Geological Quarterly, 2002, **46** (3): 281–291

Late Palaeozoic-Mesozoic development of the Skrzynno Fault (northeastern border of the Holy Cross Mts.)

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Kowalczewski Z. (2002) — Late Palaeozoic-Mesozoic development of the Skrzynno Fault (northeastern border of the Holy Cross Mts.). Geol. Quart., **46** (3): 281–291. Warszawa.

The prominent regional Skrzynno Fault, running NW–SE, crosses the northeastern periphery of the Holy Cross Mts. On either side of this fault two deep boreholes were drilled 5 km apart (Ostałów 1 and Ostałów PIG 2). A comparison of the stratigraphical successions in these boreholes enabled a reconstruction of the fault's evolution. This is a normal fault with a downthrown northeastern wall. At the sub-Cenozoic surface close to the fault plane, the lower Middle Jurassic is in contact with lowermost Lower Jurassic. The base of the Jurassic is thrown by 810 m, and the base of the Permian by 1010 m. These values suggest that the Skrzynno Fault was a synsedimentary fault, active from the Permian until the Jurassic. On the upthrown side, the Permian is underlain by the Middle Devonian, but on the downthrown side, by the Lower Carboniferous. Estimating the thickness of deposits removed from the upthrown side shows that the pre-Permian fault throw could have amounted to about 1300 m. On the downthrown side thin Rotliegend deposits are preserved. A local saline basin was formed during deposition of the Zechstein PZ1 cycle. The southwestern fault wall was subsiding during sedimentation of the upper Zechstein and in the Early Triassic — the difference in thicknesses of the Buntsandstein is nearly 200 m. Another stage of fault activity and the lowering of its northeastern wall occurred during Keuper (upper part of the Triassic) sedimentation. These deposits are thicker by approximately 300 m here, as compared with the southwestern side. Later evolution of the fault cannot be precisely reconstructed due to erosion of post-Hettangian sediments of the upthrown side. General knowledge of the geology of the region indicates that the Skrzynno Fault was strongly active in particular around the Jurassic/Cretaceous boundary and during the Paleogene tectonic inversion.

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Key words: northern Holy Cross Mts., Skrzynno Fault, borehole sections, thickness analysis, subsidence.

STRUCTURAL LOCATION OF THE AREA

The study area is located in the northeastern, Permian-Mesozoic border of the Palaeozoic core of the Holy Cross Mts. The area lies in the contact zone between the East European Platform and the Palaeozoic Platform (Caledonides) of southern Poland (Dadlez *et al.*, 1994; Znosko ed., 1998).

In the early Palaeozoic structural pattern, the area was a transitional zone between the Palaeozoic of the Holy Cross area and the Kujawy-Pomeranian Caledonides, connected through the Łysogóry unit. In the pre-Permian structural pattern, the area of interest was located within the so-called Radom-Łysogóry Block (Dadlez, 2001), at the boundary between the Łysogóry unit and the Radom Elevation. It lies at the very front (Pożaryski, 1997) or not far (Dadlez *et al.*, 1994; Krzemiński, 1999; Kotański and Mizerski, 2000) from the Variscan Deformation Front of southwestern Poland, relatively close to the Grójec Fault in the west. In the Laramide structural pattern, the genetically older Palaeozoic core is incorporated into the younger, post-Cretaceous structure of the Mid-Polish Swell.

PREVIOUS GEOLOGICAL INVESTIGATIONS

Geological exploration, in particular cartographic surveys conducted since the 1920s, resulted in the publication of *The Geological Atlas of the Holy Cross Region* at the scale of 1:100 000 (1961) and *The Geological Map of the Holy Cross Region* (without Quaternary deposits) at the scale of 1:200 000 (1961). A generalised fragment of that map is shown in Figure 1, with the Skrzynno Fault marked because of the occurrence of a gravity gradient zone (Figs. 2 and 3).

Samsonowicz (1929) discovered the Lubień-Mnichów longitudinal fault within the Kamienna River basin. Further towards the north-west, Karaszewski (1961), Daniec *et al.* (1961)

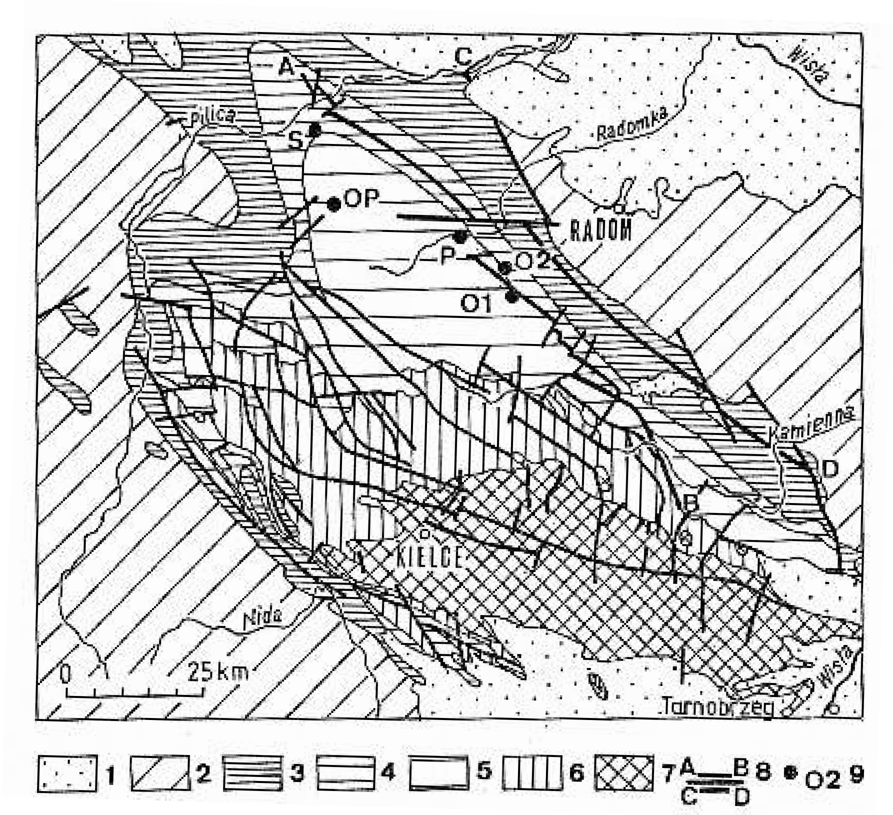

Fig. 1. Geological sketch-map of the Holy Cross area (without Quaternary deposits)

1 — Tertiary; 2 — Cretaceous; 3 — Upper Jurassic; 4 — Middle Jurassic; 5 — Lower Jurassic; 6 — Triassic; 7 — Palaeozoic; 8 — faults: A–B — Rzeczyca-Skrzynno-Lubienia, C–D — Nowe Miasto-Iłża-Bałtów; 9 — deep exploratory boreholes: O1 — Ostałów 1, O2 — Ostałów PIG 2, P — Przysucha 1, OP — Opoczno PIG 2, S — Studzianna IG 2

and Cieśla *et al.* (1961) identified and mapped (Iłża, Radom and Przysucha sheets) its prolongation. Due to poor accessibility of the area, the fault line could not be precisely delineated.

Much later, Pożaryski (1997) stated that the Skrzynno Fault is a fragment of a major, deeply rooted, vertical fault zone running NW–SE from Nowe Miasto across the Starachowice region towards Ostrowiec Świętokrzyski. According to that author the zone makes up the southwestern edge of the crystalline basement of the East European Platform and is divided into three segments by regional "early Variscan strike-slip fault zones". The northernmost segment, called by Pożaryski (*op. cit.*) the "Nowe Miasto fault", is separated from the middle segment, called the Skrzynno Fault, by a fault running nearly E–W from near Przysucha towards the Radom area (Fig. 1). According to Pożaryski (1997), the displacement of the middle segment relative to the northern segment is about 10 km towards the west.

After 1960, the Polish Petroleum Company drilled the Ostałów 1 borehole — in order to assess hydrocarbon prospects — in which over 600 m-thick Devonian deposits were encountered at a depth of 1491 m beneath the Zechstein-Lower Jurassic succession (Karaszewski, 1964). Stratigraphical and petrographical investigations proved that these deposits range from upper Emsian to lower Givetian (Żakowa *et al.*, 1986). Later, the Polish Geological Institute drilled the Studzianna IG 1 borehole in which Carboniferous (probably Lower Carboniferous) deposits were encountered at a depth of 3978 m (Jurkiewicz ed., 1988). In 1972–1973, the Polish Petroleum Company drilled the Przysucha 1 borehole in which Carboniferous deposits occur below a depth of 2334 m beneath the Permian-Mesozoic succession. Żelichowski (1972; Żelichowski *et al*., 1983; Żelichowski and Jurkiewicz, 1996) considered that the Carboniferous sequence is represented by the Tournaisian, Viséan, Namurian and even Westphalian A/B.

The analysis of contemporary geological and geophysical data brought Kowalczewski (1981, 1985) to the conclusion that the sub-Permian substrate of the northeastern border of the Holy Cross Mts. is divided into blocks by several major faults running NW–SE. One of them is the Rzeczyca-Skrzynno-Lubienia Fault, called hereafter the Skrzynno Fault. It separates the Drzewica-Szydłowiec Horst from the Odrzywół-Ćmielów Graben. The latter graben, in turn, is bounded to the north-east by the Nowe Miasto-Iłża-Bałtów Fault. The narrow and long graben may have been formed within a suture zone being a contact of the East European (pre-Vendian) Platform and the Central European (Palaeozoic) Platform. In this graben, Upper Carboniferous and Rotliegend deposits may have been protected from pre-Zechstein erosion.

In the early 1990s, the Opoczno PIG 2 and Ostałów PIG 2 boreholes were drilled for the Polish Geological Institute. The aim of the latter borehole was to verify the above-mentioned tectonic hypothesis. In the Opoczno PIG 2 borehole, Lower Carboniferous deposits were encountered at a depth of 2987.0

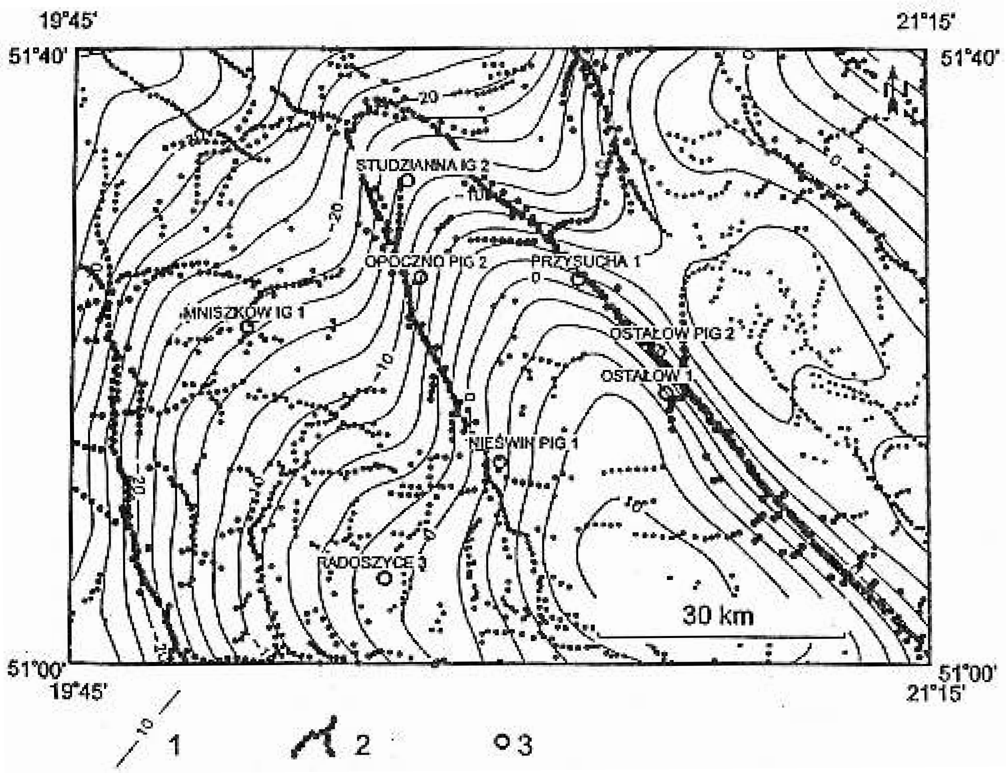

Fig. 2. Regional anomalies of the gravity field with density contacts (averaging radius r = 5 km, interval = 1 km), after Dziewińska *et al.* (2000)

1 — isolines in 10^{-5} m/s^2 (mGal); 2 — maxima of the modulus of horizontal gradient; 3 — selected boreholes

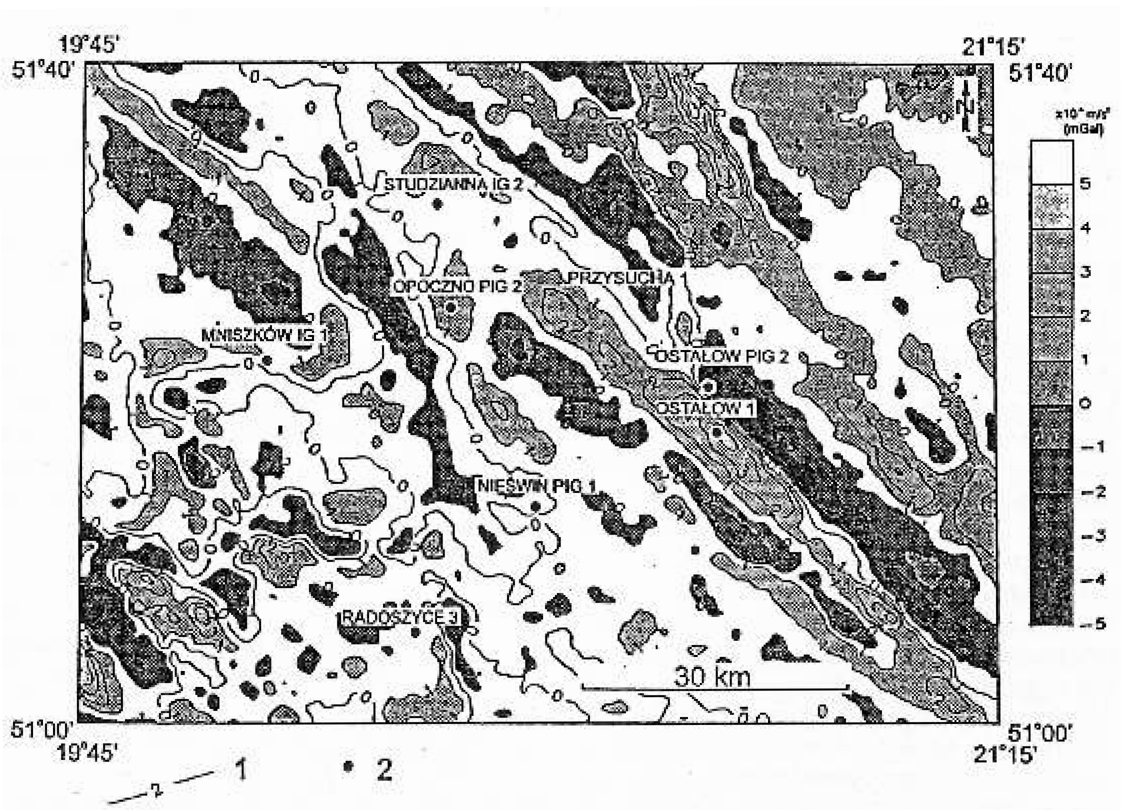

Fig. 3. Residual anomalies of the gravity field (averaging radius r = 5 km, interval = 1 km), after Dziewińska *et al.* (2000)

1 — isolines in 10^{-5} m/s^2 (mGal); 2 — selected boreholes

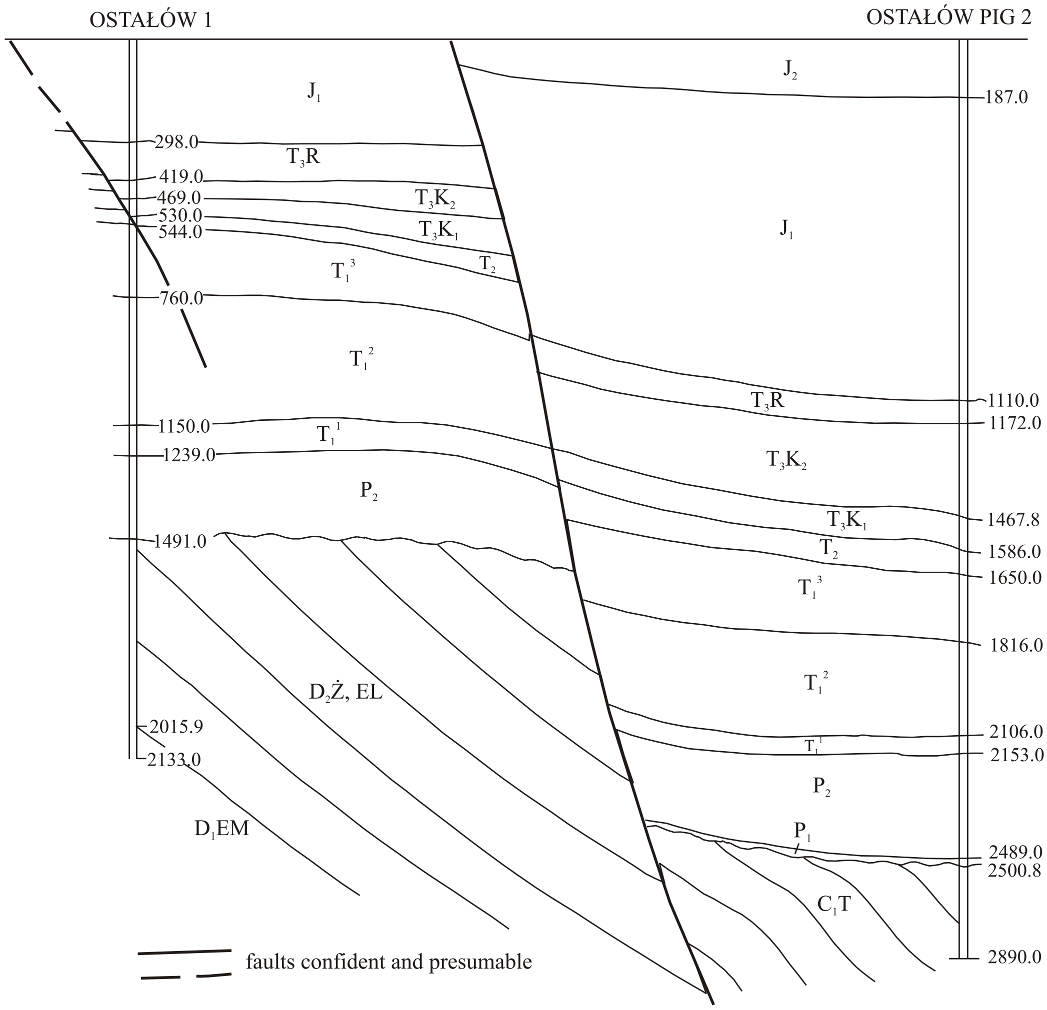

Fig. 4. Geological cross-section across the Ostałów region; horizontal scale 1:40 000

Stratigraphy: J_2 — Middle Jurassic; J_1 — Lower Jurassic; Upper Triassic: T_3R — Rhaetian, T_3K_2 — Upper Keuper, T_3K_1 — Lower Keuper; T_2 — Middle Triassic, Muschelkalk; Lower Triassic: T_1^3 — Roethian, T_1^2 — Middle Buntsandstein, T_1^1 — Lower Buntsandstein; P_2 — Upper Permian, Zechstein; P_1 — Lower Permian, Rotliegend; C_1T — Lower Carboniferous, Tournaisian; $D_2Ż$, EL — Middle Devonian, Givetian, Eifelian; D_1EM — Lower Devonian, Emsian

m beneath the Lower Jurassic, Triassic and Zechstein (Kowalczewski *et al.*, 1992; Kowalczewski ed., 1993). In the Ostałów PIG 2 borehole, thin Rotliegend deposits (11.8 m) were drilled down to a depth of 2500.8 m beneath the Lower Jurassic, Middle Jurassic, Triassic and Zechstein, unconformably overlying Carboniferous rocks. According to Żakowa, the latter would represent the Westphalian A/B (Kowalczewski ed., 1995; Kowalczewski *et al.*, 1995). However, this opinion is inconsistent with the results of studies of 26 palynostratigraphical samples, obtained by Turnau (in Kowalczewski and Jaworowski, 2000) who claims that the deposits from Opoczno and Ostałów are coeval and probably span "the later Tournaisian or, maybe, earliest Viséan". Turnau also took note of the lithological similarity of the deposits and their spore assemblages to those from Tournaisian sections of Western Pomerania. This opinion agrees with the interpretation of Krzemiński (1999), whose petrographical investigations enabled a lithofacies correlation of the Carboniferous sandstones from Ostałów and Opoczno with the Tournaisian volcaniclastic sandstones of the Gozd Formation from Western Pomerania.

A comparative analysis of geological sections from the Ostałów 1 and Ostałów PIG 2 boreholes drilled just 5 km apart, unambiguously confirmed that there is a major regional fault running in between these boreholes (Kowalczewski, 1998). The Ostałów 1 borehole was drilled on its upthrown side, and the Ostałów PIG 2 borehole on the downthrown side. The former encountered the sub-Permian basement — Middle Devonian — at a depth of 1491.0 m, the latter reached the Lower Carboniferous at a depth of 2500.8 m, i.e. 1009 m deeper (Fig. 4).

PREVIOUS GEOPHYSICAL SURVEYS AND THEIR INTERPRETATION

Geophysical surveys include gravity and seismic investigations performed across the area. On the basis of semi-detailed gravimetric surveys, the Bouguer anomaly map was constructed (Królikowski and Petecki, 1995). The map was subsequently transformed, extracting regional anomalies (Fig. 2)

Table 1

Comparison of thicknesses of coeval deposits from the Ostałów 1 and Ostałów PIG 2 boreholes

Stratigraphy	Ostałów 1 [m]	Different thickness [m (%)]	Ostałów PIG 2 [m]
J_1H.ZAR	80.0	33.0 (41.2) →	113.0
J_1H.SKŁ	70.0	50.0 (71.4) →	120.0
J_1H.ZAG	148.0	← 23.0 (18.4)	125.0
Triassic	941.0	102.0 (10.8) →	1043.0
Rhaetian	121.0	59.0 (48.7)	62.0
Keuper	111.0	303.0 (73.2) →	414.0
Upper Keuper	50.0	245.8 (83.1) →	295.8
Lower Keuper	61.0	← 57.2 (48.4) →	118.2
Muschelkalk	14.0	50.0 (78.1) →	64.0
Roethian	216.0	← 50.0 (23.1)	166.0
Middle Buntsandstein	390.0	← 100.0 (25.6)	290.0
Lower Buntsandstein	89.0	← 42.0 (47.2)	47.0
Permian	252.0	95.8 (27.5) →	347.8
Stassfurt Cycle	95.5	← 25.5 (26.7)	70.0
Leine Cycle	28.0	← 4.9 (17.5)	23.1
Aller Cycle	34.0	← 23.5 (69.1)	10.5
Werra Cycle	175.0	57.4 (24.6) →	232.4
Lower Permian		11.8 (100) →	11.8
Carboniferous, Tournaisian		390.0 (100) →	390.0
Middle Devonian	635.0	?	?

Lower Jurassic: J_1H.ZAR — Zarzecze Series, J_1H.SKŁ — Hettangian, Skłoby Series, J_1H.ZAG — Hettangian, Zagaje Series; arrows indicate increasing thickness

which project the course of deeper-seated boundaries, from residual anomalies (Fig. 3) induced by shallower-seated sources of smaller sizes (Dziewińska *et al.*, 2000). A gradient zone associated with the occurrence of the Skrzynno Fault is clear on both of these geophysical maps. It can be seen, that towards the south-east, the gradient is deflected at the fault line shown on the solid geological map (Fig. 1).

Seismic surveys have been performed since 1970. The best results were obtained for seismic images from 1990–1992, including about 625 seismic sections from the Sulejów-Tomaszów Mazowiecki-Przysucha-Radoszyce area. The deepest seismic boundary, confidently traced, is attributed to the carbonates of the basal Zechstein. Along some sectors, possible deeper-seated boundaries have been observed (Fig. 5).

In 1996 a team of specialists prepared a deep drilling project, not yet realised, for the area covering the footwall of the Skrzynno Fault. For the needs of that project two intersecting seismic profiles were performed. They run close to the Ostałów 1 and Ostałów PIG 2 boreholes (Krzywiec in Kowalczewski ed., 1996). Synthetic seismograms for these boreholes were constructed at that time, using the acoustic curve (for Ostałów PIG 2) and pseudoacoustic curve (for Ostałów 1).

Both the gravity distribution (Figs. 2 and 3) and seismic data (Dziewińska *et al*., 2000) do not confirm Pożaryski's hypothesis (1997) that the Skrzynno Fault is a prolongation of the Nowe Miasto Fault. These are two different parallel faults bordering either flank of the Odrzywół-Ćmielów Graben. The analysis of gravity maps (Figs. 2 and 3) also shows that across the area there is a system of alternating horsts and grabens aligned NW–SE.

According to Hakenberg and Świdrowska (1998), the deep crustal Nowe Miasto-Iłża-Bałtów Fault was a marginal fault zone bounding the southeastern segment of the Danish-Polish Trough from Permian until Jurassic times. The Skrzynno Fault, according to those authors, was an additional fault running within the trough, and active in the Middle and Late Triassic.

Kowalczewski (1985, 1998) suggested that the Skrzynno and Nowe Miasto faults, along with the Odrzywół-Ćmielów Graben, developed not later than the late Palaeozoic and were rejuvenated also in the Mesozoic and Cenozoic.

There are differences in interpretations of the Skrzynno Fault geometry. Krzywiec (in Kowalczewski ed., 1996) and Dziewińska *et al.* (2000) suggest that the Skrzynno Fault is a normal fault cutting both Palaeozoic and Mesozoic rocks. Krzywiec writes that "...the fault shows features of a normal listric fault because its plane becomes more horizontal towards the north-east...". Dziewińska *et al.* (2000) consider it as a normal dip-slip fault with a steep, constantly inclined fault plane.

Table 2

Comparison of thicknesses of Zechstein lithostratigraphic units in the Ostałów 1 and Ostałów PIG 2 boreholes

Stratigraphy	Ostałów 1 [m]	Different thickness [m (%)]	Ostałów PIG 2 [m]
Pzt	95.5	← 25.5 (26.7)	70.0
A3	24.0	← 72.2 (17.5)	16.8
T3+Ca3	4.0	2.3 (36.5) →	6.3
A2	6.0	← 1.3 (21.6)	4.7
Ca2	28.0	← 22.2 (79.3)	5.8
A1g	52.5	← 19.3 (36.7)	33.2
Na1	7.5	107.7 (93.4) →	115.5
A1d	82.5	← 21.7 (26.3)	61.0
T1+Ca1	32.5	← 9.5 (29.2)	23.0
PZ4	95.5	← 25.5 (26.7)	70.0
PZ3	28.0	← 4.9 (17.5)	23.1
PZ2	34.0	← 23.5 (69.1)	10.5
PZ1	175.0	57.4 (24.6) →	232.4
P_2	252.0	84.0 (25.0) →	336.0

Explanations for stratigraphic symbols as in Figs. 4, 6 and 7

Z. Kowalczewski took into consideration also the third possibility that it is a steep reverse fault with a fault plane inclined towards the SW at a high angle. Recently, Krzywiec (2000, see also fig. 6) also accepted and further developed this concept. The results of geophysical surveys obtained so far are not conclusive with respect to these alternative interpretations. I consider that the second variant seems most probable (Fig. 4). It should be also taken into account that, in the light of geophysical data, the Skrzynno Fault appears to represent a regional tectonic discontinuity deeply rooted in the basement and as such may have a complex origin and complicated internal structure. The main fault plane can be accompanied by secondary posthumous faults with differently inclined planes. The secondary faults may affect the seismic data.

ACTIVITY OF THE SKRZYNNO FAULT

RESEARCH METHODS

The borehole data is of variable quality. Information obtained from the Ostałów 1 borehole is poorer and of lower quality, as compared with that from the Ostałów PIG 2 borehole.

Boundaries of the Permian, Triassic and Jurassic lithostratigraphic successions have been determined from analyses of drillcores and cuttings, correlated with the results of well-logging data. In this I was helped by J. Malec (Devonian), S. Zbroja (Permian) and M. Kuleta (Triassic), and — for the Jurassic — by the papers of Karaszewski (1964, 1985) and Złonkiewicz (in Kowalczewski ed., 1995, 1996).

One of the basic research methods for studying the history of tectonic movements is the analysis of sediment thickness which may be directly related to sedimentation rate. It has been assumed that, from the late Palaeozoic, the thickness of generally shallow-marine to continental deposits was proportional to the subsidence rate of the basin-floor in the northern Holy Cross region, representing a cratonic area with progressively increasing tectonic stability. The successive growth of sediment columns in both walls of the Skrzynno Fault was analysed using data from the Ostałów 1 and Ostałów PIG 2 boreholes (Tabs. 1 and 2, Figs. 6 and 7).

However, the estimates are approximate for several reasons. Firstly, the thicknesses have not been corrected for compaction. Secondly, the angle at which the strata dip has been disregarded. Mesozoic and Permian beds in both the boreholes commonly dip at low angles: Liassic — 0–3°, Triassic — 2–10°, Permian — 2–15°. Only within strongly faulted zones do dips become higher, reaching 20° along short distances. In the middle part of the Zechstein section dips are up to 30°. Evaporitic beds, showing plastic deformation, are locally inclined even at 80°. Despite these local extreme values, it seems that the stratal dips do not significantly influence the thickness estimates.

The estimates are also affected by the fact that the borehole sections are disturbed by faults. However, the sections are not strongly faulted (Fig. 4). Both sections are dominated by discontinuities affecting neighbouring successions of different mechanical competence. Thus, the displacements occurred primarily along bedding or related planes and were not conspicuous. This caused the faulted beds to increase or decrease their thicknesses, measured in drillcores, by only a small amount. This conclusion is confirmed by the regional thickness analysis of Liassic, Triassic and Permian deposits. However, there are deviations from this. The thickness of the Muschelkalk, and maybe also of the Lower Keuper, has been reduced by a fault running across the Ostałów 1 section (Fig. 4).

Not all the thickness values measured on the fault sides, close to the fault plane, are related to the synsedimentary de-

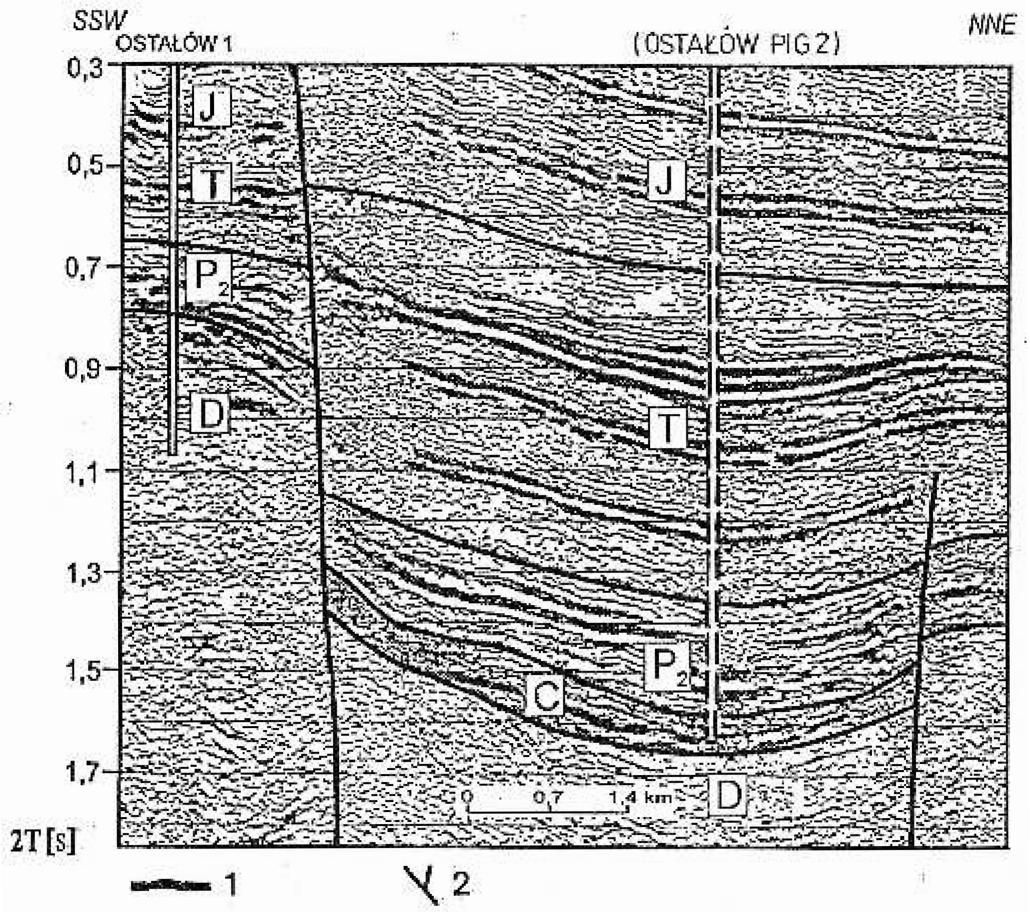

Fig. 5. Interpretation of reflection coefficient sections along a fragment of seismic profile 18-II/III-91, after Dziewińska *et al.* (2000) (with the author's supplements)

1 — major seismic horizons; 2 — tectonic zones; D — Devonian, C — Carboniferous, P_2 — Upper Permian, T — Triassic, J — Jurassic

velopment of the fault. Some differences may be due to unequal compression and pressure solution, and also due to slow flow of deposits (even if lithified) from the hanging wall towards the footwall (Jaroszewski, 1980).

Errors from these sources in the analysis, though, are not thought to significantly affect the overal conclusions.

Sedimentation rate was estimated using the *International Stratigraphic Chart* (2000), with supplements concerning the Rhaetian (4 Ma) and Zechstein (5 to 7 Ma) — adopted from Menning (1995). Other authors (Gradstein and Ogg, 1997) assume for both these units a duration of 3.9 Ma.

STRUCTURAL ANALYSIS

In the Ostałów PIG 2 borehole Permian deposits are underlain by the Lower Carboniferous, but in the Ostałów 1 borehole by the Middle (not uppermost) Devonian. Assessing the intensity of pre-Permian (late-Variscan) movements, we have to take into account the thickness of deposits eroded before the Permian in the Ostałów 1 borehole. Consideration of the regional geology of the area suggests the following original thicknesses: upper Givetian — 400 m, Frasnian — 500 m, Famennian — 140 m, Tournaisian — 250 m. Other authors report even greater thicknesses (Miłaczewski in Szulczewski *et al.*, 1996; Żelichowski and Jurkiewicz, 1996). In the Namurian(?) or after the Westphalian A/B(?) all the deposits (as well as younger Carboniferous rocks on both fault sides) were uplifted and continental conditions persisted over the area, resulting in erosion.

It is here estimated that erosion of the hanging wall may have removed not less than 1300 m of strata. This number may represent the magnitude of late Variscan throw. In any event, late Variscan deformation was considerable across the study area, with an important role played by the Skrzynno Fault. We do not know whether the displacement occurred as a single phase or in several phasess. The latter seems more probable.

During the Late Carboniferous-Early Permian, the study area was approximately level and then, at the end of Rotliegend sedimentation, began to subside again (Fig. 8). Subsidence was probably slightly greater on the downthrown side, as shown by the presence of thin Rotliegend deposits (11.8 m) in the Ostałów PIG 2 borehole. However, it is also possible that the deposits accumulated also on the downthrown side and were removed before Zechstein times.

The comparative analysis for the interval from the Permian onwards is possible only up to the lowermost Jurassic because

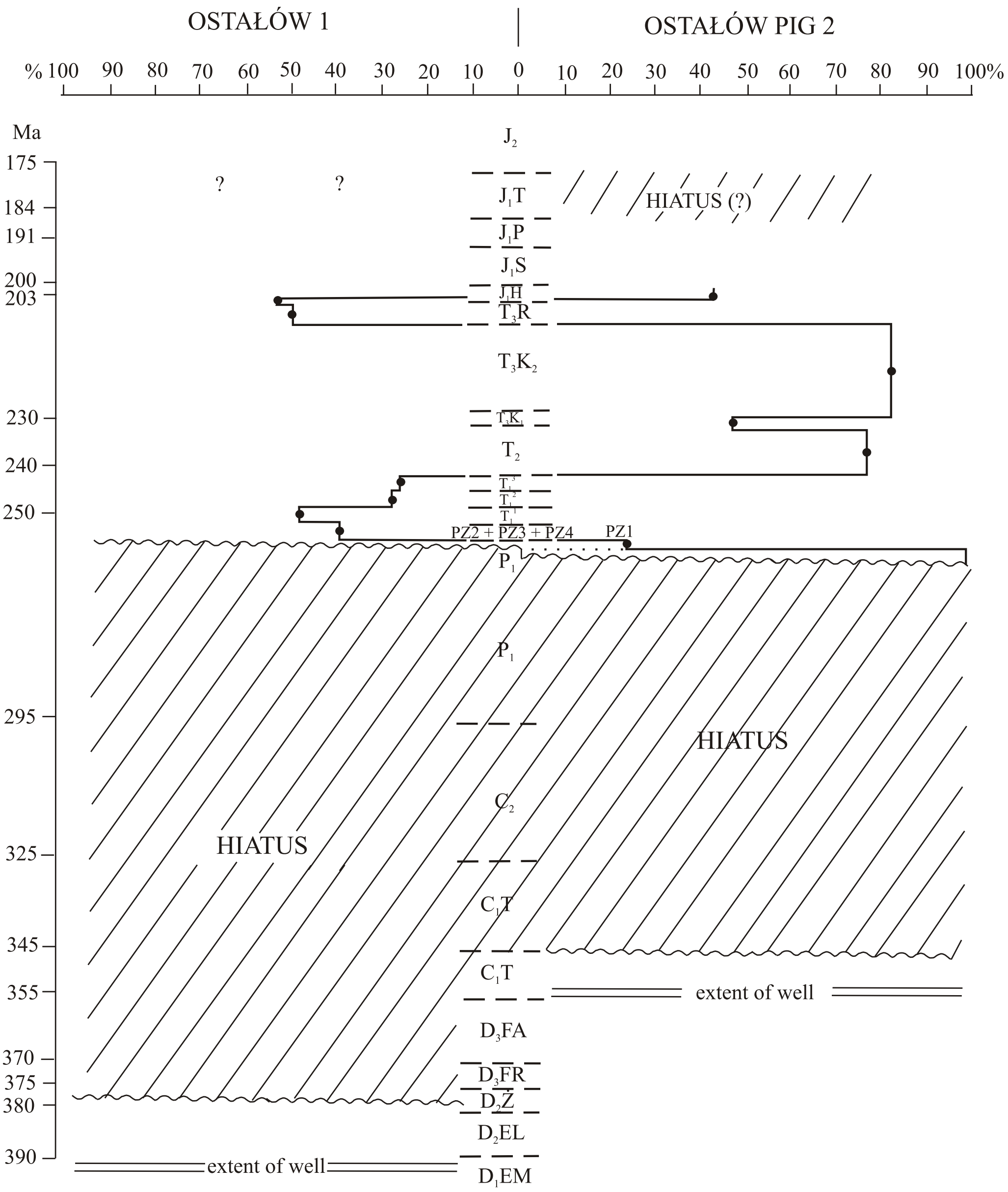

Fig. 6. Curve illustrating increasing thickness of deposits in the Ostałów 1 and Ostałów PIG 2 boreholes

Lower Jurassic: J_1T — Toarcian, J_1P — Pliensbachian, J_1S — Sinemurian, J_1H — Hettangian; Upper Permian, Zechstein: PZ4 — Stassfurt Cycle, PZ3 — Leine Cycle, PZ2 — Aller Cycle, PZ1 — Werra Cycle; C_2 — Upper Carboniferous; C_1V — Lower Carboniferous, Viséan; Upper Devonian: D_3FA — Famennian, D_3FR — Frasnian; other explanations as in Fig. 4

no younger deposits are known from the Ostałów 1 borehole. The table below shows the recent depths (metres below sea level) for the bases of the following systems in each borehole:

Stratigraphy	Ostałów 1	Ostałów PIG 2	Difference
Jurassic	125.5	922.0	796.5
Triassic	1066.5	1965.0	898.5
Permian	1318.5	2312.8	994.3

The table above together with the data from Tables 1 and 2 demonstrate that the differences change (decrease) through time. Therefore, the fault was a synsedimentary structure. The magnitude of a relative tectonic movement of the footwall was as follows: Permian — 95.8 m, Triassic — 102.0 m, from Jurassic until the recent — almost 800 m. The last value is the greatest but the period since the beginning of Jurassic is much longer than the duration of the Permian-Triassic interval. The later history of the Skrzynno Fault is unknown because deposits younger than Early Jurassic were removed. General knowl-

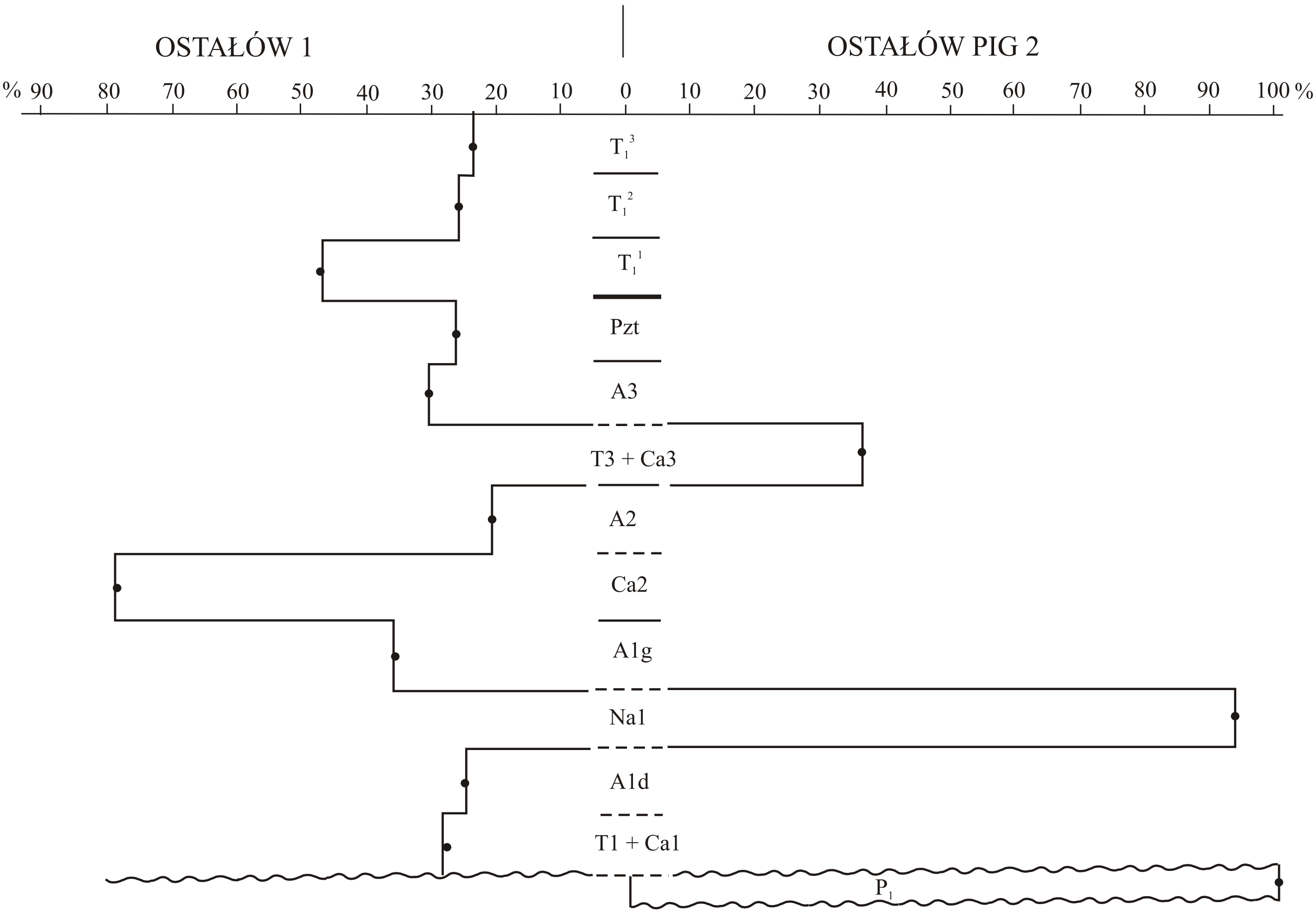

Fig. 7. Curve illustrating increasing thickness (in %) of Permian and Triassic deposits in the Ostałów 1 and Ostałów PIG 2 boreholes

Upper Permian (Zechstein) lithostratigraphy: T1+Ca1 — Copper Shale and Zechstein Limestone, A1d — Lower Anhydrite, Na1 — Oldest Halite, A1g — Upper Anhydrite, Ca2 — Main Dolomite, A2 — Basal Anhydrite, T3+Ca3 — Grey Salt Clay and Platy Dolomite, A3 — Main Anhydrite, Pzt — Top Terrigenous Series; other explanations as in Fig. 4

edge of the regional geology of this area suggests that the fault was reactivated mainly at the end of Jurassic, in the earliest Cretaceous and at the beginning of the Paleogene. The greatest displacements may have taken place in the early Paleogene, during regional inversion of the area, resulting in the formation of the Mid-Polish Swell.

EFFECT OF THE FAULT ON SEDIMENT THICKNESS PATTERN

This analysis is possible only for a section that is in common for both the boreholes, i.e. between the Permian and lowermost Jurassic (Tables 1 and 2). The analysis has also been based on graphs illustrating increases in thickness within the borehole sections (Figs. 6 and 7).

Lower Permian or Rotliegend rocks of small thickness (11.8 m) were encountered only on the downthrown side (Ostałów PIG 2), they are lacking on the hangingwall side (Ostałów 1) as a result of either non-deposition or erosion before Zechstein sedimentation. The latter seems is more probable (Fig. 8).

At the beginning of the Zechstein the whole area was inundated by the sea (PZ1 cycle). Comparison of thicknesses of the Zechstein and its lithostratigraphic units from both the boreholes (Tab. 2) reveals features characteristic of the entire Zechstein basin, in particular of its marginal zones. Carbonate and anhydrite members are thicker in the Ostałów 1 borehole than in Ostałów PIG 2. The values are as follows (accordingly): Copper Shale and Zechstein Limestone — 32.5 and 23 m; PZ1 anhydrites (total) — 135 and 94.2 m; Main Dolomite and PZ2 anhydrites — 34 and 10.5 m; Grey Salt Clay, Platy Dolomite and PZ3 Main Anhydrite — 28 and 25.1 m. This deficit in thickness within the Ostałów PIG 2 borehole was compensated in excess by a considerable increase in thickness of PZ1 salts (115.2 m, as compared with 7.5 m in Ostałów 1). According to Wagner (pers. comm.) such a configuration is typical of marginal zones of the basin where the carbonate-sulphate platform (Ostałów 1) is in direct contact with a (local?) salt-filled basin (Ostałów PIG 2). It is highly probable that the position of the platform edge was controlled by Skrzynno Fault activity.

Downthrow along the southwestern wall started during the Zechstein (PZ2 cycle) sedimentation, continued until the

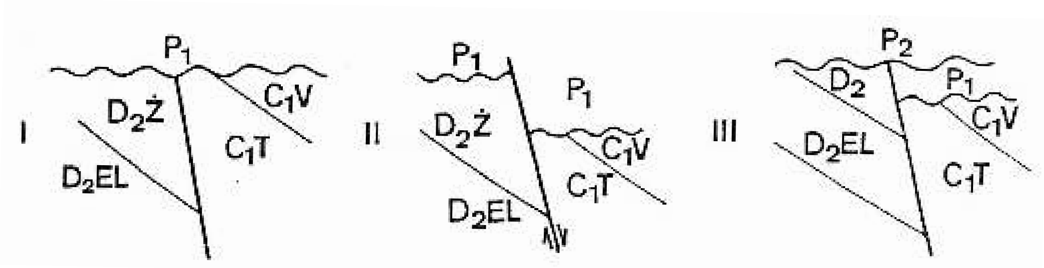

Fig. 8. A scheme of geological evolution of the Skrzynno Fault after the Early Carboniferous and before Late Permian

For explanations see Figs. 4 and 6

Zechstein/Triassic transition (horizons A3 and Pzt) and was even more accentuated in the Early Triassic. Sediment thicknesses in the Ostałów 1 and Ostałów PIG 2 boreholes, respectively, are as follows for successive stratigraphic units: Lower Buntsandstein — 47 and 89 m; Middle Buntsandstein — 290 and 390 m; Upper Buntsandstein (Röt) — 166 and 216 m.

The Skrzynno Fault might have been involved in continental rifting during the Permian and Triassic in the far northern peripheries of the Łysogóry area. Therefore, it strongly influenced the formation and development of the Holy Cross segment of the Danish-Polish Trough in the Permian and Mesozoic.

Middle Triassic (Muschelkalk) history cannot be reconstructed due to presumed tectonic thickness reduction in the Ostałów 1 borehole along the fault plane. Another distinct inflection in the tectonic trend occurred during Keuper sedimentation in the Late Triassic. Table 1 presents presumed thicknesses of the Keuper as well as of the Rhaetian. Nevertheless the total thickness of both the units is analysed as the boundary between them cannot be unambiguously drawn. The thickness in question is 323 m on the upthrown side (Ostałów 1) and 476 m on the downthrown side (Ostałów PIG 2). At that time, or at least during the Keuper sedimentation, the northeastern side was subsiding more rapidly again, with the subsidence reaching the greatest rate in upper Keuper time. As a first approximation it may be assumed that this side was lowered by *ca.* 300 m relative to the south-west.

In the Early Jurassic the tendency from the Late Triassic continued (except in the earliest Jurassic when subsidence rates were uniform). Sedimentation rate reached the highest values in the late Hettangian. It seems that in the Sinemurian and Pliensbachian, as shown by a comparison with more distant boreholes (Ostałów PIG 2 and Opoczno PIG 2), the sedimentation rate was gradually decreasing. In the Toarcian uplift of the northwestern wall is even possible, accompanied by an intermittent depositional break. Z. Złonkiewicz (pers. comm.) suggests absence of the Toarcian in the Ostałów PIG 2 section. If this is really the case than it may suggest increased activity of the fault during that time. However, the above opinion should be regarded as preliminary as the stratigraphy of the Lower Jurassic in the Opoczno area is currently under study.

CONCLUSIONS

1. The prominent regional Skrzynno Fault, running NW–SE, crosses the northeastern periphery of the Holy Cross Mts. The fault played an important role in the Mesozoic and late Palaeozoic (and maybe even earlier) history of the area. Characteristics and evolution of the fault are discussed in this paper on the basis of data from two boreholes (Ostałów 1 and Ostałów PIG 2) drilled close to the fault and on either side.

2. The Skrzynno Fault is a regional longitudinal fault, displaying temporally variable sense of throw but currently showing a downthrown northeastern wall. On the upthrown side the Permian is underlain by Givetian deposits; on the downthrown side it is underlain by the Lower Carboniferous. Based on thickness analysis of deposits removed from the upthrown side it can be speculated that the pre-Permian throw may have reached about 1300 m.

3. The total throw of the Permian base is 1010 m, whereas that of the Jurassic base is about 810 m. Comparison of these values indicates that we are dealing with a synsedimentary fault. At the sub-Cenozoic surface, along the fault plane, lowermost Jurassic deposits of the upthrown wall are in contact with Middle Jurassic rocks of the footwall. Permian-Triassic evolution of the fault proceeded in three stages. In the Permian, initially the northeastern wall was subsiding. A thin Rotliegend cover was deposited and preserved in that area. Subsequently a local saline basin developed. A thick salt series (115 m) contrasts with the Zechstein of the southwestern side composed largely of carbonates and anhydrites and nearly devoid of salts. The second stage was initiated still during upper Zechstein times, and included mainly the Early Triassic (Buntsandstein). Then, the southwestern wall was subsiding, resulting in a thickness difference of nearly 200 m. In the Late Triassic the trend became reversed again; the northeastern wall was downthrown which led to deposition of approximately 300 m of strata. Later evolution of the fault cannot be reconstructed due to erosional removal of deposits younger than the earliest Jurassic along the upthrown side in the Ostałów 1 section. General knowledge of the regional geology of the area suggests that the Skrzynno Fault could have been active at the turn of Lower and Middle Jurassic, and in particular at the Jurassic/Cretaceous transition and during the Paleogene inversion.

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