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The Oświno structure (NW Mid-Polish Trough) — salt diapir or inversion-related compressional structure?

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Interpretation of seismic data from the Pomeranian segment of the Mid-Polish Trough (MPT) shows that this part of the MPT evolved in Mesozoic times as a decoupled sedimentary basin. Regional-scale decoupling was caused by the thick Zechstein salt layer. Detailed tectonic and seismostratigraphic analysis of seismic data from the vicinity of the Oświno IG 1 well allowed for significant reinterpretation of the Oświno structure, which was previously interpreted as partly pierced salt diapir. This structure developed in Triassic to Jurassic times as a listric normal fault zone detached above the salt layer, resulting from activity of a master fault present within the pre-Zechstein basement. Two pulses of increased extension could be inferred for Oświno fault zone: Late Triassic and Mid-Late Jurassic. The Oświno fault zone was reactivated in the Late Cretaceous due to the compression responsible for inversion of the MPT. Inversion-related uplift of the axial part of the MPT created a morphological gradient and the increased pressure of uplifted overburden rocks directed towards its flanks that also contributed to reactivation of the Oświno fault zone. This fault zone, together with the Drawno-Człopa salt diapiric structure and graben system of the Fore-Sudetic Monocline, have developed due to decoupled evolution of the Mid-Polish Trough.

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INTRODUCTION

It has been for long recognised that rock salt, due to its specific bulk properties, is one of the most important components of sedimentary basins, and formation of salt structures has long been the subject of detailed studies (Jackson *et al*., 1995; Alsop *et al*., 1996). Salt structures form and evolve both in extensional and in compressional tectonic settings. Salt is of key importance during development of various compressional structures within thrust-and-fold belts, as salt layers often form preferred levels of detachments (Davis and Engelder, 1985; Letouzey *et al*., 1995; Cotton and Koyi, 2000). Within the sedimentary basins, salt flow leads to the formation of various structures such as salt diapirs, pillows and walls (Boldreel, 1985; Geil, 1991; Koyi *et al*., 1995; Koyi, 1998; Sorensen, 1998). Formation of salt structures is often triggered by tectonic activity within the basin's basement, such as extension or inversion (Erratt, 1993; Korstgard *et al*., 1993; Koyi and Petersen, 1993; Koyi *et al*., 1993; Penge *et al*., 1993; Christensen and Korstgard, 1994; Bishop *et al*., 1995; Stewart and Coward, 1995; Schulz-Ela and Jackson, 1996; Clark *et al*., 1998; Al-Zoubi and Ten Brink, 2001).

During basin extension, very important structures such as extensional forced folds (i.e. forced folds that form above normal faults) may form (Withjack *et al*., 1990; comp. Cosgrove and Ameen, 2000). Due to the presence of a ductile layer such as salt, the development of a master normal fault within the basement is, apart from the development of extensional forced folds, related to development of secondary deformations such as planar or listric normal faults detached within the salt layer (Fig. 1). Such detached secondary deformations can be located at various distances from the master basement normal fault and have different geometric characteristics, depending on various parameters such as the thickness of the ductile layer, the thickness of overburden, the amount and rate of displacement along the master fault *etc.* (Withjack and Calloway, 2000). The activity of secondary faults during deposition of the post-salt succession leads to increased thickness of the syn-tectonic succession deposited above the hangingwall. Such syn-tectonic deposits are typically characterised by a divergent seismic pattern and significantly increased thickness close to the fault plane (Prosser, 1993). Results of analogue modelling of active faulting beneath a salt layer showed that the presence of a salt layer above a basement deformed in brittle fashion might significantly mod-

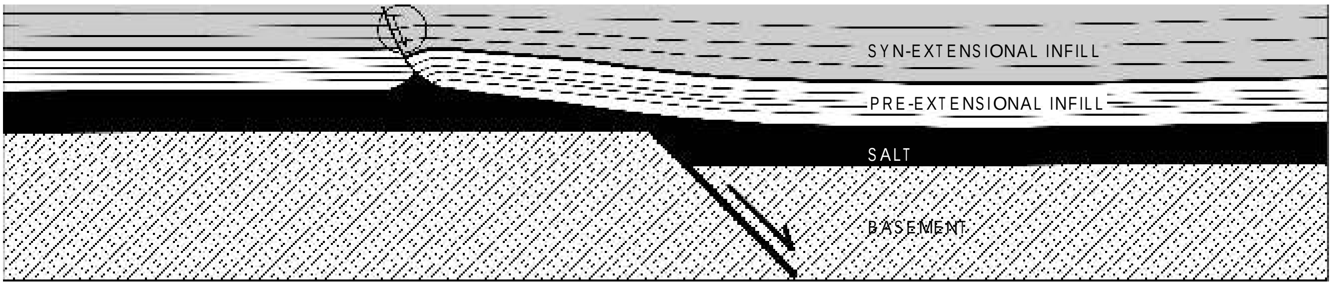

Fig. 1. Model of development of a listric normal fault within post-salt deposits due to decoupled faulting within the basement, based on results of analogue modelling (after Withjack and Calloway, 2000, modified); note local thickness increase of syn-extensional deposits above the hangingwall towards the listric fault (circle), and regional thickness increase of syn-extensional deposits towards basin centre

ify the depositional pattern of a post-salt sequence deposited during basement extension and lead to a generally more gentle stratal pattern of the sedimentary infill (Withjack and Calloway, 2000).

In this paper results of seismic data interpretation from the NW Mid-Polish Trough are presented. They document the development of a complex structure that evolved both during basin extension and inversion. Its evolution is discussed in the context of basin-scale decoupling and related detachment between pre-salt and post-salt sedimentary successions.

GEOLOGICAL SETTING

The Mid-Polish Trough (MPT) belonged to the system of epicontinental depositional basins of western and central Europe and formed the SE axial part of the Danish-Polish Basin (Ziegler, 1990; Michelsen, 1997; Van Wees *et al*., 2000). The MPT was located along the NW–SE trending Tornquist-Teisseyre Zone and stretched from the present-day Baltic Sea towards the SE (Pożaryski and Żytko, 1981; Kutek, 1994; Dadlez, 1997; Hakenberg and Świdrowska, 1997). It developed from Permian to Cretaceous times and was filled with several kilometres of sediments, mainly siliciclastics and carbonates (e.g. Pożaryski and Brochwicz-Lewiński, 1978, 1979; Dadlez, 1997; Dadlez *et al*., 1998*b*). One of the major problems concerning the evolution of the MPT, especially its parts characterised by thick Zechstein deposits, is the relationship between the regional depositional and the tectonic pattern of the syn-extensional Triassic-Lower Cretaceous succession and the tectonic activity within the pre-Zechstein basement. Within the central and NW part of the MPT, an important part of the its sedimentary infill comprises thick Zechstein evaporites (Wagner, 1998), and during basin development complex system of salt structures evolved (Fig. 2; Sokołowski, 1966, 1972; Dadlez and Marek, 1969, 1974; Pożaryski, 1977; Dadlez *et al*., 1998*a*) that formed the direct continuation of a system of salt structures known from the North-German Basin (Trusheim, 1960; Kockel, 1996; Kossow *et al*., 2000). Analysis of tectonic subsidence curves revealed that three major pulses of increased subsidence could be distinguished (Zechstein-Scythian, Oxfordian-Kimmeridgian and early Cenomanian) superimposed on a more gradual thermal subsidence pattern (Dadlez *et al*., 1995). A slightly different scenario for the MPT's subsidence was proposed by other authors (Świdrowska and Hakenberg, 1999), especially for the Cretaceous interval (increased Turonian instead of Cenomanian subsidence) using the results of regional analysis of palaeothickness maps. The NW and central parts of the MPT containing thick evaporites are characterised by an apparent lack of extensional deformation within the Mesozoic sedimentary cover related to tectonic phases of basin development (Dadlez, 1997; Stephenson and Narkiewicz, 1999; Van Wees *et al*., 2000). The Mesozoic succession is characterised by gradual thickness changes and a gentle regional depositional pattern (Dadlez, 2001).

The MPT was inverted in Late Cretaceous-Paleocene times, at which time its axial part was strongly eroded. In its SE part Palaeozoic and older MPT uplifted basement rocks are presently either exposed at the surface or covered by Miocene deposits related to development of the Carpathian foredeep ba-

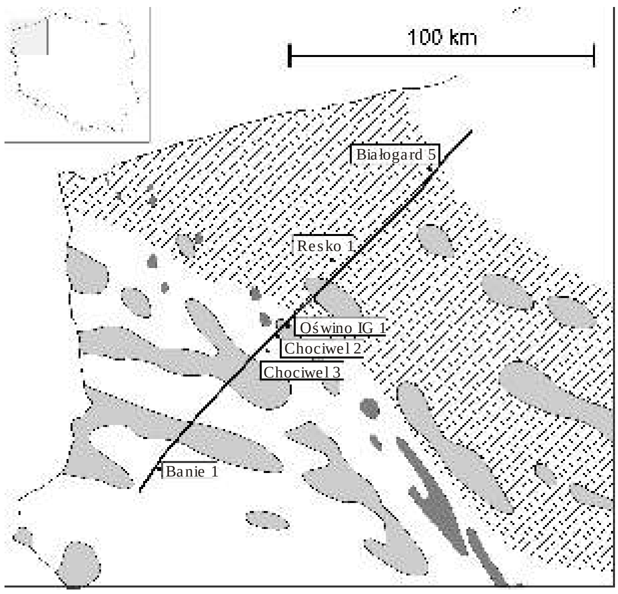

Fig. 2. Distribution of the salt structures in the Pomeranian segment of the Mid-Polish Trough

Patterned area — sub-Cenozoic subcrops of Jurassic and older deposits along the axis of the Mid-Polish Swell (onshore part only), light grey — salt pillows, dark grey — salt diapirs (after Dadlez and Marek, 1998, simplified and modified), black line — location of regional seismic profile from Fig. 3

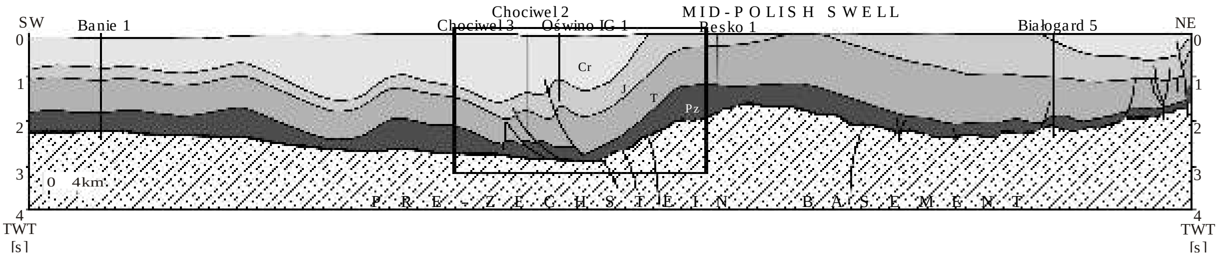

Fig. 3. Geological cross-section based on an interpreted regional seismic profile from the Pomeranian segment of the Mid-Polish Trough; location — see Fig. 1

Pz — Zechstein, T — Triassic, J — Jurassic, Cr — Cretaceous; black frame— enlarged portion of seismic profile shown on Fig. 4; TWT— two-way traveltime, approx. 4 x depth exaggeration; due to the low quality of seismic data from beneath of the Zechstein interval, major reverse faults drawn within the basement should be regarded only as hypothetical fault zones responsible for basin inversion

sin. The problem of the MPT inversion was discussed by numerous authors (e.g. Dadlez and Marek, 1969; Pożaryski, 1977; Pożaryski and Brochwicz-Lewiński, 1978, 1979; Dadlez, 1997); most of these papers however dealt mainly with the deep crustal processes responsible for basin inversion. Only for the SE and NW (offshore) parts of the MPT, published interpretations included analysis of inversion-related deformation within the Mesozoic sedimentary cover (see e.g. Hakenberg and Świdrowska, 1997; Krzywiec, 2002*a*, for more detailed discussion). The general role of regional compressional stresses in the MPT inversion was considered (e.g. Dadlez, 1980; Dadlez *et al*., 1995). However, in these models, compression was acting at a lower crustal level, and was linked to phase changes that resulted in isostatically-driven vertical movements, entirely responsible for MPT inversion (Dadlez, 2001).

Another problem related to evolution of the MPT that received relatively little attention is the relationship between basement tectonic processes and the development of various salt structures. Numerous authors have addressed this issue (Sokołowski, 1966, 1972; Dadlez and Marek, 1969, 1974; Pożaryski, 1977), but only a general link between inferred basement tectonic activity and salt movements was suggested.

DATA

Over several tens of years of exploration for hydrocarbons within the MPT, number of seismic reflection surveys have been completed within this sedimentary basin. Additionally, numerous research wells drilled by the Polish Geological Institute, and exploration wells drilled by the Polish Oil and Gas Company are located in this area. Recently, well logs from PGI research wells have been digitised and reprocessed, and together with seismic profiles can be used for detailed studies of various aspects of MPT development.

The Oświno structure is crossed by a regional seismic profile assembled from seismic lines acquired in the 70's and 80's, and recently reprocessed. The Oświno IG 1 research well drilled by the Polish Geological Institute in mid-60's is located above the crest of this structure (Jaskowiak, 1966). For this well, reprocessed well logs together with check-shot velocity data were available, enabling a fairly precise tie between seismic and well data. For interpretation presented in previous papers (Krzywiec, 2000, 2002*a*) only original check-shot data were used. Recently, reprocessed digitised velocity data became available, and these slightly differ from the original data. In particular, they suggest that syn-kinematic Cretaceous deposits are not limited to the Cenomanian-Turonian interval but that Coniacian deposits are also included (see also below). This age estimate have still to be tested against the very detailed velocity model created for this area taking into account check-shot data and sonic logs from other wells drilled in this region. The Oświno IG 1 well penetrated Cenozoic, Cretaceous and (partly) Jurassic successions. The seismic interpretation was supported by correlation with other deep wells such as Chociwel 2, Chociwel 3, Banie 1 and Resko 1 (Figs. 2 and 3).

The completed interpretation of seismic data was focused on the overall tectonic style of deformation and on the detection of local unconformities and subtle thickness changes, as these often point to various tectonic movements within the basin, either extension- or inversion-related (comp. Cartwright, 1989, 1991).

OŚWINO STRUCTURE — INTERPRETATION OF SEISMIC DATA

The present-day large-scale configuration of the Pomeranian segment of the MPT is clearly dominated by inversion-related processes. Its axial part is strongly uplifted and eroded, and forms the Mid-Polish Swell (MPS; Fig 3). Because of the low quality of seismic data from beneath the Zechstein salt layer, no direct evidence for the structural style of this uplift is available. However, taking into account the overall basin geometry observed on seismic data and comparison with the adjacent Baltic segment of the inverted MPT where the Zechstein cover is absent or very thin and it is possible to observe reverse faults related to basin inversion (Schlüter *et al*., 1997; Krzywiec, 2000, 2002*a*), it was assumed that regional uplift of the Pomeranian segment of the MPT was caused by major basement reverse faults developed within the pre-Zechstein basement (Krzywiec, 2000, 2002*a*, *b*). The area of present-day uplift (i.e. area of the MPS) is characterised by increased thickness of Zechstein and Triassic deposits. Presently, Zechstein deposits are slightly thinner in the most axial part of the MPS (Fig. 3), but this geometry could be attributed to lateral salt

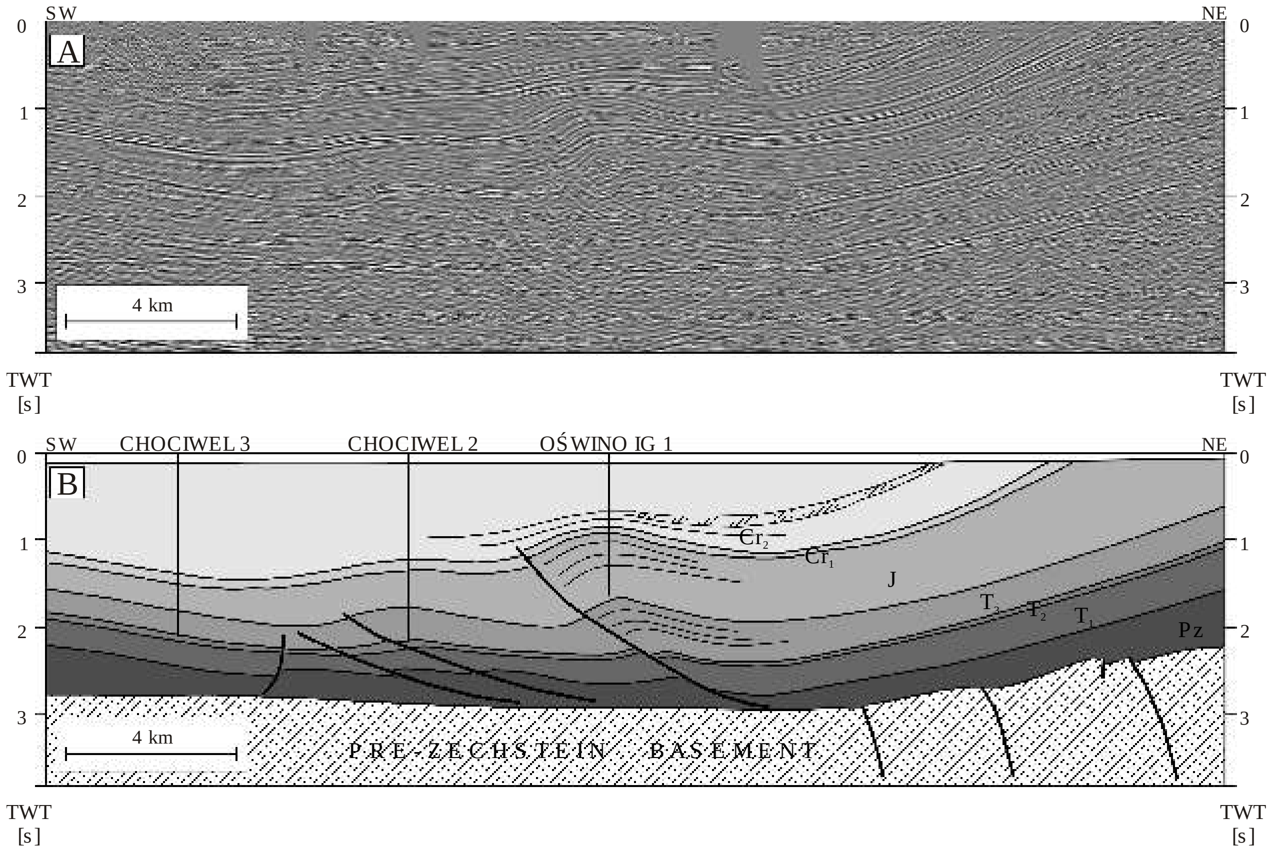

Fig. 4. Part of regional seismic profile from the Pomeranian segment of the Mid-Polish Trough showing details of the Oświno compressional structure: A — uninterpreted, B — interpreted

Pz — Zechstein, T_1 — Lower Triassic (Buntsandstein), T_2 — Middle Triassic (Muschelkalk), T_3 — Upper Triassic, J — Jurassic, Cr_1 — Lower Cretaceous, Cr_2 — Upper Cretaceous; patterned area within the Upper Cretaceous deposits — syn-kinematic deposits characterised by a thickness decrease towards the Oświno structure and towards the uplifted MPS; thin lines within Upper Triassic and Middle-Upper Jurassic deposits highlight syn-extensional deposition, thin lines within Upper Cretaceous deposits highlight syn-compressional deposition; TWT — two-way traveltime, approx. 2 x depth exaggeration; overall data quality for this profile is good, though within the SW part of the Oświno fault zone seismic reflectors (especially for Triassic interval) are less continuous, and in this region the interpretation should be regarded as approximate (see text for further explanation)

outflow towards the SW and NE sides of a significantly uplifted axial part of the MPT during basin inversion. As a result of this outflow, salt pillows located above inferred basement reverse faults might have formed (Fig. 3). Their development could also be at least partly related to syn-depositional Late Permian extensional activity of basement faults and a locally increased thickness of the Zechstein succession (see also below). Jurassic and Cretaceous successions, due to uplift and erosion, have been nearly entirely removed from the axial part of the MPS, and for this region it is difficult to estimate their initial thickness and internal depositional architecture. However, the divergent pattern of Jurassic and Lower Cretaceous reflectors on both sides of the uplifted MPS suggest that also these series had their depocenter within the MPT's axial part. All these features are in agreement with earlier conclusions that the maximum subsidence of the MPT was located in its axial part (*cf.* Pożaryski, 1957; Dadlez and Dembowska, 1959; Kutek and Głazek, 1972; Dadlez *et al.*, 1998*b*).

The Oświno structure is located close to the SW flank of the MPS (Fig. 2 and 3). This structure is located close to the inferred basement reverse fault zone, responsible for inversion and uplift of this part of the MPT. The Oświno structure has been interpreted by other authors as a partly pierced salt diapir with nearly vertical walls (comp. Dadlez, 2001). Detailed analysis of its internal structure suggests that it should be re-interpreted as an imbricated fan of blind reverse faults (thrusts) and related fault-propagation folds (Fig. 4; comp. Mitra, 1986; Dunne and Ferill, 1988). The folded hinge zone of the Oświno structure is clearly visible already at the level of the LateTriassic succession, across which the NE wall of the Oświno salt diapiric structure was drawn in an other interpretation (Dadlez, 2001). Significant thickness changes in the Triassic, Jurassic and Cretaceous deposits observed within the hinge zone of the Oświno structure (Fig. 4) are of particular importance for analysis of the evolution of this structure, as they point to different phases of its syn-depositional tectonic activity.

The hinge zone of the Oświno fault-propagation fold is characterised by an increased thickness of the uppermost Upper Triassic (not drilled by Oświno IG 1 well) and Middle to Upper Jurassic (approx. Bajocian-Tithonian) successions. This increased thickness, related to a divergent seismic pattern, is significantly asymmetrical, with a greater thickness observed close to the fault plane (Fig. 4). A slight thickness increase in the Upper Triassic deposits is observed also in the vicinity of a secondary thrust fault located towards the SW from the main Oświno structure (Fig. 4), although seismic data in this region is of significantly lower quality. A significantly increased thickness of Middle and Upper Jurassic successions in relation to the regional thickness pattern was stressed immediately after the Oświno IG 1 well was drilled (Jaskowiak, 1966).

The Jurassic deposits are covered by a Lower Cretaceous succession of generally uniform thickness. A different stratal geometry is observed for autor the Upper Cretaceous deposits. For this interval, within the hinge zone of the Oświno fault-propagation fold, significant thickness variations are observed (Fig. 4). These thickness variations characterise the Cenomanian-Turonian and most probably also the Coniacian succession (see description of data used for this interpretation presented above). Towards the limbs of the Oświno fault-propagation fold, the uppermost part of these syn-kinematic deposits are characterised by a divergent seismic pattern and increased thickness. Towards the axial part of the MPS, the uppermost part of the syn-kinematic Upper Cretaceous interval is again characterised by reduced thicknesses (Fig. 4). A subtle angular unconformity developed within the topmost part of the syn-kinematic succession suggests that the axial part of the Oświno fault-propagation fold was eroded and unconformably covered by younger (Santonian-Campanian) Upper Cretaceous deposits. This succesion is also folded and forms the upper part of the Oświno structure. It is characterised by a rather uniform thickness, hence it was assumed that during the time of its deposition the Oświno structure was not active. The folding observed suggests that the Oświno structure was reactivated during the later stages of MPT inversion. It must be stressed, however, that this folding could be also attributed at least partly to the formation of a drape anticline.

All the features described above are characteristic for inverted listric faults, which tectonic activity was contemporaneous with sedimentation, both during extension and compression-related inversion (comp. Buchanan and McClay, 1991; McClay and Scott, 1991).

DISCUSSION

Identified thickness changes within the Oświno structure together with the configuration of the pre-Zechstein basement provided a basis for construction of a model of its Mesozoic tectono-stratigraphic evolution. Two main stages of evolution of this structure were identified, related to development of the MPT and its inversion.

DECOUPLED MESOZOIC EVOLUTION OF THE MID-POLISH TROUGH — REGIONAL CONSIDERATIONS

Interpretation of seismic data from the Pomeranian segment of the MPT suggests that its Mesozoic development was controlled by basement extension, and characterised by basin-scale decoupling between the pre-Zechstein (precisely between pre-Stassfurt salt) basement and the Mesozoic sedimentary infill (comp. Krzywiec, 2000, 2002*a*, *b*). Due to such basin-scale decoupling caused by thick Zechstein evaporites, basement normal faults did not cut through post-Zechstein deposits, and the Mesozoic infill is characterised by rather smooth thickness changes and a regional divergent seismic pattern.

The results of analogue modelling of active faulting beneath the salt layer show that the presence of a thick salt layer above a basement deformed in brittle fashion strongly modifies modes of deformation of the post-salt cover sequence (Withjack and Calloway, 2000; see also Pascoe *et al*., 1999). Mechanical decoupling between two brittle layers (pre- and post-salt successions) leads to a generally more gentle depositional pattern of the sedimentary infill — gradual thickness changes, divergent seismic pattern, gentle overstepping of younger sediments, *etc*. (comp. Withjack and Calloway, 2000 and their fig. 14). This is particularly true for a relatively thick viscous salt layer. During such decoupled extensional evolution, major normal faulting is primarily restricted to the basement, and only secondary normal faults and associated deformations such as extensional forced folds or salt structures develop within the sedimentary infill (Withjack *et al*., 1990; Koyi *et al*., 1993; Koyi and Petersen, 1993; Withjack and Calloway, 2000). Within the axial part of the MPT, up to 1.5 km of Zechstein evaporites with a total thickness of salt of the order of 1km were deposited (Wagner, 1998), hence it can be assumed that due to the presence of thick salt the MPT evolved as a decoupled sedimentary basin. This is evidenced by distinct but gradual thickness increase towards the basin center observed for the Triassic, Jurassic and Lower Cretaceous successions (Fig. 3).

EVOLUTION OF THE OŚWINO STRUCTURE

A model of decoupled evolution of the MPT provided the rationale for interpretation of the Oświno structure as a zone of secondary faults developed in connection with the activity of the master basement normal fault responsible for regional subsidence of the MPT. Triassic and Jurassic phases of its development are given in Figure 5. The Oświno faults show typical features of listric faults: a curved fault plane shallowing with depth, and associated roll-over anticline (Shelton, 1984; Williams and Vann, 1987; Ellis and McClay, 1988; Xiao and Suppe, 1992; Maudit and Brun, 1998). They lack deformations within the hangingwall such as hangingwall-vergent backthrust (comp. Buchanan and McClay, 1991; McClay and Scott, 1991), but this could be possibly explained by the relatively small degree of total shortening related to faults inversion. Their syn-depositional activity is documented by the divergent pattern of syn-extensional deposits (comp. Cartwright, 1991; Prosser, 1993). The thickness increase of the Upper Triassic and Middle to Upper Jurassic deposits in the vicinity of the Oświno fault zone depicts two main phases of its extensional activity. During Triassic extension (Fig. 5A) all three Oświno normal faults were active and adjacent syn-extensional successions deposited above the hangingwall are characterised by a divergent seismic pattern. Towards the NE, towards the reconstructed MPT depocenter, Triassic deposits also show a slight but regular divergent pattern. During Jurassic extension (Fig. 5B) only the main (north-easternmost) Oświno listric fault was active and adjacent syn-extensional deposits present above its hangingwall

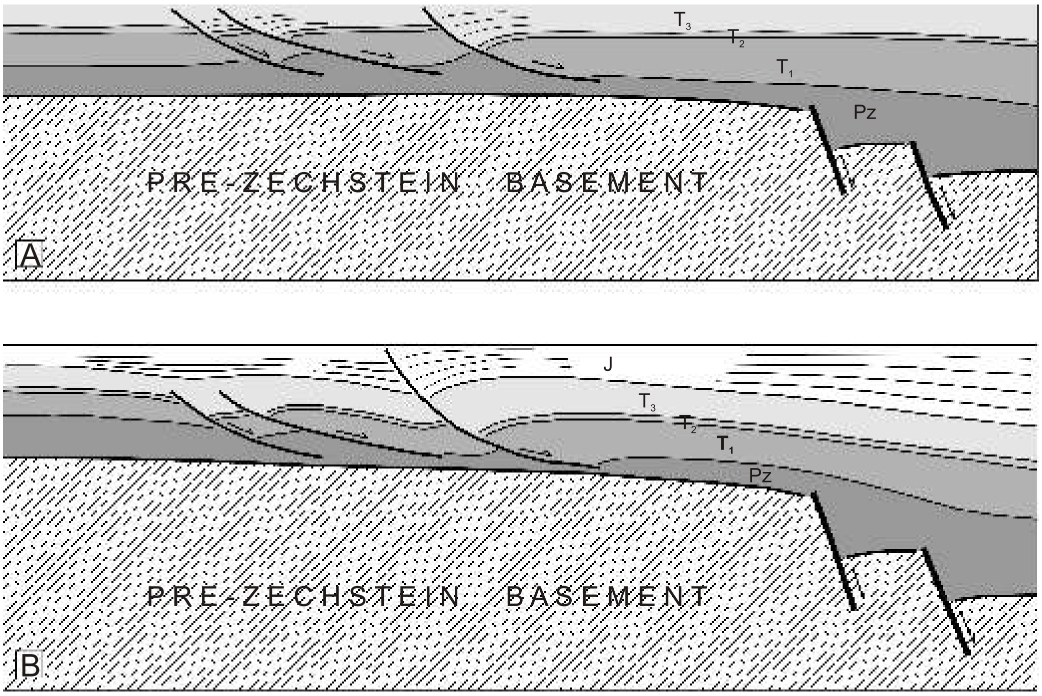

Fig. 5. Model of Late Triassic (A) and Late Jurassic (B) configuration of the Oświno structure based on the seismic profile from Figure 4 flattened on top of Triassic and top of Jurassic respectively

Approx. 2 x depth exaggeration; note significantly increased thickness and divergent seismic pattern of Upper Triassic and Middle-Upper Jurassic deposits above the hangingwall of the listric normal fault; restored salt thickness should be regarded as qualitative only; other explanations as in Fig. 4

are characterised by a divergent seismic pattern. Above two other faults of the Oświno structure, Jurassic deposits are characterised only by gradual thickness changes, possibly related to e.g. compactional adjustment of the fault zone. Because of the relevance of extensional activity of the Oświno fault zone to extensional activity of the basement master normal fault it could be postulated that activity of Oświno faults also — although indirectly — dates basement extension. A very similar scenario with gravity-driven extension of the post-salt succession related to salt withdrawal with the top salt surface acting as a detachment plane was for example proposed for development of salt-related Pliocene structures within the Dead Sea basin (Larsen *et al*., 2002). It must be however acknowledged that apart from the tectonic mechanism, salt dissolution may at least be partly invoked to explain the observed stratal pattern of the post-salt (Triassic-Jurassic) cover sequence. A recent study of the Forth Approaches Basin in the North Sea showed that basin-scale dissolution has greatly contributed to the formation of local Triassic minibasins in this area, and some of these basins resemble remarkably the reconstructed Oświno structure (comp. Cartwright *et al*., 2001, and their figs. 5c and 8c). Taking into account the location of the Oświno structure close to the inverted margin of the MPT it is however possible to assume that salt dissolution might have acted only as a secondary mechanism during development of this structure, while the tectonic mechanism presented above played a dominant role.

During basin inversion, normal basement faults may be reactivated as reverse faults and cause uplift of previously subsided basement blocks (Williams *et al*., 1989; Buchanan and McClay, 1991). Uplift of particular basement blocks often leads to formation of compressional-forced folds (Johnson and Johnson, 2002) similar to the extensional-forced folds described above. Such uplift and folding leads to localised reduction of accommodation space above the crestal part of the fold, and related thinning of syn-tectonic deposits (comp. Hardy *et al*., 1996; Bernal and Hardy, 2002). Progressive rotation of the backlimb accompanied by sediment progradation from an uplifted source area results in formation of local angular unconformities. All these features are also very common in frontal parts of foreland fold-and-thrust orogenic belts, where frontal thrusts are buried beneath water, older deposits of foredeep basins become involved in thrusting movements and are covered by younger foredeep deposits (comp. Burbank and Verges, 1994; Hardy *et al*., 1996; Krzywiec, 2001; Verges *et al*., 2002). Similar features may also be observed above basement blocks reactivated, uplifted and rotated during basin inversion (Cartwright, 1989).

On the basis of the relationship between styles of deformation within the MPT's pre- and post-salt successions caused by its decoupled evolution, it has been also assumed that the structural style of inversion tectonics was significantly influenced by the presence of a viscous salt layer. During Late Cretaceous inversion of the MPT, both the post-Zechstein sedimentary cover as well as the pre-Zechstein basement were subjected to compression, and this led to the development of various tectonic structures at both levels. Compression acting directly on post-Zechstein sedimentary cover led to reactivation and inversion of the Oświno fault zone, and local uplift of the tip of its hangingwall. Because of its earlier extensional activity, the Oświno fault zone formed the preferred site for the first stage of the inversion-related tectonic movements, therefore its direct reactivation in a compressional tectonic regime could be regarded as a first precursor of basin-scale inversion. Uplift of the hangingwall led to localised reduction of accommodation space and a related thickness decrease of syn-kinematic (i.e. syn-inversion) deposits, clearly visible onthe seismic data.

Compression acting within the sub-salt basement led to reactivation of inferred basement master normal faults that were subsequently transferred into reverse faults (Krzywiec, 2000, 2002*a*, *b*). Along these faults, the axial part of the basin was significantly uplifted. Zechstein deposits of locally increased thickness, caused by possible Late Permian extensional activity of basement master normal faults, have been transferred into salt pillows located above an uplifted hangingwall (comp. Krzywiec, 2000 and his fig. 7). Examples of such salt pillows located along the inverted SW and NE margins of the MPT, especially within its NW part, have been documented on numerous maps and seismic lines (e.g. Dadlez *et al*., 1998*a*; Dadlez and Marek, 1998; Dadlez, 2001). They can also be observed on regional seismic profiles from the Pomeranian segment of the MPT, on both sides of the uplifted central part of the basin (Fig. 3). Uplift of the MPT's axial part was most probably recorded by local depositional systems with a certain time-lag. It could be hypothesised that, during the earliest stages of axial uplift, only localised reduction of accommodation space took place within the basin's center, and at the same time the flanks of the basin were sites of continuous deposition reflected in the divergent seismic pattern. Because of strong erosion within the axial part of the uplifted MPT, that removed the entire Cretaceous and nearly all of the Jurassic sections, no evidence remains regarding the exact structural style and timing of this axial uplift. Inversion-related basement uplift also influenced the structural style of the Oświno structure as it resulted in the creation of a morphological gradient and increased pressure of overburden rocks directed towards the south-west. This pressure most probably significantly contributed to Late Cretaceous reactivation of the Oświno structure. Reactivation was due to lateral compression caused by uplift of the axial part of the MPT. The mechanism of formation of the Oświno compressional structures was therefore to certain degree probably similar to the mechanism responsible for the formation of gravity-driven fold belts on passive margins (Cobbold and Szatmari, 1991; Trudgill *et al*., 1999; Rowan *et al*., 1999, in press). Along passive continental margins, contractional fold belts develop as a result of morphological gradients related to the continental slope, and increased pressure of overburden rocks related to up-slope deposition and sediment progradation (Koyi, 1996). Major detachment surfaces are related to either salt layers or overpressured shales. The presumed inversion and uplift of the MPT is documented by a slight thickness decrease in the uppermost part of the syn-kinematic (= syn-inversion) deposits towards the NE, i.e. towards the uplifted axial part of the MPT (Fig. 4). It can be therefore assumed that, between the axial part of the uplifted MPS and the Oświno compressional structure, a small basin equivalent to ponded slope-basins known from passive margin settings formed during this stage of basin inversion (comp. Hooper *et al*., 2002).

The Oświno structure forms the northernmost part of a system of tectonic deformations extending from the Pomeranian segment of the MPT towards the Fore-Sudetic Monocline (Dadlez *et al*., 1998; Dadlez and Marek, 1998; Kwolek, 2000). Towards the south it is gradually replaced by the Drawno-Człopa salt diapiric structure, and further to the south by a system of halfgrabens. According to various detailed studies these grabens were active in Late Triassic and Jurassic times (Kwolek, 2000). It might be suggested that all these structures were initiated in Triassic and Jurassic times, and their development was controlled by decoupled evolution of the MPT. The main difference in their present-day structural style was caused by inversion of the MPT. The Oświno structure is located in immediate proximity to an inverted master fault in the basement and therefore was subjected to the most significant reactivation influenced by the uplifted axial part of the MPT. This resulted in the formation of a syn-depositional zone of reverse faults (thrusts). The Drawno–Człopa salt diapir might also have been initiated in Triassic times due to salt intrusion along two conjugate faults that developed — as in the Oświno area — as secondary deformations within the post-salt cover sequence. Because of its more distal position from the basement master fault, reverse faults (thrusts) did not develop during basin inversion. Instead, the extension-related diapiric structure was subjected to compression and dominated by vertical salt flow. The more southern part of this system of tectonic deformations located within Fore-Sudetic Monocline has mostly preserved its original structural style formed during Triassic and Jurassic extension. In general, all such structures within the Fore-Sudetic Monocline are bound by slightly rotational normal faults dipping towards the north-east, with antithetic faults dipping towards the south-west (Kwolek, 2000). They could be interpreted as secondary faults developed due to extension within the pre-Zechstein basement and decoupled extension within the post-salt succession, as in the Triassic-Jurassic development of the Oświno structure. Because of their more distal position from the basement master normal fault zone, the normal faults bounding graben structures of the Fore-Sudetic Monocline have a much less listric character than in the Oświno area. They were subjected to either little or no inversion (Kwolek, 2000), possibly partly because of their greater distance from the strongly inverted axial part of the MPT which was characterised by significant tectonic activity.

CONCLUSIONS

1. The Pomeranian segment of the Mid-Polish Trough evolved in Mesozoic times as a decoupled sedimentary basin with regional decoupling related to thick Zechstein salt.

2. The Oświno structure is interpreted as a zone of secondary listric normal faults developed due to Triassic-Jurassic activity of basement master normal fault (fault zone) responsible

for basin subsidence. This interpretation of the origin of the Oświno structure is different from previous interpretations of this structure as a partly pierced salt diapir.

3. The suggested development of secondary listric faults within the post-salt succession is in agreement with results of analogue modelling of deformation within the cover sequence during decoupled extension.

4. Two pulses of increased extension may be inferred for the Oświno fault zone: Late Triassic and Mid- to Late Jurassic (approx. Bajocian-Tithonian).

5. The Oświno fault zone was reactivated in the Late Cretaceous (approx. Cenomanian-Turonian-Coniacian) during inversion of the Mid-Polish Trough. Its final shape was attained during later (post-Campanian) stages of MPT inversion.

6. During the Late Cretaceous, the evolution of the Oświno fault zone was influenced by both (directly) compression acting within the post-Zechstein sedimentary cover, as well as (indirectly) compression acting within the pre-Zechstein basement. Compression exerted directly on the hangingwall and footwall of Oświno structure led to its reactivation and inversion, while compression within the basement led to uplift of the axial part of the MPT and SW-directed lateral compression related to increased pressure of overburden rocks.

7. The Oświno fault zone, the Drawno-Człopa salt diapiric structure and the graben system of the Fore-Sudetic Monocline might have all developed due to decoupled evolution of the Mid-Polish Trough. Their present-day different structural style may be attributed to their different distances from the axial part of the basin affected by subsidence and uplift.

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