

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

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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 budowy 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 synsedymencyjnego.

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 przelomie oksfordu i kimerydu były oparte na utożsamianiu z deniwelacjami dna aktualnej różnicy miąższości między utworami budowy 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.

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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) microbialitic-sponge or microbialitic 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; Swin-

burne & 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-

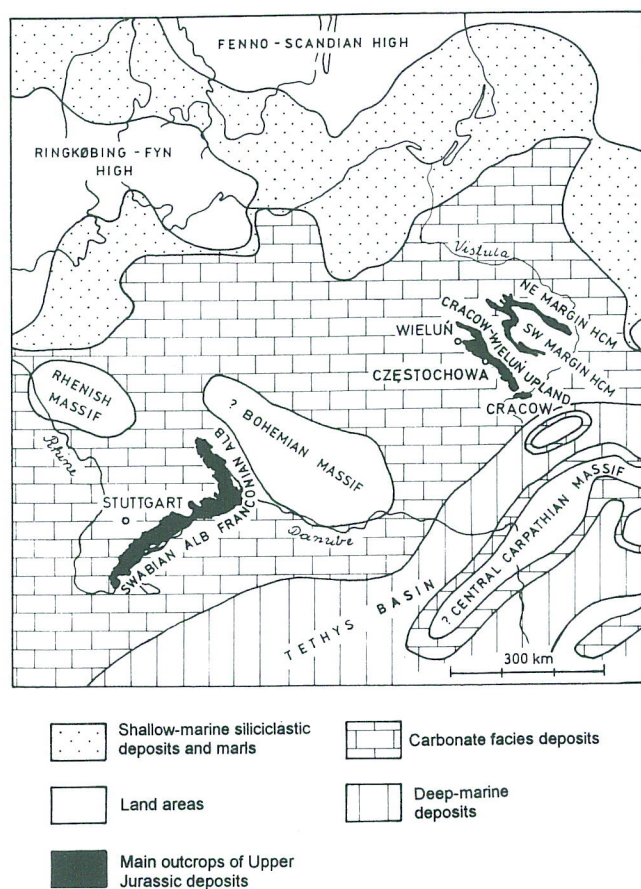


Fig. 1. Main outcrops of Upper Jurassic deposits related to palaeogeographical map of the central part of northern, stable Tethyan shelf in the Oxfordian (after Ziegler, 1990; modified). HCM – Holy Cross Mountains

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 co-exist 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 symsedimentary 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 symsedimentary relief in all the carbonate formations is based upon the influence of diversified compaction of carbonate buildups and basal 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 symsedimentary relief requires: (i) selection of at least one pair of lithological successions of the same age in a carbonate buildup and in an equivalent basal 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 & Fernández-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 cylindrical 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 neglect 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 compaction 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 distribution 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 syndepositional relief. Głazek & Wierzbowski (1972) proposed that the development of some syndepositional 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, syndepositional 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 syndepositional 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 syndepositional the dips up to 25° observed in the bioherm slope. Moreover, he supported the presence of distinct syndepositional 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 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 syndepositional 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 syndepositional 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 syndepositional 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 syndepositional tectonics on development of syndepositional 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-

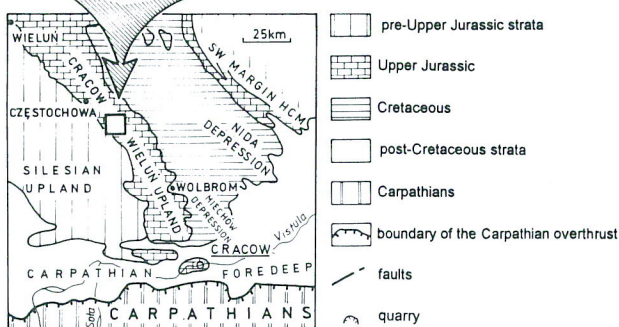
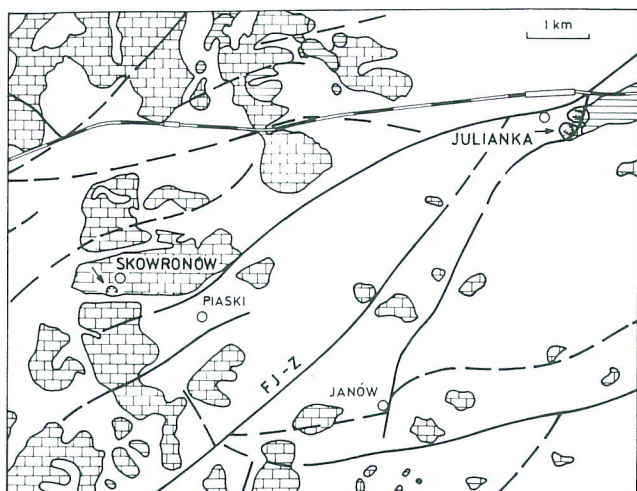


Fig. 2. Location of study area in the Cracow–Wieluń Upland and outcrops of Mesozoic rocks in Julianka and Skowronów areas (after Heliasz *et al.*, 1984) with approximate positions of faults (after tectonic sketch-map Heliasz *et al.*, 1987; simplified and modified). HCM – Holy Cross Mountains. Arrows 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

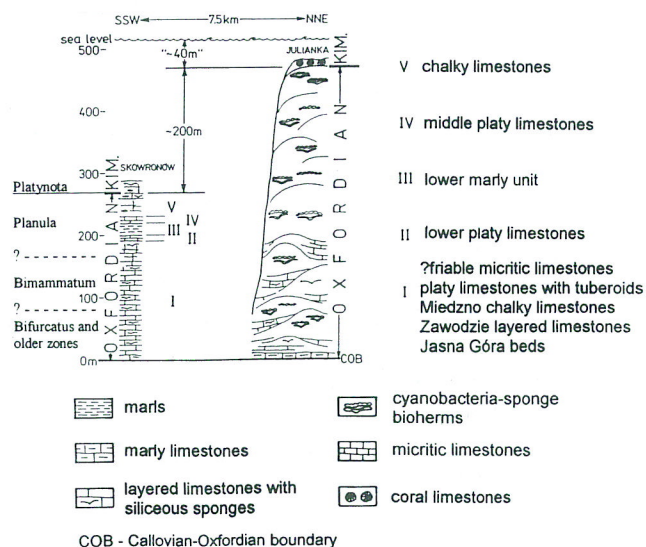


Fig. 3. Reconstruction of sea-bottom relief and bathymetry based upon borehole data after Matyja & Wierzbowski (1996). Subdivision, ammonite zones, Roman numerals and lithological types of Oxfordian deposits in the “Skowronów” borehole supplemented after Wierzbowski (1966), Kutek *et al.* (1977) and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

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).

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 (Kutec *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 tuberosids 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

Observations carried on in the Julianka quarries supported the presence of biohermal complex which comprises lithologically diversified massive (and occasionally bed-

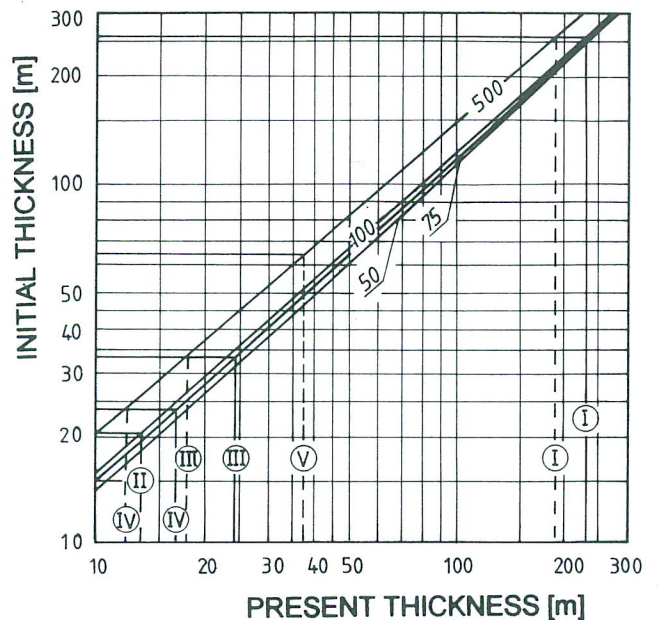


Fig. 4. Thickness calculation of Oxfordian deposits in "Skowronów" borehole at the Oxfordian/Kimmeridgian break based upon nomographs after Perrier & Quiblier (1974). Roman numerals mark lithological types distinguished in Fig. 3 and Table 1. Intersections of vertical broken lines and the frame – recent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

ded) 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-

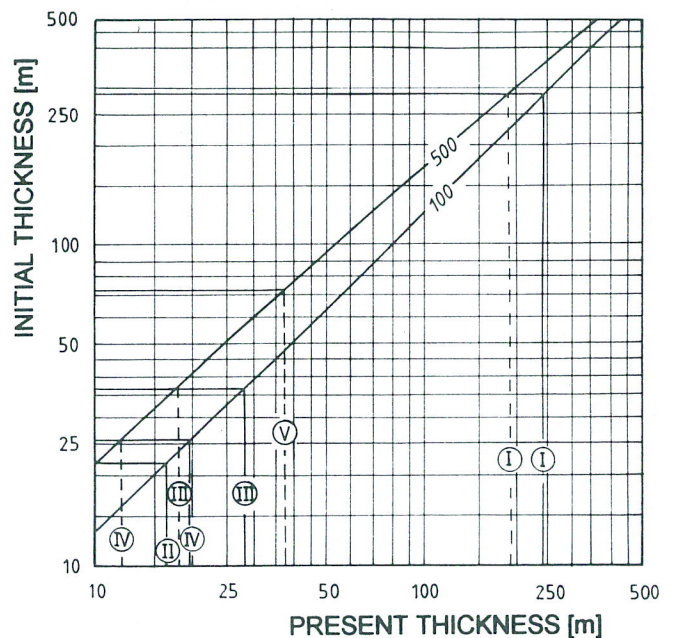


Fig. 5. Thickness calculation of Oxfordian deposits in "Skowronów" borehole at the Oxfordian/Kimmeridgian break based upon nomographs after Doglioni & Goldhammer (1988). Explanations as in Fig. 4

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, sclerospores, 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 occasionally 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 $\text{CaCO}_3 + \text{MgCO}_3$ 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

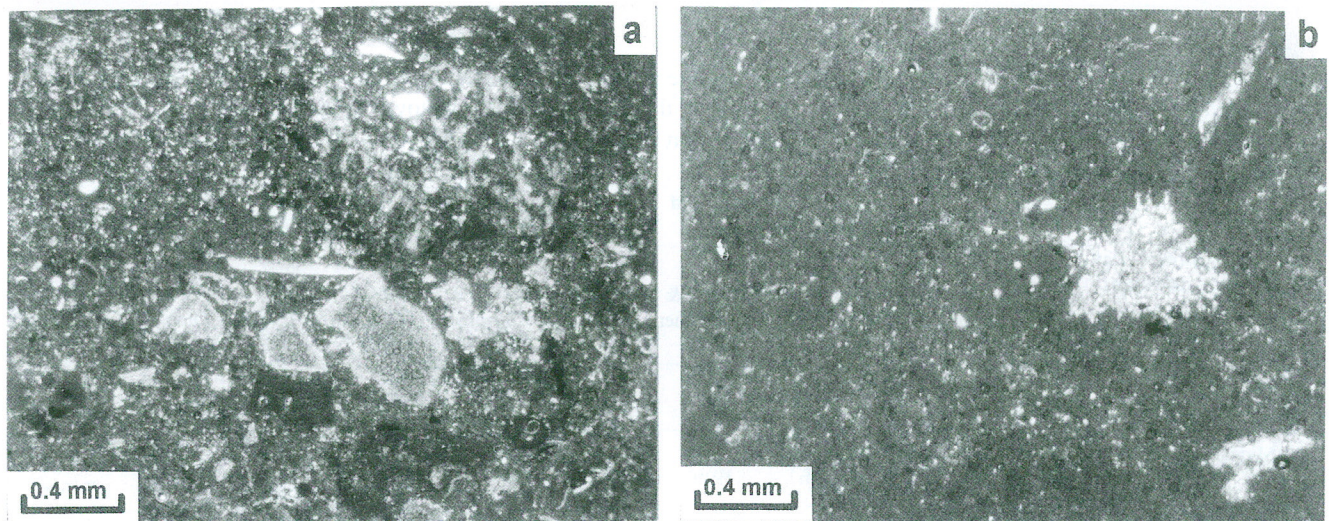


Fig. 6. Microfacies of Upper Jurassic deposits from Julianka and Skowronów areas (?Upper Oxfordian, ?Lower Kimmeridgian): **a** – massive limestone from Julianka developed as packstone with numerous bioclasts. Echinoderm plates in the center with light rims of syntaxial cement. **b** – chalky limestone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

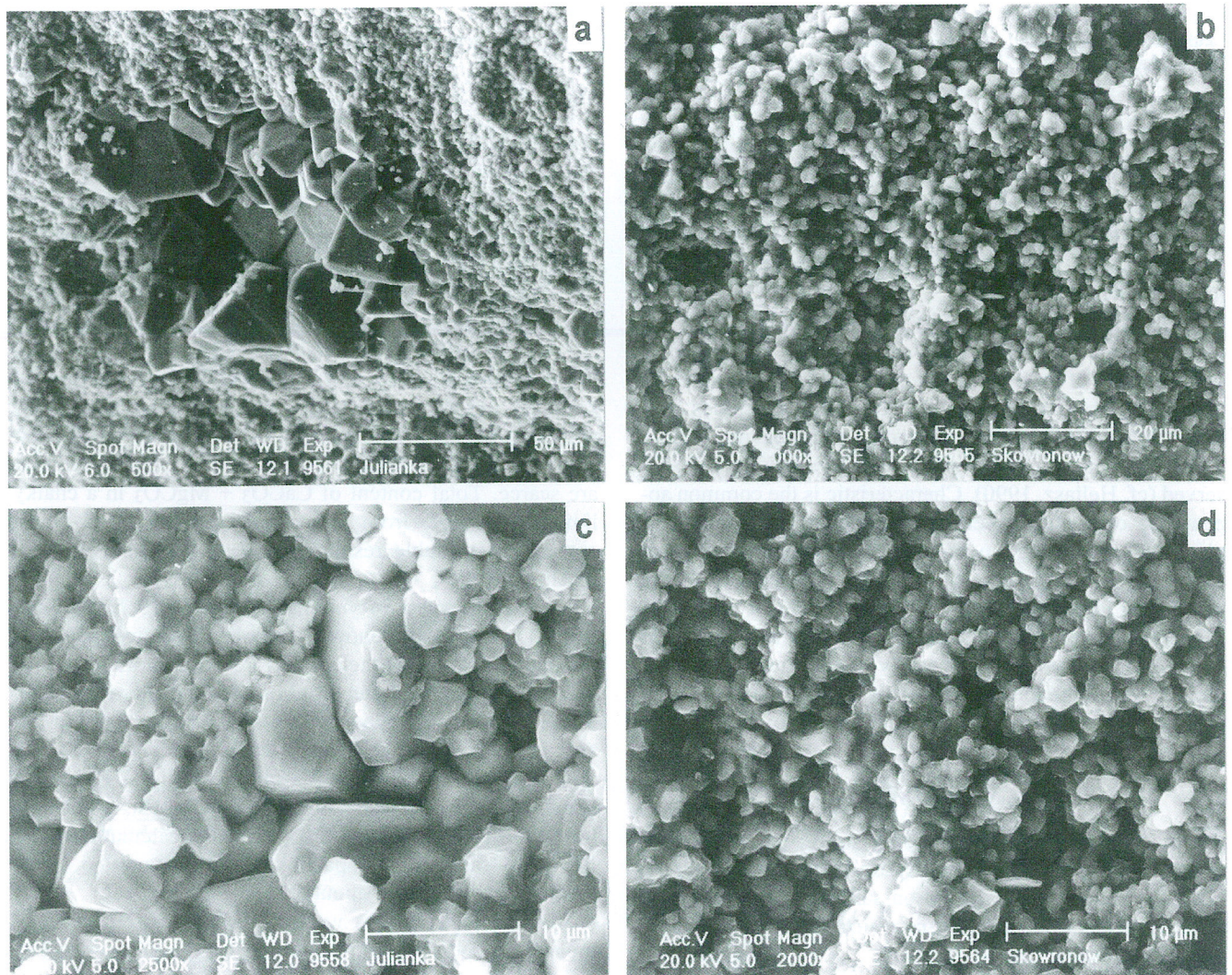


Fig. 7. Massive limestones from Julianka (**a**, **c**) and chalky limestones from Skowronów (**b**, **d**) areas under the scanning electron microscope. Principal component of chalky limestones is monotonous micrite of roughly uniform crystal size. In massive limestones coarse-crystalline, early diagenetic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



Fig. 8. Penetrations preserved in chaly 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/Callovia 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. Presum-

ably 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

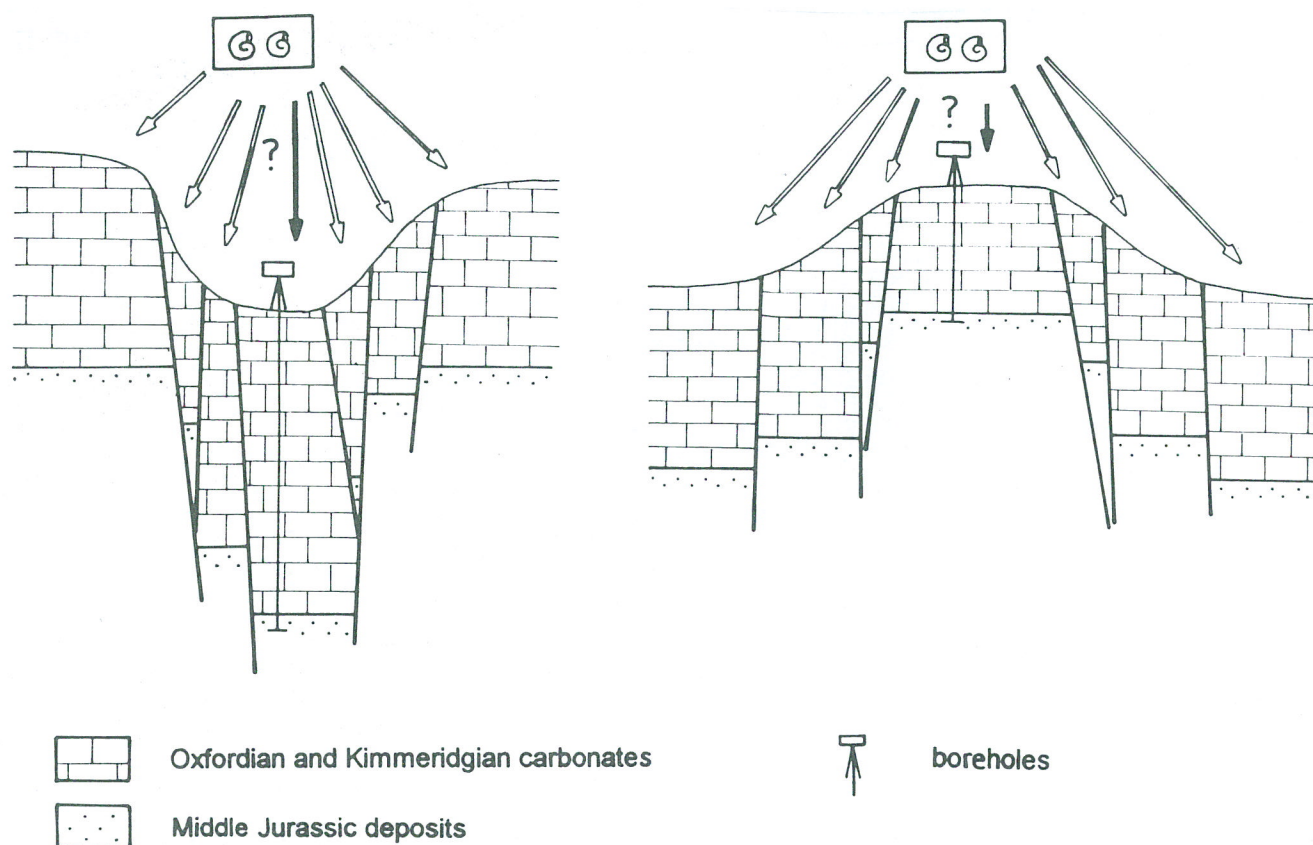


Fig. 9. Application of ammonites collected in outcrops to age determination of deposits in drill cores, in tectonically disturbed areas (schematic cross-section, out of vertical and horizontal scale). Sketch illustrates features of graben (left) and horst (right), typical of the Cracow–Wieluń Upland. 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 densely 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 undoubtedly 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 microbolic 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) neglect of thickness reduction resulted from pressure solution. Such assumptions lead to underestimation of calculated thicknesses which are probably much lower than 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 than 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 continental 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 poorly 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 microbolic 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 undoubtedly linked to temporary reduction or even cessation of growth of carbonate buildups and a dramatical increase in background sedimentation rate. Such a processes undoubtedly 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 neglect 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.

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Streszczenie

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

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Do podstawowych, kontrowersyjnych problemów środowiska sedimentacji 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 synsedymencyjnym, 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 synsedymencyjny.

Poprawna metodyka rekonstrukcji reliefu synsedymencyjnego wymaga: (i) wyznaczenia, co najmniej jednej pary równowiekowych profili litologicznych: w obrębie budowli węglanowej i w ekwiwalentnych jej osadach facji basenowej, (ii) wydzielenia w tych profilach wszystkich typów litologicznych, (iii) wyliczenia, osobno dla każdego typu litologicznego, kompacyjnej 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 rzekomym, 200 metrowym 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 górn-

jurajskich 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 płyty 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 synsedymenacyjny relief na przelomie oksfordu i kimerydu pochodzą ze "starych, archiwalnych opisów profili wierceń" (Matyja & Wierzbowski, 1996, p. 336), w których wyznaczenie 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, przyspagową część wykształconą jako "wapienie margliste", ma reprezentować osady kompleksu biohermalnego (Fig. 3).

W rejonie Julianki i Skowronowa (Fig. 2) przeprowadzono badania osadów górnourajskich 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 zglądy 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 kompaktacji 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 koralu 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 zwężonych 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 przyspagowej części łomu stwierdzono liczne ślady żerowania w miękkim, niezlifyfikowanym osadzie (Fig. 8). Na świeżych powierzchniach widoczne są niekiedy pojedyncze gąbki krzemionkowe, na których lokalnie rozwinięte są laminowane mikrokolity 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, mszyciów i ramienionogów. W mikroskopie skanningowym skała 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 kompaktacji węglanów" (Ricken, 1986, p. 14, równanie 4). Kompaktacja 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 kompaktacji 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 przelomie 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 górnourajskich 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 przelomie 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 zebranyimi w

odslonięciach, archiwalnych opisów profili wierceń, byłoby możliwe jedynie przy całkowitym braku zaburzeń uskoku 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 synsedymacyjnego nie może być stosowana nawet w obszarach niezaburzonych uskoku. 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 pominięciu zróżnicowanego oddziaływania kompaktacji. 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 kompaktacji mechanicznej, wynosiłaby, co najwyżej około 100 m (por. Tab. 1). Uwzględniając kompaktację chemiczną należałoby tę wielkość zredukować jeszcze o 20–35% (por. Goldhammer, 1997).