Geological Quarterly, 2006, **50** (1): 119–138

Evolution of the Rotliegend Basin of northwestern Poland

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Kiersnowski H. and Buniak A. (2006) — Evolution of the Rotliegend Basin of northwestern Poland. Geol. Quart., **50** (1): 119–138. Warszawa.

The Rotliegend Basin of northwestern Poland is characterized by a complex structure that reflects syndepositional reactivation of fault systems related to the Teisseyre-Tornquist (TTZ) and Sorgenfrei-Tornquist (STZ) zones. This basin is superimposed on the Caledonian Trans-European Suture Zone and encroaches eastward onto the East European Craton and southwestward onto the Variscan Externides. Latest Carboniferous and Early Permian sinistral wrench movements along the TTZ and STZ, causing disruption and erosional truncation of the Variscan foreland basin and the external Variscan fold-and-thrust belt, were accompanied by the extrusion of voluminous volcanics. During the deposition of the Upper Rotliegend sediments, earlier formed fault systems were recurrently reactivated, controlling the subsidence of an array of troughs and uplift of horst blocks. During deposition of the upper parts of the Upper Rotliegend, when tectonic activity had abated, subsidence and broadening of the Polish Basin was controlled by thermal relaxation of the lithosphere. Analysis of wireline logs, calibrated by cores, and their regional correlations permits to distinguish nine successive Upper Rotliegend depositional cycles. These involve alluvial fan, fluvial, lacustrine, playa-lake and aeolian deposits and are separated by conspicuous lithofacies and/or erosional boundaries. Lithofacies maps developed for each of these depositional cycles allowed to retrace the palaeogeographic evolution of the Polish Rotliegend Basin, with supporting cross-sections providing insight into its structural development. Palaeoclimatic factors, such as rapid humidity changes, combined with tectonic activity, played an important role in the development of the different depositional cycles and their boundaries. Tectonics controlled the development of accommodation space and the lack thereof, as well as uplift and erosion of clastic source areas. The Polish and North German Rotliegend basins were separated during the deposition of the Drawa (Parchim and Mirow) and the earlier part of the Noteć (Rambow and Eldna) formations by the vast area of palaeohigh. Subsequently this high was overstepped by sediments of the upper part of the Noteć (Peckensen and Mellin) Formation, resulting in the coalescence of these basins. A tentative correlation of depositional cycles evident in the Polish and North German Rotliegend basins is presented.

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Key words: Polish Basin, Permian, Upper Rotliegend, tectonics, stratigraphy, depositional cycles.

INTRODUCTION

This study emerged from the need to re-evaluate earlier interpretations of the tectono-stratigraphic development of the Polish Rotliegend Basin in the light of the results of new boreholes and 2D and 3D reflection-seismic data that were acquired in the context of on-going gas exploration. This paper focuses on the NW part of the Polish Rotliegend Basin in which Upper Rotliegend deposits are fullest developed, and more specifically on a regional structural analysis that aims at assessing structural controls on sediment thickness and facies development. In addition, some aspects of palaeoclimatic effects on sedimentary processes will be discussed. Furthermore, correlations between the NW Polish and NE German parts of the Rotliegend Basin will be addressed.

In NW Poland, Upper Rotliegend sediments accumulated in an area of considerable tectonic complexity that is characterized by the alignment and interaction of several super-regional dislocation zones (Fig. 1). The depositional architecture and stratigraphy of the Upper Rotliegend deposits reflects the tectonic differentiation of their pre-Permian substrate. This inspired a step-wise reconstruction of the evolution of the Polish Rotliegend Basin and the development of a new model for syn-depositional tectonics during basin subsidence.

In the West Pomerania area, studies on Rotliegend sedimentary series commenced in the 1970's in the context of oil and gas exploration that aimed at assessing the potential of Devonian, Carboniferous and Permian reservoirs. Since then, numerous boreholes were drilled yielding a host of new geologic information that was published in a number of papers dealing with structural geology (Dadlez, 1974*a*, *b*, 1978, 1990; Wagner

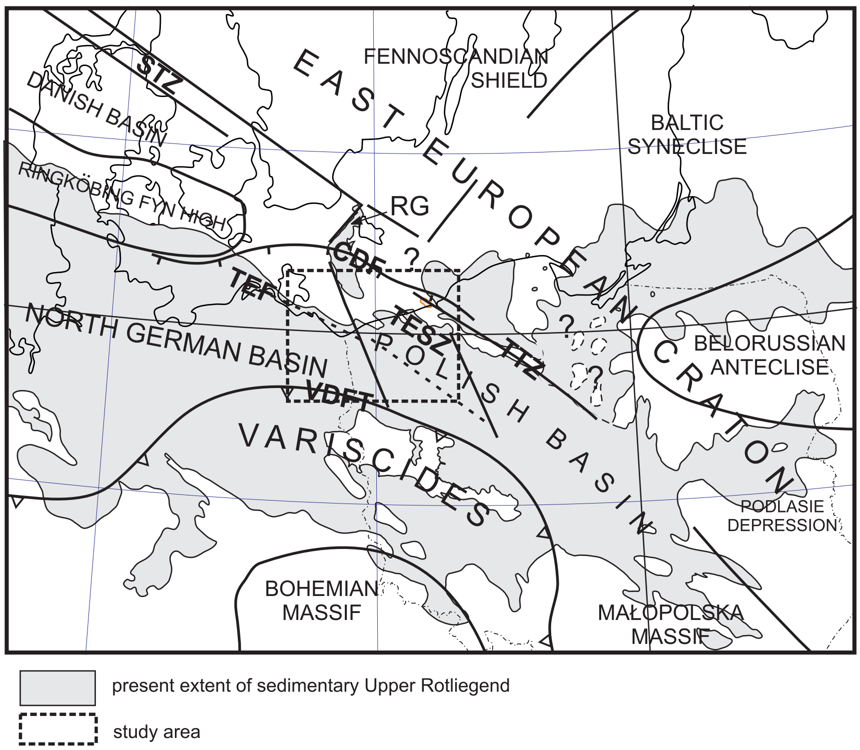


Fig. 1. Study area on the background of simplified tectonic map of the eastern part of the Southern Permian Basin

CDF — Caledonian Deformation Front; RG — Rønne Graben; STZ — Sorgenfrei-Tornquist Zone; TEF — Trans-European Fault; TESZ — Trans-European Suture Zone; Teisseyre-Tornquist Zone; VDFT — Variscan Deformation Front

et al., 1980) and the lithofacies of Upper Rotliegend deposits (Pokorski, 1978, 1987, 1988*a*, *b*, 1990). Following the discovery of several hydrocarbon accumulations in Zechstein carbonates increased drilling activity and seismic profiling brought further progress in the understanding of Rotliegend deposits and their structural relation to older basement features (Wagner, 1987; Antonowicz *et al*., 1993, 1994).

In the 1980's, Pokorski presented the stratigraphy of the Rotliegend Basin and a model for its development, as well as a tectonic background for depositional processes at regional and basin-wide scales (Pokorski, 1981, 1988*a*, *b*, 1990). He updated his interpretations, with minor amendments, during the following years (Pokorski, 1997, 1998*a*). Maps presented in these papers show the distribution, facies and thickness of a lower and upper unit of the Upper Rotliegend sedimentary series in the Pomeranian part of the Polish Basin. However, these maps reflect only partly the complex tectonic development of this basin. Kiersnowski (1997, 1998) presented a new model for the development of the Polish Rotliegend Basin that is based on depositional sequence analyses. For the NW part of this basin, he proposed a modification of the depositional history and presented new palaeogeographic models for the Rotliegend series that partly differed from those of Pokorski. These differences arose from a different analytical concept of depositional processes that includes sequence stratigraphy, palaeoclimatic effects and partly different interpretations of the significance of tectonic controls on source areas and depositional processes. Karnkowski presented in 1999 his depositional development model for the Polish Rotliegend Basin, partly incorporating the results of Kiersnowski (1997, 1998). Compared with the models of Pokorski (1990, 1997), the model of Karnkowski (1999) is more compatible with earlier published tectonic maps of the sub-Rotliegend basement, particularly in the NW part of the Rotliegend Basin. Dadlez *et al*. (1995, 1998) showed for the Permian-Mesozoic Polish Basin the important relationship between tectonics and changes in subsidence rates through time, specifically in terms of the significance of regional tectonic structures.

REGIONAL BACKGROUND

The Polish Rotliegend Basin (PRB) forms the eastern part of the Southern Permian Basin (SPB) (Kiersnowski *et al*., 1995). The PRB shares many similarities with the western and central portions of the SPB, including a common style of sedimentation controlled to a large degree by the interplay between syn-sedimentary block faulting and a fluctuating, mostly arid to semi-arid climate. However, the level of tectonic control differs across the SPB owing to differences in the availability of reactivated pre-existing basement discontinuities (Geluk, 2005). The current developmental model for the SPB assumes a major role of lithospheric thermal relaxation, post-dating the major Early Permian magmatic event, and superimposed extensional to transtensional tectonics (Van Wees *et al*., 2000). The latter appear to be particularly important in the area of the Teisseyre-Tornquist Zone, the northwestern part of which transects the NE corner of the study area (Fig. 1).

From earlier studies by Antonowicz *et al*. (1993, 1994), Dadlez (1990) and Pokorski (1988*b*, 1990) it is obvious that the structural differentiation of the pre-Permian basement and its tectonic reactivation had a strong bearing on the distribution and thickness of the Upper Rotliegend series, as evident from the isopach map given in Figure 2. In Pomerania, the Rotliegend series were deposited on top of an array of horsts, tilted fault blocks, grabens and half-grabens (Pożaryski *et al*., 1992) that involve Carboniferous and Devonian and sporadically in the east also Silurian sediments (Miłaczewski, 1987; Tomczyk, 1987; Żelichowski, 1987). Structuring of the Upper Rotliegend substratum resulted from intense latest Carboniferous-Early Permian wrench deformation along the Teisseyre-Tornquist and Sorgenfrei-Tornquist zones and associated uplift and erosion of the Variscan foreland basin and the external parts of the Variscan

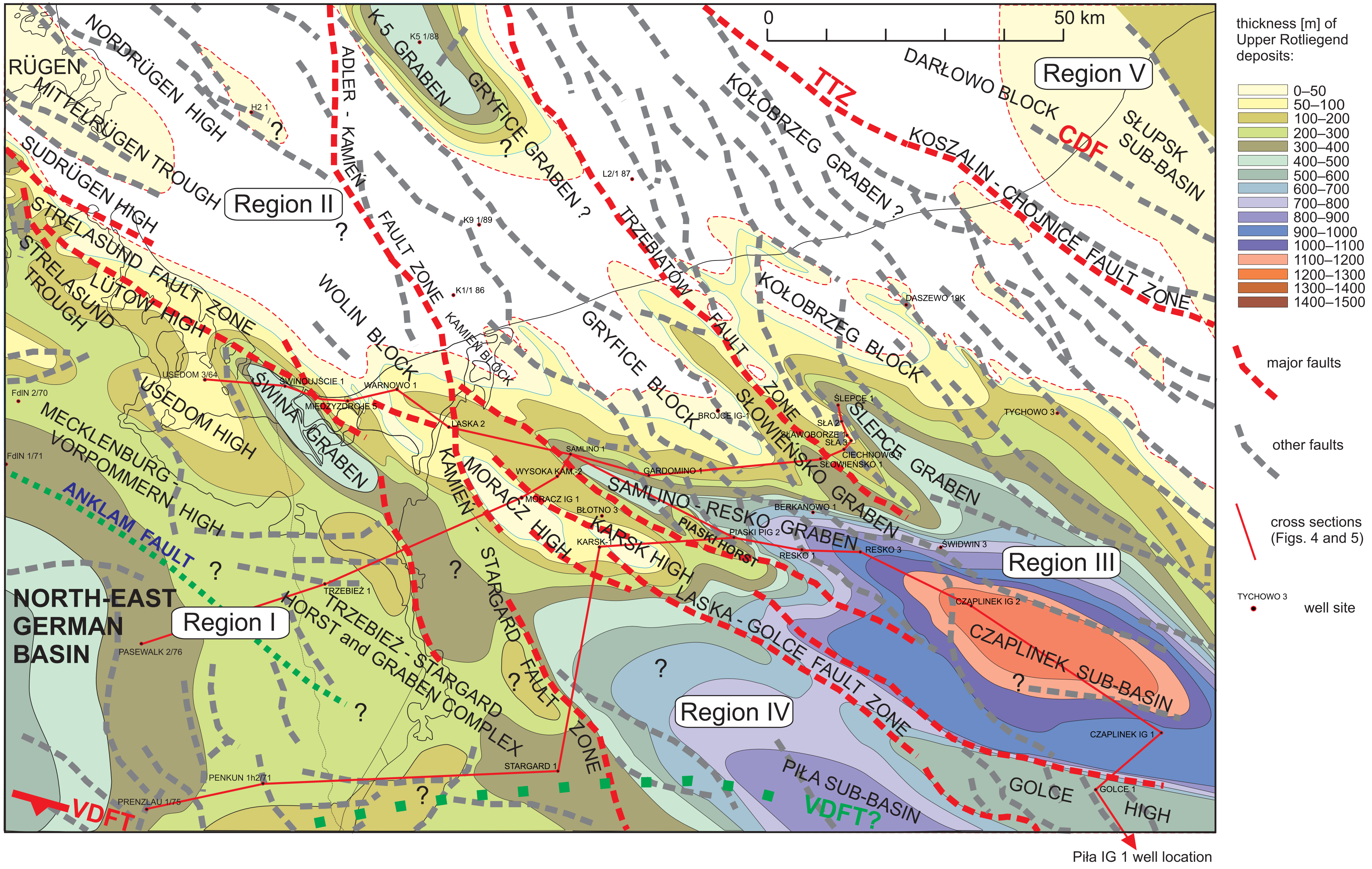


Fig. 2. Present thickness distribution of Rotliegend deposits in northwestern Poland and neighbouring German and Baltic areas

Tectonic regions I to V are described in the text; two variants of the course of the Variscan Deformation Front (VDFT) are shown in red and green; other explanations as on Figure 1 fold-and-thrust belt. This involved the reactivation of pre-existing crustal discontinuities and the development of new ones (Figs. 1 and 2; Ziegler, 1990).

The northern parts of the Polish Rotliegend Basin are fringed by and are superimposed on major crustal boundaries, tectonic activity along which, and the significance of which changed in the course of time. The oldest of these crustal boundaries corresponds to the margin of the East European Craton (EEC) that coincides in Pomerania with the Teisseyre-Tornquist Zone (TTZ). In the study area, the latter coincides with the Koszalin-Chojnice Fault Zone. Recently this margin was understood to flank to the NE the wide Caledonian-deformed Trans-European Suture Zone (TESZ) that extends westward to dislocations interpreted as being associated with the Trans-European Fault (TEF), thought to mark the margin of the Gondwana-derived East Avalonia Terrane (Nawrocki and Poprawa, 2006). In Pomerania, fault systems associated with the TTZ closely coincide with the Caledonian Deformation Front (CDF) and the EEC margin, whereas in the Baltic Sea these fault systems extend into the Precambrian crust of the EEC and form part of the Sorgenfrei-Tornquist Zone (STZ; Fig. 1). In the southern Baltic Sea, the course of the CDF turns to the NW and strikes obliquely to faults associated with the TTZ and STZ (Fig. 1). Whilst the NE and N parts of the Polish Rotliegend Basin extend beyond the CDF onto the EEC, its axial part is superimposed on the TESZ, whereas its SW, shallower parts overlay crustal domains attributed to the East Avalonia Terrane and encroach on the Variscan Externides (Figs. 1 and 2).

North of the Variscan Deformation Front (VDFT) and to the west of the Kamień-Stargard Fault Zone, relatively thin Upper Rotliegend deposits rest on Early Permian volcanics that are underlain by block-faulted Carboniferous series. This regional palaeohigh separates the Upper Rotliegend depocentres of NW Poland and NE Germany. South of the VDFT, the Polish Rotliegend Basin is fringed by palaeohighs that are upheld by the strongly folded Lower Carboniferous sediments of the Variscan Externides that are capped by Early Permian volcanic rocks. The trace of the rather ill-defined VDFT does, however, not appear to coincide with the southernmost extension of Upper Rotliegend deposits. To the north, the Rotliegend Basin is clearly limited by a system of palaeohighs (here referred to as the Western Pomerania Upland) that are upheld by Carboniferous sediments and Lower Permian volcanic rocks. The tectonic origin of these palaeohighs has, so far, not yet been documented.

MATERIALS AND METHODS

Seismostratigraphic interpretation of the studied Rotliegend deposits is seriously hampered by the poor seismic resolution at pre-Zechstein levels. Therefore, the present study is based on the analysis of wireline logs and core material of most of the wells that penetrated Rotliegend deposits in NW Poland (Pomerania), NE Germany (Mecklenburg) and the Baltic Sea. Sedimentological and petrologic analyses of cored sections permitted to establish a correlation between specific wireline log characteristics and different lithological units, facies types and to a degree also depositional environments, thus allowing to extend interpretations from cored to non-cored intervals. The analysis of borehole profiles yielded important information for the construction of spatial models showing the distribution of successive Rotliegend depositional systems and the identification of their bounding surfaces. Furthermore, definition of these bounding surfaces permitted to establish regional correlations on the base of which the effects of syn-sedimentary faulting on lateral facies and thickness changes could be assessed. Based on published and unpublished tectonic maps of the sub-Permian basement, as well as on seismically controlled structural maps of the top Upper Rotliegend (= base Zechstein PZ1), mapped fault systems were analyzed. Tectonic analyses included the interpretation of gravimetric and magnetic data (particularly vertical gradients maps) in terms of identifying potential fault zones. Faults that were recognized as having formed during the Late Cretaceous and Paleocene inversion of the Mid-Polish Trough (Krzywiec, 2006) are excluded from the map given in Figure 2.

Based on wireline log analyses of sedimentary environments, the different depositional cycles that are preserved in large parts of the Upper Rotliegend Basin were identified and characterised, and their mutual spatial relationship, composition and lateral extent determined (Fig. 3). Correlations between boreholes were performed and faults marked that in our view reflect syndepositional tectonic activity (Figs. 4 and 5). Earlier correlations between boreholes lacked, however, a proper identification of sedimentary environments and were largely based on arbitrary wireline log correlations (Pokorski, 1987), leading to erroneous interpretations. Results of these studies were subsequently used for the definition of informal lithostratigraphic units, representing allostratigraphic units (Karnkowski, 1987) or diastrophic cycles (Pokorski, 1987) that were referred to as “formations” and “members” (Pokorski, 1981, 1988*a*, *b*, 1998*a*; Hoffmann *et al*., 1997). Based on sedimentological core studies and palaeoenvironmental/palaeoclimatic interpretations, Kiersnowski (1997, 1998) applied for the first time sequence stratigraphic concepts to the entire Polish Upper Rotliegend Basin, tentatively distinguishing the individual depositional sequences. Hitherto, interpretations of the distribution and succession of different lithofacies units were based on a tectonic model for the development of the Rotliegend Basin that implied its partitioning into segments by transverse fault zones striking normal to the basin axis and the margin of the East European Craton (Pokorski, 1988*b*, 1990).

SEDIMENT THICKNESS PATTERN AND MAIN PALAEOTECTONIC UNITS

During latest Carboniferous and Early Permian times, large parts of the studied area were covered by volcanic flows and associated pyroclastic and subordinate siliciclastic sediments (Pokorski, 1990). In N Germany and Poland the volcanic activity spanned 302–295 Ma (Neumann *et al*., 2004) and was preceded by the subsidence of fault-controlled troughs in western Pomerania and northern Mecklenburg in which the Stephanian clastics of the Świniec Formation (Pokorski, 1990) and

Mönchgut-Beds of Strelasund Trough were deposited. These are covered by extrusive and pyroclastic rocks that attain maximum thickness of over 2500 m south of Rügen and 2360 in Mecklenburg-Vorpommern but decrease in thickness southeast- and eastward (Katzung and Obst, 2004). For instance, in the Stargard Szczeciński 1 borehole, 350 m of siliciclastic and pyroclastic rocks were penetrated (Maliszewska *et al*., 2003) whilst on the Moracz High volcanics are over 600 m thick. These thin out eastward towards the Trzebiatów Fault Zone which flanks the Kołobrzeg Block (Fig. 2; Pokorski, 1987, 1990). Beyond this fault zone, numerous, generally thin and isolated occurrences of volcanic rocks have been recorded (Ryka, 1978). Therefore, it is likely that the entire area of Kołobrzeg Block was initially covered by volcanic rocks, but that these were partly eroded in late Early Permian times. The intensity of this erosion and underlying wrench deformations is illustrated by the occurrence of Middle Devonian to Lower Carboniferous rocks at the base of the Rotliegend deposits. The isopach map of the Upper Rotliegend sediments, presented in Figure 2, illustrates the complex geometry of the Polish part of the Southern Permian Basin. Basement faults shown in Figure 2 are superimposed onto this map and highlight the fault control on individual, discrete Upper Rotliegend depocentres, such as the Czaplinek and Piła sub-basins, as well as on intervening and flanking highs. The principal tectonic units identified in Figure 2 are based on a number of sources (Conrad, 2001; Dadlez, 1990, 1995, 2000; Dadlez and Pokorski, 1995; Rieke *et al*., 2001; Roch *et al*., 2005; Vejbæk, 1985; Vejbæk *et al*., 1994), as well as on unpublished geological structural maps of the Piaski-Resko Area.

Whilst Upper Rotliegend sediments attain a maximum thickness of 1300 m in the Czaplinek Sub-Basin, marginal blocks are characterized by reduced thickness owing to stratigraphic condensation and/or erosion. For instance on the Piaski Horst (borehole Piaski PIG 2; Figs. 2 and 4) an about 300 m thick sedimentary package equates to a 1050 m thick interval in the Czaplinek IG 2 borehole and thus testifies to differential subsidence of this horst and the adjacent sub-basin. Syndepositional tectonic activity along the Laska-Golce Fault, that separates the Golce High from the Czaplinek Sub-Basin, is indicated by the Golce 1 borehole that penetrated about 560 m thick Rotliegend deposits, which equate to 960 m of sediments in the Czaplinek IG 1 borehole (Figs. 2 and 4). The reduced thickness of Rotliegend deposits in Golce 1 resulted both from sediment condensation and periods of significant erosion. The Laska-Golce Fault was already active during the Early Permian, as indicated by Rotliegend sediments resting on Early Carboniferous (Viséan) rocks in the Czaplinek IG 1 borehole, whereas in Golce 1 they lie on Early Permian volcanics.

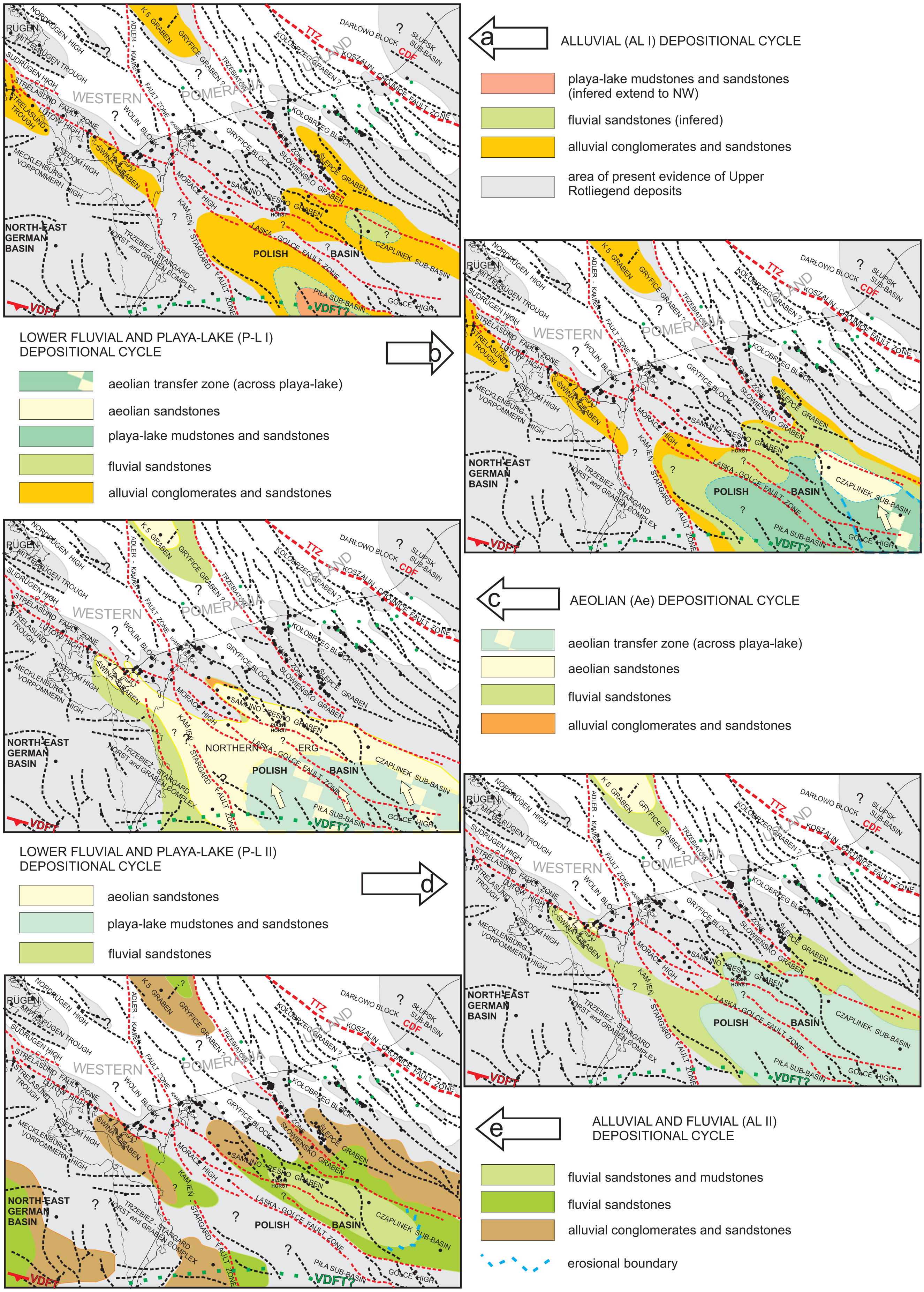
Based on an analysis of major structural features and their effects on Rotliegend sedimentation, five main regions can be distinguished in Pomerania and adjacent areas that are bounded by fault zones that partly reactivated pre-existing major crustal discontinuities, such as the TEF and TTZ, and partly by fault zones that developed during latest Carboniferous-Early Permian times. Region I is delimited to NE by the Strelasund and southern part of Kamień-Stargard Fault Zone, Region II by the Strelasund and northern Adler-Kamień Fault Zone, Region III by the Adler-Kamień Fault Zone (to the NW), Laska-Golce and Koszalin-Chojnice fault zones (to the SW), Region IV by the southern Kamień-Stargard Fault Zone (to the W) and Laska-Golce Fault Zone (to the NE), and Region V by the Koszalin-Chojnice Fault Zone to the SW (Fig. 2). The Strelasund and Laska-Golce fault zones are superimposed on the TEF whilst the Koszalin-Chojnice Fault Zone is superimposed on the TTZ (Dadlez, 2000; Dadlez *et al*., 1998; Pożaryski *et al*., 1992). The Adler-Kamień Pomorski and its prolongation in the Kamień-Stargard Fault Zone obliquely transect the CDF and the TEF and thus probably developed during the Permo-Carboniferous.

REGION I

This region straddles the transition zone between the Polish and the North German Rotliegend Basin (Katzung and Obst, 2004) and corresponds to a broad palaeohigh, referred to as the Mecklenburg-Vorpommern High in Germany (Hoffman, 1990) and as the Trzebież-Stargard Horst and Graben Complex in Poland. This high, which is upheld by Late Carboniferous sediments (Franke, 1990) that are covered by extensive Early Permian volcanics, was only overstepped by the upper parts of the Upper Rotliegend series that merely locally are thicker than 300 m (Fig. 2). More complete Rotliegend series occur only in the Strelasund Trough and Świna Graben. The Strelasund and the Kamień-Stargard fault zones bound this palaeohigh to the NE, with the ill-defined VDFT (Dadlez, 2000) forming its southern boundary. According to Hoffmann *et al.* (1998), the Mecklenburg-Vorpommern High is subdivided into two parts by the Anklam Fault (AF; Fig. 2), which constitutes a tectonic boundary in the pre-Permian basement between the Variscan Foreland area in the south and Caledonian Deformation Belt in the north. Due to poor well control in the eastern part of the Mecklenburg-Vorpommern High, the significance of the AF for the Rotliegend sedimentation is not clear, although it appears to control the NE flank of the North German Basin.

The sediments in the Strelasund Trough (over 900 m of coarse grained sediments — west of the present study area) are interpreted as belonging to the lowermost part of the upper Rotliegend (Rieke *et al*., 2001), and are further transected by a series of normal faults, running approximately from the north to the south. These faults formed in response to tectonic activity along the underlying NW–SE oriented strike-slip fault zone (Rieke *et al*., 2001). This zone and the Strelasund Trough are of an older tectonic origin, as evidenced by the thickness and spatial extent of Late Carboniferous sediments (so-called Mönchgut-Beds; Hoffmann *et al*., 1997).

The Świna tectonic trough (Pokorski, 1990), filled with over 400 m of Rotliegend deposits, is separated from the Strelasund Trough by the Lütow and Usedom palaeohighs. Probably, the Świna Graben constitutes the next segment of the chain of tectonic depressions that were controlled by activity along the Strelasund Fault Zone. The development of Rotliegend deposits in this trough is based on the Świnoujście 1 borehole, which did not pierce their full thickness. Nevertheless, according to the present authors, this profile (including probable aeolian deposits) correlates with the lower part of the Upper Rotliegend series contained in tectonic troughs located to the west (Rønne Graben) and south-west of Bornholm (K5 Graben).


a
ALLUVIAL (AL I) DEPOSITIONAL CYCLE
playa-lake mudstones and sandstones (infered extend to NW)
fluvial sandstones (infered)
alluvial conglomerates and sandstones
area of present evidence of Upper Rotliegend deposits
b
LOWER FLUVIAL AND PLAYA-LAKE (P-L I) DEPOSITIONAL CYCLE
aeolian transfer zone (across playa-lake)
aeolian sandstones
playa-lake mudstones and sandstones
fluvial sandstones
alluvial conglomerates and sandstones
c
AEOLIAN (Ae) DEPOSITIONAL CYCLE
aeolian transfer zone (across playa-lake)
aeolian sandstones
fluvial sandstones
alluvial conglomerates and sandstones
d
LOWER FLUVIAL AND PLAYA-LAKE (P-L II) DEPOSITIONAL CYCLE
aeolian sandstones
playa-lake mudstones and sandstones
fluvial sandstones
e
ALLUVIAL AND FLUVIAL (AL II) DEPOSITIONAL CYCLE
fluvial sandstones and mudstones
fluvial sandstones
alluvial conglomerates and sandstones
erosional boundary
RÜGEN
NORDRÜGEN HIGH
MITTELRÜGEN TROUGH
SUDRÜGEN HIGH
STRELASUND FAULT ZONE
STRELASUND TROUGH
LUTOW HIGH
USEDOM HIGH
MECKLENBURG-VORPOMMERN HIGH
NORTH-EAST GERMAN BASIN
WESTERN POMERANIA
ŚWINA GRABEN
WOLIN BLOCK
ADLER - KAMIEŃ FAULT ZONE
K 5 GRABEN
GRYFICE GRABEN ?
TRZEBIATÓW
GRYFICE BLOCK
MORAG HIGH
KAMIEŃ - STARGARD FAULT ZONE
TRZEBIEŻ - STARGARD HORST and GRABEN COMPLEX
SAMLINO
BESKO GRABEN
PIASKI HORST
ŚLEPCE GRABEN
SŁOWIEŃSKO GRABEN
KOŁOBRZEG BLOCK
KOŁOBRZEG GRABEN ?
POMERANIA UPLAND
KOSZALIN - CHOJNICE FAULT ZONE
DARŁOWO BLOCK
SŁUPSK SUB-BASIN
TTZ
CDF
LASKA - GOLCE FAULT ZONE
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GOLCE HIGH
POLISH BASIN
NORTHERN ERG
VDF
VDFT?
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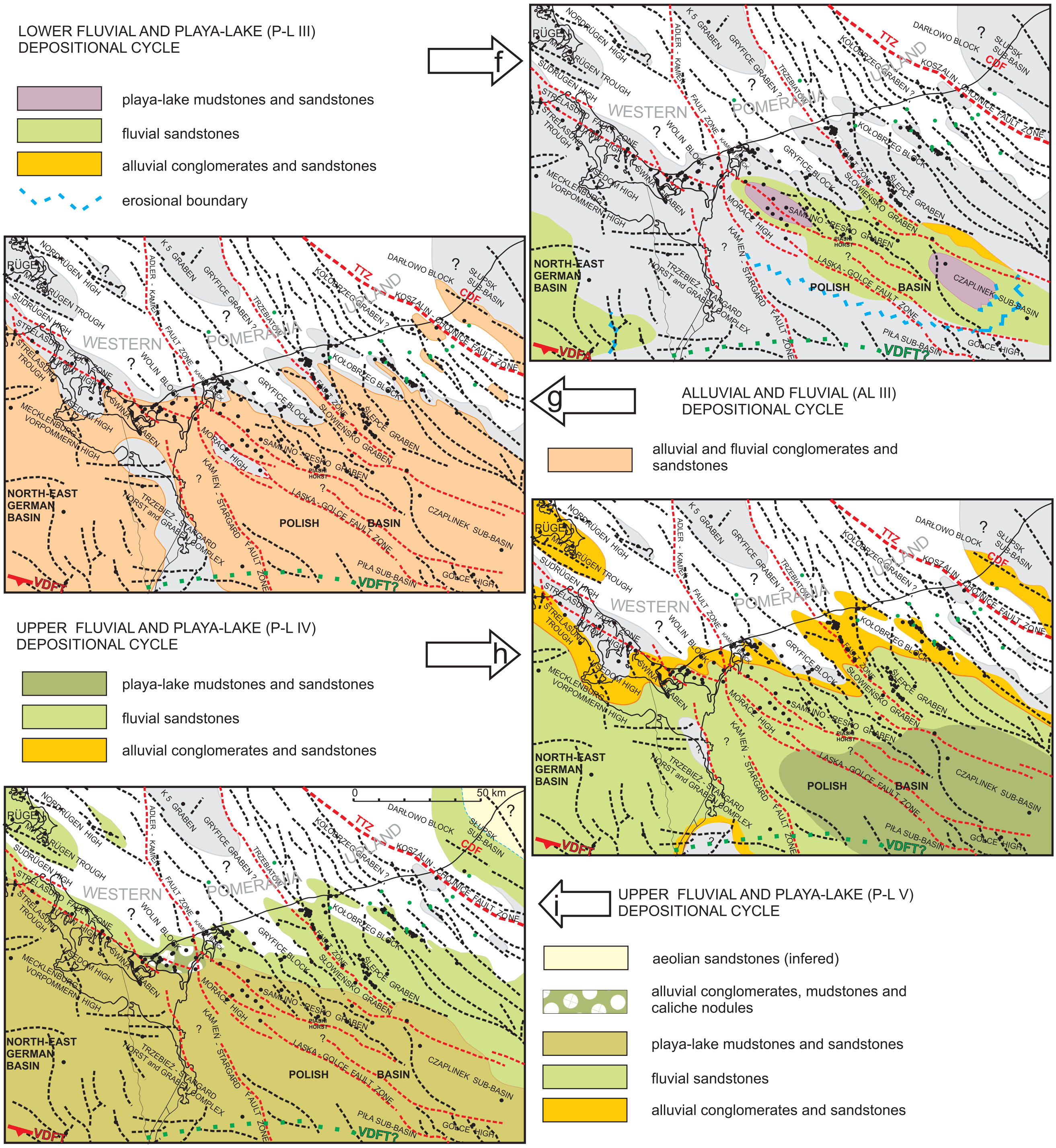


Fig. 3. Maps (a–i) of inferred extent and facies of successive depositional cycles of the Upper Rotliegend in northwestern Poland and neighbouring German and Baltic areas

Other explanations as on Figure 1

The Kamień-Stargard Fault Zone is poorly defined. Along this zone a number of palaeohighs and tectonic depressions are thought to occur. One of these depressions may be the Stargard Szczeciński Trough that contains at least 350 metres of Lower Rotliegend deposits (Maliszewska *et al.*, 2003).

The current state of knowledge, based on boreholes, allows assumption that Upper Rotliegend deposits (particularly, the Elbe Subgroup; Schöder *et al.*, 1995) occur throughout Region I, with the older deposits of Havel Subgroup (Table 1) occuring only in tectonic troughs located in the marginal zones of the area studied (Strelasund Trough, Świna Graben, Uckemark Trough).

REGION II

In the NW part of this region, Rotliegend deposits occur only as some tens of metres thick erosional remnants (*cf.* Pokorski,

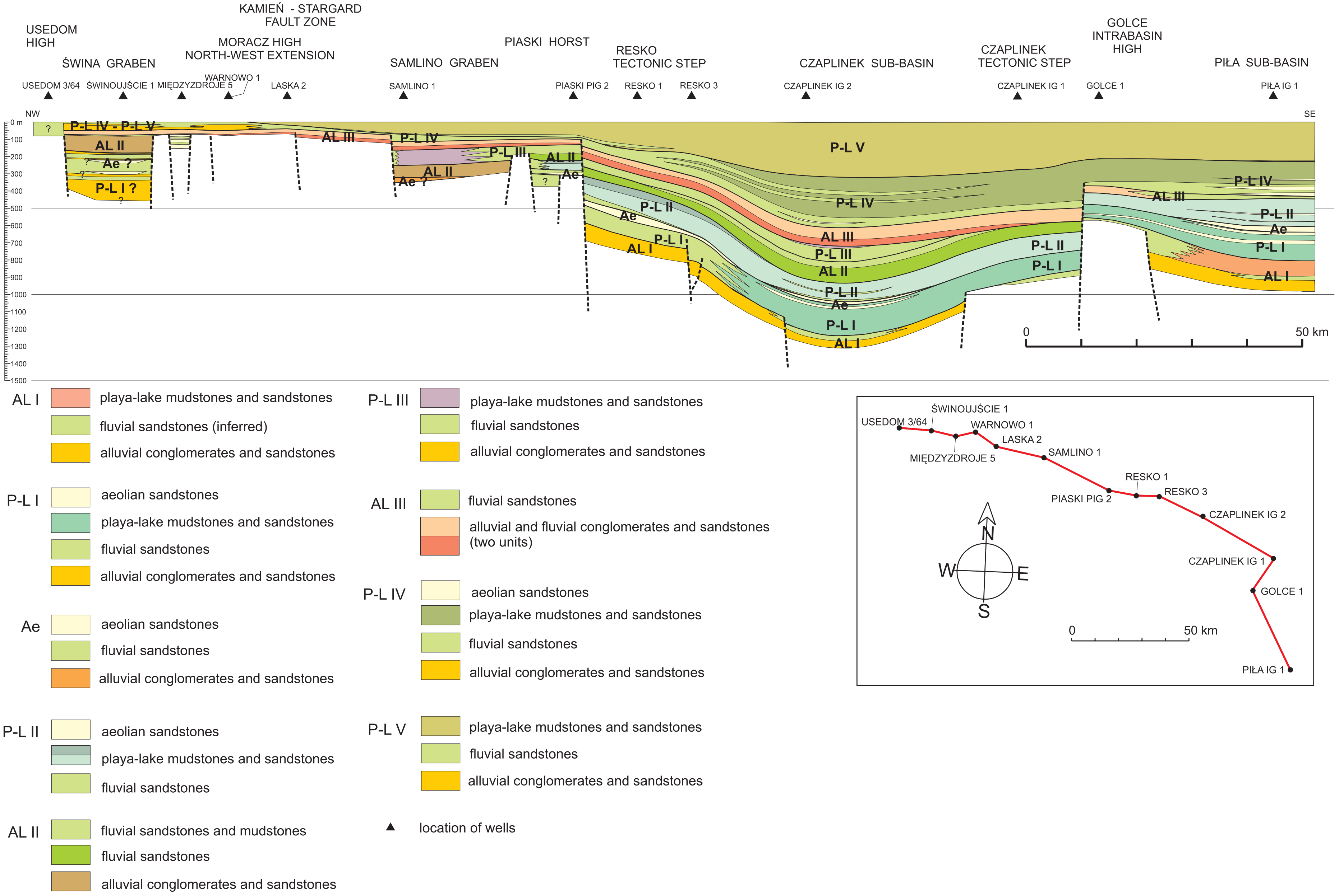


Fig. 4. Schematic cross-section showing depositional architecture of the Rotliegend deposits between Uznam (Usedom), Świnoujście–Piaski–Czaplinek, and Piła area

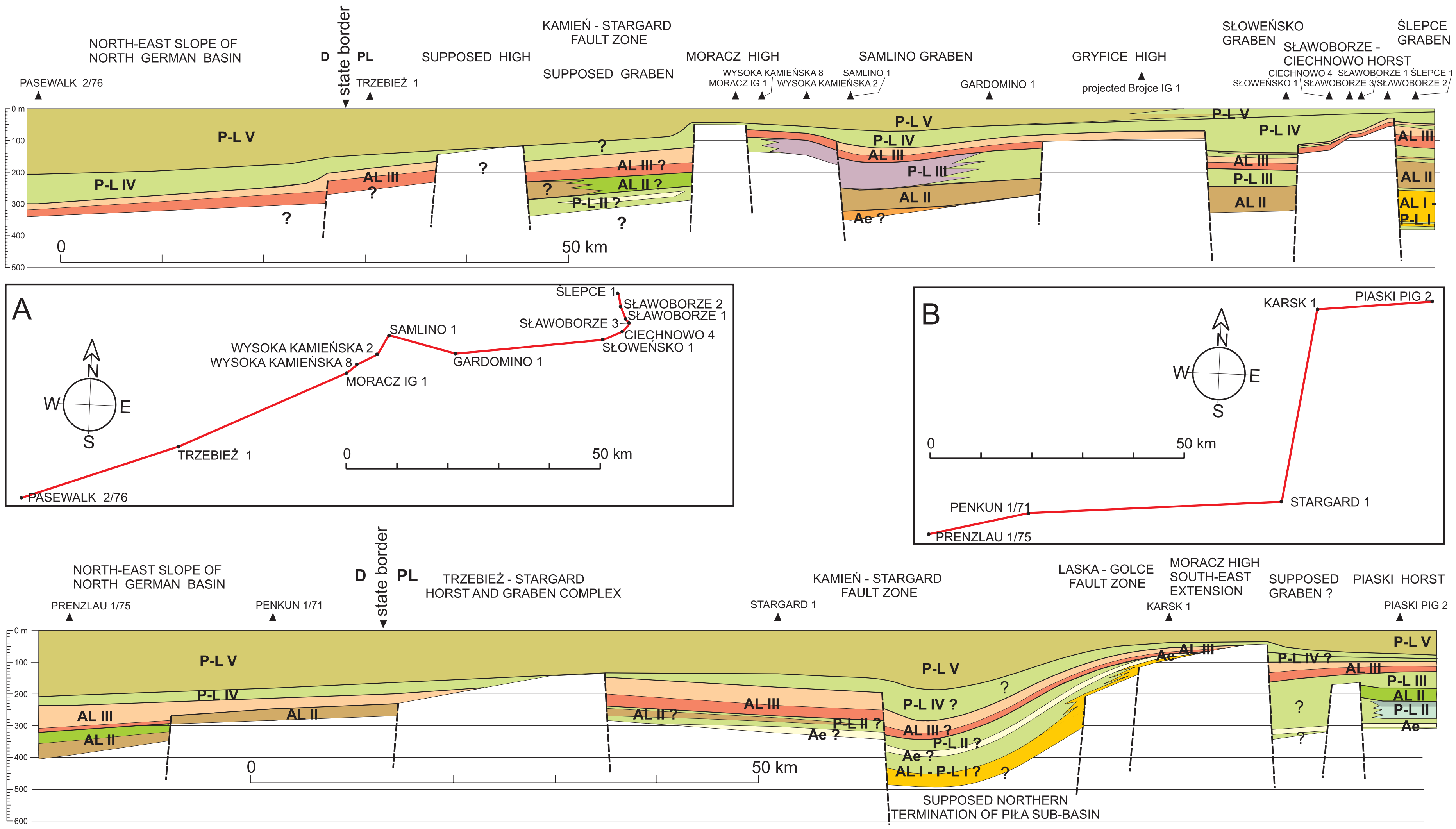


Fig. 5. A — schematic cross-section showing depositional architecture of the Rotliegend deposits between Pasewalk (Germany) and Moracz-Ślepce zone; B — schematic cross-section showing depositional architecture of the Rotliegend deposits between Prenzlau (Germany) and Stargard-Piaski zone

Other explanations as on Figure 4

1990) in the shallow Mittelrügen Trough and in isolated depressions. The substrate of volcanic and sedimentary Permian rocks consists in the southern parts of Late Carboniferous sediments (Hoffmann, 1990) and in northern parts of Early Palaeozoic sediments and Precambrian basement (Obst *et al*., 2004). Main structural elements are the Sudrügen High that is superimposed on the TEF and parallels the Strelasund Fault Zone, the Nordrügen High that coincides with the CDF, and the elevated Wolin Block that is delimited to the E by the Adler-Kamień Fault Zone and to the SW by the Strelasund Fault Zone.

REGION III

The structural configuration of the Region III is dominated by NW–SE trending fault systems of which the Trzebiatów Fault Zone, that separates the Gryfice Block in the west from the Kołobrzeg Block in the east, is the most important (Pokorski, 1990). The Czaplinek Sub-Basin, in which Upper Rotliegend sediments attain maximum thicknesses of 1300 m, occupies the SE parts of this region. By contrast, Rotliegend sediments are generally thin or missing in the NW parts of this region, except in the K5 Graben that forms an extension of the Rønne Graben (Figs. 1 and 2).

The **Gryfice Block** corresponds to an elevated area that is offset to the N by the K5 Graben (Oderbank-Trough; Katzung and Obst, 2004) and to the S by the Samlino-Resko and Słowieńsko grabens. Along the S margin of this block the limit of the PRB is very irregular and is controlled by NW–SE trending fault systems, tectonic activity along which persisted during much of Upper Rotliegend times. In the southern parts of Gryfice Block, Late Carboniferous (Westphalian and Stephanian) sediments directly underlie the Upper Rotliegend deposits (Dadlez and Pokorski, 1995). The northern parts of this block, located in the Baltic Sea, consist of the elevated Kamień Block (boreholes K1/86 and K9/89) and the Gryfice-K5 Graben, in which 205 m of Early Permian volcanics rest on Westphalian C and D sediments and in turn are covered by 445 m of Rotliegend deposits (K5/88 borehole; Lindert *et al*., 1993). Northward, the K5 Graben grades into the Rønne Graben (Fig. 2; Vejbæk, 1985; Vejbæk *et al*., 1994) in which Rotliegend deposits have been identified in two boreholes (Nielsen and Jaspen, 1991).

The **Trzebiatów Fault Zone** that separates the Gryfice and the Kołobrzeg blocks, was repeatedly reactivated and had a considerable impact on the development of Rotliegend basins, in so far as it is associated with the Słowieńsko and Ślepce grabens in which Rotliegend attains thickness of up to 300 m and exceeds 370 m, respectively.

The northern parts of the **Kołobrzeg Block** are probably devoid of Rotliegend deposits, except for the Kołobrzeg Graben that may contain some erosional remnants. By contrast, Rotliegend sediments are widely distributed in its southern parts and increase in thickness towards the Czaplinek Sub-Basin. The northern limit of Rotliegend deposits is erosional, highly irregular and appears to be fault-controlled. Whereas the occurrence of isolated remnants of Rotliegend deposits on the eastern parts of the Kołobrzeg Block suggests they were uplifted and subjected to strong erosion, its SW parts subsided conspicuously during the deposition of the Rotliegend. In the southern and central parts of the block, Middle Devonian and locally Late Devonian and Early Carboniferous sediments underlay the Rotliegend series (Dadlez and Pokorski, 1995). In the north, adjacent to the Koszalin-Chojnice Fault Zone, Middle and Late Devonian and Ordovician-Silurian rocks prevail.

The **Czaplinek Sub-Basin** forms the main depocentre of the Polish Upper Rotliegend Basin and is bounded to the SW by the Laska-Golce Fault Zone and to the NE by the Trzebiatów Fault Zone and fault systems of the Kołobrzeg Block. The lower parts of the Upper Rotliegend accumulated directly on Early Carboniferous sediments.

The hypothetical Resko-Świdwin Fault Zone (Pokorski, 1998*b*) is thought to separate the Gryfice and Kołobrzeg blocks from the central Rotliegend Basin to the south. Based on analyses performed in this paper, the existence of such a fault zone is not required, as it does not solve question of lithologic and thickness variations. In our view, the condensed or reduced thickness of the Rotliegend known from the tectonically elevated Moracz, Karsk, Piaski and Golce blocks (Figs. 2, 4 and 5) is associated with the wide Laska-Golce Fault Zone, that is aligned with the Świnoujście-Drawsko Fault (Dadlez *et al*., 1998). The latter controlled the Permian-Mesozoic development of the northern part of the Mid-Polish Trough (Antonowicz *et al*., 1993).

REGION IV

This region includes the Piła Sub-Basin in which the Upper Rotliegend attains a thickness of up to 1000 m (Fig. 4, borehole Piła IG 1; Kiersnowski, 1998). However, owing to limited control, the thickness indicated for this basin in Figure 3 must be considered as tentative. The Piła and Czaplinek sub-basins are separated by the Golce High, which was overstepped by early Rotliegend deposit but remained intermittently tectonically active until regional subsidence of these basins commenced during the later part of the Upper Rotliegend time (Fig. 4). In the Piła Sub-Basin, the substrate of the Rotliegend deposits is formed by Late Carboniferous sediments in its northern part and by Early Carboniferous ones in its southern part.

REGION V

The NW parts of this region, corresponding to the Darłowo Block (Krzywiec *et al*., 2003), are occupied by the wide and shallow Słupsk Sub-Basin that contains up to 200 m of siliciclastics, attributed to the Upper Rotliegend and the Zechstein (Fig. 2; Pokorski, 1976, 1997). The substrate of this basin is formed by flat-lying Silurian shales and, near the Koszalin-Chojnice Fault Zone, by Caledonian folded Silurian and Ordovician rocks (Podhalańska and Modliński, 2006). Owing to poor control, the architecture of the Słupsk Sub-Basin is ill-defined, particularly in the area of the Baltic Sea. This basin probably corresponds to a wide erosional depression that was carved into the soft Silurian shales during the early development stages of the Polish Rotliegend Basin. As such, the area of the Słupsk Basin may have acted as a source area for the NE parts of the Upper Rotliegend Basin (Kiersnowski, 1997). During later stages, uplift of blocks along the Koszalin-Chojnice

Fault Zone may have isolated the Słupsk Basin from the central Rotliegend Basin, resulting in infilling of the former and a decreasing clastic supply to the latter.

STRATIGRAPHIC AND DEPOSITIONAL FRAMEWORK

In the NW parts of the PRB nine successive depositional cycles are recognized that are characterized by conspicuous heterogeneity and lateral extent, and that partly correspond to the depositional sequences defined earlier by Kiersnowski (1997, see his fig. 2; tab. 1). These cycles involve the following depositional environments: a) alternating ephemeral streams and alluvial fans, representing sedimentation under arid and more humid climatic conditions; b) sandy and muddy alluvial plains; c) muddy playa lakes with a marginal admixture of sulphates and ephemeral freshwater lakes; d) aeolian deposits. These cycles contain numerous conglomerate horizons that represent alluvial fan/plain depositional systems. Their recurrent appearance in individual profiles is interpreted as reflecting diastrophic events associated with palaeorelief rejuvenations and/or palaeoclimate changes. These conglomeratic horizons advanced periodically from source areas located in the N and NE southward far into the basin, thus forming conspicuous correlative marker horizons of stratigraphic significance. On the other hand, the southern part of the basin (Czaplinek and Piła sub-basins) was dominated by relatively stable subsidence rates, resulting in the accumulation of fine-grained playa-lake deposits that attain considerable thickness. These were temporarily, and sometimes cyclically, interrupted by fluvial sands and during drier periods by aeolian sheet and dune sands.

The cycles described below form widespread sedimentary rock units, each of which relates to a genetically coherent depositional system that is bounded by isochronous surfaces. These surfaces testify to important changes in the sedimentary regime that had a strong bearing on the architecture of the evolving basin. These changes can be attributed to tectonic movements and/or conspicuous palaeoclimatic changes.

Owing to limited space depositional cycles discussed below will be described in a more detail in a forthcoming paper by Kiersnowski and Buniak.

ALLUVIAL DEPOSITIONAL CYCLE (AL I) (FIG. 3a)

Conglomerates and sandstones of the cycle AL I accumulated during the initial stage of the PRB development. In a lithostratigraphic sense, they form the lowermost part of the Drawa Fm. (Pokorski, 1981), also referred to as the Polwica Conglomerate Mb. (Karnkowski, 1994). They may also be equivalent to conglomerates occurring in the lowermost part of the Parchim Fm. in Germany (Table 1; Schöder *et al.*, 1995). These conglomerates may possibly be attributed to the Lower Rotliegend, as suggested by Kiersnowski (1997) and Maliszewska *et al.* (2003).

In the area of interest, basal Rotliegend clastics were deposited in a system of tectonically controlled troughs, the NW–SE orientation of which coincides with some of the main tectonic zones presented in Figure 2. Sediment accumulation in these depressions reflects the earliest development stage of tectonic high-rate subsidence zones, such as the Resko-Czaplinek, Ślepce and Świna grabens, with the latter finding its possible NW-ward extension in the Strelasund Trough and its SE-ward extension in the Piła Sub-Basin (Hoffmann *et al.*, 1997). At the same time, the vast system of the K5 and Rønne grabens may have developed to the SW and S of Bornholm (Vejbæk *et al.* 1994). Similarly, the “initial Phase I” dry conglomerates of the Strelasund Trough (Rieke *et al.*, 2001) may have been deposited at this time. Lower Rotliegend volcanic rocks covered areas surrounding these troughs, except for the Czaplinek Tectonic Step (Czaplinek IG 1 borehole) on which Early Carboniferous rocks were exposed.

LOWER FLUVIAL AND PLAYA-LAKE DEPOSITIONAL CYCLE (P-L I) (FIG. 3b)

Compared to the AL I deposits, the conglomerates, sandstones and mudstones of the P-L I cycle show a wider distribution, particularly in the SE part of the study area. Deposition of this sedimentary complex was accompanied by further tectonic activity in the Ślepce, Resko-Czaplinek, Świna grabens, as well as by increased subsidence rates of the Czaplinek and Piła sub-basins. Conglomerates were also deposited in the K5 Trough (Lindert *et al.*, 1993) and the Strelasund system of tectonic troughs. In the latter, characteristic “wet conglomerates” accumulated, owing to the generation of additional accommodation space in response to thermal relaxation of the lithosphere (Rieke *et al.*, 2001). The distribution of these sediments is, however, poorly constrained due to limited borehole control.

The clastic source area for the alluvial fans was located to the N and probably to the SW of the PRB. Overall, alluvial fans advanced SE-wards into the area of maximum subsidence rates, with conglomerates giving gradually way to sandstones (Resko 1, Resko 3, Berkanowo 1) and ultimately to fine-grained playa-lake deposits (Czaplinek IG 1, Czaplinek IG 2, Golce 1, Piła IG 1; Fig. 4). Furthermore, aeolian sandstones occur in this complex as intercalations in playa deposits (e.g. Piła IG 1 and probably Golce 1, and upper part of the Czaplinek IG 2 profiles; Fig. 4). These fine-grained sediments overly with a sharp contact the coarse-grained alluvial plain deposits of the AL I cycle. Such a contact is evident in areas of highest subsidence rates (e.g. boreholes Czaplinek IG 1, Czaplinek IG 2, Golce 1 and Piła IG 1) and may point towards a conspicuous palaeoclimatic change.

AEOLIAN DEPOSITIONAL CYCLE (Ae) (FIG. 3c)

Aeolian sandstones were identified in cores or were inferred from log characteristics (*) in a number of boreholes (Międzyzdroje 5, Świnoujście 1*, Karsk 1, Samlino 1*, Piaski PIG 2, Resko 1, Resko 3*, Czaplinek IG 2, Stargard 1*) (Figs. 4 and 5). All these profiles are situated far to the north of the area of main occurrence of aeolian deposits, i.e. the Eastern Erg in the Poznań region (Kiersnowski, 1997). Based on sedimentological studies of cored intervals, these stratigraphically condensed aeolian sediments represent dune and interdune deposits (sand sheets).

In terms of lithostratigraphy, the Ae cycle forms part of the Drawa Fm. (Pokorski, 1981) or Siekierki Sandstone Fm. (Karnkowski, 1994) that may equate to the aeolian sandstones of Parchim Fm. (Table 1; Schöder *et al*., 1995; Drong *et al*., 1982). In this paper, these sandstones are informally referred to as the Piaski Aeolian Sandstone Unit, after the Piaski PIG 2 borehole, where 12 m thick aeolian sandstones were found for the first time. They range in thickness between a few to maximum 50 metres in the Resko 1 profile and form a conspicuous horizon, except in the boreholes Międzyzdroje 5 and Świnoujście 1 where numerous aeolian layers occur that are separated by fluvial deposits, as seen in the K5 profile (Lindert *et al*., 1993) where the thickest aeolian layer is about 100 m thick.

The development of these extensive aeolian sandstone deposits is here interpreted as reflecting a unique and rapid palaeoclimatic shift to extremely arid conditions, allowing for long-range dune migration. During the deposition of the Ae cycle, aeolian sands migrated northward across the central playa of the PRB and covered a vast area along its margin, here referred to as the “Northern Erg” (Fig. 3c). The source area for aeolian sandstones occurring in the boreholes Resko and Piaski is located to the S of the Piła IG 1 and Września IG 1 boreholes, whilst those occurring in the Stargard Szczeciński area may have been derived from the Banie-Myślibórz High (immediately south of the study area), and those of the Międzyzdroje 5 and possibly Świnoujście 1 profiles from the eastern part of the Mecklenburg-Vorpommern High and the Usedom High. Aeolian sandstones occurring in the K5 borehole were probably derived from the Gryfice Block area. Further to the north, the aeolian and fluvial deposits interfinger in the Rønne Graben (borehole Pernille 1; Vejbæk *et al*., 1994).

LOWER FLUVIAL AND PLAYA-LAKE DEPOSITIONAL CYCLE (P-L II) (FIG. 3d)

The sediments of the Ae cycle are overlain by claystones, mudstones and sandstones that were deposited under lacustrine, playa-lake and fluvial environments, thus reflecting at the onset of the P-L II cycle a rapid return to more humid conditions. During the P-L II cycle, a freshwater lake occupied the northern part of the PRB in which mainly clays were deposited. As in the lower part of these lacustrine deposits (Resko 1 and Resko 3 boreholes) more clays occur than in its upper parts, the more clayey lower sequence presumably represents a period of maximum flooding and bathymetric stability of this lake. In profiles of the P-L II cycle, regular coarsening-upward successions are observed, reflecting the gradual progradation of fluvial plains and sparse fluvial channels into the basin from northern and possibly also western source areas. The occurrence of alternating aeolian and fluvial deposits in the Świna and K5 grabens can be compared to the alternation playa-lake and aeolian sediments in the Piła Sub-Basin (boreholes Świnoujście 1 and Piła IG 1; Fig. 4).

ALLUVIAL AND FLUVIAL DEPOSITIONAL CYCLE (AL II) (FIG. 3e)

Deposits of the AL II cycle consist of conglomeratic alluvial and sandy fluvial fans that advanced from the north into the PRB, filling the Świna, Samlino-Resko, Słowieńsko and Ślepce grabens. This is here interpreted as reflecting a tectonic rejuvenation of the palaeorelief and related erosional processes in source areas, as well as a reactivation of fault systems outlining individual grabens. Systems of partly isolated conglomeratic alluvial fans prograded into these grabens, giving basin-ward way to sand-dominated fluvial fans and possibly also playa deposits. Conglomeratic fans probably developed also on the western slopes of the Mecklenburg-Vorpommern and eastern slopes of Trzebież-Stargard Horst and Graben Complex (Fig. 3e) (Stargard and Prenzlau boreholes; Fig. 5). In the Polish Basin, sediments of the AL II cycle are assigned to the Drawa Fm. (Table 1; Pokorski, 1981) and are likely to equate to the basal parts of the Mirow Fm. in the North German Basin (Schöder *et al*., 1995).

LOWER FLUVIAL AND PLAYA-LAKE DEPOSITIONAL CYCLE (P-L III) (FIG. 3f)

The sediments of this cycle were laid down in depositional continuity with those of the preceding cycle and represent the topmost member of the Polish Drawa Fm. that equates to the upper part of the Mirow Fm. of the North German Basin. Deposits of the P-L III cycle are only preserved in areas of highest subsidence rates, such as the Samlino-Resko Graben and the axial zone of the Czaplinek Sub-Basin. Originally, they extended over a somewhat larger area but were eroded at the onset of the subsequent AL III cycle (e.g. on Czaplinek Tectonic Step, Fig. 4). Sediments of the P-L III cycle consist of fluvial sandstones and fine-grained conglomerates with mudstone intercalations, and of lacustrine mudstones in local depocentres. The source of these clastics was probably located to the N and NE, as indicated by the prevalence of lithic clasts (Maliszewska and Pokorski, 1986). This increase in clastic supply to the PRB is interpreted as heralding the progradational cycle that culminated in conglomeratic sedimentation during the subsequent AL III depositional cycle. This contradicts the view that the Noteć cycle (*sensu* Pokorski, 1981) commenced with conglomerates in the central part of the basin (Czaplinek IG 2 borehole).

ALLUVIAL AND FLUVIAL DEPOSITIONAL CYCLE (AL III) (FIG. 3g)

Deposits of this cycle are very widespread in the Polish Basin where they form the basal part of the Noteć Fm. that is equivalent to the lower part of the Dethlingen Fm. of the North German Basin (Table 1). During this cycle progradation of fluvial systems reached a peak and spread over almost the entire PRB. Following erosion of older deposits across such actively rising fault blocks as the Moracz High and the Czaplinek Tectonic Step, these were progressively onlapped and overstepped by the AL III conglomerates (Figs. 4 and 5). Whereas in the northern part of the basin the cycle consists predominantly of alluvial fan deposits, alluvial plain facies, periodically dominated by fluvial facies, prevail in its southern parts. Only in the southernmost parts of the basin, in the area to the south of the Golce 1 borehole, may the conglomeratic/sandy AL III deposits give way to sandstones. In the Czaplinek IG 1 profile, a gradual upward transition from coarse-grained (conglomeratic) alluvial fan deposits to finer fluvial deposits is observed (Fig. 4). Here, the conglomerate components consist of Devonian and Carboniferous carbonates and siliciclastic rocks. As this applies also to the boreholes Czaplinek IG 2 and Golce 1, the bulk of these conglomerates were derived from source areas located to the E and NE.

The widespread extent of the AL III deposits points to the development of an ever-expanding alluvial plain with a fairly smooth palaeorelief, and to the coalescence of the Czaplinek and Piła sub-basins. The vast area covered by sediments of this cycle reflects long-lasting erosion of source areas located to the N (West Pomerania Upland) NE and SW. At the end of the cycle, the Polish and North German parts of the Upper Rotliegend Basin were still partly separated by the vast area of palaeohigh (Fig. 3g). Deposits associated with this depositional event are represented in the eastern part of the North German Basin by the conglomerates and sandstones of the lowermost part of the Dethlingen Fm. (Schöder *et al*., 1995; Table 1).

UPPER FLUVIAL AND PLAYA-LAKE DEPOSITIONAL CYCLE (P-L IV) (FIG. 3h)

Deposits of this cycle form the middle part of the Noteć Fm. of the PRB and are essentially equivalent to the upper parts of the Dethlingen and the basal parts of the Hannover formations of the North German Basin. Although clastic influx into the PRB, mainly from northern sources, gradually abated during this depositional cycle, basin margins and intra-basinal highs (e.g. Moracz High) were slowly overstepped whilst subsidence of the Czaplinek Sub-Basin increased. At the same time activity along basin and block bounding faults decreased (Figs. 4 and 5). In the northern parts of the basin, thin alluvial conglomerates were deposited that pass southward into fluvial sandstones and mudstones which attain in the Piaski region a maximum thickness of 30 m. These small thicknesses reflect insignificant subsidence rates for this area, preventing fluvial aggradation. Correspondingly, sediments preserved in the northern, marginal parts of the basin represent multiple stages of fluvial transfer from the N to the S. To the S of the Piaski Horst, increasing subsidence rates accounted for a conspicuous thickness increase of P-L IV deposits, as well as their upward and lateral transition to playa-lake facies. In the center of the Czaplinek Sub-Basin, these deposits attain thicknesses of more than 280 m and consist of cyclically alternating fluvial sands and playa-lake clays, as evident in the Resko-Czaplinek region (Fig. 4). In the Piła IG 1 and Czaplinek IG 2 boreholes, fluvial P-L IV deposits contain thin aeolian sandstone intercalations, suggesting that by this time the Czaplinek and Piła sub-basins had amalgamated. By the end of the P-L IV cycle, the Trzebież-Stargard area had been largely overstepped, thus providing for a broad connection between the Polish and North German basins (Fig. 3h).

UPPER PLAYA-LAKE AND FLUVIAL DEPOSITIONAL CYCLE (P-L V) (FIG. 3i)

This cycle represents the terminal Upper Rotliegend deposition and is capped by the marine basal Zechstein Copper Shale. It corresponds to the top part of the Polish Noteć and the North German Hannover formations (Table 1). Sediments of the cycle occur throughout the PRB and are mostly represented by playa-lake and fluvial deposits, with the latter occurring along its northern margin and having a wider distribution in its NE marginal parts. During the cycle, the PRB subsided regionally in response to lithospheric cooling and contraction with no evidence for further reactivation of its fault systems (Figs. 4 and 5). At the same time, clastic supply to the basin, mainly from N and NE sources diminished. This accounted for the development and wide lateral extent of a playa-lake that was connected to the North German Basin. In the Polish Basin, the P-L V deposits consist of muddy sediments containing sandy intercalations and of cyclically alternating fine-grained sandstones and mudstones. Sedimentary cycles, observed in the most complete profiles (boreholes Resko 1, Resko 3, Czaplinek IG 1, Czaplinek IG 2, Golce 1, Piła IG 1) show recurrent stages of high/low rates of accommodation space development, causing fluctuations in the development of fluvial depositional system, as evidenced by fining-upward, coarsening-upward and symmetrical cycles. Analysis of these cycles in terms of their occurrence, succession and variability documents the migration of depocenters in space and time during the deposition of the playa-lake complex. In the uppermost part of Czaplinek IG 1 and Czaplinek IG 2 boreholes, brecciated levels are attributed to the growth and dissolution of salt crystals. The lack of desiccation cracks speaks, however, for the persistence of the P-L V cycle playa-lake.

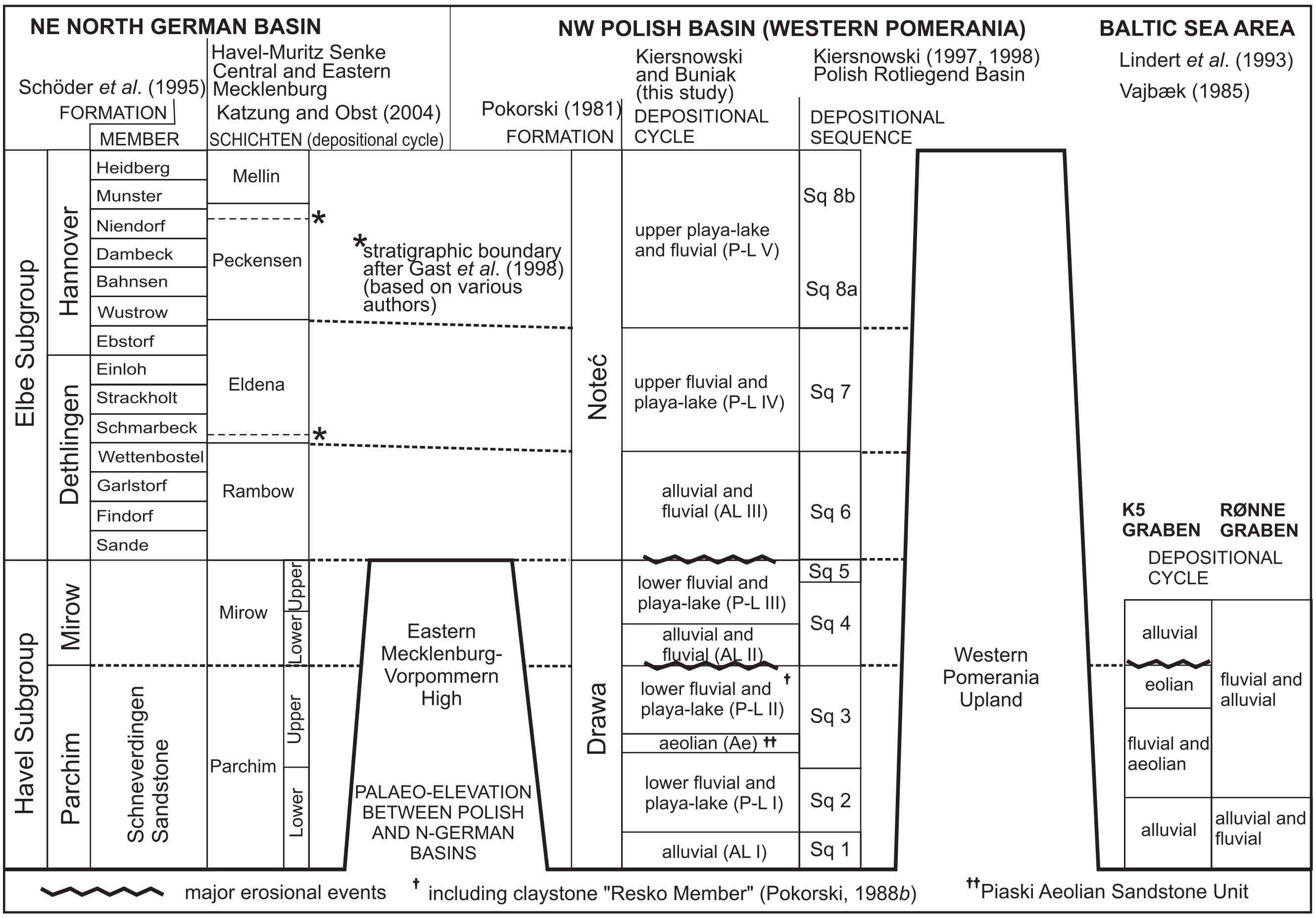
Towards the end of the Rotliegend sedimentation and prior to the transgression of the Zechstein Sea, playa deposits reached far to the north, almost to the depositional limit of Rotliegend sediments. This can be attributed to the regional thermal subsidence of the basin, a related relative rise in erosional base level and a reduction of clastic influx (Plumhoff, 1966; Rieke *et al*., 2001). Rieke *et al*. (2001) claimed that the dominance of more fine-grained deposits (the so-called "phase III" in the southern Rügen), observed in the northeastern part of the Mecklenburg-Vorpommern palaeohigh, resulted from the fact that this formerly isolated region was tilted towards the SW. This tilting was caused by the thermal subsidence of the central part of the North German Basin. Thus, during uppermost Havel and Elbe Subgroup times, the northern margin of the northeastern German basin formed. If this were so, then development of the uppermost playa-lake deposits would probably reflect one of the longest depositional periods in the development of the entire Southern Permian Basin.

ROTLIEGEND IN WESTERN POMERANIA AND EASTERN MECKLENBURG-VORPOMMERN — INTERPRETATION AND DISCUSSION

Rotliegend depositional cycles recognized in the Polish Basin appear to correlate with similar cycles in the North German Basin, as summarized in Table 1 (Gebhardt *et al*., 1991; Helmuth and Süssmuth, 1993; Rieke *et al*., 2001; 2003; Katzung and Obst, 2004). In the studied NW part of the PRB, the lower part of the Drawa Fm. (cycles AL I to P-L II) was deposited in a system of tectonically active grabens, comparable to the time-equivalent Parchim Fm. in Northern Germany

Table 1

Upper Permian (Rotliegend) stratigraphy of the NW Polish Basin (Western Pomerania), NE North German Basin and the Baltic Sea area



NE NORTH GERMAN BASIN						NW POLISH BASIN (WESTERN POMERANIA)				BALTIC SEA AREA	
Schöder *et al.* (1995) FORMATION		MEMBER	Havel-Muritz Senke Central and Eastern Mecklenburg Katzung and Obst (2004) SCHICHTEN (depositional cycle)			Pokorski (1981) FORMATION	Kiersnowski and Buniak (this study) DEPOSITIONAL CYCLE	Kiersnowski (1997, 1998) Polish Rotliegend Basin DEPOSITIONAL SEQUENCE		Lindert *et al.* (1993) Vajbæk (1985) K5 GRABEN DEPOSITIONAL CYCLE	RØNNE GRABEN
Elbe Subgroup	Hannover	Heidberg	Mellin		*stratigraphic boundary after Gast *et al.* (1998) (based on various authors)	Noteć	upper playa-lake and fluvial (P-L V)	Sq 8b	Western Pomerania Upland		
		Munster									
		Niendorf	* Peckensen								
		Dambeck									
		Bahnsen						Sq 8a			
		Wustrow									
		Ebstorf	Eldena				upper fluvial and playa-lake (P-L IV)	Sq 7			
	Dethlingen	Einloh									
		Strackholt									
		Schmarbeck	*								
		Wettenbostel	Rambow				alluvial and fluvial (AL III)	Sq 6			
		Garlstorf									
		Findorf									
		Sande					∿				
Havel Subgroup	Mirow		Mirow	Upper	Eastern Mecklenburg-Vorpommern High	Drawa		Sq 5			
							lower fluvial and playa-lake (P-L III)	Sq 4		alluvial	fluvial and alluvial
				Lower			alluvial and fluvial (AL II) ∿			∿	
	Parchim	Schneverdingen Sandstone	Parchim	Upper			lower fluvial and playa-lake (P-L II) †	Sq 3		eolian	
							aeolian (Ae) ††			fluvial and aeolian	
				Lower	PALAEO-ELEVATION BETWEEN POLISH AND N-GERMAN BASINS		lower fluvial and playa-lake (P-L I)	Sq 2			
							alluvial (AL I)	Sq 1		alluvial	alluvial and fluvial

∿ major erosional events † including claystone "Resko Member" (Pokorski, 1988*b*) ††Piaski Aeolian Sandstone Unit

(Gebhardt *et al.*, 1991; Rieke *et al.*, 2003). During the deposition of the upper part of the Drawa Fm. (cycles AL II, P-L III), the area of sedimentation expanded while fault activity persisted intermittently, as also seen during the deposition of the Mirow Fm. in Northern Germany (Gebhardt *et al.*, 1991; Schöder *et al.*, 1995). Deposits of the Noteć Fm. (cycles AL III to P-L V) reflect rapid broadening of the basin in response to cooling and contraction of the lithosphere with fault activity ending during cycle P-L IV. The cycles AL III and P-L IV correspond in the North German Basin to the Rambow and Eldena series that also reflect rapid basin subsidence (Schöder *et al.*, 1995). The cycle P-L V equates in the North German Basin to the Peckensen and Mellin Beds during the deposition of which this basin expanded significantly (Gebhardt *et al.*, 1991).

The Rotliegend sediments of the Rønne and K5-Gryfice grabens (Vejbæk *et al.*, 1994) are here thought to be equivalents of the Drawa Fm. rather than the Noteć Fm., as postulated by Hoffmann *et al.* (1997) and Pokorski (1998*b*). As such, these basins form an integral part of the graben system that began to subside at the transition from the Early to the Late Permian in the area of the TESZ in response to last pulses of wrench-deformation along the sinistral TTZ and SFTZ (Dadlez, 1990, 2000). Pokorski (1998b) claimed that infilling of the K5 Trough with aeolian deposits was time equivalent with the deposition of the Noteć Fm. We argue, however, that these troughs were formed during the early tectonic reorganization stages of the large TESZ area. Sediments infilling these troughs (alluvial/fluvial in the northern part and fluvial/aeolian in the southern part) were deposited during recurrent stages of tectonic subsidence. Aeolian deposits were formed during several stages and their occurrence is associated with period of maximum aeolian development during the deposition of the lower part of the Upper Rotliegend.

Inferred ranges of sediments representing successive formations of the Upper Rotliegend (Upper Rotliegend II) in northeastern Mecklenburg (Germany) depend on the assumed scheme of main tectonic fault zones controlling sedimentation, as well as on the assumed lithostratigraphic correlation concept (Hoffmann, 1990; Rieke *et al.*, 2001, 2003; Katzung and Obst, 2004). Moreover, the concept of stratigraphic correlation between the Polish Basin and the NE North German Basin depends on criteria on which the lithostratigraphic subdivisions are based (Pokorski 1988*a*; Schneider and Gebhardt, 1993; Hoffmann *et al.*, 1997). According to Pokorski (1981, and his co-workers), one can distinguish in the PRB two conspicuous diastrophic-sedimentary cycles corresponding to the Drawa and Noteć formations. Additionally, Pokorski (1981, 1988*a*) distinguished lithostratigraphic members, including the Resko

Mb., representing a characteristic claystone complex in the Resko 1 borehole (Table 1). However, this author abandoned distinguishing these members in his late papers (Pokorski, 1990). Later, Pokorski (1998*a*), modified his stratigraphic subdivision, introducing new, informal lithostratigraphic units based on depositional sequences, distinguished earlier by Kiersnowski (1997, 1998). Furthermore, Pokorski advanced both Drawa and Noteć formations to the rank of subgroups. These changes were aimed at unification with the changes introduced to the Rotliegend stratigraphy of the North German Basin (Hoffmann *et al*., 1997; Schöder *et al*., 1995). Another lithostratigraphic subdivision, introduced for the PRB by Karnkowski (1981, 1987), is not discussed here, as it cannot be compared to the NE North German Basin stratigraphy. The latter is based on depositional cyclicity, in which the beginning of every individual sedimentary cycle (irrespectively of its origin) is well defined (Helmuth and Süssmuth, 1993).

On the flanks of the large NW–SE oriented Mecklenburg-Vorpommern High the occurrence of **Parchim Formation** deposits is spotty according to German authors (Hoffmann, 1990; Rieke *et al*., 2003; Katzung and Obst, 2004). On the Mecklenburg-Vorpommern High, isolated remnants of Parchim deposits have been encountered that are interpreted as the fill of palaeovalleys (Lindert *et al*., 1990; Hoffmann, 1990; Rieke *et al*., 2003) through which clastics were transported southward into the depocentre of the North German Basin. In the latter, Parchim deposits attain thicknesses of over 600 m (Schwerin 1 borehole; Schöder *et al*., 1995). By contrast, to the NE of the Mecklenburg-Vorpommern High, Parchim and older deposits (Müritz Subgroup) are 500–600 m thick in the elongated Strelasund Trough (Hoffman *et al*., 1997). This trough, which parallels the Mecklenburg-Vorpommern High, is bounded to the NE by the Sudrügen High and finds its on-trend prolongation in the Świna Graben of Poland. Parchim equivalent deposits attain thicknesses of over 370 m in the Czaplinek Sub-Basin of Poland and over 400 m in the K5 Graben.

During the deposition of the **Mirow Formation**, the Mecklenburg-Vorpommern High and its extension into Poland were devoid of a stable sedimentary cover and acted as a clastic source area (Katzung and Obst, 2004). However, the SW margin of this palaeohigh was progressively overstepped during the deposition of the Mirow Fm. (see Fig. 5, boreholes Prenzlau and Penkun; Gast *et al*., 1998; Schöder *et al*., 1995). Deposits of this formation attain maximum thicknesses of 450 m in the North German Basin (borehole Schwerin 1; Schöder *et al*., 1995), and 200 m in the Czaplinek Sub-Basin of Poland (borehole Czaplinek IG 2; Fig. 5) but appear to be missing in the Strelasund Trough (Rieke *et al*., 2003). Whether the topmost 43 m thick conglomerates occurring in the K5 Graben equate to the Mirow Fm. is uncertain.

Correlations between the Rotliegend deposits of the North German and Polish basins are based on the results of the boreholes Mirow 1, Wesenberg 1, Feldberg 1, Prenzlau 1 and Penkun 1 in Germany (Schöder *et al*., 1995; Gast *et al*., 1998) and Stargard 1 in Poland (see Figs. 2 and 5B). However, as the Stargard 1 borehole cannot be unequivocally correlated with the most important Rotliegend profiles of the PRB, major uncertainties remain, with the correlation presented here being only one of several options. Therefore, comparative analyses of the depositional development of both basins in terms of tectonic and palaeoclimatic controls are of crucial importance (Kiersnowski, 1998; Karnkowski, 1999). Deposits attributed to the Mirow Fm. are in the Prenzlau 1 borehole 80 m thick, whilst in the Stargard 1 borehole deposits regarded as Mirow Fm. equivalents, are only 20 m thick (Fig. 5). The question, whether these deposits formed a continuous sedimentary cover, has not been answered as yet. During the deposition of the Mirow Fm., the North German and Polish Basins were in all likelihood still separated by the Mecklenburg-Vorpommern-Trzebież-Stargard palaeohighs, as shown in Figures 3e and f. According to published stratigraphic correlations, the Mirow Fm. deposits reach as far as east of the Prenzlau borehole location (Gast *et al*., 1998; Schöder *et al*., 1995) and probably to the Penkun borehole location. In the light of analyses presented herein, and a comparison with the Friedland 1 borehole profile, the occurrence of these deposits in the lowermost part of the Rotliegend in the Pasewalk 2 borehole is unlikely. These deposits may represent an equivalent of lower or middle part of the Rambow Beds (Table 1). In the North German Basin, the Dethlingen Fm. broadly overstepped the depositional limits of the Mirow Fm. Its distribution is limited to the NE by the Strelasund Tectonic Zone (Hoffmann *et al*., 1997) that is considered to form the axis of the Strelasund Trough (Rieke *et al*., 2001). Whereas Gebhardt *et al*. (1991) proposed that the Dethlingen Fm. extends eastward into the Polish Basin, Rieke *et al*. (2003) claimed that it does not reach beyond the German-Polish border zone. In our palaeogeographic reconstruction (Fig. 3g), we show a zone of palaeohighs, associated with the Kamień-Stargard Fault Zone that may have formed an effective barrier separating the North German and Polish basins, particularly in palaeohydrological terms.

The **Dethlingen Formation** attains a thickness of 675 m in the northern part of the North German Basin (borehole Schleswig Z1; Schöder *et al*., 1995), and its counterpart in the PRB almost 400 m (Czaplinek IG 2). However, as the boundary between the Dethlingen and Hannover formations has not yet been established in the PRB, the thickness quoted for the borehole Czaplinek IG 2 must be considered as tentative.

During the deposition of the **Hannover Formation**, the Rotliegend basins of Northern Germany and Poland attained their maximum extent and became widely connected (Fig. 3h and i). Nevertheless, the northern depositional limit of the Hannover Fm. overstepped only marginally that of the Dethlingen Fm. in the area of the Strelasund Fault Zone. The Hannover Fm. attains in the northern part of the North German Basin a thickness of almost 700 metres (borehole Schleswig Z1; Schöder *et al*., 1995), and some 300 m in the Polish Basin (Czaplinek IG 2). Deposits of the Hannover Fm. show genetic similarities in both basins, with the only difference being the absence of a typical saline facies in the Polish Basin, though numerous sediment deformation levels were observed in the upper parts of the boreholes Czaplinek IG 1 and IG 2 that can be attributed to the growth and dissolution of halite crystals.

It is still an open question whether Rotliegend formation boundaries and palaeoenvironments (including their palaeoclimatic interpretation) distinguished in the North German Basin find indeed their counterparts in the Polish Basin (Table 1). This pertains particularly to the Parchim-Mirow and

Drawa successions. For instance, the maximum northward expansion of aeolian sandstones in the North German Basin (Rieke *et al*., 2003) appears to correlate with the period of maximum sandy desert development in the PRB. The aeolian Schneverdingen Sandstone (Drong *et al*., 1982) of the Parchim Fm. that was generally deposited in grabens (Gast, 1988) is time-equivalent with the Ae cycle of maximum aeolian sediment expansion of in the SE part of the PRB where they attain thicknesses of 500–600 m in the Poznań Trough (Kiersnowski, 1997, 1998). However, so far no aeolian sandstones have been reported from the Parchim or Mirow formations in the NE part of the North German Basin (McCann, 1998; McCann *et al.* 2000). Similarly, the increase in fluvial and aeolian sandstones in the Wustrow Member (lower Hannover Fm.) of the North German Basin (Gast *et al*., 1998) appears to correlate with a rapid increase in fluvial and possibly also aeolian sandstones at the transition from cycle P-L IV to P-L V in the central parts of the Polish Basin.

Furthermore, there are differences in the structural configuration and possibly also the tectonic evolution of the North German and Polish Basins. Although is was recently accepted that the tectonic evolution of both basins was rather similar in terms of main tectonic events (Gebhardt *et al*., 1991; Plein, 1993; Hoffmann *et al*., 1997; Schneider and Gebhardt, 1993; Pokorski 1988*a*, *b*), faulting may have played a more important role in the evolution of the Polish Basin that is superimposed on the TESZ and the TTZ–STZ, at the NW termination of which the Oslo Rift opened during latest Carboniferous and Early Permian times (Neumann *et al*., 2004).

DISCUSSION AND CONCLUSIONS

Our review of the evolution of the Polish Upper Rotliegend Basin attempts to document that syn-depositional faulting exerted a conspicuous control on the facies development of the Rotliegend deposits and their characteristic multi-stage development, particularly during the accumulation of the Drawa and lower parts of the Noteć formations. Moreover, our studies show that the northern margin of the PRB is very irregular and reflects the complex tectonic structure of its pre-Permian basement, contrary to the interpretation by Pokorski (1990). In previous studies, little heed was given to the fact that the PRB was repeatedly supplied with a large amount of sediments derived from an area located to its N, here referred to as the Western Pomeranian Upland (Fig. 3). In this area deep erosion affected not only the pre-Permian basement but also earlier deposited Rotliegend sediments. Thus, the present northern limit of the Rotliegend deposits does not represent their primary depositional limit that periodically extended further. A similar view was expressed by Dadlez (1990) in his tectonic analysis of the of the SW Baltic area. In this area, coarse-grained sediments contained in numerous, poorly defined tectonic troughs may represent the youngest Rotliegend successions, though it cannot be excluded that they may be considerably older, as in the case of the K5 Graben (Table 1). It is uncertain how far south the Rotliegend deposits of the K5 Graben extend and whether they were connected with those of the the Słowieńsko Graben (Fig. 2).

The revised Upper Rotliegend isopach map presented in Figure 2 clearly reflects the structure of the pre-Permian basement and the relationship between basement fault zones and rapid lateral Rotliegend thickness changes. Previously published palaeogeographic and isopach maps were based on partly different reconstructions of the structural configuration of the basement (see maps by Pokorski 1988*b*, 1990, 1998*b*). For example, the orientation of the much quoted Słowieńsko-Ślepce-Daszewo grabens, erroneously interpreted as a fluvial palaeo-channel (Pokorski, 1990), could not be confirmed. Although the isopach map presented in Figure 2 is based on all accessible boreholes, thickness values given for large parts of the studied area must be considered as tentative owing to limited borehole control. Nevertheless, the general division of the basin into a northern shallower and the southern deeper part is well founded and conspicuous. Generally, the northern part of the PRB is characterized by an array of horst and grabens and sharp lateral thickness changes of Rotliegend deposits, reflecting the tectonic mobility of the different basement blocks. Moreover, there is evidence for repeated erosion, sediment by-pass and deposition of generally thin Rotliegend series on horsts (Fig. 5). Although the structural configuration of the pre-Permian basement beneath the Rotliegend depocentres of the southern parts of the basin is poorly controlled, it may be as complex as in its northern, shallower parts.

Considering the entire PRB, it is evident that during the deposition of the Drawa Fm. fluvial and lacustrine environments dominated its northern parts whilst aeolian and playa lake environments dominated in the south. This points towards the presence of an extensive drainage system in areas to the N and NE of the basin that is consistent with their multi-stage erosion. Apparently, considerable wetter climatic conditions dominated sedimentary processes in the northern parts of the basin than in its southern parts. In the southern parts of the basin, aeolian conditions were episodically interrupted by fluvial regime (Kiersnowski, 1997), whereas in its northern parts predominant fluvial and lacustrine conditions were interrupted by conspicuous aeolian episodes, such as the Piaski episode (Ae cycle; Fig. 3c). Earlier analyses (Kiersnowski, 1997, 1998) show that aeolian sequences are interrupted by a number of erosional/non-depositional hiatuses. These can be related to wetter periods, corresponding to fluvial/lacustrine sedimentation in the north and cyclic changes of the spatial extension of the central playa lake. In this paper, we emphasize the occurrence of aeolian deposits in the northern part of the PRB, an aspect that was generally neglected by previous authors. During periodical low humidity stages, aeolian sheet sandstones extended from the southern parts of the basin as far N as the Międzyzdroje area, where they may form potential gas reservoirs.

In the PRB, the distribution of lithofacies in time and space manifests the recurrent appearance of fluvial and aeolian environments and, as such, resembles the sedimentary evolution of Permian and Jurassic basins in USA (Mountney and Jagger, 2004; Clemmensen *et al*., 1989), as well as of the Upper Rotliegend Group in the UK sector of the southern North Sea, from which similar alternations of playa and aeolian depositional systems have been reported (Sweet, 1999). An understanding of the mutual interaction between these two depositional systems is of key importance for explaining the significance and interplay between syn-sedimentary tectonic subsidence and palaeoclimatic conditions.

In the area of the PRB differential motions of basement blocks controlled the subsidence pattern of individual troughs, the relative stability and even uplift of horsts, until regional thermal subsidence of the entire basin became dominant during the later parts of the Noteć Fm. time. The tectonic Adler-Kamień-Stargard Zone (probably a transpressional strike-slip zone) apparently played a crucial role in terms of differences in the development of the Polish and North German Rotliegend basins. The Trzebiatów Fault Zone, similar to the Adler-Kamień-Stargard Fault Zone, was activated during the Early Permian by strike-slip movements, giving rise to transtensional and transpressional deformations, and remained intermittently active during the earlier parts of the Upper Rotliegend deposition. Its activity, coupled with strike-slip movements along the Laska-Piaski Fault (Fig. 2), may be responsible for the development of Ślepce and Samlino-Resko grabens. These are probably transtensional features separated by a system of horsts along Trzebiatów Fault Zone (Trzebusz-Gorzysław-Petrykozy horsts passing to SE into Sławoborze-Ciechnowo Horst — region of Sławoborze and Ciechnowo boreholes; Figs. 2 and 5). During deposition of the of Rotliegend series, tectonically-controlled depressions paralleling the Trzebiatów Fault Zone played and important role in the development a N–S directed fluvial drainage system through which clastics were supplied to the Czaplinek depocentre from northern sources.

Wrench tectonics is most probably responsible also for the development of the Czaplinek Sub-Basin forming the main depocentre in the study area. During the accumulation of the lower Upper Rotliegend, syn-depositional faulting controlled its subsidence, as evidenced for instance along the margins of the Piaski Horst and Golce High (Fig. 4). Correspondingly, this sub-basin may be interpreted as a large pull-apart structure that remained active during the earlier stages of Rotliegend deposition before it began to subside regionally during the accumulation of the upper parts of the Rotliegend series (Fig. 2 and 4). On the regional structural cross-section, given in Figure 4, the Resko and Czaplinek tectonic steps are shown in the area of the Czaplinek Sub-Basin. In our view, these steps influenced Rotliegend sedimentation particularly during the earliest stages of basin development. Moreover, they may represent marginal elements of the pull-apart system that embraced the entire Czaplinek Sub-Basin that is bounded to the NE by an extension of the Trzebiatów Fault Zone and to the SW by the fault delimiting the Golce High to the north. Similar to the Czaplinek Sub-Basin, also the Piła Sub-Basin is interpreted as having evolved as a pull-apart structure during the deposition of the earlier part of the Upper Rotliegend.

During early evolutionary stages of the PRB, tectonic reactivation of the NE segment of the TEF played more important role than was hitherto believed. Tectonic movements of individual blocks located along the TEF allowed for the deposition of reduced or stratigraphically condensed Rotliegend sequences only.

The mid-basinal Golce High and the Czaplinek Tectonic Step were periodically uplifted and eroded and were delivering sediments to the adjacent depocentres (Fig. 4). This contradicts the model of Pokorski (1998*b*), according to which the Czaplinek-Piła part of the basin underwent continuous subsidence during the deposition of the Upper Rotliegend series.

It is proposed here that the Rønne and K5-Gryfice grabens, located to the SW and S of Borholm (Figs. 1 and 2), were activated at the same time as the grabens of the northern part of PRB during the deposition of the lower parts of the Drawa Fm. Sediments contained in these grabens span, according to our interpretation, much of this formation (Table 1) and do not equate to the Noteć Fm., as proposed by Pokorski (1998*a*). The aeolian sandstones in the K5 Graben reflect episodes of maximum northward aeolian facies expansion during the deposition of the Parchim-lower Drawa formations.

Conspicuous temporal correlations between the Rotliegend deposits of the NW parts of the Polish Basin and the NE parts of the North German Basin suggest synchronous reactivation of fault systems controlling the main stages of their evolution, as well as the onset of their regional thermal subsidence. The climate-controlled cyclicity of Rotliegend deposits requires further research on a basin-wide scale.

In summary, our analysis supports the view that in the Polish Basin, deposition of the Upper Rotliegend series was initially confined to tectonic troughs that developed under a transtensional stress field. Only during the later stages of the Rotliegend, when fault activity had decreased and ultimately ceased, were the margins of these troughs permanently over-stepped and the basin widened out in response to its thermal subsidence. In this respect, the evolution of the Polish Basin shows great similarities to that of the North German Rotliegend Basin (Gast, 1988; Gebhardt *et al*., 1991; Hoffmann *et al*., 1997).

The tectonic framework of the NW parts of the Polish Rotliegend Basin, as well as major thickness changes across faults, as outlined in Figure 2, show that syn-depositional reactivation of pre-existing fault systems played an important role, particularly during the early development stages of this basin. Underlying diastrophic events, involving the development of a composite system of faults and tectonic reactivation zones, are not yet fully understood. Nevertheless, they appear to reflect last pulses of the post-Variscan tectonic reorganization that, in time, gave way to thermal relaxation of the lithosphere as the dominant subsidence mechanism of the Late Permian and Mesozoic Polish Basin (Dadlez *et al*., 1995; Van Wees *et al*, 2000).

Acknowledgments. The authors thank the Polish Gas and Oil Company (PGNiG S.A., Piła Branch) for granting access to core material and wire-line logs of selected boreholes. We thank Dr. A. Protas for granting us access to the results of joint Polish-East Germany research on the Permian System and Dr. S. Lech for sharing with us information on the geological structure of the pre-Permian basement of West Pomerania. We appreciated discussions with and comments by E. Iwanowska (PGNiG S.A., Warsaw) concerning the tectonic evolution of the northern Polish Rotliegend Basin. We thank Dr. B. Kluge of EEG Berlin and Drs. P. Hoth and H. Rempel of the BGR Berlin for granting us access to borehole profiles from eastern Mecklenburg and wire-line logs of the K5 borehole. We also thank Dr. N. Hoffmann of the BGR Berlin for his inspiring discussion on the Rotliegend profiles of eastern

Mecklenburg and the tectonics of the Rügen and Baltic area. Our special gratitude goes to M. Geisler and Prof. dr. Ch. Breitkreuz of the TU Freiberg and Dr. J. Kopp of the Geological Survey of Brandenburg for discussions and granting us access to Rotliegend cores of a number of boreholes from the eastern part of Germany.

Finally we acknowledge the detailed review and editorial efforts of Prof. P. A. Ziegler that substantially improved the paper.

REFERENCES

ANTONOWICZ L., IWANOWSKA E., JAMROZIK J. and NOWICKA A. (1993) — Tilted block (half grabens) of the Permian basement in NW Poland — implications for hydrocarbon exploration (in Polish with English summary). Prz. Geol., **41** (2): 71–74.

ANTONOWICZ L., IWANOWSKA E. and RENDAK A. (1994) — Tensional tectonics in the Pomeranian section of the T-T Zone and the implictions for hydrocarbon exploration. Geol. Quart., **38** (2): 289–306.

CLEMMENSEN L. B., OLSEN H. and BLAKEY R. C. (1989) — Erg-margin deposits in the Lower Jurassic Moenave Formation and Wingate Sandstone, southern Utah. Geol. Soc. Am. Bull., **101**: 759–773.

CONRAD W. (2001) — Eine gravimetrisch-magnetische Diskussion des regionalen Tiefenbaus zwischen Ostsee und Lausitz. Die deutsch-polonische Kooperation zwischen 1975 und 1990 auf den Gebieten Gravimetric und Magnetik ergänzt durch eine gravimetrisch-tomografische Neubewertung ihrer Aussagen zum regionalen geologischen Bau. Z. geol. Wiss., Berlin **29** (2): 169–192.

DADLEZ R. (1974*a*) — Tectonic position of Western Pomerania (Northwestern Poland) prior to the Upper Permian (in Polish with English summary). Biul. Inst. Geol., **274**: 49–87.

DADLEZ R. (1974*b*) — Some geological problems of the Southern Baltic Basin. Acta Geol. Pol., **24** (1): 261–276.

DADLEZ R. (1978) — Sub-Permian rock complexes in the Koszalin-Chojnice zone (in Polish with English summary). Geol. Quart., **22** (2): 269–301.

DADLEZ R. (1990) — Tectonics of the Southern Baltic (in Polish with English summary). Geol. Quart., **34** (1): 1–20.

DADLEZ R. (1995) — Tectonic sketch map. Plate III. In: Geological Atlas of the Southern Baltic. (eds. R. Dadlez, J. E. Mojski, B. Słowańska, S. Uścinowicz and J. Zachowicz). Państw. Inst. Geol. Sopot-Warszawa.

DADLEZ R. (2000) — Pomeranian Caledonides (NW Poland), fifty year of controversies: a review and a new concept. Geol. Quart., **44** (3): 221–236.

DADLEZ R., NARKIEWICZ M., POKORSKI J. and WAGNER R. (1998) — Subsidence history and tectonic controls on the Late Permian and Mesozoic development of the Mid-Polish Trough (in Polish with English summary). In: Sedimentary Basins Analysis of the Polish Lowlands (ed. M. Narkiewicz). Pr. Państw. Inst. Geol., **165:** 47–56.

DADLEZ R., NARKIEWICZ M., STEPHENSON R. A., VISSER M. T. M., and VAN VEES J.-D. (1995) — Tectonic evolution of the Mid-Polish Trough, modelling implications and significance for central European geology. Tectonophysics, **252** (1–4): 179–195.

DADLEZ R. and POKORSKI J. (1995) — Devonian and Carboniferous. Plate VI. In: Geological Atlas of the Southern Baltic. (eds. R. Dadlez, J. E. Mojski, B. Słowańska, S. Uścinowicz and J. Zachowicz). Państw. Inst. Geol. Sopot-Warszawa.

DRONG H-J., PLEIN E., SANNEMANN D., SCHUEPBACH M. A. and ZIMDARS J. (1982) — Der Schneverdingen-Sandstein des Rotliegenden – eine äolische Sedimentfüllung alter Grabenstrukturen. Z. Dt. Geol. Ges. **133**: 699–725.

FRANKE D. (1990) — Der präpermische Untergrund der Mitteleuropälschen Trough – Fakten und Hypothesen. In. Geologie und Kohlenwasserstoff-Erkundung im Präzechstein der DDR, Nordostdeutsche Trough. Niedersächsische Akad. Geowissensch. Veröffentlichungen, **4**: 19–71. Hannover.

GAST R. (1988) — Rifting im Rotliegenden Niedersachsens. Die Geowissensch., **4**: 115–122.

GAST R., PASTERNAK M., PISKE J. and RASCH H.-J. (1998) — Das Rotliegend im nordostdeutschen Raum: Regionale Übersicht, Stratigraphie, Fazies und Diagenese. In: Geowissenschaftliche Ergebnisse der Kohlenwasserstoff-Exploration im Land Brandenburg und im Thüringer Becken in den Jahren 1991–1996 (Zechstein und Rotliegend). (eds. W.-D. Karnin, D. Merkel, J. Piske and S. Schretzenmayer). Geol. Jb., A **149**: 59–79.

GEBHARDT U., SCHNEIDER J. and HOFFMANN N. (1991) — Modelle zur Stratigraphie und Beckenentwicklung im Rotliegenden der Norddeutschen Trough. Geol. Jb., A **127**: 405–427.

GELUK M. (2005) — Regional synthesis of the Permian and Triassic. In: Stratigraphy and tectonics of Permo-Triassic basins in the Netherlands and surrounding areas: 101–136.

HELMUTH H.-J. and SÜSSMUTH S. (1993) — Die lithostratigraphische Gliederung des jüngeren Oberrotliegenden (Oberrotliegendes II) in Nordostdeutschland. In: Perm im Ostteil der Norddeutschen Trough. (eds. E. P. Müller and H. Porth). Geol. Jb., Reihe A **131**: 31–55.

HOFFMANN N. (1990) — Zur paläodynamischen Entwicklung des Präzechsteins in der Nordostdeutschen Trough. In. Geologie und Kohlenwasserstoff-Erkundung im Präzechstein der DDR, Nordostdeutsche Trough. Niedersächsische Akad. Geowissensch. Veröffentlichungen, **4**: 5–17. Hannover.

HOFFMANN N., POKORSKI J., LINDERT W. and BACHMANN H. (1997) — Rotligend stratigraphy, paleogeography and facies in eastern part of the central European Basin. Proc. XIII Int. Congr. On Carboniferous-Permian, Kraków. Pr. Państw. Inst. Geol., **157**: 75–86.

HOFFMANN N., JÖDICKE H., FLUCHE B., JORDING A. and MÜLLER W. (1998) — Modellvorstellungen zur Verbreitung potentieller präwestfalischer Erdgas-Muttergesteine in Norddeutschland — Ergebnisse neuer magnetotellurischer Messungen. Z. Angew. Geol. **44** (3): 140–158.

KARNKOWSKI P. H. (1981) — The current lithostratigraphy subdivision of the Rotliegendes in Poland and proposition of its formalization (in Polish with English summary). Kwart. Geol. **25** (1): 59–66.

KARNKOWSKI P. H. (1987) — Allostratigraphy and lithostratigraphy of the Rotliegend in Poland (in Polish with English summary). Kwart. Geol., **31** (1): 43–56.

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

KARNKOWSKI P. H. (1999) — Origin and evolution of the Polish Rotliegend Basin. Pol. Geol. Inst. Spec. Pap., **3**.

KATZUNG G. and OBST K. (2004) — Perm. Rotliegendes. In: Geologie von Mecklenburg-Vorpommern. (ed. G. Katzung): 98–132. E. Schweizerbart'sche Verlagsbuchhandlung. Stuttgart.

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

KIERSNOWSKI H. (1998) — Depositional architecture of the Rotliegend Basin in Poland (in Polish with English summary). In: Sedimentary Basins Analysis of the Polish Lowlands. (ed. M. Narkiewicz). Pr. Państw. Inst. Geol., **165**: 113–128.

KIERSNOWSKI H., PAUL J., PERYT T. M. and SMITH, D. B. (1995) — Facies, Paleogeography, and sedimentary History of the Southern Permian Basin in Europe. In: The Permian of the Northern Pangea, **2**: Sedimentary Basins and Economic Resources, (eds. P. A. Scholle, T. M. Peryt and D. S. Ulmer-Scholle): 119–136.

KRZYWIEC P. (2006) — Structural inversion of the Pomeranian and Kuiavian segments of the Mid-Polish Trough — lateral variations in timing and structural style. Geol. Quart., **50** (1): 151–167.

KRZYWIEC P., KRAMARSKA R. and ZIENTARA P. (2003) — Strike-slip tectonics within the SW Baltic Sea and its relationship to the inversion Mid-Polish Trough — evidence from high-resolution seismic data. Tectonophysics, **373** (1–4): 93–105.

LINDERT W., WARNCKE D. and STUMM N. (1990) — Probleme der lithostratigraphischen Gliederung des Oberrotliegenden (Saxon) im Norden der DDR. Z. Angew. Geol., **36**: 368–375. Berlin.

LINDERT W., WEGNER H.-U., ZAGORA I. and ZAGORA K. (1993) – Ein neuer Perm-Aufschluß im Seegebiet östlich von Rügen. Geol. Jb., A **131**: 351–360.

MALISZEWSKA A., KIERSNOWSKI H. and JACKOWICZ E. (2003) — Lower Rotliegend volcaniclastic rocks at Wielkopolska (Western Poland) (in Polish with English summary). Pr. Państw. Inst. Geol., **179**: 1–59.

MALISZEWSKA A. and POKORSKI J. (1986) — Mapping of results of petrographic studies on the Rotliegend in western Pomerania (in Polish with English summary). Prz. Geol., **34** (8): 427–436.

McCANN T. (1998) — The Rotliegend of the NE German Basin: background and perspectivity. Petrol. Geosc., **4**: 17–27.

McCANN T., KRAWCZYK C. M. and RIEKE H. (2000) — Integrated Basin Analysis — an Example from the Upper Rotliegend of the NE German Basin. Erdöl Erdgas Kohle, **116** (5): 261–266.

MIŁACZEWSKI L. (1987) — Devonian. In: Geological structure of the Pomerania Swell and its basement (in Polish with English summary). (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 16–21.

MOUNTNEY N. P. and JAGGER A. (2004) — Stratigraphic evolution of an aeolian erg margin system: the Permian Cedar Mesa Sandstone, SE Utah, USA. Sedimentology, **51**: 713–743.

NAWROCKI J. and POPRAWA P. (2006) — . Geol. Quart., **50** (1): 000–000.

NEUMANN E.-R., WILSON M., HEEREMANS M., SPENCER E. A., OBST K., TIMMERMAN M. J. and KIRSTEIN L. (2004) — Carboniferous-Permian rifting and magmatism in southern Scandinavia, the North Sea and northern Germany: a review. In: Permo-Carboniferous Magmatism and Rifting in Europe (eds. M. Wilson, E.-R. Neumann, G. R. Davies, M. J. Timmerman, M. Heeremans and B. T. Larsen). Geol. Soc., London, Spec. Publ., **223**: 11–40.

NIELSEN L. H. and JAPSEN P. (1991) — Deep wells in Denmark 1935–1990. Lithostratigraphic subdivision. Danmarks Geol. Unders. DGU Serie A, **31**.

OBST K., HAMMER J., KATZUNG G. and KORICH D. (2004) — The Mesoproterozoic basement in the southern Baltic Sea: insights from the G 14-1 off-shore borehole. Int. J. Earth Sc. (Geol. Rundsch.) **93**: 1–12.

PLUMHOFF F. (1966) — Marines Ober-Rotliegendes (Perm) im Zentrum des nordwestdeutschen Rotliegend-Beckens. Neue Beweise und Folgerungen. Erdöl und Kohle Erdgas Petrochemie, **10**: 713–720.

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

PODHALAŃSKA T. and MODLIŃSKI Z. (2006) — Facial development and stratigraphy of the Ordovician and Silurian of the Koszalin-Chojnice Zone and the south-western margin of the East European Craton — similarities and differences. Pr. Państw. Inst. Geol. **184** (in press).

POKORSKI J. (1976) — Rotliegend. Darłowo Beds and Miastko Beds (in Polish with English summary). In: Permian and Mesozoic of the Pomerania Trough. (ed. R. Dadlez). Pr. Inst. Geol., **79**: 10–18.

POKORSKI J. (1978) — Rotliegend. In: Lithofacies — paleogeographical atlas of the Permian of platform areas of Poland (in Polish with English summary) (ed. S. Depowski). Inst. Geol. Warszawa.

POKORSKI J. (1981) — Formal lithostratigraphic subdivision proposed for the Rotliegendes of the Polish Lowlands (in Polish with English summary). Kwart. Geol., **25** (1): 41–58.

POKORSKI J. (1987) — Rotliegend. In: Geological structure of the Pomerania Swell and its basement (in Polish with English summary). (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 51–64.

POKORSKI J. (1988*a*) — Rotliegendes lithostratigraphy in north-western Poland. Bull. Pol. Acad. Sc., **36**: 99–108.

POKORSKI J. (1988*b*) — Paleotectonic maps of the Rotliegendes in Poland (in Polish with English summary). Kwart. Geol., **32** (1): 15–31.

POKORSKI J. (1990) — Rotliegendes in the nortwesternmost Pomerania and the adjacent Baltic Basin (in Polish with English summary). Kwart. Geol., **34** (1): 79–92.

POKORSKI J. (1997) — The Lower Permian (Rotliegend) (in Polish with English summary). In: The epicontinental Permian and Mesozoic in Poland (eds. S. Marek and M. Pajchlowa). Pr. Państw. Inst. Geol., **153**: 35–62.

POKORSKI J. (1998*a*) — Prospects of the occurrence of gaseous hydrocarbons in the Rotliegend deposits (in Polish with English summary). In: Sedimentary Basins Analysis of the Polish Lowlands (ed. M. Narkiewicz). Pr. Państw. Inst. Geol., **165**: 293–298.

POKORSKI J. (1998*b*) — Rotliegend. In: Paleogeographical Atlas of the Epicontinental Permian and Mesozoic in Poland. (eds. J. Dadlez. S. Marek and J. Pokorski). Państw. Inst. Geol. Warszawa.

POŻARYSKI W., GROCHOLSKI A., TOMCZYK H., KARNKOWSKI P. and MORYC W. (1992) — The tectonic map of Poland in the Variscan epoch (in Polish with English summary). Prz. Geol., **40** (11): 643–651

RIEKE H., McCANN T., KRAWCZYK C. M. and NEGENDANK J. F. W. (2003) — Evaulation of controlling factors on facies distribution and evolution in an arid continental environment: an example from the NE German Basin. In: Tracing Tectonic Deformations Using the Sedimentary Record. (eds. T. McCann and A. Saintot). Geol. Soc., London, Spec. Publ., **208**: 71–94.

RIEKE H., KOSSOW D., McCANN T. and KRAWCZYK C. (2001) — Tectono-sedimentary evolution of the Northernmost margin of the NE German Basin between Uppermost Carboniferous and Late Permian. Geol. J., **36** (1): 19–37.

ROCH D., GEISLER M., BREITKREUTZ C., HOFFMANN R. and KIERSNOWSKI H. (2005) — Detailed geometric model of the Rotliegend succession in the Southern Permian Basin in NE Germany and NW Poland. Poster and abstract "System Earth and Biosphere Coupling", Conf. Erlangen.

RYKA W. (1978) — Permian volcanic rocks in the Baltic part of the western Pomerania (in Polish with English summary). Kwart. Geol. **22** (4): 753–772.

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

SCHÖDER L., PLEIN E., BACHMANN G. H., GAST R. E., GEBHARDT U., GRAF R., HELMUTH H.-J., PASTERNAK M., PROTH H. and SÜSSMUTH S. (1995) — Stratigraphische Neugliederung des Rotliegend im Norddeutschen Becken. Geol. Jb., Reihe A, **148**: 3–21.

SWEET M. L. (1999) — Interaction between aeolian, fluvial and playa environments in the Permian Upper Rotliegend Group, UK southern North Sea. Sedimentology, **46**: 171–187.

TOMCZYK H. (1987) — Sylurian. In: Geological structure of the Pomerania Swell and its basement (in Polish with English summary). (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 12–16.

WAGNER R. (1987) — Zechstein. In: Geological structure of the Pomerania Swell and its basement (in Polish with English summary). (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 64–81.

WAGNER R., POKORSKI J. and DADLEZ R. (1980) — Paleotectonics of the Permian basin in the Polish Lowlands (in Polish with English summary). Kwart. Geol., **24** (3): 553–569.

VAN WEES J.-D., STEPHENSON R. A., ZIEGLER P. A., BAYER U., McCANN T., DADLEZ R., GAUPP R., NARKIEWICZ M., BITZER F. and SCHECK M. (2000) — On the origin of the Southern Permian basin, Central Europe. Mar. Petrol. Geol., **17**: 43–59.

VEJBKÆK O.V. (1985) — Seismic Stratigraphy and Tectonics of Sedimentary Basins around Bornholm Southern Baltic. Danmarks Geol. Unders. DGU Serie A, **8**.

VEJBÆK O. V., STOUGE S. and POULSEN K. D. (1994) — Paleozoic tectonic and sedimentary evolution and hydrocarbon prospectivity in the Bornholm area. Danmarks Geol. Unders. DGU Serie A, **34**.

ZIEGLER P. A. (1990) — Geological Atlas of Western and Central Europe. 2nd Ed. Shell Internationale Petroleum Maatschappij B.V., Geol. Soc. Publ. House Bath.

ŻELICHOWSKI A. M. (1987) — Carboniferous. In: Geological structure of the Pomerania Swell and its basement (in Polish with English summary). (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 26–51.