Annales Societatis Geologorum Poloniae (1999), vol. 69: 63–79.

SEA-BOTTOM RELIEF VERSUS DIFFERENTIAL COMPACTION IN ANCIENT PLATFORM CARBONATES: A CRITICAL REASSESSMENT OF AN EXAMPLE FROM UPPER JURASSIC OF THE CRACOW–WIELUŃ UPLAND

Jacek MATYSZKIEWICZ

University of Mining and Metallurgy, Faculty of Geology, Geophysics and Environmental Protection,
al. Mickiewicza 30; 30-059 Cracow, Poland; E-mail: jamat@geol.agh.edu.pl

Matyszkiewicz, J., 1999. Sea-bottom relief versus differential compaction in ancient platform carbonates: a critical reassessment of an example from Upper Jurassic of the Cracow–Wieluń Upland. *Ann. Soc. Geol. Polon.*, 69: 63–79.

Abstract: The growth of carbonate buildups in the northern, stable shelf of the Tethyan Ocean was the principal factor in the development of diversified sea-bottom relief in the Late Jurassic basin. Reconstruction of this relief has been a matter of numerous controversies. This paper provides an analysis of published data on elevation differences on sea bottom along the SW margin of the Holy Cross Mts. and in the Cracow–Wieluń Upland. Moreover, methods of reconstruction of synsedimentary relief are presented.

In the Late Oxfordian the elevations on basin floor in the Częstochowa area (Cracow–Wieluń Upland) were about 100 meters at most, and were presumably even lower. The largest (over 200 meters) elevation differences of sea-bottom relief existing in the Częstochowa area at the Oxfordian/Kimmeridgian have been postulated when the recently observed differences in thickness between the deposits of carbonate buildup and of equivalent basinal facies were identified as a relief. In fact, different thickness is, in considerable part, an effect of differential compaction.

Abstrakt: Wzrost budowli węglanowych na północnym, stabilnym szelfie Tetydy był główną przyczyną powstania urozmaiconego reliefu dna w basenie późnojurajskim. Rekonstrukcja tego reliefu jest przedmiotem licznych kontrowersji. Praca analizuje dane literaturowe o wielkości deniwelacji dna z rejonu SW-obrzeżenia Gór Świętokrzyskich i Wyżyny Krakowsko-Wieluńskiej oraz omawia metodykę rekonstrukcji reliefu synsedymentacyjnego.

Deniwelacje dna basenu u schyłku oksfordu w rejonie Częstochowy wynosiły co najwyżej około 100 m a przypuszczalnie były jeszcze mniejsze. Postulowane wcześniej, ponad dwustumetrowe deniwelacje w basenie w rejonie Częstochowy na przełomie oksfordu i kimerydu były oparte na utożsamianiu z deniwelacjami dna aktualnej różnicy miąższości między utworami budowli węglanowej a ekwiwalentnymi jej utworami facji basenowej. Różnica ta jest w znacznej części wynikiem zróżnicowanej podatności osadów na kompakcję.

Key words: sea-bottom relief, carbonate buildup, bedded facies, compaction, Tethyan shelf, Late Jurassic.

Manuscript received 9 February 1999, accepted 17 August 1999

INTRODUCTION

In the Late Jurassic the northern, stable Tethyan shelf (Fig. 1) was the area of carbonate sedimentation showing distinct facies diversity. Generally, these sediments can be divided into the "*normal facies*" (term after Gwinner, 1976) and massive facies.

The term "*normal facies*" refers to bedded sediments which show a variety of lithologies. Apart from (i) microbolitic-sponge or microbolitic biostromes (cf. Dromart, 1989; Matyszkiewicz, 1989; Kott, 1989; Leinfelder *et al.*, 1994) whose microfacies is close to that of biolithites of massive facies, numerous varieties are observed of: (ii) bedded, micritic, Solnhofen-type limestones (*Plattenkalk facies*; cf. Keupp, 1977; Smoleńska, 1983, 1984; Peszat, 1991; Swinburne & Hemleben, 1994), (iii) wackestones-packstones composed of allo- and orthochemical components in variable proportions (cf. Peszat, 1964; Kutek, 1969; Gwinner, 1976; Smoleńska, 1986; Dromart *et al.*, 1994) and (iv) marls. Among these types of bedded sediments only the biostromes were subjected to the intensive, early-diagenetic cementation (cf. Heliasz & Racki, 1980; Kott, 1989; Matyszkiewicz, 1989). In the remaining bedded limestones and in the marls the early-diagenetic cementation is less pronounced or absent. The presence of penetrations in deposits laid down between the buildups indicates that these deposits were initially soft, carbonate muds (cf. Trammer, 1989; Hoffmann & Uchman, 1992). Hence, these were highly sus-

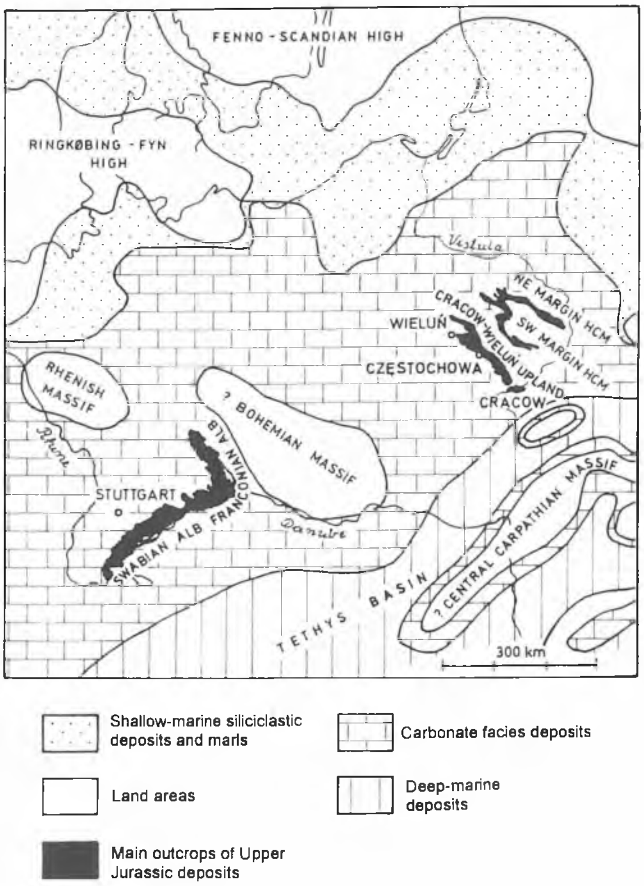

Fig. 1. Main outcrops of Upper Jurassic deposits related to palaeogeographical map of the central part of northern, stable Tethyan shelf in the Oxfordian (after Ziegler, 1990; modified). HCM – Holy Cross Mountains

ceptible to compaction which resulted in significant reduction in thickness.

The massive facies comprises a wide spectrum of carbonate buildup deposits dominated by diversified microbolites (term after Riding, 1991; cf. Schmid, 1996) which coexist locally with siliceous and calcareous sponges, corals and fine benthos. Despite widely discussed concepts on the genesis of Upper Jurassic microbolites (cf. Keupp *et al.*, 1993; Kaźmierczak *et al.*, 1996), their very early lithification has not been called in question. The literature provides numerous proofs for early-diagenetic, almost synsedimentary cementation of carbonate buildups (cf. Flügel & Steiger, 1981; Koch & Schorr, 1986; Matyszkiewicz, 1989, 1997; Trammer, 1989; Keupp *et al.*, 1990; Leinfelder *et al.*, 1994; Dromart *et al.*, 1994; Herrmann, 1996; Rehfeld, 1996; Matyszkiewicz & Krajewski, 1996; Reinhold, 1996 and others) demonstrated by development of rigid framework (cf. Matyja *et al.*, 1985; Trammer, 1989; Matyszkiewicz, 1989; Matyszkiewicz & Krajewski, 1996). Therefore, susceptibility of carbonate buildup deposits to compaction can be evaluated as very low.

The widespread appearance of siliceous sponges in some Upper Jurassic successions of the northern Tethyan shelf commonly leads to the opinion that these organisms were the principal rock-forming components. Consequently, all these highly diversified facies are categorized into the far simplified term "*sponge megafacies*" (Matyja, 1976 fide Trammer, 1982; Matyja & Pisera, 1991). As the principal rock-forming components of these rocks are microbolites (Gwinner, 1971), the term "*microbolitic facies*" seems to be more adequate. One of the essential and controversial problems of the Late Jurassic depositional environment in the northern Tethyan shelf is the reconstruction of the basin-floor relief.

METHODS OF RECONSTRUCTION OF SYNSEDIMENTARY RELIEF

Reconstruction of synsedimentary relief in all the carbonate formations is based upon the influence of diversified compaction of carbonate buildups and basinal facies on the estimated elevation differences of basin floor. Unfortunately, publications in which this method was applied are still scarce (cf. Terzaghi, 1940; Shaver, 1977; Doglioni & Goldhammer, 1988; Einsele, 1992; Saller, 1996).

Correct reconstruction of synsedimentary relief requires: (i) selection of at least one pair of lithological successions of the same age in a carbonate buildup and in an equivalent basinal facies, (ii) distinguishing of all lithological types in the successions, (iii) calculation of compactional reduction of thickness which has taken place until the time of reconstruction (separately for each distinguished lithological type) and (iv) calculation of corrected thickness for each studied succession. Only comparison of thicknesses calculated with such a procedure allows the estimation of elevation differences in a given time span. Additional assumed conditions are: similar subsidence and accumulation rates in compared fragments of sea bottom.

Calculation of thickness for each lithological type in a given time span is particularly complicated for carbonate sediments. Thickness reduction in marls originating from soft carbonate muds seems to be dependent mostly upon burial depth and reflected in porosity reduction due to the lack of cementation processes (cf. Schlanger & Douglas, 1974; Shinn & Robbin, 1983; Ricken, 1986; Bathurst, 1991; Einsele, 1992 and others). Distinct porosity reduction caused by compaction proceeds down to about 300 meter burial depth (cf. Shinn & Robbin, 1983; Moore, 1989) but is especially intensive at about 100 meter depth (Goldhammer, 1997; Lucia, 1999). According to Ricken (1985, 1986), porosity reduction in marls cannot be related exclusively to the load from overburden due to possible redistribution of carbonates in limestone-marl alternations (so-called diagenetic bedding; cf. Hudson & Jenkyns, 1969; Simpson, 1985; Ricken, 1985). Moreover, it must be taken into account that compaction of lower portions of thick, homogeneous complexes commences as early as during deposition of their middle and upper parts (Perrier & Quiblier, 1974).

As far as limestones are concerned the diagenetic history of deposits must be established, particularly the time of cementation, which is usually difficult (cf. Ricken, 1986; Wetzel, 1989; Lucia, 1999). At burial depths exceeding 300 meters the influence of pressure-dissolution processes on thickness reduction of a sediment becomes important (Shinn

& Robbin, 1983; Czerniakowski *et al.*, 1984; Bathurst, 1991).

The sediments of grain-supported type can be resistive to mechanical compaction down to even 700 meters burial depth (Goldhammer, 1997). For grain-supported limestones (mostly oolites) compaction is estimated from deformation of fabrics components, i.e. originally spheroidal grains (Coogan, 1970; cf. Ramsay & Huber, 1983). However, such method cannot be applied to mud-supported rocks. Studies of Shinn & Robbin (1983) point out that in carbonate muds the single allochems may not be deformed or crushed even if thickness reduction of sediment is significant. In such sediments the objective indicator of compaction seems to be rather the deformation degree of organic microfossils (e. g. acritarchs and dinoflagellate cysts) observed under the scanning electron microscope on polished and etched surfaces (cf. Westphal *et al.*, 1997; Westphal & Munnecke, 1997).

The continuous progress in knowledge of compaction effects in fine-grained carbonate sediments (cf. Ricken, 1987; Bathurst, 1991; Munnecke & Samtleben, 1996; Munnecke *et al.*, 1997) and of their calculation methods allows the more accurate estimations of compactional thickness reduction and enables application of such data to the evaluation of both, the accumulation and sedimentation rates (cf. Martire & Clari, 1994; Gómez & Fernåndez-Lopez, 1994; Clari & Martire, 1996). Among the numerous methods of compaction calculations in mud-supported carbonate sediments, the most common is the evaluation of deformations in originally spheroidal trace fossils (Plessmann, 1966; Crimes, 1975; Ricken, 1987; Gaillard & Jautee, 1987). This procedure is applied if the originally cyllindrical trace fossils occur in mass at the planes parallel to the bedding. According to the principles of the method, the compaction-induced deformations in the matrix and in the sediment which fills the penetrations are similar. Thus, the flattening of penetrations should be directly proportional to reduction of thickness of the whole sediment.

The line of evidence presented above bears some errors, as pointed out by Ricken (1986, 1987). The first error may result from an assumption that penetration is deformed only in one plane whereas in fact, deformation proceeds in planes both parallel and perpendicular to the loading pressure. The second error originates from the supposition that deformation of both the matrix and the penetration is the same during full time of mechanical compaction. In fact, the penetrated sediment is subjected to earlier cementation. Consequently, a specific moment susceptibility of sediment to compaction much lower than that of the matrix. Both errors cause some underestimation of the amount of compaction-induced thickness reduction of the sediment.

Two calculation methods of compaction-induced thickness reduction were published by Perrier & Quiblier (1974). The first – so-called "method of slices" can be applied to those drillings for which detailed data exist on lithology, porosity and age of sediments. In the stratigraphic column the "slices" are distinguished, which differ in lithology. Additionally, an assumption is made that for a given lithological unit the sedimentation rate is constant. Due to the application of integral calculus, this method considers variability of compaction in time caused by the increasing load from the overburden. However, the weak point is the neglection of transformation processes of minerals, particularly pressure solution, which contributes to overall thickness reduction. The second method is based upon the dependence between porosity and burial depth. The authors provide nomographs from which the initial thickness of sediments can be read for (i) known, recent thickness and (ii) estimated burial depth. However, this method cannot be applied *en block* for the successions of high lithological diversity (cf. Bathurst, 1987, 1991). Doglioni & Goldhammer (1988) and Goldhammer (1997) provided similar nomographs for carbonate muds and sands.

One of the common methods of compaction calculations is the so-called "carbonate compaction law" (Ricken, 1986, 1987) based upon the relationship between the contents of carbonates and insoluble residuum, compaction and porosity. Ricken (1986) showed mathematical formulae from which compation can be calculated if data on porosity and contents of carbonates and insoluble residuum are available.

Modelling of compaction process allowed to develop several calculation procedures for determining the initial thickness of various sediments (cf. Einsele, 1992) with the application of complicated mathematical methods (cf. Sclater & Christie, 1980; Schmoker & Halley, 1982; Baldwin & Butler, 1985; Bayer, 1989; Smosna, 1989; Einsele, 1992 and others).

HISTORY OF THE RESEARCH

The SW margin of the Holy Cross Mts. and the Cracow–Wieluń Upland are separate facies regions. However, in the Late Jurassic both areas were located in close neighbourhood (Fig. 1) and belonged to the broad, stable, northern Tethyan shelf (cf. Kutek *et al.*, 1984, 1992). This fact allows to present jointly the development of ideas on their basin floor relief.

Reconstruction of Late Jurassic synsedimentary relief in Cracow region was discussed by Dżułyński (1952, p. 157) who argued for the flat relief of low elevation differences. The inclinations up to 20° observed in platy limestone beds in the vicinity of massive limestones were explained by differential compaction (Dżułyński, 1952, p. 134-136).

Bukowy (1956, 1960) suggested the existence of basin floor relief in Cracow area and reported on inclinations about 17° up to even 45°. He interpreted such high angles as the results of compaction rather than remarkable synsedimentary relief.

Różycki (1960) claimed that complicated facies distibution pattern in the area of the Cracow–Wieluń Upland is an argument for the occurrence of several shoals and deeper furrows in the Late Jurassic basin. He was also of opinion that diversified morphology of the basin floor is manifested by slope angles in the massive limestones locally exceeding 30°.

Late Jurassic basin floor relief in the Częstochowa area was discussed by Marcinowski (1970) who explained the origin of calciturbidites as an effect of density currents transporting material downslope from sea-bottom elevations. Golonka & Haczewski (1971) considered that massive limestone in the Cracow area was laid down in a basin with distinct synsedimentary relief. Głazek & Wierzbowski (1972) proposed that the development of some synsedimentary relief in the area of Cracow–Wieluń Upland proceeded as late as in the Planula Chron (Late Oxfordian). The existence of low basin-floor elevations in the early Middle Oxfordian was noticed by Trammer (1982, 1985) who studied the development of bioherms in the Jasna Góra beds.

Late Jurassic, synsedimentary relief in the Wieluń Upland was discussed by Wierzbowski *et al.* (1983). They found that elevation differences of basin floor can be deducted from "sediment succession and the facial changes in the higher Oxfordian" (Wierzbowski *et al.*, 1983, p. 521). Development of diversified relief was suggested to result from "unequal growth of chalky limestones" (Wierzbowski *et al.*, 1983, p. 523). Furthermore, this relief was considerable flattened "during sedimentation of the lower marly unit" (Wierzbowski *et al.*, 1983, p. 523), i.e. prior to the end of the Planula Chron. In the studied area the lower marly unit shows thickness below 20 meters (Wierzbowski *et al.*, 1983, p. 520 – Fig. 2). Despite the observed high lithological variability of sediments Wierzbowski *et al.* (1983) neglected the role of differential compaction.

Smoleńska (1983, 1986) analyzed the lithology of the Upper Jurassic sediments in Częstochowa area and repeatedly pointed to the diversified effects of compaction which resulted in the inclination of platy limestone beds observed at their contacts with the massive limestones. The Late Oxfordian palaeorelief was advocated in Częstochowa area by Heliasz (1990) although no detailed numeric data were presented.

Peszat (1991), although he did not study the synsedimentary relief itself, provided numerous data on burial depth and on the influence of compaction on thickness reduction of deposits along the SW margin of the Holy Cross Mts. from which Upper Oxfordian micritic limestones have originated. According to his opinion, the sediments were laid down in the interbioherm depressions.

Irmiński (1995) critically reviewed the ideas of Znosko (1953) and Bednarek (1974) on the tectonic origin of inclined stratification observed in limestones of the Oxfordian biohermal complex in Niegowonice and Grabowa. He regarded as synsedimentary the dips up to 25° observed in the bioherm slope. Moreover, he supported the presence of distinct synsedimentary relief but underlined also the importance of compaction. Koszarski (1995) published evidence for the existence of at least 80-meter-high elevation differences of Oxfordian basin floor in Cracow area. Critical analysis of this evidence was presented by Matyszkiewicz & Krajewski (1996).

The opinion on outstanding (up to 200 meters) basin floor elevations which existed in the Late Oxfordian in the Polish part of the northern Tethyan shelf has appeared in the literature since the end of 1980-ties (Matyja *et al.*, 1989). These elevation differences were thought to occur between "hard-bottom, elevated bioherm areas and the soft-bottom, muddy, interbioherm depressions" (Matyja *et al.*, 1989, p. 34). Such relief was inferred for the basin which included "a great area of Central and Southern Poland" (Matyja *et al.*, 1989, p. 34), i.e. both the SW margin of the Holy Cross Mts. and the Cracow–Wieluń Upland. This concept was then accepted by (i) Kutek *et al.* (1992, p. 24), (ii) Wierzbowski (1992, p. 35) who described "denivelations ranging up to 200 meters" in the northern part of the Cracow–Wieluń Upland at the end of Oxfordian and (iii) Matyja & Wierzbowski (1994).

Only seven years after publishing the opinion on 200-meter differences in elevations in Late Oxfordian basin of the Polish part of the northern Tethyan shelf have Matyja & Wierzbowski (1996) presented the proofs. The proofs result from the interpretation of thickness differences of Oxfordian carbonate buildups and the equivalent interbiohermal sediments from Częstochowa area in terms of synsedimentary elevations. Matyja & Wierzbowski (1996) presented data which aimed to demonstrate permanent increase of elevations differences from 160 meters at the Bifurcatus/Bimammatum Chrons break to over 200 meters at the Planula/Platynota Chrons break (Oxfordian/Kimmeridgian boundary). Similar synsedimentary relief was suggested also by Pisera (1997) who attempted to relate heterogeneity of siliceous sponge biofacies to significant elevation differences of the sea bottom.

Matyszkiewicz (1994) paid attention to the importance of compaction in reconstruction of the origin of massive limestones from Cracow area and documented a significant influence of compaction on the formation of pseudonodular limestones. Furthermore, Matyszkiewicz (1997, p. 40) contested the existence of 200 meter-high synsedimentary relief inferred for Częstochowa area at the end of Oxfordian. Theoretically, the differences in thickness of carbonate buildups and basinal facies could be interpreted as relief effects only in Cracow area where early-lithified biostromes are equivalent deposits of the carbonate buildups. Unfortunately, collection of suitable data is impossible due to the intensive Tertiary faulting and the lack of detailed stratigraphy of Upper Jurassic successions in this area. In the same paper Matyszkiewicz (1997, p. 65) presented a schematic drawing which suggested the possible appearance of elevation differences up to about 90 meters between the biohermal complexes and the basins in which biostromes were deposited. Also, this author turned attention to the influence of synsedimentary tectonics on development of synsedimentary relief in Cracow area.

GEOLOGICAL SETTING

The area in which the suggested, 200 meter-high elevation differences have occurred in Late Jurassic basin (Matyja & Wierzbowski, 1996) is located near Julianka in the central part of the Cracow-Wieluń Upland, about 20 kilometers southeast of Częstochowa (Fig. 2). Here, the preserved Jurassic sediments reveal variable thickness, generally exceeding 450 meters (Heliasz *et al.*, 1984, 1987). The Upper Jurassic succession is represented by Oxfordian and by locally preserved Kimmeridgian deposits (Matyja & Wierzbowski, 1996), overlain by patches of Cretaceous deposits. Burial depth of Oxfordian strata at the end of Creta-

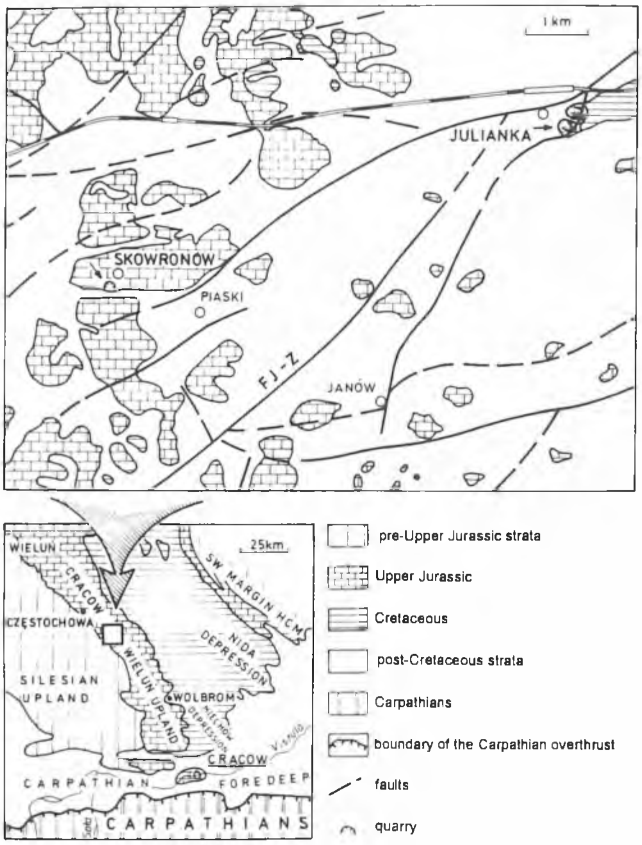

Fig. 2. Location of study area in the Cracow–Wieluń Upland and outcrops of Mesozoic rocks in Julianka and Skowronów areas (after Heliasz *et al.*, 1984) with approximate positions of faults (after tectonic sketch-map Heliasz *et al.*, 1987; simplified and modified). HCM – Holy Cross Mountains. Arrows mark sampled quarries. Notice at least two faults located between Jurassic outcrops in Julianka and Skowronów. Moreover, the Julianka quarries are located in another tectonic zone. The Julianka–Zaborze Fault (FJ-Z) is one of the largest faults in the "Janów" sheet of Detailed Geological Map of Poland 1 : 50 000

ceous can be estimated as at least 500 meters (C. Peszat & J. Rutkowski; pers. comm. 1998).

Jurassic deposits from the Julianka area were described and mentioned in several papers (e. g. Różycki, 1960; Roniewicz & Roniewicz, 1971; Heliasz & Racki, 1980; Heliasz *et al.*, 1987; Heliasz, 1990; Wierzbowski *et al.*, 1992; Głazek *et al.*, 1992). They include lithologically highly diversified biohermal complex composed of coral patch reefs and early-lithified biostromes with abundant brachiopods. Lithology of Upper Jurassic deposits from the vicinity of Skowronów was outlined by Heliasz *et al.* (1987). These are mostly chalky limestones, light-coloured, soft, locally porous and bedded. The limestones build up broad, flat hills (cf. Wierzbowski, 1966; Heliasz, 1990 and others).

Data on lithology and thickness of Oxfordian deposits on which Matyja & Wierzbowski (1996) based their concept of 200-meter synsedimentary relief at the Oxfordian/Kimmeridgian break were probably collected from the "old, archival, drilling core descriptions" (Matyja & Wierzbowski, 1996, p. 336) in which the determination of the Oxfordian base, accepted as the datum level should be "very easy" (Matyja & Wierzbowski, 1996, p. 336). The thickness of the Oxfordian sediments was probably determined by Matyja & Wierzbowski (1996) by correlation of data from the "Julianka" and "Skowronów" boreholes with the altitude of Oxfordian/Kimmeridgian boundary identified in outcrops with ammonite fauna. The "Julianka" borehole was thought to represent carbonate buildup complex whereas the "Skowronów" one was an example of the basinal facies (Fig. 3).

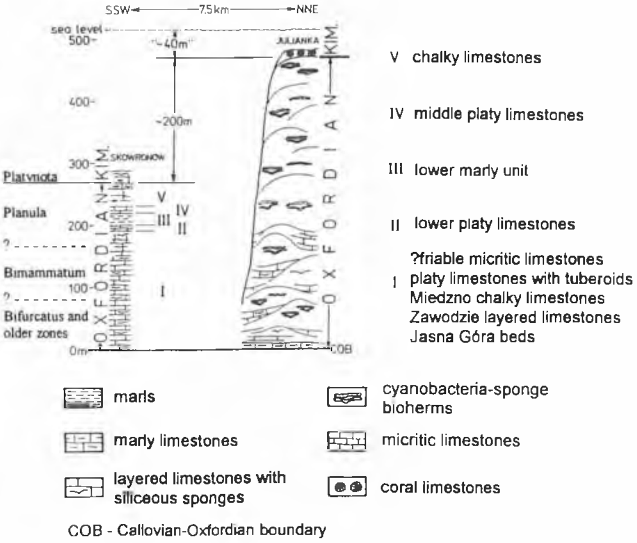

Fig. 3. Reconstruction of sea-bottom relief and bathymetry based upon borehole data after Matyja & Wierzbowski (1996). Subdivision, ammonite zones, Roman numerals and lithological types of Oxfordian deposits in the "Skowronów" borehole supplemented after Wierzbowski (1966), Kutek *et al.* (1977) and Wierzbowski *et al.* (1983)

Comparison of stratigraphic columns of the two drillings mentioned above leads to the conclusion that in the "Skowronów" borehole the 267-meter-thick Oxfordian sequence comprises (from the bottom): (i) about 190-meter-thick "marly limestones" and "layered limestones with siliceous sponges" followed by a succession of (ii) about 10 meters of "micritic limestones", (iii) over 18 meters of "marls", (iv) about 12 meters of "micritic limestones" and (v) about 37 meters of deposits the lithology of which is not described in the legend (Fig. 3). Taking into account data from the literature (Kutek *et al.*, 1977; Wierzbowski *et al.*, 1983; Smoleńska, 1986), these lithologies may correspond to: (i) the Jasna Góra beds, the Zawodzie layered limestones, the Miedzno chalky limestones, the platy limestones with tuberoids and, presumably, the friable micritic limestones, (ii) the lower platy limestones, (iii) the lower marly unit, (iv) the middle platy limestones and (v) presumably the chalky limestones. The 470 meter-thick succession of Oxfordian sediments in the "Julianka" borehole is proposed to represent the biohermal complex with the exception of several-meters-thick bottom part which is developed as "marly limestones" (Fig. 3).

METHODS

In the vicinity of Julianka and Skowronów (Fig. 2) the Upper Jurassic deposits were studied in outcrops. Samples were collected from massive limestones exposed in the Julianka quarries and from bedded, chalky limestones which crop out in the Skowronów area. From these samples polished slices and thin sections were cut for microfacies observations. Both, the massive and chalky limestones were studied under a scanning electron microscope. Moreover, in the chalky limestones from Skowronów, carbonates ($CaCO_3$ and $MgCO_3$) and insoluble residuum were analysed and porosity was measured in order to provide data for control calculations with the Ricken's method (Ricken, 1986).

Data on lithology and thickness of Oxfordian units in the "Skowronów" and "Julianka" boreholes published by Matyja & Wierzbowski (1996) were applied to the estimation of compaction effect on the recent thickness of both the basinal facies and the carbonate buildups. In the "Skowronów" sequence five lithological types were distinguished (Fig. 3). As lithological descriptions of these types in Matyja & Wierzbowski (1996) were only very general (Fig. 3), their characterization was based upon other publications from the area (Wierzbowski, 1966, 1978; Kutek *et al.*, 1977; Wierzbowski *et al.*, 1983; Smoleńska, 1983, 1984, 1986) and upon author's own observations. For the sediments from the "Skowronów" borehole both, the initial thickness and the thickness at the end of Oxfordian were determined independently using two nomographs: (i) after Perrier & Quiblier (1974, p. 516) and, (ii) for control after Doglioni & Goldhammer (1988, p. 243). Although the nomographs after Perrier & Quiblier (1974) were prepared for shales, these are applicable also to calculations of initial thicknesses of Upper Jurassic successions composed of marly limestones and marls (cf. Gygi, 1986) in which the early-diagenetic cementation is either lacking or marginal. From the nomographs after Doglioni & Goldhammer (1988) the calculations included those for carbonate mud.

Initial thickness of each lithologic unit was determined from its recent thickness at the 500 meter burial depth assumed to be the same for all units. Then, thicknesses at the end of Oxfordian were calculated from the initial thicknesses considering zero burial for the youngest Oxfordian strata (Type V, Fig. 3). Burial depths for successively older strata (Types I-IV, Fig. 3) were calculated by summation of thicknesses of overlying deposits obtained for the end of Oxfordian (Figs. 4-5, see also Table 1). As burial depths of lithological types I-IV at the end of Oxfordian calculated by summation of succeeding overburden thicknesses did not fit exactly to those given in the nomographs, the nearest values were taken for each case (Figs. 4-5, see also Table 1).

RESULTS

THE JULIANKA AREA

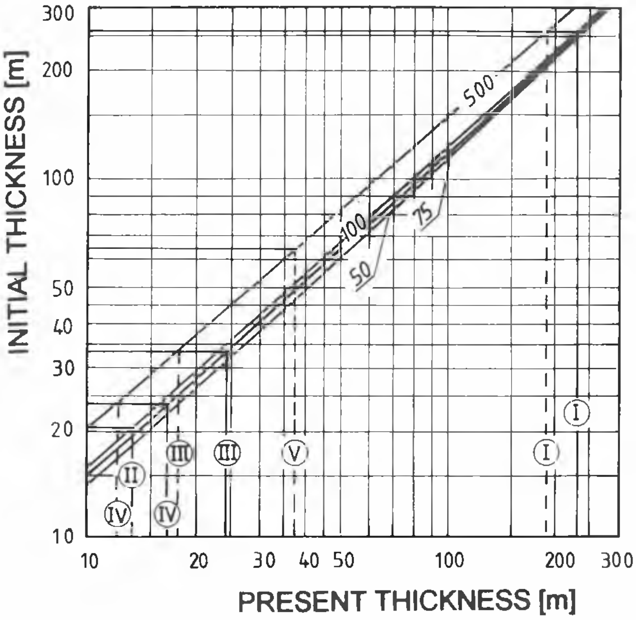

Fig. 4. Thickness calculation of Oxfordian deposits in "Skowronów" borehole at the Oxfordian/Kimmeridgian break based upon nomographs after Perrier & Quiblier (1974). Roman numerals mark litological types distinguished in Fig. 3 and Table 1. Intersections of vertical broken lines and the frame – recent thickness, intersections of vertical continuous lines and the frame – thickness at Oxfordian/Kimmeridgian break

Observations carried on in the Julianka quarries supported the presence of biohermal complex which comprises lithologically diversified massive (and occassionally bedded) limestones. A part of massive limestones contains fauna accumulations, including hermatypic corals, which enables their classification as patch reefs sediments (cf. Heliasz, 1990). Abundant fossils (particularly brachiopods) were found also in bedded limestones which contain com-

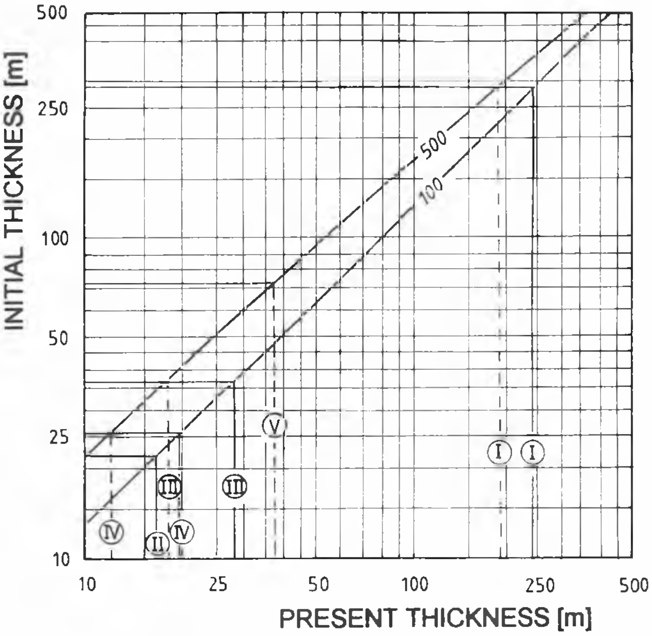

Fig. 5. Thickness calculation of Oxfordian deposits in "Skowronów" borehole at the Oxfordian/Kimmeridgian break based upon nomographs after Doglioni & Goldhammer (1988). Explanations as in Fig. 4

Table 1

Results of calculation of initial thickness and thickness at the Oxfordian/Kimmeridgian break for basinal deposits from the "Skowronów" borehole (cf. Figs. 3, 4-5). Burial depths at the end of Oxfordian shown in brackets are depth for which calculations were run. Additionally, recent compaction and compaction at the end of Oxfordian were included

Lithology	Present-day thickness	Original thickness		Thickness at the end of Oxfordian		Compaction at the end of Oxfordian		Present-day compaction		Depth of burial at the end of Oxfordian	
		after Perrier & Quiblier (1974)	after Doglioni & Goldhammer (1988)	after Perrier & Quiblier (1974)	after Doglioni & Goldhammer (1988)	after Perrier & Quiblier (1974)	after Doglioni & Goldhammer (1988)	after Perrier & Quiblier (1974)	after Doglioni & Goldhammer (1988)	after Perrier & Quiblier (1974)	after Doglioni & Goldhammer (1988)
V. Chalky limestones	37 m	63 m	72 m	63 m	72 m	0	0	42%	49%	0	0
IV. Middle platy limestones	12 m	24 m	26 m	17 m	19 m	29%	27%	50%	54%	63 m (75 m)	72 m (100 m)
III. Lower marly unit	18 m	34 m	37 m	24 m	28 m	25%	24%	47%	51%	80 m (75 m)	91 m (100 m)
II. Lower platy limestones	10 m	21 m	22 m	13 m	17 m	38%	23%	52%	55%	104 m (100 m)	119 m (100 m)
I. Marly and layered limestones	190 m	260 m	285 m	230 m	240 m	12%	21%	27%	33%	117 m (100 m)	136 m (100 m)
Total	**267 m**			**347 m**	**376 m**						

mon early diagenetic cements (cf. Heliasz & Racki, 1980). A strong lateral lithological variability observed in the quarry faces can be partly attributed to the faults of undetermined throws.

Examinations under optical and scanning electron microscopes were carried out on samples taken from the most tight varieties of massive limestones. The limestones are developed as wackestones-packstones and framestones. Locally, numerous fragments of corals, echinoderms, sclerosponges, bivalves, brachiopods and *Tubiphytes* were observed (cf. Heliasz, 1990). Characteristic is the common appearance of syntaxial cements developed on echinoderm plates (Fig. 6a). Larger pores are filled with blocky cement of crystal size increasing towards the pore center. At the margins of larger allochems, isopachous cement rims up to 0.2 mm thick were occassionally observed. Numerous aggregates of coarse-crystalline, early-diagenetic cements embedded within the micritic matrix of crystal size 2-3 µm are visible under scanning electron microscope (Figs. 7a, c).

THE SKOWRONÓW AREA

In the Skowronów area soft, finger-smearing, yellowish, chalky limestones are exposed, usually showing the bedding. Studies were carried on samples collected in the outcrop south of Skowronów, on a slope of a low hill, close to Janów–Olsztyn road (Fig. 2).

In this quarry soft, yellowish-creamy, chalky limestones were found. In the bottom part of the exposed succession numerous penetrations typical for the soft, unlithified sediment (A. Uchman; pers. comm. 1998) were observed (Fig. 8). Fresh fractures revealed single, isolated calcified siliceous sponges (on which laminated microbolites were developed) and fine bioclasts a few millimeters across.

From the microfacies point of view the chalky limestones from Skowronów area belong to mudstones-wackestones (Fig. 6b) with moderate amounts of calcareous and siliceous sponges, bryozoans and brachiopods. Under the scanning electron microscope the rock shows homogenic structure. Matrix consists of micrite crystals of average diameter about 3 µm (Figs. 7b, d). Coarse-crystalline cements are scarce. Total content of $CaCO_3 + MgCO_3$ in a chalky limestone sample from Skowronów reaches 99.54 wt.%, content of insoluble residuum is 0.16 wt.% and porosity reaches 37.2%.

Initial thickness of youngest sediments (?chalky limestones) in the "Skowronów" borehole, determined with nomographs, is about 64 meters after Perrier & Quiblier (1974) and about 72 meters after Doglioni & Goldhammer (1988). These values correspond to 42% and 49% compaction, respectively. In both cases the calculated thickness is identical with thickness at the end of Oxfordian (Table 1). Results of chemical analyses and porosity measurements of chalky limestone sample enabled the controlling calculations with Ricken's "carbonate compaction law" (Ricken 1986, p. 14, formula 4) which gave about 45%.

Similar calculations were made for the remaining lithological types of Oxfordian deposits in the "Skowronów" borehole. For the Oxfordian/Kimmeridgian break the nomographs after Perrier & Quiblier (1974) were used for burial depths 75 and 100 meters and those after Doglioni & Goldhammer (1988) for 100 meters burial (Figs. 4–5; Table

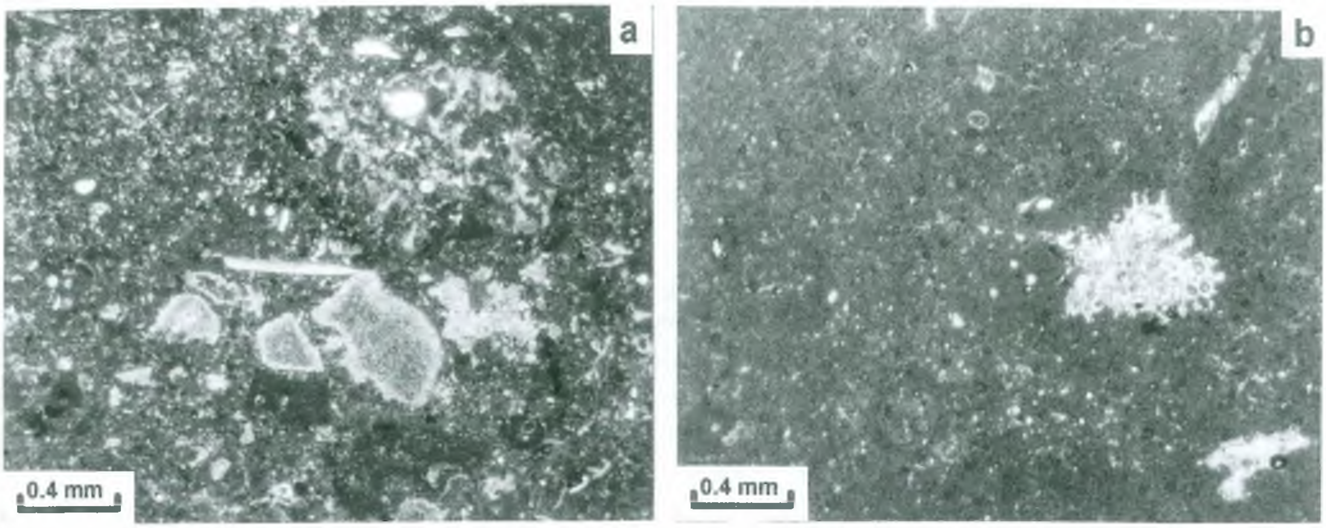

Fig. 6. Microfacies of Upper Jurassic deposits from Julianka and Skowronów areas (?Upper Oxfordian, ?Lower Kimmeridgian): **a** – massive limestone from Julianka developed as packstone with numerous bioclasts. Echinoderm plates in the center with light rims of syntaxial cement. **b** – chalky limestone from Skowronów developed as mudstone-wackestone with benthic fauna. Bryozoan fragment in the center

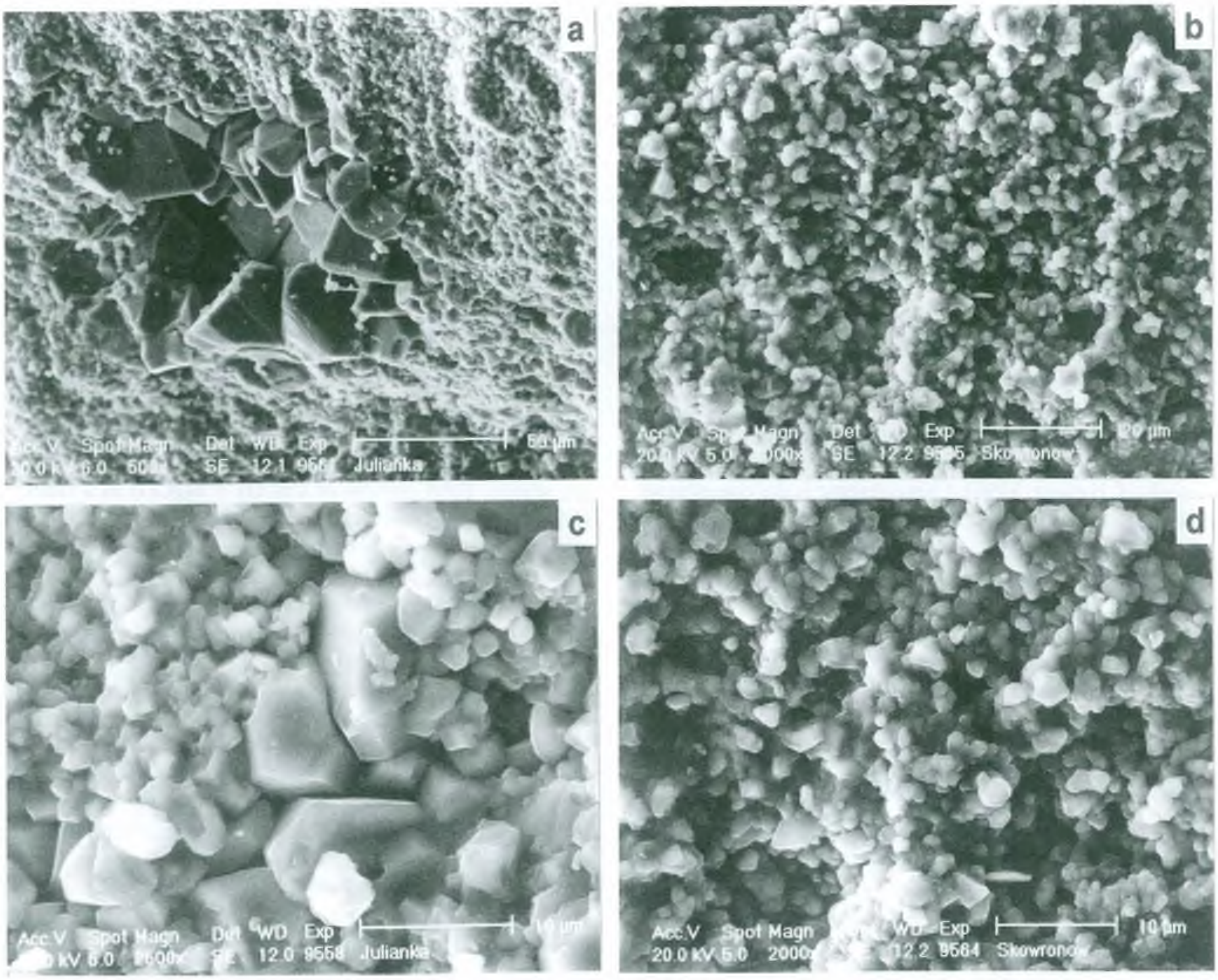

Fig. 7. Massive limestones from Julianka (**a**, **c**) and chalky limestones from Skowronów (**b**, **d**) areas under the scanning electron microscope. Principal component of chalky limestones is monotonous micrite of roughly uniform crystal size. In massive limestones coarse-crystalline, early diagenetic cements are common

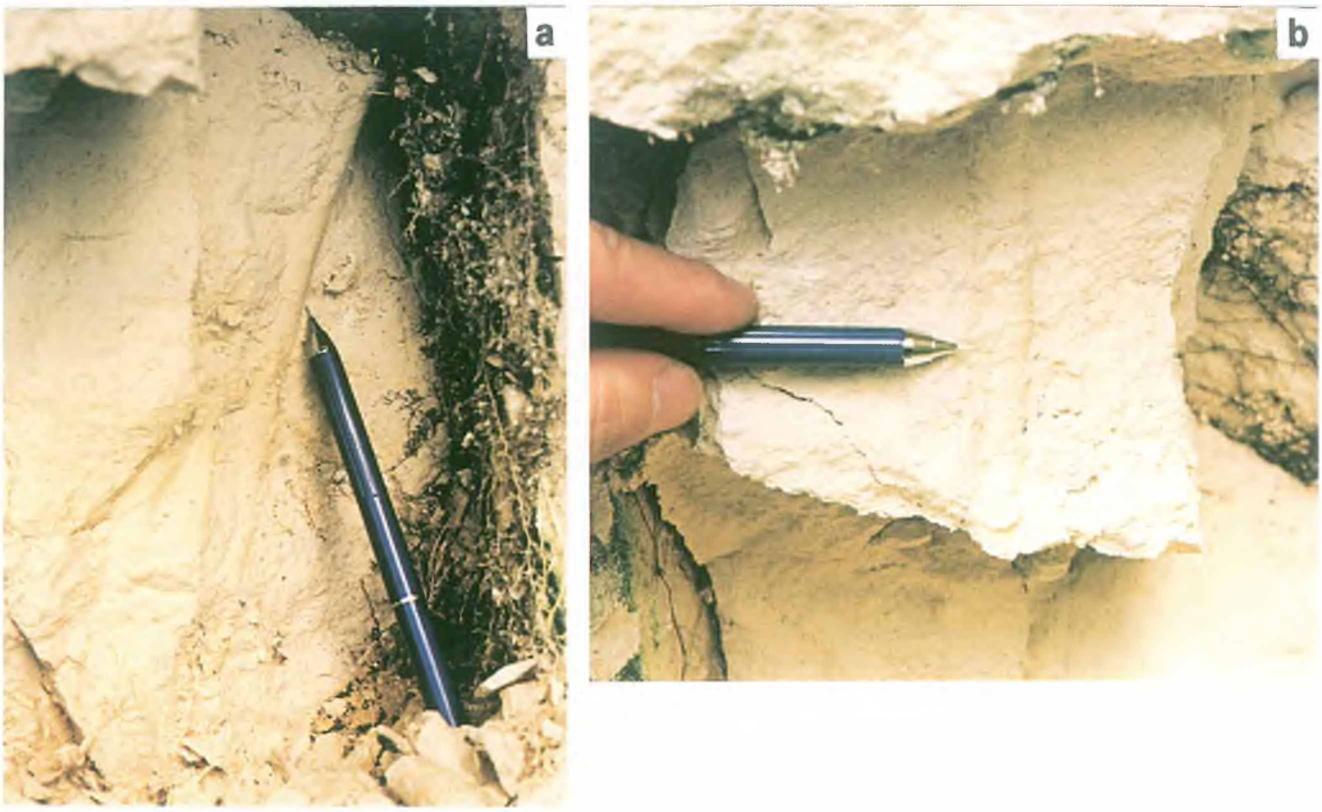

Fig. 8. Penetrations preserved in chalky limestones from Skowronów area (?Upper Oxfordian, ?Lower Kimmeridgian): **a** – length of vertical penetration exceeds 30 cm, **b** – a part of penetrations shows characteristic "chevron-type" pattern

1). Total thickness of Oxfordian strata from the "Skowronów" borehole calculated for the end of Oxfordian is about 347 meters (nomographs after Perrier & Quiblier, 1974) and about 376 meters (nomographs after Doglioni & Goldhammer, 1988).

DISCUSSION

TECTONICS OF THE AREA BETWEEN JULIANKA AND SKOWRONÓW

The thicknesses of Oxfordian sediments in "Skowronów" and "Julianka" successions reported by Matyja & Wierzbowski (1996) are doubtful due to the uncertain position of the Oxfordian top and bottom surfaces in drill cores. According to Bednarek (1974, p. 17), in Zawiercie area located about 40 kilometers southeast of Częstochowa "The Oxfordian/Callovian boundary cannot be taken as reference level because in some localities, especially in drill cores, it is not manifested by distinct lithological change".

In their paper Matyja & Wierzbowski (1996) did not provide explicit information whether ammonites which defined the Oxfordian/Kimmeridgian boundary in the studied successions originated from drillings or from outcrops. However, the discovery of two pairs of ammonites of suitable stratigraphic importance in the studied boreholes which would enable the precise localization of Oxfordian/Kimmeridgian boundary must be regarded as highly improbable, particularly if the core descriptions were archival. Presumably the ammonites were found in outcrops distant from the boreholes. Such an origin is suggested by descriptions applied to the reconstruction of another, more than 160 meters high, synsedimentary relief at the Bifurcatus/Bimammatum Chrons break (Matyja & Wierzbowski, 1996, p. 336-337).

The area between Julianka and Skowronów is characterized by the presence of numerous tectonic disturbances. Tertiary faults are known (Fig. 2) among which the Julianka–Zaborze Fault is one of the largest in the area (Więckowski, 1987). These faults separate tectonic blocks in which the thicknesses of preserved Upper Jurassic deposits are variable. Such a tectonic pattern rises an essential question: whether the outcrops which supplied the ammonites crucial for definition of the Oxfordian/Kimmeridgian boundary and the boreholes in which thicknesses of Oxfordian deposits were determined belong to the same tectonic blocks? It cannot be neglected that the outcrops are located in blocks where thicknesses of Oxfordian deposits differ from those found in the boreholes (Fig. 9). Significant throws (40-160 meters) estimated by Więckowski (1987, p. 38) suggest that the tectonic blocks are separated rather by broad, brecciated tectonic zones with numerous, second-order dislocations than single fault planes. In the Cracow–Wieluń Upland such zones can be even several hundreds of meters wide (cf. Bogacz, 1967; Felisiak, 1994; Rutkowski, 1996; Matyszkiewicz & Krajewski, 1996). Therefore, it is very possible that outcrops in which ammonites were found are located in tectonic blocks in which thicknesses of Upper Jurassic deposits differ from those measured in the boreholes.

Identification of the top of Oxfordian sequence by

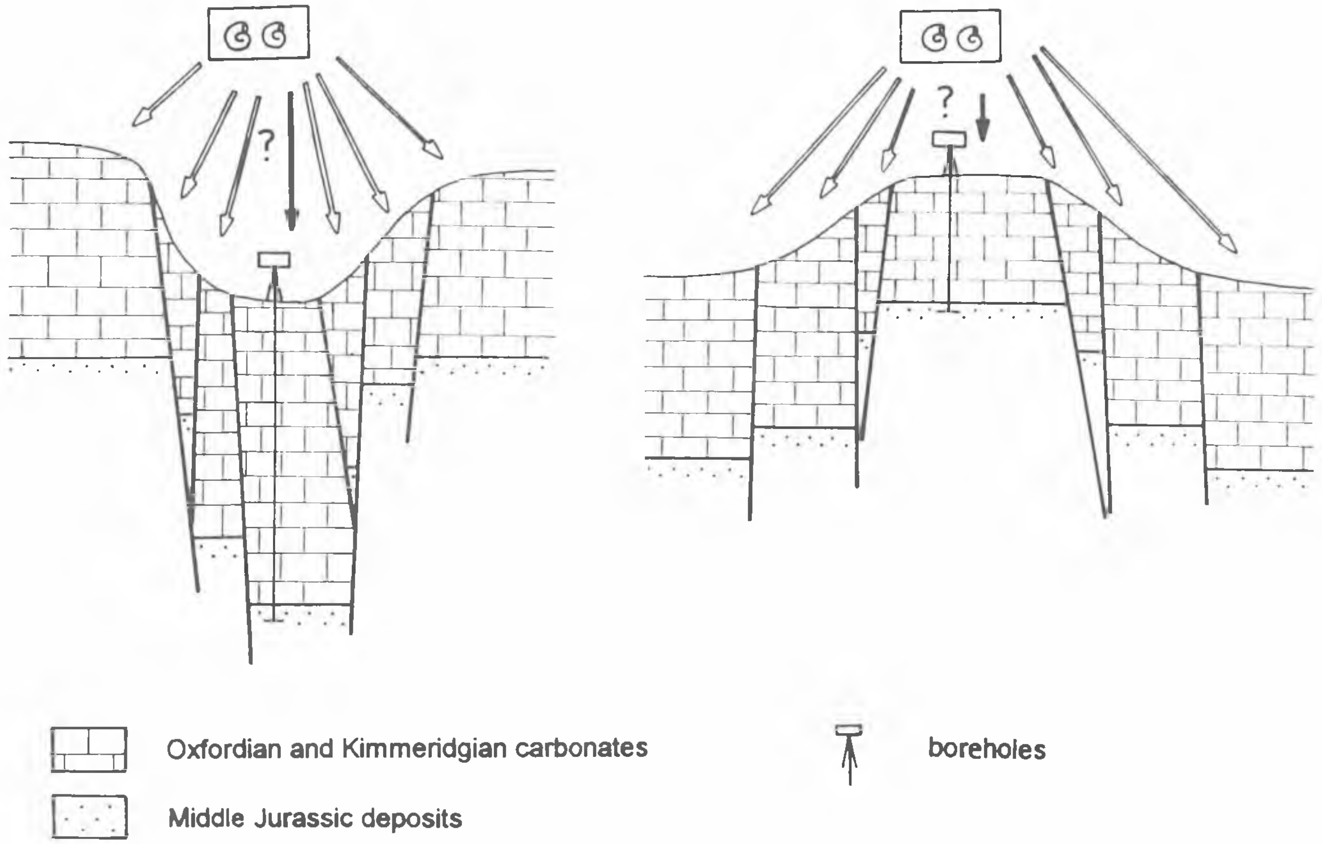

Fig. 9. Application of ammonites collected in outcrops to age determination of deposits in drill cores, in tectonically disturbed areas (schematic cross-section, out of vertical and horizontal scale). Sketch illustrates features of graben (left) and horst (right), typical of the Cracow–Wieluń Upland. Thickness of tectonic blocks separated by main and minor faults is diversified due to Cainozoic erosion. Ammonites collected in the outcrops determine correctly the stratigraphy of top part of drill core only if outcrops and boreholes are located in the same block (black arrows). In the graben the ammonites would originate mostly from blocks of lower deposit thicknesses (white arrows), often older than strata in the top of drill core. In the horst the opposite relationship occurs. If a stratigraphic boundary is determined with at least a pair of ammonites, an additional assumption must be made that both fossils were derived from the same tectonic block

means of ammonites collected in the outcrops and of archival drill-cores descriptions is acceptable only if the area between Julianka and Skowronów was completely devoid of tectonic disturbances. Taking into account the data of Więckowski (1987) and author's own observations, this condition is not met. This problem cannot be resolved without precise location of boreholes and outcrops against the background of accurate tectonic sketch map and without data on thickness of Oxfordian strata in specific tectonic blocks. It is clear, however, that the method used by Matyja & Wierzbowski (1996) cannot be applied to densly faulted tectonic zones, particularly those in the Julianka area (cf. Fig. 2).

INFLUENCE OF COMPACTION ON LITHOLOGY AND THICKNESS OF THE STUDIED SEDIMENTS

Lithological information collected in the outcrops is representative only for the uppermost parts of drill cores. Susceptibility for compaction of rocks from the lower portions of the cores can be only theoretically evaluated due to the lack of cores.

The "Julianka" section

Development of Oxfordian carbonate buildups was variable in time (Trammer, 1989; Matyszkiewicz, 1994, 1997). At the initial stage the bioherms undoubtly did not produce rigid framework (Trammer, 1989; Matyszkiewicz, 1994; cf. Flügel & Steiger, 1981) which implies some susceptibility for compaction. It is true, however, only for the bioherms from "Lower Oxfordian and early Middle Oxfordian" (cf. Matyja *et al.*, 1985, p. 19) whose thicknesses can be estimated as 1/10 to 1/20 of the present thickness of the section. Deposits from other parts of the succession are presumably close to microbolitic carbonate buildups exposed in the vicinity of Julianka, in which rigid framework was formed as a result of early cementation (Figs. 6a, 7a, c). The above consideration leads to the conclusion that in the "Julianka" succession the compaction-induced thickness reduction of sediments was insignificant and can be neglected in calculations.

The "Skowronów" section

Both the microfacies studies and scanning electron microscope observations demonstrated that chalky limestones exposed in Skowronów area reveal the absence of early diagenetic cements (Figs. 6b, 7b, d). Micrite – a dominating component of chalky limestones – originated from carbonate mud in which cementation processes commenced after burial. It is confirmed by the presence of numerous penetrations preserved in chalky limestones (Fig. 8).

Total thicknesses of deposits determined for the "Skowronów" succession for the end of Oxfordian are 347 and 376 meters (Table 1). These values exceed the present thicknesses by 80 and 109 meters, respectively. The calculations and estimations were based upon the following assumptions: (i) minimum, theoretical burial depth is 500 meters, (ii) thickness reduction of the lower marly unit is close to that of the limestones, (iii) neglection of thickness reduction resulted from pressure solution. Such assumptions lead to underestimation of calculated thicknesses which are probably much lower that the true values. Especially far-going simplification is the assumed similarity of compaction effects in sediments from which limestones and marls were formed. In Oxfordian marls from Lochen area (Swabian Alb; cf. Fig. 1), for which the estimated burial depth is over 400 meters (Ricken, 1986, p. 84) compaction determined from deformations of trace fossils is about 80%. If such compaction is considered for the lower marly unit from the "Skowronów" borehole its initial thickness should be 80–90 meters and thickness at the end of Oxfordian, although difficult to determine, should exceed 25 meters (cf. Table 1).

MORPHOLOGY AND BATHYMETRY OF THE POLISH PART OF LATE JURASSIC SHELF AT THE NORTHERN TETHYAN MARGIN

Matyja & Wierzbowski (1996) assumed the constant inclination of the shelf (about 0.1°) and claimed that at the shelf margin, located about 130 kilometers south of Częstochowa, the tops of carbonate buildups occurred at depth about 240 meters and that interbiohermal depressions were located more then 200 meters deeper. These depths were ascribed to the Planula/Platynota Chrons break (Oxfordian/Kimmeridgian boundary) but "should have been even greater" earlier (Matyja & Wierzbowski, 1996, p. 339). Hence, in the Oxfordian the margin of the Late Jurassic shelf should be deeper than 450 meters, i.e. about 250 meters deeper in comparison with the recent shelf margins. Such a line of evidence gave rise to the concept presented by Pisera (1997, p. 32) who obtained depth close to 900 meters for the Late Jurassic Swabian Alb shelf basing upon "a simple geometrical exercise" and considering 1° slope inclination.

Deduction of morphology of the northern Tethyan margin from purely geometrical constructions, excluding lithology of deposits, is an oversimplification. The evidence of Late Oxfordian syndepositional faulting in Cracow–Wieluń Upland (Kutek, 1994) suggests that probably down-to-the-basin tilting has increased the inclinations of the prograding carbonate system shortly after its deposition (cf. Saller, 1996). If an assumption is accepted that morphology of the Polish part of Late Jurassic shelf corresponded to the tectonically undisturbed carbonate ramp (cf. Read, 1982, 1985) during the whole Oxfordian, the carbonate productivities of the upper and the lower parts of such ramp must have been significantly different. Carbonate productivity directly controls the size of carbonate buildups and depends on many factors, particularly on the position of sedimentation area in relation to the photic zone, water temperature and mobility, and oxygen content. In the Late Jurassic, depositional systems of the shelf and the continental slope were remarkably different. Classic examples of lateral changes in morphology and size of Upper Jurassic buildups at the transition zone from shelf to slope were presented by Dromart *et al.* (1994). Carbonate buildups from the continetal slope usually lack the metazoan framebuilders and, first of all, are apparently smaller than those growing on the outer shelf. It is a result of the absence of larger, stable fragments of hard bedrock which could be settled by microbolites (Dromart *et al.*, 1994).

The ideas of Matyja & Wierzbowski (1996) on morphology and bathymetry of the Polish part of the northern Tethyan margin contradict also the lithology of the Upper Jurassic deposits in the Cracow area, i.e. about 100 kilometers southeast of Częstochowa. If a constant sea bottom inclination is presumed over such a distance the tops of bioherms in the Cracow area should occur deeper than 200 meters and interbiohermal depression should be located below 400 meters depth. Therefore, in the Cracow area the carbonate buildups should develop at depths corresponding to "almost abiogenic depositional environment" in the Częstochowa area (Wierzbowski *et al.*, 1983, p. 523).

Microfacies development of massive limestones from Julianka shows a distinct similarity to specific varieties of massive limestones from the Cracow area (Matyszkiewicz, 1989, 1997; Hoffmann *et al.*, 1997). However, massive limestones from Julianka differ in the presence of hermatypic corals and poorer growth of early diagenetic cements. Some features diagnostic for shallow depth and high water energy: thickness of *Tubiphytes* walls (cf. Leinfelder *et al.*, 1996) and frequent appearance of grainstones are poorely developed in Julianka deposits, in comparison to those observed in some massive limestones from the Oxfordian near Cracow. The latter reveal several features typical of sedimentation in the photic zone (Golonka & Haczewski, 1971; Matyszkiewicz & Felisiak, 1992; Hoffmann *et al.*, 1997; Matyszkiewicz, 1997). These premises lead to the conclusion that development of carbonate deposition caused changes in shelf morphology of the Polish part of northern Tethyan margin from carbonate ramp to rimmed shelf (Matyszkiewicz, 1997; cf. Jansa, 1981; Einsele, 1992).

Another idea proposed by Matyja & Wierzbowski (1996), i.e. the permanent increase of sea-bottom elevation changes since the Bifurcatus/Bimammantum Chrons break to the end of Planula Chron is not only inconsistent with the opinion of these authors on considerable levelling of basin floor during the deposition of the lower marly unit (i.e. still during the Planula Chron, cf. Fig. 3; Wierzbowski *et al.*, 1983, p. 523) but also does not consider environmental conditions of microbolites growth in Upper Jurassic carbonate buildups (cf. Keupp *et al.*, 1990; Leinfelder, 1993, 1996; Leinfelder *et al.*, 1994). The intensive growth of microbolitic carbonate buildups took place under "a complete cessation of background sedimentation" (Leinfelder *et al.*, 1994,

p. 41). Such a growth was being temporarily slowed down or even interrupted as a result of intensive supply of fine-grained material to the basin (cf. Leinfelder, 1993). The periods of low rate of carbonate buildup growth were synchronous with the periods of intensive accumulation of basinal facies. Deposition of lower marly unit which occurs in the "Skowronów" borehole is undoubtly linked to temporary reduction or even cessation of growth of carbonate buildups and a dramatical increase in background sedimentation rate. Such a processes undoubtly resulted in the decrease of sea floor relief before the end of Oxfordian.

CONCLUSIONS

Reconstruction of the Late Jurassic basin floor relief of the northern Tethyan shelf requires the selection of a pair of precisely dated successions of carbonate buildups and basinal facies, and calculation of sediments thicknesses at the moment for which the elevations differences are determined. Such a reconstruction should consider also the eustatic changes of sea level and the differences in subsidence of the compared parts of the basin as well as should estimate the accumulation rate of sediments. Unfortunately, the evidence presented by Matyja & Wierzbowski (1996) do not meet any of these requirements, as discussed earlier.

In their interpretation Matyja & Wierzbowski (1996) do not take into account the complicated tectonic pattern of studied area and basic data on compaction of carbonate sediments (cf. Ricken, 1986; Harwood, 1988; Moore, 1989; Tucker & Wright, 1990; Bathurst, 1991; Einsele, 1992 and others). Reconstruction methods of synsedimentary relief applied by Matyja & Wierzbowski (1996) cannot be accepted even for tectonically undisturbed areas. The presented proofs for remarkable sea-bottom elevation changes are based upon the identification of recent differences in thicknesses of sediments in carbonate buildups and in basinal facies as the elevation changes themselves and upon complete neglection of the effect of differential compaction. Even under an assumption that thicknesses of Oxfordian strata in compared drill cores taken by Matyja & Wierzbowski (1996) are correct, the calculated elevation changes of basin floor in Julianka and Skowronów areas at the Oxfordian/Kimmeridgian break would be less than about 100 meters if only the mechanical compaction were taken into account. If chemical compaction is added the calculated values should be reduced by another 20–35% (cf. Goldhammer, 1997). An attempt to calculate the true values of the basin floor relief changes at the end of Oxfordian is based upon the assumption which can be verified only by the results of drill-core examinations.

Acknowledgements

Constructive reviews by G. Haczewski and T. M. Peryt are gratefully acknowledged. I. Felisiak, M. Krajewski, K. Król, M. Paszkowski and J. Rutkowski kindly critized an early draft of the manuscript. For fruitful discussions and suggestions I thank R. Koch, A. Munnecke, C. Peszat, and A. Uchman. W. Mayer improved the English of this manuscript. Figures were taken by Mrs. M. Kusmierek. The study was supported within the project AGH no. 11. 140. 54.

REFERENCES

Baldwin, B. & Butler, C. O., 1985. Compaction curves. *Am. Assoc. Petrol. Geol. Bull.*, 69: 622–626.

Bathurst, R. G. C., 1987. Diagenetically enhanced bedding in argillaceous platform limestones: stratified cementation and selective compaction. *Sedimentology*, 34: 749–778.

Bathurst, R. G. C., 1991. Pressure-dissolution and limestone bedding: the influence of stratified cementation. In: Einsele, G., Ricken, W. & Seilacher, A. (eds.), *Cycles and events in stratigraphy*. Springer-Verlag, Berlin, pp. 450–463.

Bayer, U., 1989. Sediment compaction in large scale systems. *Geol. Rdsch.*, 78: 155–169.

Bednarek, J., 1974. *Budowa geologiczna strefy wychodni górnojurajskich między Zawierciem, Łazami i Pilicą*. (In Polish only). Ph. D. Thesis, Uniwersytet Warszawski, 193 pp.

Bogacz, K., 1967. The geological structure of the northern border of the Krzeszowice Graben. (In Polish, English summary). *Prace Geol.*, 41: 1–94.

Bukowy, S., 1956. Geology of the area between Cracow and Korzkwia. (In Polish, English summary). *Biul. Inst. Geol.*, 108: 17–74.

Bukowy, S., 1960. Submarine slides in the rocky limestones near Cracow. (In Polish, English summary). *Biul. Inst. Geol.*, 155: 153–168.

Clari, P. A. & Martire, L., 1996. Interplay of cementation, mechanical compaction, and chemical compaction in nodular limestones of the Rosso Ammonitico Veronese (Middle-Upper Jurassic, Northeastern Italy). *J. Sedim. Research*, 66: 447–458.

Coogan, A. H., 1970. Measurements of compaction in oolitic grainstone. *J. Sedim. Petrol.*, 40: 921–929.

Crimes, T. P., 1975. The stratigraphical significance of trace fossils. In: Frey, R. W. (ed.), *The study of trace fossils*. Springer-Verlag, Berlin, pp. 109–130.

Czerniakowski, L. A., Lohmann, K. C. & Wilson, J. L., 1984. Closed-system marine burial diagenesis, isotopic data form the Austin Chalk and its components. *Sedimentology*, 31: 863–877.

Doglioni, C. & Goldhammer, R. K., 1988. Compaction-induced subsidence in the margin of a carbonate platform. *Basin Research*, 1: 237–246.

Dromart, G., 1989. Deposition of Upper Jurassic fine-grained limestones in the Western Subalpine Basin. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 69: 23–43.

Dromart, G., Gaillard, C. & Jansa, L. F., 1994. Deep-marine microbial structures in the Upper Jurassic of Western Tethys. In: Bertrand-Sarfati, J. & Monty, C. (eds.), *Phanerozoic stromatolites II*. Kluwer Academic Publishers, Amsterdam, pp. 295–318.

Dżułyński, S., 1952. The origin of the Upper Jurassic limestones in the Cracow area. (In Polish, English summary). *Rocz. Pol. Tow. Geol.*, 21: 125–180.

Einsele, G., 1992. *Sedimentary Basins*. Springer-Verlag, Berlin, 628 pp.

Felisiak, I., 1994. Jurassic and Createaceous deposits and Alpine tectonics in Zabierzów quarry. In: Kotański, Z. (ed.) *Excursion Guidebook of Third International Meeting of peri-Tethyan Epicratonic Basins*. Polish Geological Institute, Warszawa, pp. 45–47.

Flügel, E. & Steiger, T., 1981. An Upper Jurassic sponge-algal buildup from the northern Frankenalb, West Germany. In:

Toomey, D. F. (ed.), *European fossil reef models. Soc. Econ. Paleont. Miner., Spec. Publ.*, 30: 371–397.

Gaillard, C. & Jautee, E., 1987. The use of burrows to detect compaction and sliding in fine-grained sediments: an example from the Cretaceous of S. E. France. *Sedimentology*, 34: 585–593.

Głazek, J. & Wierzbowski, A., 1972. On the alleged Kimmeridgian transgression in the Cracow Upland. (In Polish, English summary). *Acta Geol. Polon.*, 22: 45–69.

Głazek, J., Pacholewski, A. & Rożkowski, A., 1992. Karst aquifer of the Cracow–Wieluń Upland, Poland. In: Back, W., Herman, J. S. & Paloc, H. (eds.), *Hydrogeology of selected karst regions. Intern. Contrib. Hydrogeol.*, 13. Heise GmbH & Co, Hannover, pp. 289–306.

Goldhammer, R. K., 1997. Compaction and decompaction algorithms for sedimentary carbonates. *J. Sedim. Research*, 67: 26–56.

Golonka, J. & Haczewski, G., 1971. Glony i struktury biosedymentacyjne w wapieniach skalistych górnej jury okolic Krakowa. (In Polish only). *Kwart. Geol.*, 15: 1033–1034.

Gómez, J. J. & Fernández-López, S., 1994. Condensation processes in shallow platforms. *Sedim. Geology*, 92: 147–159.

Gwinner, M. P., 1971. Carbonate rocks of the Upper Jurassic in SW-Germany. In: Müller, G. (ed.), *Sedimentology of parts of Central Europe*. Kramer, Frankfurt a. M., pp. 193–207.

Gwinner, M. P., 1976. Origin of the Upper Jurassic Limestones of the Swabian Alb (Southern Germany). *Contributions to Sedimentology*, 5: 1–75.

Gygi, R. A., 1986. Eustatic sea level changes of the Oxfordian (Late Jurassic) and their effects documented in sediments and fossil assemblages of an epicontinental sea. *Eclogae Geol. Helv.*, 79: 455–491.

Harwood, G., 1988. Microscopic techniques: II. Principles of sedimentary petrography. In: Tucker, M. (ed.), *Techniques in Sedimentology*. Blackwell, Oxford, pp. 108–173.

Heliasz, Z. 1990. Sedimentation of the Upper Jurassic limestones in the Częstochowa Region of the Polish Jura Chain. (In Polish, English summary). *Prace Nauk. Uniw. Śląsk. Geologia*, 10/11: 9–49.

Heliasz, Z., Ptak, B., Więckowski, R. & Zieliński, T., 1984. *Arkusz "Janów" (846) Szczegółowej Mapy Geologicznej Polski w skali 1:50000.* Wydawnictwa Geologiczne, Warszawa

Heliasz, Z., Ptak, B., Więckowski, R. & Zieliński, T., 1987. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50000 Arkusz Janów (846).* (In Polish only). Wydawnictwa Geologiczne, Warszawa, 66 pp.

Heliasz, Z. & Racki, Z., 1980. Ecology of the Upper Jurassic brachiopod bed from Julianka, Polish Jura Chain. *Acta Geol. Polon.*, 30: 175–197.

Herrmann, R., 1996. Entwicklung einer oberjurassischen Karbonat plattform: Biofazies, Riffe und Sedimentologie im Oxfordium der Zentralen Dobrogea (Ost-Rumänien). *Berliner Geowiss. Abh.*, E19: 1–102.

Hoffmann, M., Kołodziej, B. & Matyszkiewicz, J., 1997. Upper Jurassic microbolites – examples from the Holy Cross Mts. and Cracow Upland. In: *3rd IFAA Regional Symposium & IGCP 380 International Regional Meeting, Guidebook & Abstracts.* Institute of Geological Sciences, Jagiellonian University, Cracow, pp. 16–22.

Hoffmann, M. & Uchman, A., 1992. Trace fossils from the Oxfordian platy limestones nearby Kraków. (In Polish, English summary). *Przegl. Geol.*, 40: 651–656.

Hudson, J. D. & Jenkyns, H. C., 1969. Conglomerates in the Adnet Limestones of Adnet (Austria) and the origin of the "Scheck". *N. Jb. Geol. Paläont. Mh.*, 1969: 552–558.

Irmiński, W., 1995. Upper Jurassic biohermal complex in Niegowonice and Grabowa near Zawiercie (southern Poland). (In Polish only). *Przegl. Geol.*, 43: 853–858.

Jansa, L. F., 1981. Mesozoic carbonate platforms and banks of the eastern North American margin. *Marine Geol.*, 44: 97–117.

Kaźmierczak, J., Coleman, M. L., Gruszczyński, M. & Kempe, S., 1996. Cyanobacterial key to the genesis of micritic and peloidal limestones in ancient seas. *Acta Palaeont. Polon.*, 41: 319–338.

Keupp, H., 1977. Ultrafazies und Genese der Solnhofen Plattenkalke (Oberer Malm, Südliche Frankenalb). *Abh. Naturhist. Ges. Nürnberg*, 37: 1–127.

Keupp, H., Jenisch, A., Herrmann, R., Neuweiler, F. & Reitner, J., 1993. Microbial carbonate crusts – a key to the environmental analysis of fossil spongiolites? *Facies*, 29: 41–54.

Keupp, H., Koch, R. & Leinfelder, R., 1990. Steuerungsprozesse der Entwicklung von Oberjura-Spongiolithen Süddeutschlands: Kenntnisstand, Probleme und Perspectiven. *Facies*, 23: 141–174.

Koch, R. & Schorr, M., 1986. Diagenesis of Upper Jurassic sponge-algal reefs in SW Germany. In: Schroeder, J. & Purser, B. H. (eds.), *Reef Diagenesis.* Springer, Berlin, pp. 224–244.

Koszarski, A., 1995. Tradycja a nowoczesność w interpretacji warunków powstawania wapieni górnej jury krakowskiej. Szczególna rola procesów redepozycji. Studium terenowe. (In Polish only). In: Doktor, M., Głuszek, A., Gmur, D. & Słomka, T. (eds.), *Tradycja a nowoczesność w interpretacjach sedymentologicznych. Materiały Konferencyjne IV Krajowego Spotkania Sedymentologów*, Polskie Towarzystwo Geologiczne, Kraków, pp. 9–22.

Kott, R., 1989. Fazies und Geochemie des Treuchtlinger Marmor (Unter- und Mittelkimmeridge, Südliche Frankenalb). *Berliner Geowis. Abh.*, A111: 1–115.

Kutek, J., 1969. The Kimmeridgian and uppermost Oxfordian in the SW margin of the Holy Cross Mts (Central Poland); Part II. Paleogeography. (In Polish, English summary). *Acta Geol. Polon.*, 19: 222–231.

Kutek, J., 1994. Jurassic tectonic events in south-eastern cratonic Poland. *Acta Geol. Polon.*, 44: 167–221.

Kutek, J., Matyja, B. A. & Wierzbowski, A., 1984. Late Jurassic biogeography in Poland and its stratigraphical implications. In: Michelsen, O. & Zeiss, A. (eds.), *International Symposium on Jurassic Stratigraphy*, vol. III. Geol. Surv. Denmark, Copenhagen, pp. 744–754.

Kutek, J., Matyja, B. A. & Wierzbowski, A., 1992. The Holy Cross Mountains – introduction. In: Matyja, B. A., Wierzbowski, A., & Radwański, A. (eds.), *Oxfordian & Kimmeridgian joint working groups meeting.* International Subcommision on Jurassic Stratigraphy, Warszawa, pp. 22– 26.

Kutek, J., Wierzbowski, A., Bednarek, J., Matyja, B. A. & Zapaśnik, A., 1977. Notes on the Upper Jurassic stratigraphy in the Polish Jura Chain. (In Polish, English summary). *Przegl. Geol.*, 25: 438–445.

Leinfelder, R. R., 1993. Upper Jurassic reef types and controlling factors. *Profil*, 5: 1–45.

Leinfelder, R. R., 1996. Distribution of Jurassic reef types: a mirror of structural and environmental changes during breakup of Pangea. *Canadian Soc. Petrol. Geol., Mem.* 17: 677–700.

Leinfelder, R. R., Krautter, M., Laternser, R., Nose, M., Schmid, D. U., Schweigert, G., Werner, W., Keupp, H., Brugger, H., Herrmann, R., Rehfeld-Kiefer, U., Schroeder, J. H., Reinhold, C., Koch, R., Zeiss, A., Schweizer, V., Christmann, H., Menges, G. & Luterbacher, H., 1994. The origin of Jurassic reefs:

current research developments and results. *Facies*, 31: 1–56.

Lucia, F. J., 1999. *Carbonate Reservoir Characterization.* Springer-Verlag, Berlin, 226 pp.

Marcinowski, R., 1970. Turbidites in Upper Oxfordian limestones at Jaskrów in the Polish Jura Chain. *Bull. Acad. Polon. Sc., Ser. Sc. Geol.-Geogr.*, 18: 219–225.

Martire, L. & Clari, P., 1994. Evaluation of sedimentation rates in Jurassic–Cretaceous pelagic facies of the Trento Plateau: relevance of discontinuities and compaction. *Giornale Geol.*, 56: 193–209.

Matyja, B. A., Gutowski, J. & Wierzbowski, A., 1989. The open shelf – carbonate platform succession at the Oxfordian/Kimmeridgian boundary in the SW margin of the Holy Cross Mts: stratigraphy, facies, and ecological implications. *Acta Geol. Polon.*, 39: 29–47.

Matyja, B. A. & Pisera, A., 1991. Late Jurassic European sponge megafacies: general perspective. In: *3-rd International Symposium on Jurassic Stratigraphy.* Poitiers, p. 81.

Matyja, B. A., Trammer, J. & Wierzbowski, A., 1985. Biohermy gąbkowe i gąbkowo-sinicowe jury górnej i ich pozycja paleogeograficzna. (In Polish only). In: *Materiały IX Konferencji Paleontologów.* Wydawnictwo Akademii Górniczo-Hutniczej, Kraków, pp. 18–20.

Matyja, B. A. & Wierzbowski, A., 1994. Bathymetry of Late Jurassic sponge megafacies. In: *4th International Congress on Jurassic Stratigraphy and Geology, Abstr.* Mendoza, pp. 30–31.

Matyja, B. A. & Wierzbowski, A., 1996. Sea-bottom relief and bathymetry of Late Jurassic sponge megafacies in Central Poland. In: Riccardi, A. C. (ed.), *Advances in Jurassic Research. GeoResearch Forum.* 1–2: 333–340.

Matyszkiewicz, J., 1989. Sedimentation and diagenesis of the Upper Oxfordian cyanobacterial-sponge limestones in Piekary near Kraków. *Ann. Soc. Geol. Polon.*, 59: 201–232.

Matyszkiewicz, J., 1994. Remarks on the sedimentation and diagenesis of pseudonodular limestones in the Cracow area (Oxfordian, Southern Poland). *Berliner Geowis. Abh.*, E13: 419–439.

Matyszkiewicz, J., 1997. Microfacies, sedimentation and some aspects of diagenesis of Upper Jurassic sediments from the elevated part of the Northern peri-Tethyan Shelf: a comparative study on the Lochen area (Schwäbische Alb) and the Cracow area (Cracow–Wieluń Upland, Poland). *Berliner Geowis. Abh.*, E21: 1–111.

Matyszkiewicz, J. & Felisiak, I., 1992. Microfacies and diagenesis of an Upper Oxfordian carbonate buildup in Mydlniki (Cracow area, Southern Poland). *Facies*, 27: 179–190.

Matyszkiewicz, J. & Krajewski, M., 1996. Lithology and sedimentation of Upper Jurassic massive limestones near Bolechowice, Kraków–Wieluń upland, South Poland. *Ann. Soc. Geol. Polon.*, 66: 285–301.

Moore, C. H., 1989. *Carbonate Diagenesis and Porosity. Development in Sedimentology*, 46. Elsevier, Amsterdam, 1–338 pp..

Munnecke, A. & Samtleben, C., 1996. The formation of micritic limestones and the development of limestone-marl alterations in the Silurian of Gotland, Sweden. *Facies*: 159–176.

Munnecke, A., Westphal, H., Reijmer, J. J. G. & Samtleben, C., 1997. Microspar development during early marine burial diagenesis: a comparison of Pliocene carbonates from the Bahamas with Silurian limestones from Gotland (Sweden). *Sedimentology*, 44: 977–990.

Perrier, R. & Quiblier, J., 1974. Thickness changes in sedimentary layers during compaction history; methods for quantitative evaluation. *Am. Assoc. Petrol. Geol. Bull.*, 58: 507–520.

Peszat, C., 1964. The lithology of the Jurassic carbonate rocks (southeastern margin of the Holy Cross Mts, Poland). (In Polish, English summary). *Acta Geol. Polon.*, 14: 1–78.

Peszat, C., 1991. Microstructures and origin of the Oxfordian micritic limestones in the southwestern margin of the Świętokrzyskie Mountains. (In Polish, English summary). *Arch. Mineral.*, 47: 155–188.

Pisera, A., 1997. Upper Jurassic siliceous sponges from the Swabian Alb: taxonomy and paleoecology. *Palaeont. Polonica*, 57: 3–216.

Plessmann, W., 1966. Diagenetische und kompressive Verformung in der Oberkreide des Harz-Nordrandes sowie im Flysch von San Remo. *N. Jb. Geol. Paläont. Mh.*, 8: 480–493.

Ramsay, J. G. & Huber, M. I., 1983. *The Techniques of Modern Structural Geology. Part I. Strain analysis.* Academic Press, London, 307 pp.

Read, J. F., 1982. Carbonate platforms of passive (extensional) continental margins: types, characteristic and evolution. *Tectonophysics*, 81: 195–212.

Read, J. F., 1985. Carbonate platform facies models. *Am. Assoc. Petrol. Geol. Bull.*, 69: 1–21.

Rehfeld, U., 1996. Mediating and limitating processes during the development of spongiolitic bioconstructions in Jurassic and Createaceous Strata – a paleontological, facial and geochemical analysis. In: Reitner, J., Neuweiler, F. & Gunkel, F. (eds.), *Global and regional controls on biogenic sedimentation. Part I. Reef evolution. Research reports. Göttinger Arb. Geol. Paläont.*, Sb2: 249–258.

Reinhold, C., 1996. *Prozesse, Steuerung und Produkte komplexer Diagenese-Sequenzen in süddeutschen Malm-Karbonaten.* Ph. D. Thesis, Technisches Universität Berlin, pp. 255.

Ricken, W., 1985. Epicontinental marl-limestone alternation: event deposition and diagenetic bedding (Upper Jurassic, Southwest Germany). In: Bayer, U. & Seilacher, A. (eds.), *Sedimentary and Evolutionary Cycles. Lecture Notes in Earth Sciences*, 1. Springer-Verlag, Berlin, pp. 127–162.

Ricken, W., 1986. Diagenetic bedding – a model for marl-limestone alternations. In: Bhattacharji, S., Friedmann, G. M., Neugebauer, H. J. & Seilacher, A. (eds.), *Lecture Notes in Earth Sciences*, 6. Springer-Verlag, Berlin, pp. 1–210.

Ricken, W., 1987. The carbonate compaction law: a new tool. *Sedimentology*, 34: 571–584.

Riding, R., 1991. Classification of microbial carbonates. In: Riding, R. (ed.), *Calcareous Algae and Stromatolites.* Springer-Verlag, Berlin, pp. 21–51.

Roniewicz, E. & Roniewicz, P., 1971. Upper Jurassic coral assemblages of the Central Polish Upland. *Acta Geol. Polon.*, 21: 399–422.

Różycki, Z., 1960. Stratigraphy and facies changes of Upper Dogger and Malm in Częstochowa Jura Chain. (In Polish, English summary). *Przegl. Geol.*, 8: 115–118.

Rutkowski, J., 1996. On the polygenic character of the geomorphology of Cracow region (S Poland). (In Polish, English summary). *Acta Geogr. Lodz.*, 71: 207–217.

Saller, A. H., 1996. Differential compaction and basinward tilting of the prograding Capitan reef complex, Permian, west Texas and southeast New Mexico. *Sedim. Geology*, 101: 21–30.

Schlanger, S. O. & Douglas, R. G., 1974. The pelagic ooze-chalk-limestone transition and its implications for marine stratigraphy. In: Hsü, K. J. & Jenkyns, H. C. (eds.), *Pelagic sediments: on land and under the sea. Int. Ass. Sediment. Spec. Publ.*, 1: 117–148.

Schmid, D. U., 1996. Marine Mikrobolithe und Mikroinkrustierer aus dem Oberjura. *Profil*, 9: 101–251.

Schmoker, J. W. & Halley, R. B., 1982. Carbonate porosity versus depth: a predictable relation for south Florida. *Am. Assoc.*

Petrol. Geol. Bull., 66: 2561–2570.

Sclater, J. G. & Christie, P. A. F., 1980. Continental stretching: an explanation of the post Mid-Cretaceous subsidence of the central North Sea basin. *J. Geophys. Res.*, 85: 3711–3739.

Shaver, R. H., 1977. Silurian reef geometry – new dimensions to explore. *J. Sedim. Petrol.*, 47: 1409–1424.

Shinn, E. A. & Robbin, D. M., 1983. Mechanical and chemical compaction in fine-grained shallow-water limestones. *J. Sedim. Petrol.*, 53: 595–618.

Simpson, J., 1985. Stylolite controlled layering in an homogeneous limestones: pseudo-bedding produced by burial diagenesis. *Sedimentology*: 32: 495–505.

Smoleńska, A., 1983. Lithology of the Upper Jurassic micritic limestones region of Działoszyn and Rudniki. (In Polish, English summary). *Zeszyty Nauk. AGH, Geologia*, 9: 39–66.

Smoleńska, A., 1984. Usability of the Upper Jurassic limestones of Częstochowa and Działoszyn areas based on their chemical and mineral composition and physical properties. (In Polish, English summary). *Zeszyty Nauk. AGH, Geologia*, 10: 59–105.

Smoleńska, A., 1986. Lithology of Middle Oxfordian bedded limestones of the Kraków–Wieluń Upland and their importance as raw materials. (In Polish, English summary). *Zeszyty Nauk. AGH, Geologia*, 12: 33–75.

Smosna, R., 1989. Compaction law for Cretaceous sandstones of Alaskas north slope. *J. Sedim. Petrol.*, 59: 572–584.

Swinburne, N. H. M. & Hemleben, C., 1994. The Plattenkalk Facies: a deposit of several environments. *Geobios M. S.*, 16: 313–320.

Terzaghi, R. D., 1940. Compaction of lime mud as a cause of secondary structure. *J. Sedim. Petrol.*, 10: 78–90.

Trammer, J., 1982. Lower to Middle Oxfordian sponges of the Polish Jura. *Acta Geol. Polon.*, 29: 39–49.

Trammer, J., 1985. Sponge bioherms in the Jasna Gora Beds (Oxfordian of the Polish Jura Chain). (In Polish, English summary). *Przegl. Geol.*, 33: 78–81.

Trammer, J., 1989. Middle to Upper Oxfordian sponges of the Polish Jura. *Acta Geol. Polon.*, 39: 49–91.

Tucker, M. E. & Wright, V. P., 1990. *Carbonate Sedimentology*. Blackwell, Oxford, 482 pp.

Westphal, H. & Munnecke, A., 1997. Mechanical compaction versus early cementation in fine-grained limestones: differentiation by the preservation of organic microfossils. *Sedim. Geology*, 112: 33–42.

Westphal, H., Munnecke, A., Reijmer, J. J. G. & Samtleben, C., 1997. Mechanical compaction or early cementation? An evaluation using thin-walled organic microfossils. *Terra Nostra* 97: 260–261.

Wetzel, A., 1989. Influenze of heat flow on ooze/chalk cementation: quantification from consolidation parameters in DSDP Sites 504 and 505 sediments. *J. Sedim. Petrol.*, 59: 539–547.

Wierzbowski, A., 1966. L'Oxfordien superieur et le Kimmeridgien inferieur du plateau de Wieluń. (In Polish, French summary). *Acta Geol. Polon.*, 16: 127–200.

Wierzbowski, A., 1978. Ammonites and stratigraphy of the Upper Oxfordian of the Wieluń Upland, Central Poland. *Acta Geol. Polon.*, 28: 299–333.

Wierzbowski, A., 1992. The Cracow–Wieluń Upland (Polish Jura Chain), introduction. In: Matyja, B. A., Wierzbowski, A. & Radwański, A. (eds.), *Oxfordian & Kimmeridgian joint working groups meeting.* International Subcommision on Jurassic Stratigraphy, Warszawa, pp. 34–35.

Wierzbowski, A., Matyja, B. A. & Sobieraj, K., 1992. Julianka, coral colonization of the cyanobacteria-sponge bioherms at the turn of the Oxfordian and Kimmeridgian. In: Matyja, B. A., Wierzbowski, A. & Radwański, A. (eds.), *Oxfordian & Kimmeridgian joint working groups meeting.* International Subcommision on Jurassic Stratigraphy, Warszawa, pp. 37–40.

Wierzbowski, A., Matyja, B. A. & Ślusarczyk-Radwan, D., 1983. New data on Upper Jurassic strata in the Wieluń Upland and vicinities of Burzenin and their economic value. (In Polish, English summary). *Kwart. Geol.*, 27: 517–534.

Więckowski, R., 1987. Tektonika. In: Heliasz, Z., Ptak, B., Więckowski, R. & Zieliński, T. (eds.), *Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50000, arkusz Janów (846).* (In Polish only). Wydawnictwa Geologiczne, Warszawa, pp. 37–38.

Ziegler, P. A., 1990. *Geological Atlas of Western and Central Europe*. Shell Int. Petrol., Maatsch, 239 pp.

Znosko, J., 1953. Geological structure of the Błędów and Niegowonice region near Olkusz. (In Polish, English summary). *Biul. Inst. Geol.*, 74: 1–60.

Streszczenie

RELIEF DNA MORSKIEGO A ZRÓŻNICOWANA KOMPAKCJA W KOPALNYCH PLATFORMACH WĘGLANOWYCH: KRYTYCZNE PRZESZACOWANIE PRZYKŁADU Z GÓRNEJ JURY WYŻYNY KRAKOWSKO-WIELUŃSKIEJ

Jacek Matyszkiewicz

Do podstawowych, kontrowersyjnych problemów środowiska sedymentacji w późnej jurze na północnym szelfie Tetydy (Fig. 1) należy zagadnienie rekonstrukcji reliefu dna basenu. W niniejszej pracy podjęto dyskusję z poglądem o ponad 200 metrowym reliefie synsedymentacyjnym, który miał występować w basenie obejmującym SW-obrzeżenie Gór Świętokrzyskich i Wyżynę Krakowsko-Wieluńską na przełomie oksfordu i kimerydu (Matyja *et al.*, 1989; Kutek *et al.*, 1992; Wierzbowski, 1992; Matyja & Wierzbowski, 1994). Dowody mające dokumentować ów pogląd zostały ostatnio przedstawione w pracy Matyja & Wierzbowski (1996). Niniejszy artykuł zawiera krytyczną analizę tych dowodów oraz wyniki badań przeprowadzonych przez autora w rejonie między Skowronowem a Julianką k/Częstochowy, gdzie miał zostać udokumentowany rzekomy 200 metrowy relief synsedymentacyjny.

Poprawna metodyka rekonstrukcji reliefu synsedymentacyjnego wymaga: (i) wyznaczenia, co najmniej jednej pary równowiekowych profili litologicznych: w obrębie budowli węglanowej i w ekwiwaletnych jej osadach facji basenowej, (ii) wydzielenia w tych profilach wszystkich typów litologicznych, (iii) wyliczenia, osobno dla każdego typu litologicznego, kompakcyjnej redukcji miąższości, która miała miejsce do czasu, w którym rekonstruuje się relief dna i (iv) obliczenia skorygowanej miąższości dla każdego z porównywanych profili. Dopiero porównanie miąższości tak przeliczonych profili pozwala na oszacowanie wielkości deniwelacji dna w danym czasie. W rekonstrukcji takiej winno uwzględnić się także wielkość eustatycznych wahań poziomu morza, różnice w subsydencji porównywanych części basenu oraz określić tempo akumulacji osadów.

Obszar, z którego pochodzą dane o rzekomych, 200 metrowych deniwelacjach dna w późnojurajskim basenie (Matyja & Wierzbowski, 1996) jest położony w środkowej części Wyżyny Krakowsko-Wieluńskiej, około 20 km na SE od Częstochowy (Fig. 2, 3). W rejonie tym miąższość zachowanych osadów górnojurajskich jest zmienna i sięga ponad 450 m (Heliasz *et al.*, 1984, 1987). Górna jura jest reprezentowana przez utwory oksfordu i zachowane lokalnie utwory kimerydu (Matyja & Wierzbowski, 1996), na których zalegają płaty osadów kredy. Na podstawie danych szacunkowych, głębokość pogrzebania utworów oksfordu u schyłku kredy można określić na co najmniej 500 m (C. Peszat & J. Rutkowski; inf. ustna, 1998).

Dane o litologii i miąższości utworów oksfordu, na podstawie których Matyja & Wierzbowski (1996) zrekonstruowali synsedymentacyjny relief na przełomie oksfordu i kimerydu pochodzą ze "starych, archiwalnych opisów profili wierceń" (Matyja & Wierzbowski, 1996, p. 336), w których wyznacznie spągu oksfordu przyjętego jako poziom odniesienia ma być "bardzo łatwe" (Matyja & Wierzbowski, 1996, p. 336). Miąższość osadów oksfordu, Matyja & Wierzbowski (1996) prawdopodobnie określili, korelując profile wierceń "Julianka" i "Skowronów" z rzędną wysokościową granicy oksford/kimeryd wyznaczoną w odsłonięciach, na podstawie znalezisk amonitów. Wiercenie "Julianka" ma reprezentować osady budowli węglanowej, a wiercenie "Skowronów" osady facji basenowej (Fig. 3). Z profili porównywanej pary wierceń wynika, iż w wierceniu "Skowronów" 267 metrowy profil oksfordu jest reprezentowany od spągu przez: (i) około 190 m "wapieni marglistych" i "uławiconych wapieni z gąbkami krzemionkowymi", nad którymi zalega (ii) około 10 m "wapieni mikrytowych", (iii) ponad 18 m "margli", (iv) około 12 m "wapieni mikrytowych" i (v) około 37 m osadów, których sygnatura nie jest w legendzie podana (Fig. 3). Na podstawie danych literaturowych (Kutek *et al.*, 1977; Wierzbowski *et al.*, 1983; Smoleńska, 1986) powyższe interwały mogą odpowiadać: (i) warstwom jasnogórskim, uławiconym wapieniom zawodziańskim, wapieniom kredowatym miedznowskim, wapieniom płytowym z tuberoidami i prawdopodobnie mikrytowym wapieniom pylastym (ii) dolnym wapieniom płytowym, (iii) dolnemu zespołowi marglistemu, (iv) środkowym wapieniom płytowym i (v) prawdopodobnie wapieniom kredowatym. Profil ponad 470 m osadów oksfordu w wierceniu "Julianka", pomijając jego kilkumetrową, przyspągową część wykształconą jako "wapienie margliste", ma reprezentować osady kompleksu biohermalnego (Fig. 3).

W rejonie Julianki i Skowronowa (Fig. 2) przeprowadzono badania osadów górnojurajskich występujących na powierzchni. Próby pobrano z wapieni masywnych występujących w łomach w Juliance oraz z uławiconych wapieni kredowatych odsłaniających się w rejonie Skowronowa. Z prób tych wykonano zgłady i płytki cienkie w celu przeprowadzenia badań mikrofacjalnych. Wapienie masywne i wapienie kredowate zbadano również w mikroskopie skanningowym. Ponadto w wapieniach kredowatych ze Skowronowa oznaczono zawartość węglanów ($CaCO_3$ i $MgCO_3$), nierozpuszczalnego residuum i porowatość w celu obliczenia kompakcji metodą, którą zaproponował Ricken (1986).

Obserwacje przeprowadzone w łomach w Juliance potwierdziły obecność kompleksu biohermalnego, w obrębie którego występują zróżnicowane litologicznie wapienie masywne i niekiedy wapienie uławicone. Część z wapieni masywnych zawiera nagromadzenia fauny, w tym korali hermatypowych, co pozwala określić je jako osady raf kępkowych, (por. Heliasz, 1990). Obfita fauna, szczególnie ramienionogów, występuje także w wapieniach uławiconych, cechujących się powszechnością wczesnodiagenetycznych cementów (por. Heliasz & Racki, 1980). W ścianach łomów obserwuje się lateralną, silną zmienność litologiczną, która częściowo jest związana z występowaniem uskoków o trudnym do ustalenia zrzucie. Badania w mikroskopie optycznym i skanningowym wykonano na próbach pobranych z najbardziej zwięzłych odmian wapieni masywnych. Wapienie te wykształcone są jako *wackestone-packstone* i *framestone*. Lokalnie zawierają one liczne fragmenty koralowców, szkarłupni, sklerogąbki, małże, ramienionogi i *Tubiphytes* (por. Heliasz, 1990). Zwraca uwagę powszechna obecność cementów syntaksjalnych rozwiniętych na płytkach szkarłupni (Fig. 6a). Większe pory wypełnia cement blokowy o wielkości kryształów wzrastającej ku centrum pora. Na brzegach większych allochemów widoczne są niekiedy obwódki cementu izopachytowego do 0,2 mm. W obrazie skanningowym widoczne są liczne skupienia grubokrystalicznych, wczesnodiagenetycznych cementów tkwiące w matriks utworzonym z kryształów mikrytu o przeciętnej średnicy 2–3 µm. (Fig. 7a, c).

W odsłonięciach w rejonie Skowronowa występują miękkie, brudzące palce, żółtawe wapienie kredowate, zwykle wykazujące uławicenie. Badania przeprowadzono na próbach pobranych w odsłonięciu położonym na S od Skowronowa, na stoku płaskiego wzniesienia, przy drodze Janów–Olsztyn (Fig. 2). W przyspągowej części łomu stwierdzono liczne ślady żerowania w miękkim, niezlityfikowanym osadzie (Fig. 8). Na świeżych powierzchniach widoczne są niekiedy pojedyncze gąbki krzemionkowe, na których lokalnie rozwinięte są laminowane mikrobolity oraz drobne bioklasty o kilkumilimetrowej średnicy.

Pod względem mikrofacjalnym wapienie kredowate ze Skowronowa reprezentują *mudstone-wackestone* (Fig. 6b), z niezbyt obfitą fauną gąbek wapiennych i krzemionkowych, mszywiołów i ramienionogów. W mikroskopie skanningowym skala cechuje się jednorodnością budowy. Matriks zbudowane jest z kryształów mikrytu o przeciętnej średnicy około 3 µm. (Fig. 7b, d). Grubokrystaliczne cementy występują sporadycznie. Suma zawartości węglanów $CaCO_3$ i $MgCO_3$ w próbie z wapieniach kredowatych ze Skowronowa wynosi 99,54%, nierozpuszczalnego residuum 0,16% a porowatość 37,2%. Wyniki te pozwoliły na wykonanie kontrolnego obliczenia stosując "prawo kompakcji węglanów" (Ricken, 1986, p. 14, równanie 4). Kompakcja wapieni kredowatych wyliczona w ten sposób wynosi około 45%.

Na podstawie danych zawartych w pracy Matyja & Wierzbowski (1996) o litologii i miąższościach osadów oksfordu profili "Julianka" i "Skowronów", oszacowano wpływ kompakcji na obecną miąższość osadów budowli węglanowej i facji basenowej. Przyjęto, że obecna miąższość profilu "Julianka" jest zbliżona do miąższości pierwotnej. Miąższość pierwotną i miąższość na przełomie oksford/kimeryd osadów profilu "Skowronów" wyznaczono dwiema niezależnymi metodami, na podstawie nomogramów (i) Perrier & Quiblier (1974, p. 516) i porównowczo (ii) Doglioni & Goldhammer (1988, p. 243). Nomogramy Perrier & Quiblier (1974) zostały wprawdzie opracowane dla łupków, ale stosowane są także do wyliczania pierwotnych miąższości górnojurajskich serii złożonych z wapieni marglistych i margli (cf. Gygi, 1986), w których wczesnodiagenetyczna cementacja nie występuje lub ma znaczenie marginalne. Spośród nomogramów opracowanych przez Doglioni & Goldhammer (1988) wykorzystano te, które dotyczyły mułów węglanowych.

Łączna miąższość osadów oksfordu profilu "Skowronów" na przełomie oksford/kimeryd, obliczona na podstawie nomogramów Perrier & Quiblier (1974) wynosi około 347 m a na podstawie nomogramów Doglioni & Goldhammer (1988) – około 376 m (Fig. 4–5, Tab. 1). Miąższość ta jest większa od obecnej miąższości osadów odpowiednio o 80 i 109 m.

Wnioski

Dane o miąższości osadów oksfordu w profilach "Skowronów" i "Julianka", podane przez Matyja & Wierzbowski (1996) są wątpliwe, z uwagi na trudności w precyzyjnym wyznaczeniu spągu i stropu oksfordu w profilach wierceń. Zdaniem Bednarka (1974, p. 17), w rejonie Zawiercia położonym około 40 km na SE od Częstochowy, "Granica oksfordu i keloweju nie może zostać przyjęta za poziom odniesienia ponieważ, w niektórych profilach – zwłaszcza wiertniczych – nie wiąże się z nią wyraźna zmiana wykształcenia litologicznego". Z kolei, określenie położenia stropu oksfordu, na podstawie datowania amonitami zebranymi w odsłonięciach, archiwalnych opisów profili wierceń, byłoby możliwe jedynie przy całkowitym braku zaburzeń uskokowych w rejonie Julianki i Skowronowa (por. Fig. 2, 9). W świetle pracy Więckowskiego (1987) i obserwacji autora nie znajduje to odzwierciedlenia w faktach.

Przyjęta przez Matyja & Wierzbowski (1996) metodyka rekonstrukcji reliefu synsedymentacyjnego nie może być stosowana nawet w obszarach niezaburzonych uskokowo. Rzekome dowody na występowanie znacznych deniwelacji dna opierają się bowiem na utożsamianiu z deniwelacjami obecnych różnic miąższości osadów budowli węglanowej i facji basenowej, przy całkowitym pomijaniu zróżnicowanego oddziaływania kompakcji. Gdyby nawet założyć, że podane przez Matyja & Wierzbowski (1996) miąższości oksfordu w porównywanych profilach wierceń są poprawne, to wyliczona wielkość deniwelacji dna basenu w rejonie Julianki i Skowronowa na przełomie oksfordu i kimerydu, przy uwzględnieniu jedynie kompakcji mechanicznej, wynosiłaby, co najwyżej około 100 m (por. Tab. 1). Uwzględniając kompakcję chemiczną należałoby tę wielkość zredukować jeszcze o 20–35% (por. Goldhammer, 1997).