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Subsidence and inversion in the western part of Polish Basin — data from seismic velocities

Ryszard DADLEZ[1], Waldemar JÓŹWIAK[2], Stefan MŁYNARSKI[2]

[1]*Zakład Geologii Regionalnej i Naftowej, Państwowy Instytut Geologiczny, 00-975 Warszawa, ul. Rakowiecka 4*

[2]*Zakład Geofizyki, Państwowy Instytut Geologiczny, 00-975 Warszawa, ul. Rakowiecka 4*

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Seismic interval velocities in the Baltic Formation (Triassic — Lower Bunter) have been used to calculate the scale of Mesozoic subsidence, latest Cretaceous/Palaeogene inversion and erosion in the western part of the Polish Basin. The study has been concentrated on the reconstruction of thickness of the Upper Cretaceous sediments which have been removed from vast areas after their inversion. The data enable a rough estimation only and a qualitative comparison of these processes in different areas. Their value is also limited in the territories affected by salt tectonics. It is suggested that the axial zone of the northwestern (Pomeranian) zone of the Mid-Polish Trough (MPT) started to rise at the end of Turonian. As a result, a thin cover of the Upper Cretaceous sediments was deposited here and removed later in the last stage of regional inversion of the MPT — its transformation into the Mid-Polish Swell. Farther to the south-east — but still within the Pomeranian segment — the local Zechstein salt displacements interfered with the regional uplift and caused the differentiation of the Upper Cretaceous thickness. Northwestern branch of the Mid-Polish Swell (Kołobrzeg Anticline) inverted rather in a single pulse, at the end of Cretaceous. Along the southern slope of the Polish Basin (Fore-Sudetic Monocline) the primary Upper Cretaceous thickness increased to the north and west reaching the maximum of more than 1000 m at the Polish-German boundary. In the area of the present pre-Cretaceous subcrops the Upper Cretaceous cover was thinner (300 m and less). The investigations should be continued including more reliable data from sonic logs which are scarce so far.

INTRODUCTION

One of fundamental problems in the sedimentary basin analysis of the Polish Basin is the scale of subsidence and inversion in its axial zone and in its southwestern periphery. The first area, called Mid-Polish Trough (MPT) was formed in the Late Permian (time of the Upper Rotliegend deposition) and has subsided since then till the Late Cretaceous when — as a result of its inversion — the Mid-Polish Swell (MPS) was formed (Fig. 1). It is divided into two segments: the Pomeranian Swell in the north-west and the Kuiavian Swell in the south-east. The second area, lying north of the Sudetes Mts. at the southern slope of the Polish Basin, and called the Fore-Sudetic Monocline (FSM) was uplifted twice: before the (Late?) Cretaceous and simultaneously with the MPS.

The scale of subsidence is commonly estimated basing on shale compaction. The depth related changes of compaction and of other physical properties of rocks (density and seismic velocity) are irreversible. Sediments which were buried and later uplifted retain their properties acquired in time of maximum subsidence and burial. Therefore the sections which have subsided continuously and have never been uplifted may serve as reference sections. Other sections may be compared with the reference ones and their scale of uplift may be estimated.

Shale compaction is preferably examined by the use of sonic logs (e.g. K. Magara, 1976; A. Henk, 1992; O. Michelsen, L. H. Nielsen, 1993). Since these logs are by now available from rather scarce boreholes in Poland, the measurements of seismic velocities have been used instead (L. Y. Faust, 1951). Because these measurements are less accurate than sonic logs, the results presented in this paper should be treated with caution, particularly their numerical values. This is rather a general approach to the problem showing qualitative relationships between specific areas.

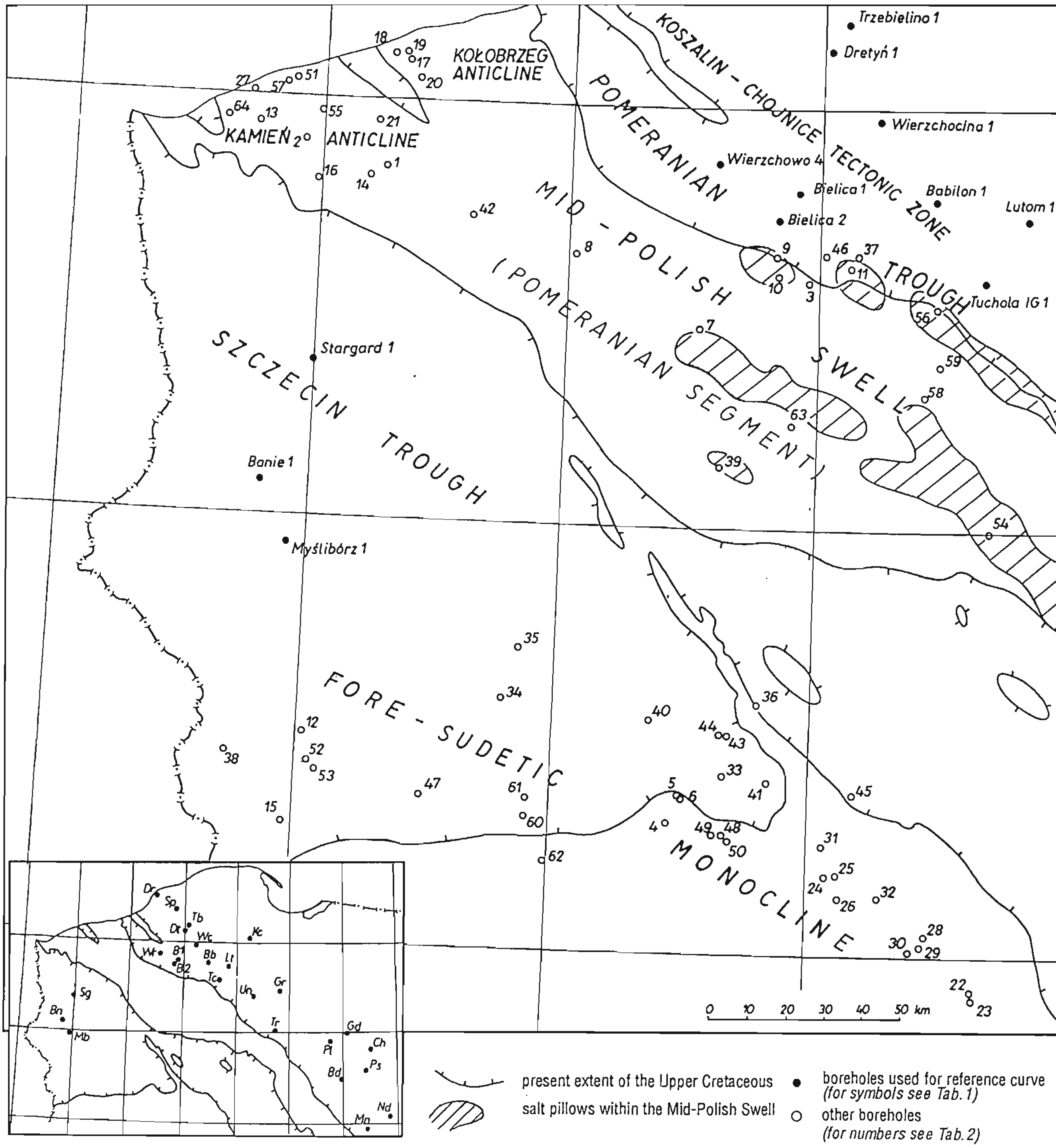

Fig. 1. Geological setting of the analyzed boreholes

Sytuacja geologiczna analizowanych otworów

METHOD

The analysis of seismic interval velocities has been limited to the western part of the Polish Basin because the data from its central and eastern parts are insufficient. The lowermost part of the Lower Triassic Buntsandstein (so-called Baltic Formation — A. Szyperko-Teller, 1982) has been selected for this analysis. This formation is the equivalent of the Bunter Shale in the North Sea area which was investigated from the same point of view (J. P. P. Marie, 1975). The advantages of these deposits are following:

— they occur in the entire area; they were nowhere uplifted so much as to be eroded and they are accessible in many boreholes;

— they are characterized by a very uniform shaly development which eliminates the random changes of seismic velocities;

— their average thickness is 350 m (275–433 m in investigated boreholes); it means that 15–25 measurements could be made within every borehole section which increases the reliability of average velocity values.

The main shortcoming of the Baltic Formation is that it overlies directly the Zechstein salts and therefore in the areas where salt tectonic was active (southeastern part of the Pomeranian Swell — see Fig. 1) it does not represent the regional trend of subsidence. Above salt structures it did not subside so deeply as in depressions among them. Simplified cross-section in Figure 2 shows the subsidence history of the Baltic Formation in the area of salt tectonics. Salt displacements started at the end of the Muschelkalk deposition (Ladinian — Fig. 2a). The distance between the Baltic Formation and the Zechstein base was then equal along the whole cross-section. Due to salt outflow from point A and its accumulation in point B during successive time intervals (Figs. 2b and c) till the end of Cretaceous (Fig. 2d) the subsidence of the Baltic Formation in point A was more than 50% greater than in point B. It is comparable with the regional subsidence of the Zechstein bottom in point A only.

From this point of view the Rotliegend shales (the Noteć Formation — J. Pokorski, 1981) lying below the Zechstein base would be more adequate. However, this formation occurs along the axis of the MPT only; on both slopes of the MPT it is replaced by sandy formations. So, there are no reference sections in the same facies to compare the non-inverted with inverted areas.

Several methods of calculation of the interval velocities have been tested. First, they were calculated on the basis of the average time recorded at specific depths for different shotpoints. Second, the interval velocities presented in tables and diagrams have been used. Third, the average mean velocities for the top and bottom of the Baltic Formation have been calculated by interpolation between the nearest measurement points. Since the differences between these three methods appeared to be great, the fourth method has been applied for this work, namely the usage of the velocity curve: travel times of seismic waves at the top and base of the Baltic Formation have been read from the curve and the mean velocity has been calculated by dividing its thickness by the difference of travel times.

Table 1

Reference curve boreholes

Borehole	Velocity [m/s]	Borehole	Velocity [m/s]
Darłowo 4 (Dr)	2420	Myślibórz 1 (Mb)	4080
Dretyń 1 (Dt)	2740	Bielica 1 (B1)	4110
Trzebielino 1 (Tb)	2780	Gradzanowo 2 (Gd)	4120
Słupsk IG 1 (Sp)	2870	Stargard 1 (Sg)	4180
Kościerzyna IG 1 (Kc)	3070	Banie 1 (Bn)	4200
Wierzchocina 1 (Wc)	3120	Płońsk IG 2a (Ps)	4250
Lutom 1 (Lt)	3400	Unisław IG 2 (Un)	4310
Grudziądz 2 (Gr)	3620	Wierzchowo 4 (Wr)	4370
Tuchola IG 1 (Tc)	3770	Bodzanów IG 1 (Bd)	4390
Polik IG 1 (Pl)	3860	Bielica 2 (B2)	4410
Babilon 1 (Bb)	3870	Toruń 1 (Tr)	4570
Nadarzyn IG 1 (Nd)	3920	Mszczonów IG 2 (Mn)	4730
Ciechanów 1 (Ch)	4060		

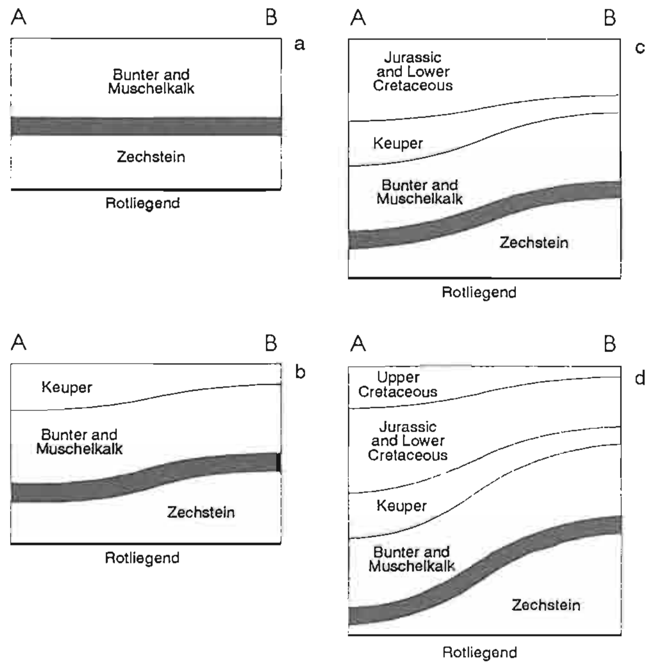

Fig. 2. Development of subsidence of the Baltic Formation (black) versus subsidence of the Zechstein base (bold line) in the area of salt tectonics

Rozwój subsydencji formacji bałtyckiej (czarne) i spągu cechsztynu (gruba linia) w obszarze tektoniki solnej

Travel times have been read from the curve with accuracy of 10 ms. Assuming the average thickness of the Baltic Formation = 350 m — it is sufficient for calculation of mean velocities with accuracy of about 50 m/s which — projected on the reference curve — equals the difference of about 100 m of subsidence or uplift.

Reference curve (Fig. 3) has been constructed with the least square method on the basis of 25 boreholes (Tab. 1) with full, uninterrupted Mesozoic sequence topped by Maastrichtian, located in the depressions rimming the MPS (Fig. 1). It is assumed that the present position of Baltic Formation in these profiles is the deepest one attained by it during geological evolution.

The weaknesses of this curve (Fig. 2) are twofold:

— significant dispersion of reference points;

— the fact that only 3 boreholes are situated in the Szczecin Trough (Fig. 1) adjacent to the MPS from the south-west and at the same time lying between the MPS and FSM uplifted areas; remaining boreholes are located in the northeastern (Pomeranian and Warsaw Troughs), partly in Central Poland. More data from further reference boreholes will probably change the shape of reference curve and, consequently, the estimate of the subsidence and uplift. For exa-

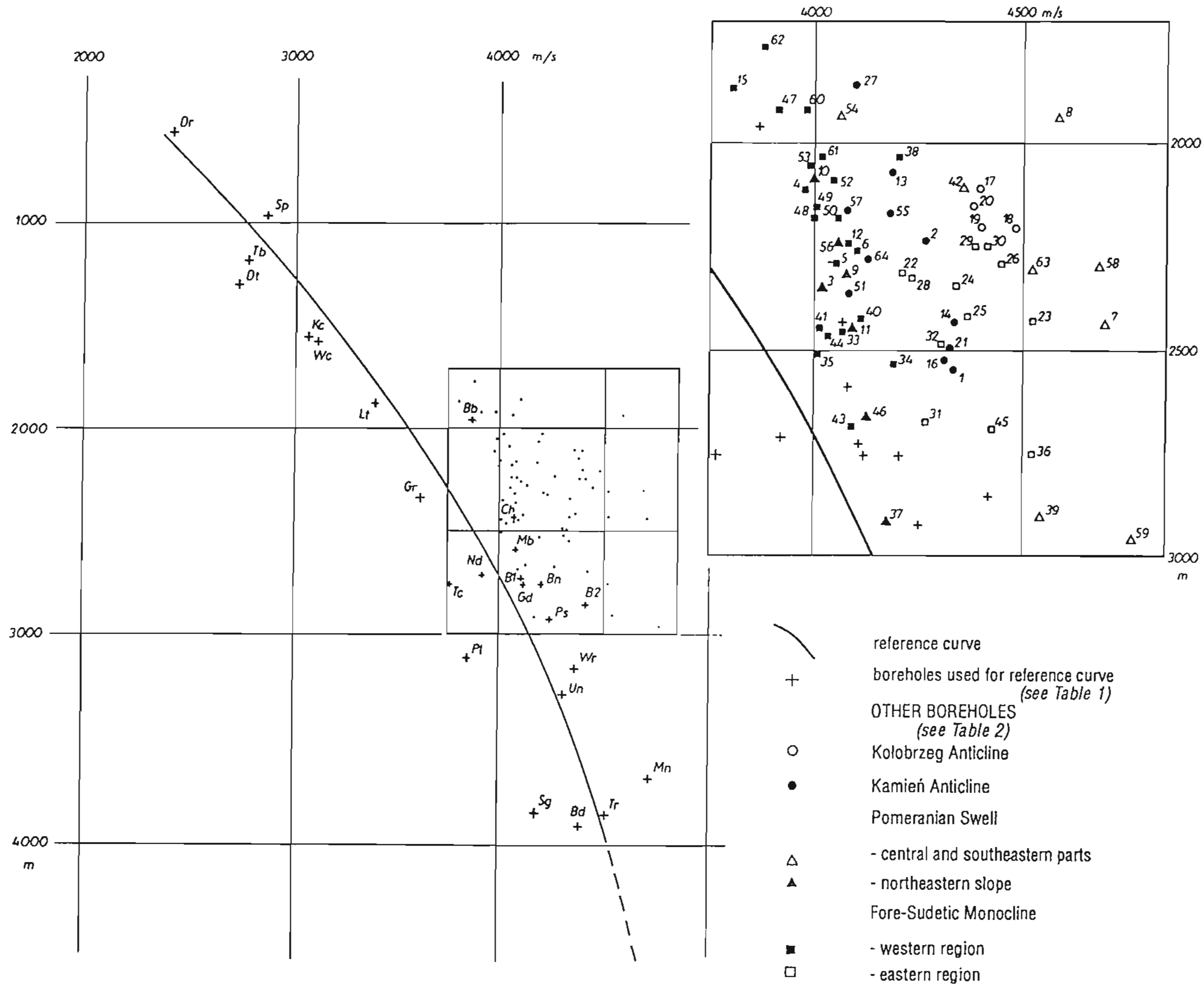

Fig. 3. Baltic Formation — seismic interval velocities versus depth

Sejsmiczne prędkości interwałowe a głębokość formacji bałtyckiej

mple, a change of 1° in the inclination of reference curve causes — at depths of more than 3000 m — the differences of about 150 m/s and, consequently, of 300 m of subsidence or uplift. That is the main reason of the qualitative character of our study.

In conclusion, the errors derived from the averaging of the velocity curve, the accuracy of the travel time reading and the precision of the reference curve are the main sources of errors of the method.

Apart from the reference boreholes, the velocity data from 145 boreholes were at our disposal at the start of our work. They were divided into two groups: that with measurements made every 50 m (= 6–7 measurement points in the Baltic Formation) and that with the interval of measurements every 15–25 m (12–25 points). The first group (36 boreholes) was eliminated because of small accuracy. In the next step almost a half of the remaining boreholes was also eliminated for following reasons.

First, there are some records which may be suspected of being disturbed by undercompaction of sediments. The main uncertainty in the estimation of shale compaction is the possibility of undercompaction caused by overpressure of fluids (see K. Magara, 1976). Unfortunately, this problem was not investigated separately in the area in question. However, there are groups of boreholes located on a single structure with significant differences in velocities. The best example are the boreholes on the Buk Anticline: three of them with higher velocity values indicated the uplift of 550–650 m while the remaining three — of only 300–350 m. The latter were rejected because the sediments are supposed to be undercompacted.

Second, the whole set of 30 boreholes situated in the strongly tectonically involved Koszalin–Chojnice zone (Fig. 1) and characterized by highly dispersed velocity values has been rejected.

Table 2

Boreholes used for estimating the subsidence and uplift

Number of borehole	Borehole	Baltic Formation		Measurement interval [m]	Velocity [m/s]	Max. estimated subsidence [m]	Number of borehole	Borehole	Baltic Formation		Measurement interval [m]	Velocity [m/s]	Max. estimated subsidence [m]
		top	bottom						top	bottom			
1	Barkowo 1	2326.0	2740.0	20	4340	3450	33	Lusówko 1	2274.0	2661.0	15	4060	2820
2	Benice 3	2045.0	2412.5	15	4270	3260	34	Międzychód 2	2342.5	2734.0	15	4190	3080
3	Brzozówka 2	2176.0	2510.0	15	4020	2750	35	Międzychód 3	2318.0	2698.0	15	4010	2730
4	Buk 6	1941.0	2289.0	20	3970	2660	36	Objezierze IG 1	2608.0	2895.0	15	4520	3960
5	Buk 7	2096.0	2445.0	15	4060	2820	37	Olszanowo 1	2735.0	3083.5	15	4180	3060
6	Buk 8	2084.0	2425.0	15	4100	2900	38	Ośno IG 2	1871.5	2190.0	15	4200	3100
7	Czaplinek IG 1	2242.5	2635.0	15	4700	4650	39	Piła IG 1	2716.0	3099.0	15	4540	4040
8	Czaplinek IG 2	1729.0	2140.5	15	4590	4220	40	Pniewy 2	2251.5	2595.0	15	4120	2940
9	Czarne 3	2142.5	2500.0	15	4080	2860	41	Poznań 1	2262.0	2628.0	15	4010	2730
10	Czarne 5	1905.5	2256.0	15	4000	2720	42	Resko 1	1922.0	2320.0	15	4360	3500
11	Debrzno IG 1	2267.0	2607.0	15	4100	2900	43	Rokietnica 1	2540.0	2815.0	15	4090	2880
12	Drogomin 2	2068.0	2434.0	15	4070	2840	44	Rokietnica 3	2305.0	2635.5	20	4030	2770
13	Dusin 1	1895.0	2245.0	15	4190	3080	45	Siekierki Wk. 1	2509.0	2866.0	15	4420	3660
14	Gardomino 1	2280.5	2626.0	15	4340	3450	46	Sokole 1	2493.5	2831.0	15	4130	2960
15	Gądków Wk. 1	1693.0	2035.0	25	3800	2380	47	Staropole 1	1747.5	2078.0	25	3910	2550
16	Golczewo 1	2322.5	2690.0	15	4320	3400	48	Stęszew 1	1997.0	2337.5	15	4000	2720
17	Gorzysław 2	1947.5	2289.0	15	4400	3600	49	Stęszew 2	1990.0	2328.5	20	4000	2720
18	Gorzysław 8	2045.5	2373.0	15	4480	3840	50	Stęszew 4	2000.5	2340.0	15	4060	2820
19	Gorzysław 9	2035.5	2372.0	15	4400	3600	51	Strzeżewo 1	2202.0	2524.0	15	4090	2880
20	Gorzysław 10	1980.5	2328.0	15	4380	3540	52	Sulęcin 3	1924.0	2246.0	15	4040	2790
21	Gryfice 1	2307.5	2665.5	15	4330	3420	53	Sulęcin 5	1897.0	2225.0	15	3990	2700
22	Jarocin 1	2165.0	2471.0	25	4210	3120	54	Szubin IG 1	1717.0	2149.5	15	4070	2840
23	Jarocin 3	2273.0	2590.0	15	4530	4000	55	Świerzno 1	1992.0	2334.0	15	4180	3060
24	Kaleje 3	2175.0	2506.5	15	4340	3450	56	Witkowo 1	2064.0	2432.5	25	4060	2820
25	Kaleje 4	2249.0	2584.0	20	4360	3500	57	Wrzosowo 1	2006.0	2336.0	20	4080	2860
26	Kaleje 7	2125.0	2457.5	20	4440	3720	58	Zabartowo 1	2108.5	2505.0	15	4690	4600
27	Kamień Pom. 3	1681.0	2037.5	15	4110	2920	59	Zabartowo 2	2763.5	3158.0	15	4760	4950
28	Klęka 1a	2159.0	2495.0	25	4230	3160	60	Zbąszynek IG 2	1757.0	2105.0	15	3980	2680
29	Klęka 7	2076.0	2399.0	20	4390	3570	61	Zbąszynek IG 3	1855.0	2210.0	15	4020	2750
30	Klęka 14	2087.0	2406.0	15	4410	3630	62	Zbąszyń 2	1593.5	1955.0	15	3880	2500
31	Kórnik 1	2505.0	2841.0	20	4270	3260	63	Złotów 2	2105.0	2497.0	15	4520	3960
32	Krzykosy 1a	2324.0	2659.0	15	4310	3370	64	Żółwino 1	2108.0	2448.5	20	4130	2960

RESULTS

64 boreholes which remained after this selection are presented in Table 2 and on the diagram showing the relationships between the interval velocities and the depth to Baltic Formation (Fig. 3).

As a result of the Late Cretaceous/Early Tertiary inversion of the MPT and its later erosion, predominantly Lower Jurassic strata occur presently on the sub-Cainozoic surface in the Pomeranian segment of the MPS. Locally there are also the Triassic subcrops in this area. Reconstruction of the primary thicknesses of the Jurassic and Lower Cretaceous series is rather simple since the younger Jurassic and even Lower Cretaceous strata escaped erosion in local grabens as well as in a broader depression between the Pomeranian and Kuiavian segments of the MPS. Jurassic and Lower Cretaceous isopachs run obliquely to the present erosional subcrop of the Upper Cretaceous bottom because their thicknesses decreased northwestwards along the MPT. Their course can be easily extrapolated into the area from where the strata were removed by later erosion.

The interpretation of the Upper Cretaceous is more difficult. Its isopachs on both sides of the MPS are post-erosional; they run parallel to the post-erosional subcrop of the Upper Cretaceous bottom. The Upper Cretaceous thickness preserved in depressed areas bordering the MPS is variable: the greatest values approach 1500 m north-east of the Pomeranian segment of the MPS, and 2200 m south-west of it. What was the thickness in the area of the MPS itself? If the MPS began to rise up at the end of Late Cretaceous, the thickness in the MPT could be intermediate between the both values mentioned above or even greater assuming increased tectonic subsidence along the MPT axis. However, it is more probable that the uplift started as early as during the Coniacian (R. Dadlez, 1980). This supposition is supported: (1) by the Turonian shaly and carbonate facies pattern which is independent from the erosional boundaries of the MPS (M. Jaskowiak-Schoeneichowa, A. Krassowska, 1988); (2) by the local clastic input to the neighbouring troughs in the Coniacian and Campanian; and (3) by the regional comparisons with other

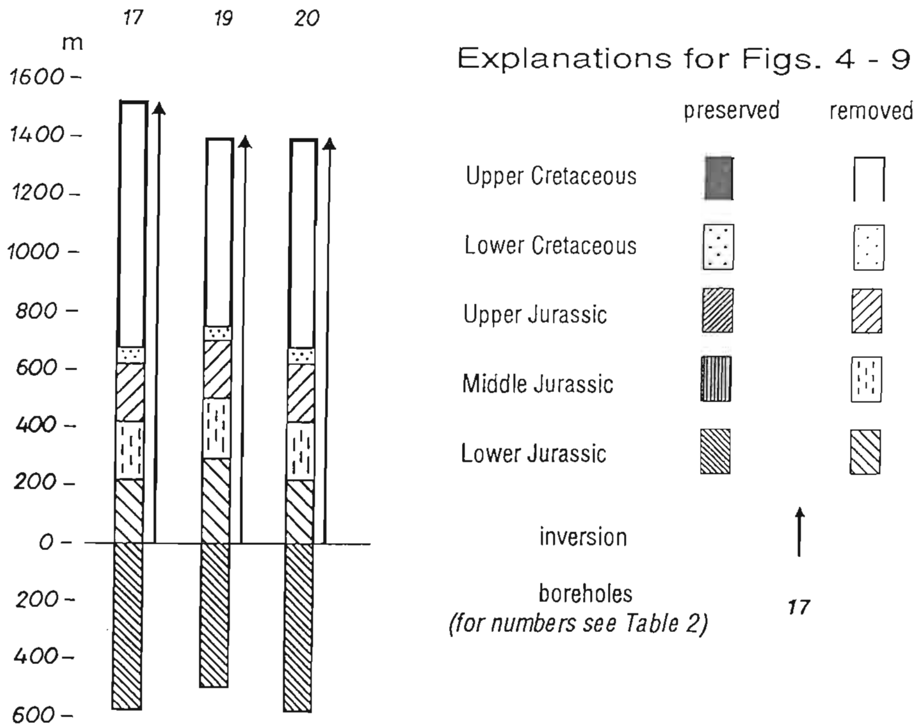

Fig. 4. Kołobrzeg Anticline

Antyklina Kołobrzegu

inverted structures in Central and Western Europe (P. A. Ziegler, 1990).

The uplifting MPS was eroded first in the submarine and then in the subaerial environments. The clastics shed from the MPS may have appeared in the surrounding areas only then when the erosion removed the carbonate-marly deposits of the Upper Cretaceous and reached the sandy beds of Lower Cretaceous and Jurassic. During the Palaeogene the clastics were probably transported predominantly far to the south, towards the active Carpathian margin.

In the FSM the Upper Cretaceous deposits escaped erosion in several, narrow grabens, being surrounded by Jurassic or even Triassic. Therefore, we know that the Upper Cretaceous covered the whole area but we do not know the thickness of this cover. Lower Cretaceous does not occur here or its thickness is very small. The estimate of the Jurassic thickness is more difficult than in the MPS area because we are here on the flank of the basin, where the thickness decreases gradually to the south-west. The isopachs are parallel to the post-erosional boundaries. Therefore, the analysis has been limited to the external parts of the FSM where — in the zone of Jurassic subcrops — the thickness from neighbouring boreholes could be easily extrapolated.

Because of these reasons our study of the amount of subsidence and uplift has concentrated on the reconstruction of the pre-erosional Upper Cretaceous thickness. However — since the data are not very precise (see introduction) — it was too risky to draw a map of these primary thicknesses.

Interpretation of the data presented in Table 2 has been made along the following principles. The interval velocity of the Baltic Formation was transformed into its maximum subsidence (e.g. 4020 m/s = 2750 m, 4030 m/s = 2770 m, 4040 m/s = 2790 m *etc.* — see Table 2)[1]. Then the present depth of the formation midpoint has been subtracted from the maximum subsidence (e.g. 2770–2470 = 300 m) giving the amount of uplift. If the Upper Cretaceous occurs in the investigated borehole (e.g. 200 m of preserved Upper Cretaceous) its present thickness has been added to the above value giving 500 m of its primary thickness. If, however, the uppermost Jurassic was encountered below the Tertiary, then the reconstructed 100 m of the Lower Cretaceous thickness is subtracted from the subsidence value, giving the primary Upper Cretaceous thickness = 200 m. Figures 4–9 show the selected results of these calculations.

KOŁOBRZEG ANTICLINE

MPS bifurcates near the Baltic coast into two branches: northern Kołobrzeg Anticline and northwestern Kamień Anticline, separated by the Trzebiatów Syncline (Fig. 1). The western limb of the Kołobrzeg Anticline is a zone of steep dips, flexures and locally also faults. The eastern limb is characterized by rather gentle dips. Boreholes analyzed (17,

[1] In order to obtain the subsidence of the Zechstein base — but only in the areas not affected by salt tectonics — one must simply add to this value the cumulative thickness of the Zechstein and the part of Baltic Formation below its midpoint.

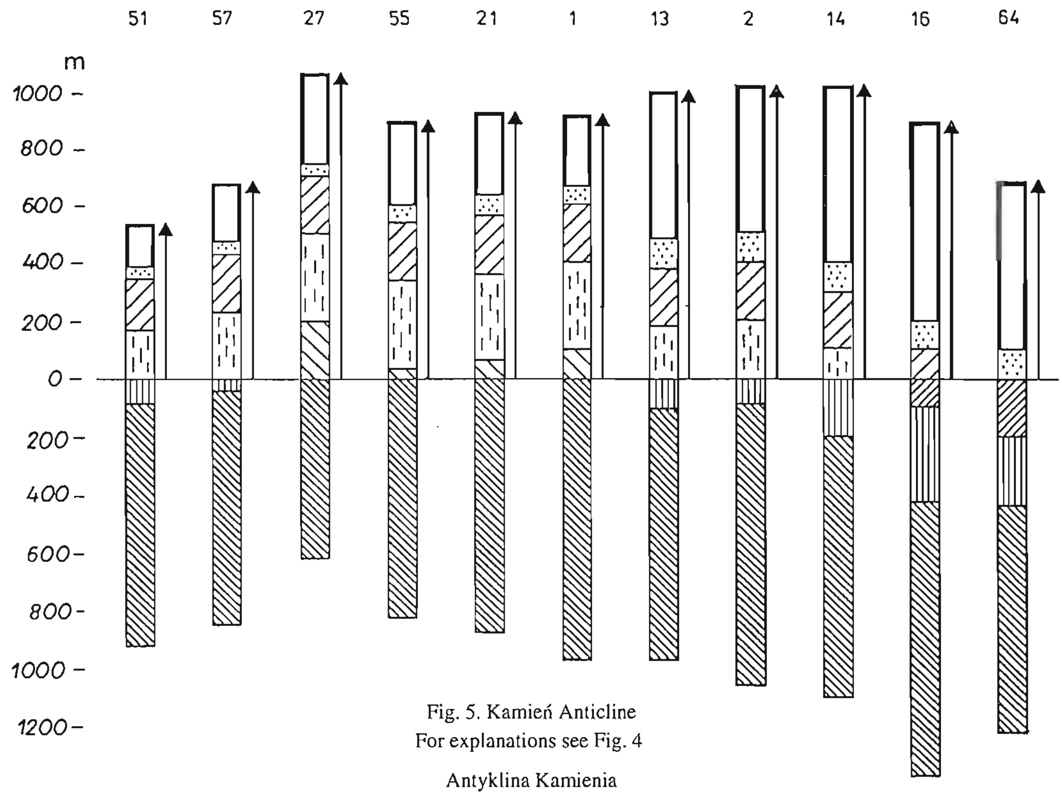

Fig. 5. Kamień Anticline
For explanations see Fig. 4

Antyklina Kamienia
Objaśnienia przy fig. 4

19 and 20)[2] are located in the axial zone where the Lower Jurassic strata appear at the sub-Quaternary surface, contrasting sharply with the Upper Cretaceous filling in the adjoining syncline. Maximum subsidence of the Baltic Formation was about 3600 m (Tab. 2) in comparison with its present depth of about 2100–2200 m. It gives the amount of uplift = 1400–1500 m (Figs. 4 and 10). Assuming the cumulative thickness of the eroded part of the Lower Jurassic together with the Middle Jurassic, Upper Jurassic and Lower Cretaceous at about 700–800 m we obtain 600–800 m of the eroded Upper Cretaceous (Figs. 4 and 11).

KAMIEŃ ANTICLINE

This branch of the MPS is rather symmetric, with the uppermost Lower Jurassic appearing in its hinge zone at the sub-Cainozoic surface, locally also (in transversal graben) with the Middle Jurassic. Middle and Upper Jurassic and Lower Cretaceous subcrop along the limbs of the anticline. Maximum subsidence (3400 m) was noted in the axial zone and on the southern limb. The same zone is characterized by the strongest uplift reaching 1100 m; along the northern limb it was 500–700 m and along the southern limb — 700–900 m (Figs. 5 and 10). Taking into account the average thicknesses of the eroded strata up to the Upper Cretaceous base, there remains about 100–200 m for the non-existing Upper Cretaceous cover along the northern limb (boreholes 51 and 57) and about 300 m along the axis of the anticline (boreholes 27, 55, 21 and 1), while in the southern limb (boreholes 13, 2, 14, 16 and 64) the appropriate number amounts from 500 to 700 m (Figs. 5 and 11). All these values suggest that the uplift of the Kamień Anticline — contrary to its present symmetric form — may have been asymmetric: the northern limb and hinge zone uplifted earlier (during the Late Cretaceous) and the southern limb — later, as was the case with the Kołobrzeg Anticline.

POMERANIAN SWELL

Central part. This is a tectonic block which was not affected by salt tectonics (Fig. 1) similarly to both anticlines discussed above. Therefore, the reconstruction of the primary thicknesses of the eroded strata is more reliable than in the southeastern area of the MPS. However, there are two records only in this area (boreholes 42 and 8). Subsidence and uplift seem to increase southeastwards along the MPS axis from 3500 to 4200 m and from 1400 to 2300 m, respectively (Fig. 10). If the Jurassic through Lower Cretaceous thickness in the first borehole were like that from the Kamień Anticline, then the thickness of the removed Upper Cretaceous would be about 400 m. In the second borehole — in spite of calculations pointing to thicker cover of this age — this value may have been of the same order (Fig. 11) because the Jurassic-Lower Cretaceous thicknesses are supposed to increase along the

[2]Numbers in brackets refer to numbers given in Table 2.

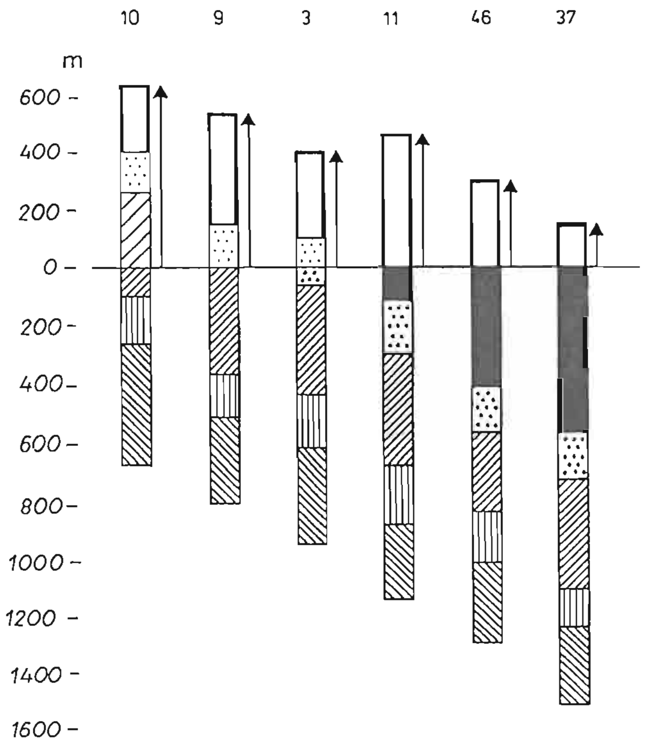

Fig. 6. Mid-Polish Swell — northeastern slope
For explanations see Fig. 4

Wał śródpolski — stok północno-wschodni
Objaśnienia przy fig. 4

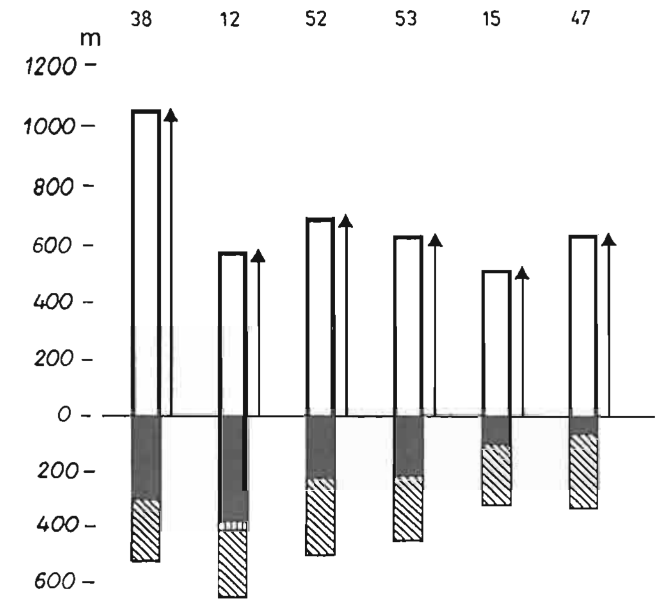

Fig. 7. Fore-Sudetic Monocline — western region — western line
For explanations see Fig. 4

Monoklina przedsudecka — region zachodni — linia zachodnia
Objaśnienia przy fig. 4

axis of the former MPT to the south-east. This estimation points to the early uplift of this segment of the MPT, similar to that of the Kamień Anticline.

Northeastern slope. This area is located on both sides of the boundary between the MPS and the Pomeranian Trough and — simultaneously — at the northern limit of the territories involved in salt tectonics (Fig. 1). Relatively clear picture appears from a group of several boreholes (10, 9, 3, 11, 46 and 37 — see Fig. 6), aligned obliquely to the northeastern slope of the Pomeranian Swell, partly within this unit and partly in the neighbouring Pomeranian Trough filled in with the Upper Cretaceous. Cumulative subsidence in this zone is about 2700–3000 m. Various stratigraphic formations crop out on the sub-Cainozoic surface: from the remnants of the Upper Jurassic (100 m thick) at the western end of this line to the relatively thick Upper Cretaceous (nearly 600 m) at its eastern end. Consequently, the amount of uplift is estimated, respectively, at more than 600 to barely 150 m. The primary thickness of the Upper Cretaceous was from 700 m in the lowered western part to 200 m in the uplifted eastern part (Fig. 11). Since some boreholes are located above salt pillows (Fig. 1), the influence of salt movements on the Upper Cretaceous thickness is very probable.

Southeastern part. Subsidence was there the greatest noted in the whole area (4000–5000 m, see Table 2, boreholes 7, 39, 58, 59, 63). However, the interpretation is here very difficult because of the advanced salt tectonics (compare Fig. 2). A single borehole only (59) is situated in the centre of a syncline from beneath of which the Zechstein salts were squeezed out (the present Zechstein thickness decreases here to 350 m). The remaining boreholes lie on the limbs of vast, strongly uplifted salt pillows (Fig. 1), where the Zechstein thickness is from 1200 to 1700 m. According to the reflection

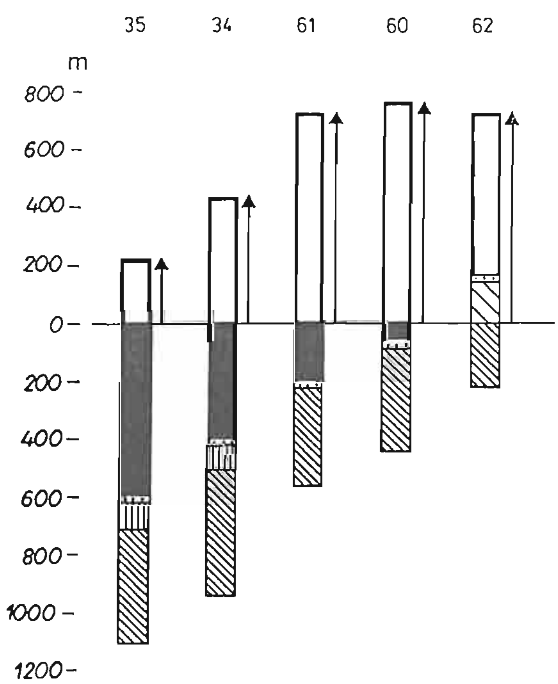

Fig. 8. Fore-Sudetic Monocline — western region — middle line
For explanations see Fig. 4

Monoklina przedsudecka — region zachodni — linia środkowa
Objaśnienia przy fig. 4

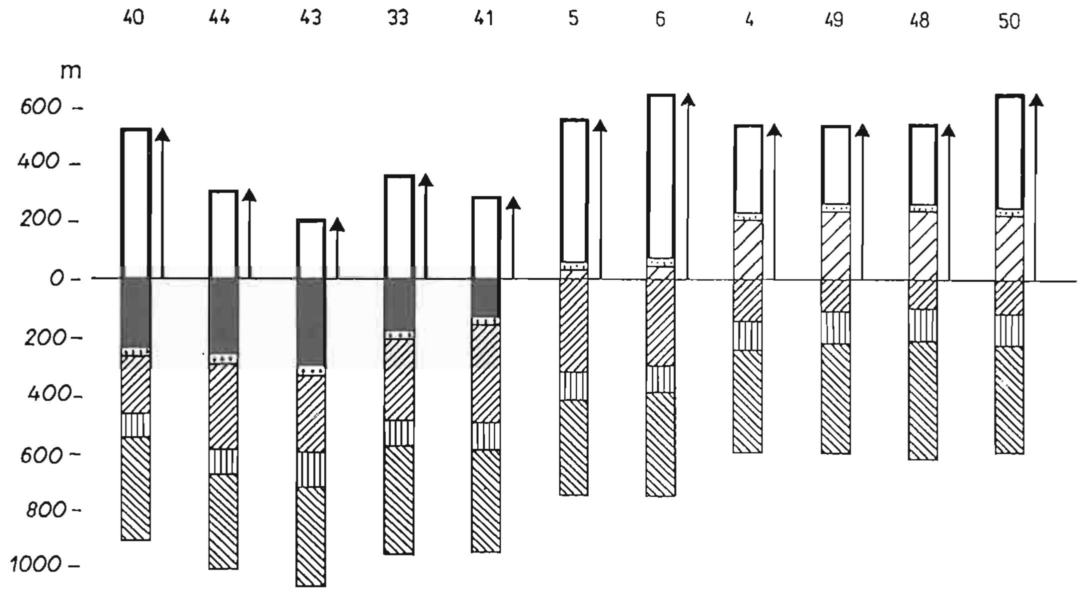

Fig. 9. Fore-Sudetic Monocline — western region — eastern group
For explanations see Fig. 4

Monoklina przedsudecka — region zachodni — grupa wschodnia
Objaśnienia przy fig. 4

seismic data the maximum thickness in their crests exceeds 2000 m. So, the borehole 59 only may represent the regional subsidence (5000 m) and uplift (about 2300 m). Yet, it is situated on the former slope of the MPT. In the axial zone the subsidence might have reached 6000 m (or more?). The reconstructed Upper Cretaceous cover in borehole 59 was about 1100 m thick. The neighbouring borehole 58 reveals the coeval cover of 400 m only. This difference indicates once more the mobility of salts during the Late Cretaceous and may be a measure of its differential movements. It is characteristic that the last mentioned value is similar to that in the boreholes along the northeastern slope (see above), also affected by salt tectonics.

In the remaining boreholes (7, 63, 39) the comparison of the scale of uplift (and inferred scale of erosion) = 1100–1900 m with the Jurassic-Lower Cretaceous thicknesses which can be assumed from the surrounding areas = 1500–2500 m, leaves no space for a significant part of those series, let alone the Upper Cretaceous cover. It indicates that the actual thickness above salt pillows must have been smaller whereas the Upper Cretaceous cover was thin, if any. It implies that in the southeastern part of the MPS the Zechstein salts were active during the Late Cretaceous. The deposits of this age may have reached significant thicknesses between salt pillows and may have been strongly reduced (or even missing) above these structures. This is confirmed by the extreme situation in the borehole 54, located near the top of the most strongly uplifted salt pillow (Zechstein thickness = 2700 m) in the southeastern periphery of the area. It encountered the Lower Jurassic strata below the Cainozoic. Here, about 900 m of eroded strata must have contained at least the uppermost part of the Lower Jurassic, the Middle and Upper Jurassic and the Lower Cretaceous. They must have been strongly reduced due to salt uplift, because the regional thickness of the coeval part of the sequence is estimated in the depressed zones of the area at more than 2500 m. It is possible that this structure was devoid of the Upper Cretaceous cover. Such a situation is even more probable farther to the south-east — in the Kuiavian segment of the MPS — where the salt tectonics is more intense.

FORE-SUDETIC MONOCLINE

Western region. In the eastern part of this region which in general is situated along the southern slope of the former MPT (Fig. 1), the sequences are reduced but there are no greater gaps in the sections. Westwards, a disconformity appears below the Upper Cretaceous strata which lie penecordantly upon older rocks. The gap increases to the west and at the western end the Upper Cretaceous overlies Lower Jurassic. It is a result of a slight pre-Late Cretaceous uplift of this part of the monocline.

An exceptional position is taken here by the borehole 38 (Fig. 7) which shows the reconstructed Upper Cretaceous thickness of 1400 m. The remaining boreholes can be divided into three groups (Figs. 7–9) each of them aligned roughly in the N–S direction, perpendicular to isopachs and to present Mesozoic subcrops. The trends of the Upper Cretaceous thickness chan- ges recorded along these lines are very similar.

The western line (boreholes 12, 52, 53 and 15 — Fig. 7) shows the reconstructed thickness decreasing southwards from about 1000 m to more than 600 m (Figs. 7 and 11). Along the middle line (Fig. 8) the boreholes 35, 34, 61 and 60 record a fairly uniform Upper Cretaceous thickness of 800–900 m while the southernmost profile (62) — a rapid decrease to

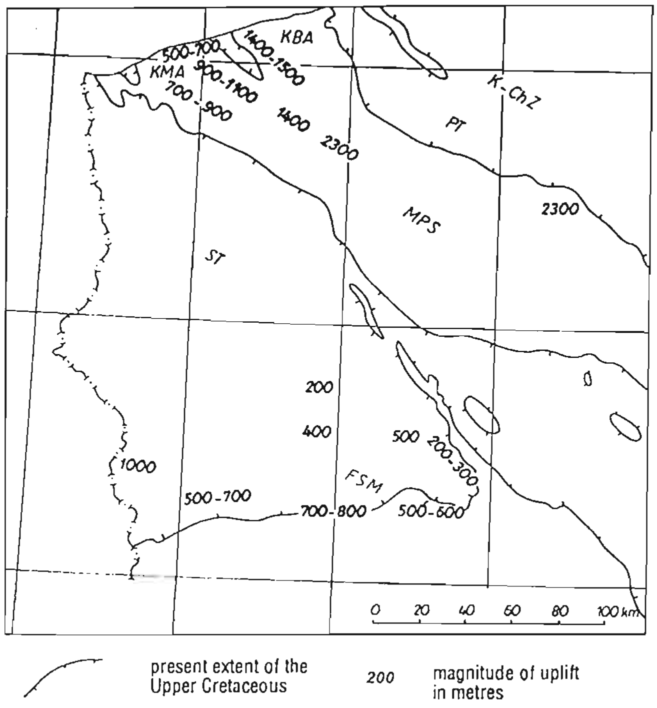

Fig. 10. Sketch of probable magnitude of uplift
FSM — Fore-Sudetic Monocline, K-ChZ — Koszalin–Chojnice Zone, KBA — Kołobrzeg Anticline, KMA — Kamień Anticline, MPS — Mid-Polish Swell, PT — Pomeranian Trough, ST — Szczecin Trough

Szkic przypuszczalnej wielkości wypiętrzenia
FSM — monoklina przedsudecka, K-ChZ — strefa Koszalina–Chojnic, KBA — antyklina Kołobrzegu, KMA — antyklina Kamienia, MPS — wał śródpolski, PT — niecka pomorska, ST — niecka szczecińska

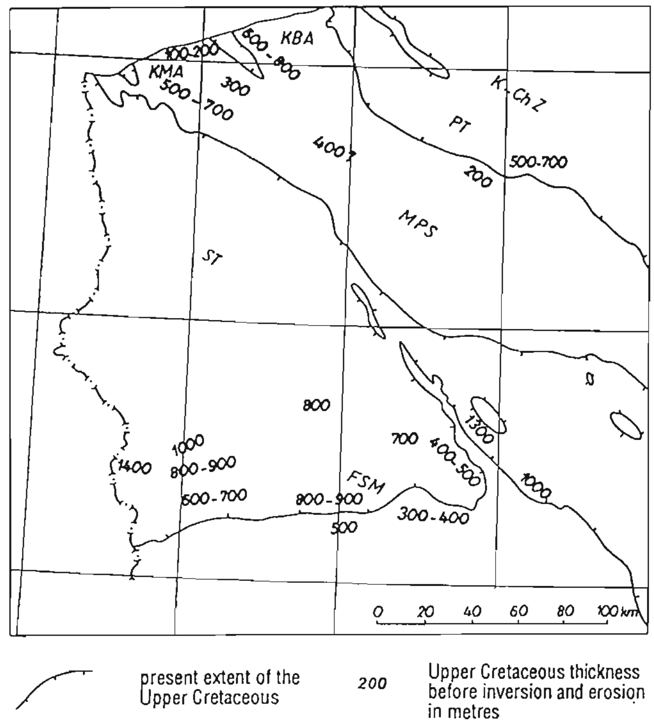

Fig. 11. Sketch of reconstructed Upper Cretaceous thickness
For letter symbols see Fig. 10

Szkic odtworzonych miąższości kredy górnej
Symbole literowe patrz fig. 10

about 500 m (Fig. 11). The last point is situated in the belt of the sub-Tertiary Lower Jurassic subcrop. In the eastern group of boreholes (Figs. 9 and 11) the northernmost one (40) reveals the primary Upper Cretaceous thickness of 700 m. Southeastwards it decreased to 400–500 m (boreholes 44, 43, 33 and 41). In the belt along the subcrop of the Upper Cretaceous base (boreholes 5 and 6) the thickness was perhaps slightly greater (?500–600 m) and farther to the south it decreased again to 300–400 m (boreholes 4, 49, 48 and 50).

In general, the magnitude of uplift in this region decreased to the south-east in the western group of boreholes from 1000 to 500–700 m (Fig. 10). Along the middle line it decreased to the north towards the areas which were not inverted at all. The reconstructed Upper Cretaceous thickness decreases eastwards and southwards. Along the present, post-erosional boundary of this series its primary thickness was of the order of 300–500 m, and probably decreased towards the centre of the FSM.

Eastern region. The results are here differentiated and ambiguous. This is because of tectonic structures of two types. A few synsedimentary grabens exist in this area and a partly pierced salt diapir is located at its northeastern end. The stronger tectonic involvement may have caused both the differentiation of data and the possible overpressure of rocks which disturbed the results (as in the case of boreholes 22, 28, 31 and 32). The amount of uplift seems to be significantly greater than in the western region, in some cases reaching even 1500 m. Borehole 36 with fairly thick Upper Cretaceous (reconstructed thickness — nearly 1300 m — Fig. 11) lies in the rim syncline of the mentioned diapir and seems to evidence its growth during this time interval.

CONCLUSIONS

1. Inversion of the axial zone of the Mid-Polish Trough in its northwestern segment — together with the Kamień Anticline — started during the Late Cretaceous (after the Turonian?). Its maximum magnitude in the axial zone was about 1000 m near the Baltic coast and increased to more than 2000 m in the central part of the MPS. It resulted in the relatively thin cover of the Upper Cretaceous rocks. At the same time thicker sediments accumulated northeast of this in-

cipient uplift. The Kołobrzeg Anticline, located in this area, inverted rather in a single pulse, at the end of Cretaceous. Its scale of inversion was about 1500 m.

2. In the southeastern part of the Pomeranian Swell the local growth of salt pillows in the latest Cretaceous probably interfered with the regional inversion of the entire MPS. This is a complicated process which should be modelled in future, beginning with areal balancing of the primary Zechstein thickness and reconstruction of the successive stages of tectonic salt displacements.

3. Western region of the Fore-Sudetic Monocline was characterized by differential uplift which increased generally towards the west and south from 200–400 to 800 and 1000 m. It was covered by fairly thick Upper Cretaceous thickening significantly to the west towards the German province of Brandenburg. In the northern peripheries of the FSM a cover 800–1000 m thick existed, decreasing to 400–500 m to the south. Considerable part of this cover (up to 600–700 and 300–400 m, respectively) has been removed after the Cretaceous. Along the present Jurassic subcrops this cover was thinner (300 m or less). In the eastern region the results are ambiguous but the amount of uplift seems to be generally greater than in the western region: 1500 m or more.

4. The method applied has a limited accuracy and makes possible a rough estimate only of subsidence, uplift and erosion. However, it gives an overall orientation in the scale of these processes. The data should be continuously collected and interpreted. The growing number of sonic logs should be an independent source of information as well as should serve for verification of the results.

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SUBSYDENCJA I INWERSJA W ZACHODNIEJ CZĘŚCI BASENU POLSKIEGO — DANE Z PRĘDKOŚCI SEJSMICZNYCH

Streszczenie

Dokonano próby oceny skali subsydencji, inwersji i poinwersyjnej erozji w zachodniej części basenu polskiego, wykorzystując dane o interwałowych prędkościach sejsmicznych formacji bałtyckiej (piaskowiec pstry). Są one miarą kompakcji osadów ilastych, a zatem maksymalnego pogrążenia formacji. Ponieważ stopień kompakcji, osiągnięty w momencie tego pogrążenia, jest nieodwracalny, zatem przez porównanie go z obecną głębokością występowania można ocenić wielkość inwersji, odnosząc go do stopnia kompakcji w profilach, które inwersji nie podległy. Dane obarczone są dość dużym błędem, zatem pozwalają tylko na ogólną ocenę i na jakościowe porównanie skali wspomnianych procesów w różnych regionach obszaru. Oprócz tego, w obszarze działania tektoniki solnej ocena nie dotyczy całkowitej subsydencji kompleksu cechsztyńsko-mezozoicznego, ponieważ formacja bałtycka leży nad solami cechsztyńskimi. Analizę skoncentrowano na rekonstrukcji pierwotnych miąższości kredy górnej, dzisiaj usuniętych z rozległych obszarów.

Dane te sugerują, że osiowa strefa północno-zachodniego (pomorskiego) segmentu bruzdy śródpolskiej zaczęła się dźwigać pod koniec turonu. Wielkość podniesienia w osi oceniono na ponad 1000 m w obszarze nadbałtyckim. Ku SE zwiększa się ona do ponad 2000 m w centralnej części wału pomorskiego. W rezultacie utworzyła się tutaj tylko cienka pokrywa skał górnokredowych (200–400 m), która została później usunięta w ostatnim stadium regionalnej inwersji bruzdy i jej przekształcenia w wał śródpolski. Dalej ku południowemu wschodowi, ale jeszcze w granicach segmentu pomorskiego bruzdy, lokalne przemieszczenia tektoniczne soli cechsztyńskich, rozpoczęte w późnym triasie, powodowały zróżnicowanie miąższości górnej kredy i interferowały z regionalnym wypiętrzaniem. Północno-zachodnia gałąź wału

śródpolskiego (antyklina Kołobrzegu) odznaczała się silnym wypiętrzeniem (rzędu 1500 m), grubszą pokrywą górnej kredy (600–800 m) i podlegała inwersji raczej w jednym pulsie pod koniec kredy.

Wzdłuż południowego stoku basenu polskiego (monoklina przedsudecka) wypiętrzenie było — jak się zdaje — ogólnie silniejsze w części wschodniej (na wschód od Poznania — rzędu 1500 m) niż zachodniej. W tym ostatnim obszarze było ono największe na zachodzie i malało ku północy i wschodowi. Tutaj też pierwotne miąższości górnej kredy wzrastały ku północy i zachodowi do maksymalnych wartości ponad 1000 m. W strefie obecnego podkenozoicznego zasięgu tego oddziału miąższości były znacznie mniejsze (300 m lub mniej).

Gromadzenie danych i ich interpretacja powinny być kontynuowane. Należy je uzupełniać danymi z pomiarów akustycznych w otworach wiertniczych, których liczba jest obecnie niewielka, ale które są powszechnie wykorzystywane w tym samym celu i zapewne dokładniejsze.