THE ROTLIEGEND SEQUENCE STRATIGRAPHY IN THE POLISH BASIN

Relationships between the tectonic and climatic factors

Sequence stratigraphy is mainly used to study marine sediments although — unconformity bounded units have been distinguished for a long time in continental deposits. This methodology was successfully applied in the Rotliegend division of the Southern Permian Basin (P. Gralla, 1988; R. E. Gast, 1991; C. S. Yang, S. D. Nio, 1993; G. T. George, J. K. Berry, 1993, 1994). In the divisions proposed above the climatic changes were considered to be a factor responsible for water-level oscillations in the central lake. These variations determined sedimentary conditions at low and high stands of water level similar to sequence successions observed in marine profiles.

In the case of continental series it should be carefully assumed that only a single factor controlled sedimentation in the basin. Influence of tectonics and climate on sediment supply has been defined for a long time in many continental basins although the terminology used only sometimes relates to nomenclature and methodology of sequence stratigraphy (see K. W. Shanley, P. J. McCabe, 1994). In Poland similar attempts have also been done for the Rotliegend series, using units bounded with discontinuity surfaces (allostratigraphic units – P. H. Karnkowski, 1986b, 1987b; sequences – H. Kiersnowski, 1997b). In these divisions tectonics was assumed as a principal factor, controlling deposition, erosional processes and intensified accumulation of coarse clastics.

Recently the author have attempted to distinguish sequences in the Rotliegend of the Polish Permian Basin considering both climatic and tectonic factors. Their role and importance were commented in previous chapters. In this chapter principles of distinguishing sequences in the basin

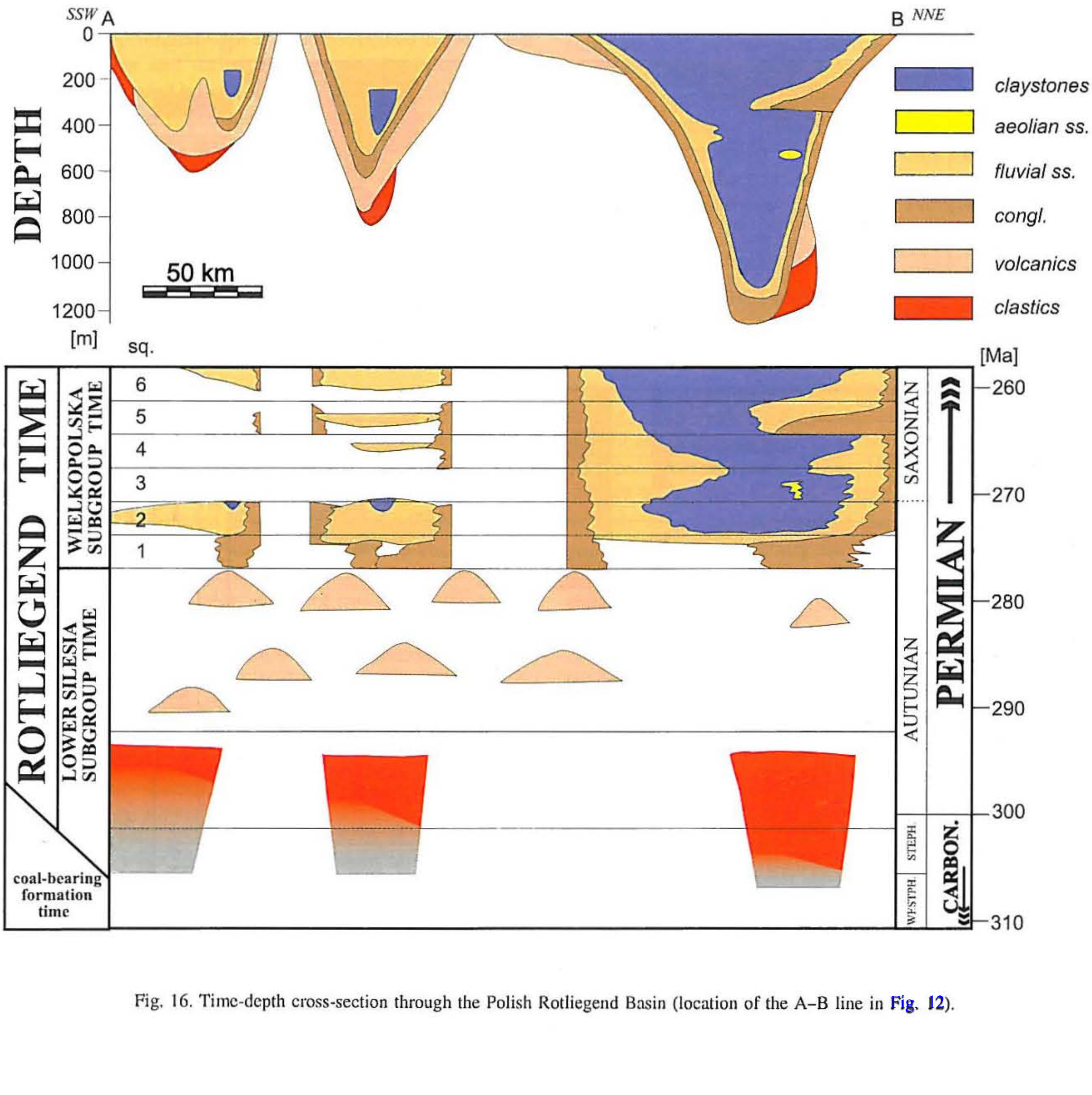


Fig. 16. Time-depth cross-section through the Polish Rotliegend Basin (location of the A–B line in Fig. 12).

will be presented. The term "sequence" used here corresponds with the definition stated by the Exxon Group — "A sequence is a stratigraphic unit composed of a relatively comforable succession of genetically related strata ... bounded at its top and base by unconformities or their correlative conformities." (R. M. Mitchum Jr. *et al.,* 1977, p. 53).

At least two tectonic pulses could be distinguished within the Dolsk Formation. The older one may be correlated with the so-called Intra-Stephanian phase but the younger one may have acted during the Autunian. These pulses are well evidenced in the Dolsk Fm. from the Sudetic Basins and less — in the Polish Permian Basin. Climatic influence on sedimentation of the Dolsk deposits is indicated by a change in colour. Initially, only single intercalations of red sediments occurred in the succession but later they dominated. In 1987 this author (P. H. Karnkowski, 1987b) proposed to distinguish a lower part of the Dolsk Fm., consisting of interbedded red and black series, as the Kwisa Alloformation. Recently these alloformations may be defined as sequences, but after the author's own experience and opinions of other researchers such an initiative seems premature. The Dolsk Fm. occurs locally in the Polish Permian Basin so it is found quite seldom and only few pieces of core are known. In such a situation the distinguishing of true sequences within this formation will not explain problems of Late Carboniferous and early Permian sedimentation in the Polish Basin. First of all it is necessary to determine such sequences in the Sudetic basins and describe them properly in areas with plenty of geological data enabling further studies. After those investigations the sequences established may be more reliably applied to the less recognized parts of the Polish Permian Basin.

A quite different character shows the Wyrzeka Volcanics Formation. It consists mainly of volcanic and pyroclastic rocks so classical depositional sequences cannot be distinguished there. But also in this case the term "cyclicity" is commonly used; two or one volcanic cycles, probably tec-

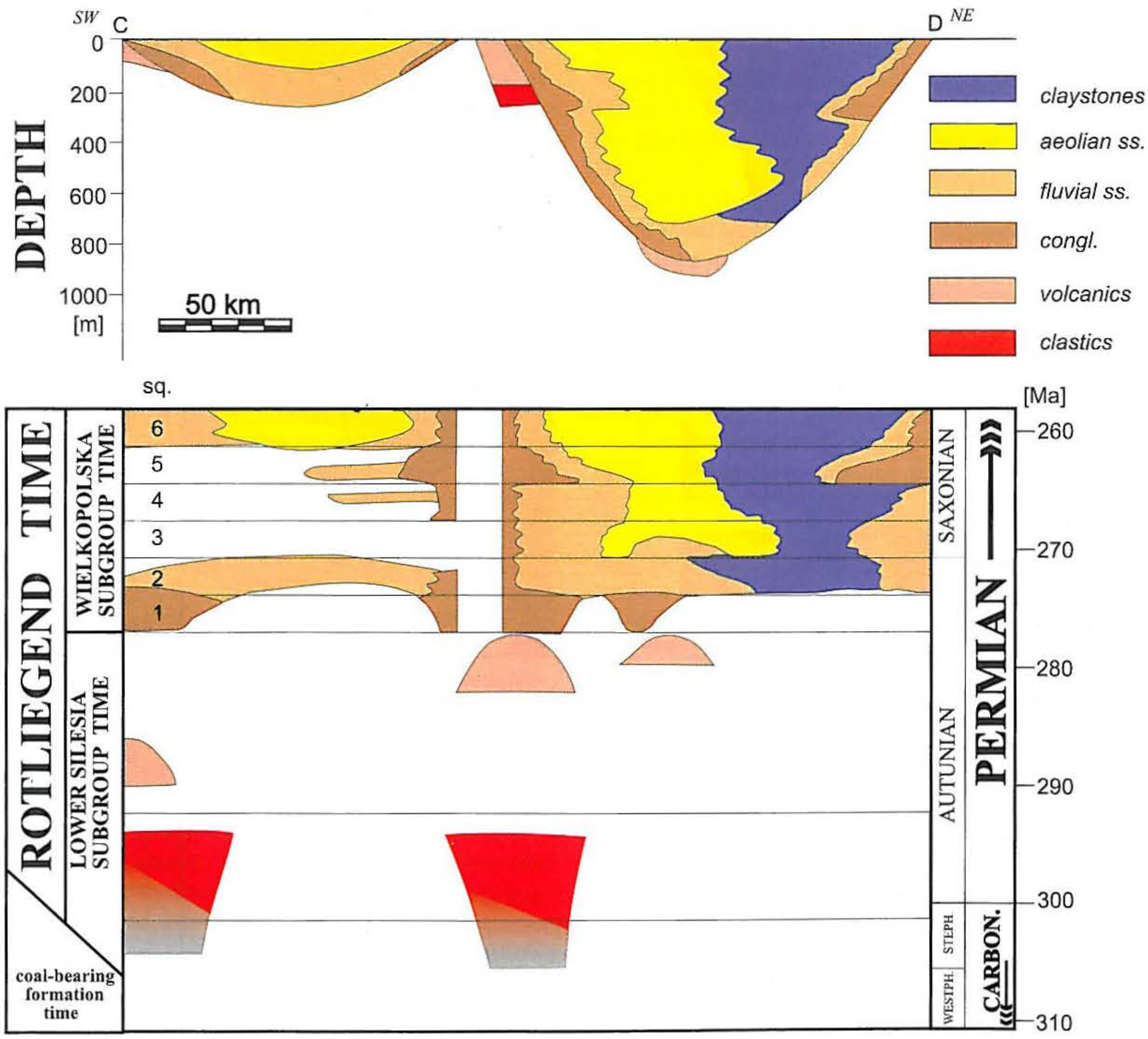


Fig. 17. Time-depth cross-section through the Polish Rotliegend Basin (location of the C–D line in Fig. 12).

tonically controlled, were described there (W. Ryka, 1981; E. Jackowicz, 1994, 1995). In Poland the correlation of volcanic phenomena is insufficiently geochronologically dated so credible conclusions on their cyclicity within the Polish Permian Basin seem premature. In such a case the author understands the Wyrzeka Volcanics Fm. — after his own studies and conclusions — as a single sequence, consisting of volcanic, pyroclastic and sedimentary episodes. If the future petrographic studies enable a distinguishing of co-eval complexes and series, a more detailed sequencial division will be possible.

Sequences are more easily distinguished within the Wielkopolska Subgroup based on two tectonic and one climatic episodes (Fig. 15). Tectonic episodes are reflected by the Polwica Conglomerate Member and Solec Conglomerate Member deposits. They are separated by sediments reflecting the onset of aeolian accumulation. Such a stratification enabled distinguishing of six sequences within the Wielkopolska Subgroup: 1st sequence related to a tectonic episode occuring after the end of volcanic activity (corresponding to the Polwica Conglomerates Member and its equivalents); 2nd sequence correlated with sediments located between the Polwica Member and series of the main dry episode; 3rd sequence represented by series of the main dry climatic episode; 4th sequence expressed by deposits located between the series of the main dry episode and the Solec Member; 5th sequence attributed to the Solec Conglomerate Member and genetically related sediments; 6th sequence evidenced by series located above the Solec Member and beneath the marine Zechstein succession.

Relationships between rock units and sequences

Sequences as chronostratigraphic units are in most cases diachronic in relation to lithological divisions, within which they are distinguished, so such a correctness probably refers also to the above proposed sequences. A chronostratigraphic reconstruction of the Rotliegend chart — due to lack of index fossils — can not be verified and is partly hypothetical. From the other side it is based on evident tectonic-climatic events occurring in the Polish Rotliegend Basin and it may only be more precisely defined in future. Two geological sections through the Polish Rotliegend Basin, both in a depth and time scale were constructed (Figs. 16, 17) to illustrate relationships between lithostratigraphic units and sequences. Some lithostratigraphic units are additionally enriched with genetic attributes. The Siekierki Sandstones Fm. was subdivided into aeolian and fluvial sandstones. The most visible elements are large stratigraphic gaps occurring between sequences in some areas. The presented sketch simplified only the complex geological history of the basin, with numerous sedimentary and erosional episodes. It intended to underline a possible occurrence of many sedimentary gaps and long periods of non-deposition and erosion. Only such a methodical construction enables at some stage to reconstruct evolution of the Roliegend rocks in the Polish Permian Basin.

EVOLUTION OF THE POLISH PERMIAN BASIN IN ROTLIEGEND TIME

Lower Silesia Subgroup Time

The reconstruction of evolution of the Polish Permian Basin in Rotliegend time begins from pre-volcanic and volcanic periods, when a real Polish Basin did not exist yet. The Silesian Subgroup, comprising the Dolsk Fm. and Wyrzeka Volcanics Fm., originated directly before the foundation of the Polish Basin frames. Analysis of the individual formations and the changes occurring during their development enabled to define succession stages of transformation of the Variscan pattern into the new Permo-Mesozoic basin. Rotliegend time was a period when the main remodelling of the Late Carboniferous pattern took place succeeded by a development of epicontinental sedimentation within the Permian Basin.

Pre-volcanic period (Dolsk Fm.)

The Dolsk Fm., including the uppermost series of the Late Carboniferous and Autunian, relates in some manner to the Late Carboniferous depositional model, dominated by a generation of coal-bearing formations. In some regions, e.g. Pomerania area, the Intra-Sudetic Basin or Upper Silesian Basin, this depositional style continued within the Dolsk Fm. In other places (North-Sudetic and Eastern Fore-Sudetic basins, Lower Silesian Basin, Wielkopolska Basin) the Upper Carboniferous deposition occurred just in the Late Westphalian or Stephanian. A knowledge of sedimentary evolution during this period is limited due to erosional removal of a significant part of deposits just before the pre-volcanic and after post-volcanic periods (Fig. 18). The Dolsk Fm. consists of both grey, black and red clastics and it locally contains tectonic discordances dated at the Carboniferous and Permian boundary. Generally its deposits originated in a continental environment, under fluvial and lacustrine conditions. It should be emphasized that these sediments occur in this part of the Wolsztyn Ridge, which became an uplifted and eroded area in the Late Rotliegend (P. H. Karnkowski, K. Rdzanek, 1982). If such an uplifting tendency had taken place just during deposition of the Dolsk Fm., this region would have been devoid of sediments or it would have been reflected in the character of the Dolsk rock components. Nothing similar was observed so this confirms that the Wolsztyn Ridge did not exist yet in the Early Rotliegend. A character of the Dolsk Fm. deposits in the Wielkopolska region suggests rather their distal than proximal position with respect to source areas (P. H. Karnkowski, 1987a, 1994).

A change in colour from black and grey to red-brown within the Dolsk Fm. profile resulted certainly from climatic variations. A direct reason of such a change is the decrease of organic matter in sediment favouring the dominance of oxidation processes over reduction ones. So climate drying

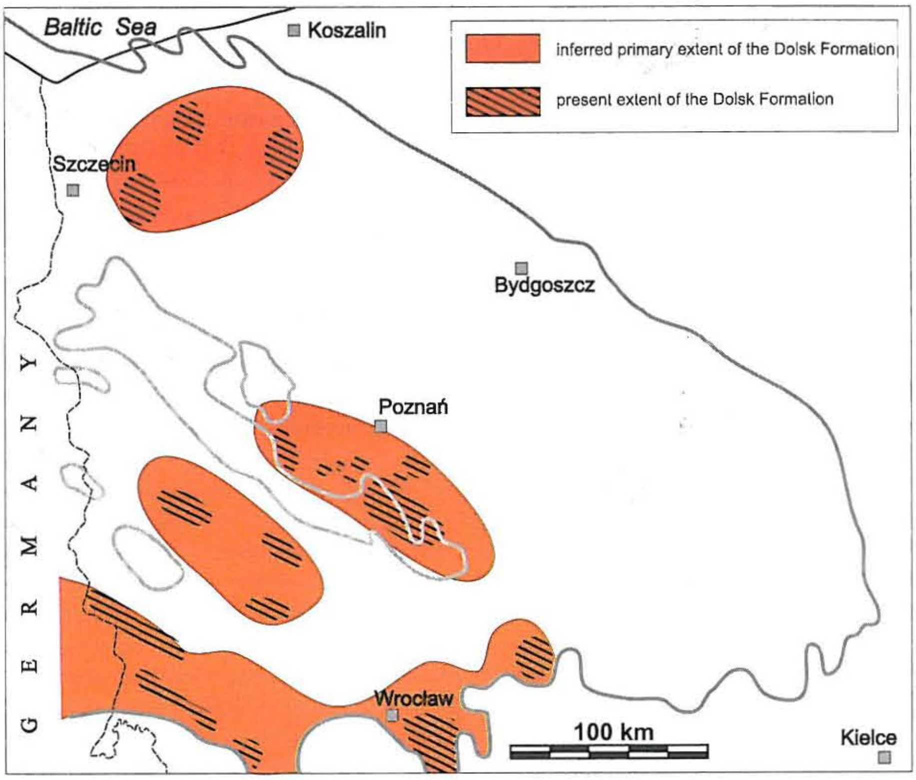


Fig. 18. Pre-volcanic period palaeogeography.

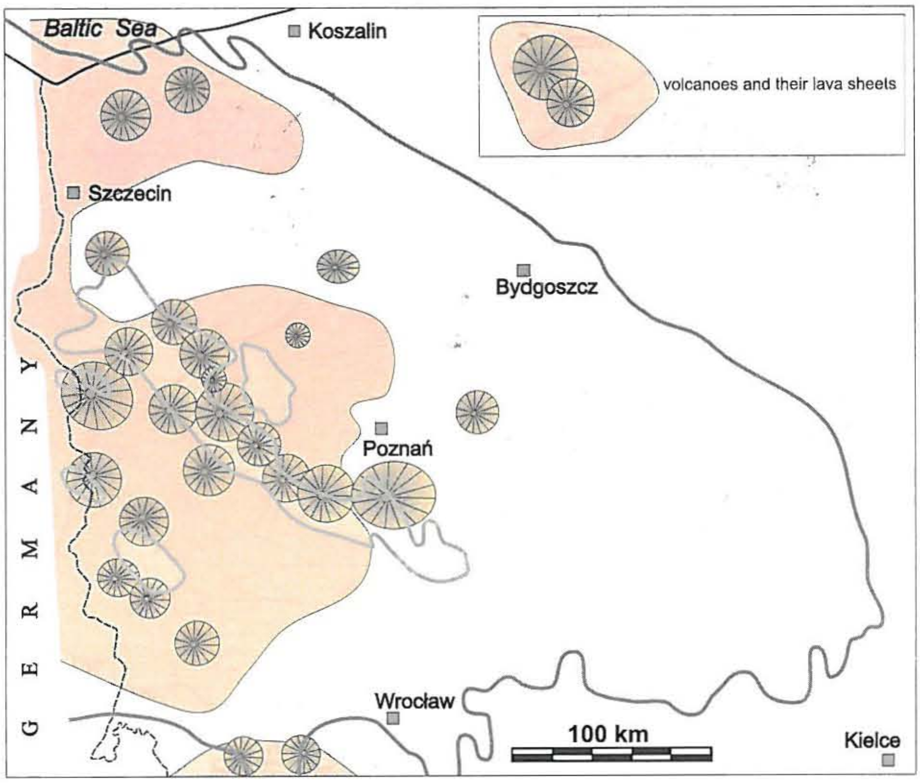
at the end of the Carboniferous is more drastically reflected in plant evolution than in sedimentary conditions. In the Dolsk Fm. sediments, especially in its upper part, there are no evidences of seasonal water deficit. The nature of deposition, particularly common occurrence of brownish clay-silty sediments, suggests a lacustrine and subordinary fluvial environment. Clay, and sporadically coarser material was mainly transported into broad subbasins. Diachroneity of red colour observed in the Dolsk Fm. deposits (earlier in the Pomerania area — in late Westphalian; later in the Sudetic basins — in the Autunian) informs about slow changes of sedimentary conditions. It seems that the Late Carboniferous (Stephanian) and earliest Permian (Early Autunian) period was devoid of any significant tectonic events and sedimentary conditions successively developed, being controlled by a slow change of climate. There is also lack of evidence of a dramatic termination of the Dolsk Fm. deposition. Directly beneath volcanic rocks, covering the Dolsk Fm., there are no specific features, suggesting that the termination of clastic deposition could be related to any extraordinary events. The Saalian movements, considered to be a factor stopping the Dolsk Fm. accumulation, induced also erosion of a part of the pre-volcanic series.

Volcanic period (Wyrzeka Volcanics Fm.)

Volcanic rocks in the Rotliegend sections are very common in different basins of Western and Central Europe. Volcanics built up an important lithostratigraphic unit and usually they are distinguished in the rank of formation. The Polish Permian Basin volcanic rocks were also established as the Wyrzeka Volcanics Formation. Intensive erosion which took place after the volcanic episode partly removed the volcanites and thin lowermost Rotliegend deposits. The volcanic rocks which are preserved occur most frequently in the grabens where lowermost Rotliegend deposits (Dolsk Formation) are distinguished as well. In the complete Rotliegend sequence, above the volcanics, thick clastic sedimentary rocks are recorded which in the Polish Permian Basin were established as the three formations and combined into the Wielkopolska Subgroup. The position of volcanics in the middle part of the Rotliegend section indicates their relation to the earlier events; one also can find relations between volcanics and the overlying deposits (P. H. Karnkowski, 1987a, 1994).

The occurrences of the volcanic rocks in the Polish Permian Basin are limited to their western part (Fig. 19). The volcanic event was related to the Saalian movements which in the first phase ceased sedimentation and later involved a great erosion of the Dolsk Fm. The main phase of these movements induced lava extrusion and eruption of pyroclastic material. Generally, the volcanics consist subordinately of acid volcanic rocks (rhyolites, rhyodacites). In some places trachytes and trachybasalts compose a large volume of volcanics. In the places where the thickness of volcanics is greater than an average value (centres of volcanism) the lower part of the section is built of neutral volcanic rocks and the upper part by acid ones. In other places where the thickness of volcanics is smaller than the average value, the acid volcanic rocks commonly occur. This regularity suggests only a single volcanic cycle with neutral volcanism at the beginning and acid one at the end of the cycle. Acid lava covered larger area outside the volcanism centres. Based on such suppositions, the palaeogeographic image of volcanic

Fig. 19. Volcanic period palaeogeography.



centres and vast lava covers was reconstructed (Fig. 19). Special attention would be paid on the northern border of the Wolsztyn Ridge, where a lot of volcanic centres developed.

The age of volcanites is established mainly by the superposition law. Volcanic rocks overlie the Dolsk Fm. which age is biostratigraphically dated as Stephanian/Autunian; hence the age of volcanism is defined as Autunian. Between the youngest flysch deposits (Namurian A, i.e. the beginning of Variscan orogeny) and the Rotliegend volcanism event in the Polish Permian Basin a gap existed, calculated at 30–40 millions years long. At this time the Variscides were formed and in some regions, sedimentation (often with coal beds) within foreland basins developed. In Central and Western Poland, outside the Variscan deformation front, there was no typical foredeep basin filled with thick Upper Carboniferous deposits. Only the Upper Silesian Basin with coal-bearing formations is located directly outside the Variscan deformation front. In other areas (Wielkopolska, Pomerania regions) thin Upper Carboniferous deposits are recognized in isolated places. Then, it is difficult to speculate about a great thickness and vast extent of the Upper Carboniferous deposits. The sketch of volcanic rocks distribution (Fig. 11) shows that volcanics occur both within the Variscides and outside them. It is difficult to attribute the occurrence of volcanics to Variscan zones defined. However, detailed geological studies indicate that volcanism in the Polish Permian Basin was attached to great lineaments being active in the younger Palaeozoic. On the other hand, the tectonic zones originated only from activity of the Polish Permo-Mesozoic Basin are observed (P. H. Karnkowski, 1980a, b). During Rotliegend time there were at least two tectonic systems: the older one — attached to deep lineaments which were often a way for lava migration, and the younger one — induced by the stress field during the earliest phase of the evolution of the Polish Basin. Reactivation of older tectonic system during the volcanic episode resulted from a creation of a new sedimentary basin, and volcanic activity was the first stage of this process. In this context, the Rotliegend volcanism would rather be attached to the first episode of the Polish Basin evolution than to the Variscides (P. H. Karnkowski, 1995a).

Wielkopolska Subgroup Time

Termination of volcanic processes commenced at the same time as the first phase of Polish Basin development. Erosion of lava covers, formed in tectonically active zones, supplied a large amount of clastic material into the established Polish Basin. A specific structure was the Wolsztyn Ridge, which existed during the whole Late Rotliegend as an uplifted element.This enabled to form the Lower Silesia and Wielkopolska subbasins and — first of all — supplied a lot of clastics from eroded volcanoes and volcanic covers. The formation and later existence of the Wolsztyn Ridge induced a characteristic drainage system. This system transported and distributed clastics into individual parts of the Rotliegend Basin. Palaeogeographic reconstructions of each sequence of the Wielkopolska Subgroup were possible due to data from numerous exploration wells, prospecting the Rotliegend deposits.

Post-volcanic sequence (1)

During the whole volcanic activity period the Saalian tectonic movements continued also long after the termination

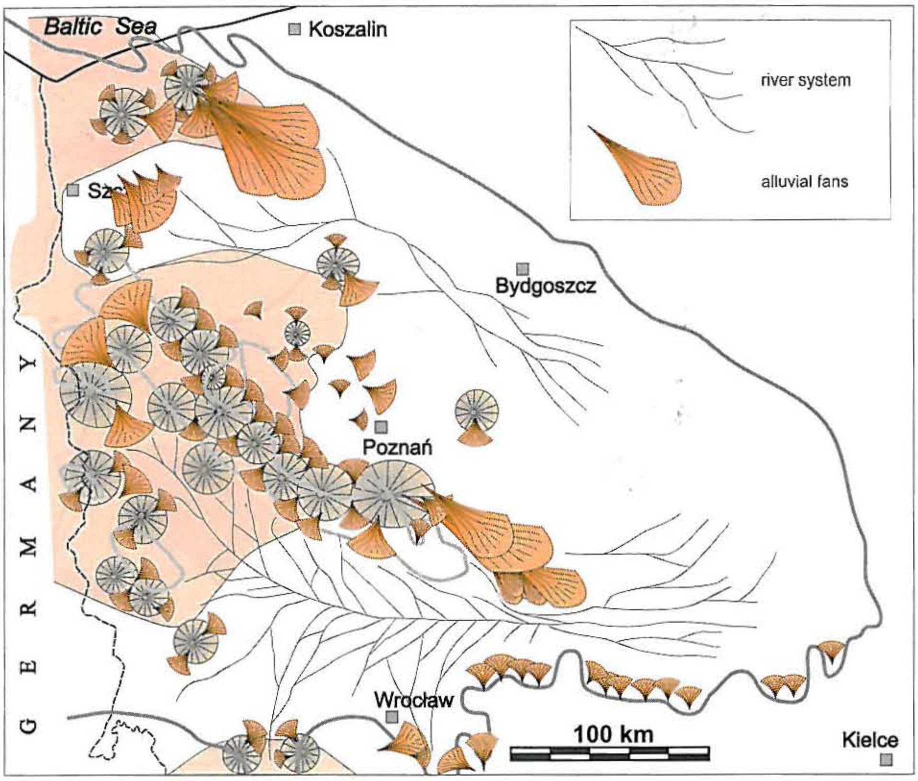


Fig. 20. Post-volcanic sequence (1) palaeogeography.

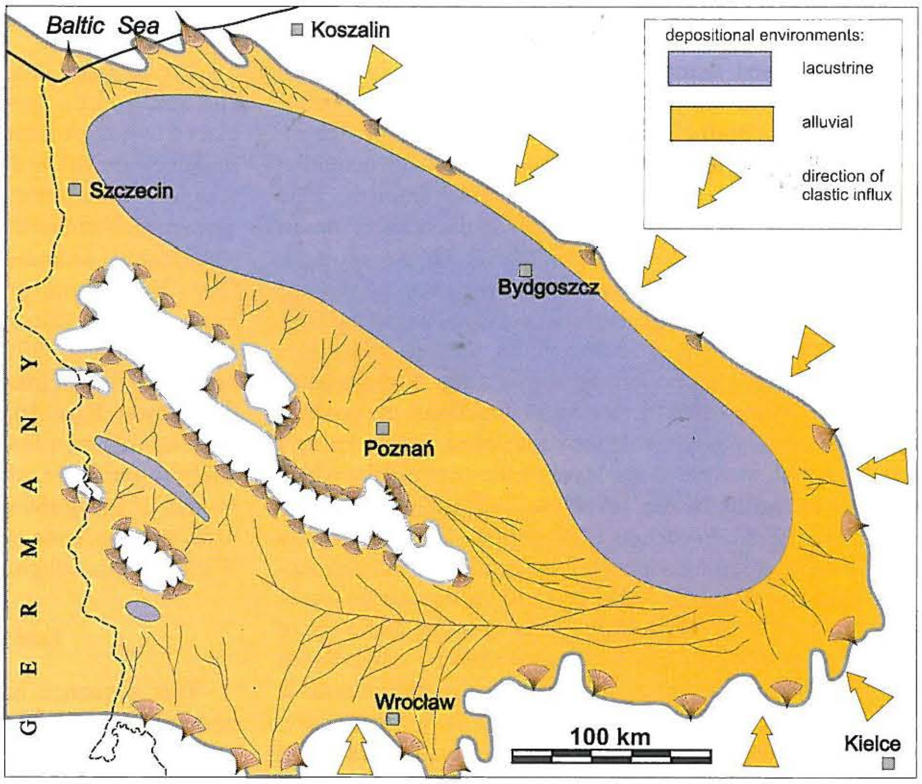
of activity of volcanic processes. They were reflected as a series of conglomerates and breccias occurring directly above volcanic rocks. These conglomerates are composed of porly sorted and porly rounded coarse material, indicating its short transport in a form of gravitational slumps, flood fans or mud flows developed in areas of differentiated topography. Conglomerate beds are sometimes intercalated with sandstone or siltstone layers, containing dessication cracks as well as frequent intraclasts and clay chips in sandy beds. These deposits occur in several characteristic zones: mainly on the margins of the Wolsztyn Ridge, in marginal zones of lava covers and in tectonic zones, transfering clastics into the Polish Basin, for instance — the Poznań–Kalisz and Czaplinek zones (Fig. 20). Coarse deposits accumulated at that time belong to the Polwica Conglomerate Member and the lower part of the Książ Wlkp. Conglomerate Fm. (P. H. Karnkowski, 1977, 1987a, c, 1994, 1997a, b). In sections with the almost continuous occurrence of conglomerates the Książ Formation was distinguished, but in others, with conglomerates located in the lowest part of the section, the Polwica Conglomerate Member was established. These conglomerates were fixed as the first sequence which was genetically related to last pulses of the Saalian tectonic movements.

The palaeogeographic sketch of the initial post-volcanic period (Fig. 20) illustrates that a part of the Polish Basin is devoid of basal coarse deposits. It results from two reasons: the first one — conglomerates and breccias were related to active tectonic zones or margins of lava covers; the second one finer, sandy and clay material accumulated — due to transport selection — at some distance from flood and slump fans. Relatively thick intercalations of sandstones and claystones are observed within conglomerate series so the dominant deposition of such material was located outside main conglomerate fields. On this sketch, the drainage directions and zones within the Polish Basin controlling fine material transport towards the basin center are schematically indicated. Such a supposition is quite credible because the next episode (pre-main dry sequence) has a facies pattern confirming a basin configuration during later sedimentary episodes.

Pre-main dry sequence (2)

This sequence is bounded from the bottom by the top surface of the conglomerate unit and from the top — by sediments indicating a significanit arid climatic period (Fig. 21). Deposition of the 2-nd sequence took place partly in subaqueaceous conditions so traces of rapid climatic drying are observed nowhere. The lithofacies pattern in the Polish Basin reflects frames that existed later till the Zechstein marine transgression. The basin center was occupied by a lake with dominant clay deposition, whereas its borders were occupied by fluvial facies. Lithofacies distribution was distinctly asymmetrical because the southwestern basin margin was a ten to twenty times wider than the northeastern one. Such dimension differences resulted from the occurrence of the Wolsztyn Ridge and similar structural elements which manifested themselves as active tectonic elevations in the Roliegend palaeogeographical scheme of the southwestern basin part (P. H. Karnkowski, 1994, 1997a). Moreover, the southwestern basin margin was characterized by much lower subsidence than areas located in the basin center. Such

Fig. 21. Pre-main dry sequence (2) palaeogeography.



palaeomorphological-palaeotectonic pattern induced a specific drainage system and clastic transport directions. The narrow sand-dominated zone, located between the north-eastern basin border and the area occupied by clay lithofacies, suggests very low morphological variability of source area and absence of tectonic movements. Concluding, the hinterland of the NE basin margin became poorly differentiated, with a very low tectonic activity.

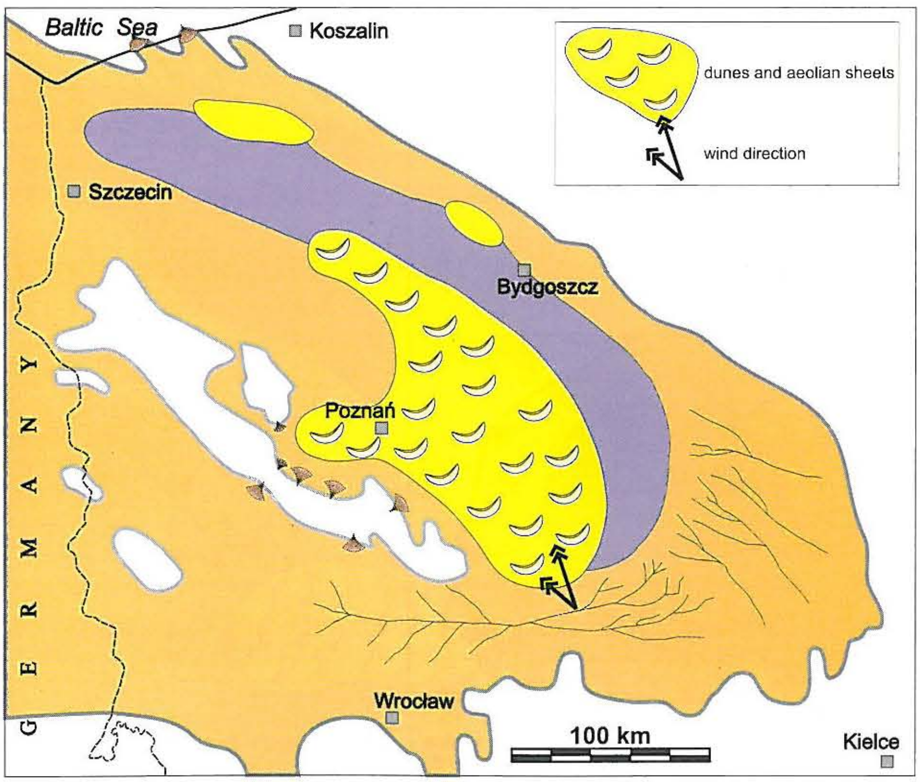


Fig. 22. Main dry sequence (3) palaeogeography.

Main dry sequence (3)

The first and second sequences were strongly characterized by fluvial and tectonic factors but the third sequence demonstrates a high climatic influence. At that time the remarkable dry period of the Rotliegend climate evolution began. Such a successive drying continued from the Late Carboniferous but at that moment first deposits of desert provenance developed — aeolianites (P. H. Karnkowski, 1994). They accumulated on the southwestern side of the central lake, which simultaneously decreased its extent. Dipmeter data indicate that southern and southeastern winds prevailed during that period. So the location of dune fields was controlled by three factors: wind directions, the position of supplementary sand fields area developed earlier during a fluvial period, and the water level of the central lake which determined groundwater level oscillations (G. Kocurek, 1981, 1988; S. G. Fryberger *et al.,* 1988). The groundwater level enabled trapping and stabilization of accumulated aeolian sediments (Fig. 22). Other types of sedimentation weakly manifested themselves during that episode, and a lot of sandy and pelitic material was transported by wind. Sands accumulated as aeolianites and pelites were blown outside the basin or they were partly deposited in a central lake. Obviously, quantitative relationships between erosion and accumulation volumes in individual areas are difficult to estimate but the author supposes that from the beginning of the main dry sequence deposition, the southwestern area of the basin (located southwest of the Wolsztyn Ridge) was a special transfer area, devoid of accumulation and acting as a way for clastics transport towards a basin center (Fig. 22).

Post-main dry sequence (4)

The extreme climatic oscillation described above, and characterized by development of aeolianites, was later replaced by a more humid period. So the boundaries of the new sequence are defined by aeolianites at the base and by tectonically determined deposits at the top (the Solec Conglomerate Member). The extent of aeolian sedimentation significantly decreased, but the central lake area extended (Fig. 23). Fluvial processes also intensified discharge of more material into the central basin (P. H. Karnkowski, 1987a, c, 1994, 1997a, b). Then the Lower Silesia region became mainly a transfer area, probably without accumulation (comp. Figs. 16, 17). It should be underlined that the material transport from the Wolsztyn Ridge took place parallely to the ridge, along the Poznań–Kalisz tectonic zone, instead of using the shortest way towards the basin center. This tectonic zone was active from the beginning of the Wielkopolska Subgroup deposition.

Late tectonic sequence (5)

This sequence is characterized by the occurrence of coarse clastics horizon (the Solec Conglomerate Member), generated by a strong tectonic impulse of the Altmark movements (Fig. 24). This tectonic episode induced thick conglomeratic horizons in some places and limited the pelite-dominated area in the central basin. Subsidence rate within the whole Rotliegend Basin increased and erosion in source areas was intensified, increasing clastics discharge (P. H. Karnkowski, 1977, 1987a, c, 1994, 1997a, b).

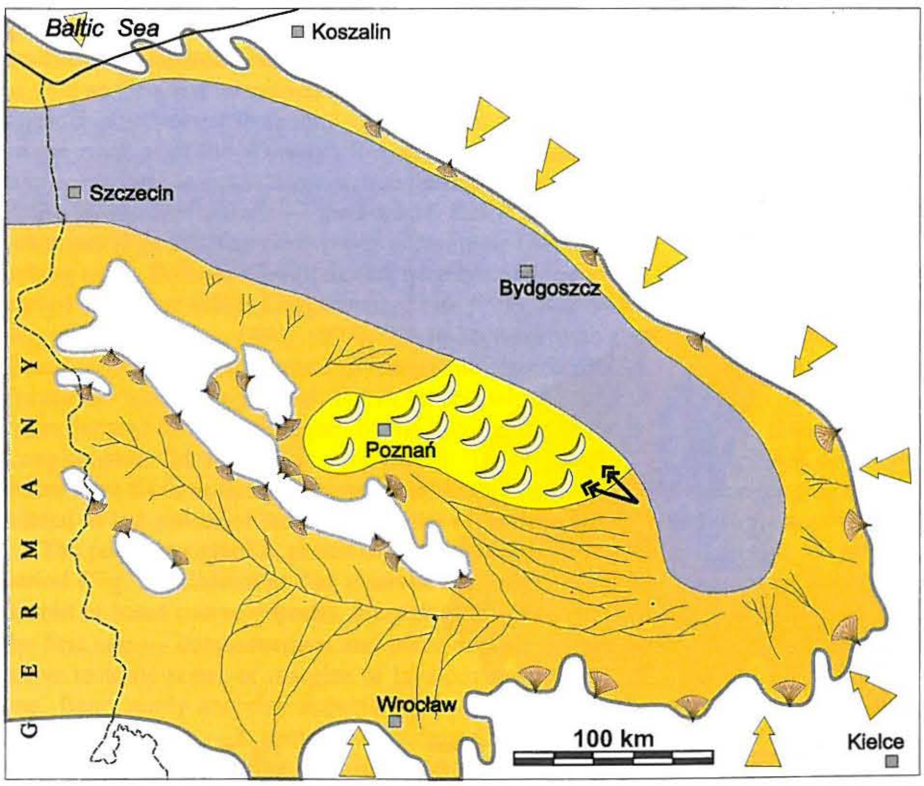
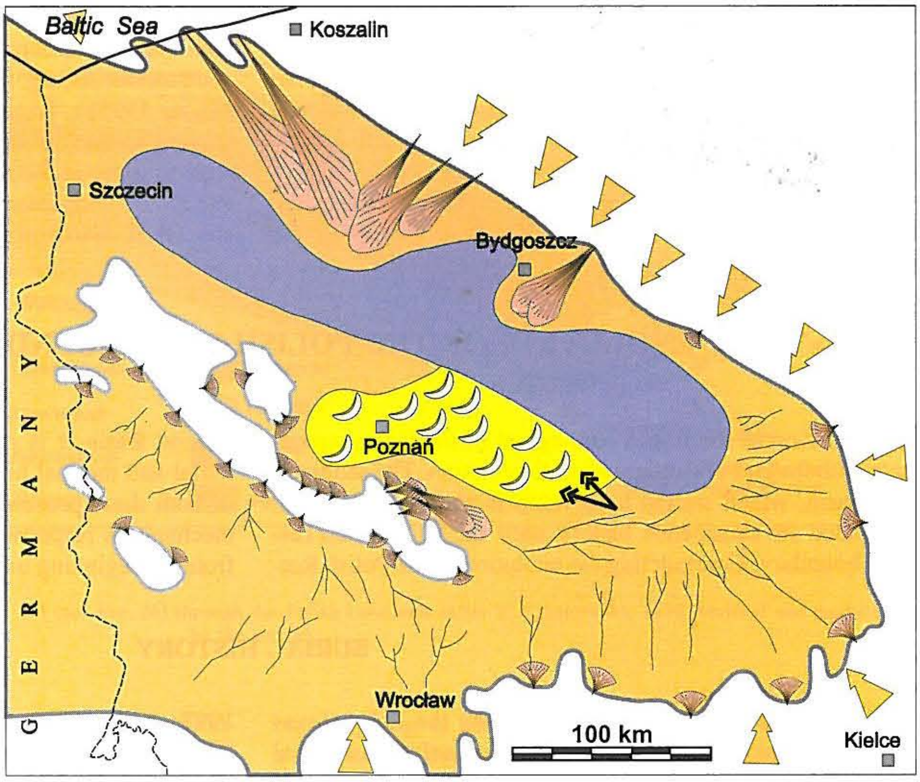


Fig. 23. Post-main dry sequence (4) palaeogeography.

Fig. 24. Late tectonic sequence (5) palaeogeography.



Pre-Zechstein sequence (6)

The last sequence is related to a period of final clastic sedimentation in the Polish Rotliegend Basin. It is bounded from the top by marine deposits — in this case, the continental sediments were transformed by the invading Zechstein sea. During this phase of the basin development the palaeogeography significantly changed: the extent of aeolianites increased distinctly towards the Lower Silesia area (Fig. 25). According to the author's opinion such a change was caused

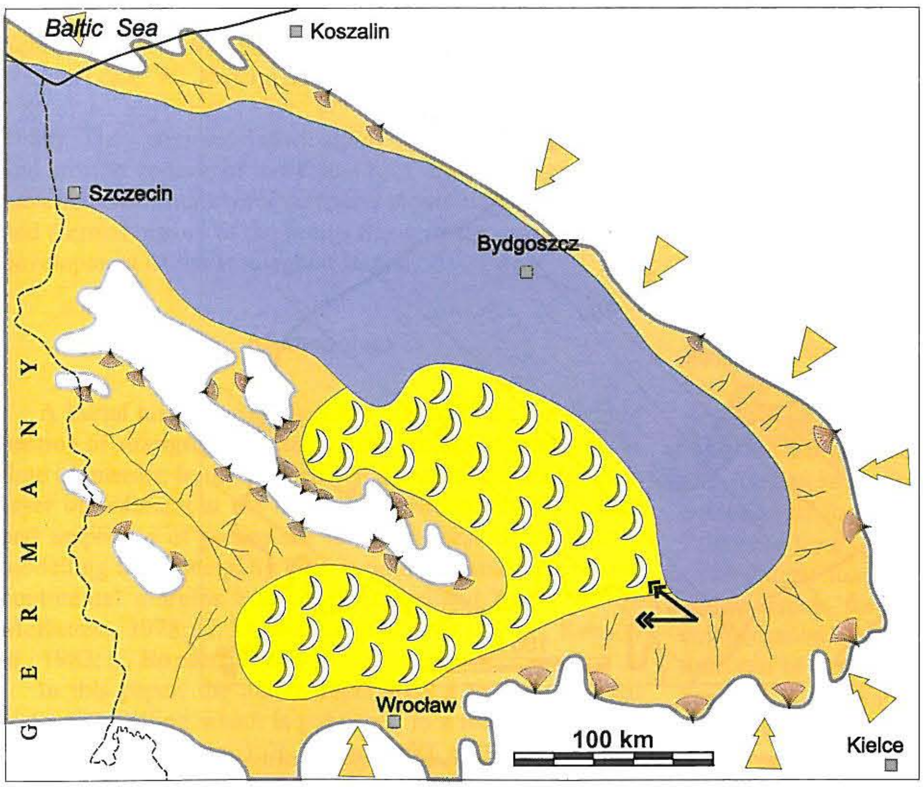


Fig. 25. Pre-Zechstein sequence (6) palaeogeography.

by no extraordinary event (aeolian sedimentation continued from the beginning of the main dry sequence in the Poznań region), but it resulted from increased subsidence rate in the eastern part of the Lower Silesia subbasin. This subsidence caused a favourable hydrological system of a shallow subsurface groundwater level and enabled preservation of former dune fields by their overburden. The invaded Zechstein sea flooded various older deposits: clay sediments of the central lake, dune fields with dunes several tens of meters high and fluvial deposits as well as areas devoid of Rotliegend sediments, e.g. the Wolsztyn Ridge (P. H. Karnkowski, 1986a, 1995b). Rapidly transgressing sea only partly destroyed former relief, the remains of which are visible in copper mines in the Lower Silesia region, and may be reconstructed with seismic and drill data in the Wielkopolska area (P. H. Karnkowski *et al.*, 1997b).

EVOLUTION OF THE POLISH ROTLIEGEND BASIN-FILL

Evolution of the Polish Rotliegend Basin did not terminate with the end of Rotliegend sedimentation. The sedimentary basin, which started to develop in the early Permian, continued its subsidence history until the Cretaceous/Tertiary boundary. Commenting the evolution of the Polish Rotliegend Basin it is necessary to consider also all its later burial and thermal history. Reconstruction of main features of both these processes will enable to recognize better the mechanisms responsible for the Polish Basin development, from its beginning until its Laramide inversion.

BURIAL HISTORY

Fourteen geological sections, crossing the Polish Lowlands (P. Karnkowski, 1979), were a basic analytical material for such a reconstruction. They were revised and corrected by the author as well as compared with materials applied for the elaboration of maps of horizontal cutting (Z. Kotański, 1997a, b; the present author cooperated in the preparation of these maps). Other new, unpublished geological cross-sections have also been done (P. H. Karnkowski, 1996b). The location of all sections is presented in **Fig. 26**. One selected cross-section — VII (as an example) applied in this paper as

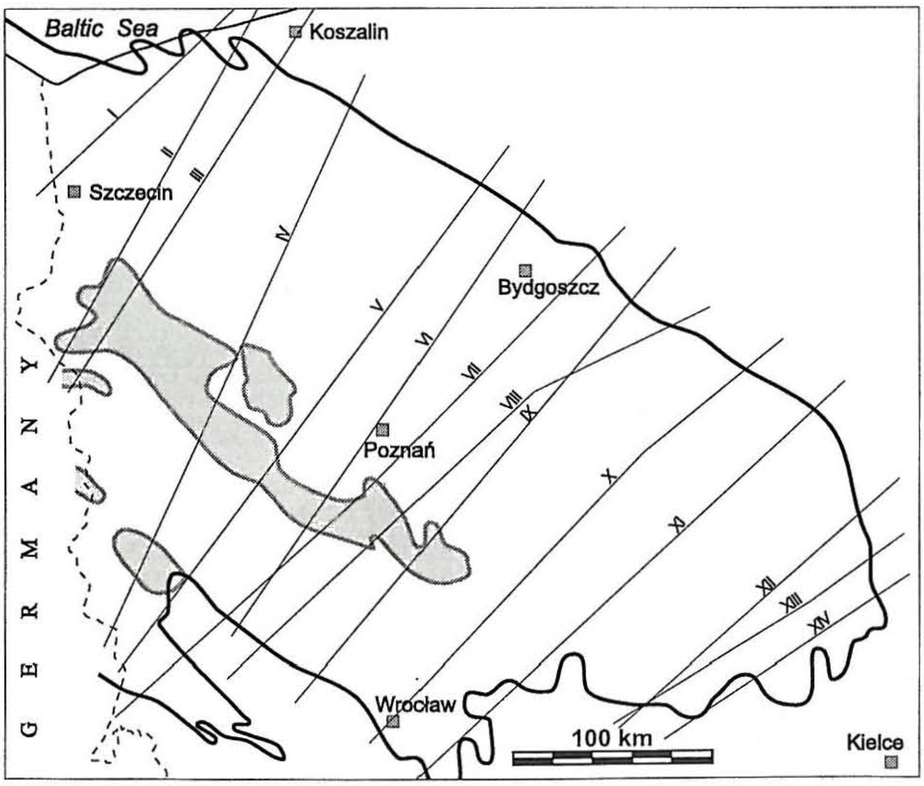


Fig. 26. Location of the geological cross-sections used by the author for burial and thermal analysis.

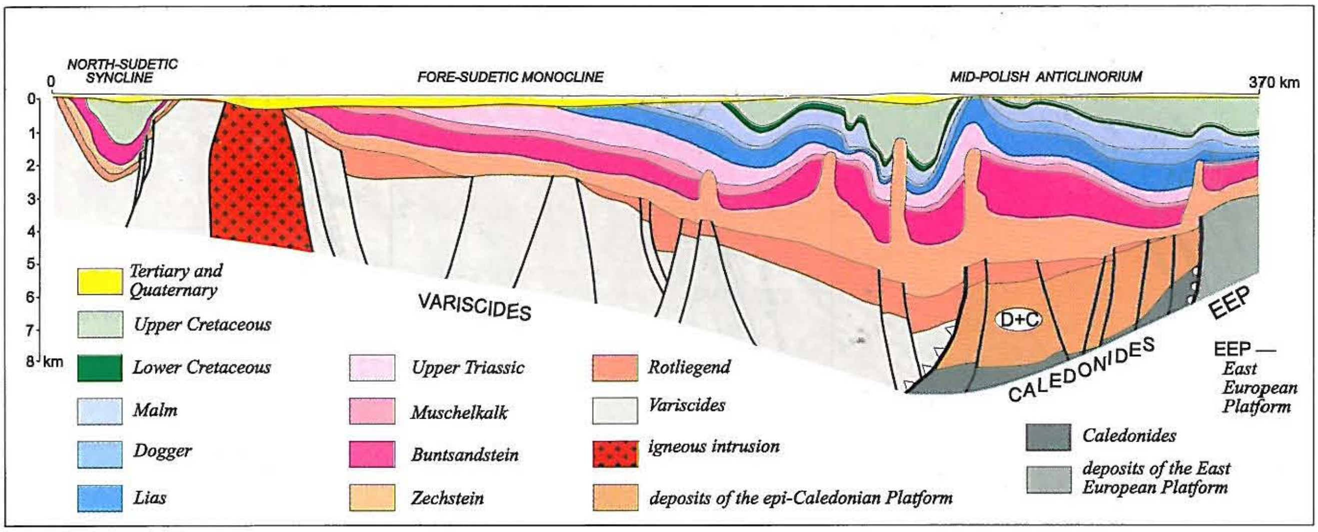


Fig. 27. Geological cross-section along line VII (see Fig. 26) through the Polish Lowlands (after P. Karnkowski, 1979, verified and modified by the author).

a geological background for final images of computer simulation and for illustration of organic matter maturity in the Polish Basin is also presented here (Fig. 27).

The geological sections mentioned above have been used mainly for collecting numerous data, applied later in computer modelling. To obtain the most complete and credible data, many geological maps have been additionally used, especially these ones enclosed in publications of the Polish Geological Institute (R. Dadlez, 1987a, b, 1989; K. Dayczak-Calikowska, W. Moryc, 1988; Z. Deczkowski, M. Franczyk, 1988a, b; J. Gajewska, 1988a, b; M. Jaskowiak-Schoeneichowa, A. Krassowska, 1988; S. Marek, 1988; T. Niemczycka, W. Brochwicz-Lewiński, 1988; J. Pokorski, 1988a; A. Szyperko-Teller, W. Moryc, 1988; R. Wagner, 1988). They supplied informations on thickness, lithology and erosion volume of individual rock units. Collected data have been used mainly for computer modelling of subsidence and thermal history of the Polish Basin which started the rift development of the Rotliegend Basin.

Methodology

A burial history analysis relies primarily on the decompaction of stratigraphic units to their correct thickness at the time of interest. It also depends on the water depths for each layer of sediment at the time of deposition and the timing and amplitude of palaeo-sea level changes. Burial history modelling has principally been used in the study of passive continental margins and other extensional basins (D. P. McKenzie, 1978; G. D. Karner *et al.*, 1983; C. E. Keen *et al.*, 1983; L. Royden, 1986).

In this paper, the author reports on a PC-based burial history modelling which is published in a manual for basin analysis (P. A. Allen, J. R. Allen, 1990, p. 278–281). This programme (**BS** – the present author abreviation) is based on backstripping to reconstruct the depositional and tectonic basin history. Backstripping, as discussed by M. S. Steckler, A. B. Watts (1978), involves a removal of sediment loads and also water loads due to changes in sea-level. The result of this process is the calculation of the total subsidence and tectonic subsidence in the absence of surface loads.

For purpose of modelling the tectonic subsidence in the Polish Rift Basin, a set of pseudo-wells located along geological cross-sections (Fig. 26) was prepared. Geological log for each pseudo-well was compiled on the basis of palaeothickness and facies maps of the Permian to Upper Cretaceous stages in Poland (K. Dayczak-Calikowska, W. Moryc, 1988; Z. Deczkowski, M. Franczyk, 1988a, b; J. Gajewska 1988a, b; M. Jaskowiak-Schoeneichowa, A. Krassowska, 1988; S. Marek, 1988; T. Niemczycka, W. Brochwicz-Lewiński, 1988; J. Pokorski, 1988a; A. Szyperko-Teller, W. Moryc, 1988; R. Wagner, 1988). Erosion events were considered as well. For each stage average lithology was established.

The geological time scales of W. B. Harland *et al.* (1989) and M. Menning (1995) were adopted for the analysis. The Rotliegend time used in the modelling is restricted only to the Upper Rotliegend (above the volcanic formation) and this time is evaluated as 15 Ma.

In this study, a one-dimensional (1D) deterministic model was used to reconstruct the burial processes related to the evolution of the Polish Rift Basin from Rotliegend to the Paleocene time.

Sediment loading takes an account of crustal isostatic compensation, for which two mechanisms (local isostatic compensation, and flexural or regional isostatic compensation) can be used (A. B. Watts, W. B. F. Ryan, 1976; M. S. Steckler, A. B. Watts, 1978; G. D. Karner *et al.*, 1993). All the models of isostatic compensation are based on the Archimedes' principle. In the first mechanism, the lithosphere is regarded as an elastic plate, in which columns of

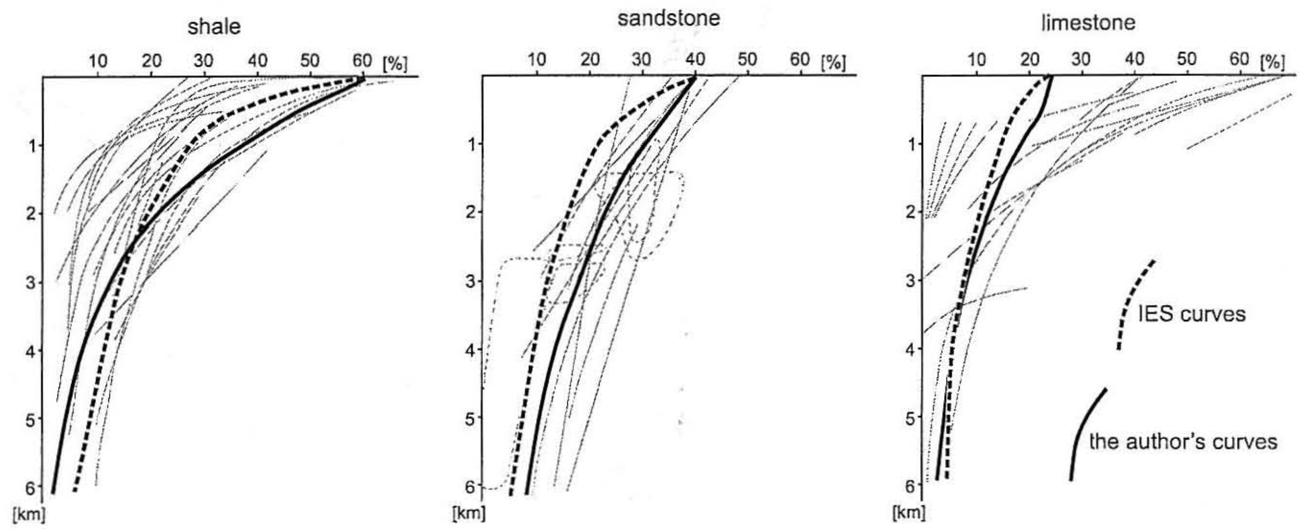


Fig. 28. Depth-porosity curves used in the IES-PetroMod application and the author's curves used in the backstripping procedure on the background of empirical curves defined by different authors (see IES-PetroMod, 1993).

sediment move independently of one another (Airy-type isostasy). In the second mechanism, the lithosphere is regarded as an elastic plate, in which compensation occurs at a regional scale (flexural isostasy). Because the Polish Rift Basin is an intracratonic basin, with a relatively simple tectonic history, the Airy-type isostatic model was chosen to calculate the tectonic subsidence (G. C. Bond, M. A. Kominz, 1984).

One of the significant factor considered for tectonic subsidence calculation is the compactional correction. Relation between a porosity-depth variability is a problem still under studies and the results obtained are distinctly different for some lithological types. Despite such differences it is an average paramater statistically chosen *(c)*, defining porosity-depth relation and it is applied for elaborated algorithms. In the case of BS program, used by the author, such a procedure is more complicated because the author coincidentally operated application of another program (PetroMod) for a reconstruction of a thermal history, in which values of the coefficient *(c)* became arbitrarily defined by the program designer. To nivelate a difference between coefficient values used by both programs the author has calculated such values of coefficient for individual lithological types that depth-porosity resulted curves are relatively comparable. Figure 28 illustrates differences between the original parameters of PetroMod program and the values accepted by the author. The curves used here are presented on a background of empirical results of a depth-porosity relation, obtained by various scientists for three main lithologies: shales, sandstones and limestones.

This assumption, commented broadly above, became very significant, because it enabled a controll of calculation correction by two independent programs (BS and PetroMod). Although the PetroMod program calculates only total subsidence instead of tectonic one, it can be easily comparable with results obtained by BS program. In both these programs a total subsidence value includes a compactionally corrected deposit thickness and palaeobathymetric and palaeoeustatic correction values because a burial depth is commonly related to a sea level. Two figures (Figs. 29, 30) illustrate a lowering of the Rotliegend top at the end of Jurassic and Cretaceous. Data for these map processing came from values calaculated by PetroMod program and they are related to contemporary sea level. These maps will be later commented in detail but the methodology of subsidence calculation used for their construction should be emphasized here.

For the analysis of basin burial history the value of tectonic subsidence is very useful, being the value of tectonically controlled sinking, without overloading of any deposits. Commonly such calculations are realized for well sections. In a case of the basin discussed, with irregular borehole distribution but with sufficient seismic sections, several thousands of such pseudo-well sections have been prepared basing on the existed maps. Such a procedure was introduced earlier (e.i. R. Dadlez *et al.,* 1995) and it seems to have rational principles. The second reason for choosing this method of construction of pseudo-wells, located along 14 presented sections, was to show a range of tectonic subsidence not only in a time span but first and foremost in its spatial pattern. Several maps were constructed (Figs. 31–39), which present a scale of tectonic subsidence for individual geological epochs or periods. The method proposed here to mark the areas with defined intervals of tectonic subsidence value, seems to be more appropriate for the whole basin characteristics because it underlines the main basin elements and better illustrates the dominated regions. One aspect of such data generalization should also be emphasized. It is the problem of error scale, which accompanied each calculated value. Data applied for calculation are always average values (for instance — lithology, subsidence time or thickness data) and a final result may be charged with an error of 10–20% of real value (in some cases — more). Each such calculation,

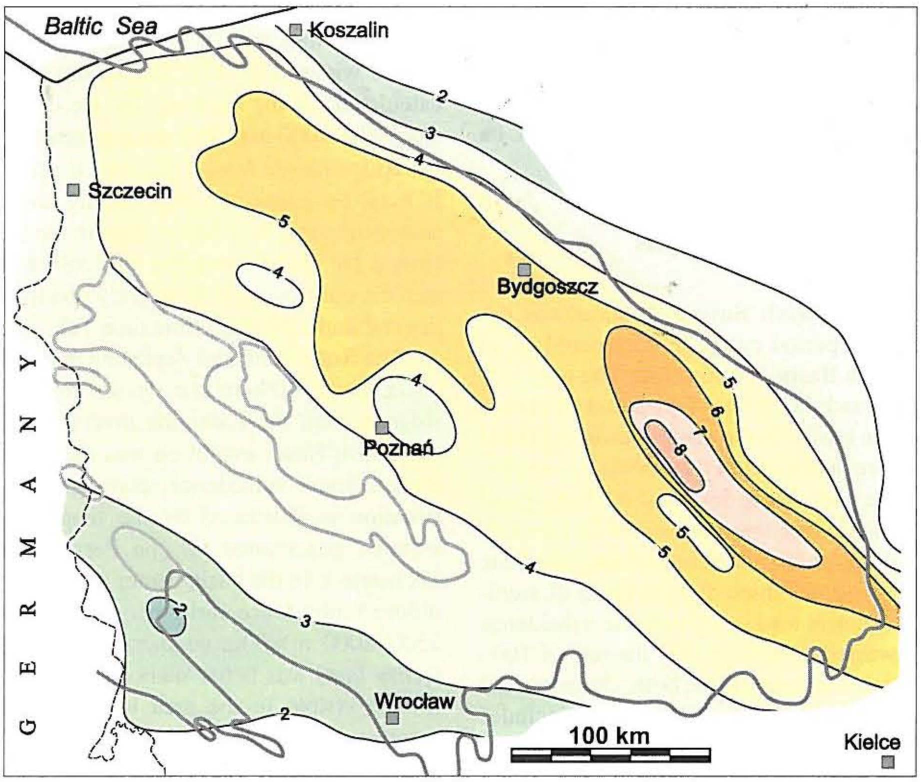


Fig. 29. Top of the Rotliegend at the end of Jurassic in the Polish Basin (below sea level in km).

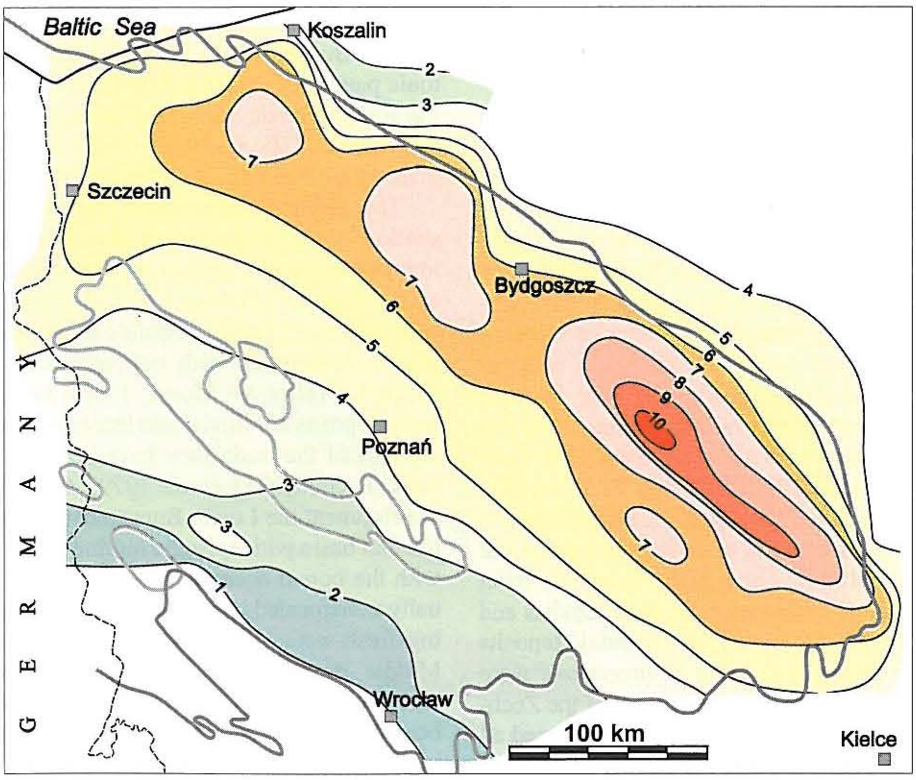


Fig. 30. Top of the Rotliegend at the end of Cretaceous in the Polish Basin (below sea level in km).

related to the whole sedimentary basin, due to irregular distribution of data reliability must be considered in some mistrust interval, estimated by the author at ±10%. Values, numbered on these maps, have not included palaeobathymetric and palaeoeustatic corrections. This problem will be presented and discussed in the chapter on the page 66.

Tectonic subsidence analysis

The first stage of the Polish Basin evolution was the Rotliegend. The volcanic period could be considered as an earliest stage of the Polish Basin development. The post-volcanic sediments had already a distinct facies and thickness pattern within the whole basin. In the central, most subsided basin part clay facies prevailed and in the remaining area — sandy and conglomerate ones. More details of the Rotliegend stratigraphy and sedimentology were presented in previous chapters. The map of tectonic subsidence during the Late Rotliegend (Fig. 31) illustrates three distinct areas of significant subsidence: the central area, with tectonic subsidence of 250–750 m, southwestern subbasin with the rate of 100–500 m and the area located between these both, characterized by subsidence value of 0–100 m. The latter region includes the Wolsztyn Ridge, without a Rotliegend sediment cover, so calculated subsidence rate should be zero.

Commenting tectonic subsidence within the Late Rotliegend basin a distinction of the area without or very low (0–100 m) rate, which became less marked during later stages of the basin evolution should be underlined. This conspicuous belt with very low tectonic subsidence was clearly related to contemporaneous thermal field, what is profoundly explained in the chapter on thermal history of the basin.

The Zechstein transgression invaded the Rotliegend Basin of a clearly defined pattern. The whole area of former Rotliegend deposition was flooded and the transgression extended farther, especially onto the East European Platform. Such a wide marine expansion resulted from a very low position — beneath sea level — of the Rotliegend basin bottom. This also enabled a rapid transgression (P. H. Karnkowski, 1986b) onto highly peneplenized area of the East European Platform. The epicontinental Zechstein sea was shallow, with a limited connection with the Late Permian marine basin, extending in the area of recent Arctic. Dry and hot climate favoured evaporitic sedimentation. The three oldest Zechstein cyclothems (PZ1, PZ2 and PZ3) are of a carbonate-evaporite character. The youngest PZ4 cyclothem with its 5 sub-cyclothems consists of terrigenous-evaporite sequences (R. Wagner, 1994). The peripheries of the relict basin limited due to saline evaporation became sebkhas and playas where sedimentation of red continental deposits prevailed. In a more inland area these environments were replaced by rivers, lakes, and dunes. At the turn of the Zechstein sedimentation of red continental deposits dominated all over the entire basin. Predominantly, the Zechstein deposits are overlain by Lower Buntsandstein ones, under which the original extents of the Zechstein cyclothems have been preserved.

The main areas of tectonic subsidence during the Zechstein were the same as in the Late Rotliegend but they extended wider (Fig. 32). The values of tectonic subsidence calculated for the basin center are of 500–750 m (sporadically 750–1000 m). Only the southeastern part of the Wolsztyn Ridge (*sensu lato*) distiguished itself in basin dynamics. It may be suspected that during the Zechstein tectonic subsidence rate was higher than in the Rotliegend. It is confirmed by calculations but palaeobathymetric and palaeoeustatic corrections may slightly change this image for Rotliegend and Zechstein time (see Tab. 1, p. 67).

The Rotliegend and Zechstein period lasted about 20 mln years, about 10% of the whole time of Polish Basin subsidence, until the Laramide inversion. This initial phase of the Polish Basin evolution was characterized on extremely high tectonic subsidence, compared to later phases. This situation is illustrated by the map (Fig. 33) of summary tectonic subsidence for the Permian (Late Rotliegend + Zechstein). In the basin center the total value of tectonically induced subsidence varies between 1000 and 1500 m (locally 1500–2000 m). The southern part of the Wolsztyn Ridge *(sensu lato)* was better marked than the northern one, what is best visible in the area located northeast of Wrocław. Another area of relatively higher tectonic subsidence (Lower Silesia Subbasin) was located northwest of Wrocław. During the whole Permian the majority of areas located southwest of the most subsiding part of the Polish Basin was characterized by the occurrence of several zones of higher and lower subsidence. These less subsiding zones during the part or the whole Late Rotliegend became denudated areas or had a very low subsidence rate.

The Buntsandstein Basin inherited the main palaeotectonic pattern of the Zechstein Basin. Its development during the Early Triassic continued as succesive phases of expansion and stagnation, with each next expansion more intensive than the former one.

The Early Buntsandstein sedimentary basin, initially shallow-marine, later a periodically drying inland basin of low salinity was a subject to sedimentation of fine-grained clastic deposits of a clayey and silty type, locally calcareous, with infrequent inserts of oolitic limestones and/or silty limestones, sometimes with concentrations of anhydrites (A. Szyperko-Teller, W. Moryc, 1988). Sandstones appearing in these deposits are fluvial and littoral origin; only in the southern part of the basin they have been defined as the aeolian ones (R Gradziński *et al.*, 1979). Only in its early stage of development the Lower Buntsandstein Basin was an epicontinental basin with episodic marine character, communicated with the boreal ocean in the west. Later on, the basin gradually transformed into a vast, closed and periodically emerging fresh-water oligotrophic lake. At the beginning of the Middle Buntsandstein, the basin recovered its expansive character. A southern seaway was opened with the Tethyan ocean. Sedimentation in the Middle Buntsandstein was taking place in a shallow intra-continental marine basin. A significant change became the northeastward displacement of the Mid-Polish Trough axis, increase of its subsidence gradient (A. Szyperko-Teller, W. Moryc, 1988) as well as ex-

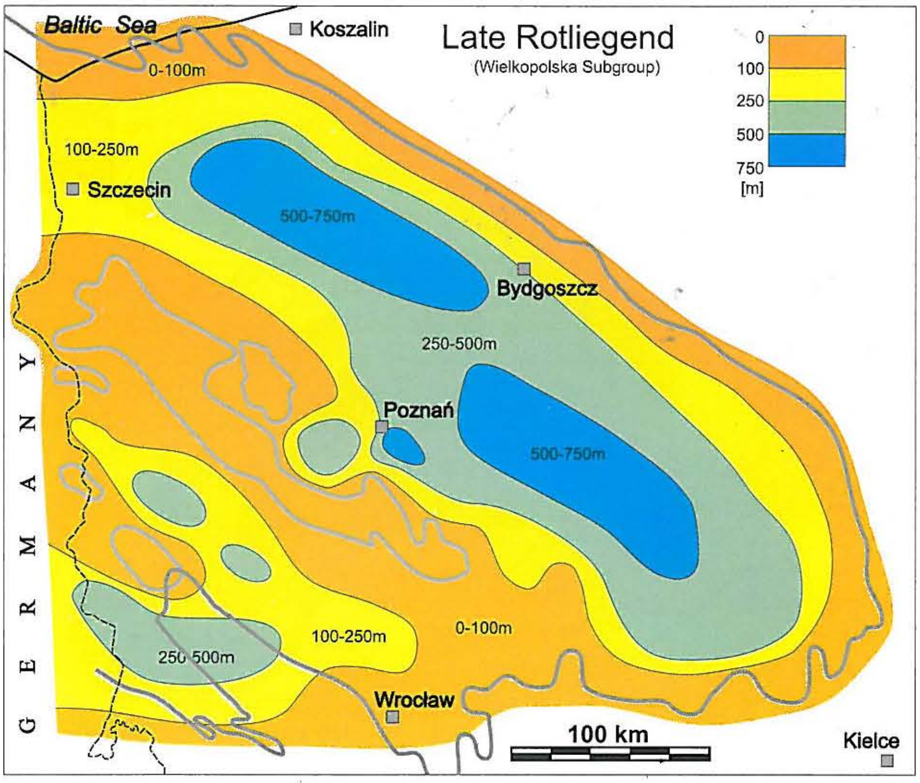


Fig. 31. Tectonic subsidence in the Late Rotliegend within the Polish Basin.

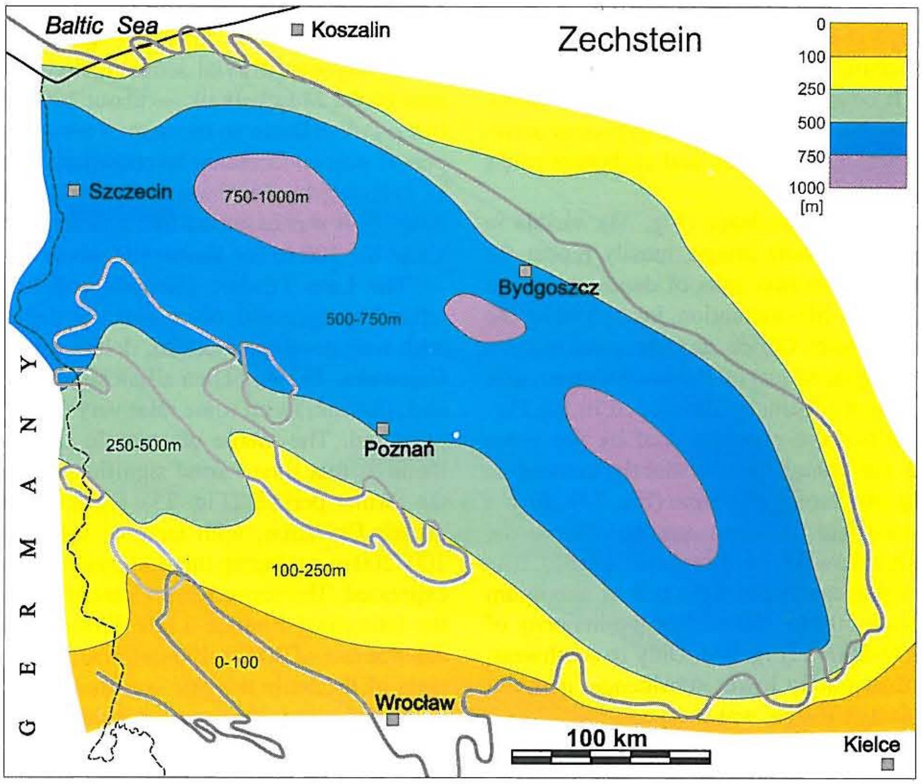


Fig. 32. Tectonic subsidence in the Zechstein within the Polish Basin.

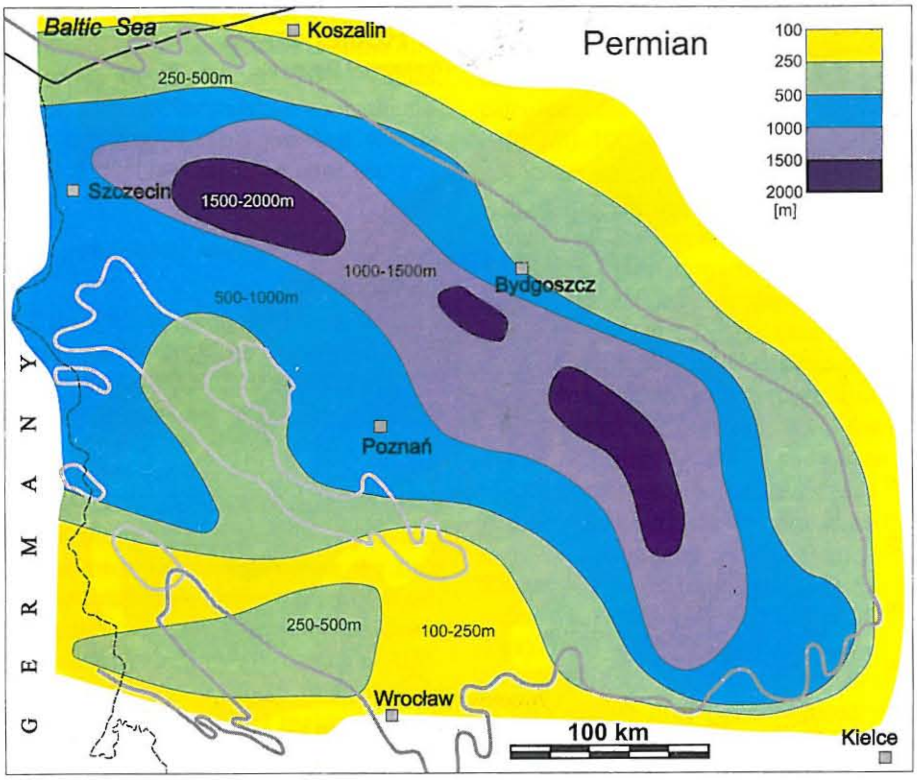


Fig. 33. Tectonic subsidence in the Permian within the Polish Basin.

tending of sedimentary basin frames in the area located northwest of the trough at that time.

The Roetian deposition was initiated with a transgression of the Tethyan Sea. It covered most of the area of Poland. Lithofacies of the Roetian developed as a gypseous-anhydritic cover with inserts of fine-clastic and carbonate rocks and seldom rock salts.

The zones of maximum subsidence (Fig. 34), visible in the Early Triassic palaeotectonic image, mostly repeat the former structures. They form two belts of depressions: the northeastern belt with NW–SE orientation, located along the margin of the East European Craton and the southwestern one of similar direction, placed just on the southwestern side of the Mid-Polish Trough (distinctly developed in the Permian). Both these belts were characterized by the same subsidence rate and the trough was distinctly marked as a dominant subsiding structure at that time (Fig. 34). Such a character of subsidence had not been acquired before the Lower Jurassic (Z. Deczkowski, M. Franczyk, 1988b). The tectonic subsidence value calculated for a belt of maximum depressions varied from 500 to 750 m. For the majority of the area it reached 250–500 m (Fig. 34). Only in southwestern Poland a zone of distinctly lower subsidence, partially belonging to the Wolsztyn Ridge, was marked.

The Muschelkalk sedimentary basin was a continuity of the former basin of the Late Buntsandstein. Sedimentation took place in a shallow epicontinental open sea; marine deposits of the carbonate lithofacies, predominantly limestones formed at that time. At the turn of the Muschelkalk and Keuper the sea retreated from the area of Poland. During the Early Keuper only a shallow inland basin existed in which deltaic-lagoonal-fluvial sediments were deposited. A thickness of the Muschelkalk — about 200 m — is very uniform in the Polish Basin so the map of tectonic subsidence for this period was unnecessary to construct because differentiation of calculated values would fall within limits of error. To simplify it was assumed that a tectonic subsidence rate was about 80–100 m for almost the whole basin area.

The Late Triassic (Keuper and Roetian) was characterized by lagoonal or continental deposition, the last one with well developed fluvial, deltaic and lacustrine facies (J. Gajewska, 1988b). Then siliciclastic sediments (sandstones and siltstones) with some relatively thick evaporitic interbeds prevailed. The image of tectonic subsidence in the Polish Basin at that time varied significantly from the patterns of the former periods (Fig. 35). Especially the Szczecin–Bydgoszcz Elevation, with tectonic subsidence rate of merely 100–200 m, replacing there a former subsiding zone was well expressed. The second new element developed later, became the latitudinal Słubice–Łódź Trough, with a tectonic subsidence rate of 300 to 400 m (locally up to 500 m). For other parts of the basin the rate was mainly 200–300 m. Hitherto presented maps of tectonic subsidence for the Permian and Triassic periods indicates that the clearly displayed frames of the Polish Basin in Permian time were intensively obscured at the end of the Triassic: primary subsidence centers were displaced or completely disappeared and the average tectonic subsidence rate — calculated for a time unit —

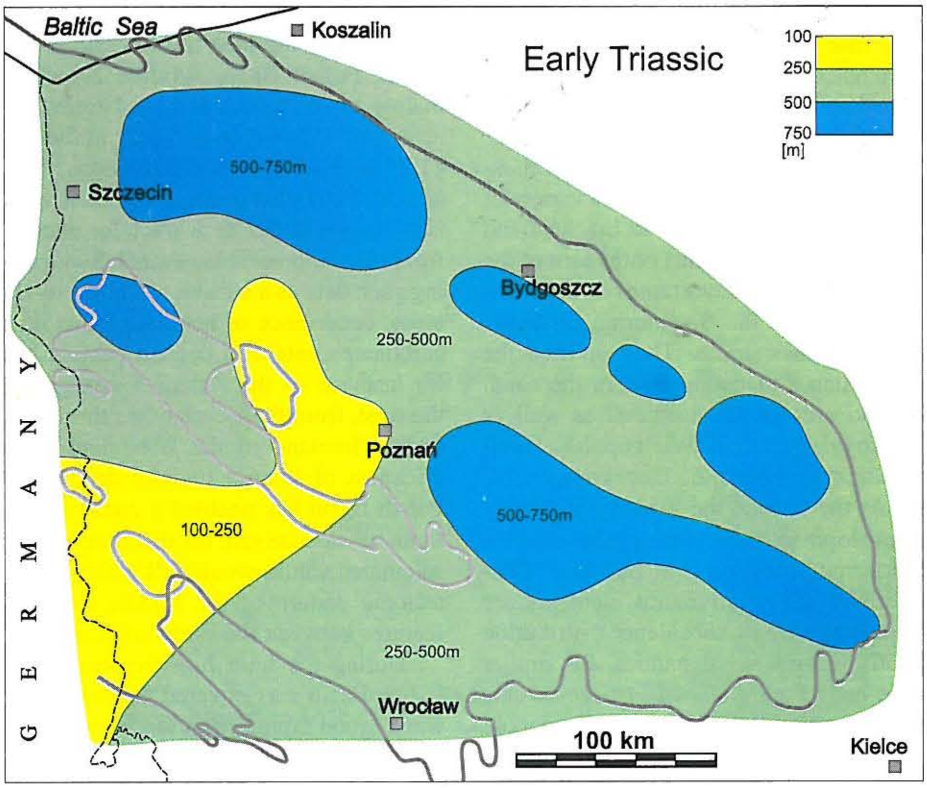


Fig. 34. Tectonic subsidence in the Early Triassic within the Polish Basin.

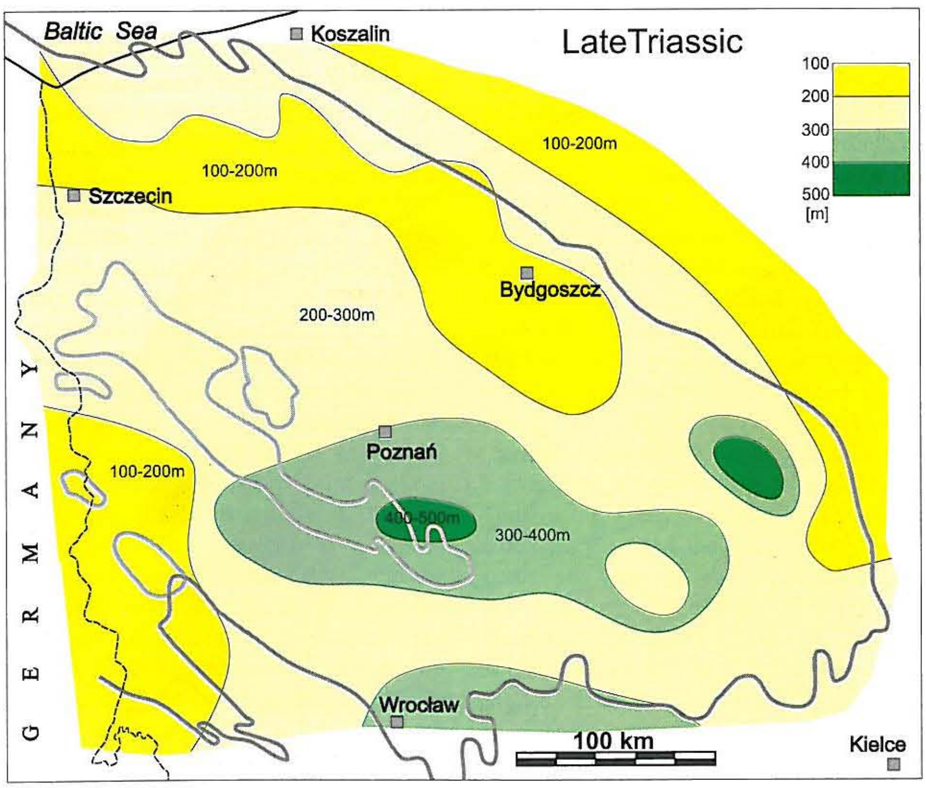


Fig. 35. Tectonic subsidence in the Late Triassic within the Polish Basin.

decreased from 50–100 m per 1 mln years during the Permian to 10–20 m per 1 mln years in the Late Triassic.

The Lower Jurassic epicontinental sediments in the Polish Lowlands developed in a vast inland basin which was several times affected by short-lasted marine ingressions. The Lower Jurassic sequences developed as a platform association of sands and clays, accumulated within a variety of sedimentary conditions from a fresh-water to brackish and marine environments. Tectonic movements of the turn of the Roetian and Early Jurassic defined new frames of sedimentary basin, which at the end of the Sinemurian distinctly differed from the latest Triassic basin. They uplifted the Sudetic domain and Silesian–Cracowian land in the south and the Mazury–Suwałki area in the northeast as well as some parts of the Wielkopolska region (Wielkopolska Swell - R. Dadlez, M. Franczyk, 1976; Z. Deczkowski, M. Franczyk, 1988a, b). At the turn of the Triassic and Early Jurassic the graben development took place in the zone located along the eastern margin of the East European Platform. All these described above structural elements are clearly visible on the map of tectonic subsidence distribution for this period (Fig. 36). Subsidence dynamics was similar as in the Late Triassic but location of main palaeotectonic elements was different. The Mid-Polish Trough was marked again as a group of depocenters, located directly along the margin of the East European Platform. Such a situation was partially stimulated by the formation of the Wielkopolska Swell.

Middle Jurassic sedimentary basin became remarkably expansive so the next transgressions occupied a wider area of the Polish Basin. Middle Jurassic sediments consist mainly of claystones and sandstones and its average thickness is of 150–400 m and only in the Kutno region — up to 1100 m (K. Dayczak-Calikowska, W. Moryc, 1988). The area of dominated tectonic subsidence was still the Mid-Polish Trough, acted as a tract for successive transgressions from the southeast. However, J. Świdrowska (1994) comparing such data as a subsidence intensity, lability of denudated areas, occurrence of nektonic fauna of open sea as well as carbonate content in deposit cement has suggested that — for instance — the Aalenian transgression developed from the west, from the German Sea through a depression formed on the foreland of the Bohemian Massif. Relatively low thickness of Middle Jurassic deposits in most areas of the Polish Basin has unabled a construction of the map of tectonic subsidence rate for this time because differentiation of calculated values would fall within limits of error. A palaeotectonic pattern of the Middle Jurassic shows transitional features between the Early and Late Jurassic.

During the Late Jurassic almost the entire area of the Polish Basin was covered by the epicontinental sea. There was a good communication with the Tethyan ocean to the south and with a boreal sea to the north as well as with marine basins in both the western and eastern directions. The nature of the basin was regressive, gradually contracting as far as a size of a small basin was formed, with its waters

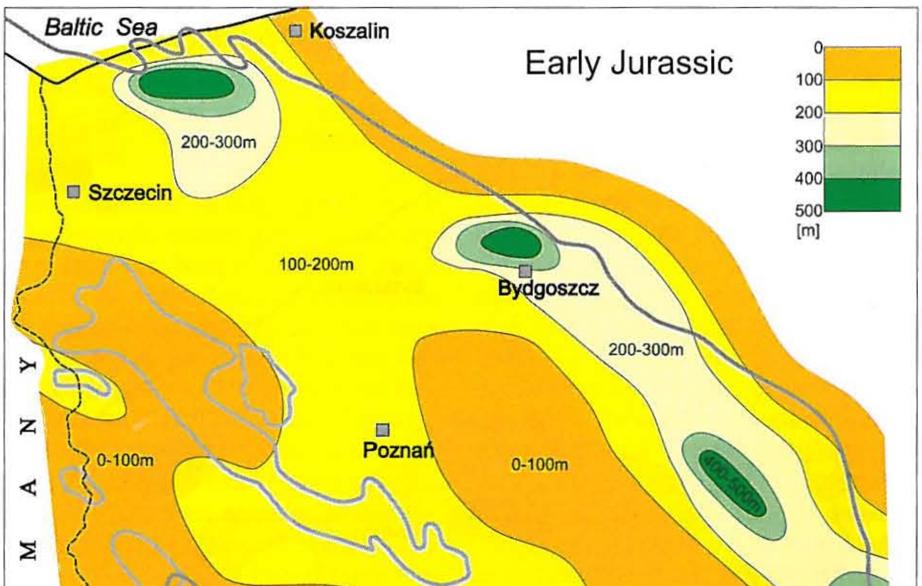


Fig. 36. Tectonic subsidence in the Early Jurassic within the Polish Basin.

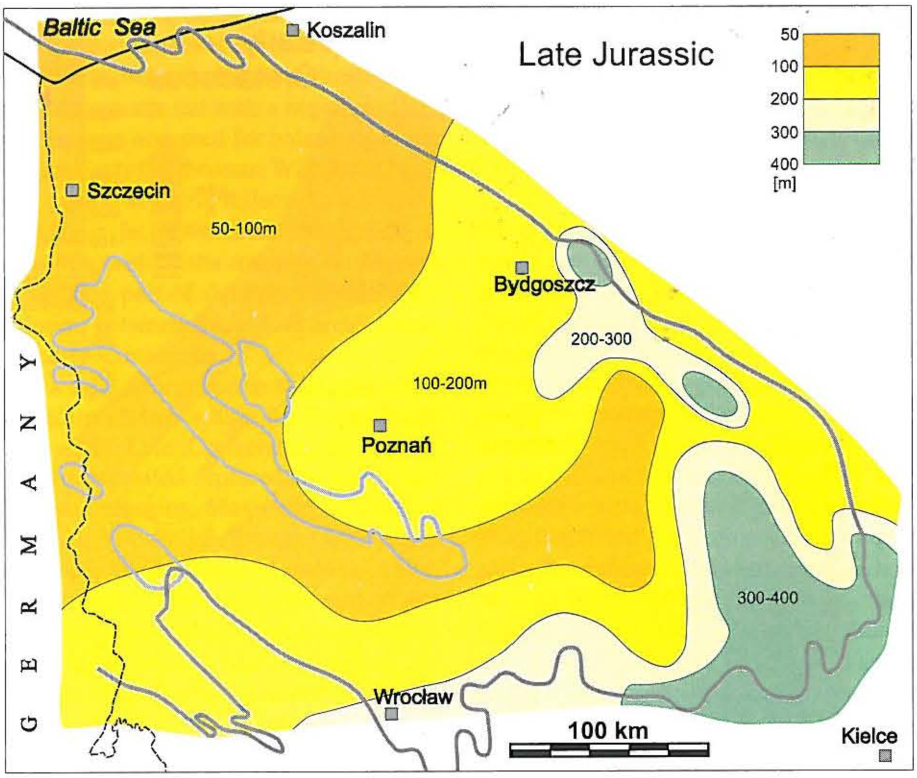


Fig. 37. Tectonic subsidence in the Late Jurassic within the Polish Basin.

freshened at the end of the Jurassic (T. Niemczycka, W. Brochwicz-Lewiński, 1988). Calculated tectonic subsidence rates indicated a significant dynamic variability within the basin (Fig. 37). Its northern part was characterized by a very low rate (50–100 m). Tectonic activity renewed in the southern part of the basin was expressed as an extended area of increased tectonic subsidence. Such an extension of the Polish Basin developed during the Late Jurassic mainly in subhorizontal transtensional conditions in the NNE–SSW direction (M. Hakenberg, J. Świdrowska, 1997).

Due to tectonic activity and loading subsidence the Rotliegend deposits in the Polish Basin were subsided locally to a significant depth already at the end of the Jurassic. In the Mid-Polish Trough the Rotliegend top was situated at about 8 km below contemporaneous sea level (Fig. 29). Maximum value of total tectonic subsidence for this top occurred along the margin of the East European Platform, defining the contour of the Mid-Polish Trough. This trough is divided into two segments: its southern part is narrow and deep, and the northern — wider and shallower. The boundary between them is located along the Bydgoszcz latitude. Although, individual areas of lower and higher subsidence existed during the Permian–Jurassic history of the basin evolution, changing location with time, the summary image at the end of the Jurassic displays two dominant zones: the trough and its low-inclined southwestern slope. Such a pattern was characterized mainly by a short Late Permian–Early Triassic episode, lasted about 25 mln years, when about 80% of Permian–Triassic sediments were accumulated. Presentation of the map of the Rotliegend top subsidence at the end of the Late Jurassic aimed to illustrate a scale of basin loading by infilling sediments. Concentration of such a great amount of deposits within the Mid-Polish Trough caused that a loading subsidence component in total subsidence prevailed over tectonic subsidence. Loading resulted from a significant water weight of invaded sea, might have caused (and really did it) a subsidence of basin bottom as well as a development of additional accomodation space for newly formed sediments. Within the Mid-Polish Trough, showing a maximum thickness of Permo-Mesozoic deposits, this phenomenon could develop more easily than in other parts of the Polish Basin.

At the turn of the Jurassic and Cretaceous the southwestern margin of the Polish Basin was uplifted and eroded. During the Early Cretaceous continuous deposition took place only within the Mid-Polish Trough. This basin was connected with two palaeogeographic provinces: the boreal province in the northwest and the Tethys in the south, and southeast (S. Marek, 1988). In the Fore-Sudetic area all Jurassic and a part of Triassic deposits were eroded so the Upper Cretaceous transgressive sediments overlie there the Buntsandstein or Muschelkalk series. Demonstration of burrowing and erosion phenomena on the map of tectonic subsidence requires application of negative values of this parameter (Fig. 38). As during burrowing a part of subsidence results from a tendency to achieve isostatic balance

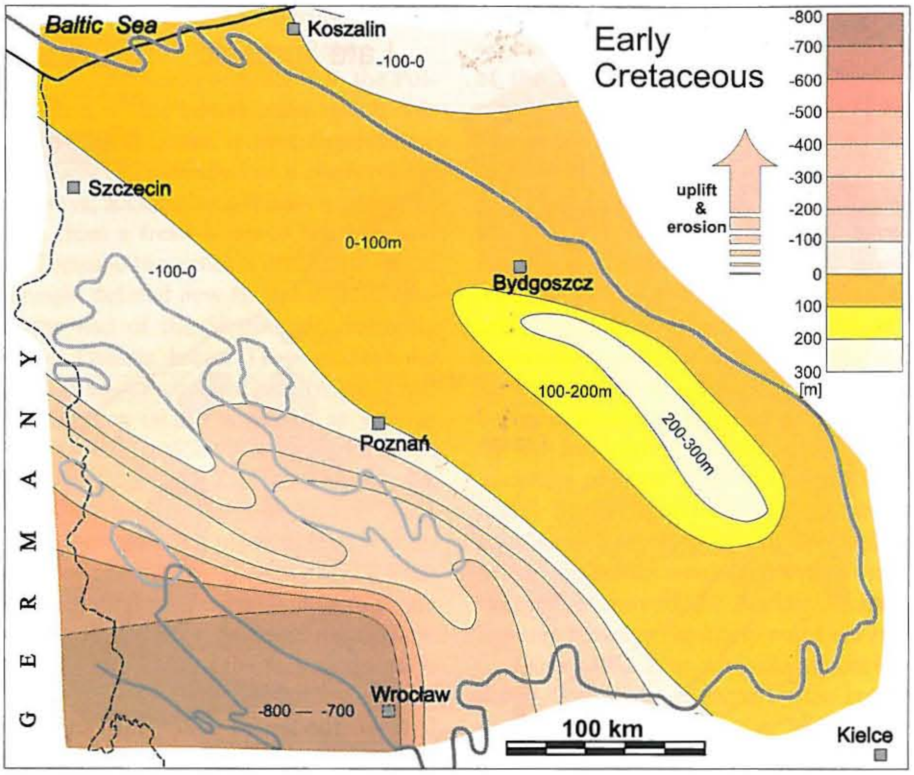


Fig. 38. Tectonic subsidence in the Early Cretaceous within the Polish Basin.

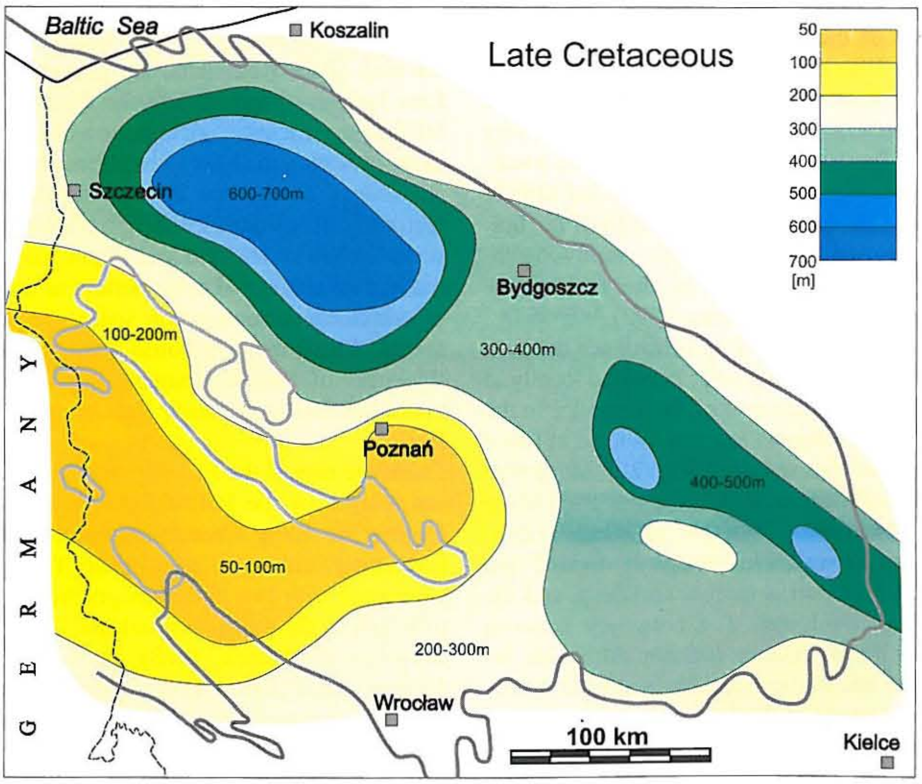


Fig. 39. Tectonic subsidence in the Late Cretaceous within the Polish Basin.

so the similar assumptions refer to erosion phenomena, when removing of a part of overburden should involve uplifting of the examined area to preserve isostatic balance. Erosion was considered as a subsidence process but with a negative effect (Fig. 38). Such principles were accepted for balancing of the tectonic subsidence of the Early Cretaceous. Within the Mid-Polish Trough, only its central segment reflected a relatively high influence of a tectonic factor in basin subsidence. It should be noticed that this part of the trough was located opposite to the most uplifted part of the Fore-Sudetic area. A genetic-tectonic relation between these both areas seems very close during the Early Cretaceous.

During the Albian a new transgression took place and a vast area of marine sedimentation within the Polish Basin continued during the whole Late Cretaceous. In the depocenter carbonate facies prevailed replaced by marly and sandy deposits in the basin margins. Maximum subsidence rate was situated within the Mid-Polish Trough (J. Kutek, J. Głazek, 1972; W. Pożaryski, W. Brochwicz-Lewiński, 1979; M. Hakenberg, J. Świdrowska, 1998). At the turn of the Cretaceous and Tertiary this area was submitted to a tectonic inversion and the Mid-Polish Anticlinorium developed. Its uplift was accompanied by significant erosion, which removed mainly Cretaceous and a part of Jurassic deposits. The southwestern part of the basin also emerged and most of the Upper Cretaceous series, located there, were eroded. Basing on sections of the Upper Cretaceous deposits within synclinories and reconstructed thickness of eroded parts, the calculated value of tectonic subsidence during the Late Cretaceous was presented on a separate map (Fig. 39). It documents that dominant subsidence rate for the Mid-Polish Trough was 300–500 m but locally up to 600–700 m.

The Late Cretaceous transgression was the largest one in the history of the Polish Basin. It widened connections with the Tethys or seas located on the East European Platform and it flooded almost all Europe, leaving widespread carbonate (chalk) lithofacies. This phenomenon (especially in the case of the Late Cretaceous sea level rise as well as a water depth in the basin) have a significant influence on a proper calculation of tectonic subsidence rate. This value on all the presented maps was calculated without palaeoeustatic and palaeobathymetric corrections. But these corrections have not been omitted. In geological modelling of the Polish Basin with PetroMod program such corrections are implied in the algorithm, so it was able to estimate the most reliable value of maximum subsidence of the Rotliegend top at the late Upper Cretaceous. In the earliest Late Jurassic this top — within the Mid-Polish Trough — was located at the average depth of 7 km beneath contemporaneous sea level but at the end of the Cretaceous it locally reached a depth of 8–10 km (comp. Figs. 29, 30).

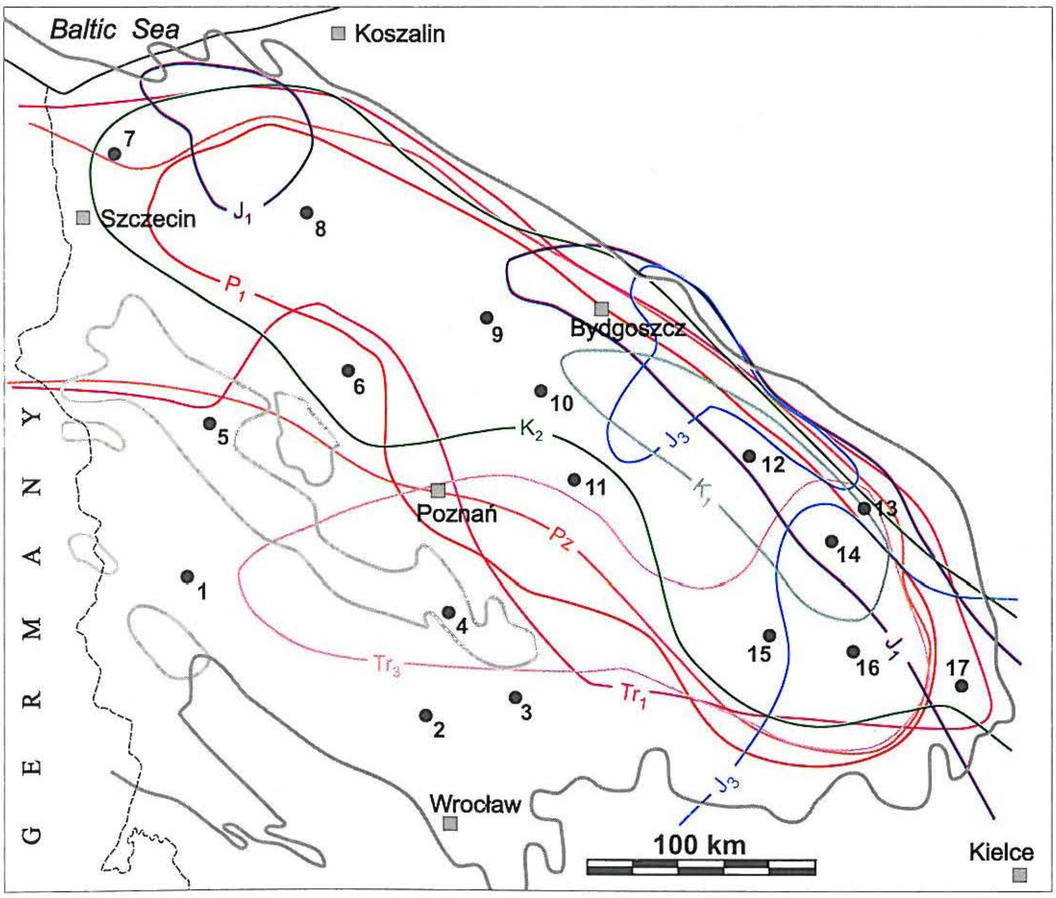


Fig. 40. Permo-Mesozoic depocentres of tectonic subsidence in the Polish Basin (tectonic subsidence curves for points 1–17 are presented in Fig. 41).

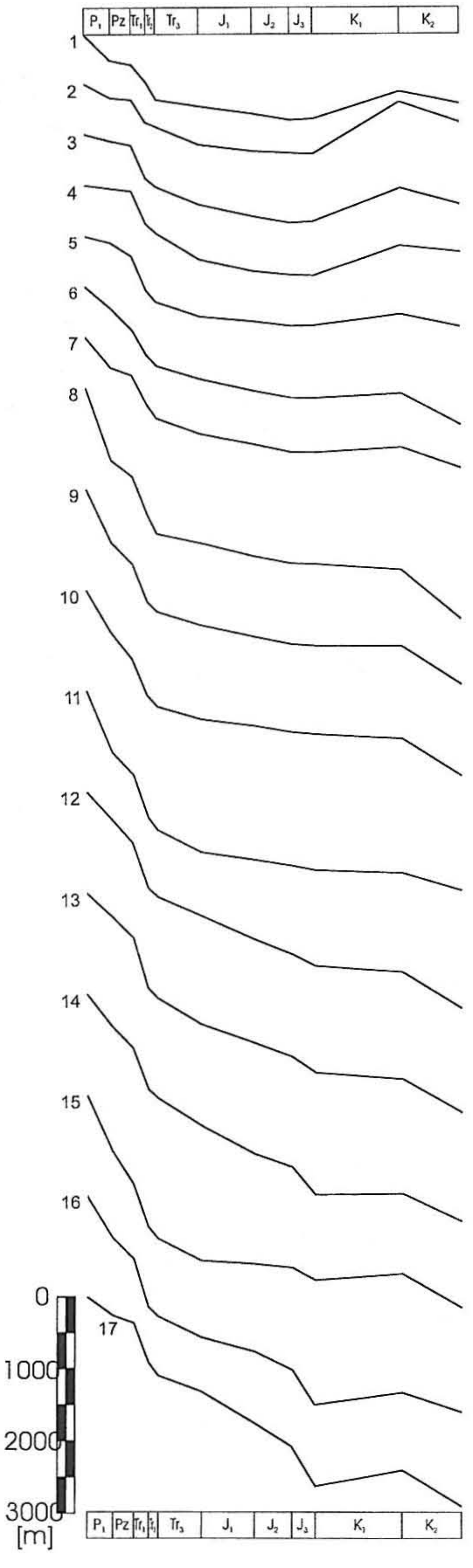


Fig. 41. Tectonic subsidence curves for characteristic places of the Polish Basin (see Fig. 40 for points 1–17 location).

The analysis of tectonic subsidence demonstrates distribution of subsidence values for each stage of the Polish Basin evolution. Location of subsidence centers indicates that they were mainly related to the Mid-Polish Trough. It is better visible on the summary map, illustrating position of main areas of tectonic subsidence and contour of the Polish Rotliegend Basin as a background (Fig. 40). The margin of the East European Platform is especially remarkable there. It limited a development of tectonic subsidence from the north-east. A propagation zone of subsidence centers but of smaller scale is also noticeable in the south-west.

To characterize individual parts of the sedimentary basin, some estimations of tectonic subsidence rates during the Permo-Mesozoic period have been done. A dozen or so representative sites were chosen for each basin part (Fig. 41). These points do not represent individual boreholes although in many cases they correspond with them: points 1–5 are typical of the area located southeast of the Mid-Polish Trough, points 7–10 represent the Pomeranian part of the Polish Trough, points 11–17 — the Kujawy–Wielkopolska segment of the Polish Trough. The graphs illustrated in Figure 41 show that the evolution of the area may be subdivided into several stages of increased and decreased tectonic subsidence. The first phase, including the Rotliegend, Zechstein and Early Triassic (Buntsandstein), characterizes high tectonic subsidence rate. It was followed by a stage of decreased subsidence but of different intensity in various basin parts. The area with maximum subsidence and with almost continuous deposition from the Rotliegend until Late Cretaceous was located within the Kujawy region. It is manifested on the graphs (Fig. 41, points 12–14) by almost constant tectonic subsidence rate during all the Permian and Mesozoic. In the southern part of this area the increase of tectonic subsidence was observed for the Late Jurassic (Fig. 41, points 14–17) but such a tectonic episode can be noticed only there. In the Pomeranian area (Fig. 41, points 7–10) two phases are distinguished: the high subsidence phase of Permian-Early Triassic time and the later phase, more moderate. Graphs for the southwestern part of the basin have a similar characteristic (Fig. 41, points 1–6) but the Early Cretaceous period was manifested by an uplift of the basement. In all the graphs the next increase of tectonic subsidence rate was recorded in the Late Cretaceous. It should be reminded here that the calculations and comments are devoid of any correction referred to contemporary palaeoeustatic and palaeobathymetric conditions. Just after considering the influence of the basin position versus contemporaneous sea level and of loading resulted from water weight of transgressing seas it will be possible to characterize in detail evolution of tectonic subsidence during burrowing of the Polish Rotliegend Basin.

Palaeobathymetric and palaeoeustatic corrections

Considering the burial history of any sedimentary basin it should also be regarded the water depth during the adequate sedimentary period as well as the difference between contemporary and recent sea level. This is a quite difficult question, charged with an error. If palaeobathymetry is precisely defined then the problem of its stability in time is often questioned. Computer algorithms commonly assume relatively long intervals of geological time so there always exists some suspicion that the applied palaeobathymetric or palaeoeustatic parameter is unadequate for the considered time interval. So in this paper, in a context of tectonic subsidence, these problems were decided to be discussed separately to demonstrate their importance as well as to emphasize the validity of such a calculation on a correction of final conclusions.

Water depth in a sedimentary basin is defined according to sedimentary features, geochemical, isotopic and palaeobiological (palaeoecological) data observed. All these information enable only to determine an approximate water depth. Nevertheless, the attempts of palaeobathymetric as well as palaeoeustatic reconstructions are more common. Development of sequence stratigraphy required a construction of curves of eustatic sea level changes. Despite of existed controversies between different authors the most popular is the graph of EXXON Group (Mesozoic..., 1988) and it was a source of data used in this paper.

Initial data for the calculation are listed in Table 1. For water palaeodepth the some range of values was assumed with an eustatic palaeo-sea level — as constant values. Calculated correction of tectonic subsidence which resulted from palaeobathymetric and palaeoeustatic correction, is located in an interval depending on a palaeobathymetric parameter applied. Due to reality from one side and a controversy of palaeobathymetric-eustatic relations during the Late Jurassic and Late Cretaceous from the other, these values are presented alternatively. A function applied for calculation of this correction is taken from the formula of G. C. Bond, M. A. Kominz (1984); see also P. A. Allen, J. R. Allen (1990, p. 272).

The Rotliegend basin developed under continental conditions but the Zechstein transgression character suggests its location beneath contemporary sea level (P. H. Karnkowski, 1986b, 1995b). For calculations a value of 150–250 m beneath the recent sea level was applied and the resulted correction value is from +200 to +360 m. It means that the earlier estimated tectonic subsidence value (Fig. 31) should be increased to obtain total tectonic subsidence. Practically, the values presented on the map of tectonic subsidence for Rotliegend time have to be increased from 200 to 300 m. Also on the graph of tectonic subsidence curves for selected points of the Polish Basin (Fig. 41) the fragments of curves for Rotliegend time will increase their inclination.

A water depth interval assumed for the Zechstein was 100–200 m and the eustatic palaeolevel was zero so the calculated correction value was from –200 to –100 m. It means that values presented on the map of Zechstein tectonic subsidence should be diminished by 100–200 m. After palaeobathymetric and palaeoeustatic corrections the tectonic subsidence of the Rotliegend is higher than in the Zechstein. But assuming the longer duration of the Rotliegend it is highly probable that during the Late Permian (Rotliegend + Zechstein) the values of tectonic subsidence were similar.

The Early Triassic (Buntsandstein) was a period of dominant continental and shallow-marine sedimentation. The assumed data (Tab. 1) indicate that the influence of palaeobathymetric (PB) and palaeoeustatic (PE) corrections may be omitted.

The Middle Triassic (Muschelkalk) is characterized by PB-PE correction from –20 to +80 m. The Muschelkalk thickness is almost uniform so the resulted map of tectonic

Table 1

Palaeobathymetric (PB) and palaeoeustatic (PE) corrections for a proper calculation of tectonic subsidence in the Polish Basin

Time	Palaeowater depth [m]	Palaeosea level relative to the present [m]	Tectonic subsidence correction value due to palaeobathymetry and eustasy [m]
Late Cretaceous (version 1)	300–700	350	–200 — +200
Late Cretaceous (version 2)	300–700	600	–560 — –140
Early Cretaceous	0–100	100	–140 — –40
Late Jurassic (Malm) (v. 1)	200–400	250	–160 — +40
Late Jurassic (Malm) (v. 2)	200–400	350	–200 — –100
Middle Jurassic (Dogger)	50–100	50	–20 — +30
Early Jurassic (Lias)	0–50	50	–70 — –20
Late Triassic	0–50	50	–70 — –20
Middle Triassic (Muschelkalk)	50–150	50	–20 — +80
Early Triassic (Buntsandstein)	0–50	0	–50 — 0
Late Permian (Zechstein)	100–200	0	–200 — –100
Early Permian (Rotliegend)	0	–150 — –250	+200 — +360

subsidence will be undifferentiated. A value of PB-PE correction is of the same range as the calculated subsidence value so it manifests a scale of uncertainty for individual basin parts. Generally the total tectonic subsidence value for the Muschelkalk may be estimated at 150 m.

Late Triassic represented similar palaeogeographic conditions as the Early Triassic but the level of the Panthalassa ocean of that time was defined at about 50 m above its recent position. Such a situation caused that PB-PE correction is located between –70 m and –20 m. It only slightly influences a total tectonic subsidence value and may be neglected to the data presented on the corresponding map (**Fig. 35**).

The Early Jurassic represents palaeobathymetric conditions similar to the Late Triassic ones so that the conclusions on subsidence are comparable.

The Middle Jurassic marine basin was slightly deeper so the values of PB-PE corrections are very low and may be omitted.

Significant increase in water depth took place during the Late Jurassic (B. A. Matyja, A. Wierzbowski, 1996). For a calculation higher depth values of 250 m and 350 m was assumed for contemporary position of sea level (above recent level). Maximum interval of PB-PE correction attained is from –200 to +40 m. It practically means that tectonic subsidence data in deep parts of the basin (**Fig. 37**) should be increased by the same value whereas data from shallower regions should be reduced by another values. During the Late Jurassic the northern and northwestern part of the Polish Basin was characterized by a subsidence value between 50 and 100 m. Clay lithofacies prevailed indicating a relatively shallow-water conditions. If the above presented values (50–100 m) are reduced by PB-PE correction by about 100 m the recorded subsidence for this area would only result from loading and could act without a tectonic factor. The southern part of the basin represented quite a different situation because it was dominated by carbonate facies of deeper-water origin (B. A. Matyja, A. Wierzbowski, 1995, 1996). In this case the tectonic value calculated at about 300–400 m should be increased with the PB-PE correction by about 50 m (**Tab. I**) and the total tectonic subsidence will be of 350–450 m. This last value indicates a significant increase of subsidence at that time. Because these higher values were noticed farther to the southeast, the next rifting phase in Late Jurassic time is suggested (J. Kutek, 1994; M. Hakenberg, J. Świdrowska, 1997). However, it was limited only to the southeastern part of the Mid-Polish Trough.

The Early Cretaceous was characterized by the intensive marine regression and erosion of the south western basin. Tectonic subsidence in the Mid-Polish Trough (**Fig. 38**) was estimated at 100–300 m. The calculated value of PB-PE correction reduces it down to several tens of metres (**Tab. I**).

The Late Cretaceous was a period of maximum transgression during the Mesozoic history of Poland and Europe (J. M. Hancock, E. G. Kauffman 1979). Depth of this marine basin was estimated at several hundreds meters (J. M. Hancock, 1975, 1987) and contemporary sea level position was also very high. For calculations this last parameter was evaluated alternatively for 350 m and 600 m. If the shallower water depth is considered (300 m) the values of PB-PE correction locate between –560 m and –200 m, so data presented on the map (**Fig. 39**) should be reduced by the same value. If the water depth is less than 300 m the correction value will be higher. In the extreme case, when the Late Cretaceous sea level would be about 600 m above its recent position and the sea depth would be less than 300 m the calculated total tectonic subsidence could be near zero. It is certain that tectonic subsidence values, presented on the map of the Late Cretaceous (**Fig. 39**) should be significantly reduced. Consequently, the majority of the Late Cretaceous basin was uninfluenced by tectonic subsidence and all submergence results from the weight of basin water and sediments accumulated. If conditions of very high sea level (about 600 m) and relatively shallow basin (200–300 m) existed in the Mid-Polish Trough, they would have involved a subsidence process being the effect of loading by deposits and waters infilling the sedimentary basin. In this case external tectonic factors were unnecessary, initiating subsidence in the Late Cretaceous basin and the responsible mechanism for subsidence would be a simple loading subsidence caused by a sea transgression.

Such an opinion is the first time exclaimed in the Polish geological literature, but overall remarks on this subject were published earlier (R. Dadlez *et al.,* 1994b, 1995). If it is accepted it may simplify the evolution scheme of the the Polish Basin — Late Permian and Early Triassic would represent the main rifting phase and later development will result from thermal relaxation. The Late Jurassic rifting episode would be expressed only in the southern part of the Mid-Polish Trough. To obtain the complete burial history of the Polish Rotliegend Basin it should be supplemented with its thermal history.

THERMAL HISTORY

State of knowledge on thermal field in Poland

Analysis of evolution of any sedimentary basin requires a study of its thermal history, mainly in a sense of variability of heat flow distribution in time and space. Heat produced by processes acted within the Earth's interior convects to the surface and disperses there. Temperature increases slowly with a depth toward the Earth's center but the recent temperature field is heterogenous. Linear increase of temperature with depth is disturbed by such factors as among others: diverse thermal properties of rocks (i.e. thermal conductivity), tectonic phenomena (faults, deep fractures), thickness differentiation of continental crust as well as irregularities of distribution of local thermal points (i.e. hot spots, rifts). All these phenomena change in time accompanying the successive phases of evolution of individual sedimentary basins. The fundamental parameter in geothermal studies is the tem-

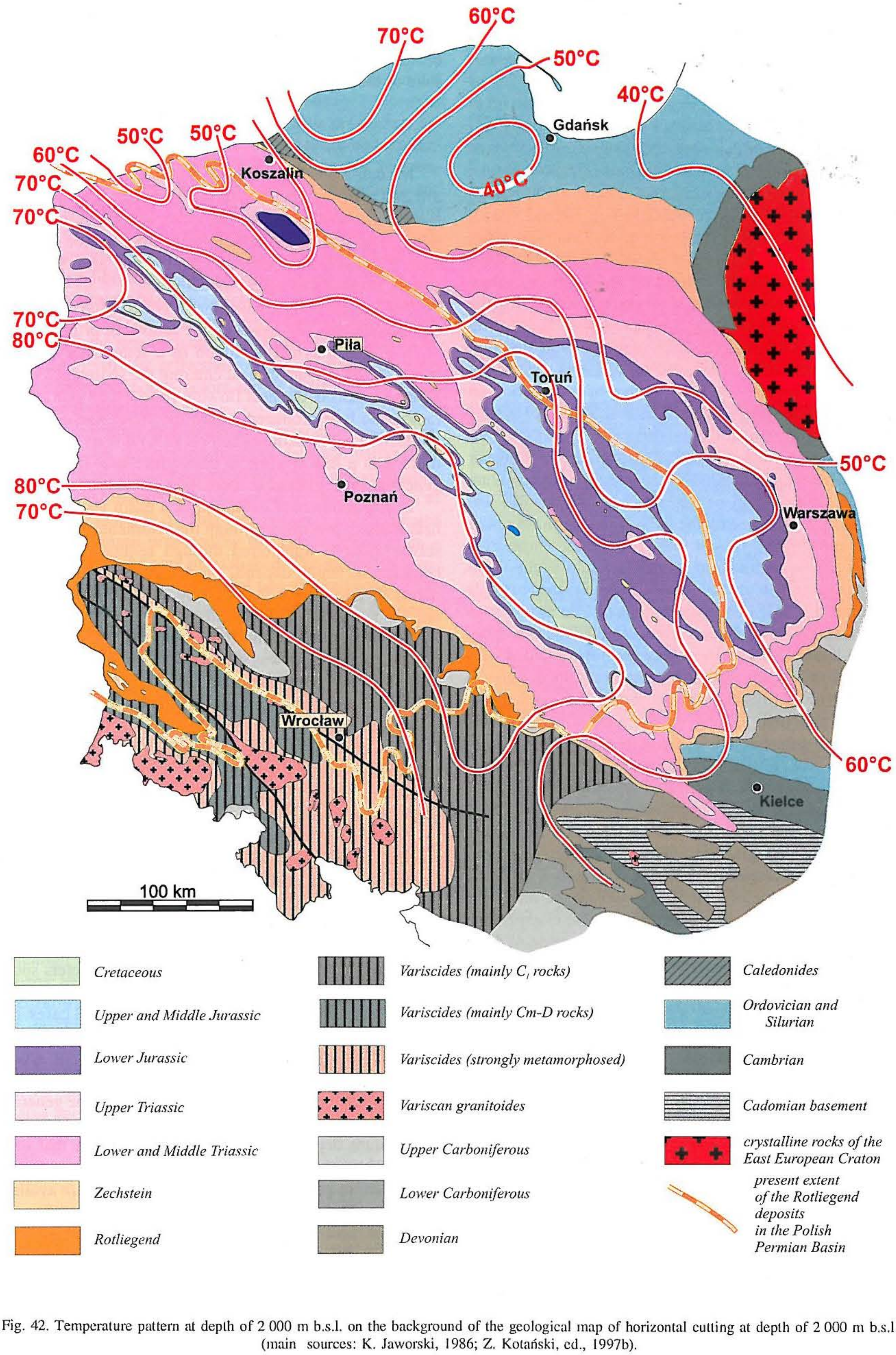


Fig. 42. Temperature pattern at depth of 2 000 m b.s.l. on the background of the geological map of horizontal cutting at depth of 2 000 m b.s.l. (main sources: K. Jaworski, 1986; Z. Kotański, ed., 1997b).

perature measured in boreholes under conditions of stabilized heat balance. The measured data enable construction of maps, illustrating temperature distribution of individual stratigraphic surfaces or horizontal surfaces located at different depths. First type of maps presents temperature values of considered prospective geological surface. The second type clearly illustrates temperature changes at assigned horizontal depth. Both map types were published in Poland (i.e. J. Majorowicz, 1975, 1979, 1982, 1984; K. Jaworski, 1986, 1987, 1988a, b, 1991; S. Plewa *et al.*, 1992; S. Plewa, 1994). The author has applied for studies the results of temperature measures (from several hundreds of wells), collected by the Polish Oil and Gas Company (Archive of the Geological Bureau GEONAFTA) and the maps of temperature distribution (K. Jaworski, 1986, 1987, 1988a, b, 1991). The above mentioned data became the main source of information on the temperature field in Poland. The best analytical effects are obtained by presentation of temperature field on geological maps of horizontal cutting (Z. Kotański, ed., 1997b), for instance — the map (compiled by the author) of temperature distribution at the depth of 2000 m b.s.l. for central and western Poland, occupied by the Rotliegend Basin (Fig. 42). This map and similar types of maps illustrate a temperature increase from the northeast to southwest as far as the Wielkopolska area (maximum value) and slow decrease towards the Sudetes (Fig. 42). The East European Platform area is characterized by lower temperatures than the Palaeozic platform. Maximum temperature values are not coincided with the Mid-Polish Trough. The area of highest temperatures is located southwest of this structure and it is limited to the Wielkopolska region. Basing on the analysis of maps of temperature distribution it is difficult to define precisely geological structures responsible for recently observed character of heat field. Value of surficial heat flow is the most objective parameter reflecting a geothermal pattern of heat supplied to the Earth's surface. It is calculated from variations of geothermal gradient value in boreholes and from laboratory determinations of thermal conductivity of rock samples. So the value of heat flow could not be measured directly in boreholes but it may be defined due to expensive and arduous temperature measures after termination of drilling (each measure may last several weeks) and comparable laboratory analyses aimed to determine heat conductivity of individual formations or stratigraphic units. After these initial expensive studies further calculations are quite simple but such a prolonged procedure caused that so far similar heat flow studies have been done only in about 90 boreholes in the whole area of Poland, but for the Polish Rotliegend Basin — only in 27 wells (S. Plewa, 1994). The heat flow maps (J. Majorowicz, 1975, 1979, 1982, 1984; S. Plewa *et al.*, 1992; S. Plewa, 1994), constructed basing upon these data, differ strongly between one another and are unsuitable for analysis of the Rotliegend Basin evolution. Such a small amount of valuable data, enabling reconstruction of surficial heat flow in Poland, caused that the authors of the report, presenting fundamental problems on deep geological and geophysical investigations of Poland area (A. Guterch *et al.*, 1996) have concluded that "...in Poland there is no research center, which continues study on a heat field so the present state of this branch is catastrophic."

Methodology

In such a situation the aim, defined by the author, was difficult to reconstruct the thermal history of the Polish Basin basing on several hundreds of temperature measures in boreholes and few results of heat flow determinations from this area. The only one method to realize this attempt was the computer-aided geological modelling.

The applied software was the IES-PetroMod (1993), with composed algorithm based on the following principles:

1. The geothermal evolution of a sedimentary rock depends on the amount of heat entering the sedimentary basin, which consists of the heat flowing from the deep mantle and radiogenic heat produced within the crust. Radiogenic heat production within sedimentary rocks is unlikely to contribute more than a few mW/m^2 to the surface heat flow, and can generally be neglected in modelling calculations.

2. The geothermal evolution of a basin also depends on heat transfer processes through the sedimentary rocks themselves. Heat is transferred through sedimentary strata by conduction, which depends on the mineral matrix and the nature of pore-filling fluid and by convection, which is related to the circulation of fluids.

3. During most of the Earth's history, the surface temperature distribution was much more even than at present. A routine in the preprocessor estimates palaeo-temperatures from a temperature versus latitude and geological time chart.

4. A prerequisite for any heat flow or thermal gradient determination is the definition of an upper boundary temperature at the sediment surface or sediment/water interface as an annual mean value.

5. The simulation program offers a more accurate method of determining present heat flow, as all thermal properties of the lithologies are taken into account, resulting in a more accurate thermal conductivity determination. A match of measured and calculated present temperatures will therefore lead to a more accurate present heat flow value.

6. Geochemical reactions play an important role in the calibration of temperature histories with parameters such as vitrinite generation, the smectite-illite reaction or some isomerisation and aromatisation processes. In all cases, there is an initial substance which is converted in one or more subreactions into one or more final products. All subreactions are assumed to be first order reactions and their reaction rate is calculated with the Arrhenius law. Thus the generation of these calibration parameters is assumed to have a time-temperature dependency of the same order as that of the hydrocarbon generation process. If maturation or concentration values of generated calibration substances are available, temperature histories can be checked and calibrated.

7. The most commonly used thermal maturation indicator is the reflectance of the vitrinite maceral in coal, coaly particles, or dispersed organic matter, which increases as a function of temperature and time from approximately 0.25% R_0 at the peat stage to more than 4% R_0 at the meta-anthracite

stage (B. Durand *et al.*, 1986). Vitrinite reflectance plays an important role in the determination of source rock maturates as it is widely available, relatively easy to use.

8. Two basic types of thermal calibration parameters are used in routine basin simulation studies: measured temperatures and measured maturity indicators. Measured temperatures, due to their direct relationship to thermal gradients and thermal conductivities, can therefore be used to determine the correct heat flow value. However, measured temperatures can only be used to calibrate the recent heat flow values. The calibration of longer-term thermal processes, i.e. palaeotemperatures or palaeo-heat flow, is possible by using organic material which records the effects of temperature through geologic time as maturity indicators. Using the present measured vitrinite reflectance figures, palaeo-heat flow and other interdependent factors can be corrected and tested by additional simulation runs.

The assumptions and limitations presented above constitute a base for preparation of input data and parameters, calibrating correctness of accepted principles and simulation conditions (distribution maps of temperature and maps of vitrinite reflectance R_0). This last parameter is presented mainly on the maps prepared by the Geological Bureau – GEONAFTA and they are unpublished. The author has used information enclosed in the special unpublished report (The Robertson Group..., 1991), listing all obtained so far determinations of vitrinite reflectance from the following horizons: the top of pre-Permian surface, bottom of the Zechstein succession, Main Dolomite unit, Lower (Liassic), Middle (Dogger) and Upper (Malm) Jurassic. There were also processed data of vitrinite reflectance, determined for rocks of the pre-Permian basement and Zechstein copper-bearing shales, to explain genesis of polymetallic mineralization observed at the Weissliegendes and Zechstein contact (S. Speczik, 1987; S. Speczik, A. Kozłowski, 1987).

Input data were also obtained from the 14 geological cross-sections from the Polish Basin (P. Karnkowski, 1979), which have earlier been used for a subsidence analysis (comp. Figs. 26, 27). Data on geological time, lithology, thickness and erosion scale for individual stratigraphic units have been arranged along these profiles from the special publication on the palaeotectonics of the Polish Permo-Mesozoic basins (K. Dayczak-Calikowska, W. Moryc, 1988; Z. Deczkowski, M. Franczyk, 1988a, b; J. Gajewska, 1988a, b; M. Jaskowiak-Schoeneichowa, A. Krassowska, 1988; S. Marek, 1988; T. Niemczycka, W. Brochwicz-Lewiński, 1988; J. Pokorski, 1988a; A. Szyperko-Teller, W. Moryc, 1988; R. Wagner, 1988). A palaeobathymetric correction was also applied in modelling but it has a significant value only in the case of the Late Jurassic and Late Cretaceous periods.

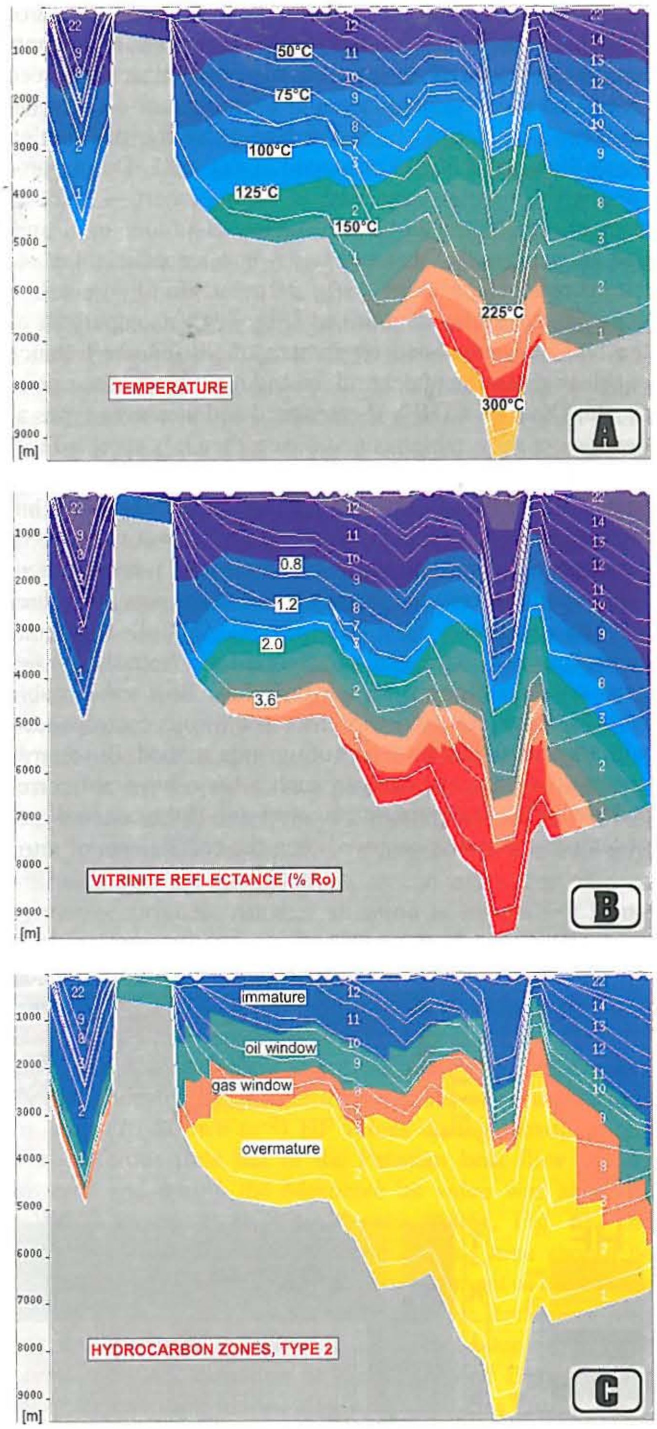


Fig. 43. Selected results of computer-aided simulation (PetroMod) along line VII (see Figs. 26, 27) with application of the heat flow numerical model presented on Fig. 44B.

Heat flow modelling

One of the input parameters, obligatory existed in a group of basic data and applied for computer simulation, is the heat flow value. This is practically unknown (see previous comments). In the first simulation a default value of heat flow of about 60 mWm^{-2} has been used for each section. Data processing has produced an image of temperature distribution along the section, comparable with real measures. Later, the established value of heat flow has been corrected depending on a difference between true and simulated temperature values in in the sections. Such a correction was proportional to a deviation value. After introducing proved new values of heat flow a repeated simulation was done. Similar attempts have been repeated so long till the concordance between calculated and measured values of a temperature distribution has been obtained. Computer image of such a distribution along the section VII is presented in Fig. 43A. During processing there are also realized — among others — calculations of organic matter transformation as a function of time and temperatue and then converted into a coefficient of vitrinite reflectance (Fig. 43B). Intervals for hydrocarbon generation are also determined (Fig. 43C). Comparison of the real and calculated coefficient of vitrinite reflectance enables calibration of determined and real values of temperature and heat flow (HF). If calculated and measured types of parameters show a high concordance, then it is accepted that input values of heat flow are credible. At the beginning, a time-constant heat flow value was applied for modelling but the first result has never been satisfactory, and corrections of assumed heat flow and repeated simulations were required. Due to that, the resulted image of introduced new HF values became more and more complicated. Compiled sections were processed in the geological time scale from the Rotliegend until the Recent. Primarily, a heat flow value stable with time was assumed and processed results corresponded with measured data for a part of the area studied. But a large group of results, obtained in such a way, have not corresponded with calibrating parameters and if the concordance of temperatures was achieved then the coefficients of vitrinite reflectance (R_0) disagreed and vice versa. Only a single regularity observed at this stage of processing was assigned to a situation of temperature concordance but corresponding with too low R_0 values for Zechstein organic matter. In turn, a conformity of measured and calculated vitrinite reflectance coefficient (R_0) was related to increased temperature values in heat field characteristics. The sole method to solve this problem was the assumption that over a part of the area studied the distribution of heat flow changed with time. The group of results, distinctly unordered to a stable — with time — heat flow distribution ("changeable"), was characteristic of the southwestern part of the Polish Basin, mainly for the Fore-Sudetic Monocline (Fig. 44A). The most significant tectonic event in this region, possibly responsible for distinct changes of heat supply volume to the Earth's surface, was the remarkable uplift and erosion of thicker Jurassic and Upper Triassic complexes (comp. Figs. 38, 41), which took place during the Early Cretaceous. It was settled that at the turn of the Jurassic and Cretaceous, the part of the area was subjected to a significant change of heat flow value. From that moment the majority of studied cross-sections located in the south-western region, was divided into two intervals of different thermal history, with the boundary placed at the turn of Jurassic–Cretaceous (Fig. 44B). Such an assumption enabled calculation of recent heat flow distribution and generation of its higher values for the Rotliegend–Late Jurassic time interval. The above described procedure refers to a digital image of heat field variability in time and space,

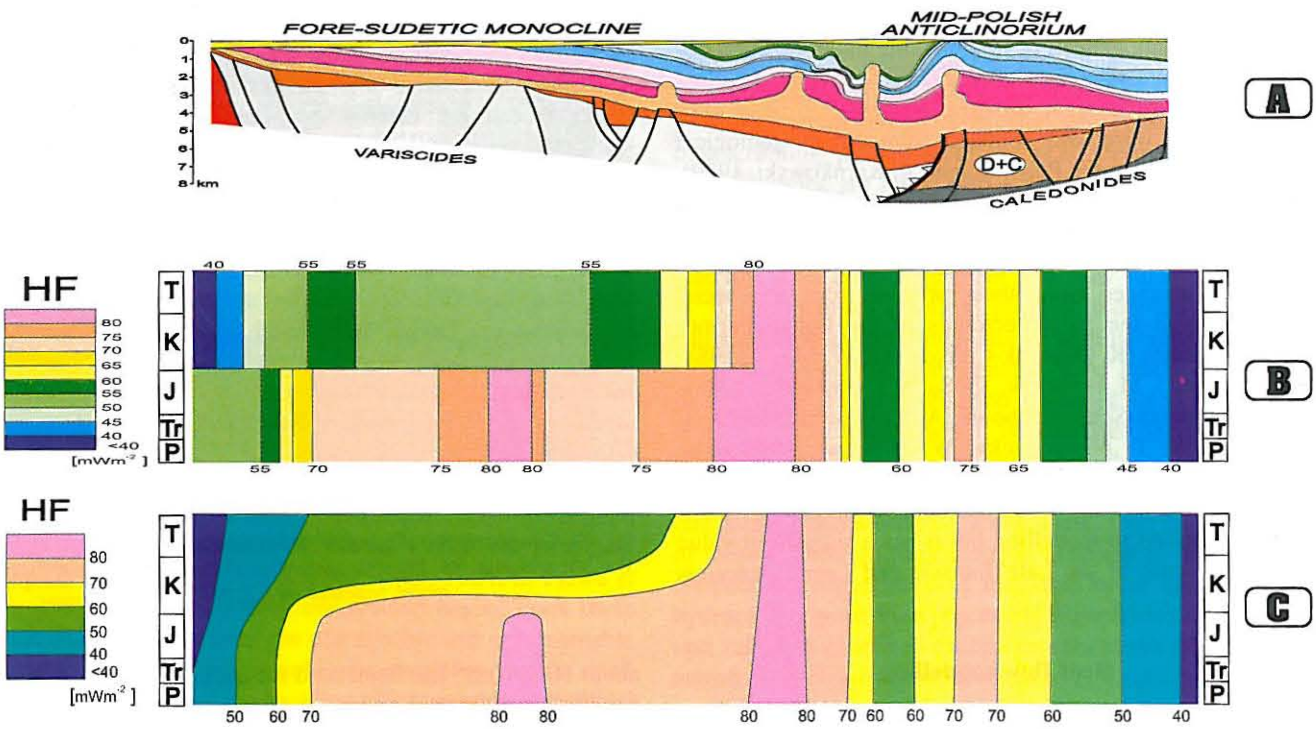


Fig. 44. Model of the heat flow values distribution along line VII.

A — geological cross-section along line VII (see Figs. 26, 27), B — values of heat flow used for simulation — numerical model, C — geological model of heat flow from the Late Permian to Recent.

and it consequently indicates that all processed values must be digitalized and infill all fields of assumed input parameters. It is known that a digital image may only be an approximation of geological reality. Attempts how to make it more comparable with geological facts, are presented by the author in Fig. 44B, C. Comparison of both images clearly indicates that distinctly visible boundaries of digital model should be interpreted — in a geological image — as processes developed in a time interval. Concluding, the presented digital model is the simplest case of possible alternative versions of heat flow variability in the Polish Basin. It is easy to explain that initial heat flow values from the area of the recent Fore-Sudetic Monocline was higher than they are determined by computer simulations and cooling process began earlier. Such a situation is quite possible and easy to simulate but there are no calibrating parameters, confirming such an assumption. The elaborated model of heat field changes in time and space in the Polish Basin, has to explain at first what the thermal history of deposits, infilling the Polish Rotliegend Basin was. This answer is fundamental for further considerations on hydrocarbon generation in the Zechstein and Rotliegend complexes. If heat flow values, obtained here by computer modelling, enable such an analysis in petroleum practice the principal foundations of this model seem to be correct.

Heat flow in the Polish Basin: present and past

Two maps have been prepared resulting from the attempts of reconstruction of the heat flow in central and western Poland. The first one refers to a time interval from the Recent to the Jurassic–Cretaceous boundary (Fig. 45) and it may be approximately considered as the recent HF distribution. The second map illustrates heat flow values for the Rotliegend–Late Jurassic period (Fig. 46). Both these maps were produced basing on digital data used in computer simulations. Data were grouped along geological sections, so locally, the extents of various fields placed between sections, were difficult to interpret. But the final image is much more differentiated than this one compiled only basing on heat flow measures in few boreholes. By the way, values recorded in wells have been compared with data of the presented map (Fig. 45) and they coincide in most cases.

The map of heat flow distribution for the Cretaceous–Recent time interval (**Fig. 45**) — representing practically the recent heat flow distribution — differs from the map of temperature distribution. It results from lithology of the sequences. The Zechstein deposits, containing salts and sulphates, significantly influence a heat transfer. Salts have more than twice as high thermal conductivity as most rocks and they play an important role in a heat transfer. Diagenetic rate, matrix type or porosity also determine thermal conductivity. So the constructed maps of temperature distribution, commonly founded on a horizontal section, show temperature measured at the same depth but very frequently within different geological formations. These ones may be surrounded and overlain by rocks of different coefficients of thermal conductivity. In such a case the detailed final conclusions on heat flow distribution, based on analysis of temperature distribution, seems to be risky and sometimes false.

On the heat flow map for the Cretaceous–Cenozoic period (Fig. 45) the area with higher recent HF values is located in the eastern Wielkopolska region. But it is a non-uniform area and it may be subdivided into distinct belts of increased and lowered values. The second region of higher HF value is the southwestern part of the Fore-Sudetic Monocline, mainly the area located southwest of Koszalin and east of the East European Platform margin.

The image of heat flow distribution for the Rotliegend–Late Jurassic period (Fig. 46) coincides with the former map only within the Mid-Polish Trough. Higher heat flow values were observed in the southeastern part of the Polish Basin during Rotliegend–Late Jurassic time. A large anomaly is especially visible between Poznań and Wrocław and two smaller ones occur at the western state border. Between these anomalies there is the area of relatively lower heat flow values, which expanded later. The reasons why such high positive anomalies occur should be sought at first in initial phases of the Polish Basin generation, in Rotliegend time. Intensive volcanism became an expression of increased heat flow at that time. But a comparison of two maps: map of occurrences of Rotliegend volcanics and heat flow distribution for the Rotliegend–Late Jurassic interval, clearly indicates that not more than two positive anomalies, located at the western state border, may be directly related to the volcanic phenomena. In the area of largest positive anomaly, volcanics are absent and there are no evidences of their former occurrence. Another situation is recognized in the Western Pomerania, where relicts of Rotliegend volcanism are visible but heat flow values for this period (P_1–J_3) are low. Volcanic areas are always characterized by higher heat flow but in the discussed case it is quite reversed. Previous studies of the author on this problem (P. H. Karnkowski, 1996a) indicated that Western Pomerania was characterized by high (70–80 mWm^{-2}) HF values during Devonian and Carboniferous time but in the Permian heat flow rapidly lowered and during the Mesozoic its value was about 40 mWm^{-2} (comp. P. H. Karnkowski, 1996a, Fig. 6). The Devonian–Carboniferous evolution of this area should be related to the Upper Palaeozoic rift development of the eastern branch of the Rheno-Hercynian Basin. The Rotliegend volcanism developed in this area under extension conditions, connected with formation of the Rotliegend Basin but the lava effusion took place along renewed older fault system. Volcanic processes were not related to the crust thinning but only to reactivation of deeply founded older faults. Such a mechanism caused that magma migration paths towards the Earth's surface were very narrow and after a partial relaxation of extensional stresses this process quickly finished. Hot but thin lava covers quickly cooled and few narrow volcanic chimneys were unable to conduct so much heat toward the surface. In the Zechstein geothermal conditions, existing in Western Pomerania, were comparable with the recent ones.

Two volcanic centres, located nearby the western state border, developed in a quite different way. Their average heat flow value calculated for the P_1–J_3 time interval, was

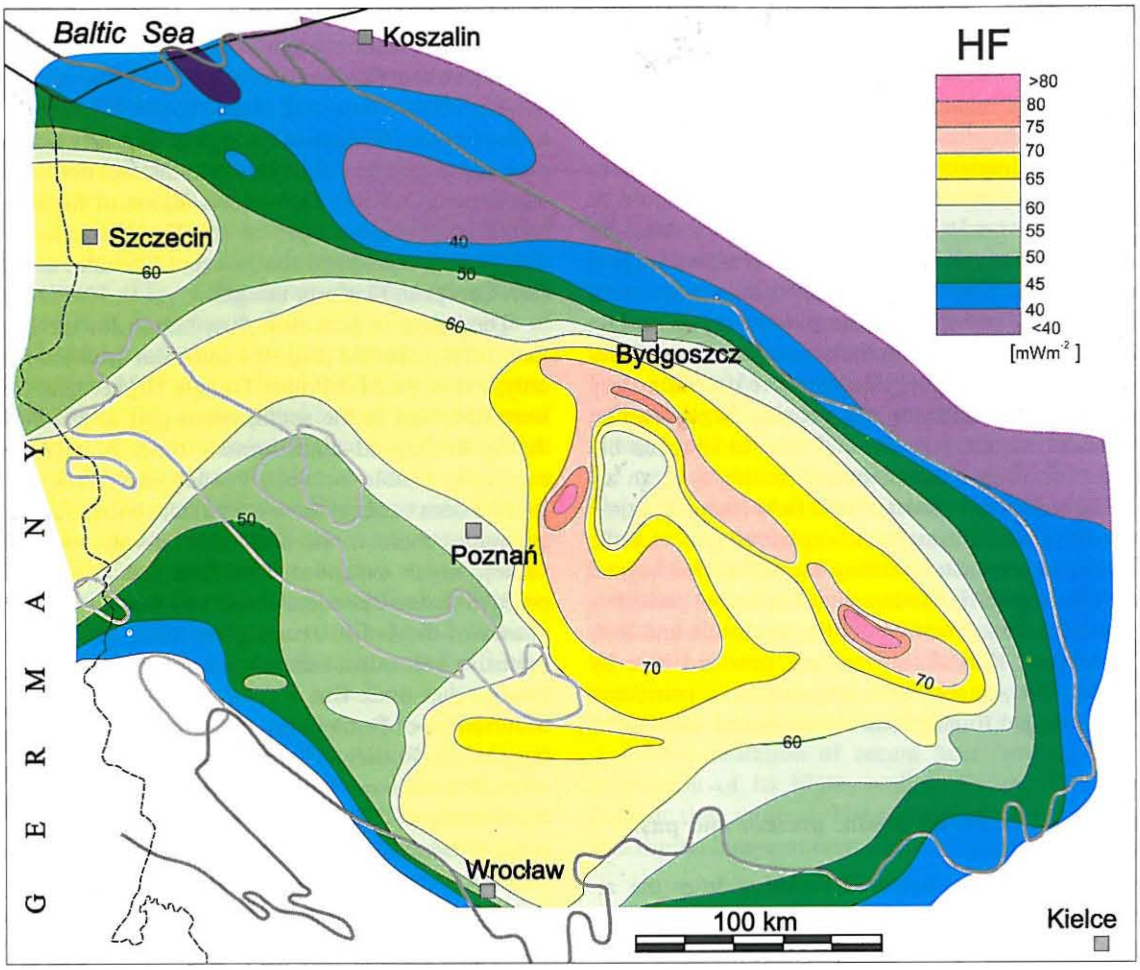


Fig. 45. Map of average heat flow values in the area of the Polish Rotliegend Basin during Cretaceous to present time obtained from the computer-aided simulations (PetroMod).

very high (<80 mWm^{-2}) evidencing that during the Late Rotliegend or Zechstein and maybe in the Early Triassic this value was significantly higher and it partially decreased in time due to decline of heat supply from deeper parts of the Earth's crust. If these effussives had been so normal as those observed in Western Pomerania there would have been no evidences of heating just in the Zechstein. Lava covers also occur, east of both the centres, but any special geothermal anomalies are unknown there. So the more pronounced area is located between Poznań and Wrocław, where the highest anomaly of average heat flow (<90 mWm^{-2}) for the P_1–J_3 period was recorded. This area is at present devoid of Rotliegend volcanics and there are no evidences that they could primarily exist. The occurrence of this largest geothermal anomaly during the P_1–J_3 period is explained by heat supply resulted from the crust thinning and/or generation of granitic batholithes, as it was discussed for western Poland by A. Dąbrowski, J. Majorowicz (1977). During the P_1–J_3 period in the central part of the Polish Trough the narrow zone of high HF values was distinguished, related rather to deep crust fractures than Permian volcanism. This suspicion is confirmed by the long-lasting character of the anomaly, which had the similar HF values also in the Cretaceous–Cenozoic period.

Modelling the heat flow distribution along the previously mentioned earlier geological sections has also considered its influence on the pre-Permian rocks. Most of the measured values of vitrinite reflectance coefficient (R_0) for rocks of the Permian basement (mainly Lower Carboniferous) from the Polish Basin correspond more or less with data obtained during modelling. Such a coincidence suggests the significant role of distribution and scale of heat flow in the area during the Permian, Mesozoic and Cenozoic. But there still exists a single high positive anomaly within the Permian basement, located east of Wrocław oustside the Rotliegend Basin area (comp. A. Lokhorst, 1997), of still unknown origin.

The thermal history of the Polish Basin-fill shows that at the beginning of the Rotliegend volcanic period the high geothermal anomalies occurred in the western part of the developing basin. They were located in the Wrocław–Poznań belt and farther west. Initially these anomalies were

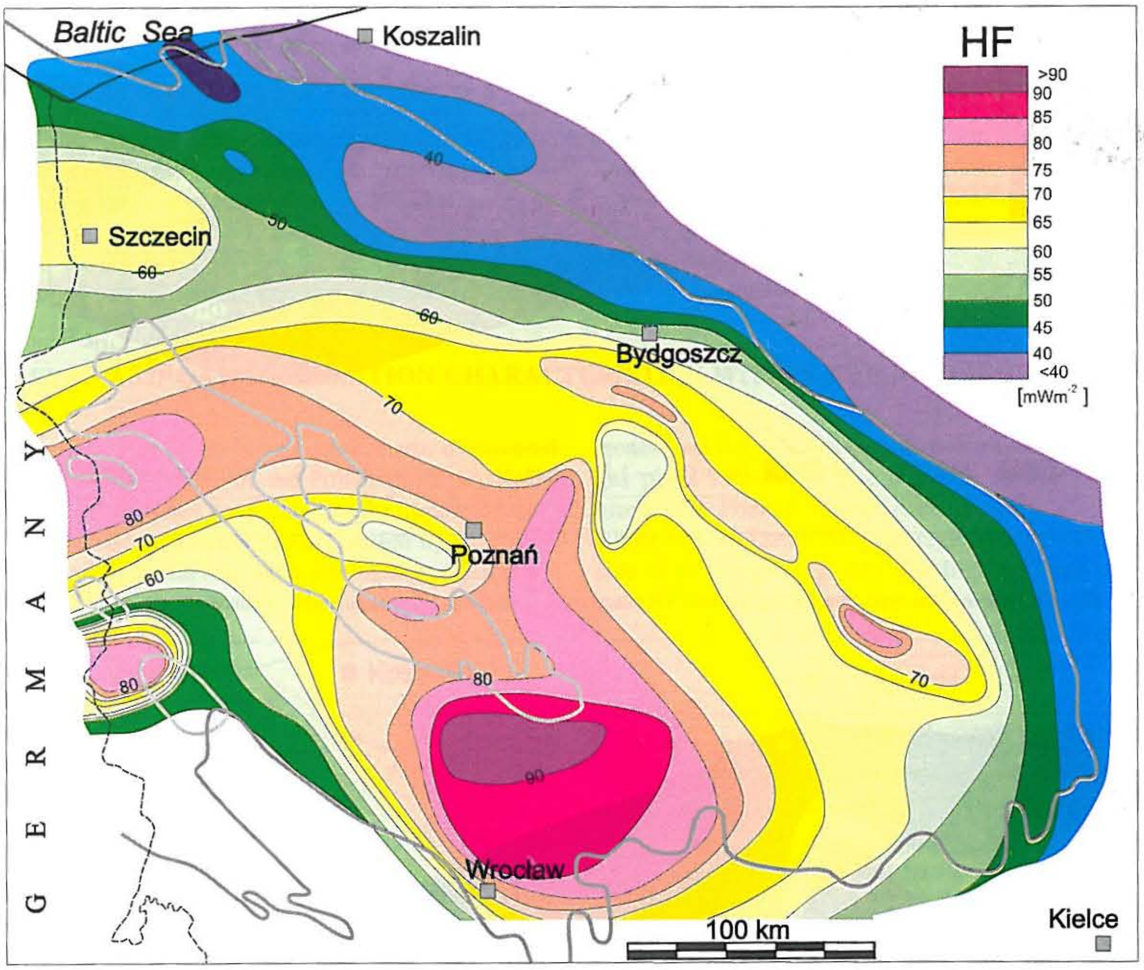


Fig. 46. Map of the average heat flow values in the area of the Polish Rotliegend Basin during Late Rotliegend to Late Jurassic period obtained from the computer-aided simulations (PetroMod).

characterized by a higher value than calculated average HF values of the P_1–J_3 period and they had to reach values of 100–150 mWm^{-2} during the Late Permian–Early Triassic interval. Such high values are related to syn-rift stages of the sedimentary basin development. During Late Triassic and Jurassic time some cooling of rift heat field took place, but turning point in thermal evolution of the Polish Basin was at the Jurassic/Cretaceous boundary when the southwestern part of the Polish Basin was uplifted and intensively eroded. Then a heat flow supply into the southern part of the Polish Basin decreased and distinct features of the previous epoch were obliterated in the heat flow field image. Without computer modelling the reconstruction of the Permian heat flow would be impossible.

Heat flow versus hydrocarbon generation in the Polish Basin

Knowledge on heat flow value variations is applied not only to tectonic analysis but also to modelling of hydrocarbon generation. The Rotliegend series contain gas fields and Zechstein carbonates — both gas and oil deposits. A fundamental question of current prospective works is the occurrence of "oil window" that means zones with potentially preserved liquid hydrocarbons. Explanation for such a question also allows to define zones containing various kinds of natural gas or zones in which hydrocarbon generation has not begun yet. The reconstruction of thermal history of the Polish Rotliegend Basin parallely enabled calculation of matter maturity and presentation of the Polish Basin by sections and maps in the light of potential hydrocarbon generation. Schematic images of hydrocarbon generation zones, obtained from computer simulation (**Fig. 43C**), were transformed into geological sections — for instance, section VII (**Fig. 27**) with a defined extent of oil window. If anywhere and at any time liquid hydrocarbons were generated within the Polish Basin so they had the most possible chance to preserve in areas of "oil window".

A problem of distribution of generation zones and hydrocarbon preservation is easier to be analysed on structural maps of individual reservoir rock complexes. Using the 14 geochemical sections — one of them is presented in **Fig. 47**

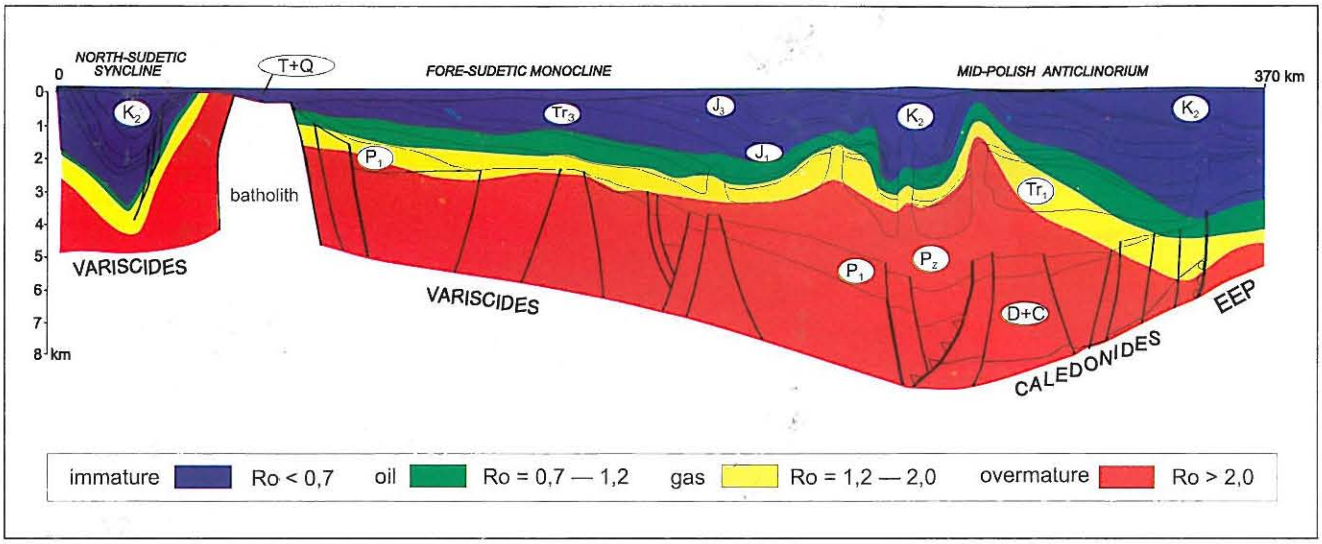


Fig. 47. Hydrocarbon type zones along the line VII based on the computer-aided simulations (PetroMod), see also Fig. 43.

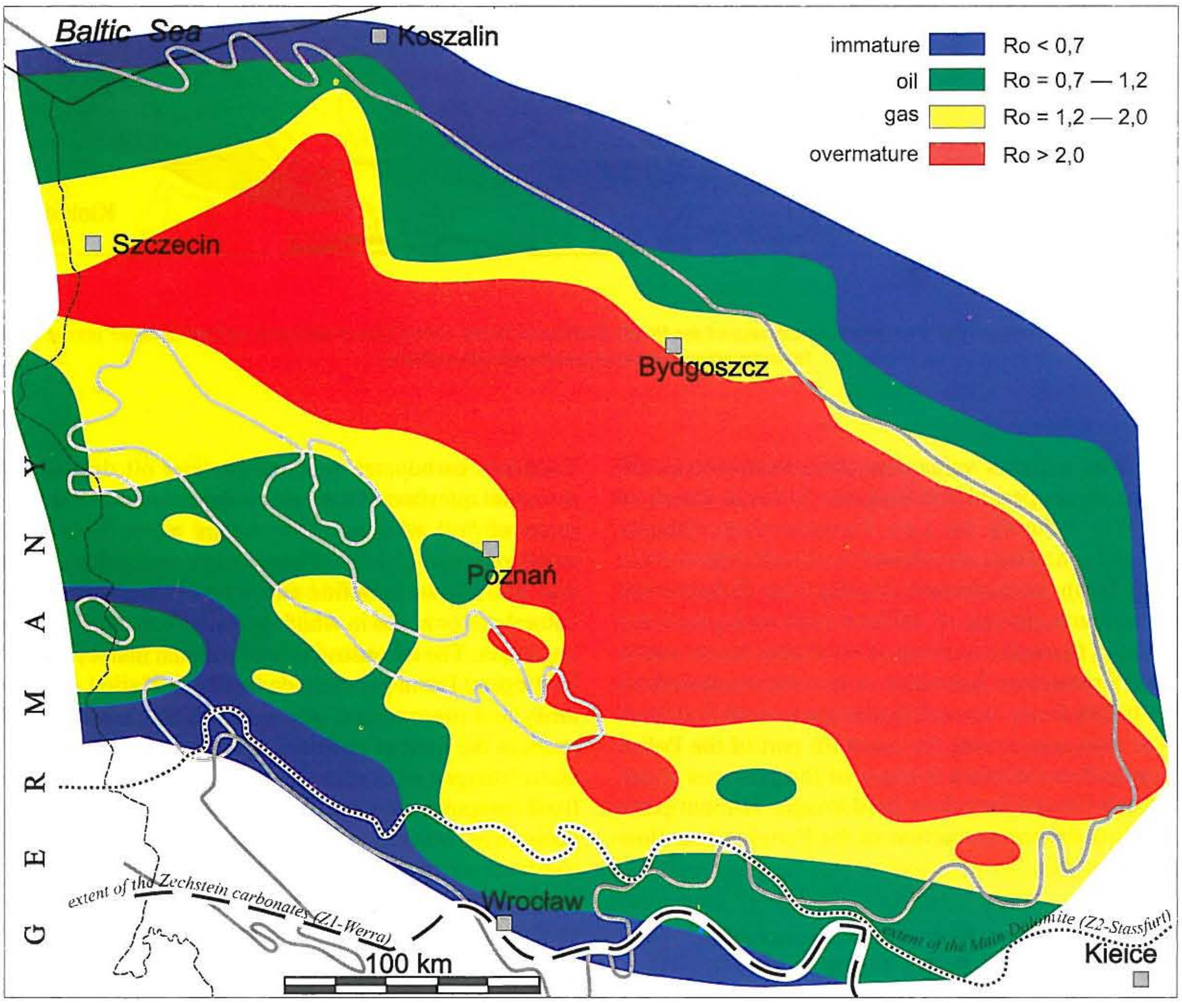


Fig. 48. Map of the organic matter maturity at the top of Rotliegend/bottom of Zechstein in the area of the Polish Rotliegend Basin (based on the results of PetroMod computer simulations along 14 regional cross-sections, compare Figs. 26, 43, 47).

— the map of such zones, extending on the Rotliegend top/Zechstein bottom surface has been compiled (Fig. 48). This map also illustrates the extent of the Zechstein Limestone (Ca1) and Main Dolomite (Ca2) units (the latter located 200–400 m higher than Zechstein Limestone). The main aim of the presented map is to focus on relations between the evolution of the Polish Rotliegend Basin-fill (its burial and thermal history) and distribution of zones of organic matter maturity. So the relations between location of gas or oil plays in the Zechstein deposits and thermal history of individual places are understandable. If only the subsidence history and stable with time heat flow values will be considered, the varied distribution of numerous hydrocarbon types observed in the area of the Fore-Sudetic Monocline and adjacent regions would be unexplained. The presented map illustrates a summary effect of subsidence and thermal history of the Polish Rotliegend Basin-fill. Such a synthetical map becomes one of the fundamental tools of petroleum play.

GAS FIELDS AND GAS COMPOSITION CHARACTERISTICS WITHIN THE ROTLIEGEND DEPOSITS

Several tens of gas fields have been hitherto discovered within the Rotliegend series of the Polish Basin (P. Karnkowski, 1993, 1996). They are located in the uppermost part of sandy Rotliegend sediments and are sealed by Zechstein evaporites (Fig. 49). Reservoir rocks are mainly eolian sandstones (see Fig. 25) and their distribution determines regional gas plays location. These deposits concentrate in two regions: the Poznań region located north of the Wolsztyn Ridge and the Lower Silesian region located on the southern side of this ridge (Fig. 49). The high regional inclination of

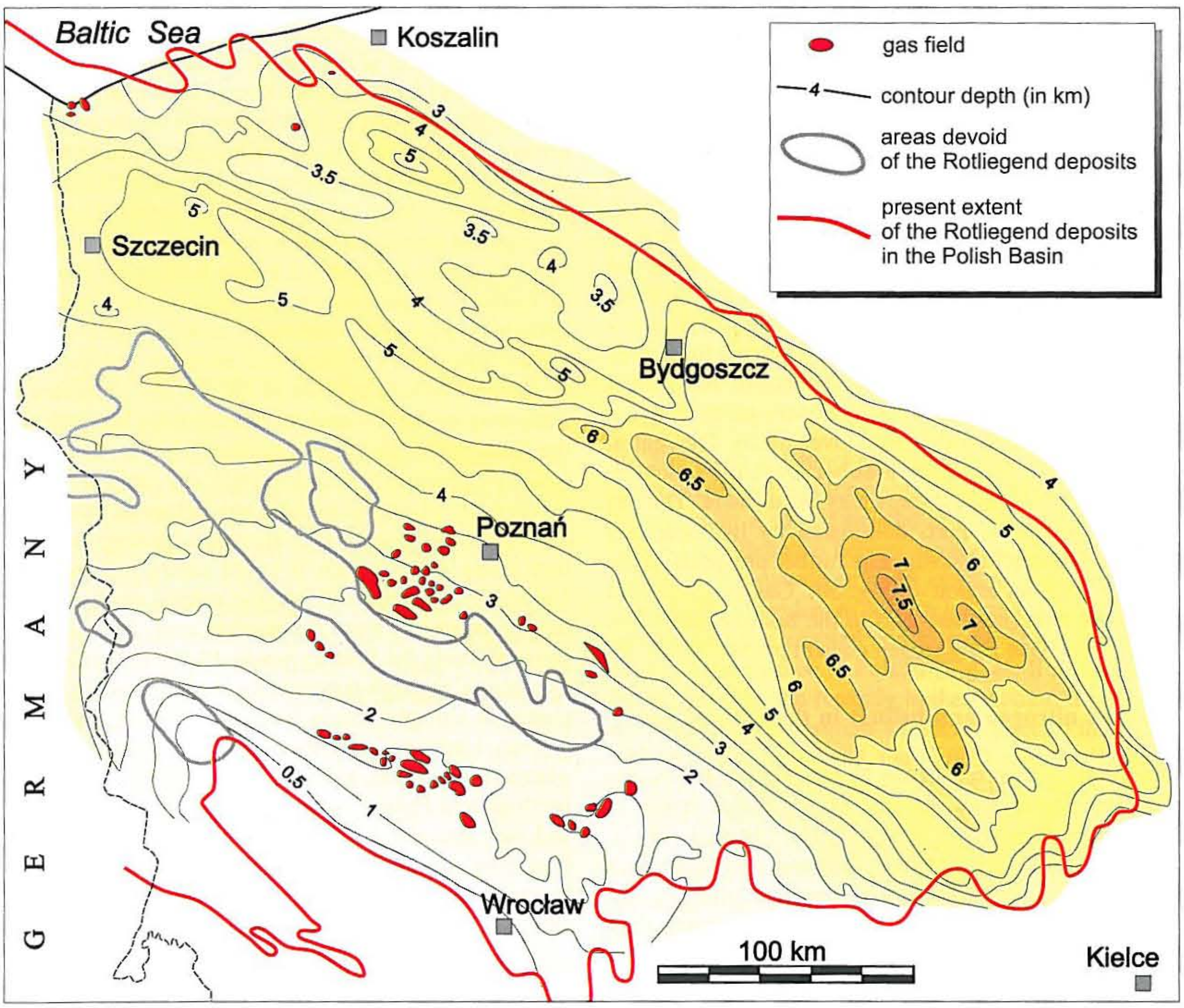


Fig. 49. Gas fields in the uppermost part of the Rotliegend deposits on the background of the present top Rotliegend/bottom of Zechstein contour map (after P. Karnkowski, 1993).

the Rotliegend top in many regions impedes formation of large structural traps. In areas with a regional inclination of 2–3° the minimum high of such a trap must be over 30 m to preserve there trapped hydrocarbons (P. H. Karnkowski, 1985).

Most of the discussed gas fields represent structural traps but part of them occur within buried palaeodunes so they should be included into a stratigraphic trap category. Also gas plays adjacent to the Wolsztyn Ridge, where rapid facies transitions between aeolianites and fluvial sediments are observed, may be classified as lithofacies traps (T. Wolnowski, 1983). In western Pomerania only few gas fields have been found within the Rotliegend succession. Current prospective works are organized to discover gas fields also within lithofacies traps (P. H. Karnkowski *et al.*, 1997a, b). Such possibilities as: progressively better seismic images of geology beneath the Zechstein horizon, application of 3D seismics, better procedures of seismic data processing and detailed studies on architecture of depositional systems in the Rotliegend basin make this type of investigations seem very promising (P. H. Karnkowski *et al.*, 1997a, b). The discovery of stratigraphic traps is quite difficult because the Zechstein–Mesozoic cover is characterized by frequent lithological and thickness variations complicating construction of a proper velocity model which enables suitable conversion of the time/depth section. But these problems are successively solved and new discoveries seem very probable. Occurrence of significant part of the Rotliegend series at a large depth limits more intensive exploration of this unit. The Rotliegend top, located at a depth of about 3000 m below recent sea level, occupies a dominant part of the basin, so any geological prospects is very expensive and risky there. But such a situation does not indispose the foreign investors for further explorations and recently most of the Polish Rotliegend Basin area is subdivided into concessionary plots; they are managed both by Polish and foreign investments. The central part of the basin is a perspective area because large structures or stratigraphic (lithofacies) traps may occur there. The gas composition from this part, dominated by hydrocarbons (over 75% of volume) also suggests further prospects in the basin center (Poznań region — Fig. 50). Gas samples from western Pomerania (northern part of the basin) contain less than 25% of methane but nitrogen content is over 75 vol. %.

Origin of nitrogen and helium in the natural gas

Natural gas, recovered in the North-German Basin, adjacent to the Pomeranian segment of the Polish Basin, is dominated by nitrogen (over 90% — P. Gerling *et al.*, 1997). Such an extremely high content is differently explained but the main reason is that nitrogen is generated from organic matter in sedimentary basin at higher temperatures than methane. Nitrogen-rich gases are mainly formed during the final stage of gas generation, when sedimentary rocks grade into metamorphic ones (R. Littke *et al.*, 1995; G. H. Neunzert *et al.*, 1996). The Westphalian coals, in the North-German Basin, deeply buried and highly mature at present (P. Gerling *et al.*, 1997) are indicated as a source of organic matter.

Another discussed alternative explanation supposes nitrogen generation from igneous or metamorphic basement rocks (D. Haendel *et al.*, 1986; E. R. Oxburgh, R. K. O'Nions, 1987; R. K. O'Nions, E. R. Oxburgh, 1988; G. Everlien, U. Hoffmann, 1991). It is also suspected that nitrogen-rich gases may be derived from the mantle (F. Freund, 1984) and should be accompanied by helium gas (H. Hiyagon, B. M. Kennedy, 1992). Helium concentration in gases from the German Basin is relatively low (<0,3 vol. %, except of some local anomalies) although helium is regarded as being of radiometric (crustal) origin (R. Littke *et al.*, 1995).

In spite of the very precise isotopic analytical methods, applied now for studies of nitrogen ($^{15}N/^{14}N$) and helium ($^{3}He/^{4}He$) or other noble gases (C. J. Ballentine, R. K. O'Nions, 1993), the final conclusions on genesis of nitrogen, found in natural gas, are very general and moderate. Although geochemical data from the German Basin indicate that nitrogen generation from organic matter is probably the most important source of nitrogen but other provenance such as from the mantle (R. Littke *et al.*, 1995) is also unexcluded.

Distribution and content of nitrogen and helium within natural gas found in the Polish Rotliegend series are rarely published and many data are known only from archives. The map of nitrogen and helium content in Rotliegend deposits, presented here (Fig. 50), was constructed basing on the newest elaborations of the Geological Bureau – GEONAFTA (P. Karnkowski, 1993; G. Kopczyńska, 1994). Data from the commented map came from exploitation wells and test samplings. The central part of the Polish Rotliegend Basin, devoid of isolines image, illustrates a lack of data there. In the remaining area, with extremely small amount of data, the dashed lines mark helium and nitrogen content. Both nitrogen and helium content in natural gas presented on the same map enables to analyse relationships between them. In the Pomeranian area, with relatively high nitrogen content (45–80%), helium is found sporadically, only in single wells in a few gas plays and without any industrial value. It seems that helium occurrence is connected with deep faults or fracture zones along which it could easily migrate upwards. Variability of nitrogen content in natural gas is also interesting; it decreases from the west to east, from the German Basin towards the East European Platform. In Germany the hypothesis on high-temperature transformation of organic matter as nitrogen source is accepted so the analogous suggestion could be considered for the Pomeranian region, where temperatures, affected Carboniferous source rocks of northwestern Poland, were lower than in the German Basin and they decreased from the west to east. On the maps of heat flow values (Figs. 45, 46), from the Rotliegend until Recent, this region is characterized by generally lower HF values. Thermal modellings of this area (P. H. Karnkowski, 1996a) indicate that high HF values dominated until the Zechstein. This heating produced so intensive organic matter maturity that during the next 300 mln years the Carboniferous source rocks, subjected to lower thermal regime, could slowly mature and release nitrogen and methane. It seems that the region extending between Szczecin and Koszalin is

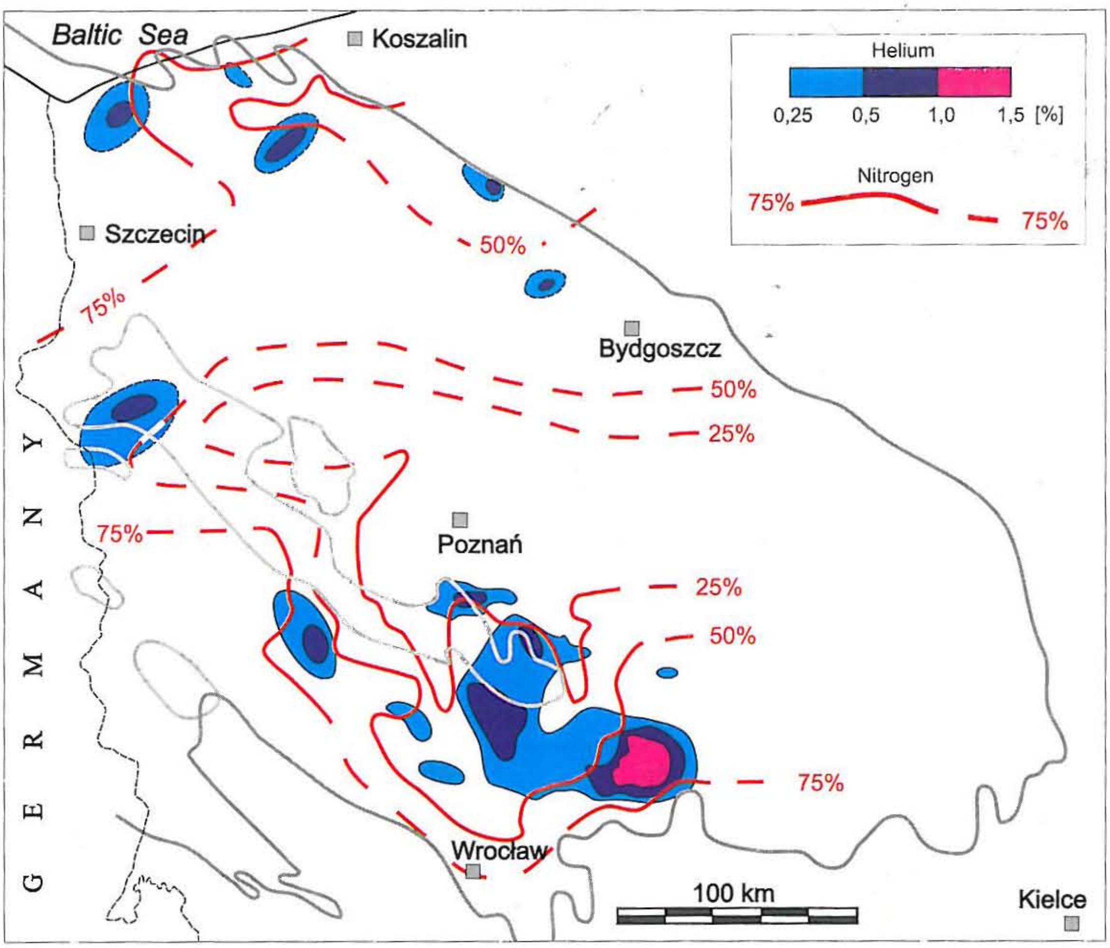


Fig. 50. Contents of the nitrogen and helium in the natural gas within the Rotliegend deposits (after P. Karnkowski, 1993; G. Kopczyńska, 1994).

comparable — in a genetic sense — to the German Basin. This is quite evident because the late Palaeozic history of the discussed regions was related to the marginal zone of the Rheno-Hercynian Basin, which was later included into the Variscides foreland.

A quite different distribution of helium and nitrogen content and their mutual relationship is visible in the southern part of the Polish Rotliegend Basin: nitrogen content increases there towards the basin margins but helium concentration belongs only to one distinct area (northeast of Wrocław) and is noticed not only in single wells but also within the whole gas plays. This is one of few places in the world, from which a condensed gas supplies industrial amount of helium. So there is not only a high helium content in natural gas plays but also its large volume. Nitrogen content is also high there, ranging from 40 to 75 vol. %. Methane content increases towards the basin center and the characteristic spots of higher methane amount within a nitrogen-helium field suggest its migration from a basin center to the south.

Location of high helium concentration corresponds to the area of the highest heat flow during the Late Permian, Triassic and Jurassic in the whole Polish Basin (comp. Figs. 45, 46, 50). Such a distinct convergence of these two elements is not accidental and it combines generation of giant helium amount with a source located in an area of very high heat flow value. Because helium occurrences, may be sourced only from the mantle or lower crust, so described here case should exhibit evidences confirming such a hypothesis. Deep seismic sections enabled construction of the structural map of the Moho surface in Poland (Fig. 4). It illustrates that in the region with the recently highest helium amount, and in which during the Permian–Mesozoic interval the area of the highest heat flow existed, the Earth's crust is thinned down to 30 km. Farther south of the Fore-Sudetic Block the similar position of Moho surface is recently recorded but its position results from a high rate of Cenozoic uplift of this region (A. Żelaź-niewicz, 1995). It may be accepted that the described palaeothermal-geochemical-tectonic anomaly, located about 60 km northeast of Wrocław, presents an evidence for the Late Permian–Early Mesozoic rifting process. A problem of rifting and existence of the Polish rift will be discussed in the next chapter.

Some remarks should be added to the problem of the origin of natural gases found in the Rotliegend series. High nitrogen content is noticed in the marginal southern part of the Polish Rotliegend Basin, in which — during the Permian and Early Mesozoic — anomalies of high heat flow values occurred. Maturity of Carboniferous source rocks from this area and the area of low nitrogen content (e.g. the Wielkopolska region) is similar, so it is supposed that nitrogen as well as helium recorded around the distinct palaeo-heat flow anomaly have a crustal/mantle provenance. If the origin of nitrogen in gases from Rotliegend deposits in Pomerania seems to correspond to German studies (R. Littke *et al.*, 1995; P. Gerling *et al.*, 1997) then the nitrogen, observed in Rotliegend sediments of the Fore-Sudetic Monocline, is suspected of inorganic, crustal/mantle genesis. This problem – the origin of nitrogen found in natural gas — seems to be a relatively new one and it requires further investigations.

POLISH RIFT BASIN — A MODEL

The development and evolution of the Polish Rotliegend Basin was hitherto presented as results of fragmentary analyses (i.e. analysis of palaeogeography, subsidence and thermal history, etc.). But elements constituting the history of a sedimentary basin ought to enable a construction of a model, connecting comprehensively and logically tectonic and tectonophysical reasons of basin origin and of its successive development stages. To obtain such a final image it is necessary to discuss all relationships between the geological structure of the crust as well as thermal and burial history of the basin.

Geotectonics constructed two fundamental models of basin formed by lithospheric extension. The first one assumes a homogenous thinning of the lithosphere (D. P. McKenzie, 1978) and the second one involves a displacement on a large-scale of a gently dipping shear zone which occurs throughout the crust (B. Wernicke, 1985; M. P. Coward, 1986). Within extensional stress field there may develop

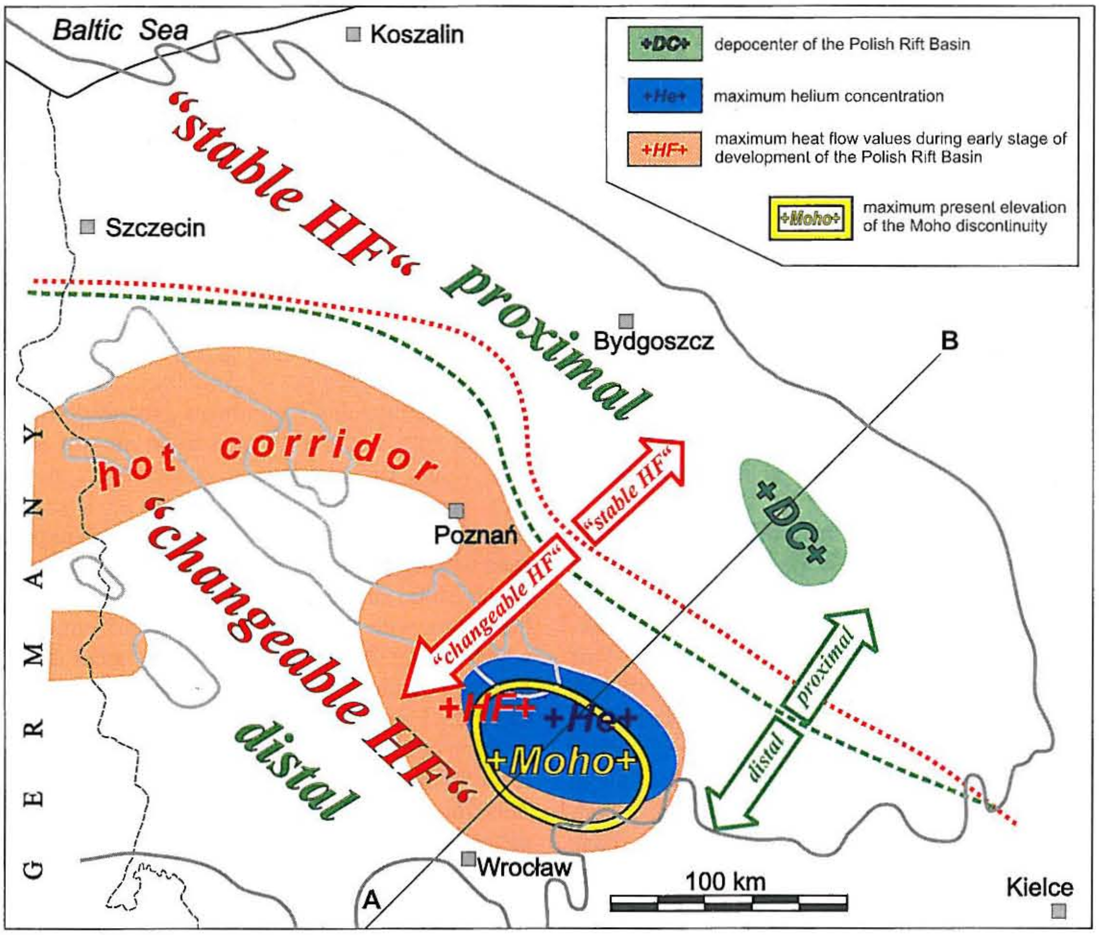


Fig. 51. Main tectonic and thermal features of the Polish Rift Basin; "stable HF" means that throughout development of the Polish Rift Basin in this area the values of heat flow were more or less stable, "changeable HF" means that during Permian to Late Jurassic time the heat flow values were much higher than in the Cretaceous–present time period, compare Figs. 45 and 46; distal and proximal part of the Polish Rift Basin was established on its burial history, compare Figs. 31-40; A–B — lokation of cross-section presented in Fig. 52.

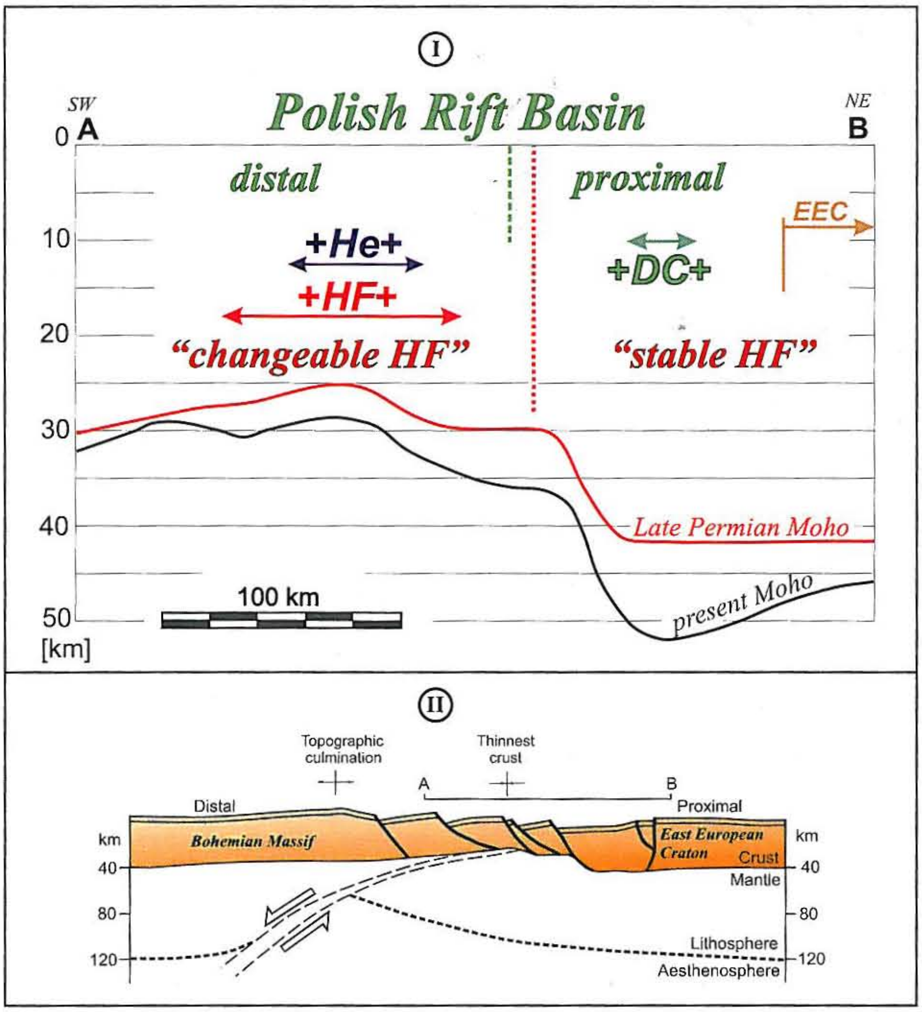


Fig. 52. Model for the Polish Rift Basin. **I** — Present and Permian restoration of the Moho discontinuity in the Polish Rift Basin along line A–B in Fig. 51 (other explanations as in Fig. 51), **II** — hypothetical geological cross-section through the Polish Rift Basin in Late Permian time (based on the model presented by B. Wernicke 1985.

only two strain types defined as: a pure shear geometry producing a symmetrical lithospheric cross-section (D. P. McKenzie, 1978) and a simple shear geometry with a through-going low-angle detachment dividing the lithosphere into an upper and lower plates and producing a highly asymmetrical lithospheric cross-section (B. Wernicke, 1985). The mechanism responsible for both basin formation is a lithospheric stretching and a rift becomes a place of such an extension. Recent rifts are mostly characterized by distinctly increased heat flow and volcanic activity as well as by a thinned crust.

Analysis of the Polish Rotliegend Basin evolution involves a fundamental question: what kind of the basin it was? Some questions are more easily solved when resulted from studies on elementary aspects of the Polish Basin geology. Geometry of the basin discussed is the most simple problem. Subsidence analysis indicates explicitly that the northeastern part of the basin was characterized by higher subsidence. This area is called the Mid-Polish Trough and the most complete Permian–Mesozoic sequences are preserved there. The southwestern basin area is characterized by a significantly lower subsidence and numerous non-deposition and erosion episodes (i.e. in the Rotliegend, Early Jurassic or Early Cretaceous). Concluding, the geometry of sedimentary sequences was asymmetrical in their character and high subsidence of the proximal part of the basin was accompanied by low subsidence or uplift of a distal basin area.

The thermal history of the Polish Basin suggests the existence of high positive anomalies of heat flow within the distal part of the basin during its initial phase of development. On the surface they were manifested as Permian volcanic activity. The stage of thermal transformation of organic matter and recent temperature distribution in the area studied have enabled — due to computer modelling — to prove that high heat flow values ("hot corridor") were located in a zone between Wrocław and Poznań and farther west (Fig. 50).

The configuration of Moho surface in Poland determined by deep seismic sections provides that the area of a thinner crust occurs in the distal part of the Polish Basin (see Fig. 4). Because the Sudetes and adjacent areas have been significantly uplifted in Meso-Cenozoic time above the Fore-Sudetic Monocline it may be assumed that the Moho surface in the area of a distal part of the basin (Fore-Sudetic Monocline) during Permian and early Mesozoic time was located at higher position than in surrounding regions. Such a position is recorded by the structural anomaly of Moho surface, located northeast of Wrocław, for which the crust bottom is recently noticed at the depth of less than 30 km. This structure is accompanied by the highest palaeogeothermal anomaly as well as highest concentration of helium within natural gas (Figs. 51, 52/I).

The results of analysis of burial and thermal history of the Polish Basin as well as configuration of the Moho surface in Poland, where its uppermost position is accompanied by a very high helium concentration, seem to suggest the asymmetrical style of basin model. Such a model explains logically interrelations between the above described main elements controlling the Polish Basin evolution, and it facilitates to understand the origin and to determine the moment when the main structural basin pattern was initiated. In such a case the Rotliegend volcanism in the Polish Lowlands is the first evidence of rifting. Connection of volcanism with the area of the thinner crust and of contemporary higher heat flow values is unquestioned. The basin asymmetry and clastic deposition during the initial period of the Wielkopolska Subgroup sedimentation, noticeable within the central part of the Polish Basin (in the Polish Trough), and synchronic intensive erosion of large uplifted elements (i.e. Wolsztyn Ridge) of distal part of the basin were marked as early as at the beginning of intensive subsidence. Permian volcanism was dated at 290–270 mln y. B. P. (I. Wendt *et al.*, 1985) and because it is related to an extensional regime so the age of rifting onset may be determined for the Early Permian (about 280 mln y. B. P.). The phenomena of the end of the Variscan epoch, which terminated deposition within the Rheno-Hercynian and Saxo-Thuringian basins as well as initiated formation of thrusting orogenes, also continued in the Late Carboniferous period in this part of Europe. But just in the Stephanian, in both areas of the Variscan orogene and its foreland, strike-slip movements were mainly manifested (P. Aleksandrowski, 1995; P. Aleksandrowski *et al.*, 1997). They caused development of small pull-apart basins, the relicts of which are now — for instance, the East Fore-Sudetic Basin or the basin recognized on the margin of the Upper Silesian region. Similar examples are in the area of the future Polish Basin where the fragments of Autunian and Stephanian deposits are preserved (Dolsk Fm.), being the remnants of such small basins. Their local occurrences are strictly connected with dominant tectonic zones, being active at least from the beginning of the Permian until Cenozoic. Activity of such zones is unquestioned — for instance, the Dolsk fault sytem or Poznań–Oleśnica fault zone (P. H. Karnkowski, 1980). The Late Upper Carboniferous (Stephanian) is considered to be the distinct stage of tectonic development of the Polish Lowlands but it still proceded the Polish Basin formation. It was characterized by development of small pull-apart basins. Because the formation of the Polish Rift Basin began during the Early Permian the Stephanian–Autunian, a strike-slip tectonic regime was stopped and did not continue during the Late Permian. Extension conditions in the simple shear regime, occurring in the early Upper Permian, enabled creation of the actual Polish Basin.

Considering relations between the Polish Basin formation and patterns of former sedimentary basins, existed in this area, it is clearly concluded that boundaries of the Polish Rotliegend Basin were determined by the margins of the Rheno-Hercynian and Saxo-Thuringian basins. So the Polish Rotliegend Basin developed in the area, the basement of which contains deposits of eastern parts of both the basins mentioned. Location of a subduction zone of the Variscan orogene in the area of Poland is still under consideration (comp. Z. Cymerman, M. A. Piasecki, 1994; P. Aleksandrowski, 1995; A. Żelaźniewicz, 1997; B. Wajsprych, 1997) but a formation of a thinned crust zone in the distal part of the Polish Basin may result from a weakness zone, occurred in the Variscan subduction region. The author would not attempt to solve this problem but only to punctuate such a possibility. Data, presented in this work, seem to prove the real relation between development of the Polish Rotliegend Basin and the patterns of the former Variscan basins. Accommodation of giant structural elements to formerly existed structural patterns is commonly known. Its best example is the East-European Craton margin, which controlled development of the Palaeozoic and Mesozoic sedimentary basins in Poland.

The above presented arguments and data univocally indicate the asymmetric, rift character of the Polish Basin, which first phase of development was the volcanism and deposition of the Rotliegend series (Fig. 52/II). The best model of such origin (formation and later development) is the rift model presented by B. Wernicke (1985), that assumes simple shear on lithospheric scale (with subsequent modifications — see B. Wernicke, 1990).

Sedimentation in the Polish Rotliegend Basin was controlled by tectonic factors such as an intensive rifting but it was manifested within individual sedimentary sequences as thicker conglomerate formations or members. Local sedimentological observations have not confirmed unusual processes of transport, erosion or deposition in a rifting regime. But analysis of geological processes going on within the initial rift basin allows to recognize better a role of each factor responsible for development of the Polish Rotliegend Basin.

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REFERENCES

ALEKSANDROWSKI P., 1995 — The significance of major strike-slip displacements in the development of Variscan structure of the Sudetes (SW Poland) [Eng. Summ.]. *Prz. Geol.*, **43**, 9: 745–754.

ALEKSANDROWSKI P., KRYZA R., MAZUR S., ŻABA J., 1997 — Kinematics data on major Variscan strike-slip faults and shear zones in the Polish Sudetes, northeast Bohemian Massif. *Geol. Mag.*, **134**: 727–739.

ALLEN P. A., ALLEN J. R., 1990 — Basin analysis – principles and applications. Blackwell Oxford.

ANDREAS D., HAUBOLD H., KATZUNG G., 1975 — Zur Grenze Stefan/Autun (Karbon/Perm). *Z. Geol. Wiss.*, **3**, 7: 699–716.

ANTONOWICZ L., IWANOWSKA E., RENDAK A., 1994 — Tensional tectonics in the Pomeranian section of the T-T zone and the implication for hydrocarbons exploration. *Geol. Quart.*, **38**, 2: 289–306.

BALLENTINE C. J., O'NIONS R. K., 1993 — The use of natural He, Ne and Ar isotopes as constraints on hydrocarbon transport. In: J. R. Parker (Ed.), Petroleum Geology of Northwest Europe: Proceedings of 4th Conference. Petroleum Geology of Northwest Europe: 1339–1345. The Geological Society, London.

BANKWITZ P., 1993 — Crustal types of Eastern Central Europe. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-20**, (255): 13–17.

BARANOWSKI Z., HAYDUKIEWICZ A., KRYZA R., LORENC S., MUSZYŃSKI A., URBANEK Z., 1990 — Outline of the geology of the Góry Kaczawskie (Sudetes, Poland). *N. Jb. Geol. Palaont. Abh.*, **179**, 2/3: 223-257.

BARRON E.J., FAWCETT P.J., 1995 — The climate of Pangea: A revision of climate model simulation. In: P. A. Scholle, T. M. Peryt, D. S. Ulmer-Scholle (Eds.), The Permian of Northern Pangea. **1**: 37–52. Springer-Verlag.

BELKA Z., AHRENDT H., FRANKE W., WEMMER K., 1997 — Provenance of clastic material in the Cambrian and Devonian rocks of Palaeozoic terranes of southern Poland: evidence from K/Ar ages of detrital muscovite. *Terra Nostra*, **97/5**: 23–25.

BEŁKA Z., SKOMPSKI S., 1988 — Mechanism of sedimentation and facial location of the Coal Limestone in southern Holy Cross Mts. [Eng. Summ.]. *Prz. Geol.*, **36**, 8: 442–448.

BERTHELSEN A., 1993 — Where different geological philosophies meet: the Trans-European Suture Zone. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-20**, 255: 19–32.

BŁASZCZYK J. K., 1981 — Paleomorphology of Weissliegendes top as the control facies variability on ore-bearing series of Lubin Copper Field, southwestern Poland. *Geol. Sudetica*, **16**: 195–217.

BLUNDELL D., FREEMAN R., MUELLER S. (Eds.), 1992 — A Continent revealed: the European geotraversel: 1–275. University Press Cambridge.

BOHDANOWICZ K., 1930 — O możliwości wykrycia złóż ropnych w Wielkopolsce. *Spraw. Pr. Pol. Komit. Energ.*, **4**: 25–28.

BOHDANOWICZ K., 1936 — Some problems of petroleum geology [Eng. Summ.]. *Ann. Soc. Geol. Polon.*, **12**: 486–568.

BOJKOWSKI K., 1978 — Palaeogeography of the Carboniferous in the Lublin and Silesia-Cracow areas [Eng. Summ.]. *Pr. Inst. Geol.*, **86**: 1–39.

BOJKOWSKI K., DEMBOWSKI Z., 1988 — Paleogeografia karbonu Lubelskiego Zagłębia Węglowego na tle paleogeografii karbonu Polski. *Pr. Inst. Geol.*, **122**: 18–26.

BOJKOWSKI K., ŻELICHOWSKI A. M., 1980 — An outline of palaeogeography of the Namuriam B-C and Westphalian in Poland. *Biul. Inst. Geol.*, **328**: 37–59.

BOND G. C., KOMINZ M. A., 1984 — Construction of tectonic subsidence curves for the early Paleozoic miogeocline, southern Canadian Rocky Mountains: implications for subsidence mechanism, age of breakup, and crustal thinning. *Geol. Soc. Amer. Bull.*, **95**: 155–173.

BROCHWICZ-LEWIŃSKI W., POŻARYSKI W., TOMCZYK H., 1981 — Large-scale strike-slip displacements along SW margin of the East European Platform in the early Palaeozoic [Eng. Summ.]. *Prz. Geol.*, **29**, 8: 385–397.

BROOKFIELD M. E., 1977 — The origin of bounding surfaces in ancient aeolian sandstones. *Sedimentology*, **24**: 303–332.

BULL W. B., 1964 — Alluvial fans and near-surface subsidence in western Fresno County, California. *U. S. Geol. Surv. Prof. Pap.* **437A**: 1–70.

BUŁA Z., JACHOWICZ M., 1996 — The Lower Palaeozoic sediments in the Upper Silesia Block. *Geol. Quart.*, **40**, 3: 299–336.

CAMERON T. D. J., 1993 — 4. Triassic, Permian and pre-Permian of the Central and Northern North Sea. In: R. W. O'B. Knox, W. G. Cordey (Eds.), Lithostratigraphic nomenclature of the UK North Sea. Nottingham.

CHLEBOWSKI R., 1995 — Volcanism in the Lower Carboniferous of the Holy Cross Mts. (Central Poland) [Eng. Summ.]. *Prz. Geol.*, **43**, 7: 543–545.

CHOROWSKA M., 1978 — Dewon zachodniej części obszaru przedsudeckiego. Przewodnik 50 Zjazdu PTG w Zielonej Górze : 108–113.

COLLINSON J. D., JONES C. M., BLACKBOURB G. A., BESLEY B. M., ARCHARD G. M., McMAHON A. H., 1993 — Carboniferous depositional systems of Southern North Sea. In: J. R. Parker (Ed.), Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference: 677–687. The Geological Society, London.

COWARD M. P., 1986 — Heterogeneus streching, simple shear and basin development. *Earth Planet. Sci. Lett.*, **80**, 3/4: 325–336.

CROWELL J. C., 1995 — The ending of the Late Paleozoic ice age during the Permian period. In: P. A. Scholle, T. M. Peryt, D. S. Ulmer-Scholle (Eds.), The Permian of Northern Pangea, **1**: 62–74. Springer-Verlag.

CYMERMAN Z., 1991 — Do exist terranes in the Sudetic Mountains? [Eng. Summ.]. *Prz. Geol.*, **39**, 10: 450–457.

CYMERMAN Z., 1998 — Controvercies about a geological division of the Sudetes [Eng. Summ.]. *Prz. Geol.*, **46**, 6: 530–536.

CYMERMAN Z., PIASECKI M. A., 1994 — The terrane concept in the Sudetes, Bohemian Massif. *Geol. Quart.*, **38**, : 191–210.

CYMERMAN Z., PIASECKI M. A., SESTON R., 1997 — Terranes and terrane boundaries in the Sudetes, northeastern Bohemian Masif. *Geol. Mag.*, **134**: 717–725.

CZARNOCKI J., 1936 — Überblick der Stratigraphie und Paläographie des Unterdevons im Polnischen Mittelgebirge. *Spraw. Państw. Inst. Geol.*, **8**, 4: 129–162.

CZARNOCKI J., 1951 — Z zagadnień paleogeograficznych i złożowych cechsztynu w Polsce. *Pr. Państ. Inst. Geol.*, **7**: 19–25.

CZARNOCKI S., 1935 — Nafta w Wielkopolsce i na Kujawach. *Prz. Górn.-Hutn.*, **27**: 94–104.

DĄBROWSKI A., MAJOROWICZ J., 1977 — Depth distribution of Curie Point and its influence on magmatic field [Eng. Summ.]. *Kwart. Geol.*, **21**, 4: 691–704.

DADLEZ R., 1974 — Tectonic position of Western Pomerania (north-western Poland) prior to the Upper Permian. *Biul. Inst. Geol.*, **274**: 49–82.

DADLEZ R., 1978 — Sub-Permian rock complexes in the Koszalin–Chojnice zone [Eng. Summ.]. *Kwart. Geol.*, **22**: 269–301.

DADLEZ R., 1980a — Mapa tektoniczna cechsztyńsko-mezozoicznego kompleksu strukturalnego na Niżu Polskim, skala 1:500 000. Państw. Inst. Geol. Warszawa.

DADLEZ R., 1980b — Tectonics of the Pomeranian Swell (NW Poland) [Eng. Summ.]. *Kwart. Geol.*, **24**: 741–767.

DADLEZ R., 1982 — On the interpretation of the Early Palaeozoic sequences in the Toruń 1 borehole [Eng. Summ.]. *Prz. Geol.*, **30**, 6: 273–276.

DADLEZ R., 1987a — Phanerozoic basinal evolution along the Teisseyre–Tornquist Zone. *Kwart. Geol.*, **31**: 263–278.

DADLEZ R., 1987b — Zechstein–Mesozoic complexes. In: A. Raczyńska (Ed.), Geological structure of the Pomeranian Swell and its basement [Eng. Summ.]. *Pr. Inst. Geol.*, **119**: 186–195.

DADLEZ R., 1989 — Epicontinental Permian and Mesozoic basins in Poland [Eng. Summ.]. *Kwart. Geol.*, **33**, 2: 175–198.

DADLEZ R., 1990 — Tectonics of the Southern Baltic [Eng. Summ.]. *Kwart. Geol.*, **34**, 1: 1–20.

DADLEZ R., 1993 — Teisseyre–Tornquist Tectonic Zone in Poland. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-20**, 255: 49–51.

DADLEZ R., 1997 — Epicontinental basins in Poland: Devonian to Cretaceous – relationships between the crystalline basement and sedimentary infill. *Geol. Quart.*, **41**, 4: 419–423.

DADLEZ R., FRANCZYK M., 1976 — Palaeogeographic and palaeotectonic significance of the Wielkopolska Ridge (Central Poland) in Lower Jurrasic Epoch [Eng. Summ.]. *Biul. Inst. Geol.*, **295**: 27–55.

DADLEZ R., KOWALCZEWSKI Z., ZNOSKO J., 1994a — Some key problems of the pre-Permian tectonics of Poland. *Geol. Quart.*, **38**, 2: 169–190.

DADLEZ R., NARKIEWICZ M., STEPHENSON R. A., VISSER M. T. M., 1994b — Subsidence of the Mid-Polish Trough in the Permian and Mesozoic [Eng. Summ.]. *Prz. Geol.*, **42**, 9: 715–720.

DADLEZ R., NARKIEWICZ M., STEPHENSON R. A., VISSER M. T. M., VAN WEES J.-D., 1995 — Tectonic evolution of the Mid-Polish Trough: modelling implications and significance for central European geology. *Tectonophysics*, **252**: 179–195.

DADLEZ R., POKORSKI J., 1996 — Geological interpretation of the DSS profile LT-7, NW Poland. In: EUROPROBE. Trans European Suture Zone – Workshop. Wroclaw-Książ, Abstract.

DAYCZAK-CALIKOWSKA K., MORYC W., 1988 — Evolution of sedimentary basin and palaetectonics of the Middle Jurassic in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 117–136.

DECZKOWSKI Z., FRANCZYK M., 1988a — Palaeothickness, lithofacies and palaeotectonics of the Norian and Rhaetian in Polish Lowland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 93–104.

DECZKOWSKI Z., FRANCZYK M., 1988b — Palaeothickness, lithofacies and palaeotectonics of the epicontinental Lower Jurassic in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 105–116.

DEPCIUCH T., LIS J., SYLWESTRZAK H., 1975 — K-Ar age of the cristalline basement rocks of north-east Poland [Eng. Summ.]. *Kwart. Geol.*, **19**, 4: 759–779.

DEPOWSKI S. (Ed.), 1978 — Lithofacies-palaeogeographical atlas of the Permian of the platform area of Poland. Państw. Inst. Geol. Warszawa.

DOKTOROWICZ-HREBNICKI S., 1954 — Mapa geologiczna Górnośląskiego Zagłębia Węglowego, skala 1:50 000. Inst. Geol. Warszawa.

DON J., 1995 — Problem hercynidów i waryscydów w Sudetach. *Prz. Geol.*, **43**, 9: 738–744.

DURAND B., ALPERN B., PITTION J. L., PRADIER B., 1986 — Reflectance of vitrinite as a control of thermal history in sediments. In: J. Burrus (Ed.), Thermal modeling in sedimentary basins: 441–474. Editions Technip, Paris.

DVOŘAK J., 1982 — The Devonian and lower Carboniferous in the basement of the Carpathian south and southeast of Ostrava (Upper Silesia Coal Basin), Moravia, Czechoslovakia). *Z. deutsch. Geol. Ges.*, **133**, 3: 551–570.

DYBOVA-JACHOWICZ S., KIERSNOWSKI H., TRZEPIERCZYŃSKA A., 1991 — Górny perm północno-wschodniego obrzeżenia Gornośląskiego Zagłębia Węglowego. XIV Sympozjum – Geologia formacji węglonośnych Polski: 13–18.

DYMENT J., 1989 — SWAT et les bassins celiques: relation avec la crôut hercynienne, néoformation du Moho. *Bull. Soc. geol. France*, **8**, V(3): 477–487.

DZIEDZIC K., 1961 — Lower Permian of the Intra-Sudetic Basin. *Studia Geol. Pol.*, **6**: 1–121.

DZIEDZIC K., TEISSEYRE A. K., 1990 — The Hercynian molasse and younger deposits in the Intra-Sudetic Depression, SW Poland. *N. Jb. Geol. Palaont. Abh.*, **179**: 285–305.

DZIK J., 1983 — Early Ordovician conodonts from the Barrandian and Bohemian-Baltic faunal relationships. *Acta Palaeont. Pol.*, **28**, 3–4: 327–368.

EVERLIEN G., HOFFMANN U., 1991 — Nitrogen in natural gas. *Erdöl und Kohle, Erdgas*, **44**: 166–172.

FALKE H., 1972 — The continental Permian in North and South Germany. In: H. Falke (Ed.), Rotliegend, Essays on European Lower Permian. *Inter. Sed. Petrogr. Ser.*, **15**: 43–113. Brill, Leiden.

FALKE H., 1974 — Das Rotliegende des Saar-Nahe-Gebietes. *Jber. Mitt. Oberrheim Geol. Ver. N. F.*, **56**: 1–14.

FALKE H., 1976 — Problems of the continental Permian in the Federal Republic of Germany. In: H. Falke (Ed.), The continental Permian in Central, West and South Europe: 38–52. Dortrecht, Holland.

FEYS R., GREBER Ch., 1972 — L'Autunien et la Saxonien en France. In: H. Falke (Ed.), Rotliegend, Essays on European Lower Permian. *Inter. Sed. Petrogr, Ser.*, **15**: 114–136. Brill, Leiden.

FRANKE D., 1993 — The southern border of Baltica – a review of the present state of knowledge. *Precambrian Research*, **64**: 419–430.

FRANKE W., ŻELAŹNIEWICZ A., PORĘBSKI S., WAJSPRYCH B., 1993 — The Saxothuringian zone in Germany and Poland: differences and common features. *Geol. Rundschau*, **82**: 583–599.

FREUND F., 1984 — H_2 and N_2 gas from magmatic rocks – a solid state viewpoint. *Oil & Gas Journal*, **82**, 34: 140–141.

FRYBERGER S. G., AHLBRANDT T. S., ANDREWS S., 1979 — Origins, sedimentary features and significance of low angle eolian "sand sheet" deposits. Great Sand Dunes National Monument and vicinity, Colorado. *J. Sed. Petrol.*, **49**: 733–762.

FRYBERGER S. G., AL-SARI A. M., CLISHAM T. J., 1983 — Eolian dune, interdune, sand sheet, and siliciclastic sabkha sediments of an offshore prograding sand sea, Dhahran area, Saudi Arabia. *AAPG Bulletin*, **67**: 280–312.

FRYBERGER S. G., KRYSTINIK I. F., SCHENK C. J., 1988 — Stokes surfaces and the effects of near-surface groundwater-table on aeolian deposition. *Sedimentology*, **35**: 21–41.

GAJEWSKA J., 1988a — Palaeothickness and lithofacies of the Muschelkalk and Lower Keuper and the Middle Triassic palaeotectonics in Polish Lowland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 73–82.

GAJEWSKA J., 1988b — Palaeothickness, lithofacies and palaeotectonics of the Upper Keuper in Polish Lowland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 83–92.

GARETSKY R. G., 1993 — The East European Craton (EEC) adjoining the Tornquist–Teisseyre Zone. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-20** (255): 65–68.

GAST R. E., 1991 — The perennial Rotliegend Saline Lake in NW Germany. *Geol. Jb.*, **A 119**: 25–59.

GAST R. E., 1993 — Sequenzanalyse von äolischen Abfolgen im Rotliegenden und deren Verzahnung mit Kustensedimenten. *Geol. Jb.*, **A 131**: 117–139.

GEBHARDT U., SCHNEIDER J., HOFFMAN N., 1991 — Modelle zur Stratigraphie und Beckenentwicklung im Rotliegenden der Norddeutschen Senke.. *Geol. Jb.*, **A 127**: 405–427.

GEORGE G. T., BERRY J. K., 1993 — A new lithostratigraphy and depositional model for the Upper Rotliegend of the UK Sector of the Southern North Sea. *Geol. Soc. Spec. Publ.*, **73**: 291–319. London.

GEORGE G. T., BERRY J. K., 1994 — A new paleogeographic and depositional model for the Upper Rotliegend, offshore the Netherlands. *First Break*, **13**, 3: 147–158.

GERLING P., IDIZ E., EVERLIEN G., SOHNS E., 1997 — New aspects on the origin of nitrogen in natural gas in Northern Germany. *Geol. Jb.*, **D 103**: 65–84.

GLENNIE K. W., 1970 — Desert sedimentary environments. *Developments in Sedimentology*, **14**. Elsevier Amsterdam.

GLENNIE K. W., 1972 — Permian Rotliegendes of northwest Europe interpreted in the light of modern desert sedimentation studies. *AAPG Bulletin*, **56**: 1048–1071.

GLENNIE K. W., 1984a — The structural framework and the Pre-Permian history of the North Sea area. In: K. W. Glennie (Ed.), Introduction to the petroleum geology of the North Sea: 17–40. Blackwell Scientific Publication, Palo Alto, California.

GLENNIE K. W., 1984b — Early Permian – Rotliegend, In: K. W. Glennie (Ed.), Introduction to the petroleum geology of the North Sea: 41–60. Blackwell Scientific Publication, Palo Alto, California.

GŁAZEK J., 1995 — A Caledonian orogen in Poland? (VORTRAG). *Nachr. Dt. Geol. Ges.*, **54**: 74–75.

GÓRECKA T., 1969 — Stratigraphic position of the Upper Carboniferous series from the Rybno borehole (Lower Silesia, SW Poland) [Eng. Summ.]. *Prz. Geol.*, **17**, 9: 431–433.

GÓRECKA T., 1970 — Results of microfloristic research of Permo-Carboniferous deposits found in the area between Jawor and Lubań (SW Poland) [Eng. Summ.]. *Kwart. Geol.*, **14**, 1: 52–62.

GÓRECKA T., GRODZICKI A., JUROSZEK C., KŁAPCIŃSKI J., LORENC S., MIERZEJEWSKI M., PARKA., SACHAŃBINSKI M., ŚLUSARCZYK S., TEMPLIN L., 1978 — Pre-Permian rocks of eastern part of the Fore-Sudetic Monocline [Eng. Summ.]. *Pr. Nauk. Inst. Górn. Polit. Wrocł. Seria: Monografie*, **25**, 11: 1–143.

GÓRECKA T., JUROSZEK C., KARWOWSKI L., KŁAPCIŃSKI J., LORENC S., MIERZEJEWSKI., SACHAŃBINSKI M., ŚLUSARCZYK S., 1977a — The crystalline rocks and Carboniferous deposits of the Fore-Sudetic Monocline, The Żary Perycline and the adjacent part of Fore-Sudetuc Block [Eng. Summ.]. *Pr. Nauk. Inst. Górn. Polit. Wrocł. Seria: Monografie*, **22**, 9: 1–92.

GÓRECKA T., PARKA Z., ŚLUSARCZYK S., TEMPLIN L., 1977b — The results of the palynological studies of sub-Permian sediments of the SE part of the Fore-Sudetic Monocline [Eng. Summ.]. *Pr. Nauk. Inst. Górn. Polit. Wrocł., Stud. Mater.*, **24**, 12: 29–55.

GRADZIŃSKI R, 1982 — Explanatory notes to the lithotectonic molasse profile of the Upper Silesia Basin (Upper Carboniferous–Lower Permian). In: H. Lützner, G. Schwab (Eds.), Tectonic regime of molasse epochs. *Veröff. Zentralinst. Phys. Erde*, **66**: 225–237.

GRADZIŃSKI R., GĄGOL J., ŚLĄCZKA A.,, 1979 — The Tumlin sandstones (Holy Cross Mts., Central Poland): Lower Triassic deposits of eolian dunesand interdune areas. *Acta Geol. Pol.*, **29**, 2: 151–175.

GRALLA P., 1988 — Das Oberrotliegende in NW-Deutchland – Lithostratigraphie und Faziesanalyse. *Geol. Jb.*, **A 106**: 3–59.

GRALLA P., VISSER C., 1995 — Southern Rotliegend Basin: Development from isolated salt pan to an intracontinental playa lake. *Terra Nostra*, **7**: 54–55.

GROCHOLSKI A., 1982 — Crystalline series of the Fore-Sudetic Block and the connected prospects in a light of new data. *Biul. Inst. Geol.*, **341**: 97–116.

GROCHOLSKI A., 1986 — Proterozoik and Palaeozoic of southwestern Poland in light of new data. *Biul. Inst. Geol.*, **355**: 7–29.

GROCHOLSKI A., 1987 — The Palaeozoic of southwestern Poland [Eng. Summ.]. *Geol. Sudetica*, 22: 69–90.

GROCHOLSKI W., 1972 — Mlodopaleozoiczne struktury północnego obrzeżenia bloku przedsudeckiego w podlożu monokliny przedsudeckiej. *Prz. Geol.*, **20**, 3: 160.

GROCHOLSKI W., 1981 — The main tectonic outline of the pre-Permian deposits of Wielkopolska. Proceed. Symp. Central Europ. Permian: 155–160. Jablonna, 1978, Warszawa.

GUTERCH A., GRAD M., JANIK T., MATERZOK R., LUOSTO U.,YLINIEMI J., LUCK E., SCHULZE A., FORSTE K., 1994 — Crustal structure of the transition zone between Precambrian and Variscan Europe. *C. R. Acad. Sci. Paris*, **318**, ser. II: 1489–1496.

GUTERCH A., GRAD M., MATERZOK R., TOPORKIEWICZ S., 1983 — Structure of the Earth's crust of the Permian Basin in Poland. *Acta Geophys. Pol.*, **31**: 128–131.

GUTERCH A., GRAD M., MATERZOK R., PERCHUĆ E., 1986 — Deep structure of the Earth's crust in the contact zone of the Paleozoic and Precambrian Platforms in Poland (Teisseyre-Tornquist zone). *Tectonophysics*, **128**: 251–279.

GUTERCH A., GRAD M., MATERZOK R., PERCHUĆ E., JANIK T.,GACZYŃSKI E., DOAN T. T., BIAŁEK T., GADOMSKI D., MŁYNARSKI S., TOPORKIEWICZ S., 1991 — Structure of the lower crust of the Paleozoic Platform in Poland form sesismic wide-angle and near vertical reflection surveys. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-19**,236: 41–62.

GUTERCH A., LEWANDOWSKI M., DADLEZ R., POKORSKI J., WYBRANIEC S., ŻYTKO K., GRAD M., KUTEK J., SZULCZEWSKI M., ŻELAŹNIEWICZ A., 1996 — Basic problems of deep geophysical and geological investigations of Poland [Eng. Summ.]. *Publ. Inst. Geoph. Pol. Acad. Sc.* , **M-20**, 294: 1–44.

HAENDEL D., MÜHLE K., NITZSCHE H.-M. STIEHL G., WAND U., 1986 — Isotopic variation of the fixed nitrogen in metamorphic rocks. *Geochim. Cosmochim. Acta*, **50**: 749–758.

HAKENBERG M., ŚWIDROWSKA J., 1997 — Propagation of the south-eastern segment of the Polish Trough connected with bounding fault zones (from Permian to the Late Jurrassic). *C. R. Acad. Sci. Paris*, **324**, serie IIa: 793–803.

HAKENBERG M., ŚWIDROWSKA J., 1998 — Evolution of the Holy Cross segment of the Mid-Polish Trough during the Cretaceous. *Geol. Quart.*, **42**, 3: 239–262.

HANCOCK J. M., 1975 — The petrology of the Chalk. *Proceedings of the Geologists' Association*, **86**, 4: 499–535.

HANCOCK J. M., 1987 — Sea-level changes in the British region during the Late Cretaceous. *Proceedings of the Geologists' Association*, **100**, 4: 565–594.

HANCOCK J. M., KAUFFMAN E. G., 1979 — The great transgressions of the Late Cretaceous. *J. Geol. Soc. Lond.*, **136**: 175–186.

HARLAND W. B., ARMSTRONG R. L., COX A. V., CRAIG L. E., SMITH A. G., SMITH D. G., 1989 — A geologic time scale. Cambridge University Press.

HAUBOLD H., KATZUNG G., 1975 — Die Position der Autun/Saxon-Grenze (unteres Perm) in Europa und Nordamerika. *Schriften geol. Wiss.*, **3**: 87–138.

HEDEMANN H. A., MASCHEK W., PAULUS B., PLEIN E., 1984 — Mitteilung zur lithostratigraphischen Gliederung des Oberrotliegenden im nordwestdeutschen Becken. *Nachr. Dt. Geol. Ges.*, **30**: 100–107.

HELMUTH H. J., SÜSSMUTH S., 1993 — Die lithostratigraphische Gliederung des jungeren Oberrotliegenden (Oberrotliegendes II) in Nordostdeutchland. *Geol. Jb.*, **A 131**: 31–55.

HIYAGON H., KENNEDY B. M., 1992 — Noble gases in CH_4-rich gas fields. *Geochim. Cosmochim. Acta*, **56**: 1569–1589.

HOFFMAN N. , 1990 — Zur paläodynamischen Entwicklung des Prazechsteines in der Nordostdeutschen Senken. *Nds. Akad. Geowiss. Veröfftl.*, **4**: 5–18.

HOFFMAN N., KAMPS H. J., SCHNEIDER J., 1989 — Neuerkenntnisse zur Biostratigraphie und Palaodynamik des Perms in der NordostdeutschenSenken – ein Diskossionsbeitrag. *Z. Angew. Geol.*, **35**, 7: 198–207.

HOFFMANN N., POKORSKI J., LINDERT W., BACHMANN G. H., 1997 — Rotliegend stratigraphy, palaeogeography and facies in eastern part of the central European Basin. Proc. XIII Int. Congr. on Carbonif.-Permian, Kraków. *Pr. Państw. Inst. Geol.*, **157**: 75–86.

HYDE W. T., KIM K.-Y., CROWLEY T. J., 1990 — On the relation between polar continentality and climate studies with a nonlinear seasonal energy balance model. *Jour. Geophys. Res.*, **95**: 18653–18668.

IES-PetroMod, 1993 — Manual for the PetroMod application. Julich.

JACKOWICZ E., 1994 — Permian volcanic rocks from the northern part of the Fore-Sudetic Monocline [Eng. Summ.]. *Pr. Państw. Inst. Geol.*, **145**: 1–47.

JACKOWICZ E., 1995 — Lower Rotliegend volcanic rocks from the western part of the Polish Lowland. *Terra Nostra*, **7**: 67–69.

JASKOWIAK-SCHOENEICHOWA M., KRASSOWSKA A., 1988 — Palaeothickness, lithofacies and palaeotectonics of the epicontinental Upper Cretaceous in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 177–198.

JAWOROWSKI K., 1979 — Cambrian marine transgression in northern Poland. *Pr. Inst. Geol.*, **94**: 5–80.

JAWOROWSKI K., 1982 — Depositional conditions of Precambrian and Cambrian sediments in northern Poland [Eng. Summ.]. *Prz. Geol.*, **30**, 5: 220–224.

JAWORSKI K., 1986 — Mapa temperatur i gradientów geotermicznych na głębokościach – 1500 m, 2500 m, 3500 m dla obszaru Niżu Polskiego, 1:500 000. Arch. B. G. Geonafta.

JAWORSKI K., 1987 — Mapa temperatur i gradientu geotermicznego w stropie osadów czerwonego spągowca, 1:500 000. Arch. B. G. Geonafta.

JAWORSKI K., 1988a — Mapa temperatur i gradientów geotermicznych w stropie dolomitu głównego na Niżu Polskim, 1:500 000. Arch. B. G. Geonafta.

JAWORSKI K., 1988b — Mapa temperatur i gradientów geotermicznych w stropie osadów malmu na Niżu Polskim, 1:500 000. Arch. B. G. Geonafta.

JAWORSKI K., 1991 — Mapa temperatur i gradientów geotermicznych w spągu osadów karbonu, 1:500 000. Arch. B. G. Geonafta.

JERZYKIEWICZ J., 1973 — Preliminary results of the microfloristic investigations and stratigraphic position of the Athracosia Shale (Lower Permian of the Intra-Sudetic Basin) [Eng. Summ.]. *Kwart. Geol.*, **17**, 2: 285–292.

JERZYKIEWICZ J., 1975 — Spore-pollen assemblages of the Carboniferous/Permian boundary of the Okrzeszyn area [Eng. Summ.]. *Kwart. Geol.*, **19**, 3: 559–568.

JERZYKIEWICZ J., 1977 — Wyniki badań palinologicznych osadów karbonu i permu na monoklinie przedsudeckiej. *Prace Nauk. Inst. Górn. Polit. Wrocł.*, **24**, 12: 4–27.

JERZYKIEWICZ T., KIJEWSKI P., MROCZKOWSKI J., TEISSEYRE A. K., 1976 — Origin of the Weisliegendes deposits in the Fore-Sudetic Monocline. *Geol. Sudetica*, **11**: 57–100.

JOHNSON G. A. L., 1961 — Lateral variation of marine and deltaic sediments in cyclothemic deposits with particular reference to the Visean and Namurian of northern England. C-R 4th Congr. pour l'Avancement des Etudes de Strat. Géol. Carbon., **2**: 323–330.

JOHNSON H., WARRINGTON G. STOKER S. J., 1994 — 6. Permian and Triassic of the Southern North Sea. In: R. W. O'B. Knox, W. G. Cordey (Eds.), Lithostratigraphic nomenclature of the UK North Sea. British Geological Survey, Nottingham.

JUBITZ K. B., ZNOSKO J., FRANKE D. (Eds.), 1986 — Tectonic Map, International Geological Correlation Programme No. 86: South-West Border fo the East European Platform, 1:1 500 000. Berlin.

KARNER G. D., DRISCOL N. W., WEISSEL J. K., 1993 — Response of the lithosphere to in-plane force variations. *Earth Planet. Sci. Lett.*, **114**: 397–416.

KARNER G. D., STECKLER M. S., THORNE J. A., 1983 — Long term thermo-mechanical properties of the lithosphere. *Nature*, **304**: 250–252.

KARNKOWSKI P., 1979 — Wgłębne przekroje geologiczne przez Niż Polski. Wyd. Geol. Warszawa.

KARNKOWSKI P., 1981 — Geological conditions of occurrence of hydrocarbons in the Permian of the Polish Lowland. Proceed. Symp. Central Europ. Permian: 568–573. Jabłonna, 1978, Warszawa.

KARNKOWSKI P., 1983 — Major orogenic phases affecting foreland of the Carpahians [Eng. Summ.]. *Prz. Geol.*, **31**, 12: 629–633.

KARNKOWSKI P., 1993 — Złoża gazu ziemnego i ropy naftowej w Polsce, T. 1. Niż Polski. Towarzystwo Geosynoptyków „Geos", AGH Kraków.

KARNKOWSKI P., 1996 — Oil and gas fields in Poland. In: G. Wessely, W. Liebl (Eds.), Oil and gas in Alpidic thrustbelts and basins of Central and Eastern Europe. *EAGE Special Publication*, **5**: 3–15.

KARNKOWSKI P., KRZYSZTOFOWICZ Z., SOLAK M., 1978 — Geological structure of Zechstein substratum in the Permian Basin [Eng. Summ.]. *Kwart. Geol.*, **22**, 4: 735–751.

KARNKOWSKI P., SOKOŁOWSKI J., STEMULAK J., 1966 — Odkrycie pierwszego w Polsce złoża gazu ziemnego w utworach czerwonego spągowca. *Geof. i Geol. Naft.*, **1–2**: 1–6.

KARNKOWSKI P., SOLAK M., ŻOŁNIERCZUK T., 1991 — Rozwój basenów ropo- i gazonośnych Wielkopolski. Przew. 62 Zjazdu Pol. Tow. Geol.: 24–31. Poznań.

KARNKOWSKI P. H., 1977 — Facies analysis of the Rotliegendes in the northern part of the Fore-Sudetic Monocline (Poznań–Śrem region) [Eng. Summ.]. *Acta Geol. Pol.*, **27**, 4: 481-495.

KARNKOWSKI P. H., 1980a — The palaeotectonics of platform cover in the Wielkopolska region [Eng. Summ.]. *Prz. Geol.*, **28**, 3: 146–151.

KARNKOWSKI P. H., 1980b — Outline of tectogenesis of the platform cover in the Wielkopolska area (W Poland). *Acta Geol. Pol.*, **30**, 4: 485–505.

KARNKOWSKI P. H., 1981 — The current lithostratigraphy subdivision of the Rotliegendes in Poland and proposition of its formalization [Eng. Summ.]. *Kwart. Geol.*, **25**, 1: 59–66.

KARNKOWSKI P. H., 1985 — Conditions of the gas fields forming process in the Wielkopolska region (W Poland) [Eng. Summ.]. *Kwart. Geol.*, **29**, 2: 355–368.

KARNKOWSKI P. H., 1986a — The nature of Zechstein transgression versus origin of the Weissliegendes in the Wielkopolska area (northern Fore-Sudetic Monocline, western Poland) [Eng. Summ.]. *Geol. Sudetica*, **21**, 2: 101–122.

KARNKOWSKI P. H. , 1986b — Allostratigraphic units – a proposition of new formal units in the Polish stratigraphic subdivisions [Eng. Summ.]. *Prz. Geol.*, **34**, 5: 255–257.

KARNKOWSKI P. H., 1987a — Lithostratigraphy of the Rotliegend in the Wielkopolska region [Eng. Summ.]. *Kwart. Geol.*, **31**, 4: 643–672.

KARNKOWSKI P. H., 1987b — Allostratigraphy and lithostratigraphy of the Rotliegend in Poland [Eng. Summ.]. *Kwart. Geol.*, **31**, 1: 43–56.

KARNKOWSKI P. H., 1987c — Facies analysis of the Wielkopolska Group (Upper Rotliegend) in the northern part of the Fore-Sudetic Monocline [Eng. Summ.]. *Prz. Geol.*, **35**, 4: 187–192.

KARNKOWSKI P. H., 1991 — Problems of tectonic movements in the Rotliegendes [Eng. Summ.]. *Prz. Geol.*, **39**, 7–8: 352–356.

KARNKOWSKI P. H., 1992 — Development of ideas on lithostratigraphy and cyclicity of the Permian deposits of the Silesia-Cracow region – implications, complications and applications [Eng. Summ.]. *Prz. Geol.*, **40**, 8: 473–478.

KARNKOWSKI P. H., 1994 — Rotliegend lithostratigraphy in the central part of the Polish Permian Basin. *Geol. Quart.*, **38**, 1: 27–42.

KARNKOWSKI P. H., 1995a — Rotliegend volcanism in the Polish Permian Basin and its relation to the Variscides. *Terra Nostra*, **7**: 74–76.

KARNKOWSKI P. H., 1995b — Upper Rotliegend - Zechstein: Terrestrial-marine sedimentary succession in the Wielkopolska region. XIII Int. Congr. on Carboniferous-Permian, Kraków, Exc. Guide A-3: 23–37. Państw. Inst. Geol. Warszawa.

KARNKOWSKI P. H., 1995c — Stratigraphic gas traps within the Rotliegend deposits in the Polish Permian Basin. EAPG 57th Conf. and Technical Exhibition, Glasgow, Ext. Abstr., **2**: P 522. Glasgow.

KARNKOWSKI P. H., 1996a — Thermal history and hydrocarbon generation in the area of Dobrzyca Structure (Western Pomerania, Poland) [Eng. Summ.]. *Prz. Geol.*, **44**, 4: 349–357.

KARNKOWSKI P. H., 1996b — Budowa basenu permsko-mezozoicznego i jego podłoże na mapach ścięcia poziomego. In: Z. Kotański (Ed.), Budowa geologiczna Polski na mapach scięcia poziomego 1:500 000. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

KARNKOWSKI P. H., 1997a — Palaeogeography and palaeotectonics of the Rotliegend in the Polish Permian Basin. Proc. XIII Int. Congr. on Carbonif.–Permian, Kraków. *Pr. Państw. Inst. Geol.*, **157**: 97–106.

KARNKOWSKI P. H., 1997b — Impact of source area on the Rotliegend sedimentary records in the Polish Permian Basin: implications for gas fields investigations [Eng. Summ.]. In: J. Wojewoda (Ed.), Obszary źródłowe: Zapis w osadach, **1**: 7–24. Wind, Wrocław.

KARNKOWSKI P. H., KIERSNOWSKI H., CZAPOWSKI G., 1996 — Lithofacies (stratigraphic) gas traps in the light of geological/geophysical data (Polish Permian Basin). *Oil and Gas News from Poland*, **6**: 81–98.

KARNKOWSKI P. H., KIERSNOWSKI H., CZAPOWSKI G., 1997a — Rotliegend stratigraphic gas traps versus depositional systems in the Polish Permian Basin. Proc. XIII Int. Congr. on Carbonif.–Permian, Kraków. *Pr. Państw. Inst. Geol.*, **157**: 345–352.

KARNKOWSKI P. H., KIERSNOWSKI H., CZAPOWSKI G., 1997b — Sedimentological and geophysical data as a tool for prediction of the Rotliegend stratigraphic gas traps (Polish Permian Basin). Proc. XIII Int. Congr. on Carbonif.–Permian, Kraków. *Pr. Państw. Inst. Geol.*, **157**: 353–360.

KARNKOWSKI P. H., RDZANEK K., 1982 — Some remarks on basement of the Permian in the Wielkopolska region. *Kwart. Geol.*, **26**, 2: 327–340.

KATZUNG G., 1968 — Perm. In: Grundriss der Geologie der DDR: 199–218. Akademie-Verlag, Berlin.

KATZUNG G., 1982 — Explonatory notes to the lithotectonic molasse profile of the Central European Depression (North-East German Depression, G. D. R.). In: H. Lützner, G. Schwab (Eds.), Tectonic Regime of Molasse Epochs. *Veroff. Zentralinst. Phys. Erde*, **66**: 209–224.

KATZUNG G., 1988 — Tectonics and sedimentation of Variscan molasses. *Z. geol. Wiss.*, **16**, 9: 823–884.

KEEN C.E., BEAUMONT C., BOUTILIER R., 1983 — A summary of thermo-mechanical model results for the evolution of continental margins based on three rifting prosesses. *AAPG Mem.*, **34**: 725–728.

KIERSNOWSKI H., 1983 — Rozwój sedymentacji utworów klastycznych późnego paleozoiku w okolicach Brzegu. *Prz. Geol.*, **31**: 475–479.

KIERSNOWSKI H., 1991 — Litostratygrafia permu północno-wschodniego obrzeżenia Górnośląskiego Zagłębia Węglowego - nowa propozycja. *Prz. Geol.*, **39**, 4: 198–203.

KIERSNOWSKI H., 1995 — Origin and development of the Late Paleozoic, Eastern Fore-Sudetic Basin [Eng. Summ.]. Materiały Sesji 64 Zjazdu PTG: 19–35. Wrocław.

KIERSNOWSKI H., 1997a — Upper Permian eolian complex in Poland. Proc. XIII Int. Congr. on Carbonif.–Permian, Kraków. *Pr. Państw. Inst. Geol.*, **157**: 107–110.

KIERSNOWSKI H., 1997b — Depositional development of the Polish Upper Rotliegend Basin and evolution of its sediment source areas. *Geol. Quart.*, **41**, 4: 433–456.

KIERSNOWSKI H., MALISZEWSKA A., 1985 — Coarse-clastic Rotliegendes sediments of the Siewierz-Olkusz region in the light of new data [Eng. Summ.]. *Prz. Geol.*, **33**, 4: 181–192.

KIERSNOWSKI H., PAUL J., PERYT T. M., SMITH D. B., 1995 — Facies, paleogeography, and sedimentary history of the southern Permian Basin in Europe. In: P. A. Scholle, T. M. Peryt, D. S. Ulmer-Scholle (Eds.), The Permian of Northern Pangea, **2**: 119–136. Springer-Verlag.

KŁAPCIŃSKI J., 1967 — A contribution to stratigraphy and palaegeography of the Rotliegendes in the Fore-Sudetic Monocline (SW Poland) [Eng. Summ.]. *Ann. Soc. Geol. Polon.*, **37**, 4: 467–489.

KŁAPCIŃSKI J., 1971 — Lithology, fauna, stratigraphy and palaeogeography of the Permian in the Fore-Sudetic Monocline [Eng. Summ.]. *Geol. Sudetica*, **5**: 77–135.

KŁAPCIŃSKI J., HAYDUKIEWICZ J., LORENC S., 1978 — Utwory skalne podłoża podpermskiego południowej części regionu poznańskiego z wybranych otworów wiertniczych. Arch. B. G. Geonafta.

KŁAPCIŃSKI J., JAROSZEK CZ., SACHAŃBINSKI M., 1975 — New data on the crystalline basement in the Fore-Sudetic area [Eng. Summ.]. *Geol. Sudetica*, **10**, 2: 7–46.

KNIESZNER L., SOLAWA W., 1980 — Seismic mapping of the Upper Palaeozoic in north-western Poland [Eng. Summ.]. *Prz. Geol.*, **28**, 3: 165–168.

KOCUREK G., 1981 — Significance of interdune deposits and bounding surfaces in eolian dune sands. *Sedimentology*, **28**, 4: 753–780.

KOCUREK G., 1988 — First order and super bounding surfaces in eolian sequences - bounding surfaces revisited. *Sedimentary Geology*, **56**: 193–206.

KOCUREK G., HAVHOLM K. G., 1993 — Eolian sequence stratigraphy - a conceptual framework. *AAPG Mem.*, **58**: 393–409.

KOCUREK G., HAVHOLM K. G., DEYNOUX M., BLAKEY R. C., 1991 — Amalgamated accumulation resulting from climatic and eustaic changes, Akhar Erg, Mauritania. *Sedimentology*, **38**, 4: 751–772.

KOPCZYŃSKA G., 1994 — Mapa składu chemicznego gazu ziemnego w utworach czerwonego spągowca i wapienia cechsztyńskiego na Niżu Polskim, skala 1:200 000. Arch. B. G. Geonafta.

KOREJWO K., 1969 — Stratigraphy and paleogeography of the Namurian in the Polish Lowland. *Acta Geol. Pol.*, **19**, 4: 609–709.

KOREJWO K., TELLER L., 1967 — Stratigraphy of Lower Carboniferous from the Sulów 1 and Lamki 1 boreholes [Eng. Summ.]. *Acta Geol. Pol.*, **17**, 2: 299–313.

KOSSMAT F., 1927 — Gliederung des varistischen Gebirgsbaues. *Abhandlungen Sachsischen Geologischen Landesamts*, **1**: 1–39.

KOTAŃSKI Z., 1997a — Geology of Poland on the maps of horizontal cutting [Eng. Summ.]. *Prz. Geol.*, **45**, 6: 605–618.

KOTAŃSKI Z. (Ed.), 1997b — Geological atlas of Poland: Geological maps of horizontal cutting, 1:750 000. Państw. Inst. Geol. Warszawa.

KOTAS A., 1973 — Występowanie kambru w podłożu Górnośląskiego Zagłębia Węglowego. *Prz. Geol.*, **21**, 1: 37.

KOTAS A., 1982 — Zarys budowy geologicznej Górnośląskiego Zagłębia Węglowego. In: Przewodnik 54 Zjazdu Pol. Tow. Geol.: 45–72. Sosnowiec.

KOTAS A., MALCZYK W., 1972a — The Paralic series of the Lower Namurian stage of the Upper Silesia Coal Basin [Eng. Summ.]. *Pr. Inst. Geol.*, **61**: 329–426.

KOTAS A., MALCZYK W., 1972b — The Upper Silesian Sandstone Series of the Upper Namurian stage of the Upper Silesia Coal Basin [Eng. Summ.]. *Pr. Inst. Geol.*, **61**: 427–466.

KOWALCZEWSKI Z., 1968 — The Miedziana Góra conglomerates in the western part of the Świętokrzyskie Mountains [Eng. Summ.]. *Prz. Geol.*, **16**, 1: 20–23.

KOWALCZEWSKI Z., 1981 — Key problems of the tectonics of Palaeozoic core of the Holy Cross Mts. [Eng. Summ.]. *Prz. Geol.*, **29**, 7: 334–340.

KOWALCZEWSKI Z., 1990 — Coarse grained Cambrian rocks in central south Poland [Eng. Summ.]. *Pr. Inst. Geol.*, **131**: 1–82.

KOZŁOWSKI S., PARACHONIAK W., 1967 — Permian volcanism in the North-Sudetic Basin [Eng. Summ.]. *Pr. Muz. Ziemi*, **11**: 191–222.

KOZUR H., 1988 — The Age of the Central European Rotliegendes. *Z. geol. Wiss.*, **16**, 9: 907–915.

KRAWCZYŃSKA-GROCHOLSKA H., 1978 — Karbon w podłożu zachodniej części monokliny przedsudeckiej. Przew. 50 Zjazdu Pol. Tow. Geol.: 113–118. Zielona Góra.

KRAWCZYŃSKA-GROCHOLSKA H., GROCHOLSKI W., 1976a — Some remarks on the Carboniferous rocks in the NW margin of the Fore-Sudetic Block [Eng. Summ.]. *Kwart. Geol.*, **20**, 1: 53–63.

KRAWCZYŃSKA-GROCHOLSKA H., GROCHOLSKI W., 1976b — Deep geological structures in the Poznań region in the light of 1973–1975 investigations [Eng. Summ.]. *Prz. Geol.*, **23**, 9: 520–524.

KRÓLIKOWSKI C., 1993 — Analysis of gravity anomalies as related to the basement in the Tornquist-Teisseyre Zone in Northwestern Poland. *Publ. Inst. Geoph. Pol. Acad. Sc.* **A-20**, 255: 105–109.

KRÓLIKOWSKI C., PETECKI Z., 1995 — Atlas grawimetryczny Polski. Państw. Inst. Geol. Warszawa.

KUCHCIŃSKI J., 1973 — Tectonic development of the Rotliegendes (Lower Permian Basin in North-West Poland [Eng. Summ.]. *Biul. Inst. Geol.*, **264**: 223–235.

KURSHS V., GIRST STINKULIS L., 1998 — Middle Devonian clastic and carbonate transitional facies in the eastern Baltic. In: 15th International Sedimentological Congress: 488–489. Alicante.

KUTEK J., 1994 — Jurassic tectonic events in south-easten cratonic Poland. *Acta Geol. Pol.*, **44**, 3–4: 167–221.

KUTEK J., GŁAZEK J., 1972 — The Holy Cross area, Central Poland, in the Alpine Cycle. *Acta Geol. Pol.*, **22**, 4: 603–653.

KUTZBACH J. E., GALLIMORE R. G., 1989 — Pangean climates: Megamonsoons of the megacontinent. *J. Geophys. Res.*, **94**: 3341–3357.

LANGFORD R. P., 1989 — Fluvial-eolian interactions: part 1 - modern systems. *Sedimentology*, **36**, 6: 1023–1035.

LANGFORD R. P., CHAN M. A., 1989 — Fluvial-eolian interactions: part 2 - ancient systems. *Sedimentology*, **36**, 6: 1037–1052.

LENDZION K., 1970 — The Cambrian North-East Poland. In: Geology of Poland, **1**: 157–166. Inst. Geol. Warszawa.

LENDZION K., 1983 — Rozwój kambryjskich osadów platformowych Polski. *Pr. Inst. Geol.*, **105**: 1–55.

LEWANDOWSKI M., 1987 — Results of the preliminary paleomagnetic investigations of some Lower Paleozoic rocks from the Holy Cross Mts. (Poland). *Kwart. Geol.*, **31**, 4: 543–556.

LEWANDOWSKI M., 1991 — New paleomagnetic data from the Early Devonian sandstones of the Holy Cross Mts. and their geotectonic implications. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-19**, 236: 17–39.

LEWANDOWSKI M., 1993 — Paleomagnetism of the Paleozoic rocks of the Holy Cross Mts. (Central Poland) and the origin of the Variscan orogen. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-23**, 265: 1–85.

LEWANDOWSKI M., 1994 — Palaeomagnetic constraints for Variscan mobilism of the Upper Silesian and Małopolska Massifs, southern Poland. *Geol. Quart.*, **38**, 2: 211–230.

LEWANDOWSKI M., 1995 — Palaeomagnetic constraints for Variscan mobilism of the Upper Silesian and Małopolska Massifs, southern Poland - reply. *Geol. Quart.*, **39**, 2: 283–292.

LINDERT W., WARNECKE D., STUMM M., 1990 — Probleme der Lithostratigraphischen Korrelation des Oberrotliegenden (Sakson) im Norden der DDR. *Z. Angew. Geol.*, **36**, 10: 368–375.

LIPIARSKI J., 1971 — La flore du Permien inférieur apparaissant dans le travertine de Karniowice aux environs de Cracovie [Fr. Summ.]. *Pr. Inst. Geol.*, **58**: 5–112.

LITTKE R., KROOSS B., IDIZ E., FRIELINGSDORF J., 1995 — Molecular nitrogen in natural gas accumulations: generation from sedimentary organic matter at high temperatures. *AAPG Bulletin*, **79**, 3: 410–430.

LOKHORST A. (Ed.), 1997 — NW European Gas Atlas: composition and isotope ratios of natural gases. (only CD-ROM version). Amsterdam.

LORENC S., 1983 — Petrogenesis of the Wojcieszów crystalline limestones (Góry Kaczawskie, Sudetes). *Geol. Sudetica*, **18**: 61–119.

LÜTZNER H., 1987 — Sedimentary and volcanic Rotliegendes of the Saale Depression. In: H. Lützner (Ed.) Symposium on Rotliegendes in Central Europe, Excursion Guidebook: 1–197. Potsdam.

LÜTZNER H., 1988 — Sedimentology and basin development of intramontane Rotliegend basins in Central Europe. *Z. geol. Wiss.*, **16**, 9: 845–863.

LÜTZNER H., ELLENBERG J., FALK F., 1981 — Sedimentology and basin development of Rotliegend deposits in the Saale Trough. Proceed. Symp. Central Europ. Permian: 239–252. Jabłonna, 1978, Warszawa.

ŁOBANOWSKI H., PRZYBYŁOWICZ T., 1979 — Tidal flat and flood-plain deposits in the Lower Devonian of western Lublin Upland (after the boreholes Pionki 1 and Pionki 4). *Acta Geol. Pol.*, **29**, 4: 383–407.

ŁYDKA K., SIEDLECKI S., TOMCZYK H., 1963 — On the Middle Ludlovian conglomerates in the Cracow region. *Bull. Acad. Pol. Sc. Ser. Sc. Geol. Geogr.*, **11**, 2: 93–99.

MAJOROWICZ J., 1975 — Heat flow on the Polish Lowland territory. *Acta Geophys. Pol.*, **3**: 259–275.

MAJOROWICZ J., 1979 — Earth thermal field in relation to tectonic structure of the Polish Lowlands. *Biul. Inst. Geol.*, **307**: 5–60.

MAJOROWICZ J., 1982 — On ambiguities in interpretation of geothermal field distribution of the platform areas in Poland [Eng. Summ.]. *Prz. Geol.*, **30**, 2: 86–94.

MAJOROWICZ J., 1984 — Problems of tectonic interpretation of geothermal field distribution in the platform areas of Poland. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-13**, 160: 149–166.

MAKRIS J., WANG S. R, 1994 — Crustal structure at the Tornquist-Teisseyre Zone in the Southern Baltic Sea. *Z. geol. Wiss.*, **22**, 1–6: 47–54.

MALEC J., 1990 — New data on the Devonian from Bukowa Góra (Holy Cross Mts., central Poland [Eng. Summ.]. *Kwart. Geol.*, **34**, 3: 559–560.

MALEC J., 1993 — Upper Silurian and Lower Devonian in the western Holy Cross Mts. *Geol. Quart.*, **37**, 4: 501–556.

MALISZEWSKA A., POKORSKI J., 1978 — Pyroclastic rocks of the Obrzycko Member (Autunian) in the western part of Polish Lowland [Eng. Summ.]. *Kwart. Geol.*, **22**, 3: 511–536.

MAREK S., 1988 — Paleothickness, lithofacies and palaeotectonics of the epicontinental Lower Cretaceous in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 157–174.

MARIAŃCZYK E., 1973 — New data on the geology of the Bronkowice region [Eng. Summ.]. *Prz. Geol.*, **21**, 3: 158–160.

MARTEAU P., FEYS R., 1989 — Le Bassin d'Autun. In: J.-J. Chateaunef, G. Farjanel (Eds.), Synthese Géologique des Bassins Permiens Francais: 65–71. Édition du BRGM.

MASTALERZ K., 1990 — Lacustrine succesions in fault-bounded basins: 1. Upper Antracosia Shale (Lower Permian) of the North Sudetic Basin, SW Poland. *Ann. Soc. Geol. Polon.*, **60**: 75–106.

MASTALERZ K., KUROWSKI L., WOJEWODA J., 1993 — Litostratygafia i ewolucja basenu śródsudeckiego w karbonie i permie. Materiały II Krajowego Spotkania Sedymentologów: 65–89. Wrocław.

MATTE Ph., 1986 — Tectonics and plate tectonics model for the Variscan belt of Europe. *Tectonoph.*, **126**: 329–374.

MATTE Ph., MALUSKI H., RAJLICH P., FRANKE W., 1990 — Terrane boudaries in the Bohemian Massif: result of large scale Variscan shearing. *Tectonoph.*, **177**: 151–170.

MATYJA B. A., WIERZBOWSKI A., 1995 — Biogeographic differentiation of the Oxfordian and Early Kimmeridgian ammonite faunas of Europe, and its stratigraphic consequences. *Acta Geol. Pol.*, **45**, 1–2: 1–8.

MATYJA B. A., WIERZBOWSKI A., 1996 — Sea-bottom relief and bathymetry of Late Jurassic sponge megafacies in Central Poland. *GeoResearch Forum*, **1–2**: 333–340. Transect Publications, Switzerland.

MATYJA H., 1993 — Upper Devonian of Western Pomerania. *Acta Geol. Pol.*, **43**, 1–2: 28–94.

MATYJA H., NARKIEWICZ M., 1992 — Conodont biofacies succesion near the Frasnian/Famennian boundary, some Polish examples. *Cour. Forsch.-Inst. Senckenberg*, **154**: 125–147.

McCANN T., 1996 — Pre-Permian of the north-east German Basin. *Geological Journal*, **31**: 159–177.

McKENZIE D. P., 1978 — Some remarks on the development of sedimentary basin. *Earth Planet. Sci. Lett.*, **40**: 25–32.

MEISSNER R., WEVER T., FLÜH E. R., 1987 — The Moho in Europe – implication for crustal development. *Annales Geophysicae*, **5B**, 4: 357–364.

MENNING M., 1995 — A numerical time scale for the Permian and Triassic periods: an integrated time analysis. In: P. A. Scholle, T. M. Peryt, D. S. Ulmer-Scholle (Eds.), The Permian of Northern Pangea. **1**: 77–97. Springer-Verlag.

MESOZOIC-CENOZOIC CYCLE CHART, 1988 — In: C. K. Wilgus, B. S. Hastings, C. G. S. C. Kendal, H. Posamentier, C. A. Ross, J. Van Wagoner (Eds.), Sea-level changes: an integrated approach. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, 42. Tulsa, Oklahoma, USA.

MIECZNIK J. B., 1981 — Lithostratigraphic investigations of the Upper Silesian in the Głuszyca vicinity (Mid-Sudetic Basin [Eng. Summ.]. *Kwart. Geol.*, **25**, 1: 11–23.

MIGASZEWSKI Z., 1995 — Occurrence of pyroclastic rocks in the Lower Carboniferous of the Holy Cross Mts. (Central Poland) [Eng. Summ.]. *Prz. Geol.*, **43**, 1: 7–10.

MILEWICZ J., 1976 — Rotliegendes around the Fore-Sudetic Block [Eng. Summ.]. *Kwart. Geol.*, **20**, 1: 81–95.

MILEWICZ J., 1981 — The influence of the tectonics on sedimentation of the Rotliegendes in south-western Poland. Proceed. Symp. Central Europ. Permian: 273–280. Jabłonna, 1978, Warszawa.

MILEWICZ J., 1985 — A proposal of formal stratigraphic subdivision of the infill of the North Sudetic Depression [Eng. Summ.]. *Prz. Geol.*, **33**, 7: 385–390.

MILEWICZ J., PAWŁOWSKA K., 1961 — Atlas geologiczny Polski; Zagadnienia stratygraficzno-facjalne, z. 7 – perm, czerwony spągowiec. Inst. Geol. Warszawa.

MIŁACZEWSKI L., 1981 —The Devonian of the south-eastern part of the Radom–Lublin area (eastern Poland) [Eng. Summ.]. *Pr. Inst. Geol.*, **101**: 1–90.

MIŁACZEWSKI L., 1987 — Dewon: Stratygrafia i charakterystyka litologiczna. In: A. Raczynska (Ed.), Budowa geologiczna wału pomorskiego i jego podłoża. *Pr. Inst. Geol.*, **119**: 16–21.

MITCHUM Jr. R. M., VAIL P. R., THOMPSON S. III, 1977 — Seismic stratigraphy and global changes of sea level, part 2; the depositional sequences as a basic unit for stratigraphic analysis. In: C. E. Payton (Ed.), Seismic stratigraphy – applications to hydrocarbon exploration. *AAPG Memoir*, **26**: 53–62.

MIZERSKI W., 1979 — Tectonics of the Łysogóry unit in the Holy Cross Mts. *Acta Geol. Pol.*, **29**, 1: 1–38.

MIZERSKI W., 1992 — Tectonics of the Cambrian sequences in the Holy Cross Mountains [Eng. Summ.]. *Prz. Geol.*, **40**, 3: 142–146.

MIZERSKI W., 1995 — Geotectonic evolution of the Holy Cross Mts. in Central Europe. *Biul. Państw. Inst. Geol.*, **372**: 1–49.

MIZERSKI W., 1998 — Main problems of tectonics and tectogenesis of the Paleozoic in the Holy Cross Mts. (Central Poland) [Eng. Summ.]. *Prz. Geol.*, **46**, 4: 337–342.

MŁYNARSKI S., 1982 — Geology of deep basement in Poland: results of seismic refraction investigations [Eng. Summ.]. *Kwart. Geol.*, **26**, 2: 285–296.

MODLIŃSKI Z., 1982 — The development of Ordovician lithofacies and palaetectonics in the area of the Precambrian platform in Poland [Eng. Summ.]. *Pr. Inst. Geol.*, **102**: 1–66.

MROCZKOWSKI J., SKOWRONEK C., 1980 — Rotliegendes sediments in the northern part of the North-Sudetic Basin [Eng. Summ.]. *Geol. Sudetica*, **15**: 125–141.

NARKIEWICZ M., 1985 — Studies on the Devonian carbonate shelf of southern Poland [Eng. Summ.]. *Prz. Geol.*, **33**, 5: 253–258.

NARKIEWICZ M., 1987 — Events on the Late Devonian shelf in southern Poland and their stratigraphical significance [Eng. Summ.]. *Kwart. Geol.*, **31**, 4: 581–598.

NARKIEWICZ M., 1988 — Turnings points in sedimentary development in the Late Devonian in southern Poland. In: N. J. McMillan, A. F. Embry, D. J. Glass (Eds.), Devonian of the World. *Can. Soc. Petrol. Geol. Mem.*, **14**, 2: 619–635.

NAWROCKI J., 1995 — Palaeomagnetic constraints for Variscan mobilism of the Upper Silesian and Małopolska Massifs, southern Poland - discussion. *Geol. Quart.*, **39**, 2: 271–292.

NEDERLANDSE AARDOLIE MAATSCHAPPIJ B. V. AND RIJKS GEOLOGISCHE DIENST, 1980 — Stratigraphic nomenclature of the Netherlands. Het Koninklijk Nederlands Geologisch Mijnbouwkundig Genootschap: 1–77. Amsterdam.

NEMEC W., PORĘBSKI J., 1977a — Weissliegendes sandstones: A transition from fluvial-aeolian to shallow-marine sedimentation (Lower Permian of the Fore-Sudetic Monocline). 1. Sedimentary structures and textural differentiation. *Ann. Soc. Geol. Polon.*, **47**, 3: 387–418.

NEMEC W., PORĘBSKI J., 1977b — Weissliegendes sandstones: A transition from fluvial-aeolian to shallow-marine sedimentation (Lower Permian of the Fore-Sudetic Monocline). 2. A study in significance of rock coloration. *Ann. Soc. Geol. Polon.*, **47**, 4: 513–554.

NEMEC W., PORĘBSKI S. J., 1981 — Sedimentary environment of the Weissliegendes sandstones in Fore-Sudetic Monocline. Proceed. Symp. Central Europ. Permian: 281–293. Jablonna 1978, Warszawa.

NEUNZERT G. H., LITTKE R., SCHOLTEN S. O., 1996 — Dynamics of natural gas generation and accumulation in Northern Germany. EAGE 58th Conference and Technical Exhibition, Abstracts: L016. Amsterdam.

NIEMCZYCKA T., BROCHWICZ-LEWIŃSKI W., 1988 — Evolution of the Upper Jurassic sedimentary basin in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 137–156.

OBERC J., 1972 — Sudety i obszary przyległe. Budowa geologiczna Polski, t. IV. Tektonika, cz. 2: 5–307. Warszawa.

OBERC J., 1987 — History of the Palaeozoic tectonic movements in south-western Poland [Eng. Summ.]. *Kwart. Geol.*, **31**, 4: 523–530.

OLEWICZ Z. R., 1959 — Baseny sedymentacyjne i strukturalne ziem Polski. *Pr. Inst. Naft.*, **63**: 1–44.

OLIVER G. J. H., CORFU F., KROGH T. E., 1993 — U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. *J. Geol. Soc. London*, **150**: 355–369.

O'NIONS R. K., OXBURGH E. R., 1988 — Helium, volatile, fluxes and the development of continental crust. *Earth Planet. Sci. Lett.*, **90**: 331–347.

ORŁOWSKI S., 1975 — Lower Cambrian trilobites from Upper Silesia (Goczałkowice 1 borehole). *Acta Geol. Pol.*, **25**, 3: 337–383.

ORŁOWSKI S., 1988 — Stratigraphy of the Cambrian system in the Holy Cross Mts. *Kwart. Geol.*, **32**, 3–4: 525–531.

OXBURGH E. R., O'NIONS R. K., 1987 — Hellium loss, tectonics and terrestrial heat budget. *Science*, **237**: 1583–1588.

PAPROTH E., 1987 — L'Erope de la fin du Westphalien a l'Autunien.. *Ann. Soc. Geol. Nord*, **56**: 77–85.

PAPROTH E., 1989 — Die paläogeographische Entwicklung Mittel Europas im Karbon. *Geol. Jb. Hessen*, **117**: 53–68.

PARKA Z., ŚLUSARCZYK S., 1988 — Stratygrafia osadów karbońskich podłoża monokliny przedsudeckiej. *Pr. Nauk. Inst. Górn. Polit. Wrocł., Seria: Monografie*, **43**, 20: 1–47.

PARRISH J.T., 1995 — Geologic evidence of Permian climate. In: P. A. Scholle, T. M. Peryt, D. S. Ulmer-Scholle (Eds.), The Permian of Northern Pangea. **1**: 53–61. Springer-Verlag.

PASZKIEWICZ A., 1936 — Zagadnienie wielkopolsko-pomorsko-kujawskiego zagłębia naftowego. Kcynia. Cz. I, II. Księg. N. Gieryna. Bydgoszcz (nakład autora).

PASZKOWSKI M., 1987 — The Rotliegendes vadose carbonate deposits of the Sławków Trough [Eng. Summ.]. *Prz. Geol.*, **35**, 4: 192–194.

PASZKOWSKI M., 1988 — Dinantian Basin in the Kraków area: an attempt of synthesis [Eng. Summ.]. *Prz. Geol.*, **34**, 4: 200–207.

PASZKOWSKI M., SZULCZEWSKI M., 1995 — Late Paleozoic carbonate platforms in Polish part of the Moravia–Małopolska shelf. XIII Int. Congr. on Carbonif.-Permian, Kraków, Exc. Guide B-4: 5–12. Państw. Inst. Geol Warszwa.

PERROUD H., ROBARDET M., BRUTON D. L., 1990 — The position of the Baltic shield during the Ordovician. *Annales Geophysicae, E.G.S.*, (abstract), **46**.

PERYT T., 1978 — Microfacies of the carbonate sediments of the Zechstein Werra and Stassfurt cyclothems in the Fore-Sudetic Monocline [Eng. Summ.]. *Studia Geol. Pol.*, **54**: 1–88.

PERYT T. M., WAŻNY H., 1978 — Condensed sequences of the Zechstein Limestone in the northern part of the Fore-Sudetic Monocline (W Poland) [Eng. Summ.]. *Kwart. Geol.*, **22**: 549–570.

PLEIN E., 1993 — Bemerkungen zum Ablauf der paläogeographischen Entwicklung im Stefan und Rotliegendes Norddeutschen Beckens. *Geol. Jb.*, **A 131**: 99–116.

PLEWA S., 1994 — Rozkład parametrów geotermalnych na obszarze Polski. Wydawnictwo CPPGSMiE Kraków.

PLEWA M., PLEWA S., POPRAWA D., TOMAŚ A., 1992 — Poland. In: Geothermal Atlas of Europe. Gotha.

POKORSKI J., 1971 — Lower Permian in the Podlasie Depression [Eng. Summ.]. *Kwart. Geol.*, **15**, 3: 589–604.

POKORSKI J., 1974 — The Rotliegendes of the Precambrian Platform - thickness and facies [Eng. Summ.]. *Kwart. Geol.*, **18**, 1: 80–89.

POKORSKI J., 1976a — The Rotliegendes of the Polish Lowlands. *Prz. Geol.*, **24**, 6: 318–324.

POKORSKI J., 1976b — Rotliegendes: Darłowo and Miastko Beds. In: R. Dadlez (Ed.), Permian and Mesozoic of the Pomerania Trough [Eng. Summ.]. *Prace Inst. Geol.*, **79**: 10–18.

POKORSKI J., 1978a — Stratigraphy, lithology and palaegeography of the Rotliegendes. In: S. Depowski (Ed.), Lithofacies-palaeogeographical atlas of the Permian of the platform area of Poland: 7–8. Państw. Inst. Geol. Warszawa.

POKORSKI J., 1978b — Outline of the Rotliegendes Basin development in the Polish Lowland area [Eng. Summ.]. *Prz. Geol.*, **26**, 12: 686–693.

POKORSKI J., 1978c — The Rotliegendes in north-eastern part of the Podlasie basin [Eng. Summ.]. *Kwart. Geol.*, **22**, 3: 537–547.

POKORSKI J., 1981a — Proposal of formal lithostratigraphic subdivision of the Rotliegendes in the Polish Lowland [Eng. Summ.]. *Kwart. Geol.*, **25**, 1: 41–58.

POKORSKI J., 1981b — Paleogeography of the Upper Rotliegendes in the Polish Lowlands. Proceed. Symp. Central Europ. Permian: 56–68. Jabłonna, 1978, Warszawa.

POKORSKI J., 1988a — Palaeotectonic maps of the Rotliegendes in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 15–32.

POKORSKI J., 1988b — Rotliegendes lithostratigraphy in NW Poland. *Bull. Pol. Acad. Sci., Earth Sci.*, **36**, 1: 99–108.

POKORSKI J., 1989 — Evolution of the Rotliegendes Basin in Poland. *Bull. Pol. Acad. Sci., Earth Sci.*, **37**, 1–2: 49–55.

POKORSKI J., WAGNER R., 1972 — Stratygrafia i paleogeografia permu.. *Biul. Inst. Geol.*, **252**: 121–134.

POŻARYSKI W., 1964 — Outline of Palaeozoic and Mesozoic tectonics of the Polish Lowland [Eng. Summ.]. *Kwart. Geol.*, **8**, 1: 1–41.

POŻARYSKI W., 1987 — Paleozoik podpermski. In: A. Raczyńska (Ed.), Budowa geologiczna wału pomorskiego i jego podłoża. *Pr. Inst. Geol.*, **119**: 174–185.

POŻARYSKI W., 1990 — The Middle Europe Caledonides - wrenching orogen composed of terranes [Eng. Summ.]. *Prz. Geol.*, **38**, 1: 1–9.

POŻARYSKI W., 1991 — The strike-slip terrane model for the North German-Polish Caledonides. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-19**, 236: 3–15.

POŻARYSKI W., BROCHWICZ-LEWIŃSKI W., 1979 — On the Mid-Polish Aulacogene [Eng. Summ.]. *Kwart. Geol.*, **23**, 2: 271–290.

POŻARYSKI W., BROCHWICZ-LEWIŃSKI W., TOMCZYK H., 1982a — On heterochronous character of the Teisseyre-Tornquist Line [Eng. Summ.]. *Prz. Geol.*, **30**, 11: 569-574.

POŻARYSKI W., DEMBOWSKI Z. (Eds.), 1984 — Geological map of Poland and adjoining countries (without Cenozoic, Mesozoic and Permian formations), scale 1:1 000 000. Inst. Geol., Warszawa.

POŻARYSKI W., GROCHOLSKI A., TOMCZYK H., KARNKOWSKI P., MORYC W., 1992 — The tectonic map of Poland in the Variscan epoch [Eng. Summ.]. *Prz. Geol.*, **40**, 11: 643–651.

POŻARYSKI W., KARNKOWSKI P. (Eds.), 1992 — Tectonic map of Poland during the Variscan time, scale 1:1 000 000. Państw. Inst. Geol. Warszawa.

POŻARYSKI W., KOTAŃSKI Z., 1978 — Baikalian, Caledonian and Variscan events in the forefield of the East European Platform. *Z. deutsch. Geol. Ges.*, **129**: 391–402.

POŻARYSKI W., TOMCZYK H., 1968 — Assyntian orogen in south-east Poland. *Biul. Inst. Geol.*, **237**: 13–27.

POŻARYSKI W., TOMCZYK H., BROCHWICZ-LEWIŃSKI W., 1982b — Tectonics and palaeotectonic evolution of the sub-Permian rocks between Koszalin and Toruń (Pomerania) [Eng. Summ.]. *Prz. Geol.*, **30**, 12: 658–665.

POŻARYSKI W., WITKOWSKI A., 1990 — Geological structure of the Southern Baltic area (without Cenozoic) [Eng. Summ.]. *Prz. Geol.*, **38**, 5–6: 221–227.

RACKI G., 1993 — Evolution of the bank to reef complex in the Devonian of the Holy Cross Mountains. *Acta Palaeont. Pol.*, **37**, 2–4: 87–182.

RONIEWICZ P., CZAPOWSKI G., GIŻEJEWSKI J., KARNKOWSKI P. H., 1981 — Variability in depositional environments of the Rotliegendes of the Poznań area. Proceed. Symp. Central Europ. Permian: 262–272. Jabłonna, 1978, Warszawa.

ROYDEN L., 1986 — A simple method for analyzing subsidence and heat flow in extentional basins. In: J. Burrus (Ed.), Thermal modeling in sedimentary basins: 49–73. Editions Technip Paris.

RYBA J., 1979 — Karbon górny w rejonie Kamienia Pomorskiego w porównaniu z Rugią i Hiddensee. Mat. Konf. Nauk. w Tucznie. Arch. B. G. Geonafta.

RYKA W., 1978a — Rotliegendes volcanic rocks in Poland [Eng. Summ.]. *Prz. Geol.*, **26**, 12: 694–697.

RYKA W., 1978b — Permian volcanic rocks from the Pomerania region [Eng. Summ.]. *Kwart. Geol.*, **22**, 4: 753–772.

RYKA W., 1981 — Some problems of the Autunian volcanism in Poland. Proceed. Symp. Central Europ. Permian: 165–179. Jabłonna, 1978, Warszawa.

RYKA W., 1982 — Precambrian evolution of the East European Platform in Poland [Eng. Summ.]. *Kwart. Geol.*, **26**, 2: 257–272.

RYKA W., 1984 — Deep structure of the crystalline basement of the Precambrian Platform in Poland.. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-13**, 160: 47–61.

RYKA W., 1985 — The evolving of old Precambrian structures in the marginal zone of the East-European Platform.. *Publ. Inst. Geoph. Pol. Acad. Sc.*, **A-16**, 175: 29–42.

RYKA W., POKORSKI J., 1978 — Map of the Autunian volcanic rocks, 1:1 000 000. In: S. Depowski (Ed.), Lithofacies-palaeogeographical atlas of the Permian of the platform area of Poland. Państw. Inst. Geol., Warszawa.

SAWICKI L. , 1995 — Structures of the eastern parts of the Fore-Sudetic Block [Eng. Summ.]. In: Materiały sesji 64 Zjazdu Pol. Tow. Geol.: 11-18. Wrocław.

SCHNEIDER J., GEBHARDT U., 1993 — Litho- und Biofaziesmuster in intra- und extramontanen Senken des Rotliegend (Perm, Nord- und Ostdeutschland). *Geol. Jb.*, **A 131**: 57–98.

SCHRÖDER L., PLEIN E., BACHMANN G. H., GAST R. E., GEBHARDT U., GRAF R., HELMUT H.-J., PASTERNAK M., PORTH H., SÜSSMUTH S., 1995 — Stratigraphische Neugliederung des Rotliegend im Norddeutschen Becken. *Geol. Jb.*, **A 148**: 3–21.

SCOTESE C. R., McKERROW W. S., 1990 — Revised world maps and intoduction. In: W. S. McKerrow and C. R. Scotese (Eds.), Palaeozoic palaeogeography and biogeography. *Geol. Soc. of London, Mem.*, **12**: 1–21.

SHANLEY K. W., McCABE P. J., 1994 — Perspectives on the sequence stratigraphy of continental strata. *AAPG Bulletin*, **78**, 4: 544–568.

SIEDLECKA A., 1963 — Sediments of the Rotliegendes in the north-eastern periphery of the Upper Silesia Coal Basin. *Bull. Pol. Acad. Sci., Earth Sci.*, **11**: 83–91.

SIEMASZKO E., 1978 — Permian volcanic rocks in the south-western part of the Fore-Sudetic Monocline [Eng. Summ.]. *Kwart. Geol.*, **22**, 3: 571–581.

SKOMPSKI S., 1995 — Tectonic framework and development of sedimentation at the margin of the East European Platform. XIII Int. Congr. on Carbonif.-Permian, Kraków, Exc. Guide A-2: 5–9. Państw. Inst. Geol. Warszawa.

SKOMPSKI S., 1996 — Stratigraphic position and facies significance of the limestone bands in the subsurface Carboniferous succesion of the Lublin Upland. *Acta Geol. Pol.*, **48**, 3–4: 171–268.

ŚLĄCZKA A. (Ed.), 1985 — Potrójna IG 1. Profile głębokich otworów wiertniczych Instytutu Geologicznego, **59**: 1–166.

SOKOŁOWSKI J., 1967 — Geology and structure of the Sudetic foreland. [Eng. Summ.]. *Geol. Sudetica*, **3**: 191–367.

SOPER N. J., ENGLAND R. W., SNYDER D. B., RYAN P. D., 1992 — The Iapetus suture zone in England, Scotland and eastern Ireland: A reconstruction of geological and deep seismic data. *J. Geol. Soc. London*, **149**: 697–700.

SPECZIK S., 1987 — Origin of Kupferschiefer mineralization as suggested by coal petrology and organic geochemical studies. *Acta Geol. Pol.*, **37**, 3–4: 167–187.

SPECZIK S., KOZŁOWSKI A., 1987 — Fluid inclusion study of epigenetic veinlets from the Carboniferous rocks of the Fore-Sudetic Monocline (Southwest Poland). *Chemical Geology*, **61**: 287–289.

STECKLER M. S., WATTS A. B., 1978 — Subsidence of the Atlantic-type continental margin off New York. *Earth Planet. Sci. Lett.*, **41**: 1–13.

STEEL R. J., 1974 — New Red Sandstone floodplain and piedmont sedimentation in the Hebridean Province, Scotland. *J. Sedim. Petrol.*, **44**: 336–357.

STILLE H., 1924 — Grundfragen der Vergleichenden Tektonik. Verlag von Gebrüder Borntraeger, Berlin.

STILLE H., 1948 — Die kaledonische Faltung Mitteleuropeas im Bilde der gesamteuropäischen. *Z. deutsch. Geol. Ges.*, **100**: 223–226.

STRATIGRAPHIC nomenclature of the Netherlands, 1980 — *Geol. Mijnb. Gen.*, **32**: 16–20.

STUPNICKA E., 1992 — The significance of the Variscan orogeny in the Świętokrzyskie Mountains (Mid-Polish Uplands). *Geol. Rundschau*, **81**, 2: 561-570.

ŚWIDROWSKA J., 1994 — Direction of the Aalenian transgression in the area of the Mid-Polish Trough. *Geol. Quart.*, **38**, 2: 319–336.

ŚWIDROWSKA J., HAKENBERG M., 1995 — Paleotectonic evolution of the Koszalin-Chojnice late Devonian Basin (Western Pomerania, Northern Poland). *Bull. Pol. Acad. Sci., Earth Sci.*, **44**, 1: 17–36.

SZULCZEWSKI M., 1971 — Upper Devonian conodonts, stratigraphy and facial development in the Holy Cross Mts. *Acta Geol. Pol.*, **1**, 21: 1–129.

SZULCZEWSKI M., 1977 — Main facial regions in the Palaeozoic of the Holy Cross Mts. [Eng. Summ.]. *Prz. Geol.*, **25**, 8–9: 429–432.

SZULCZEWSKI M., 1981 — Dewon środkowy i górny zachodniej części Gór Świętokrzyskich. Przew. 53 Zjazdu Pol. Tow. Geol.: 68–82. Kielce.

SZULCZEWSKI M., 1995 — Depositional evolution of the Holy Cross Mts. (Poland) in the Devonian and Carboniferous – a review. *Geol. Quart.*, **39**, 4: 471–488.

SZULCZEWSKI M., RACKI G., 1981 — Early Frasnian bioherms in the Holy Cross Mts. *Acta Geol. Pol.*, **31**, 3–4: 147–162.

SZYPERKO-TELLER A., MORYC W., 1988 — Evolution of the Buntsanstein sedimentary basin in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 53–72.

TEISSEYRE W., 1893 — Całokształt płyty paleozoicznej Podola galicyjskiego. Rzecz o przyszłych wierceniach głębokich na Podolu opolskim. *Kosmos*, **18**: 319–336.

TEISSEYRE W., 1921 — La limite interne de l'affaissement subcarpathique et ses relation avec la bordure de Flysch carpathique. *Spraw. Państw. Inst. Geol.*, **1**, 2/3: 123–138.

TGL 25234/12, 1980 — Fachbereichstandard Stratigraphishe Skala der DDR – Perm. Berlin.

THE ROBERTSON GROUP, 1991 — The petroleum geology and hydrocarbon potential of Poland. Special Report (Confidential). Arch. B. G. Geonafta.

TOMASIK J., 1988— A new interpretation of the topography and facies of the uppermost Rotliegendes in the Fore-Sudetic area. *Z. geol. Wiss.*, **16**, 11/12: 1089–1096.

TOMCZYK H., 1963 — Ordovician and Silurian rocks in the basement of the Carpahian Foredeep [Eng. Summ.]. *Ann. Soc. Geol. Polon.*, **33**, 1–3: 289–320.

TOMCZYK H., 1974 — Góry Swiętokrzyskie. In: Budowa geologiczna Polski, T. 4, Tektonika, cz. 1, Niż Polski: 128–198. Inst. Geol., Warszawa.

TOMCZYK H., 1988 — The Łysogóry region and East European Platform in the Caledonian–Variscan cycle [Eng. Summ.]. *Prz. Geol.*, **36**, 1: 9–16.

TOMCZYK H., 1994 — Starszy paleozoik na mapach ścięcia poziomego w skali 1:500 000 w północnej i południowo-wschodniej Polsce. *Pos. Nauk. Państ. Inst. Geol.*, **51**, 3: 2–4.

TOMCZYK H., PAJCHLOWA M., TOMCZYKOWA E., 1977 — Poland. The Silurian-Devonian boundary. In: The Silurian Devonian boundary. IUSG, Ser. A, **5**: 65–68.

TOMCZYKOWA E., TOMCZYK H., 1994 — The Wenlock/Ludlow boundary based on biostratigraphical and geophysical data of Poland. IUGS Subcom. Silurian Stratigraphy, Field meeting 1994. *Bibl. Geol.* B-A 30/1994: 152–154. Vienna.

TORNQUIST A., 1908 — Die Feststellung des Südwestrandes des baltisch-russischen Schieldes und die geotektonische Zugehörigheit der ost-preussischen Scholle. *Schr. Phys. Ökonom. Ges. Königsberg*, **49**, 1: 1–12.

TORNQUIST A., 1910 — Geologie von Ostpreussen, vol. 1. Verlag von Gebrüder Borntraeger, Berlin.

TWIDALE C. R., 1978 — On the origin of pediments in different structural settings. *Amer. J. of Sci.*, **278**: 1138–1176.

TWIDALE C. R., 1979 — The character and interpretation of some pediment mantels. *Sedimentary Geology*, **22**: 1–20.

TURNAU E., JAKUBOWSKA L., 1989 — Early Devonian miospores and age of the Zwoleń Formation (Old Red sandstone facies) from Ciepielów IG 1 borehole. *Ann. Soc. Geol. Polon.*, **59**: 391–416.

URBANEK Z., ŻELAŹNIEWICZ A., KEMNITZ H., HERMSDORF N., LINNEMENN U., 1995 — Western Sudetes (Lugicum): Stratigraphy. In: R. D. Dalmeyer, W. Franke, K. Weber (Eds.), Pre-Permian geology of central and eastern Europe: 315–327. Springer, New York.

VAN DER VOO R., 1988 — Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes: Comparison of paleomagnetism with paleoclimatology and biogeographical patterns. *Geol. Soc. Amer. Bull.*, **100**: 311–324.

WAGNER R., 1988 — Evolution of the Zechstein Basin in Poland [Eng. Summ.]. *Kwart. Geol.*, **32**, 1: 32–52.

WAGNER R., 1994 — Stratigraphy and development of the Zechstein Basin in Poland [Eng. Summ.]. *Pr. Państw. Inst. Geol.*, **146**: 1–71.

WAJSPRYCH B., 1995 — The Bardo Mts. rocks complex: the Famenian–Lower Carboniferous pre-flysch (platform)-to-flysch (foreland) basin succesion, the Sudetes. In: O. Kumpera, M. Paszkowski, B. Wajsprych (Eds.), Transition of the Early Carboniferous pelagic sedimentation into synorogenic flysch. XIII Int. Congr. on Carbonif.–Permian, Kraków. Exc. Guide A-5: 23–42. Państw. Inst. Geol. Warszawa.

WAJSPRYCH B., 1997 — Litho-tectono-stratigraphic structure of the Sudetes orogenic upgrowth in the light of fossil sedimentary records [Eng. Summ.]. In: J. Wojewoda (Ed.), Obszary źródłowe: zapis w osadach, **1**: 65–80. Wind, Wroclaw.

WATS A. B., RYAN W. B. F., 1976 — Flexure of the lithosphere and continental margin basins. *Tectonophysics*, **36**: 24–44.

WEBER K. J., 1987 — Computation of initial well productivities in aeolian sandstone on the basis of geologic model, Leman gas field, U. K. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, **41**: 333–354.

WENDT I., HOHNDORF A., WENDT J. J., MULLER P., WETZEL K., 1985 — Radiometric dating of volcanic rocks in NW-Saxony by combined use of U-Pb and Sm-Nd. *Terra Nostra*, **7**: 147–148.

WERNICKE B., 1985 — Uniform-sense normal simple shear of the continental lithoshere. *Can. J. Earth Sci.*, **22**, 1: 108–125.

WERNICKE B., 1990 — The fluid crystal layer and its implications for continental dynamics.. In: M. H. Salisbury, D. M. Fountain (Eds.), Exposed cross-sections of the continental crust: 509–544. Kluwer Academic Publishers.

WITZKE B. J., HECKEL P. H., 1988 — Paleoclimatic indicators and inferred Devonian paleolatitudes of Euramerica. In: M. J. McMillan, A. F. Ebry, D. J. Glass (Eds.), Devonian of the World, vol. 1, Regional Synthesis. *Can. Soc. Petrol. Geol. Mem.*, **14**: 49–63.

WOJEWODA J., MASTALERZ K., 1989 — Climate evolution, allo- and autocyclicity of sedimentation: an example from the Permo-Carboniferous continental deposits of the Sudetes, SW Poland [Eng. Summ.]. *Prz. Geol.*, 37, 4: 173–180.

WOLNOWSKI T., 1983 — Warunki akumulacji gazu ziemnego w osadach saksonu w złożu Ujazd. *Nafta*, **6**: 167–170.

WYŻYKOWSKI J., 1958 — Research of copper ores in the Fore-Sudetic Zone [Eng. Summ.]. *Prz. Geol.*, **6**, 1: 17–22.

WYŻYKOWSKI J., 1961 — Remarks on the geological structure of north western part of the Fore-Sudetic Block and its environments [Eng. Summ.]. *Prz. Geol.*, **9**, 4: 182–186.

WYŻYKOWSKI J., 1963 — The recent results of geological investigations in the Kożuchów region [Eng. Summ.]. *Prz. Geol.*, **11**, 4: 182–187.

WYŻYKOWSKI J., 1964 — Rotliegendes formation in the Sudetic Foreland [Eng. Summ.]. *Prz. Geol.*, **12**, 7/8: 319–323.

YANG C. S., BAUMFALK A., 1990 — Milankovitch cyclicity in the Upper Rotliegend Group of the Netherlands offshore. In: P. L. de Boer, D. G. Smith (Eds.), Orbital forcing and cyclic sequences. Int. Assoc. Sedim. Spec. Publ., **19**: 47–67.

YANG C. S., NIO S. D., 1993 — Application of high-resolution sequence stratigtaphy to the Upper Rotliegend in the Netherlands Offshore. In: P. Weimer, H. Posamentier (Eds.), Siliciclastics Sequence Straigraphy, Recent Developments and Applications. *AAPG Memoir*, **58**: 285–316.

ZASADY polskiej klasyfikacji, terminologii i nomenklatury stratygraficznej, 1975 — *Instrukcje i metody badań geologicznych*, z. 33. Inst. Geol. Warszawa.

ZIEGLER P. A., 1978 — North-Western Europe: tectonics and basin development. *Geol. Mijnbouw.*, **57**: 589–626.

ZIEGLER P. A., 1982 — Geological Atlas of Central and Western Europe. pp. 130 + 40 plates. Elsevier Sci. Publ. Amsterdam.

ZIEGLER P. A., 1984 — Caledonian and Hercynian crustal consolidation of Western and Central Europe – a working hypothesis. *Geol. Mijnbouw.*, **63**: 93–108.

ZIEGLER P. A., 1986 — Geodynamic model for the palaeozoic crustal consolidation of Western and Cental Europe. *Tectonophysics*, **126**: 303–328.

ZIEGLER P. A., 1990 — Geological Atlas of Western and Central Europe, 2nd. ed. Geol. Soc. Publ. House, Avon, UK. Shell Internationale Petroleum Maatschappij B.V. Den Haag.

ZNOSKO J., 1962 — Present status of knowledge of geological structure of deep substratum of Poland beyond the Carpathians [Eng. Summ.]. *Kwart. Geol.*, **6**, 3: 485–511.

ZNOSKO J., 1965 — Problem kaledonidów i granicy platformy prekambryjskiej w Polsce. *Biul. Inst. Geol.*, **188**: 5–72.

ZNOSKO J., 1974 — Outline of the tectonics of Poland nad the problem of the Vistulicum and Variscicum against the tectonics of Europe. *Biul. Inst. Geol.*, **274**: 7–47.

ZNOSKO J., 1979 — The Teisseyre - Tornquist zone in the light of geological and geophysical investigation. *Bull. Pol. Acad. Sci., Earth Sci.*, **27**, 1/2: 33–36..

ZNOSKO J., 1981 — Tectonic framework of the Permian events in the Polish area. Proceed. Symp. Central Europ. Permian: 127–154. Jabłonna, 1978, Warszawa.

ZNOSKO J., 1984 — Tectonics of southern part of Middle Poland (beyond the Carpathians). *Z. deutsch. Geol. Ges.*, **135**: 585–602.

ZNOSKO J., 1986 — Polish Caledonides and their relation to the other European Caledonides. *Ann. Soc. Geol. Polon.*, **56**, 1–2: 33–52.

ZWIERZYCKI J., 1947 — Zagadnienie soli potasowych w Polsce. *Prz. Górn.*, **3**: 912–926

ZWIERZYCKI J., 1951 — Sole potasowo-magnezowe na północ od Wrocławia. *Pr. Państw. Inst. Geol.*, **7**: 257–295.

ŻAKOWA H., 1970 — The Lower Carboniferous. In: S. Sokołowski (Ed.), Geology of Poland. Stratigraphy – Pre-Cambrian and Palaeozoic: 379–409. Inst. Geol., Warszawa.

ŻAKOWA H., SZULCZEWSKI M., CHLEBOWSKI R., 1984 — The Upper Devonian and Carboniferous of the Borków Syncline [Eng. Summ.]. *Biul. Inst. Geol.*, **345**: 5–134.

ŻELAŹNIEWICZ A., 1995 — Fore-Sudetic part of the Góry Sowie Block [Eng. Summ.]. *Ann. Soc. Geol. Polon. -Spec. ed.* Przewodnik 66 Zjazdu PTG: 85–109. Wrocław.

ŻELAŹNIEWICZ A., 1997 — The Sudetes as a Palaeozoic orogen in Central Europe. *Geol. Mag.*, **134**: 691–702.

ŻELAŹNIEWICZ A., CWOJDZIŃSKI S., ENGLAND R. W., ZIENTARA P., 1997 — Variscides in the Sudetes and the reworked Cadomian orogen: evidence from the GB2A seismic reflection profiling in southwestern Poland. *Geol. Quart.*, **41**, 3: 289–308.

ŻELICHOWSKI A. M., 1964a — Carboniferous rocks in the basement of the Fore-Sudetic Monocline [Eng. Summ.]. *Prz. Geol.*, **12**, 5: 224–227.

ŻELICHOWSKI A. M., 1964b — Problems of lithology and stratigraphy of the Lower Carboniferous in Poland [Eng. Summ.]. *Kwart. Geol.*, **8**, 3: 524–541.

ŻELICHOWSKI A. M., 1979 — Geology structure of the marginal basin basement at the boundary of its Warsaw and Lublin sections [Eng. Summ.]. *Kwart. Geol.*, **23**, 1: 125–139.

ŻELICHOWSKI A. M., 1983 — Lithological associations of the Carboniferous in Poland [Eng. Summ.]. *Prz. Geol.*, **31**, 6: 342–350.

ŻELICHOWSKI A. M., 1987a — Development of the Carboniferous of the SW margin of East European Platform in Poland. *Prz. Geol.* , **35**, 5; 230–237.

ŻELICHOWSKI A. M., 1987b — Karbon. In: A. Raczyńska (Ed.), Budowa geologiczna wału pomorskiego i jego podłoża. *Pr. Inst. Geol.*, **119**: 152–155.

GENEZA I EWOLUCJA POLSKIEGO BASENU CZERWONEGO SPĄGOWCA

Polski basen czerwonego spągowca jest częścią wielkiego basenu sedymentacyjnego zwanego południowym basenem permskim, leżącym w zachodniej i centralnej Europie (Fig. 1). Jednocześnie jest on częścią basenu polskiego (Fig. 2). Polski basen czerwonego spągowca (PBCS) położony jest na obszarze platformy paleozoicznej (Fig. 3). Grubość skorupy ziemskiej na omawianym obszarze waha się od 50 do 30 km; głębsze zaleganie powierzchni Moho koresponduje z bruzdą polską, a płytsze — z obszarem przedsudeckim (Fig. 4). Historia rozwoju polskiego basenu czerwonego spągowca rozpoczęła się na przełomie karbonu i permu. Jednak w jego rozwoju można odnaleźć pewne elementy zakorzenione aż w kambrze (np. strefę Teisseyra–Tornquista). Przedpermska historia geologiczna Polski wyjaśnia istnienie niektórych przyszłych, ważnych elementów w polskim basenie czerwonego spągowca (PBCS). Na podstawie szkiców paleogeograficznych paleozoiku w Polsce (Fig. 5–7) można zauważyć, że północno-wschodnia i południowo-wschodnia granica PBCS nawiązuje do marginalnej strefy basenu renohercyńskiego. W podłożu PBCS występują w przeważającej części sfałdowane i słabo zmetamorfizowane skały młodszego paleozoiku (waryscydy), a tylko w części północno-wschodniej — osady platformy epi-kaledońskiej (Fig. 8).

Polski basen czerwonego spągowca składa się z kilku subbasenów, które można wyróżnić na podstawie indywidualnych cech ich rozwoju i charakterystycznego dla nich zespołu sekwencji osadowo-wulkanicznych. Wyróżnia się tutaj: basen wschodnioprzedsudecki (rów Laskowic), basen śródsudecki, basen północnosudecki, basen dolnosląski, basen wielkopolski, basen centralny i basen pomorski (Fig. 9). Szczególną strukturą w obrębie PBCS jest wał wolsztyński, który rozdziela basen dolnośląski od wielkopolskiego. Erozja wału wolsztyńskiego dostarczyła dużych ilości materiału klastycznego do osadów czerwonego spągowca. Znajomość rozkładu głównych litofacji w PBCS umożliwiła skonstruowanie schematu litostratygraficznego czerwonego spągowca w basenie polskim (Fig. 10). Najstarsze, podwulkaniczne czerwone (czasami szare i czarne) osady zaliczono do formacji Dolska. Wyżej leżące skały wulkaniczne wyróżniono jako formację wulkanitów z Wyrzeki. Ich miąższość na obszarze Polski waha się od kilkunastu do kilkuset metrów, co wyraźnie kontrastuje z miąższością wulkanitów stwierdzonych we wschodnich Niemczech (Fig. 11). Powyżej wulkanitów, aż do kontaktu z cechsztyńskim łupkiem miedzionośnym występują czerwone skały klastyczne (iłowce i mułowce — formacja iłowców z Piły; piaskowce — formacja piaskowców z Siekierek; zlepieńce — formacja zlepieńców z Książa Wlkp.). Ich miąższość w centralnej części basenu przekracza 1000 m, a w południowo-zachodniej wynosi średnio ok. 300 m. Najwyższa część osądów czerwonego spągowca, w facjach piaszczystych i zlepieńcowych, często ma barwę białą lub szarą (biały spągowiec). Ten fenomen sedymentologiczny, ze względu na bliskość morskich osadów cechsztyńskich, jest obiektem wnikliwego zainteresowania geologów. Liczne rdzenie wiertnicze z obszaru Wielkopolski dostarczyły dodatkowych obserwacji wyjaśniających genezę białego spągowca. Jest to osad pochodzenia lądowego lub morskiego, który pierwotnie miał barwę czerwoną (brunatną), lecz wskutek oddziaływania redukcyjnych roztworów pochodzących ze środowiska sedymentacji łupka miedzionośnego został odbarwiony (utlenione związki żelaza nadające osadom barwę czerwoną zostały zastąpione przez siarczki żelaza) (Fig. 13, 14).

Rozwój sedymentacji w polskim basenie czerwonego spągowca był kontrolowany głównie przez tektonikę i klimat. Szczegółowe badania sedymentologiczne pozwoliły określić udział tych dwóch czynników w kształtowaniu osadów w PBCS. Wyraźna zmiana klimatyczna, z warunków wilgotnych na suche, nastąpiła dopiero w górnym czerwonym spągowcu (i to nie w jego najniższej części). Ruchy tektoniczne zaznaczały się natomiast poprzez tworzenie miąższych kompleksów zlepieńców (ogniwo zlepieńców z Polwicy i ogniwo zlepieńców soleckich) (Fig. 15). Takie spojrzenie na opracowywaną sukcesję osadów czerwonego spągowca umożliwiło wyróżnienie kilku sekwencji w obrębie podgrupy wielkopolskiej (Fig. 15). Analiza rozwoju PBCS z wykorzystaniem wypracowanego podziału sekwencyjnego wykazuje istnienie licznych luk sedymentacyjnych, szczególnie w południowej części basenu (Fig. 16, 17). Szkice paleogeograficzne poszczególnych sekwencji ilustrują natomiast zasięgi występowania głównych środowisk depozycyjnych (Fig. 18–25).

Ewolucja polskiego basenu czerwonego spągowca nie skończyła się wraz z transgresją cechsztyńską. Wypełnienie PBCS podlegało dalszej ewolucji związanej z rozwojem polskiego basenu permsko-mezozoicznego i trwało aż do końca kredy, kiedy to nastąpiła inwersja basenu i w jego centralnej części zostało utworzone antyklinorium śródpolskie. Aby móc śledzić ewolucję wypełnienia PBCS wykonano dla tego obszaru analizę historii pogrążania i analizę historii termicznej. Podstawą analizy było 14 przekrojów geologicznych przez basen polski (Fig. 26, 27). Posługiwano się w tym celu programami komputerowymi przystosowanymi do obliczania wielkości subsydencji całkowitej i subsydencji tektonicznej z uwzględnieniem poprawki kompakcyjnej (Fig. 28). Strop czerwonego spągowca z końcem jury osiągnął w najbardziej pogrążonej części basenu głębokość ponad 8 km poniżej poziomu ówczesnego morza (Fig. 29), a z końcem kredy przekroczył głębokość 10 km (Fig. 30). W tym czasie strop czerwonego spągowca w południowo-zachodniej części basenu był pogrążony tylko na głębokość 2–4 km. Aby lepiej zrozumieć przyczyny powstania PBCS i mechanizm subsydencji w basenie polskim wykonano obliczenie wielkości subsydencji tektonicznej dla wybranych etapów sedymentacji (Fig. 31-41). Obliczono również poprawki paleobatymetryczne i paleoeustatyczne w celu skorygowania uprzednio obliczonych wartości subsydencji tektonicznej. W trzech przypadkach obliczona poprawka paleobatymetryczno-paleoeustatyczna (PP) ma istotne znaczenie dla wykonanych map (Fig. 31-41); dla czerwonego spągowca — gdzie trzeba do obliczonych wartości dodać poprawkę PP, czyli wartość subsydencji tektonicznej powiększy się o ok. 200 m; dla późnej jury — od obliczonych wartości należy odjąć poprawkę PP, czyli wartość subsydencji tektonicznej zmniejszy się o ok. 150 m; i dla późnej kredy — od obliczonych wartości trzeba odjąć poprawkę PP, czyli wartość subsydencji tektonicznej zmniejszy się o ok. 200–300 m. Historia subsydencji basenu polskiego na omawianym obszarze pokazuje, że okres późnego permu i triasu był główną fazą ryftowania, a późniejszy rozwój basenu wynikał z relaksacji termicznej. Późnojurajski epizod ryftowy zaznaczył się tylko w południowej części omawianego obszaru. Wydaje się, że w czasie okresu poźnokredowego nie wystąpił żaden szczególny zewnętrzny mechanizm tektoniczny sprzyjający subsydencji, a sama subsydencja w czasie wielkiej transgresji morskiej była w zdecydowanej większości wywołana przez obciążenie wodą i osadami tworzącymi się w basenie.

Odtworzenie historii termicznej basenu wymaga znajomości m. in. rozkładu współczesnego pola cieplnego (Fig. 42). Wykonując komputerowo wielokrotne symulacje ewolucji termicznej wzdłuż wybranych profili geologicznych uzyskuje się różne wyniki końcowe, które trzeba konfrontować z rozkładem współczesnego pola cieplnego i wartością współczynnika refleksyjności witrynitu w różnych formacjach geologicznych. Dopiero po uzyskaniu zgodności tych dwóch wartości kontrolnych można wynik symulacji uznać za pozytywny (Fig. 43). Główną zmienną w czasie przeprowadzanych symulacji jest wartość powierzchniowego strumienia cieplnego, który musi być dobierany nie tylko wzdłuż profilu (w przestrzeni), ale również w czasie geologicznym (Fig. 44). Symulacje komputerowe wykonane wzdłuż 14 profili geologicznych przez basen polski pozwoliły zestawić mapy rozkładu średniego strumienia cieplnego dla dwóch okresów: od późnego permu do końca jury i od kredy do dziś (Fig. 45, 46). Wyniki analiz komputerowych pozwoliły też zestawić mapę dojrzałości materii organicznej w utworach cechsztynu, aby móc ją porównywać z mapą występowania węglowodorów na Niżu Polskim (Fig. 47, 48).

Analizując historię termiczną basenu polskiego widać, że w początkach procesów wulkanicznych w czerwonym spągowcu występowały wielkie anomalie geotermiczne w jego zachodniej części. Anomalie te charakteryzowały się wysoką wartością strumienia cieplnego (100–150 mWm^{-2}) w czasie późnego permu i triasu. Tak wysokie wartości odpowiadają przeważnie synryftowemu etapowi rozwoju basenu. W czasie późnego triasu i jury wystąpiło pewne schłodzenie tego pola cieplnego, ale punktem zwrotnym w historii termicznej basenu polskiego było pogranicze jury i triasu, kiedy południowo-zachodnia część omawianego basenu została znacznie wyniesiona i zerodowana. Wtedy to wartość powierzchniowego strumienia cieplnego w południowo-zachodniej Polsce istotnie zmalała, a wyraźne cechy termiczne poprzedniej epoki zostały zatarte.

Występowanie złóż gazu w osadach czerwonego spągowca ograniczone jest do najwyższej części sekwencji osadowej. Dotychczasowe poszukiwania doprowadziły do odkrycia szeregu złóż. Intensywność poszukiwań ograniczona jest jednak głębokością zalegania stropu czerwonego spągowca w basenie polskim (Fig. 49). Skład gazu ziemnego wykazuje niekiedy znaczne zaazotowanie oraz istotne wzbogacenie w hel (Fig. 50). Duże ilości helu w gazie umożliwiają jego wydobywanie na skalę przemysłową. Najwyższe koncentracje helu w gazie ziemnym, tak pod względem objętościowym jak i ilościowym, są zlokalizowane w tym samym miejscu, co stwierdzona w wyniku analizy termicznej permsko-jurajska wysoka anomalia geotermiczna i jednocześnie najpłycej tutaj występująca powierzchnia Moho w Polsce (Fig. 51).

Wyniki analizy historii pogrążenia i historii termicznej analizowanej części basenu polskiego, jak również konfiguracja powierzchni Moho i związanych z nią anomalii paleogeotermicznych i wysokich koncentracji helu wskazują na asymetryczny model budowy basenu (Fig. 52). Strefa wysokich anomalii paleogeotermicznych, rozciągająca się od obszaru między Wrocławiem i Poznaniem i dalej na zachód, mogła być głównym obszarem ryftowania. Powyższe dane wskazują na ryftowy charakter basenu polskiego, którego pierwszym etapem rozwoju był wulkanizm i późniejsza sedymentacja w czasie czerwonego spągowca.