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Reconstruction of the pre-compactional thickness of the Zechstein Main Dolomite in northwest Poland

Grażyna Semyrka[1]*, Marzena Gancarz[2], Zbigniew Mikołajewski[3]

[1]AGH University of Science and Technology, Faculty of Geology, Geophysics and Environment
Protection, Department of Fossil Fuels, Mickiewicza 30, 30-059 Kraków, Poland
[2]AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Department of Gas
Engineering, Mickiewicza 30, 30-059 Kraków, Poland
[3] Polish Oil and Gas Co. SA, Branch of Geology and Exploitation, Department of Projects in Piła, Staszica 9,
64-920 Piła, Poland
* corresponding author, e-mail: gsemyrka@agh.edu.pl

Abstract

Our reconstruction of the pre-compactional thickness of the Main Dolomite strata from the so-called Grotów Peninsula (northwest Poland) was based on macroscopic observations of drill cores from three wells: Mokrzec-1, Sieraków-4 and Międzychód-5. These wells are located in various palaeogeographical zones of the Main Dolomite and cored rocks represent a range of microfacies. The amount of compactional reduction in thickness of the Main Dolomite was estimated by summing the total heights (W_{st}) of all stylolites encountered in logs of these wells. For calculations, a generalised model of a drill core was developed, which embraced all types of stylolite seams present in the Main Dolomite succession studied. Also the method of stylolite dimensioning was demonstrated. The number of stylolites in the drill cores studied varied from 511 in the Sieraków-4 well to 1,534 in the Międzychód-5 well. In all cores studied low-amplitude macrostylolites predominated, but the reduction of thickness was controlled mostly by the low- and medium-amplitude macrostylolites. The largest number of stylolites was found in the grainstone/packstone microfacies. The turnout of stylolites depends of microfacies. The highest density of stylolites was documented in mudstones/wackestones (24 stylolites per metre of rock thickness) and the lowest in boundstones (14 stylolites per metre of rock thickness). The low-amplitude stylolites appear most frequently in the mudstone/wackestone microfacies (15 stylolites per metre of rock thickness); in grainstones/packstones, rudstones/floatstones and boundstones middle-amplitude stylolites are rare (3 stylolites per metre of rock thickness). The degree of compaction of the Main Dolomite succession studied varied from 6 to 10%; hence, its calculated initial thickness also varied in the wells studied: from 41.3 m in the Sieraków-4 well to 56.9 m in the Mokrzec-1 well and to 97.1 m in the Międzychód-5 well. The volumes of reservoir fluids expelled during compaction of 1 m^3 of Main Dolomite carbonates were estimated as 56 l in the Sieraków-4 well, 90 l in the Mokrzec-1 well and 97 l in the Międzychód-5 well.

Keywords: compaction, solution seam, stylolitic seam, thickness reduction

1. Introduction

The initial thickness of sediments can be reconstructed with various methods and from such reconstructions the amount of compaction can be estimated (see e.g., Shinn & Robin, 1983; Aplin et al., 1995; Goldhammer, 1997; Westphal, 1998; Westphal & Munnecke, 1997; Broichhausen et al., 2005; Katsman & Aharonov, 2006; Kochman, 2006). However, the fastest and simplest method is macroscopic analysis of drill cores (Stockdale, 1926; Mossop, 1972, Waschs & Hein, 1974; Kaplan, 1976; Peacock & Azzam, 2006; Vandeginste & John, 2013).

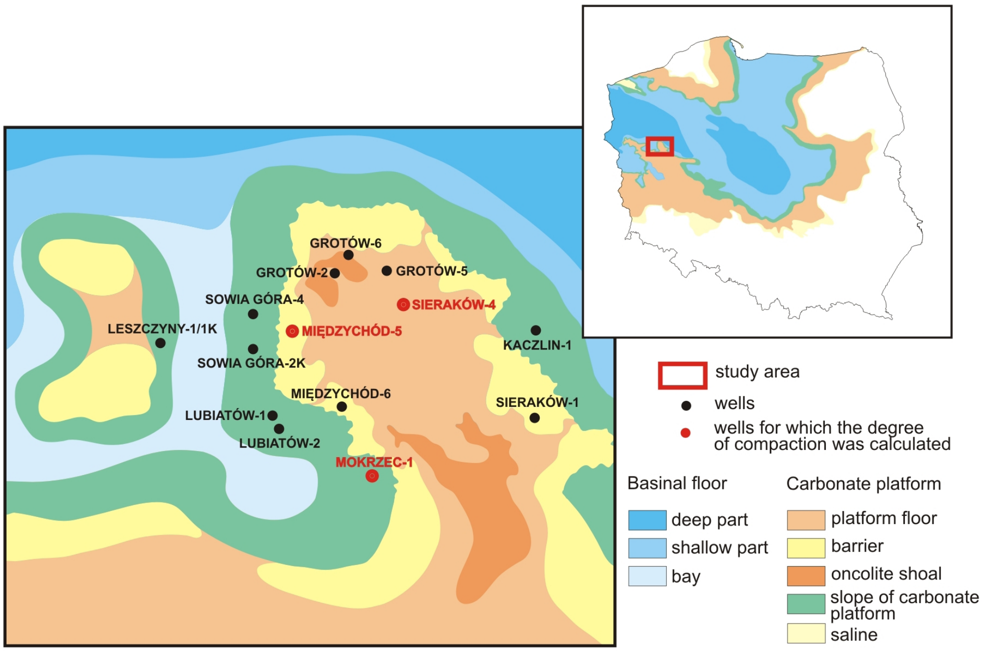

Fig. 1. The study area plotted on a palaeogeographical map of the Main Dolomite in the Polish Zechstein Basin (modified after Kotarba & Wagner, 2007)

During compaction, the load from the overburden results in pressure solution of carbonate rocks and formation of stylolite seams. Hence, the thickness reduction of rocks (which is a measure of the amount of compaction) can be estimated by summing the heights of all stylolites existing in the interval studied.

The stylolitisation process plays a double role. First, it records the intensity of compaction and reflects the expulsion of reservoir fluids during primary migration and, second, it controls the transformation of reservoir from porous to dual, porous-fractured. The systems of tectonic fractures together with the systems of stylolite seams both influnce the migration of reservoir fluids (Stockdale, 1926; Ramsden, 1952; Radlicz, 1966; Dunnington, 1967; Semyrka, 1985; Strzetelski, 1977; Koepnick, 1988; Aydin, 2000; Agosta et al., 2009; Agosta et al., 2010; Heap et al., 2014).

In the Polish Zechstein Basin stylolites are common in the Main Dolomite succession. The so-called "Grotów Peninsula" was selected as a study area because of the large number of core samples and analytical data and assessment reports available (Fig. 1).

In order to reconstruct the pre-compactional thickness of the Main Dolomite succession, a generalised model of a drill core was developed from the macroscopic observations of lithostratigraphic columns from 15 wells. The wells represent various palaeogeographical zones of the Main Dolomite basin, from toe-of-slope of a carbonate platform with a bay shoal to a barrier and a lagoon (Fig. 1).

There are five methods for estimating the thickness of material dissolved along a stylolite: the maximum stylolite height (Stockdale, 1926; Glover, 1968; Mossop, 1972; Kaplan, 1976; Bathurst, 1984), the thickness of a stylolite seam (Stockdale, 1926; Heald, 1955; Barrett, 1964), the condensation of heavy minerals along a stylolite seam (Young, 1945; Heald, 1955), the displacement of pre-existing veins (Conybeare, 1949; Bushinskyi, 1961; Wasch & Hein, 1974) and the reconstruction of truncated fossils and oolites (Bushinskyi, 1961; Wasch & Hein, 1974). One of the commonest methods is to measure maximum stylolite height. In the present paper we propose to measure the average height and thickness of stylolites as a means of determining thickness reduction and calculating compaction.

2. Compaction

Compaction is a diagenetic densification of sediment under the pressure exerted by the load of overburden. The diagenesis advances due to a combined effect of geometric (mechanical compaction) and mineralogical (chemical compaction) changes within the sediment controlled by its primary lithological composition and sedimentary conditions (Dunnington, 1967; Coogan, 1970; Bathurst, 1975, 1987, 1995; Moore, 2001; Flügel, 2004; Tucker &

Wright, 1990; Katsman et al., 2005; Ehrenberg, 2006; Twardowski & Traple, 2008).

The mechanical compaction proceeds with various intensity during early diagenesis, down to burial depth of about 200 m and results in dense packing of grains, expulsion of water and reduction of porosity/permeability (Dunington, 1967; Bathurst, 1975, 1987, 1995; Shinn & Robbin, 1983; Ricken, 1987; Choquette & James, 1990; Clari & Martire, 1996; Goldhammer, 1997; Moore, 2001; Katsman et al., 2005).

The chemical compaction starts at a burial depth of about 200-300 m and includes a variety of processes: cementation, dissolution and recrystallisation, which change the structure of sediment. Controlling factors are: temperature, type of porosity, degree of infilling of pore space, susceptibility of particular minerals to dissolution and the presence of clay minerals (Wanless, 1979; Buxton & Sibley, 1981; Scholle & Halley, 1985; Leythaeuser et al., 1995).

Dissolution of minerals under the load of overburden is named "pressure solution" and results in the formation of stylolitic seams, and solution seams. Usually, pressure solution develops along various discontinuities (e.g., bedding planes, fractures, clay laminae) and is controlled by the presence of pore fluids. Pressure solution is effective when maximum stress appears at grain-to-grain contacts and results in stylolitisation, removal of water from clay minerals and expulsion of reservoir fluids. Solutes are then transported to the zones of lower stress, in consistence with the Riecke principle (Füchtbauer, 1974). As a result, the stylolite seams can be filled with residue composed of e.g., clay minerals and/or organic matter (Park & Schot, 1968; Neugenbauer, 1973; Bathurst, 1975; Larsen & Chilingar, 1979; Choquette & James, 1990; Matyszkiewicz, 1996; Środoń, 1996; Agosta & Kirschner, 2003; Ehrenberg, 2006; Ben-Itzhak et al., 2012; Rustichelli et al., 2012).

Compaction affects all geological formations but its results are different in particular rocks depending of lithology and susceptibility of rocks to this process. It is generally believed that susceptibility of pure carbonates to mechanical compaction is insignificant. Calcium carbonate can be dissolved at the contacts of lithologically different rocks buried at depths of some hundreds of metres and then the secondary calcium carbonate can be precipitated as a pore cement. Hence, such rocks become lithified and thus resistant to mechanical compaction. Consequently, their initial thickness is preserved (Bathurst, 1975, 1987; Ricken, 1987; Matyszkiewicz, 1996; Moore, 2001; Kiełt, 2002; Flügel, 2004; Tucker & Wright, 1990). Lithification is accelerated by unstable carbonate minerals and increasing temperature.

Considering details of the lithification process, the amount of compaction in the Main Dolomite was calculated only from the effects of stylolitisation.

3. Geological setting

The so-called "Grotów Peninsula" is located in the western part of the Polish Zechstein Basin (Fig. 1). The basin reveals highly diverse sea floor morphology which controlled facies development of the Main Dolomite rocks. In particular, we interpret deep- and shallow-marine, high- and low-energy environments varying in bathymetry and in microfacies. The Main Dolomite was deposited on carbonate platforms and microplatforms (barriers and lagoons), platform slope and toe-of-slope, and a carbonate ramp (for details see e.g., Peryt & Dyjaczyński, 1991; Wagner, 1994; Protas & Wojtkowiak, 2000; Jaworowski & Mikołajewski, 2007; Kotarba & Wagner, 2007; Słowakiewicz & Mikołajewski, 2009; Czekański et al., 2010).

In the carbonate platform environment, the high-energy zones produced mostly the grainstones with boundstone horizons (mainly sublittoral carbonate muddy sands; also carbonate sands and carbonate sandy muds), whereas the low-energy zones were dominated by mudstones, wackestones and packstones with abundant bioclasts (mainly dark grey sublittoral carbonate sandy muds and carbonate muds; carbonate muddy sands and microbial sediments being frequent). In the carbonate barriers, the high-energy environments gave rise to grainstone and boundstone formation, rarely to packstones, wackestones, floatstones and rudstones. Peri- and sublittoral carbonate sands and microbial sediments are predominant. Carbonate muddy sands occur fairly frequently. Carbonate sandy muds and carbonate conglomerates are rare. The platform slopes, occupying the border zone between the shallow-marine, high-energy platform and the deep-marine, low-energy basinal plain produced a variety of microfacies: mudstones, wackestones, packstones, grainstones, floatstones, rudstones and boundstones. There is a co-occurrence of sublittoral carbonate sands and muddy sands, carbonate sandy muds and muds. Carbonate conglomerates, sedimentary breccia and microbial sediments have also been observed. Typical of the toe-of-slope environment were mudstones and packstones intercalated by floatstones. Mostly the same sediments as those known from both the plat-

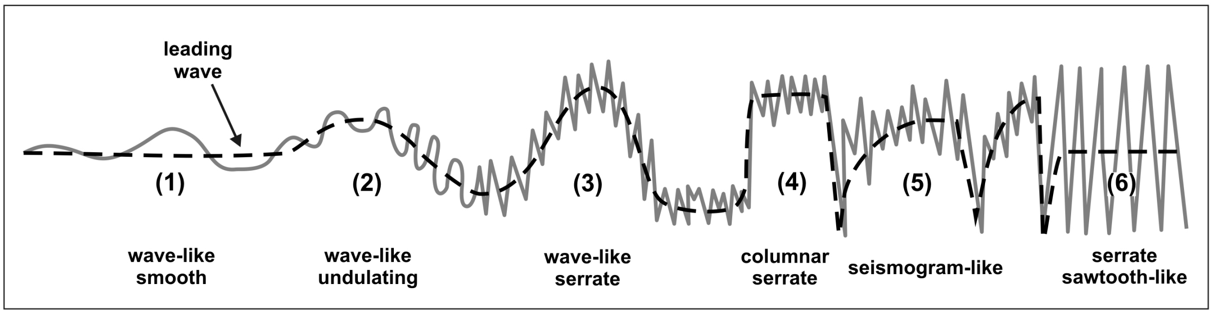

Fig. 2. Evolution sequence of stylolites

form slope and basin floor. Especially characteristic is the presence of carbonate sands with a carbonate mud admixture, carbonate muds and interbeds of carbonate conglomerates. Anhydrite conglomerates are observed in the lower portion of the section. Finally, the low-energy basinal plain environment led to the formation of mostly mudstones and laminated strata with bio-sedimentary structures (sublittoral dark grey carbonate muds and carbonate sandy muds; occasional carbonate muddy sands, thin microbial sediments) (Wagner, 1994; Kotarba & Wagner, 2007; Jaworowski & Mikołajewski, 2007).

4. Methods

Macroscopic observations of drill cores from the Grotów Peninsula revealed the common presence of stylolite seams in the Main Dolomite succession. The stylolites differ in origin and morphology: from almost simple through wave-like to columnar and seismogram-like, according to the sequence of stylolite evolution (Fairbridge, 1968; Park & Schot, 1968; Strzetelski, 1977; Andrews & Railsbak, 1997; Sheppard, 2002; Sinha-Roy, 2002; Renard et al., 2004; Schmittbuhl et al., 2004; Brouste et al., 2007; Ben-Itzhak et al., 2012) (Fig. 2).

Stylolites observed in the Main Dolomite successions fall into three morphological types: wave-like, columnar and serrate with the two last-named most often encountered in samples studied. Apart from horizontal stylolites, concordant with the bedding planes and produced by increasing load from the overburden, we observed also slicolites, i.e., stylolites inclined to the bedding planes, which were produced by tectonic stress (Bushinskiy, 1961; Radlicz, 1966; Kijewski & Kaszper,1973; Strzetelski, 1977; Peryt, 1978; Dadlez & Jaroszewski,1994; Ebner et al., 2009; Bonnetier et al., 2009; Krzesińska et al., 2010).

Based on macroscopic observations, we developed a generalised model of a drill core, which presents various types of stylolite seams and methods of their dimensioning (Fig. 3).

The reduction of the length of a drill core (R_{st}) resulting from evolution of a single stylolite is a sum of all its elements (h), i.e., amplitude of leading wave and heights of columns, teeth and secondary peaks, and average aperture of stylolite (g_{st}), which gives the total height of a stylolite (W_{st}). Taking into account the limited resolution of the human eye for stylolite apertures smaller than 1 mm, we applied in calculations the double value of the average aperture of a stylolite ($2g_{st}$). We also assumed that stylolites of < 2mm amplitudes are microstylolites and those of > 2 mm macrostylolites. Among the latter we distinguished low-amplitude (2–10 mm), medium-amplitude (10–50 mm) and high-amplitude (> 50 mm) stylolites.

In the drill-core model (Fig. 3) of recent length H_{ob} = 15 cm and diameter 3.5 cm, we included eight types of stylolite:

- wave-like, smooth macrostylolite – total height (W_{st1}) is the sum of average aperture (g_{st} = 1 mm) and amplitude of leading wave (h_f = 3,5 mm):

$$W_{st1} = g_{st} + h_f = 1 + 3.5 = 4.5 \text{ mm};$$

- simple, serrate microstylolite – total height (W_{st2}) is the sum of double aperture ($2g_{st} = 2 \cdot 0.5$ mm) and average height of teeth (h_z = 1 mm):

$$W_{st2} = 2g_{st} + h_z = 1 + 1 = 2 \text{ mm};$$

- wave-like, serrate macrostylolite – total height (W_{st3}) is the sum of double aperture ($2g_{st} = 2 \cdot 0.2$ mm), average amplitude of leading wave (h_f = 5 mm) and average height of teeth (h_z = 1.5 mm):

$$W_{st3} = 2g_{st} + h_f + h_z = 0.4 + 5 +1.5 = 6.9 \text{ mm};$$

- wave-like, smooth, irregular macrostylolite – total height (W_{st4}) is the sum of double aperture ($2g_{st} = 2 \cdot 0.2$ mm), average height of secondary peaks (h_o = 1.6 mm) and amplitude of leading wave (h_f = 4.5 mm):

$$W_{st4} = 2g_{st} + h_o + h_f = 0.4 + 1.6 + 4.5 = 6.5 \text{ mm};$$

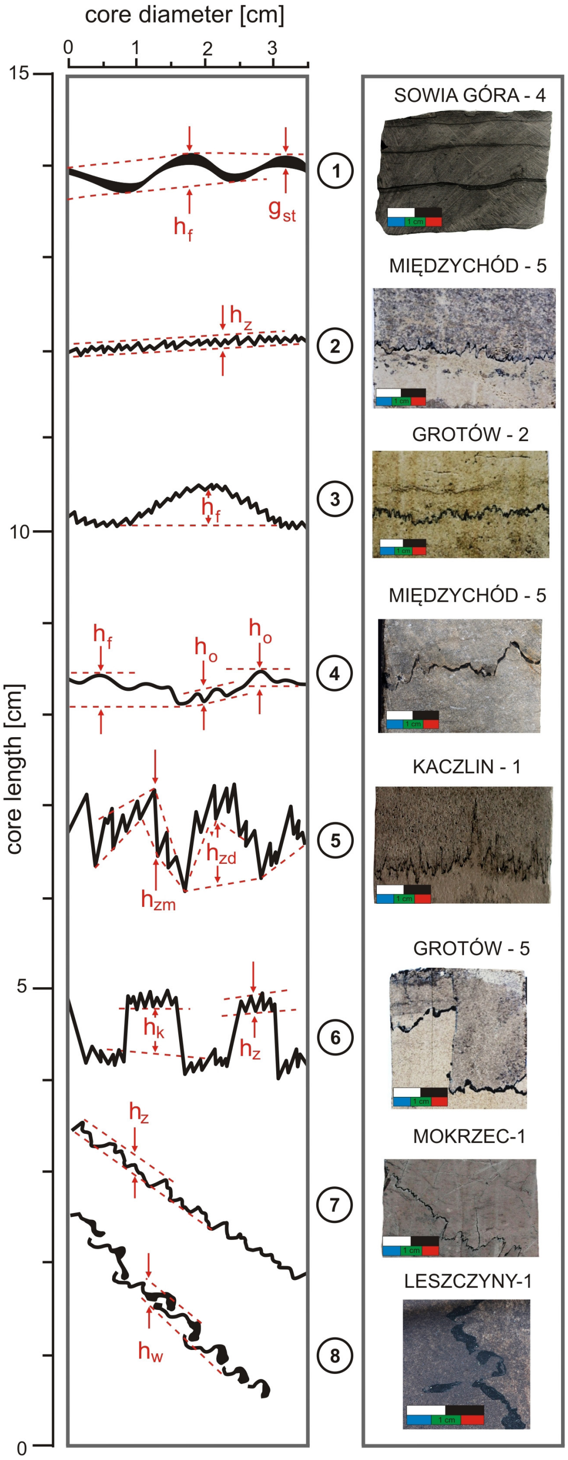

Fig. 3. Model of a drill core showing eight types of stylolite seams used for demonstration of a calculation method of compactional reduction of thickness.
1 – wave-like, smooth; 2 – simple, serrate; 4 – wave-like, smooth, irregular; 5 – seismogram-like; 6 – columnar, serrate; 7 – irregularly serrate; 8 – kink-like; h_f – amplitude of leading wave, g_{st} – aperture of stylolite, h_z – height of teeth, h_o – height of secondary peaks, h_{zm} – height of small teeth, h_{zd} – height of large teeth, h_k – height of column, h_w – height of kinks

- seismogram-like macrostylolite – total height (W_{st5}) is the sum of double aperture ($2g_{st} = 2 \cdot 0.6$ mm), average height of large teeth ($h_{zd} = 8.7$ mm) and average height of small teeth ($h_{zm} = 4.5$ mm) measured vertically:

$$W_{st5} = 2g_{st} + h_{zd} + h_{zm} = 1.2 + 8.7 + 4.5 = 14.4 \text{ mm};$$

- columnar, serrate macrostylolite – total height (W_{st6}) is the sum of double aperture ($2g_{st} = 2 \cdot 0.6$ mm), average height of columns ($h_k = 10.1$ mm) and average height of teeth ($h_z = 1.5$ mm):

$$W_{st6} = 2g_{st} + h_k + h_z = 1.2 + 10.1 + 1.5 = 12.8 \text{ mm};$$

- irregularly serrate microstylolite – total height (W_{st7}) is the sum of double aperture ($2g_{st} = 2 \cdot 0.2$ mm) and average height of teeth ($h_z = 1.3$ mm) measured vertically:

$$W_{st7} = 2g_{st} + h_z = 0.4 + 1.3 = 1.7 \text{ mm};$$

- kink-like macrostylolite – total height (W_{st8}) is the sum of average aperture ($g_{st} = 1.2$ mm) and average height of kinks ($h_w = 2$ mm) measured vertically:

$$W_{st8} = g_{st} + h_w = 1.2 + 2 = 3.2 \text{ mm}.$$

As concluded from the descriptions, proper identification and measurements of stylolite components are crucial for their dimensioning because average values of component heights are added in order to obtain the total height of a given stylolite (W_{st}) (Fig. 3).

The amount of stylolite-induced reduction of drill core length (R_{st}) is calculated as the sum of the heights of all stylolites in the core interval studied, according to the formula:

$$R_{st} = \Sigma W_{st1\text{-}8} = 0.45 + 0.2 + 0.69 + 0.65 + 1.44 + 1.28 + 0.17 + 0.32 = 5.2 \text{ cm}$$

Taking into account the present length of the core (H_{ob}) and the amount of reduction (R_{st}), we can calculate the approximate initial core length (H_p) as well as the degree of compaction K_{st} and the compaction coefficient k_{st}:

$$H_p = H_{ob} + R_{st} = 15 + 5.2 = 20.2 \text{ cm}$$

$$K_{st} = R_{st}/H_p \cdot 100\% = 5.2/20.2 \cdot 100\% = 26\%$$

$$k_{st} = R_{st}/H_p = 5.2/20.2 = 0.257$$

When the value of compaction coefficient ($k_{całk}$) is known we can approximate the volume of reservoir fluids ($W_{pzł}$) expelled from 1 m^3 of rock during compaction. In the model presented this is $W_{pzł} = 257\ l/m^3$.

5. Results

The methodology of reconstruction of pre-compactional thickness of sediments and determination of the volume of reservoir fluids expelled during primary migration presented here was applied to the samples derived from three wells: Mokrzec-1, Sieraków-4 and Międzychód-5. These wells are located in specific palaeogeographical zones of the Grotów Peninsula. The Mokrzec-1 well represents a toe-of-slope of carbonate platform, the Międzychód-5 well is located in the barrier zone and the Sieraków-4 well represents a shoal within the carbonate ramp (Fig. 1). These wells were selected due to high diversity and greater number of stylolite seams contained in drill cores.

In the lithostratigraphic columns of the wells studied, the following microfacies groups were distinguished in the Main Dolomite succession: mud-dominated (mudstones/wackestones), grain-dominated (grainstones/packstones and rudstones/floatstones) and biogenic (boundstones) (Dunham, 1962; Gradziński et al., 1986; Jaworowski & Mikołajewski, 2007; Mikołajewski & Słowakiewicz, 2008).

5.1. The Mokrzec-1 well

The Mokrzec-1 well is located at the margin zone of the carbonate platform slope and the basinal plain (Fig.1). The Main Dolomite was found at a depth of 3,313.5–3,261.8 m (thickness: 51.7 m). Three microfacies groups were identified: mud-dominated, grain-dominated with prevailing

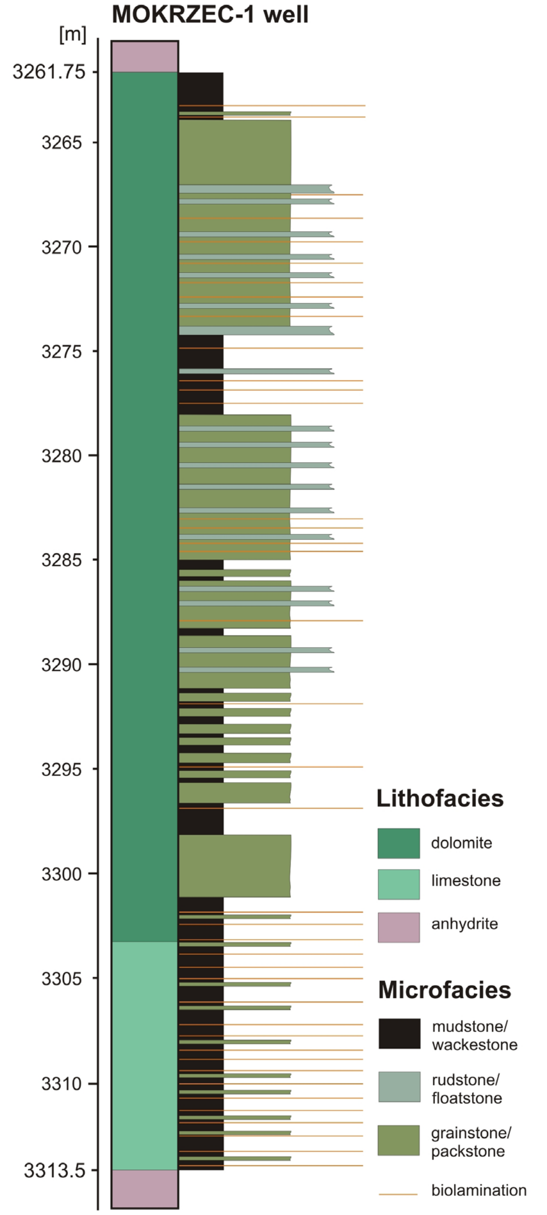

Fig. 4. Lithological and microfacies column of the Mokrzec-1 well (after Mikołajewski, 2007)

Table 1. Numbers and total stylolite heights in particular microfacies of the Main Dolomite in the Mokrzec-1 well

Mokrzec-1 well						
Microfacies	Total number of stylolites [n]	Total height of stylolites [mm]	Micro-	Macrostylolites		
			< 2 mm	2–10 mm	10–50 mm	> 50 mm
			Number of stylolites [n] Total height of stylolites [mm]			
Grainstone/packstone	428	2371	124 62	245 1315	59 994	–
Mudstone/wackestone	555	2389	171 85	342 1596	42 708	–
Rudstone/floatstone	55	361	137	31 158	11 196	–
Total	1038	5121	308 154	618 3069	112 1898	–

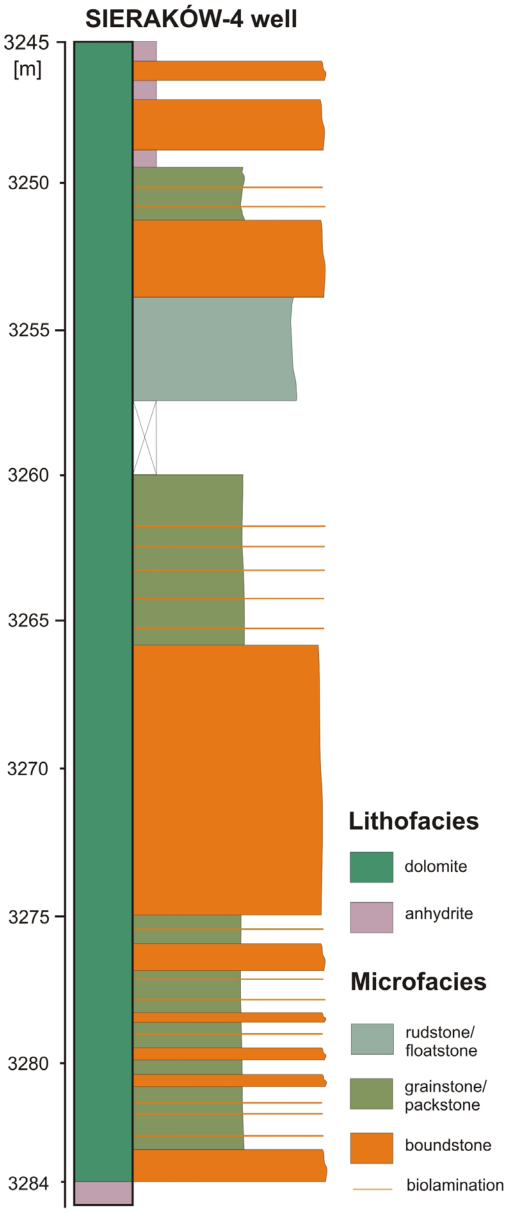

Fig. 5. Lithological and microfacies column of the Sieraków-4 well (after Mikołajewski, 2007)

grainstones/packstones, and boundstones containing biosedimentary laminae (Fig. 4).

In the column analysed 1,038 stylolites were measured. Their total height is 5,121 mm, which corresponds to their compactional reduction of thickness due to stylolitisation. In detail, 308 microstylolites of a total height of 154 mm and 730 macrostylolites of a total height of 4,967 mm were analysed. Among macrostylolites, 618 belonged to the low-amplitude group (total height 3,069 mm) and 112 represented the medium-amplitude group (total height 1,898 mm) (Table 1). The largest number of stylolites was observed in the mudstone/wackestone microfacies. These are mostly low-amplitude stylolites and they contribute decisively to thickness reduction of this facies (and also to that of the grainstone/packstone microfacies), whereas medium-amplitude stylolites predominate in thickness reduction of the rudstone/floatstone microfacies (Table 1).

The Main Dolomite succession observed in the Mokrzec-1 well is dominated by grainstone/packstone and mudstone/wackestone microfacies (Fig. 4). Low-amplitude stylolites prevail and they control the overall thickness reduction of succession analysed (Table 1). Our observations revealed also that the highest amplitudes of stylolites occurred in mudstone/wackestone (33.1–42.3 mm) and grainstone/packstone (35.5–41.8 mm) microfacies.

The stylolite-generated thickness reduction of the Main Dolomite succession in the Mokrzec-1 well is $R_{st} = 5.1$ m and its reconstructed initial thickness is $H_p = 56.85$ m. The calculated coefficient of compaction is $k_{całk} = 0.090$, which enables us to estimate the volume of reservoir fluids expelled from the Main Dolomite due to compaction to be $W_{pzł} = 90$ l/m^3 of rock.

5.2. The Sieraków-4 well

The Sieraków-4 belongs to the lagoonal zone of carbonate platform and is located within a local,

Table 2. Numbers and total stylolite heights in particular microfacies of the Main Dolomite in the Sieraków-4 well

Sieraków-4 well						
Microfacies	Total number of stylolites [n]	Total height of stylolites [mm]	Micro-	Macrostylolites		
			< 2 mm	2–10 mm	10–50 mm	> 50 mm
			Number of stylolites [n] Total height of stylolites [mm]			
Boundstone	263	1082	87 44	156 720	20 318	–
Grainstone/ Packstone	209	859	68 34	122 537	19 288	–
Rudstone/ floatstone	39	390	10 5	14 99	15 286	–
Total	511	2331	165 83	292 1356	54 892	–

high-energy shoal (Fig.1). The Main Dolomite succession was encountered at a depth of 3,284–3,245 m (thickness: 39 m). A characteristic feature is the predominance of boundstones over grain-dominated microfacies (grainstones/packstones and rudstone/floatstone) (Fig. 5).

In the succession analysed 521 stylolites were measured, of total height 2,331 mm. Among them were 165 microstylolites of a total height of 83 mm and 346 macrostylolites of a total height of 2,248 mm. The macrostylolites included 292 low-amplitude (total height 1,356 mm) and 54 medium-amplitude (total height 892 mm) stylolites (Table 2). The largest number of stylolites was encountered in boundstones. Most of them were low-amplitude microstylolites, which controlled the reduction of thickness within this microfacies. Similar relationships were found in grainstone/packstone microfacies, but in rudstones/floatstones medium-amplitude macrostylolites were decisive for thickness reduction (Table 2). In the Sieraków-4 well, the Main Dolomite succession is dominated by the boundstone microfacies (Fig. 5) and low-amplitude macrostylolites, which controlled thickness reduction of the core interval studied (Table 2). Macroscopic observations showed that stylolites of highest amplitudes occur in boundstones (31.8–32.2 mm).

The amount of stylolite-induced thickness reduction of Main Dolomite strata in the Sieraków-4 well is $R_{st} = 2.3$ m and the reconstructed initial thickness is $H_p = 41.3$ m. The calculated coefficient of compaction is $k_{całk} = 0.056$, which allowed us to estimate the volume of reservoir fluids expelled due to compaction from the Main Dolomite at this locality as $W_{pzl} = 56$ l/m^3 of rock.

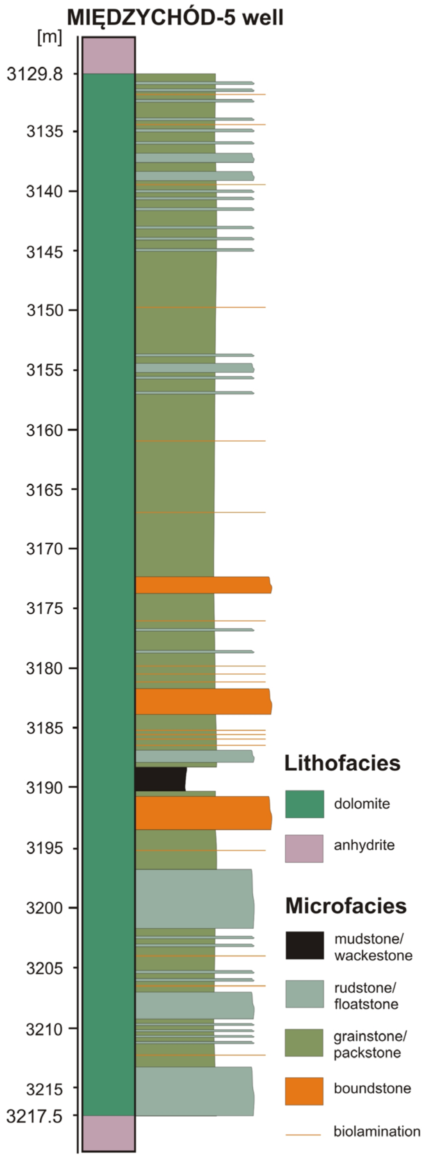

Fig. 6. Lithological and microfacies column of the Międzychód-5 well (after Mikołajewski, 2007)

Table 3. Numbers and total stylolite heights in microfacies of the Main Dolomite in the Międzychód-5 well

Międzychód-5 well						
Microfacies	Total number of stylolites [n]	Total height of stylolites [mm]	Micro-	Macrostylolites		
			< 2 mm	2–10 mm	10–50 mm	> 50 mm
			Number of stylolites [n] Total height of stylolites [mm]			
Grainstone/ Packstone	1147	6281	323 162	680 3505	140 2401	4 213
Rudstone/ floatstone	284	2339	43 22	168 948	71 1267	2 102
Boundstone	80	718	16 8	37 255	27 455	–
Mudstone/ wackestone	23	144	7 4	12 81	4 59	–
Total	1534	9482	389 196	897 4789	242 4182	6 315

5.3. The Międzychód-5 well

The Międzychód-5 well is located in the barrier zone of the Main Dolomite (Fig. 1). Its succession was found at a depth of 3,217.5–3,129.8 m (thickness: 87.7 m). A diverse assemblage of microfacies was identified, inclusive of grain-dominated (grainstones/packstones, rudstones/floatstones) and biogenic (boundstones) ones. Rarely, a mud-dominated microfacies (mudstones/wackestones) was observed as well (Fig. 6).

In the succession analysed, we measured 1,534 stylolites of a total height of 9,482 mm. Among them were 389 microstylolites of a total height of 196 mm and 1,145 macrostylolites of a total height of 9,286 mm. Macrostylolites included 897 low-amplitude examples (total height 4,789 mm), 242 medium-amplitude ones (total height 4,182 mm) and six high-amplitude stylolites (total height 315 mm) (Table 3). The largest number of stylolites (mostly low-amplitude macrostylolites) was observed in grainstone/packstone microfacies and these forms contributed decisively to the reduction of its thickness. In both boundstones and rudstones/floastones, medium-amplitude macrostylolites prevailed and controlled thickness reduction (Table 3). In the Międzychód-5 well, the Main Dolomite succession is dominated by grainstone/packstone microfacies (Fig.6). Commonest are low-amplitude macrostylolites, but low- and medium-amplitude macrostylolites similarly contributed to thickness reduction (Table 3). Macroscopic observations revealed that stylolites of highest amplitudes occur in grainstones/packstones (52–55.5 mm) and rudstones/floatstones (50.4–51.8 mm) microfacies.

The stylolite-induced reduction of Main Dolomite thickness in the Międzychód-5 well is R_{st} = 9.4 m and the reconstructed initial thickness is H_p = 97.1 m. The calculated coefficient of compaction $k_{całk}$ = 0.097 enabled us to estimate the volume of reservoir fluids expelled from the sediments studied during compaction to be $W_{pzł}$ = 97 l/m^3 of rock.

6. Discussion and conclusions

In the study area stylolitisation of Main Dolomite sediments is a common feature. The amount of thickness reduction corresponding to the amount of compaction was determined in the three wells; Mokrzec-1, Sieraków-4 and Międzychód-5, which represent various microfacies types reflecting a range of depositional environments.

The number of stylolites observed in the Main Dolomite succession studied varied from 511 in the Sieraków-4 well to 1,534 in the Międzychód-5 well. The highest density of stylolites was found in the Mokrzec-1 well: 20 stylolites per metre of rock thickness and the lowest density of stylolites in the Sieraków-4 well: 15 stylolites.

The turnout of stylolites depends of microfacies. The highest density of stylolites was found in mudstones/wackestones (24 stylolites per metre of rock thickness) and the lowest density in boundstones (14 stylolites). The low-amplitude stylolites appear most frequently in mudstone/wackestone microfacies (15 stylolites per metre of rock thickness); rare are middle-amplitude stylolites in grainstones/packstones, rudstones/floatstones and boundstones (3 stylolites per metre of rock thickness).

The analysis of drill cores revealed that the occurrence of stylolites is not restricted to any particular palaeogeographical zone of the Main Dolomite carbonate platform (toe-of-slope, barrier, carbonate ramp) and does not depend of depth. All types of stylolites distinguished are more or less regular and show variable amplitudes and apertures. In all three wells, low-amplitude macrostylolites predominated, but thickness reduction was controlled mostly by low- and medium-amplitude macrostylolites (e.g., in the Międzychód well the stylolite-induced reduction thickness is R_{st} = 9.4 m and total height of low-amplitude stylolite is 4.789 m and total height of medium-amplitude stylolite is 4.182 m). Hence, we conclude that the amount of thickness reduction depends of the amplitudes of stylolites and on their number in the successions analysed. This is confirmed by the relatively great thickness reduction (315 mm) estimated in the Międzychód-5 well which resulted from the action of merely six high-amplitude macrostylolites. In the wells studied, the amount of thickness reduction changed from 2.3 m in the Sieraków-4 well, through 5.1 m in the Mokrzec-1 well to 9.4 m in the Międzychód-5 well. The calculated degrees of compaction were: 6%, 9% and 10%, respectively. The amounts of thickness reduction calculated in our study, 6 to 10%, correspond very well to values published by Stockdale (1926) for the Columbus Limestone (approx. 5%), by Mossop (1972) for the Reef Limestone (5.3 to 7.8%), by Waschs & Hein (1974) for the Franciscan Limestone (10%), by Kaplan (1976) for limestones (approx. 7–8%), by Peacock & Azzam (2006) for limestones and dolomites (3.8 to 7%) and by Vandeginste & John (2013) for limestone (7–12%).

The initial thickness of Main Dolomite sediments calculated from the amount of thickness reduction was 41.3 m in the Sieraków-4 well, 56.9 m in the Mokrzec-1 well and 97.1 m in the Międzychód-5 well.

The volume of reservoir fluids expelled by compaction during primary migration of Main Dolomite strata depended mostly of stylolite density and on their heights (amplitudes). Our calculations revealed that 1 m^3 of Main Dolomite carbonate supplied variable volumes of reservoir fluids; from 56 l in the Sieraków-4 well, through 90 l in the Mokrzec-1 well to 97 l in the Międzychód-5 well.

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