy events (*cf.* Seilacher *et al.*, 1985; Machalski, 1993).

The overlying deposits of the Wierzbica Oyster Lumachelle consist of *Nanogyra* lumachelle beds (generally composed of non-crushed shells, and only subordinately of their detritus) interlayered with micritic limestone and marly beds. Bed surfaces covered with flat oyster shells of *Deltoideum delta* occur commonly in the uppermost part of the discussed interval (Machalski, 1989). The whole sequence of these deposits attains a thickness of about 25 m and is made up in equal proportions of *Nanogyra* lumachelles and micritic limestones and marls.

Similar deposits composed of *Actinostreon* lumachelles, and the overlying *Nanogyra* lumachelles and micritic limestones and marls were recognized at Iłża (Dąbrowska, 1953) and at Marylin–Śniadków (Dembowska, 1953).

The Ożarów Oyster Lumachelle as described in detail by Gutowski (1992) attains about 20 m in thickness being truncated erosionally by Albian deposits. It consists mostly of *Nanogyra* lumachelle beds, composed of non-crushed shells and of their hash, and subordinately of marly beds.

The discussed deposits yielded some ammonites found especially at the Wierzbica section. These include: *Ataxioceras hypselocyclum hypselocyclum* (Fontannes) (Gutowski, 1992, pl. 4: 5; 1998, pl. 1: 3, and *Ataxioceras* (*Parataxioceras*) *lothari huguenini* Atrops (originally referred to as *A. hypselocyclum hypselocyclum*, see Gutowski, 1992, pl. 4: 4; 1998, pl. 1: 4; Pl. 1: 9) occurring directly above the *Actinostreon* bed in the lower part of the section and, indicative of the uppermost part of the Hypselocyclum Zone: the Lothari Subzone and the *semistriatum* horizon (Atrops, 1982); as well as *Garnierisphinctes semigarnieri* (Geyer) (Gutowski, 1992, pl. 6: 2; 1998, pl. 1:6) and *Crussoliceras atavum* (Schneid) (Gutowski, 1992, pl. 6: 1, 2; 1998, pl. 2: 4), in the middle part of the section (see also Kutek, 1983), indicative of the Divisum Zone. The overlying marls and lumachelles rich in *Nanogyra* shells contain Mediterranean-Submediterranean ammonites of the closely related genera *Crussoliceras* and *Garnierisphinctes* (see Enay *et al.*, 2014), found both in the Wierzbica and Ożarów quarries, indicating the flooding of the older carbonate platform area. The concentration of their shells, as noted about 20–30 m above the indicated *Actionostreon* lumachelle, suggests stratigraphical condensation correlated with a high sea-level, presumably at the end of the Crusoliensis Subchron of the Divisum Chron.

The overlying deposits (distinguished herein as subinterval 4b; see also Gutowski, 1992, 1998, 2006a) are absent in the southern part of the north-eastern margin of the Holy Cross Mountains because of the Neo-Cimmerian uplift and following erosion. Their most complete sequence is in the north, especially at Wierzbica quarry, although because of the soft nature of the rocks it is generally poorly exposed here. The deposits attain here about 110 m in thickness as seen in core sections (Pożaryski *in*: Malinowska, 1970, p. 167, 168). They consist of well-bedded marls and clays containing thin subordinate intercalations of lumachelles with *Nanogyra*; exceptionally a pronounced subunit of lumachelle, 3 m thick, has been observed in the middle part of the discussed interval. Presumably the upper part of the Divisum Zone, which is correlated with the Uhlandi Subzone and is marked by the common appearance of aspidoceratid ammonites (mostly *Pseudhimalayites*) in other areas of the Holy Cross Mts., may be present here. The topmost regressive part of the major sequence I: 4 is seen only in boreholes at Wierzbica (Pożaryski *in*: Malinowska, 1970, p. 168) where it consists of dolomitic siltstones with small quartz grains, locally shell debris, and fragments of wood.

These deposits were distinguished by Dąbrowska (1983a) as the Kotlarka Claystone and Lumachelle member and by Gutowski (1992, 1998, 2006b) as the Guzów Clays and Lumachelles. They were recognized and described also in other places of the north-eastern margin of the Holy Cross Mts., mostly at Iłża (Pożaryski, 1948, Dąbrowska, 1953, 1983a) and Krogulcza (Malinowska, 1970). It should be remembered that the characteristic detrital bioclastic oyster lumachelle, recognized as the Malenie level and placed originally at the top of the Guzów Clays and Lumachelles by Gutowski (1992, 1998, 2006b) is actually excluded from the discussed stratigraphical interval and placed in the following one (see below).

Detailed biostratigraphical data coming from the deposits discussed are rather scarce. The ammonites coming from the directly underlying and the overlying deposits strongly suggest, however, that at least a large part of the discussed interval corresponds to the Acanthicum/Mutabilis Zone of the Upper Kimmeridgian.

Oyster lumachelle – bioclastic-detrital limestone to nerineid limestone – dominated interval (Upper Kimmeridgian: middle Eudoxus Zone – to lowermost Autissiodorensis Zone) (I: 5)

These are the youngest Jurassic deposits exposed in the north-eastern margin of the Holy Cross Mts. They have been studied – mostly in their northern sector of occurrence – at Malenie and Krzyżanowice near Iłża (Pożaryski, 1948; Dąbrowska, 1953, 1957, 1983a, and earlier papers cited therein) – the description given below with new observations refers mostly to that area, but similar deposits are known also at Wierzbica and Krogulcza. Additionally, coeval deposits differing somewhat in their development (see Pożaryski, 1948, 1976) recognized already outside the north-eastern margin of the Holy Cross Mts., at the Annopol–Rachów Anticline – are also briefly commented on below.

The succession of deposits at Malenie and Krzyżanowice consisted in its lower part (see Pożaryski, 1948; Dąbrowska, 1953, 1957) of lumachelles composed mostly of oyster and terbratulid shells (with some addition of other shells – mostly "*Trigonia*"), about 4 m in thickness. Overlying deposits included a prominent sandstone bed composed of abundant shell hash with quartz and glauconite grains – a few tens of centimeters thick, and the "upper detrital lumachelle" composed mostly of shell detritus with a marked admixture of detrital quartz and chert grains – up to about 1 cm in diameter. These deposits attained from about 1–2 m to even 4 m in thickness. All of them were distinguished by Dąbrowska (1983a) as the Malenie Lumachelle and Siltstone member. Detailed studies of the section, exposed recently at Krzyżanowice, have revealed in detail, however, a more complicated structure pattern. The section begins here with deposits possibly representing a middle part of the unit discussed above – from the prominent sandstone bed – 0.65 m in thickness (base not exposed), and the directly overlying deposits of the "upper detrital lumachelle": there then come 0.38 m – organodetrital limestone bed, with at the top a 0.05 m layer of sandstone; then 0.60 m – organodetrital limestone, with at the top a 0.05 m sandstone; then 1.10 m organodetrital limestone, with at the top sandstone. These deposits are distinctly cross-bedded with well-distinguished cross-bedding sets, generally inclined (up to about 20°), mostly to the west. These deposits are evidently of nearshore character (*cf.* Dąbrowska, 1953, 1957) showing cross-laminated sets generally inclined towards the west which is generally consistent with the projected, approximately longitudinal elevation of the substrate related to the Nowe Miasto–Iłża–Bałtów Fault Zone. Moreover, it may be suggested that the specific development of the deposits of the lower part of the sequence was partly influenced by tectonic activity within this fault zone.

The overlying younger deposits at Malenie–Krzyżanowice include a fairly thick subunit of limestones in which nerineid gastropods are dominant, about 6 m in thickness. It contains beside nerineids (*Nerinea*, *Cryptoplocus*, *Nerinella* and others), also other gastropods (*Harpagodes*, *Natica*), bivalves (ostreids, "*Trigonia*"), and brachiopods (Karczewski, 1960, 1983; Wieczorek, 1983; see also Dąbrowska, 1957, 1983a), and locally vertebrate bone accumulations, especially of turtles (Borsuk-Białynicka, Młynarski, 1968) and pliosaurids (Tyborowski, Błażejowski, 2019). The youngest deposits are marls without macrofaunal rests, but with ostracods, attaining from several centimeters to about 2 m in thickness (Dąbrowska, 1957). These deposits were distinguished by Dąbrowska (1983a) as the Krzyżanowice Nerineid Limestone bed and by Gutowski (1992, 1998, 2006b) as the Krzyżanowice Nerineid Limestone.

Similar deposits although poorly exposed and generally not studied in detail, are known also in some other areas north-west of Malenie–Krzyżanowice, like Zalesice at Wierzbica, and Krogulcza (see Pożaryski, 1948; Malinowska, 1970). A more complete succession of these deposits seen in boreholes near Wierzbica (Pożaryski *in*: Malinowska, 1970, p. 168) includes about 7 metres of siltstones with small bivalves, organodetrital limestones with quartz and chert grains with glauconite, and sandy dolomites with some bivalves, which are overlain by limestones containing numerous bivalves and gastropods, a few metres in thickness. Similar deposits were also pierced by shafts and shallow boreholes at Ruda Wielka and Krogulcza where the "Krogulcza oyster lumachelle" is overlain by nerineid limestones a few metres thick topped locally by gray marls (Różycki, 1939).

The chronostratigraphical interpretation of all these deposits has been well established recently due to new finds of ammonites in the "detrital lumachelle" of the lowermost part of the discussed interval at Krzyżanowice. The occurrence here of *Aulacostephanus eudoxus* (d'Orbigny) (Pl. 4: 1; see also Tyborowski, Błażejowski, 2019, fig. 2B) along with *Aspidoceras caletanum* (Oppel) (Pl. 4: 2) can be treated as indicative of the Caletanum Subzone of the middle part of the Eudoxus Zone of the Upper Kimmeridgian (*cf.* Hantzpergue, 1989). On the other hand, the occurrence of the previously only known ammonite from directly overlying deposits – a small cardioceratid referred to as "*Amoeboceras* ex gr. *anglicum* (Salfeld)" coming from nerineid limestones (Dąbrowska, 1957, 1983a) – unfortunately not illustrated and lost – is consistent with such a stratigraphical interpretation. This ammonite, referred to the small-sized genus *Nannocardioceras*, suggests the uppermost part of the Eudoxus Zone or the lowermost part of the Autissiodorensis Zone of the Upper Kimmeridgian (*cf.* Wierzbowski, Wierzbowski, 2019). Still younger are marly deposits occurring markedly in boreholes towards the north, near Radom, overlying here nerineid limestones – they can be attributed to the uppermost Kimmeridgian (see Cieśliński, Pożaryski, 1970, p. 190). The marked development of these marly deposits (see also Pożaryski *et al.*, 1958) indicates also the gradual disappearance of the discussed oyster lumachelle to nerineid limestone interval towards the north.

The corresponding deposits east of the Holy Cross Mts. are exposed in the Annopol–Rachów Anticline where they have been studied in detail by Pożaryski (1948, 1976). These deposits are lumachelles with terebratulids below, resting directly on marls to clays with *Nanogyra*, and covered by dolomites with fragments of bivalve shells, which are in turn capped by oyster lumachelles with detrital quartz and chert grains. The latter, attaining here about 5–6 m in thickness, show marked lithological similarity to the "upper detrital lumachelle" at Krzyżanowice in the north. These are overlain by a thin layer of sandstone, followed by marly dolomites, about 6 m thick, showing some intercalations of hard limestones, which show also some similarity to the youngest limestones at Krzyżanowice. All these deposits can be thus correlated with the Upper Kimmeridgian (Pożaryski, 1976; Niemczycka, 1976, fig. 22).

The development of the discussed transgressive-regressive stratigraphical interval/sequence I: 5 resulted from the activity of wider, possibly climatically controlled factors but superimposed on the local tectonic uplift. The occurrence of nerineid chalky limestones following the near-shore bioclastic-detrital limestones is generally considered to be a consequence of deepening of the environment. It is also a stratigraphical interval from which the ammonite *Nannocardioceras* was reported (Dąbrowska, 1957). It is worth noting that this group of ammonites marks the maximum of marine transgression at the boundary between the Eudoxus Chron and the Autissiodorensis Chron during the Late Kimmeridgian, not only in Poland but also in other areas of central and north-western Europe (*e.g.*, Hantzpergue, 1995; Gygi *et al.*, 1998; Wierzbowski, Wierzbowski, 2019). The decline of the whole sequence is marked possibly by deposition of marls with a poor assemblage of ostracods (Dąbrowska, 1957). Neglect of the regional character of the discussed sequence as stated by Świdrowska *et al.* (2008, p. 51) who recognized "no evidence of a large regional role of the discontinuity surface proven in the Eudoxus Zone in NE margin of the Holy Cross Mts" is thus not accepted herein.

SHALLOW-WATER CARBONATE SUCCESSION OF THE NORTH-WESTERN MARGIN OF THE HOLY CROSS MOUNTAINS

LOCATION AND CRITERIA OF STRATIGRAPHICAL SUBDIVISION

The Upper Jurassic deposits are exposed from the south-eastern limb of the Gielniów Anticline through the Tomaszów Mazowiecki Syncline and down (southwards) to the Sulejów Anticline (Fig. 1). The southern boundary of the north-western margin of the Holy Cross Mts. is placed half way between Sulejów and Przedbórz, near Stobnica and Ręczno (Kutek, 1962). Three main groups of outcrops (including those no longer existing, but described in the past) are distinguished: (1) between Tomaszów Mazowiecki and Opoczno in the north-east, (2) the environs of Sulejów, (3) between Stobnica and Ręczno in the south. Additionally, the succession of the Upper Jurassic deposits has recently become well known due to several shallow drillings placed at the north-eastern and southern limbs of the Tomaszów Mazowiecki Syncline (Matyja, Wierzbowski, 2014). Seven main stratigraphical intervals in the succession characterized by different lithology and controlled biostratigraphically are distinguished and correlated with older lithostratigraphical units recognized here (Kutek, 1961, 1962; Matyja, Wierzbowski, 2014). The discussed succession attains the widest stratigraphical extent in the whole Holy Cross Mountains, ranging from the Lower Kimmeridgian to the Lower Tithonian.

The intervals recognized in the Upper Jurassic succession (Fig. 2) are interpreted as major transgressive-regressive sequences (II: 1–7). The sequences I: 1–2 correspond to the COK megasequence, the sequences II: 3–4 to the LUK megasequence, and the sequence II: 5–7 to the KVB megasequence of Kutek (1994). It appears that the stratigraphical content of megasequences in the north-western margin of the Holy Cross Mts is, however, somewhat different from that in the north-eastern margin (see above), which confirms the tectono-stratigraphic status of these units, and the diachronous character of their boundaries (*cf.* Kutek, 1994; Wierzbowski, 2020). This is especially the case of the boundary between the COK and LUK megasequences which in the north-western margin runs within the lower part of the Hypselocyclum Zone, whereas in the north-eastern margin it lies within the upper part of the Hypselocyclum Zone.

The development of major sequences II: 1–7 was controlled by changes of sea-level which strongly influenced the spatial and temporal distribution of the deposits. These resulted both from orbitally-controlled eccentricity cycles, but also from superimposed synsedimentary tectonic phenomena. The Upper Jurassic bedded and massive sponge limestones of the Częstochowa Sponge Limestone Formation, underlying shallow-water carbonates, are indicative of a deep-water neritic environment. They show a marked reduction in their thickness northwards from Opoczno and the Grójec Fault Zone. The synsedimentary tectonic movements occurred here during the early Late Oxfordian – mostly in the Bifurcatus Chron (Matyja, Wierzbowski, 2014). The discussed tectonic phenomena in the north-western margin demonstrated also their marked effects directly thereafter during the Hypselum Chron of the Late Oxfordian which resulted in a marked difference in thickness of the overlying micritic limestones of the Pilica Fm. These deposits generally smoothed the existing original topographic denivelations on the sea-floor between the older buildups and basins within the sponge megafacies (Matyja, Wierzbowski, 2014, fig. 2).

DESCRIPTION AND INTERPRETATION OF STRATIGRAPHICAL SUCCESSION (II)

Chalky limestone (locally with oolites) – dominated interval (Lower Kimmeridgian: Bimammatum to Platynota zones) (II: 1a, b)

This interval consists of soft porous chalky limestones containing abundant hermatypic corals, nerineid gastropods, rudistid and other bivalves, brachiopods, echinoids and other faunal components (Barczyk, 1961). Locally, smaller-scale bodies of oolitic limestones are encountered, especially in higher part of the interval discussed, but the most common are oncolitic limestones (Wieczorek, 1975). These deposits correspond jointly to the upper part of the "Rauracian" and the whole "Astartian" of Barczyk (1961), to an upper part of lithological Complex I and the whole of Complex II of Wieczorek (1975), and to the "coral formation" and a lower part of the "oolitic formation" (the latter corresponding to the lower member of the Kurnędz Limestones – D_1) of Matyja and Wierzbowski (2014).

The base of the discussed deposits is placed at the top of the bedded limestones with cherts and massive sponge limestones corresponding to the Częstochowa Sponge Limestone Formation, covered by micritic limestones of the Pilica Formation, both encountered in boreholes at the southern limb of the Tomaszów Mazowiecki Syncline, and also seen in isolated outcrops in the past at Opoczno and south of Sulejów (Dmoch, 1958; Barczyk, 1961; Merta, 1972; Matyja, Wierzbowski, 2014). The ammonites found in these deposits are indicative of the Bifurcatus Zone and at least the lower part of the Hypselum Zone of the Upper Oxfordian (Matyja, Wierzbowski, 2014, see also Barczyk, 1961, and Merta, 1972). These indicate that the base of the chalky limestone dominated interval is placed not far from the base of the Bimammatum Zone (*i.e.* the base of the Kimmeridgian).

A well separated marly unit a few metres in thickness is seen in the middle of the discussed chalky limestone interval. It was encountered in boreholes in the southern limb of the Tomaszów Mazowiecki Syncline (Matyja, Wierzbowski, 2014). Possibly the same marly level denoted as bed 7 was recognized in an outcrop at Komorniki, south of Sulejów (Barczyk, 1961). The latter locality yielded some ammonites found in the directly underlying bed 6 along with corals and other abundant fossils – referred to as *Perisphinctes fontannesi* (Choffat) (see Barczyk, 1961, pl. 7: 1) – which is an *Orthosphinctes* – like the form known from the lowermost Kimmeridgian. The discussed marly unit can be possibly compared with the Latosówka Marl Member known from the upper part of the Planula Zone in the Wieluń Upland, and other parts of the Holy Cross Mts. (*e.g.*, Wierzbowski, 2017). This marly unit separates a lower part of the discussed chalky limestone interval attaining at least about 100 m in thickness from its upper part, about 150 m thick (denoted previously as the separate lithostratigraphical unit as discussed above, and distinguished herein as II: 1a and II: 1b subintervals). It was treated in the past as defining the top of the "Rauracian" (Barczyk, 1961) – but this "stage" appeared to include here both the typical deposits of the sponge megafacies (*i.e.* corresponding to the Częstochowa Sponge Limestone Fm.) below with *Taramelliceras* (*Richeiceras*) *pichleri* (Oppel) [(see Barczyk, 1961, p. 10, 75), being in fact *T.* (*R.*) cf. *tricristatum* (Oppel), as interpreted herein, indicative especially of the lower part of the Hypselum Zone of the uppermost Oxfordian (Wierzbowski, Matyja, 2014)], and the overlying coralliferous limestones of the lowermost Kimmeridgian.

The deposits seen in outcrops south of Sulejów representing higher parts of the upper chalky limestone-dominated interval, and corresponding to beds 8–21 of Barczyk (1961, 1980), have been subdivided by Wieczorek (1975) into three lithostratigraphical complexes. The lower one consists mainly of oncolitic limestones (erronously referred to as "coarse oolitic limestones" by Barczyk, 1961, 1980). This complex contains numerous solenoporoids, hermatypic corals, thick-walled bivalves (oysters, rudistids), and nerineid gastropods indicating shallow-water conditions of moderate turbulence. The middle complex consists mainly of micritic and peloidal limestones with less numerous faunal assemblages generally indicative of a calmer sedimentary environment. The remains of a terrestrial flora described by Premik and Zabłocki (1925) possibly came from that part of the succession. The upper complex shows a larger lithological differentiation of deposits with fairly common oncolitic limestones indicating generally shallow-water, of weak to moderate water activity.

The chronostratigraphical position of the discussed youngest deposits of the chalky limestone-dominated interval has been based mostly on the interpretation of fairly numerous ammonites coming from the single bed 22 known from several outcrops near Podkurnędz, directly above the whole succession (see Barczyk, 1961). In accordance with the interpretation of these ammonites, the underlying deposits were attributed in the past to an upper part of the Platynota Zone and a lower part of the Hypselocyclum Zone (Wieczorek, 1975), or even to the Planula Zone and a lower part of the Platynota Zone (Barczyk, 1980). In fact, the original palaeontological interpretation of these ammonites needs essential revision, which is given below as follows: "*Perisphinctes pseudobreviceps* Wegele" (Barczyk, 1961, p. 21, 76–77, pl. 5: 5) = *Orthosphinctes* (*Orthosphinctes*) *polygyratus* (Reinecke); "*Perisphinctes* cf. *pseudobreviceps* Wegele" (Barczyk, 1961, p. 24) = *Orthosphinctes* (*Orthosphinctes*) *freybergi* Geyer; "*Planites lictor* (Fontannes)" (Barczyk, 1961, p. 24, 77–78, pl. 8) = *Orthosphinctes* (*Lithacosphinctes*) *evolutus* (Quenstedt) (Pl. 2: 1); "*Rasenia* cf. *stephanoides* (Oppel)" = *Orthosphinctes* sp.; "*Rasenia trimera* (Oppel)" (Barczyk, 1961, p. 18, 79–80, pl. 7: 2) = *Vielunia conspicua* (Schneid) (Pl. 3: 5); "*Ataxioceras semistriatum* Schneid" (Barczyk, 1961, pl. 5: 3) = microconch (or juvenile) of *Vineta* (Pl. 3: 3), whereas another not illustrated specimen is an unidentified Aulacostephanidae (?*Vineta*) (Pl. 3: 4); in addition, a single not illustrated specimen referred to as *Rasenia* cf. *trimera* (Oppel) in the collection of Barczyk (1961), coming from the same bed 22, is very close to *Rasenia* (*Pachypictonia*) *dorsata* (Schneid) (Pl. 3: 1), and is similar to a specimen collected by the present author in rubble in Podkurnędz quarry, possibly coming from the same level (Pl. 3: 2). In consequence, the whole assemblage of ammonites appears indicative of the Polygyratus Subzone, and possibly the lowermost Desmoides Subzone, representing the lower and the lowermost middle parts of the Platynota Zone (*cf.* Atrops, 1982; Wierzbowski, 2017, 2022). The revised assemblage of ammonites is also very close to that composed mostly of representatives of *Orthosphinctes* with subgenera *Orthosphinctes*, *Lithacosphinctes* and *Ardescia* known from a middle part of the upper member (D_2) of the Podkurnędz limestones at Podkurnędz quarry, as described by Matyja and Wierzbowski (2014). All these ammonites are indicative of a stratigraphical level at the boundary between the lower and middle parts of the Platynota Zone, showing here and elsewhere (*cf.* Wierzbowski, 2017) features of stratigraphical condensation. In consequence, the discussed ammonite assemblage firmly locates the boundary between the chalky limestone-dominated interval (II: 1), and the overlying oolite-marly-dominated interval (II: 2) at the boundary between the lower and the middle part of the Platynota Zone, and thus indicates that the underlying deposits of the upper part of the chalky limestone-dominated interval correspond mostly, if not totally, to the lower part of the Platynota Zone only.

Summarizing, the shallow-water deposits of the chalky limestone dominated interval spread across a rather flat area of the whole north-western margin of the Holy Cross Mts., with little to moderate variation in their sediment type (depending on the local occurrence of corals *versus* nerineid gastropods and rudistid bivalves, and/or abundance of oncolites, and micritic matrix), except for local incursion of oolites. The whole sequence may be subdivided into two smaller-scale sequences I: 1a and I: 1b, with their boundary placed at the eminent marly unit corresponding to the Latosówka Marl Mbr., formed at the end of the Planula Zone, and having a regressive character. The beginning of the II: 1 sequence corresponds possibly to the base of the Bimammatum Zone, *i.e.* to the base of the Kimmeridgian, and the top of the sequence is located directly below the boundary between the lower and the middle parts of the Platynota Zone. These lower and the upper boundaries of the sequence correspond to the over-regional transgressive surfaces resulting possibly from the orbitally-controlled cyclicity.

Oolitic to marly limestone/marl – dominated interval (Lower Kimmeridgian: Platynota to Hypselocyclum zones) (II: 2)

This stratigraphical interval corresponds nearly to the whole "Lower Kimmeridgian" of Barczyk (1961, 1980: beds 22–37) and almost the whole Complex III of Wieczorek (1975), except the youngest beds 38–39 yielding the ammonites and treated herein as the basal part of the overlying stratigraphical interval II: 3. The discussed stratigraphical interval corresponds also to a middle part of the "oolite" formation of Matyja and Wierzbowski (2014) including the upper member of the Kurnędz Limestones (D_2) and the overlying marly unit (D_3). The latter was correlated by Matyja and Wierzbowski (2014) with the "lowermost marly unit" of Kutek (1968) from the SW margin of the Holy Cross Mts. = Góry Marl Member of Wierzbowski (2017), but it seems better to compare it with a still higher marly unit – the Kiełczygłów Marl Member (Wierzbowski, Głowniak, 2018; see also Wierzbowski, 2017).

The stratigraphical interval in its lower part, attaining 45–60 m in thickness, consists of micritic limestones and marls with some bodies of oolitic limestones showing large-scale cross-bedding (Wieczorek, 1975; Matyja, Wierzbowski, 2014). The faunal content is diversified – in some beds there are encountered nerineid gastropods and even corals (in the lowermost part only), in others – rich assemblages of bivalves and brachiopods (Barczyk, 1961). A distinct marly unit, a few metres thick, occurs in the lowermost part of the interval, but some marly beds are seen also in its upper part (Matyja, Wierzbowski, 2014). These two marly levels correspond possibly to the Zapole Marl Bed, and the Góry Marl Member (*cf.* Wierzbowski, 2017), respectively.

The upper part of the discussed interval consists of oolitic and organodetrital limestones, well seen in boreholes (Matyja, Wierzbowski, 2014), but poorly seen in outcrop (*cf.* Barczyk, 1961), and of the overlying thick (about 20 to nearly 40 m thick) marly unit composed of marls with intercalations of marly limestones. The latter is recognized in cores at the north-eastern and southern limbs of the Tomaszów Mazowiecki Syncline (Matyja, Wierzbowski, 2014), and in outcrops south of Sulejów, where it yields rich microfaunal assemblages of foraminifers and ostracods (Barczyk, 1961).

The stratigraphical position of the whole oolite to marly-dominated interval (II: 2) can be defined by an ammonite fauna discovered at it base and indicating the boundary between the lower and the middle parts of the Platynota Zone (see above), and another one occurring at the top of the discussed interval, being indicative of the lower part of the Hypselocyclum Zone (see below). Especially well developed is the marly unit at the top which may be correlated with the Kiełczygłów Marl Mbr., having a wide distribution in central Poland (Wierzbowski, 2017, 2020). It is referred to the lower part of the Hypselocyclum Zone (the lower part of the Hippolytense Subzone), and it closes the discussed sequence.

Oncolitic to oolitic and marly limestone – dominated interval (Lower Kimmeridgian: Hypselocyclum Zone) (II: 3)

It is convenient to distinguish this interval as a special one in the north-western margin because of a specific combination of lithological features not recognized in any other area of the Holy Cross Mountains. The lower part of the discussed stratigraphical interval was studied by Matyja and Wierzbowski (2014) in boreholes drilled in the north-eastern and southern limbs of the Tomaszów Mazowiecki Syncline, corresponding to the northern and central parts of the north-western margin. This part of the succession was distinguished by these authors as the uppermost part of the "oolitic" formation, and additionally as the member D_4. It consists of oncolitic, oolitic and bioclastic limestones which attain usually about 22–30 m in thickness, but in areas of stronger development of oolitic limestones may reach even up to 43 m as noted in the Kunice borehole. Similar deposits were seen in the outcrops 38–40 south of Sulejów corresponding to beds 38 and 39 of Barczyk (1961, 1980) which yielded some ammonites.

The higher part of the interval discussed consists of micritic marly limestones and marls attaining up to about 70 m in thickness as seen in the boreholes. These deposits were previously attributed to the lower part of the "coquina" formation (Matyja, Wierzbowski, 2014), but they differ from typical deposits of this formation in lacking or with a very rare occurrence of oyster lumachelles (*cf.* Wierzbowski, Głowniak, 2018). It is worth noting that in the Łęczno borehole section located at the westernmost part of the north-western margin, a few kilometers south-west of Sulejów, a packet of oolitic limestones a few metres thick has been recognized directly above the top of the discussed stratigraphical interval, which can be correlated with the basal part of the "coquina" formation (see below). The precise recognition of the boundary between the deposits of the discussed interval and the overlying ones of the "coquina" formation has been not always possible in the outcrops at Sulejów (*cf.* Barczyk, 1961) from which only fragmentary sections were described, and their detailed correlation was difficult. Nevertheless some of these deposits, like those from outcrops 41, 42, 45, can be possibly attributed to the discussed stratigraphical interval.

The ammonites found in the lowermost level of the discussed stratigraphical interval (bed 39 at Sulejów – see Barczyk, 1961) include: *Involuticeras involutum* (Quenstedt) (Barczyk, 1961, pl. 9: 1; see also Pl. 2: 2), *Aspidoceras* sp., and *Ataxioceras* – originally referred to as *A.* aff. *semistriatum* Schneid (Barczyk, 1961, p. 30, 75–76) which seems, however, closer to the subgenus *Schneidia* (*cf.* Atrops, 1982) and may be referred to as *Ataxioceras* (*Schneidia*) sp. (Pl. 3: 7). This interpretation suggests that the lowermost level of the discussed stratigraphical interval runs possibly within the Hippolytense Subzone of the Hypselocyclum Zone. Because the ammonites coming from the overlying stratigraphical interval are generally indicative of the Divisum Zone (see below), this indicates that the stratigraphical range of the oncolitic to oolitic and marly limestone – dominated interval has to correspond mostly to the Hypselocyclum Zone.

Similarly developed deposits to those of the lower part of the interval II: 3 have been recognized in outcrops westward of the area of study – in the western part of the Łódź Depression (from Burzenin to northern part of the Wieluń Upland), and along the Kleszczów Graben (Szczerców and Bełchatów brown-coal fields) to the Radomsko Elevation. These deposits include: the Brzyków Oncolite Bed at Burzenin (Wierzbowski, 2017, *cf.* also Kowalski, 1958), units C, D, E, F of the "oolitic" formation at the Szczerców brown coal-field and in the northern part of the Wieluń Upland (Wierzbowski, 2017), and the Smotryszów Oolite at Kodrąb in the Radomsko Elevation (Kutek, 1968; Wierzbowski, Głowniak, 2018). All these deposits yielded abundant ammonites indicative of a fairly narrow stratigraphical interval from the Hippolytense Subzone to the lowermost part of the Lothari Subzone of the Hypselocyclum Zone. These deposits were distinguished as representing the lower part of the Burzenin Formation and its correlatives (Wierzbowski, 2017; Wierzbowski, Głowniak, 2018), indicating the transition from shallow-water deposits of the "oolite" formation to deeper water deposits with ammonites, marking thus the beginning of the LUK megasequence of Kutek (1968).

The deposits of the upper part of sequence II: 3, represented by micritic marly limestones and marls belonging to a higher part of the Hypselocyclum Zone, can be attributed to the Majaczewice Member of the Burzenin Formation because of their lithological similarity to typical deposits of this member, representing a deeper-water open-marine environment (Wierzbowski, 2017). Their distribution, as is the case with the older deposits of the sequence, strongly suggests the synsedimentary tectonic activity of the Grójec Fault Zone (*cf.* Wierzbowski, 2020).

Nanogyra lumachelle to marly limestone – dominated interval (upper Lower Kimmeridgian to lower Upper Kimmeridgian: Hypselocyclum/Divisum to lower Eudoxus zones) (II: 4)

This is lithologically a fairly uniform stratigraphical interval consisting mostly of *Nanogyra* lumachelles interbedded with marly limestones and marls. Only locally, near the base, are there recognized deposits of a different lithology. These include a few metres-thick oolitic limestone packet seen north-west of Sulejów in borehole Łęczna (Matyja, Wierzbowski, 2014, fig. 1), as well as nodular limestones with dispersed oolite grains at outcrop 50 near Dobra, east of Sulejów (Barczyk, 1961); there is also the case of a thin oyster bed (0.5 m in thickness) crowded with *Actinostreon* shells as seen in outcrop 43 at Sulejów (Barczyk, 1961). The whole stratigraphical interval ranges up to about 100 m in thickness (Matyja, Wierzbowski, 2014). It corresponds strictly to the Stobnica beds (or Stobnica lumachelles) as defined by Kutek (1962; see also Matyja, Wierzbowski, 2014), which represent one of the subunits within the widely defined "coquina" formation (see Kutek, 1994; Kutek, Zeiss, 1997).

The oldest ammonite found near the base of the discussed interval has been referred to as "*Ataxioceras* aff. *barbatum* Schneid" by Barczyk (1961, p. 33, 70, pl. 6), but it is a giant *Involuticeras*, similar to some other representatives of the genus known from the Holy Cross Mts. (see *e.g.*, Wierzbowski, 2022, pl. 13), generally indicative of the Hypselocyclum Zone and the Divisum Zone. Somewhat younger are: *Progeronia ernesti* (de Loriol) (Barczyk, 1961, p. 32, 78, 79, pl. 9: 2), *Pseudhimalayites uhlandi* (Oppel) (Barczyk, 1961, p. 33, 81; pl. 10), and *Prorasenia quenstedti* Schindewolf (= "*Rasenia* cf. *stephanoides*" in Barczyk, 1961, p. 33, 79, pl. 5: 4) (Pl. 3: 6), all found near Sulejów and indicative of the Divisum Zone.

A younger ammonite assemblage was discovered at the top of the discussed interval in outcrops near Stobnica. It includes (Kutek, 1961, 1962): *Aulacostephanus eudoxus eudoxus* (d'Orbigny), *Aulacostephanus pseudomutabilis pseudomutabilis* (de Loriol) and *Aulacostephanus pinguis* Durand – which are generally indicative of the lower part of the Eudoxus Zone.

The *Nanogyra* lumachelle to marly limestone interval represents the next major sedimentary sequence revealing a substantial transgressive surface at its base. This is evidenced by the occurrence of a few metres thick unit composed of oolites and/or the reworked oyster lumachelles of *Actinostreon* shells. These deposits stretch in a NE–SW direction in the north-western margin from Sulejów and Łęczno as described above, and further to Bąkowa Góra near Przedbórz, from where similar deposits composed of oolites with *Actinostreon* lumachelles have been described (Kutek, 1968). The same deposits continue in a south-western direction, down to Chełmo in the Radomsko Elevation, revealing an about 20 m thick succession of cross-bedded oolitic limestones (Kutek, 1968). Such localized distribution of these deposits strongly suggests tectonic uplift along the Grójec Fault Zone as the principal cause of their origin.

The overlying thick deposits composed of interbeds of *Nanogyra* lumachelles and marly limestones show a marked similarity to deposits of the upper part of sequence I: 4 in the north-eastern margin of the Holy Cross Mts. The deposits in the north-western margin are, however, richer in ammonites which indicates a more open-marine environment. Their stratigraphical position is firmly proved here as ranging from the uppermost Hypselocyclum/Divisum zone boundary of the Lower Kimmeridgian to the lower part of the Eudoxus Zone of the Upper Kimmeridgian. These deposits correspond generally to the "coquina" formation, the upper boundary of which with overlying Pałuki Formation is interpreted as the tectonically-controlled boundary of the transgressive-regressive sequences (Kutek, 1994; Kutek, Zeiss, 1997).

Marl and clay to marly limestone – dominated interval (Upper Kimmeridgian – middle Eudoxus to Autissiodorensis zones) (II: 5)

This interval, about 45–60 metres thick, as recognized in cores in the Tomaszów Mazowiecki Syncline corresponds generally to the lower part of the Pałuki Fm. (Dembowska, 1979). It consists of the monotonous marl and marly limestone with interbeds of micritic limestones of the Bratków Marl Member (Matyja, Wierzbowski, 2014). These deposits are well dated by numerous ammonites indicative of the middle-upper parts of the Eudoxus Zone to the Autissiodorensis Zone of the Upper Kimmeridgian (Kutek, Zeiss, 1997).

The middle Eudoxus Zone marks the beginning of a new transgressive pulse in Poland and everywhere (*e.g.*, Wierzbowski, Wierzbowski, 2019, and earlier papers cited therein). It corresponds to the appearance of the oyster lumachelles and bioclastic-detrital limestones beginning the sequence I: 5 in the north-eastern margin of the Holy Cross Mts. The origin of these deposits was stimulated at least partly due to tectonic uplift along the active fault zone (see above). No evidence of the occurrence of such deposits is recognized at the studied north-western margin of the Holy Cross Mountains.

Silty marls and silty clays – dominated interval (Lower Tithonian – Klimovi to lower Scythicus zones) (II: 6)

The upper part of the Pałuki Fm. consists of the silty marls and silty clays, subordinately siltstones, marls and marly limestones of the Brzostówka Marl Member, about 65 m in thickness (Matyja, Wierzbowski, 2014). It was studied both in cores, but in the past mostly in outcrops at Tomaszów Mazowiecki and adjoining areas in the north, but also at Stobnica in the south. The deposits yielded abundant ammonites indicative of the Klimovi Zone, the Sokolovi Zone, the Pseudoscythica Zone, the Puschi Zone = Tenuicostata Zone and the lower part of the Scythicus Zone (Kutek, 1961, 1962; Kutek, Zeiss, 1974, 1997, and older papers cited therein).

The base of the interval generally corresponding to the Brzostówka Marl Member is marked by the occurrence of fine detrital siliciclastic material, mostly of quartz and muscovite – but its appearance is slightly diachronous. This material appeared earlier in the south-west where the Kimmeridgian – Tithonian boundary runs a few meters above the base of the Brzostówka Marl Member (*i.e.* the lowermost part of the member is of latest Kimmeridgian age), and slightly later in the north where the Kimmeridgian/Tithonian boundary is placed nearly at the base of the Brzostówka Marl Member (Matyja, Wierzbowski, 2014). The appreciable quantities of fine siliciclastic material, not known in older parts of the succession, were transported possibly, as indicated above, from southern directions. The deposits show also a low content of carbonates, when compared with underlying ones in the succession (Kutek, Zeiss, 1997, fig. 3B, C), but also some other features of their own, including a marked abundance of agglutinated foraminifers (*e.g.*, Barwicz-Piskorz, Tarkowski, 1984). This stratigraphical interval of the Early Tithonian from the boundary with the Kimmeridgian to a lower part of the Scythicus Zone, corresponding to the upper part of the Pałuki Fm. (the Brzostówka Marl Mbr.), represents thus the specific palaeoenvironmental conditions possibly indicative of the dominance of a more humid climate (see also comments at the end of the study).

Limestone – dominated interval (Kcynia Fm.) (Lower Tithonian – upper Scythicus to lowest Virgatus zones) (II: 7)

This uppermost part of the discussed succession in the north-western margin of the Holy Cross Mts., comprises limestones corresponding to the Kcynia Formation (*cf.* Dembowska, 1979). It occurs only at the northern part of the area of study, in the central and north-western parts of the Tomaszów Mazowiecki Syncline, as seen in outcrops: especially at Tomaszów Mazowiecki in the past (*e.g.*, Kutek, 1967), and currently at the Owadów–Brzezinki quarry near Sławno; but it was also penetrated by numerous boreholes (*e.g.*, Witkowski, 1969; Matyja, Wierzbowski, 2014).

These limestones attaining 26 m in thickness, capped erosionally by Lower Cretaceous deposits (mostly Valanginian), may be generally subdivided into chalky limestones with a diversified marine fauna (ammonites, bivalves, echinoderms) (Sławno Limestone Member) below, and specific micritic, mostly thin-bedded limestones with the mass-occurrence of small-shelled bivalves *Corbulomima* ("*Corbulomima* limestones") above. The latter has yielded unusually well-preserved marine and terrestrial fossils, including reptiles, fishes, insects and horseshoe crabs (*e.g.*, Błażejowski *et al.*, 2016). They are capped along the well-developed omission surface by organodetrital limestones (sometimes called "Serpulite") with oysters, bryozoans, and locally very numerous serpulids (Matyja, Wierzbowski, 2016a, and older papers cited therein).

The ammonites found in the chalky limestones of the Sławno Limestone Mbr. are mostly of NE Subboreal ("Volgian") character. They are indicative of the upper part (Zarajskensis Subzone) of the Scythicus Zone. Those occurring above, in the "*Corbulomima* limestones" and organodetrital limestones at the top, indicate the Gerassimovi Subzone of the lowermost Virgatus Zone. The discussed deposits have yielded, although less numerously, NW Subboreal ammonites indicative of the Fittoni Zone and the Albani Zone of the "Upper Kimmeridgian" and "Portlandian" [*i.e.* Tithonian] of southern England (Matyja, Wierzbowski, 2016a).

The interval dominated by the limestones of the Kcynia Formation points to a sudden decrease in terrigenous input when compared with the directly underlying deposits. This indicates an environmental change towards aridification, which finds its spectacular confirmation in detailed studies of coeval deposits in other areas in Poland and in Europe (Grabowski *et al.*, 2021, and earlier papers cited therein). The occurrence of these deposits indicates the foundation of a younger shallow-water carbonate platform in the area of the Holy Cross Mountains. However, because of the later NeoCimmerian elevation these deposits were mostly erosionaly removed from the area and are preserved only locally in the north-western margin (see also comments at the end of the study).

SHALLOW-WATER CARBONATE SUCCESSION OF THE SOUTH-WESTERN MARGIN OF THE HOLY CROSS MOUNTAINS

LOCATION AND CRITERIA OF STRATIGRAPHICAL SUBDIVISION

The Upper Jurassic of the south-western margin of the Holy Cross Mts. (Fig. 1) represents a rather narrow and strongly folded strip of deposits stretching in a NW–SE direction and composed of densely-spaced short anticlines and synclines (see Kutek, 1968, fig. 1). These deposits generally outcrop well and have been accessible in numerous, mostly small, but also some large quarries, partly abandoned (*e.g.*, Sobków quarry), but some still active (Bukowa and Małogoszcz quarries). These Upper Jurassic shallow-water deposits occur from the environs of Przedbórz and Dobromierz in the north-west, through Oleszno, Bukowa, Gruszczyn, Małogoszcz and Bolmin in the middle, down to Brzegi, Korytnica, Wymysłów and Celiny in the south-east (Kutek, 1968; *cf.* also Wierzbowski, 2020). Five main stratigraphical intervals, well documented biostratigraphically and characterized by different lithology, are recognized in the succession studied (III: 1–5; Fig. 2). These are correlated with older lithostratigraphical units distinguished here (*cf.* Kutek, 1968; Wierzbowski, 2020). The detailed characteristics of the shallow-water succession in the south-western margin of the Holy Cross Mts., has been presented recently (Wierzbowski, 2020), thus, the comments given below list the most important lithological and stratigraphical features of the discussed intervals.

The five stratigraphical intervals recognized (III: 1–5) can be interpreted as major transgressive-regressive sequences, as is the case in other margins of the Holy Cross Mountains. They can be compared also to the megasequences COK, LUK and KVB of Kutek (1994): the sequences III: 1–3 correspond to the upper part of the COK megasequence, whereas sequences III: 4 and III: 5 to megasequences LUK and KVB, respectively. The development of the sequences here was also strongly controlled by changes of sea-level, resulting from orbitally-controlled excentricity cycles, and by synsedimentary tectonic activity, especially the Holy Cross Fault System in the north, and the Zawiercie–Busko Fault Zone in the south (Wierzbowski, 2020).

DESCRIPTION AND INTERPRETATION OF STRATIGRAPHICAL SUCCESSION (III)

Massive coral limestones and corresponding bedded grainstone – dominated interval (Lower Kimmeridgian: Planula Zone) (III: 1)

The Upper Jurassic deep-water deposits of the sponge megafacies showed marked differentiation in their sedimentary development, beginning especially from the early Hypselum Chron of the Late Oxfordian. This resulted in the formation of large cyanobacteria-sponge biohermal complexes in the northern and southern parts of the south-western margin, generally of latitudinal orientation, separated by interbiohermal basins filled with micritic limestones with poor fauna (Matyja, 1977, 2015; see also Wierzbowski, 2020). The core of the discussed interval consists of generally poorly known organodetrital massive coral limestones located at the top of older biohermal complexes of massive limestones of the Częstochowa Sponge Limestone Formation (Matyja, 1977; Matyja *et al.*, 1989). The hermatypic corals of the families Latomeandridae, Microsolenidae and Stylinidae, as recognized in these limestones, are generally treated as indicative of rather deeper-water conditions (Roniewicz, 2004). The settlement of the "deep-water" coral assemblages at the top of the biohermal complexes, and the subsequent development of grainstone fans of the shallow-water origin were controlled possibly by some sea-level fall.

It is generally assumed that the growth of the coral assemblages took place synchronously or directly before the development of the oolitic-oncolitic-bioclastic shoals, which formed submarine fans within adjoining basinal micritic limestones. These fans corresponded to various types of grainstones occurring within the deep-water micritic limestones of the Pilica Formation (placed in the Siedlce Limestone Member in the south-western margin of the Holy Cross Mts.), representing deposits of the interbiohermal basins (Matyja *et al.*, 1989; Wierzbowski, 2020).

The ammonites recorded from the deposits associated with discussed grainstone beds belong mostly to genera *Subnebrodites* and *Orthosphinctes*, including forms such as *S. laxevolutum* (Fontannes), *S. planula* (Zieten), both co-occurring in the upper part of the succession with *S. schroederi* (Wegele). This assemblage is indicative of the middle to upper parts of the Planula Zone, and this strongly suggests that the massive coral limestones belong also to the Planula Zone (Matyja *et al.*, 1989; Wierzbowski, 2020).

The upper boundary of the discussed stratigraphical interval is marked by the main discontinuity surface developed at the top of the Pilica Formation, and characterized by rich assemblages of burrowing and boring organisms (*cf.* Kaźmierczak, Pszczółkowski, 1968; Gruszczyński, 1986). The development of the discontinuity surface resulted mostly from synsedimentary tectonic activity at the end of the Planula Chron, and the appearance of associated high turbulence events resulting from accelerated shallowing of the basin (Wierzbowski, 2020).

The depositional setting of all these coral limestones and associated grainstones was clearly related to the appearance of a large shallow-water sea area stretching from the southern parts of the Holy Cross Mts towards the west. It corresponded to the tectonically-controlled formation of the youngest part of the shallow-water carbonate platform in the south-western part of the Holy Cross Mts., and its original western prolongation to the Częstochowa Upland (preserved only fragmentarily due to pre-Albian erosion), during the Early Kimmeridgian (at the end of Planula Chron).

Chalky limestone – dominated interval (Lower Kimmeridgian: uppermost Planula to lower Platynota zones) (III: 2)

This is lithologically fairly uniform interval consisting predominantly of soft, porous, "chalky" limestones with abundant fossils including commonly occurring hermatypic corals – usually sparsely placed in the beds, but forming also flat biostromes of the patch-reef type (Roniewicz, 1966; Roniewicz, Roniewicz, 1971), solenoporoids, bivalves (rudistids and oysters), gastropod nerineids and others. The development of chalky limestones indicates the sedimentation of a fairly uniform facies in a relatively quieter and deeper water zone (Roniewicz, Roniewicz, 1971; Matyja *et al.*, 1989). The base of the chalky limestone unit is marked by the occurrence of lithologically very variable deposits distinguished as the "basal unit". These include micritic limestones and marly limestones passing into variable grainstones, resting directly over the prominent discontinuity surface, as discussed above. All these deposits are attributed to the Piekielnica Coral Limestone Member of the Bukowa Formation, attaining about 35 metres in thickness at their type section at Bukowa (Wierzbowski, 2020). The top of the discussed stratigraphical interval corresponds to the base of the Leśnica Limestone Member of the Bukowa Formation represented by various micritic and organodetrital-oolitic limestones, and it is also marked by the discontinuity surface (Kaźmierczak, Pszczółkowski, 1968, see also Wierzbowski, 2020).

The chronostratigraphical position of the discussed chalky limestone dominated interval, as based on the few recorded ammonites, can be placed at the boundary between the uppermost part of the Planula Zone, and the lower part of the Platynota Zone. The ammonites found in the more fossiliferous, directly overlying deposits of the lower part of the Leśnica Limestone Member, are indicative of the topmost part of the lower Platynota Zone (Polygyratus Subzone) – possibly at the transition to its middle part – the Desmoides Subzone (Wierzbowski, 2020). According to this dating, the changes of sea level, possibly responsible for the development of the main discontinuity surfaces, were induced by orbitally-controlled climatic oscillations of the 405-kyr eccentricity cycle (Wierzbowski, 2017, 2020; see also Boulila *et al.*, 2008, 2010).

Oolite and micritic limestone to marl – dominated interval (Lower Kimmeridgian: lower/middle Platynota Zone to upper Hypselocyclum Zone) (III: 3a–c)

This interval consists of three main parts: the lower and middle parts composed of oolitic and micritic limestones with the locally intervention of marls (III: 3a, b), and the upper part composed mostly of micritic limestones and marls (III: 3c). The lower part (III: 3a) includes the Leśnica Limestone Mbr. and the Góry Marl Mbr. of the Bukowa Formation, whereas the middle part (III: 3b) includes the Małogoszcz Oolite Formation up to the Celiny Oncolite Bed (*cf.* Wierzbowski, 2020).

The lower part of discussed interval consists mostly of micritic limestones laterally passing into oolitic limestones. The section seen at Bukowa quarry, being characteristic of this part of the succession shows micritic limestones, locally with marly intercalations, yielding some ammonites, followed by cross-bedded oolites, and overlain by marls (Roniewicz, 1967), the latter corresponding to the Góry Marl Mbr. The ammonites found in the underlying limestones are indicative of the lower part of the Platynota Zone, representing possibly its topmost part, near the boundary with the middle part of this zone (Wierzbowski, 2020). The corresponding deposits in the northernmost and southernmost parts of the south-western margin of the Holy Cross Mts., show a somewhat different facies pattern consisting predominantly of oolitic and other grained (organodetrital) limestones with a marked reduction of micritic limestones, and the total disappearance of the Góry Marl Member (Kutek, 1968; Pszczółkowski, 1970b; see also Wierzbowski, 2020, fig. 4).

The middle part of discussed interval is represented in the central part of the south-western margin, between Oleszno, Krasocin and Gruszczyn in north-west, to Żerniki, Brzegi and Korytnica in south-east, by a characteristic set of deposits. In its lower part, it consists of micritic limestones (Rogalów Limestone Mbr.), followed by two prominent oolitic units (Głuchowiec Oolite Mbr. and Sobków Oolite Mbr.), sandwiched by thin-bedded micritic and fine-grained limestones with cherts (Mieronice Banded Limestone Mbr.) – all of them belonging to the Małogoszcz Oolite Formation. These deposits are covered by the characteristic oncolitic unit – the Celiny Oncolite Bed (Wierzbowski, 2020, and older papers cited therein). Ammonites occur mostly at the base and top of the discussed deposits. Those found in the Rogalów Limestone Mbr. at the base of the succession, are indicative of the middle to upper parts of the Platynota Zone. On the other hand, the ammonites found in the upper part of the Sobków Oolite Mbr., and in the Celiny Oncolite Bed are characteristic of the lowermost part of the Hypselocyclum Zone – the *lussasense* horizon of the lower part of the Hippolytense Subzone (Wierzbowski, 2020). The common occurrence of ammonites at the levels discussed resulted possibly from sea-level rise induced by the orbitally controlled excentricity cycles (Wierzbowski, 2020).

The corresponding deposits recorded from the northernmost and southernmost parts of the south-western margin of the Holy Cross Mts. differ in several features from those recognized in its central part. Here oolitic and other grained limestones become dominant, whereas the occurrence of micritic limestones is markedly reduced.

Sedimentation of oolite limestones was strongly controlled tectonically by the activity of the Holy Cross Fault System in the north, and the Zawiercie–Busko Fault Zone in the south. On the other hand, the central part of the south-western margin displays a somewhat different facies pattern. Here the cross-bedded large oolite units (from the basal part of the Leśnica Limestone Mbr., the Głuchowiec Oolite Mbr., and the Sobków Oolite Mbr.) are commonly associated with prominent micritic limestone units (the Rogalów Limestone Mbr., and the Mieronice Banded Limestone Mbr.), being underlain, sandwiched within and overlain by marly units (the Zapole Marl Bed, the Góry Marl Mbr., and the Kiełczygłów Marl Mbr.) (see Wierzbowski, 2020; *cf.* also Kutek, 1968; Pszczółkowski, 1970b). A similar facies pattern is observed also westward from the south-western margin of the Holy Cross Mts., in adjoining parts of the Miechów/Nida Depression, where lithological units strictly corresponding to those discussed above have been recognized in the boreholes: Włoszczowa IG 1, Węgleszyn IG 1 and Jędrzejów IG 1 (Jurkiewicz *et al.*, 1969; Złonkiewicz, 2009). The distribution of these deposits indicates the general latitudinal direction of the main sedimentary facies zones. The character of these deposits suggests strongly that their sedimentation was to a large degree controlled by climatic factors and the related changes of sea-level (Wierzbowski, 2020). Summarizing, the deposits of the lower to middle parts of the interval discussed (III: 3a, b) accumulated over a large shoal commonly of an open marine environment, bordered in the north and south by the tectonically active zones, where smaller-scale changes of sea-level were markedly accentuated in the type of sedimentation, only in some intervals revealing more restricted environmental conditions (Góry Marl Mbr., Mieronice Banded Limestone Mbr.).

The upper part of the discussed stratigraphical interval (III: 3c) corresponding to the Spinkowa Góra Formation consists of marls of the Kiełczygłów Marl Member followed by micritic limestones with subordinate intercalations of organodetrital-oolitic limestones belonging to the Grabki Limestone Member (Wierzbowski, 2020). Towards the north, near Dobromierz and Przedbórz, these deposits pass laterally into the "Oolite-platy member" of Kutek (1968) displaying an increase in oolitic material. These deposits rest here directly on oncolitic limestones (of the Celiny Oncolite Bed) attaining locally even up to 10 m in thickness, but without the intervening marly deposits of the Kiełczygłów Marl Member, as seen commonly in the south (Kutek, 1968).

The discussed micritic limestones and marls of the Spinkowa Góra Formation contain a monotonous faunal assemblage, composed mostly of some bivalves and crustaceans, without cephalopods. These deposits and fauna strongly suggests the restricted environment character, markedly different from that developed in the lower to middle parts of the interval. The coeval oolitic limestones deposited north and south of the area of occurrence of the restricted environment deposits indicate the synsedimentary uplift along the main tectonic zones – the Holy Cross Fault System in the north, and some faults possibly related to the Zawiercie – Busko Fault Zone in the south. This tectonic activity resulted in the strong elevation of the main area of the south-western margin in relation especially to the northern foreland, corresponding to some parts of the north-western margin of the Holy Cross Mts., and some adjoining areas (Wierzbowski, 2020).

The uppermost part of the upper stratigraphical interval discussed comprises a set of marls and overlying "sublithographic" limestones with a very poor fauna. The former corresponds to the Dobromierz Marl Member, the latter to the Buczyna Limestone Member (Wierzbowski, 2020). At the top of the Dobromierz Marl Mbr., in northern part of the south-western margin, at Dobromierz and Przedbórz, oolitic-organodetrital limestones, locally with the admixture of fine siliciclastic detrital material, are encountered. These herald the incoming of the "coquina" formation (Kutek, 1968, 1994: Wierzbowski, 2020), representing most possibly the environment of tidal flats.

The chronostratigraphical position of the upper part of the discussed interval generally corresponds to the bulk of the Hypselocyclum Zone, as shown by datings of the directly older and the directly younger deposits. No ammonites have been ever found, however, in the discussed deposits.

Oyster lumachelle to micritic limestone and marl to clay dominated interval (Lower Kimmeridgian to Upper Kimmeridgian: uppermost Hypselocyclum to lowermost Eudoxus zones) (III: 4)

This stratigraphical interval attains over 200 m in thickness in its full development in the south, between Staniewice and Wymysłów (Kutek, 1968). More northwards, at Małogoszcz, the whole preserved part of the succession, however, displays only 110 m in thickness (Matyja *et al.*, 2006) because its upper part has been removed here by erosion due to pre-Albian Neo-Cimmerian movements (Kutek, 1968, Pszczółkowski, 1970a, b).

The lithostratigraphical classification of the discussed deposits has been influenced markedly by the study of Kutek (1968) who distinguished here several local units. These included especially in their lower part the Skorków Lumachelle which comprised the *Actinostreon* ("*Lopha/Alectryonia*") lumachelles below, and the *Nanogyra* lumachelles above; these were commonly sandwiched by oncolite limestones, and usually underlain and overlain by micritic limestones with abundant biodetrital material and numerous shells of myid bivalves. Younger lithostratigraphical units included two thicker members composed mostly of *Nanogyra* shells and their hash – the Brzegi Lumachelle and the Staniewice Lumachelle, generally strongly developed in the south – between Bizorenda–Brzegi and Staniewice. On the other hand (see Kutek, 1962), the limestone to marl-clay dominated parts of the succession, showing also the common occurrence of *Nanogyra* interbeds, could be easily accommodated in the another lithostratigraphical unit – the Stobnica beds or lumachelles. The whole stratigraphical interval corresponded to the "coquina" formation, informally distinguished by Kutek (1994) after Dembowska (1979).

A somewhat different classification of the youngest deposits of the interval studied was proposed by Pszczółkowski (1970a, b). He treated jointly the Brzegi Lumachelle and the Staniewice Lumachelle as a single unit composed of interbedded *Nanogyra* lumachelles and marl to clay beds – generally showing a substantial development of the former towards the south. The main problem has remained the position of the Top Lumachelle of Kutek (1968) treated by Pszczółkowski (1970b) as a part of the same succession, displaying, however, several distinctive features which results in its treatment herein as representing a separate stratigraphical interval (see below).

The chronostratigraphical interpretation of the discussed stratigraphical interval is based on the ammonites described mostly by Kutek (1968, 1994), and subsequently discussed by Matyja *et al.* (2006), but also numerous new determinations which will be published elsewhere. The oldest assemblage of ammonites at the base of the discussed interval is indicative of the uppermost part of the Hypselocyclum Zone – the *semistriatum* and the *perayensis* horizons of the uppermost of the Lothari Subzone (see Kutek, 1994; Matyja, Wierzbowski, 2000). The middle and higher parts of the Skorków Lumachelle, in the lower part of the studied interval, yielded numerous ammonites indicative of the Divisum Zone (Kutek, 1968; Matyja *et al.*, 2006), both of the Crusoliensis Subzone and of the Uhlandi Subzone.

The ammonite fauna recorded in the upper part of the marl to clay dominated part of the discussed interval at Małogoszcz, composed of specimens of *Orthaspidoceras schilleri* (Oppel) (Pl. 4: 3), indicates that it exposes the Upper Kimmeridgian Mutabilis Zone, directly below the boundary with the Eudoxus Zone (Matyja *et al.*, 2006): the species is indicative of the *schilleri* horizon of the Lallierianum Subzone of the uppermost Mutabilis Zone (*cf.* Hantzpergue, 1989, 1995). The level with *Orthaspidoceras* is overlain here by a few metres thick unit composed of biodetrital lumachelles with *Nanogyra*, *Gervillia* and "*Trigonia*" as well as oolitic limestones interbedded with clayey-marly and micritic limestones (Matyja *et al.*, 2006). It seems that this unit has been distinguished by Pszczółkowski (1970a) as the lowermost key-horizon "a" of the aerial photo interpretation of the Upper Kimmeridgian succession between Małogoszcz and Brzeźno in the south-western margin of the Holy Cross Mts. Towards the south the unit is laterally replaced by some lower beds of the Brzegi Lumachelle – Staniewice Lumachelle (Pszczółkowski, 1970b). This correlation strongly suggests that the overlying parts of the lumachelle units are younger, and may correspond already to the lowermost part of the Eudoxus Zone.

The whole interval III: 4 corresponds to the transgressive-regressive LUK megasequence of the oyster lumachelle deposits especially well recognized in the south-western margin of the Holy Cross Mts. The lower boundary of the sequence seems to be slightly diachronous here. Some oolitic intercalations and lenses of detrital limestones with small quartz grains are seen in sections in the northern parts of the area, at Dobromierz and Oleszno, already in the micritic limestones of the Buczyna Limestone Mbr., representing the topmost part of the Spinkowa Góra Fm. (correlated with interval/sequence III: 3) (*cf.* Kutek, 1994; Wierzbowski, 2020; see also above). The directly overlying *Actinostreon* lumachelles of the lowermost part of the sequence III: 4 yielded here the ammonite *Ataxioceras lothari* (Oppel) indicative of the upper (but rather not the uppermost) part of the Lothari Subzone of the Hypselocyclum Zone. These sections differ, however, markedly from the corresponding part of the succession at the boundary between intervals/sequences III: 3 and III: 4 in more southern areas of the south-western margin. Such is *e.g.* the case of the Małogoszcz quarry section, where the monotonous sequence of micritic limestones is topped with the prominent hard-ground surface and followed by micritic limestones with biodetrital material. The latter deposits representing already the lowermost part of the interval/sequence III: 4 yielded some ataxioceratid ammonites indicative of the topmost part of the Lothari Subzone – the *semistriatum* to *perayensis* horizons (Kutek, 1994; Matyja *et al.*, 2006). The overlying *Actinostreon* lumachelles are here markedly younger corresponding to the Crusoliensis Subzone of the Divisum Zone. All these local facies changes were possibly related to the relative vertical synsedimentary tectonic movements and existing basin to swell palaeotopography.

On the other hand, the concentration of ammonite shells within the sequence studied suggests additionally the occurrence of stratigraphical condensations, some of them presumably correlated with high sea-level, possibly controlled by climatic cycles. Such levels can be recognized at the top of the Hypselocyclum Zone, and at the top of the Divisum Zone (Uhlandi Subzone) corresponding to the minima of eccentricity cycles (*cf.* Boulila *et al.*, 2008, 2010; see also Wierzbowski, 2017, 2020).

Another level fairly rich in ammonite shells occurs at the top of the succession at Małogoszcz quarry, where numerous specimens of *Orthaspidoceras* indicate the presence of the *schilleri* horizon of the topmost part of the Mutabilis (Acanthicum) Zone, and suggest the next stratigraphical condensation event. The overlying various biodetrital and oolitic limestones show some sea level fall which may correspond to the lowermost Eudoxus Zone (*cf.* Hantzpergue, 1995; see also Wierzbowski, Wierzbowski, 2019).

Sandy oyster lumachelle to clay dominated interval (Upper Kimmeridgian: Eudoxus Zone) (III: 5)

This stratigraphical interval is preserved only in the southernmost part of the south-western margin, between Staniewice and Gołuchów–Wymysłów. It consists of detrital lumachelles with a marked share of *Nanogyra* shell hash and admixture of siliciclastic detrital quartz and glauconite grains. These deposits, locally showing cross-bedding, are distinguished as the Top Lumachelle by Kutek (1968). They are locally overlain by marly to clayey deposits fragmentarily preserved below the Albian–Cenomanian sandstones and siltstones (Pszczółkowski, 1970a, b). Evidently no ammonites have been described as coming from that interval, possibly except for a single specimen of *Pararasenia quenstedti* Durand, which could has come, however, either from the uppermost part of the underlying interval (see Kutek, 1968, pl. 7: 3a, b), and which is characteristic of the Mutabilis Zone and a lower part of the Eudoxus Zone (Ziegler, 1962). Nevertheless, the position of the discussed interval within the Upper Jurassic succession of south-western margin of the Holy Cross Mts. and its lithology strongly suggest its correlation with some levels of the Eudoxus Zone of the Upper Kimmeridgian.

The data coming from the youngest part of the succession in the south-western margin of the Holy Cross Mts. are very scarce. It seems, however, that the appearance here of lumachelles rich in siliciclastic material, marks the beginning of a new sedimentary cycle, possibly controlled by tectonic phenomena, and corresponding to the sequence I: 5 in the north-eastern margin of the Holy Cross Mountains.

HISTORY OF SEDIMENTATION

The development of sedimentation in the Holy Cross Mountains area during the Late Jurassic was controlled mostly by climate and tectonics, especially well recognized in the formation of shallow-water carbonate deposits. The generally warm climate had a strong effect on the formation of different types of limestones, especially in relation to relative sea-level changes as based on orbitally-controlled sedimentary cyclicity, and as the result of tectonic vertical movements of fault blocks. The changes in sedimentary successions as recognized in the development of the particular sequences in the Holy Cross Mts. areas, can be thus interpreted as the net-result of the orbitally-forced climate changes and superimposed tectonic phenomena.

The appearance of shallow-water carbonate deposits near the boundary between the Middle and the Upper Oxfordian, at the transition from the Transversarium to the Bifurcatus zones, is recognized in the north-eastern margin of the Holy Cross Mountains. The shallowing of the basin was related here to strong tectonic uplift along the Nowe Miasto–Iłża–Bałtów Fault Zone which resulted in the formation of the coral buildups of sequence I: 1 (Gutowski, 1992, 1998). The coeval uplift, however, covered also a large latitudinally stretching area corresponding to the whole Holy Cross Mts. and the adjoining the Miechów/Nida Depression and the Cracow–Silesian Monocline (Częstochowa Upland) towards the west, bordered by the Grójec Fault Zone in the north-west, and the Zawiercie–Busko Fault Zone in the south (Fig. 3). The uplift resulted in the sudden growth, especially along some tectonic zones, of huge, deep-neritic, cyanobacteria-sponge biohermal complexes beginning in the Bifurcatus Chron and it simultaneously stimulated the development of deep interbiohermal basins (*e.g.*, Matyja, 1977; Matyja, Wierzbowski, 1996). The whole area represented a prominent elevation being structurally a fragment of the Variscian fold belt, and having in its substrate the older Caledonian, Sandomirian and Cadomian structures. It consisted of two main blocks – the Łysogóry Block in the north, and the Kielce and/or Małopolska Block in the south, with their boundary along the Holy Cross Fault System (*e.g.*, Aleksandrowski, Mazur, 2017).

The detailed biostratigraphical data strongly confirm the development already during the Bifurcatus Chron of the thick succession of micritic limestones of the Pilica Fm. northwards from the occurrence of the sponge limestones of the Częstochowa Sponge Limestone Fm. at Opoczno (north-western margin of the Holy Cross Mts.) due to the tectonic activity of the Grójec Fault Zone (Matyja, Wierzbowski, 2014). The synsedimentary activity of the same fault is also observed at the boundary between the Częstochowa Upland and the Wieluń Upland more towards the south-west where the very thick succession of micritic limestones of the Pilica Fm., underlain by bedded sponge limestones, is developed in the north against the massive limestones complexes in the south (see Matyja, Wierzbowski, 2016b; Wierzbowski, 2017).

In the Upper Jurassic substrate of the Carpathian Foredeep, south of the Holy Cross Mts., the onset of sedimentation of the marly deposits of the Niwki Fm., occurred during the Bifurcatus Chron, directly above the sponge limestones of the Łękawica Fm., but also with strong simultaneous development of the latter deposits in adjoining areas (Matyja, 2009, 2015). Large biohermal complexes surrounded by bedded limestones and marls were recognized here in seismic data (Słonka, Krzywiec, 2020). Also further westwards, in the southern part of the Częstochowa Upland, the transition from the Kroczyce Biohermal Complex to the Pilica Interbiohermal Basin, at the southern boundary of the Częstochowa Upland (*cf.* Matyja, 2009), possibly occurred at the same time. It seems highly probable that the strong facies changes in the discussed areas were related to synsedimentary activity of the Zawiercie–Busko Fault Zone.

The succeeding tectonic activity included mostly the areas of the north-western margin of the Holy Cross Mts., where the shallow-water coralliferous chalky limestones of sequence II: 1 accumulated near the Oxfordian/Kimmeridgian boundary, during the late Hypselum Chron or early Bimammatum Chron (Matyja, Wierzbowski, 2014). The elevation of this area was fault bounded – by the Grójec Fault Zone in the north-west, and possibly by the Holy Cross Fault System in the south. It is also likely that a coeval mild uplift included other areas placed south and west of the Holy Cross Fault System. This could explain the appearance here of massive sponge limestones ranging stratigraphically from the Hypselum and/or Bimammatum zones to

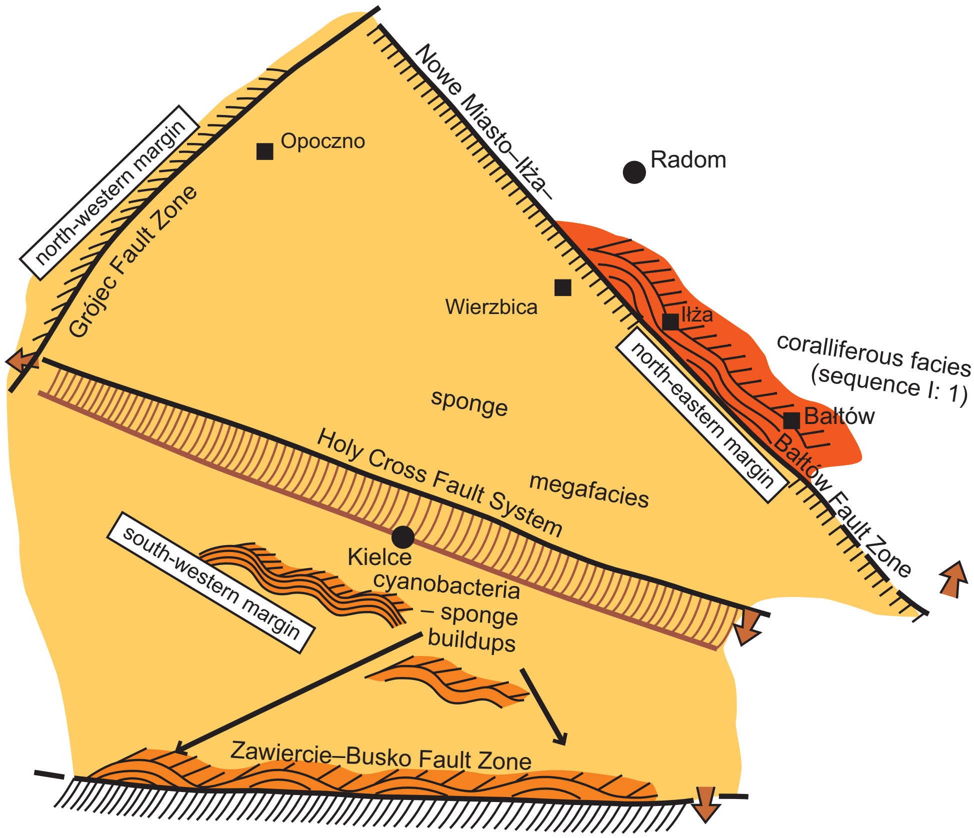

Fig. 3. Sketch of the distribution of the main facies assemblages of the Late Oxfordian in the Holy Cross Mountains (interval/sequence I: 1, and sponge megafacies deposits)

Arrows indicate directions of tectonic movements

the Planula Zone. This refers also to the development of thick units corresponding to the bedded micritic limestones of the Pilica Fm. belonging mostly to the Planula Zone. Such a composition of the biohermal complexes and the adjoining interbiohermal basins marks a new phase in their inter-relations as recognized in the south-western margin of the Holy Cross Mts. (Matyja, 1977), and in the central and northern parts of the Częstochowa Upland (Wierzbowski, 2017).

The base of the Kimmeridgian (*i.e.* the base of the Bimammatum Zone in the Submediterranean subdivision, *cf.* Wierzbowski *et al.*, 2023a) is, however, additionally affected by a sea-level rise as denoted by the over-regional transgressive surface resulting possibly from orbitally-controlled cyclicity. It is well seen in the shallow-water succession at the base of the transgressive deposits of sequence I: 2 of the north-eastern margin of the Holy Cross Mts. at Wólka Bałtowska (Liszkowski, 1972). In a deep-water open marine environment this phenomenon is marked by the appearance of condensed deposits with ammonite shell accumulation which occur in the Pilica Fm., in the Wolica Bed, in south-western margin of the Holy Cross Mts. (see Matyja, 1977; Matyja *et al.*, 1989; Wierzbowski, 2020), but also by the sudden change in composition of the ammonite assemblages and of geochemical data at the corresponding omission surface in the bedded limestones of the deep-water sponge megafacies in the Bobrowniki section, Wieluń Upland (Wierzbowski *et al.*, 2016). The discussed sea-level rise in the north-western margin of the Holy Cross Mts. possibly resulted in a marked increase in thickness of the shallow-water lowermost Kimmeridgian chalky limestones as an effect of aggradation and gradual sinking of the substrate which followed the initial tectonic uplift.

During the Late Oxfordian and the earliest Kimmeridgian some other, possibly also orbitally-controlled, sea level changes have been recognized in the sections of central Poland. The lowest one occurs at the top of the Bifurcatus Zone, including mostly the lowermost part of the Hypselum Zone, of the Upper Oxfordian. This is well-marked in the deeper water successions of the sponge megafacies in the

Częstochowa Upland (Wierzbowski, Matyja, 2014), but also at the north-western margin of the Holy Cross Mts. (Matyja, Wierzbowski, 2014), being, however, rather poorly recognized in the shallower-water successions of the north-eastern and south-western margins. Possibly the occurrence of some oncolitic limestones dividing the older deposits with foliaceous deeper-water coral assemblages from younger ones with the massive coral assemblages of sequence I: 1 in the north-eastern margin of the Holy Cross Mts. could correspond to that level. The other transgressive levels in the lowermost Kimmeridgian, such as that at the lower Hauffianum Subzone, and at the base of the Planula Zone well seen in the deep-water succession of the Wieluń Upland (*cf.* Matyja, Wierzbowski, 1997; Wierzbowski *et al.*, 2010; Wierzbowski, 2022) are not unequivocally recognized in the studied shallow-water successions of the Holy Cross Mountains. It seems, however, likely that the appearance of a succession of more open marine chalky limestones overlying the micritic limestones with remnants of terrestrial flora (top of subinterval I: 2a in north-western margin) can be related to the early Hauffianum Subchron.

The shallow-water succession in the south-western margin of the Holy Cross Mts. commences with the formation of coral buildups settled on the older cyanobacteria-sponge bioherms and related fans of various grainstones preserved as lenses in the basinal deep-water micritic limestones of the Pilica Fm. (Matyja, 1977; Matyja *et al.*, 1989). The directly overlying shallow-water deposits developed along the prominent discontinuity surface, show wide distribution, and mark the transition from the diversified sea-bottom relief of coral buildups and basin topography (sequence III: 1), to the fairly uniform shallow-water carbonate platform conditions of the dominant coralliferous bedded chalky limestones (sequence III: 2) of the Bukowa Formation (Wierzbowski, 2020). The regional data indicate the wide geographical distribution of coral buildups and coralliferous chalky limestones from the south-western margin of the Holy Cross Mts. to the northern part of the Częstochowa Upland (*e.g.*, Roniewicz, Roniewicz, 1971; Matyja, Wierzbowski, 1996). The occurrence of similar shallow-water deposits formed within a fairly short time-interval at the end of the Planula Chron – beginning of the Platynota Chron of the Early Kimmeridgian, strongly suggests the tectonic elevation of a wide area, possibly related to the activity of the Holy Cross Fault System. The consequence of this tectonic uplift was the attainment of the fairly uniform morphological character of the whole shallow-water carbonate platform of the Holy Cross Mountains and some adjoining areas.

The fairly uniform facies pattern of the carbonate platform resulted in the wide distribution of the marly deposits corresponding to the Latosówka Marl Mbr. of the upper part of the Planula Zone. This regressive marly unit originally recognized in the Wieluń Upland at the foreland of the carbonate platform (*e.g.*, Wierzbowski, 1966 – where it was described as "the lower marly unit" along with two younger marly units – all of them treated as the beginning of successive sedimentary complexes), is now widely recognized both in the north-western and the north-eastern margins of the Holy Cross Mts. The occurrence of this unit has been treated as "controlled by tectonic events, but possibly superimposed on the climatic cycles" (Wierzbowski, 2017, p. 72). The decline of the siliciclastic sedimentation of the Latosówka Marl Mbr. corresponding to the topmost part of the Planula Zone (Galar Subzone) was marked by the minimum of the of the 405-kyr eccentricity cycle indicating a higher sea-level over the carbonate platform of the Holy Cross Mts. (Wierzbowski, 2020; *cf.* Boulila *et al.*, 2008, 2010).

The top of the chalky limestone units (sequences I: 2, II: 1 and III: 2) is marked everywhere by a discontinuity surface, and the directly overlying deposits yield fairly abundant ammonites generally indicative of the lower part of the Platynota Zone, close to the boundary between the Polygyratus Subzone and the Desmoides Subzone (see stratigraphical comments at the description of the successions above; see also Wierzbowski, 2020). This level is close to the minimum of the 405-kyr eccentricity cycle, and thus corresponds to the very high sea-level as recognized in southern France (Boulila *et al.*, 2008, 2010), and as shown commonly by stratigraphical condensations in the Wieluń Upland in the open marine environment in the foreland of the carbonate platform (Wierzbowski, 2017, and older papers cited therein). The distinct marly intercalations, corresponding to the Zapole Marl Bed from the Wieluń Upland (Wierzbowski, 2017, 2023), are often associated with the discussed boundary in the Holy Cross Mts., as seen at Iłża–Zuchowiec and Śniadków in the north-eastern, and at Podkurnędz in the north-western margins.

The overlying deposits show a more diversified facies pattern, but generally are characterized by the occurrence of large bodies of oolitic limestones, especially well-developed in the north-eastern and the south-western margins of the Holy Cross Mts. (Fig. 4). The distribution of oolitic limestones was possibly controlled by synsedimentary tectonic activity which was responsible for development of structurally controlled elevations of sea-floor like that along the Nowe Miasto–Iłża–Bałtów Fault Zone, the Holy Cross Fault System, the Zawiercie–Busko Fault Zone, and local associated smaller-scale faults (see comments at detailed description of the successions; see also Wierzbowski, 2020). The general facies scheme includes also several other facies types associated with oolite units, especially that of micritic limestones of local restricted environments.

The marly deposits situated between two main oolite limestone to micritic limestone units in the north-western

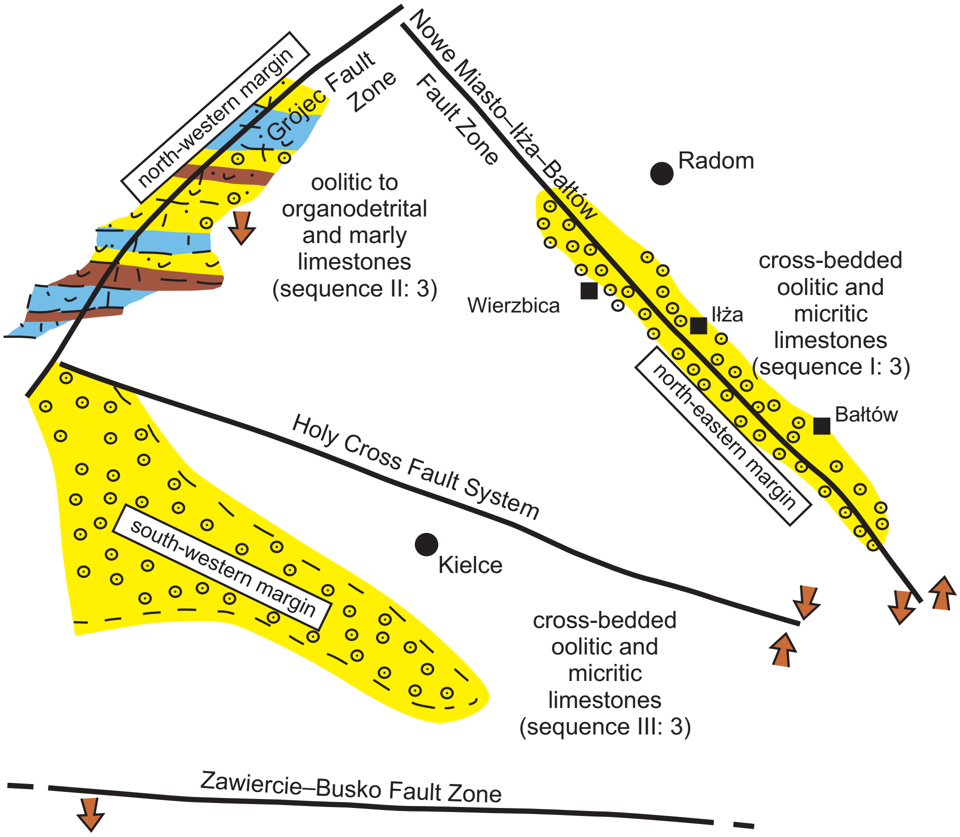

Fig. 4. Sketch of the distribution of the main facies assemblages during the latest Platynota – earliest Hypselocyclum chrons of the Early Kimmeridgian in the Holy Cross Mountains (intervals/sequences I: 3, II: 2, and III: 3): areas of occurrence of facies assemblages are somewhat enlarged in relation to their preserved range

Arrows indicate direction of tectonic movements

(Błaziny–Skarbka units *versus* Wierzbica–Ożarów units) and the south-western margins (Leśnica Limestone Mbr. *versus* Malogoszcz Oolite Fm.) are correlated with the Góry Marl Mbr., recognized earlier in the Wieluń Upland as representing the foreland of the carbonate platform (Wierzbowski, 2017, 2020). This marly unit was formed in a not fully-marine environment of possibly of lowered salinity corresponding to a set of shallow lagoons developed from the eastern to south-western parts of the carbonate platform during the middle Platynota Chron (Wierzbowski, 2020). The formation of this unit was possibly controlled by climatic factors but was superimposed on tectonic activity which resulted in increased supply of silicilastic-marly deposits in the generally regressive interval of a lower sea-level. On the other hand, the sedimentatation of the overlying Małogoszcz Oolite Formation in the south-western margin clearly represents a succession from a transgressive segment at its base, through a regressive segment in the middle to a transgressive segment with common ammonites of the basal Hypselocyclum Zone at the top. The cyclostratigraphic correlations as based on detailed ammonite stratigraphy suggests that the Małogoszcz Oolite Fm. was deposited approximately during a single short (100-kyr) eccentricity cycle (Wierzbowski, 2020).

All these data coming from the south-western and north-eastern margins of the Holy Cross Mts. suggest the fairly rapid, and climatically-controlled sedimentation of the discussed oolite-micritic-marly deposits of the lower parts of sequence I: 3a, b and sequence III: 3a, b. The age correlative sequence II: 2 from the north-western margin is less lithologically differentiated, and possibly developed in a somewhat deeper marine environment.

More towards the west in the substrate of the Neogene brown-coal field at Szczerców and Kiełczygłów, in the northern part of the Wieluń Upland, are known biodetrital chalky limestones with abundant hermatypic corals which represent the lateral counterpart of the upper part of the oolite deposits from the Holy Cross Mts. Still further toward the west in the Wieluń Upland, but also southwards, they pass laterally into the bedded chalky limestones with abundant fauna, especially siliceous and calcareous sponges, but locally also with occasional foliaceous hermatypic corals. These deposits attributed to the Kule Chalky Limestone Mbr. are underlain by the marly deposits of the Góry Marl Mbr. (Wierzbowski, 2017; *cf*. also Wierzbowski, 1966). All of them represent the moderately shallow-water environment at the outer margin of the shallow-water carbonate platform deposited from the middle Platynota Chron to the earliest Hypselocyclum Chron of the Lower Kimmeridgian.

The marly deposits of the Kiełczygłów Marl Mbr. overlying oolitic limestones in the middle of sequence III: 3 (south-western margin), and occurring at the top of sequence II: 2 (north-western margin), record the stratigraphical interval of the Hypselocyclum Zone heralding the large palaeogeographical changes in the development of the carbonate platform of the Holy Cross Mts. In the south-western margin, this interval comprises the directly overlying limestones of the Grabki Limestone Mbr. developed in a restricted environment, and bordered to the north and south by oolitic limestones, developed in a markedly higher energy regime. These deposits are, however, succeeded everywhere by marly deposits (Dobromierz Marl Mbr.) and micritic "sublithographic" limestones (Buczyna Limestone Mbr.), both deposited in the restricted environment (Kutek, 1968; Wierzbowski, 2020). On the other hand, the oolitic and oncolitic limestones of sequence II: 3 overlying the marly deposits of the Kiełczygłów Marl Mbr. in the north-western margin, and the corresponding deposits of adjoining parts of the Wieluń Upland from the west, represent a wide external zone of the higher energy regime of the carbonate platform which existed here for a longer time during the early Hypselocyclum Chron (Wierzbowski, 2017).

The spatial distribution of oolitic and oncolitic limestones in the north-western margin, and especially of their oolite units, seems to be closely related to the extent of the Gójec Fault Zone (*cf*. Matyja, Wierzbowski, 2014, fig. 2). This zone of occurrence of the discussed deposits continues also towards the south-west along the same fault zone down to the Radomsko Elevation, and then possibly westwards along the western prolongation of the Holy Cross Fault System, at least to the Szczerców–Bełchatów coal-fields area. Such a distribution of the deposits strongly suggests synsedimentary fault control on their sedimentation. Additionally, as the development of these deposits took place near the minimum of the 405-kyr. eccentricity cycle during the late Hippolytense Subchron (Boulila, 2008, 2010; *cf*. Wierzbowski, 2017, 2020), this explaines the local attainment also of a fairly large thickness of these deposits being an effect of aggradation due to a rapid relative sea-level rise.

The overlying deposits of the upper part of sequence II: 3 can be attributed to the Majaczewice Member of the Burzenin Formation, representing a deeper-water open-marine environment (Wierzbowski, 2017). Their extensive distribution, not only in the north-western margin of the Holy Cross Mts., but also westwards over large areas of the northern part of the Wieluń Upland (Wierzbowski, 2017), and the Radomsko Elevation (Wierzbowski, Głowniak, 2018), marks the first stage of flooding of the carbonate platform of the Holy Cross Mts. and adjoining areas during the Hypselocyclum Chron of the Early Kimmeridgian (Fig. 5).

The oyster lumachelle-dominated interval (sequences I: 4a, b, II: 4, III: 4) is evidently of transgressive character bringing open-marine faunas, including ammonites, onto the whole shallow-water carbonate platform. The first stage of transgression is shown by the occurrence of oolitic limestones associated with *Actinostreon* lumachelles along the Grójec Fault Zone from the north-western margin of the Holy Cross Mts. (from Sulejów to Przedbórz) down to the Radomsko Elevation. The *Actinostreon* lumachelles ("*Lopha/Alectryonia*" lumachelles) composed of densely packed shells have been interpreted as lag deposits originating from reworking of primary sediments during the high-energy events (Seilacher *et al*., 1985; Machalski, 1993), thus their co-occurrence with oolites confirms such an environmental interpretation. The same lumachelles were recorded from a narrow stratigraphical interval at the top of the Hypselocyclum Chron, both in the north-eastern margin at Wierzbica (Gutowski, 1992, 1998) and in the south-western margin at Dobromierz (Kutek, 1994; Wierzbowski, 2020), directly above the tidal flat deposits with siliciclastic material. This suggests the presence of a wide embayment opening toward the north-west in between the elevated fault blocks: with the north-eastern margin bounded by the Nowe Miasto–Iłża–Bałtów Fault Zone, and the south-western margin bounded by the Holy Cross Fault Zone (Fig. 5). The subsequent direction of the marine transgression can be interpreted from the appearance of high-energy deposits generally in a higher stratigraphical position southwards as shown by the Małogoszcz section, where the *Actinostreon* lumachelles appeared much later, during the Crusoliensis Subchron of the Divisum Chron, and possibly eastwards as shown by the character of deposits in the Wierzbica section. Such a palaeogeographical interpretation is generally consistent with that proposed for the older stratigraphical intervals of the Hypselocyclum Zone (see above).

The most common lithological type of oyster lumachelle is, however, that composed of *Nanogyra* shells, generally corresponding to the Stobnica beds/lumachelles (Kutek, 1961, 1962; see also Matyja, Wierzbowski, 2014). and treated as indicative of a deeper-water environment (Machalski, 1993). This is especially common in the north-western mar-

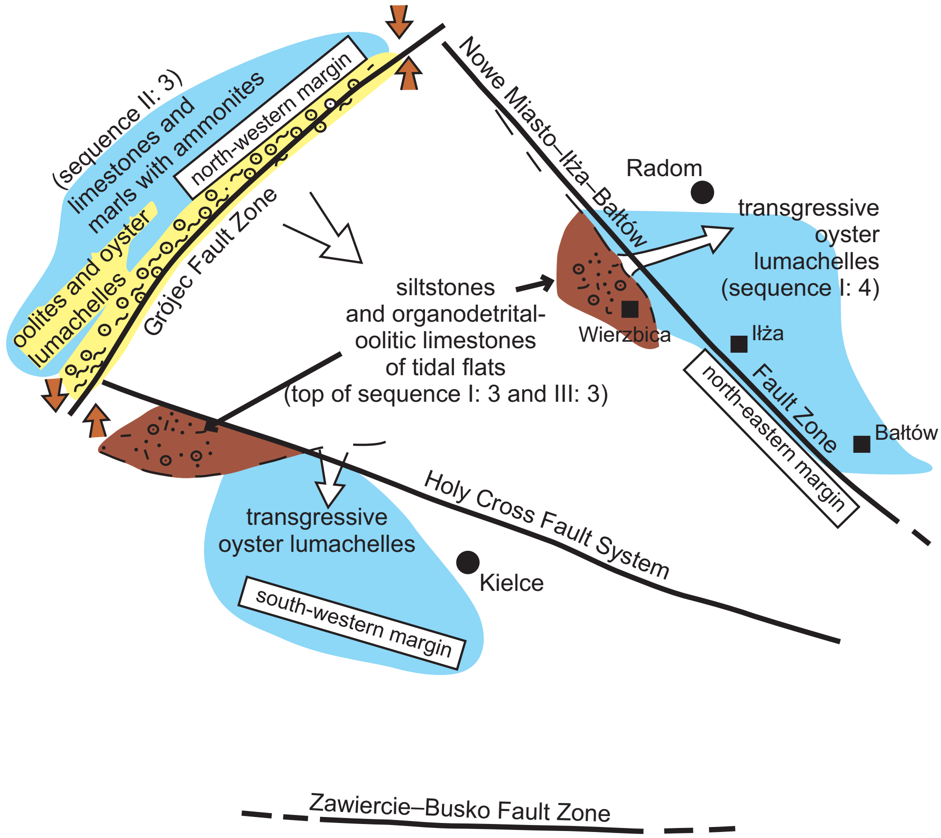

Fig. 5. Sketch of the development of transgression and of facies assemblage distribution during the Hypselocyclum Chron of the Early Kimmeridgian in the Holy Cross Mountains (interval/sequences I: 4, II: 3 and III: 4); areas of occurrence of facies assemblages are somewhat enlarged in relation to their preserved range

White arrows indicate directions of transgression: from early Hypselocyclum Chron in the west, to late Hypselocyclum Chron in the north-east and south; brown arrows indicate direction of tectonic movements

gin, being also dominant in higher parts of the oyster lumachelle interval in the north-eastern and the south-western margins of the Holy Cross Mts. Some condensation levels marked by concentration of ammonite shells are also associated with mass-occurrences of *Nanogyra* shells – in the Uhlandi Subzone of the Divisum Zone, and higher in the upper part of the Mutabilis/Acanthicum Zone – at the *schilleri* horizon. All these levels are interpreted as climatically controlled, possibly related to long eccentricity cycles.

The overlying deposits represented by oyster-terebratulid lumachelles and bioclastic detrital lumachelles overlain by chalky limestones with abundant shallow-marine fauna, especially nerineid gastropods (sequence I: 5), represent the recurrence of the environment of the shallow-water carbonate platform onto the north-eastern margin of the Holy Cross Mts. These are the youngest deposits preserved here of Late Kimmeridgian age, corresponding to the Eudoxus Zone – from its middle part to the Autissiodorensis Zone. Towards the north and the west (including the north-western Holy Cross Mts. margin) the deposits are laterally replaced by the deep-water clay to marl and marly limestone sequence (sequence II: 5) of the Pałuki Fm. (Bratków Marl Mbr., see Matyja, Wierzbowski, 2014). Southwards, at the south-western margin of the Holy Cross Mts., possibly a further belt of shallow-water facies represesented by sandy oyster lumachelles (Top Lumachelle of Kutek, 1968) was developed (Fig. 6). Such a paleogeographical location of shallow-water facies suggests synsedimentary tectonic uplift along the Nowe Miasto–Iłża–Bałtow Fault Zone in the east and possibly the Zawiercie–Busko Fault Zone in the south. Additionally, climatic oscillations, giving rise to some increase of sea-level from the middle Eudoxus Chron to the transition between the Eudoxus-Autissiodorensis chrons, were also responsible for the development of the discussed sequence.

Younger Late Jurassic deposits are known from the north-western margin only, being removed by erosion during the Early Cretaceous from other areas of the Holy Cross

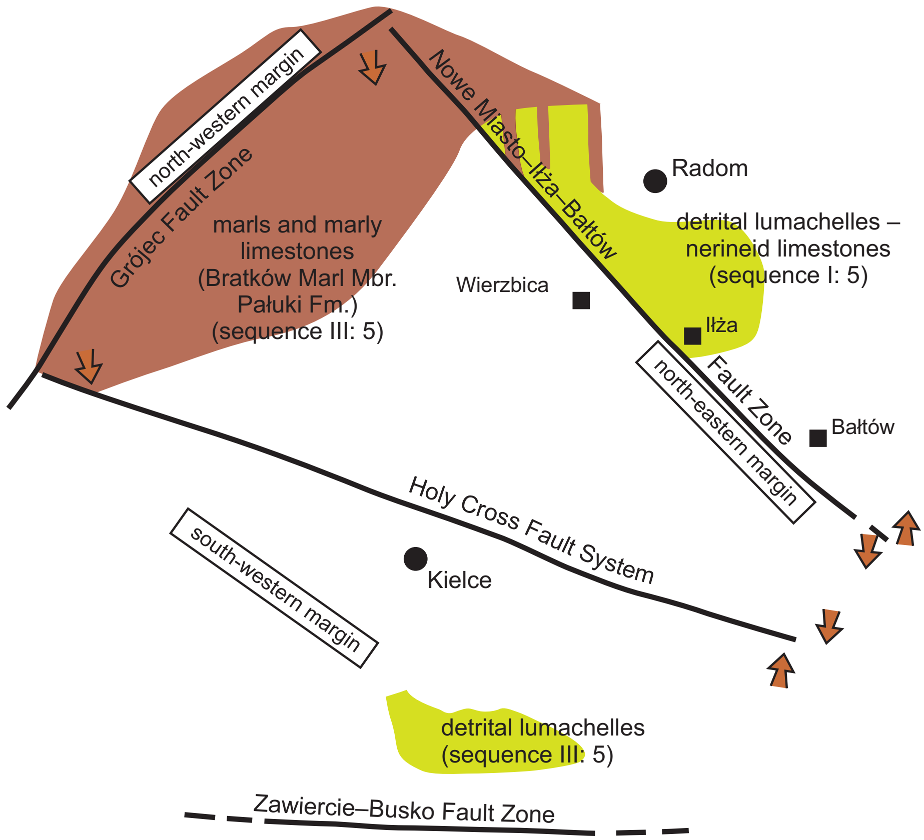

Fig. 6. Sketch of the development of the main facies assemblages during the middle to late Eudoxus Chron of the Late Kimmeridgian in the Holy Cross Mountains (intervals/sequences I/5, II/5 and III/5); areas of occurrence of facies assemblages are somewhat enlarged in relation to their preserved range

Arrows indicate direction of tetctonic movements

Mountains. The sequence in the upper part of the Pałuki Formation includes deposits of the Brzostówka Marl Mbr. fairly rich here in fine siliciclastic detrital material occurring in predominantly mud facies. The deposits have yielded numerous ammonites (Kutek, Zeiss, 1997) which occur from the Kimmeridgian-Tithonian ("Volgian") boundary and range up to the lower part of the Scythicus Zone of the Lower Tithonian. Corresponding marly deposits have been reported from boreholes in the substrate of the northern part of the Carpathian Foredeep, south of the Holy Cross Mountains. They represent the upper part of the Niwki Fm., showing the presence of an ammonite, originally described as *Orthosphinctes* sp. (Gutowski *et al.*, 2007), but which is representative of the markedly younger ammonite lineage *Discosphinctoides–Sarmatisphinctes–Ilovaiyskaya* being diagnostic for the uppermost Kimmeridgian (Autissiodorensis Zone) to the lowermost Tithonian interval (see Matyja, 2009). Moreover, the stratigraphical revision of the whole Upper Jurassic sequence in the Carpathian Foredeep area (Matyja, 2009, and earlier papers cited therein) has shown that the sponge megafacies deposits of the Łękawica Fm. range here up to the Lower Kimmeridgian and occur directly below the marly deposits of the Niwki Fm., which precludes the occurrence in that place and time of the shallow-water carbonate deposits known from the Holy Cross Mts. area. This indicates that the southern boundary of the shallow-water carbonate platform of the Holy Cross Mts., is possibly of fault-bounded character because of Zawiercie–Busko Fault Zone activity, and thus it did not reach more southern areas of the Carpathian Foredeep. The occurrence of the discussed fairly thick marly deposits of similar age either overlying the shallow-water carbonate platform deposits in the north-western margin of the Holy Cross Mts., or constituting the upper part of a more deeper water succession south of the carbonate platform in the Carpathian Foredeep area, suggests the development of a uniform blanket of marly facies during the latest Kimmeridgian-earliest Tithonian over the whole Holy Cross Mountains and adjoining areas. This is consistent with the occurrence above, both in the north-western margin of the Holy Cross Mts. and in the

Carpathian Foredeep area, of shallow-water limestones (of the Kcynia Fm., and of the Swarzów Fm., respectively) indicating the development of a new shallow-water carbonate platform (Matyja, 2009) during the Tithonian (and earliest Cretaceous), having possibly also a wide lateral extent.

The discussed succession of widely lateraly distributed marly deposits with detrital siliciclastic material, followed by shallow-water carbonates, may be interpreted in terms of long-time climatic changes from humid to arid intervals (ranging to about 2.4 myr for a full cycle and about 1.2 myr in a half cycle) which can be correlated with transgressive and regressive tendencies. Such an interpretation was given for the corresponding stratigraphical intervals IA and IB of the Lower Tithonian ("Lower to Middle Volgian") by Grabowski *et al.* (2021) in the central part of Polish Basin in the sedimentary sequence of deposits in borehole Kcynia IG 2 borehole as based on high-resolution chemostratigraphic study and correlations with other successions in Europe.

Possibly these long-term climatic cycles occur also within the older part of the successions studied in the Holy Cross Mountains, but they are not so sharply distinguished, because of the lower lithological contrast and superimposed effect of local synsedimentary tectonic activity. Nevertheless, some suggestions on the occurrence of these cycles were given by Wierzbowski (2022) who distinguished four stages of diversification of ammonite faunas in several lineages, especially within the family Aulacostephanidae, subdivided into two groups:

– group 1 including: the stratigraphical interval of the uppermost Oxfordian (turnover at the base of the Pseudocordata Zone = uppermost Bifurcatus Zone), and of the middle part of the Lower Kimmeridgian (turnover at the uppermost part of the Baylei Zone = the base of the Platynota Zone), both of them represented by rather poorly diversified aulacostephanid assemblages, with gradually emerging new genera, and but a few new endemic lineages;
– group 2 including: the stratigraphical interval of the lowermost Kimmeridgian (turnover at the base of the Kimmeridgian corresponding to the Pseudocordata/Baylei = Hypselum/Bimammatum zone boundary), and of the upper part of the Lower Kimmeridgian (turnover at the Hypselocylum/Divisum zone boundary and the base of the Askepta Subzone), both representing episodes of strong aulacostephanid radiation. The intervals of group 1 are correlated with the 2nd order regressive cycles, whereas those of group 2 with the 2nd order transgressive cycles (cf. Gygi *et al.*, 1998). It is highly probable that the evolutionary development of ammonites discussed was related to the major cycles of sea-level changes, which at least partly resulted from long-time climate oscillations; the duration of each ranged about 1.2 myr.

CONCLUSIONS

Late Oxfordian to Early Tithonian sedimentation was dominated by shallow-water carbonates with some intervening episodes of deeper-water clay to marly deposits. It spread across the area representing a prominent elevation being structurally a fragment of the Variscian fold belt, and having in its substrate older Caledonian, Sandomirian and Cadomian structures. This area corresponding during the Jurassic to the elevated part of the Northern Tethyan Shelf – the so-called "Meta-Carpathian Arch", includes the present Laramian structure of the Holy Cross Mts., as well as those of the northern part of the of the Miechów/Nida Depression, and of the Cracow–Silesian Monocline, adjoining from the west. The present distribution of the Late Jurassic deposits in the discussed area is strictly related to the post-Jurassic episodes of tectonic deformation and related erosion of deposits – the Neo-Cimmerian during Early Cretaceous, and the Laramian at the Cretaceous/Palaogene boundary ones.

The development of sedimentation during the Late Jurassic was controlled by tectonics related to the activity of synsedimentary faults and climatically induced changes of sea-level. The cyclicity in the development of sedimentation recognized as local sequences (intervals) in particular margins of the Holy Cross Mts.,where the Upper Jurassic are preserved (I: 1–5 in north-eastern margin, II: 1–7 in north-western margin, and III: 1–5 in south-western margin), can be generalized using the megasequences COK, LUK and KVB of Kutek (1994) introduced as three main tectono-stratigraphic units for central Poland. Some modifications of their characteristics as applied to the area of study are presented below.

The onset of shallow-water sedimentation following the development of the deep-neritic sponge megafacies took place during the Late Oxfordian when a large bank of latitudinal orientation corresponding to the area of study became uplifted. It resulted in the appearance of the coral limestones which settled the tops of the older deeper-water cyanobacteria-sponge buildups, and a set of chalky limestone deposits successively spreading around, forming a wide shallow-water carbonate platform, towards the west and south. The uplift continued during the Planula Chron and some intervals of the Hypselocylum Chron representing the final stage of the COK megasequence – up to the end of local sequences: I: 3, II: 2, and III: 2. The development of the COK megasequence was possibly related to tectonic activity in the Tethyan domain (cf. Matyja, 2015).

The early stage of marine trangression of the LUK megasequence began in the Hippolytense Subchron of the Hypselocyclum Chron in the north-western margin of the Holy Cross Mts. (sequence II: 3), and in adjoining areas to the west, but it occurred later in the north-eastern margin (I: 4) and the south-western margin (sequence III: 4) – at the end of the Hypselocyclum Chron, leading to an almost complete flooding of the older shallow-water carbonate platform. It is interesting to note that an isochronous, possibly tectonically induced change in sedimentation occurred in some areas of northern Poland (Kujawy area) where deep-water marls and limestones with ammonites have appeared during the earliest Hypselocyclum Chron covering the siltstones and silty limestones of the Łyna Formation (Matyja, Wierzbowski, 1998; cf. also Wierzbowski, 2020). This suggests that the development of the LUK megasequence was stimulated by tectonic activity related to the Middle Polish Trough (*cf.* Dadlez, 1997).

A smaller uplift in the north-eastern margin and south-western margin of the Holy Cross Mts. during the Eudoxus Chron and the formation there of shallow-water deposits, suggesting the temporary reconstruction of the carbonate platform, corresponds already to "some level low" in the next megasequence of KVB of Kutek (1968) – but possibly it would be more reasonable to recognize this interval as representing an independent megasequence.

The spatial and time interpretation of the youngest Late Jurassic deposits (KVB megasequence) in the discussed area of the Holy Cross Mts. is highly speculative because of their fragmentary preservation due to later erosion. It seems, however, that during the latest Kimmeridgian and nearly the whole Early Tithonian the area was strongly lowered being the place of sedimentation of deeper-water clay and marly deposits. The new uplift related to the marked climate change towards aridification occurred in the late Early Tithonian, and led to the formation of the new carbonate platform possibly covering the whole area of the Holy Cross Mountains, which completely changed the older palaeogeography.

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PLATE 1

**Uppermost Oxfordian to Lower Kimmeridgian ammonites
from the north-eastern margin of the Holy Cross Mts. (succession I)**

Fig. 1. *Microbiplices anglicus vieluniensis* Wierzbowski et Matyja = *Microbiplices microbiplex* (Quenstedt) *in*: Gutowski (1992, pl. 5: 3, 1998, pl. 1: 2), Bałtów. IGPUW/27/22

Fig. 2A, B. *Plasmatites lineatus* (Quenstedt), lateral (A) and ventral (B) view, part of the outer whorl preserved is the body-chamber, Eugeniów. IGPUW/27/58

Fig. 3A, B. *Vineta* aff. *streichensis* (Oppel) = *Discosphinctes virgulatus* (Quenstedt) or *Discosphinctes* sp. *in*: Liszkowski, 1972, lateral view (A), enlarged to show details of inner whorls (B), Wólka Bałtowska (Wolanka river valley). IGPUW/27/52

Fig. 4. *Orthosphinctes* (*Orthosphinctes*) cf. *tiziani* (Oppel), Skarbka Dolna. IGPUW/27/51

Fig. 5. *Trenerites* sp. = *Idoceras* (*Subnebrodites*) sp. *in*: Gutowski (1992, pl. 3: 2, 1998, pl. 1: 1), Błaziny. IGPUW/27/15

Fig. 6. *Vielunia conspicua* (Schneid) = *Rasenia* (*Eurasenia*) cf. *vernacula* (Schneid) *in*: Gutowski (1992, pl. 5: 4, 1998, pl. 1: 5), Marylin–Śniadków. IGPUW/27/23

Fig. 7. *Vielunia* sp. = *Rasenia* (*Eurasenia*) sp. *in*: Gutowski (1992, pl. 5: 6), Wierzbica quarry, bed 3. IGPUW/27/24

Fig. 8. *Eurasenia frischlini* (Oppel), phragmocone, Wierzbica quarry, bed 6e (7/8), uppermost part *in*: Wierzbowski (2023, fig. 3). IGPUW/27/70

Fig. 9. *Ataxioceras* (*Parataxioceras*) *lothari huguenini* Atrops = *Ataxioceras hypselocyclum hypselocyclum* (Fontannes) *in*: Gutowski (1992, pl. 4: 4, 1998, pl. 1: 4). Wierzbica quarry, bed 26, directly above bed with *Actinostreon.* IGPUW/27/18

Phragmocone/body-chamber boundary is arrowed

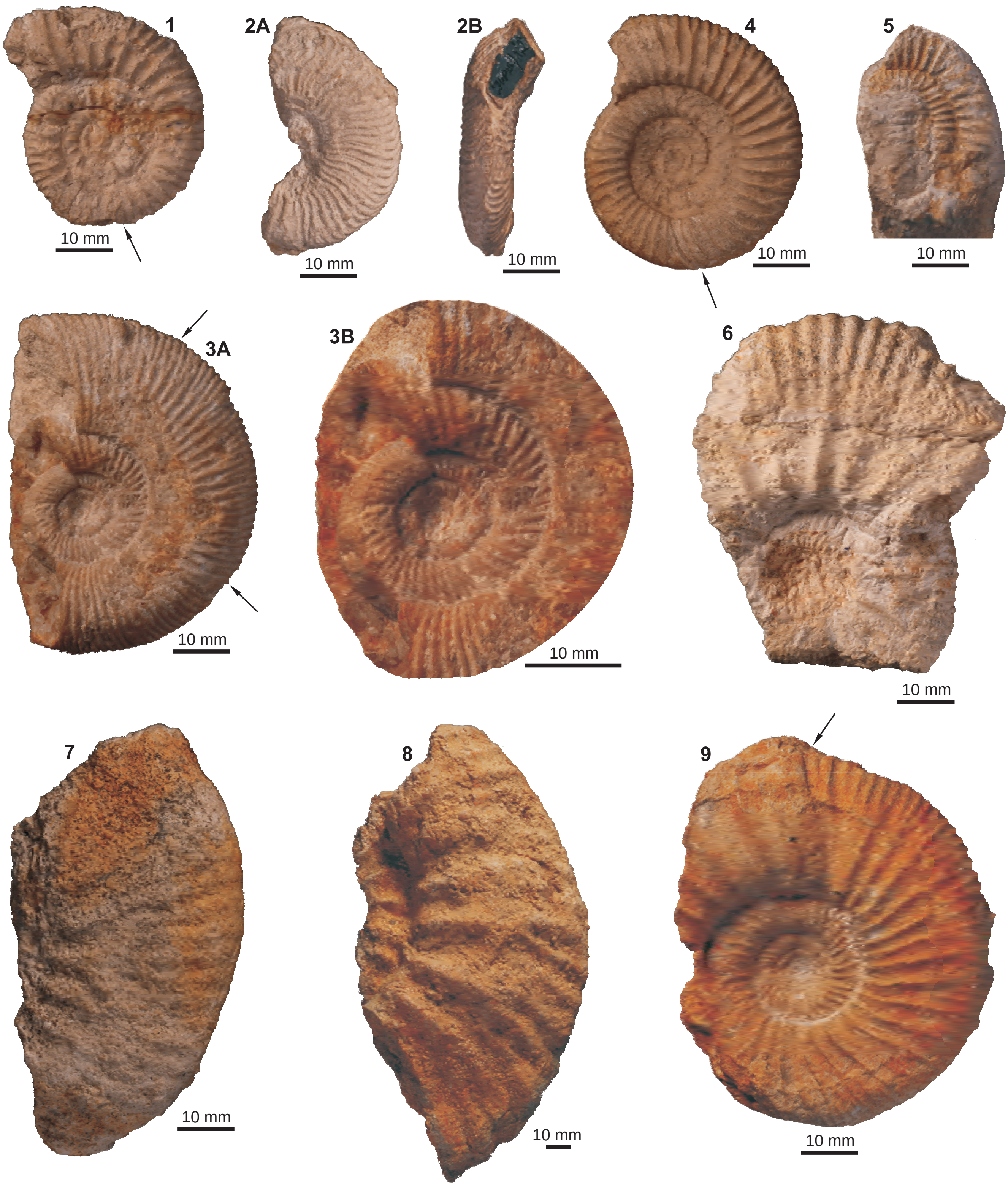

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PLATE 2

Lower Kimmeridgian ammonites from the north-western margin of the Holy Cross Mts. (succession II)

Fig. 1. *Orthosphinctes* (*Lithacosphinctes*) *evolutus* (Quenstedt) = *Planites lictor* (Fontannes) *in*: Barczyk (1961, p. 24, 77, 78, pl. 8), phragmocone, Sulejów (locality 29). IGPUW/A//4/13

Fig. 2. *Involuticeras involutum* (Quenstedt) *in*: Barczyk (1961, p. 80, 81, pl. 9: 1), Sulejów (locality 38), phragmocone. IGPUW/A/4/26

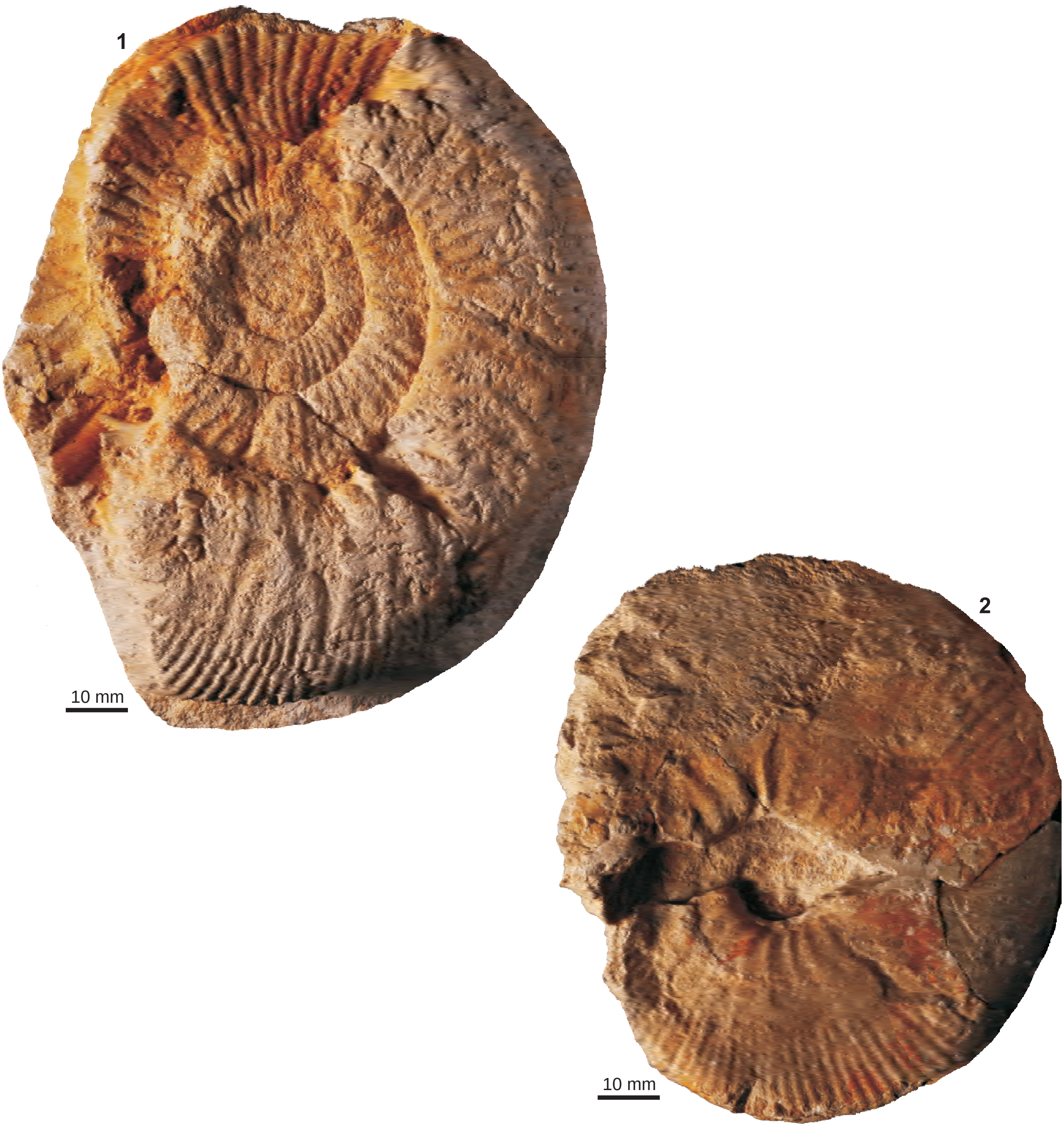
1
10 mm
2
10 mm

PLATE 3

Fig. 1. *Rasenia* (*Pachypictonia*) cf. *dorsata* Schneid = *Rasenia* cf. *trimera* (Oppel) *in*: Barczyk (1961, p. 18, 79, 80, pl. 7: 2), Podkurnędz (locality 21), phragmocone. IGPUW/A/4/23,25

Fig. 2. *Rasenia* (*Pachypictonia*) cf. *dorsata* Schneid, Podkurnędz quarry, phragmocone. IGPUW/A/4/28

Fig. 3. *Vineta* sp. (microconch or juvenile) = *Ataxioceras semistriatum* Schneid *in*: Barczyk (1961, p. 75, 76, pl. 5: 3), Podkurnędz (locality 21). IGPUW/A/4/2

Fig. 4. Aulacostephanidae indet (? *Vineta* sp.) = *Ataxioceras semistriatum* Schneid *in*: Barczyk (1961, p. 18), Podkurnędz (locality 21). IGPUW/A/4/3

Fig. 5. *Vielunia conspicua* (Schneid) = *Rasenia trimera* (Oppel) *in*: Barczyk (1961, p. 18, 79, 80, pl. 7: 2), phragmocone, Podkurnędz (locality 21). IGPUW/A/4/22

Fig. 6. *Prorasenia quenstedti* Schindewolf = *Rasenia* cf. *stephanoides* (Oppel) *in*: Barczyk (1961, p. 33, 79, pl. 5: 4), dolina Radońki (locality 49). IGPUW/A/4/16

Fig. 7. *Ataxioceras* (*Schneidia*) sp. = *Ataxioceras* aff./cf. *semistriatum* Schneid *in*: Barczyk (1961, p. 30, 75, 76), Sulejów (locality 39), phragmocone. IGPUW/A/4/4

Phragmocone/body-chamber boundary is arrowed

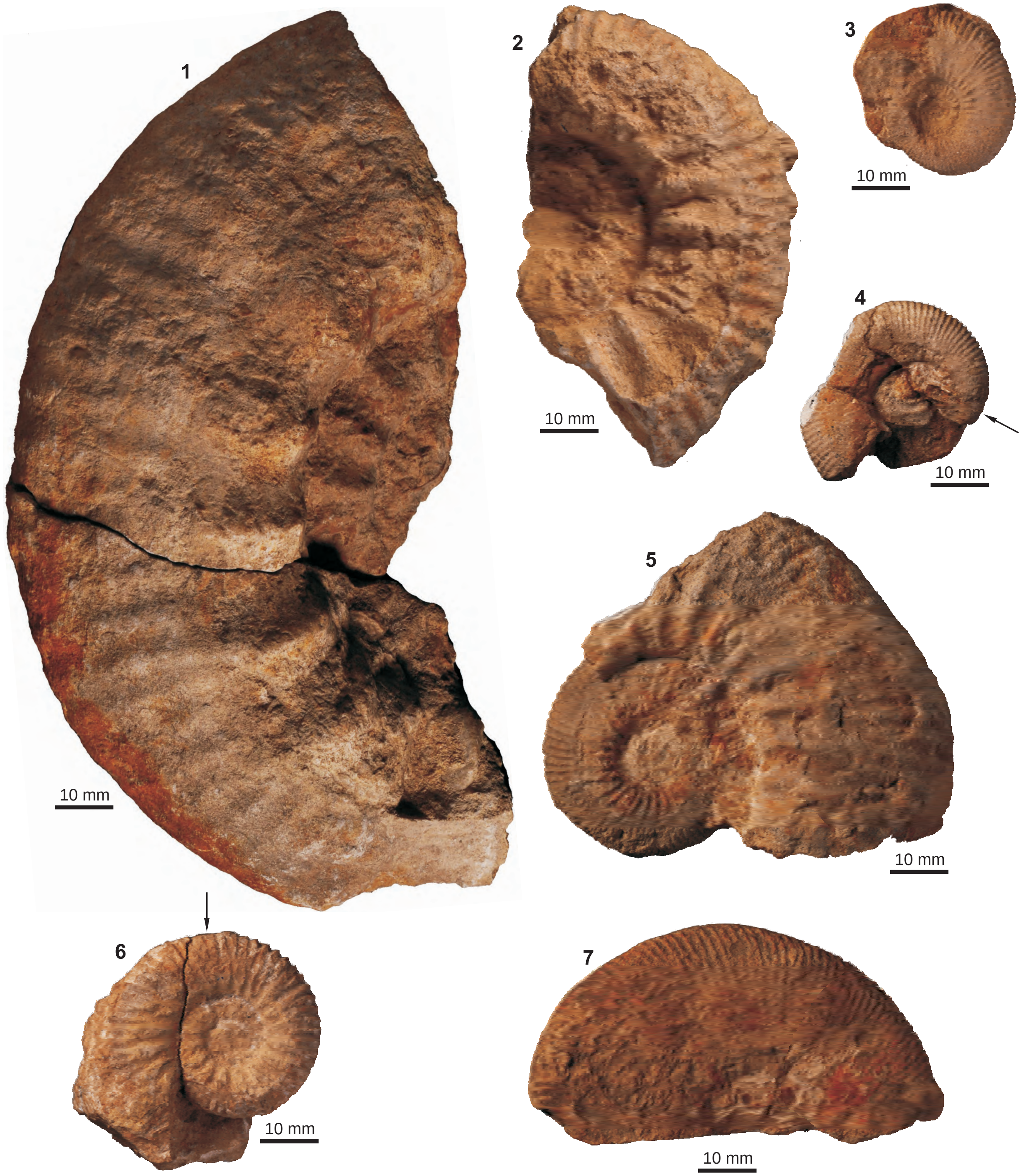

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PLATE 4

Upper Kimmridgian ammonites from the north-eastern margin (succession I) and the south-western margin (succession III) of the Holy Cross Mts.

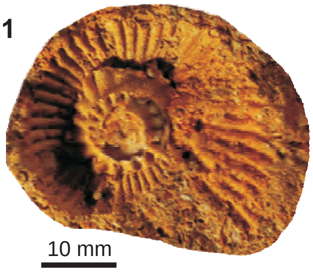
Fig. 1. *Aulacostephanus eudoxus* (d'Orbigny), Krzyżanowice, detrital lumachelles, phragmocone. ZPAL V 69/2

Fig. 2. *Aspidoceras caletanum* (Oppel), Krzyżanowice, detrital lumachelles. ZPAL V 69/3

Fig. 3. *Orthaspidoceras schilleri* (Oppel), Małogoszcz cement work quarry, marls and clays of the upper part of the section, directly below biodetrital lumachelles and oolites. MWG UW ZI/100/151

Phragmocone/body-chamber boundary is arrowed

1



2

3