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Strike-slip tectonics within the SW Baltic Sea and its relationship to the inversion of the Mid-Polish Trough—evidence from high-resolution seismic data

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Abstract

The SW Baltic Sea occupies an area where crustal-scale regional tectonic zones of different age merge and overlap, creating a complex tectonic pattern. This pattern influenced the evolution of the Mesozoic sedimentary basin in this area. We present an interpretation of new high-resolution seismic data from the SW Baltic Sea which provided new information both on modes of the Late Cretaceous inversion of this part of the Danish–Polish Mesozoic basin system as well as on relationship between tectonic processes and syn-tectonic depositional systems. Within the Bornholm–Darłowo Fault Zone, located between the Koszalin Fault and Christiansø Block, both strike-slip and reverse faulting took place during the inversion-related activity. The faulting was related to reactivation of extensional pre-Permian fault system. Syn-tectonic sedimentary features include a prominent, generally S- and SE-directed, progradational depositional system with the major source area provided by uplifted basement blocks, in particular by the Bornholm Block. Sediment progradation was enhanced by downfaulting along a strike-slip fault zone and related expansion of accommodation space. Closer to the Christiansø Block, some syn-tectonic deposition also took place and resulted in subtle thickness changes within the hinge zones of inversion-related growth folds. Lack of significant sediment supply from the inverted and uplifted offshore part of the Mid-Polish Trough suggests that in this area NW–SE-located marginal trough parallel to the inversion axis of the Mid-Polish Trough did not form, and that uplifted Bornholm Block played by far more prominent role for development of syn-inversion depositional successions.

Keywords: SW Baltic; Mid-Polish Trough; High-resolution seismic data; Inversion tectonics; Strike-slip movements; Syn-tectonic sedimentation; Marginal troughs

1. Introduction

Classical models of inversion of extensional fault systems are based on simple transition from extension to compression, and inversion of sense of movement along the fault plane (Coward, 1994; Hayward and Graham, 1989). Such a tectonic scenario requires either homogeneous basement plate undergoing deformation which does not contain any significant inherited fault zones that might be reactivated within the applied stress field, or more or less perpendicular

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orientation of inherited fault zones to the extensional and compressional stress fields. Regional obliquity of inherited basement faults and the stress field often results in formation of transverse fault zones during rifting and subsequent basin development (Cartwright, 1987), as well as strike-slip movements and development of positive flower structures during inversion (Harding, 1985; Woodcock and Schubert, 1994; Lihou and Allen, 1996). Within hinge zones of inversion-related folds, thickness reductions of syn-inversion deposits accompanied by localised progradational pattern are often observed and indicate syn-depositional tectonic activity (Cartwright, 1989).

High-resolution seismics is a very powerful research tool in studies of the Cenozoic evolution of the offshore areas, as is shown, e.g. by recent studies of Cenozoic history of the Danish North Sea. In this area, shallow seismic profiles imaged both detailed depositional architecture of Cenozoic deposits (Michelsen et al., 1998; Clausen et al., 1999), often deformed by tectonic (e.g. glacitectonic) and erosional processes (Huuse and Lykke-Andersen, 2000a,b), as well as their immediate substratum (Huuse, 1999). Regional coverage of shallow seismic data combined with well information and petroleum seismic data provided a database allowing for construction of a regional model of Cenozoic evolution of this large offshore area (Clausen and Huuse, 1999; Huuse et al., 2001).

New offshore high-resolution seismic data from the southern Baltic Sea are presented here. This data set documents modes of the Late Cretaceous inversion tectonics within the wide zone stretching between the island of Borholm and the Polish coast, in particular large amount of strike-slip deformations related to the inversion. The interpretation has led to an updated and refined tectonic map of the SW Baltic Sea.

2. Geological setting

The SW Baltic Sea forms part of a very complicated area where several important regional tectonic zones and lines overlap and merge, including Sorgenfrei–Tornquist Zone (STZ), Teisseyre–Tornquist Zone (TTZ) and the Caledonian deformation front (Fig. 1; Pharaoh, 1999 and references therein). Research projects including deep seismic reflection profiling have been completed in this area (EUGENO-S Working Group, 1988; BABEL Working Group, 1991; Meissner et al., 1994), and numerous alternative hypotheses have been formulated on various aspects of its present-day crustal structure and geodynamic evolution (e.g. Pegrum, 1984; Tanner and Meissner, 1996; Berthelsen, 1998). However, even the basic features that characterise SW Baltic Sea and surrounding areas such as the extent of Baltica and Avalonia blocks, existence of the Trans-European Fault, and the presence and exact location of Caledonian deformation front are still discussed and no consensus has been reached yet (Thybo, 1997, 2001; Franke, 1990; Dadlez, 2000; Lassen et al., 2001; McCann and Krawczyk, 2001).

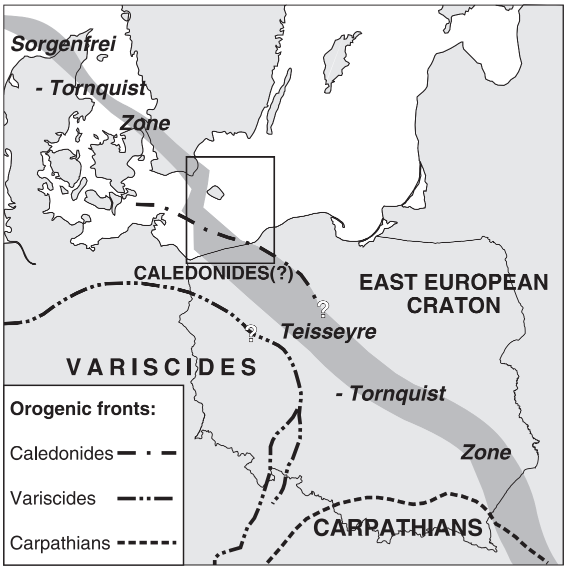

Fig. 1. Location of the study area (rectangle) and its relationship to the major crustal features of the North Europe, including the Precambrian East European Platform, the Palaeozoic West European Platform, the Caledonian, Variscan and Carpathian orogenic fronts, the Tornquist–Teisseyre Zone (TTZ) and the Sorgenfrei–Tornquist Zone (STZ) (after Pharaoh, 1999, simplified and modified).

During Permian through Cretaceous times several sedimentary basins and sub-basins of the so-called Peri-Tethys domain developed in Western and Central Europe due to post-orogenic destruction of the Variscan foreland initiated by Late Carboniferous wrenching and strike-slip movements (Brochwicz-Lewiński et al., 1984; Ziegler, 1990; van Wees et al., 2000). Significant subsidence and deposition took place along the Sorgenfrei–Tornquist Zone in Scania and

Kattegat (Norling and Bergstrom, 1987; Mogensen and Jensen, 1994; Michelsen, 1997) and the Teisseyre–Tornquist Zone (TTZ) in Poland. Along the TTZ, the Polish Basin developed with its mostly subsided axial part, Mid-Polish Trough (MPT; Pożaryski and Brochwicz-Lewiński, 1978; Dadlez et al., 1995; van Wees et al., 2000). During Late Cretaceous–Cenozoic inversion of the Peri-Tethyan epicontinental sedimentary basins, various faults and fault zones have been reactivated and gave rise to the development of the inversion structures (e.g. Ziegler, 1989; Ziegler et al., 1995; Roure and Colletta, 1996). In a regional sense, spreading within the Atlantic domain, and Alpine–Carpathian collision have generated compressional stresses that were transferred into the foreland plate and resulted in reactivation and inversion of faults responsible for the formation of Mesozoic sedimentary basins. During inversion of Peri-Tethyan domain also the sedimentary basins developed along the STZ and TTZ underwent inversion (e.g. Pożaryski and Brochwicz-Lewiński, 1978; Vejbæk and Andersen, 1987; Mogensen and Jensen, 1994; Dadlez, 1997; Dronkers and Mrozek, 1991; Krzywiec, 2000, 2002a).

A complicated regional stress field generated by the Atlantic spreading and the Alpine–Carpathian collision superimposed on equally complicated regional fault pattern related to both pre-Permian (Variscan and Caledonian) tectonic events and Permian–Mesozoic basin development, resulted in various modes and amounts of inversion. During the Late Cretaceous inversion of the MPT, including its offshore part located in the SW Baltic Sea, various inversion-related structures developed like reverse faults and associated fault-propagation folds, and NW–SE- or SE–NW-oriented flower structures induced by strike-slip movements (Pożaryski, 1977; Antonowicz et al., 1994; Strzetelski et al., 1995; Schlüter et al., 1997; Krzywiec, 2000, 2002a).

The onshore NW part of the MPT, located in immediate vicinity of the study area, is built of several crustal blocks related to Palaeozoic and Precambrian platforms (Znosko, 1979; Guterch et al., 1994; Dadlez, 1997, 2000; Petecki, 2001; Królikowski and Petecki, 1997). The MPT can be traced towards the area SW of Bornholm (Fig. 2). In this region, the NW–SE trending Kamien Pomorski–Adler and Koszalin faults form NE and SW borders of the inverted

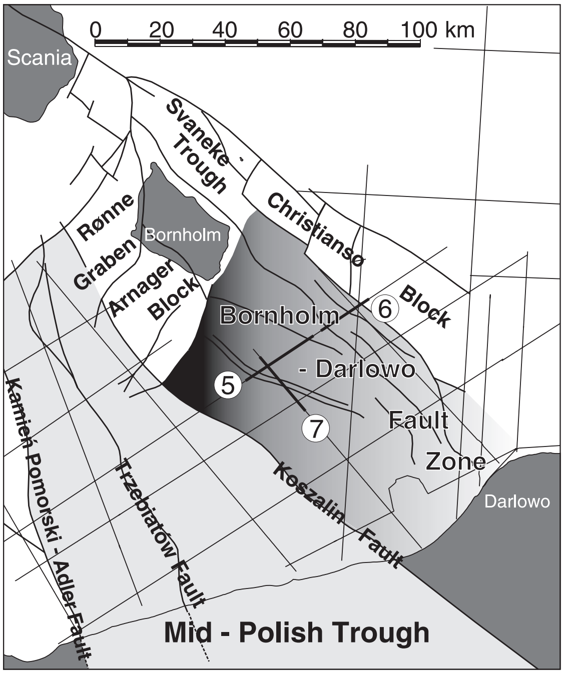

Fig. 2. Tectonic map of the Bornholm–Darłowo Fault Zone (according to Kramarska et al., 1999, modified and supplemented using results of Deeks and Thomas, 1995; Vejbæk, 1985; Vejbæk et al., 1994, and unpublished Petrobaltic maps). Thin lines—shallow high-resolution seismic lines, thick lines with numbers—location of seismic examples with appropriate figure numbers.

MPT, respectively (Fig. 2; Dadlez and Młynarski, 1967; Dadlez, 1974, 1976; Pożaryski et al., 1978; Liboriussen et al., 1987; Pożaryski and Witkowski, 1990; Thomas et al., 1993; Dadlez et al., 1995; Kramarska et al., 1999). These two fault zones form an extensional (possibly partly transtensional) fault system inverted in a compressional (possibly partly transpressional) tectonic regime. Asymmetric fault-propagation folds developed within the Mesozoic basin infill above major inversion-related reverse faults within the pre-Zechstein basement (Schlüter et al., 1997; Krzywiec, 2000, 2002a; Dadlez, 2001). It is not possible to precisely determine the onset of inversion in this part of the MPT due to significant uplift of inversion anticlines, related deep erosion and lack of preserved syn-inversion deposits.

In the transition area between STZ and TTZ, several tectonic units are distinguished including the NW part of the MPT, Svaneke Trough, Bornholm

Block, Christiansø Block; Rønne Graben and Arnager Block (Fig. 2; Vejbæk, 1985; Vejbæk et al., 1994; Deeks and Thomas, 1995).

During the Mesozoic, within the transition area between the STZ and the TTZ comprising the present-day Bornholm island and its surroundings (Fig. 2), Triassic to Jurassic and Lower Cretaceous deposition took place due to extensional phase of basin development (Gravesen et al., 1982; Schlüter et al., 1997). Strike-slip movements resulted in formation of pull-apart basins like the Rønne and the Arnager Grabens (Liboriussen et al., 1987; Vejbæk, 1985; Ziegler, 1990; Thomas et al., 1993; Deeks and Thomas, 1995). Remnants of the Mesozoic sedimentary cover have been drilled by exploration wells (Rempel, 1992; Vejbæk et al., 1994) and are accessible in limited outcrops on Bornholm (Gravesen et al., 1982). They represent Triassic continental rift sediments, Lower Jurassic lacustrine and deltaic deposits related to basin expansion, Mid Jurassic regressive deposits, and Lower Cretaceous transgressive deposits related to the next phase of basin expansion (Gravesen et al., 1982). Late Cretaceous inversion of the entire Danish–Polish basin system coupled with relatively rigid behaviour of uplifted Bornholm Block resulted in localized deviations of regional stress trajectories and related complicated tectonic movements around this basement pop-up structure, which represents a large-scale overstep in the strike-slip fault system between the STZ and the TTZ (cf. Deeks and Thomas, 1995). Inversion-related uplift of particular basement blocks led to their localised erosion and formation of syn-tectonic deposits that were prograding from uplifted blocks towards local depocentres (Deeks and Thomas, 1995).

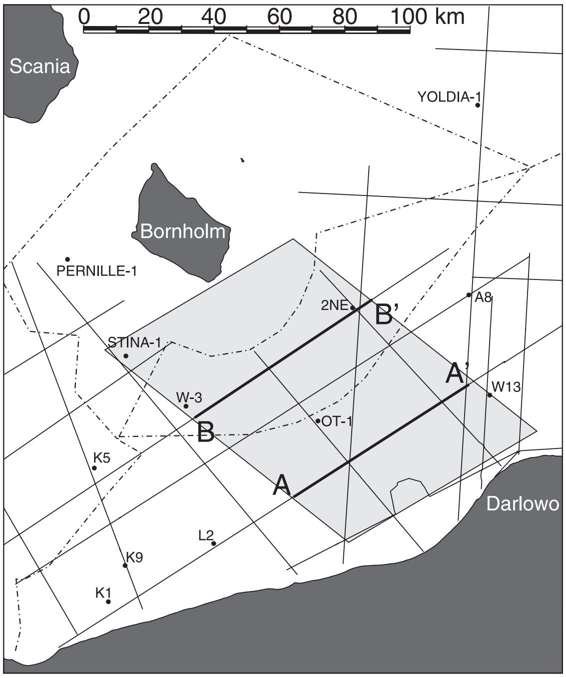

Fig. 3. Location of the study area and shallow high-resolution seismic profiles (thin lines) acquired within the SW Baltic Sea (after Kramarska et al., 1999). A–A′ and B–B′-parts of the shallow high-resolution seismic profiles crossing the Bornholm–Darłowo Fault Zone shown on Fig. 4, dashed lines—territorial borders, dots—wells (A8, K1, K5, K9, L2, Stina-1, Pernille-1 and Yoldia-1 are deep petroleum wells, OT-1, W-3, W-13 and 2NE are shallow cartographic wells).

3. Seismic data acquisition and processing

High-resolution seismic data from the SW Baltic Sea were acquired within the Polish territorial waters and economic zone, and partly within the adjacent German, Danish and Swedish economic zones (Kramarska et al., 1999; Figs. 2 and 3). Location of acquired seismic profiles in the study area was mostly NW–SE and SW–NE, and was related to trends of major tectonic units (Fig. 3). Three field campaigns were organised in years 1996, 1997 and 1998 using research vessel “Dr Lubecki” provided by the Maritime Institute from Gdansk. The Netherlands Institute of Applied Geoscience (TNO) provided seismic field equipment. Navigation data were supplied by DGPS vessel location system. The Texas Instruments 10″ sleevegun was deployed as a source of seismic waves, and the Prakla-Seismos 12 channel streamer was used for seismic data recording. The length of each channel was 12.4 m, and distance between channels was 12.5 m. The seismic recording system consisted of MGS 12-channel Marine Data Acquisition System, which provided sixfold coverage. Sampling rate for the majority of acquired seismic profiles was set to 0.5 ms and recording time was either 0.8 or 1 s.

Seismic data acquired during 1996 cruise were processed at the Netherlands Institute of Applied Geoscience (TNO) using ProMAX processing software (Landmark Graphics), and seismic data acquired during 1997 and 1998 cruises were processed at the Department of Geophysics, Polish Geological Institute using FOCUS software. The velocity analysis was completed at about each 500 CDP, i.e. for about each 3 km. After NMO and data stack, post-stack predictive deconvolution was applied in order to remove multiple reflections related to a sea bottom. Migration was not applied to the acquired data, as its possible effect would not significantly enhance data quality.

Data quality could be described as moderate to very good. Lowest quality characterises areas located close to the coastline and with thick gravel cover on sea bottom. Within the Bornholm–Darłowo Fault Zone data quality is good to very good, with vertical resolution in order of a few metres. For the entire acquired seismic data set a major problem during data interpretation was the presence of strong multiple events related to a sea bottom, but for data from the Bornholm–Darłowo Fault Zone, this event did not significantly influence accuracy of a completed interpretation.

4. Interpretation of the seismic data

The processed seismic data were loaded into the Landmark Graphics interpretation system, together with available well data that included stratigraphy and time–depth data from selected petroleum wells drilled by the Petrobaltic oil company (Rempel, 1992; Schlüter et al., 1997). Additionally, selected Petrobaltic seismic data were also available during interpretation of shallow high-resolution seismic data. However, they were available for most western and eastern parts of the S Baltic Sea only; in particular, no petroleum seismic and well data were available from the Bornholm–Darłowo Fault Zone.

A large number of kilometres of high-resolution seismic data have been acquired. However, due to the large area surveyed (line spacing in an order of 15–20 km or larger), acquired data provided only general insight into the complicated sedimentary architecture and tectonic pattern of post-Palaeozoic sedimentary cover. Earlier published maps were based on seismic surveys with limited coverage due to complex pattern of the state boundaries; in particular, very limited data were accessible for the area between Bornholm and the Polish coast.

In 1970–1980 extensive shallow seismic profiling programme was completed within the southern Baltic Sea. During this experiment both single- and multichannel seismic profiles have been acquired (Sviridov et al., 1995). Some of multichannel profiles, located to the S and SE from the Bornholm, slightly overlap with seismic lines described in this paper and could be correlated with them. Interpretation of the high-resolution seismic data was also supported by the published geological maps of the study area that were constructed using petroleum seismic data (Vejbæk, 1985; Vejbæk et al., 1994; Deeks and Thomas, 1995; Schlüter et al., 1997). Additionally, selected unpublished Petrobalic seismic structural maps were also used. This allowed for preparation of a much more detailed tectonic map for this part of the southern Baltic Sea (Fig. 2).

In the area between Bornholm and onshore Poland, it is likely that a fairly complete Upper Cretaceous succession is present, and that Maastrichtian deposits crop out on the sub-Cenozoic surface (Pożaryski et al., 1978; Jaskowiak-Schoeneich and Pożaryski, 1979; Pożaryski and Witkowski, 1990; Uścinowicz and Zachowicz, 1993). Cretaceous deposits most probably rest mostly on Silurian basement. Only close the Polish coastline, in relatively narrow belt, Permian, Triassic and Jurassic deposits are also present beneath the Cretaceous cover (Kramarska et al., 1999). Due to the lack of deep wells within the Bornholm–Darłowo Fault Zone, location of the boundary between Palaeozoic and Mesozoic complexes is based on long-distance correlation with offshore and onshore wells (Fig. 3), very often across large fault zones, and should therefore be regarded as tentative.

In the area between Bornholm to the NW and the Polish coast (vicinity of Darłowo city) to the SE, and the Koszalin Fault to the SW and the Christiansø Block to the NE, a wide zone of reverse and strike-slip faults related to inversion of the Danish–Polish Basin has been detected using high-resolution seismic data (Kramarska et al., 1999). This zone forms a direct continuation of the tectonic zone known from the immediate SW surroundings of Bornholm including the Bornholm Block and the Svaneke Trough (Vejbæk et al., 1994; Deeks and Thomas, 1995; Sviridov et al., 1995). It is proposed hereby to name this zone the Bornholm–Darłowo Fault Zone (Fig. 2). Faults are most prominent in NW part of the Bornholm–Darłowo Fault Zone;

towards the Polish coast they become more diffuse and die out. Within the onshore area no traces of this fault zone have been identified (Dadlez and Młynarski, 1967; Dadlez, 1974, 1976, 1990; Pożaryski et al., 1978; Pożaryski and Witkowski, 1990).

Two regional shallow high-resolution seismic profiles show the general sedimentary and tectonic pattern for the Upper Cretaceous sedimentary cover and their Palaeozoic (most probably Silurian) basement (Fig. 4). These profiles cross Bornholm–Darłowo Fault Zone and are located between the inverted MPT to the SW (bordered by the Koszalin Fault), and the uplifted Christiansø Block to the NE (Figs. 2 and 3). Within the Upper Cretaceous succession, angular unconformities, reverse faults and related folds can be observed. The degree of complexity is clearly higher towards the NW, towards Bornholm (profile B), while towards the SE (profile A), a less complex tectonic pattern can be observed. Such diversity of the observed tectonic pattern was caused by more intense Late Cretaceous tectonic movements in immediate vicinity of the present-day Bornholm area, and less intense tectonic activity closer to the present-day Polish coastline. In Figs. 5 and 6 enlarged parts of regional profile B are presented. They document in more details some intra-Cretaceous depositional patterns and tectonic deformations. Within the central Bornholm–Darłowo Fault Zone the identified faults are steep, and often form pop-up structures and positive flower structure, typical for a strike-slip environment (Fig. 5). Flower structure is identified along the SW border of uplifted basement block (cf. Deeks and Thomas, 1995, and their Fig. 8). This block (termed Ustka Block according to Vejbæk et al., 1994) is characterised by a slightly thicker pre-Permian sedimentary cover overlying the crystalline basement. The SE border of this increased thickness can be correlated with the identified strike-slip fault (cf. Vejbæk et al., 1994, and their profile C from Fig. 2). It can therefore be postulated that this fault was active as an extensional feature in Palaeozoic times, and that it was reactivated in transpressional, most probably dextral, regime during Late Cretaceous inversion of the Danish–Polish basin system (cf. Deeks and Thomas, 1995). A very complex tectonic and sedimentary pattern developed during this reactivation within the Upper Cretaceous succession (Fig. 5). Observed angular unconformities could be associated with localised sediment progradation caused by erosion of blocks uplifted during the inversion, but along this profile they are most probably observed at a high angle to the general direction of sediment progradation. Associated folding and faulting could be related to basement wrenching, which commonly results in

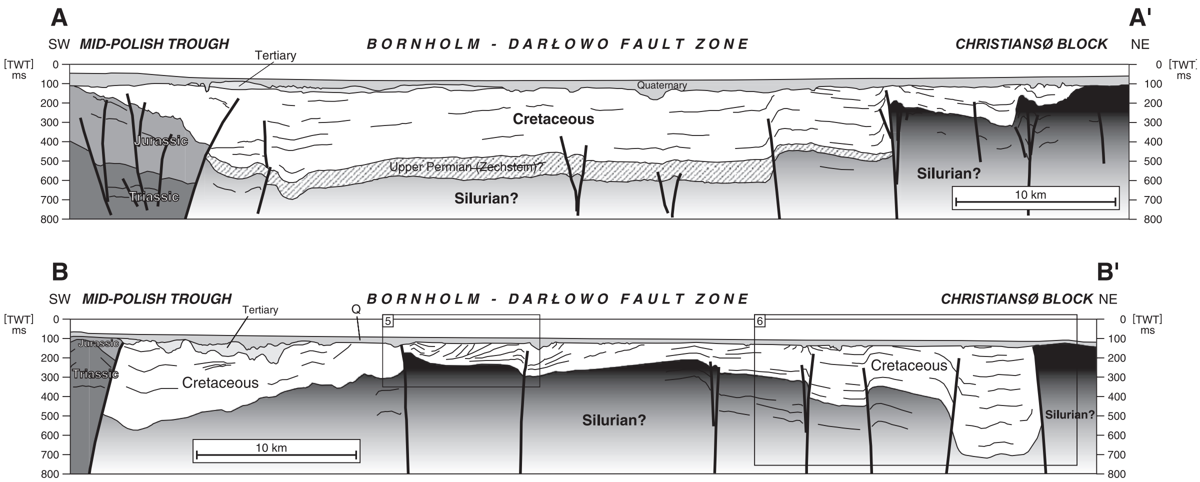

Fig. 4. Regional geological profiles based on shallow high-resolution seismic data across the Bornholm–Darłowo Fault Zone (modified after Kramarska et al., 1999). See Fig. 3 for location. Reverse faults developed within the Bornholm–Darłowo Fault Zone due to inversion of the Mid-Polish Trough. Due to lack of deep wells detailed stratigraphy of the sub-Cretaceous interval and position of its top should be regarded as tentative. Black boxes—location of seismic examples with numbers of relevant figures.

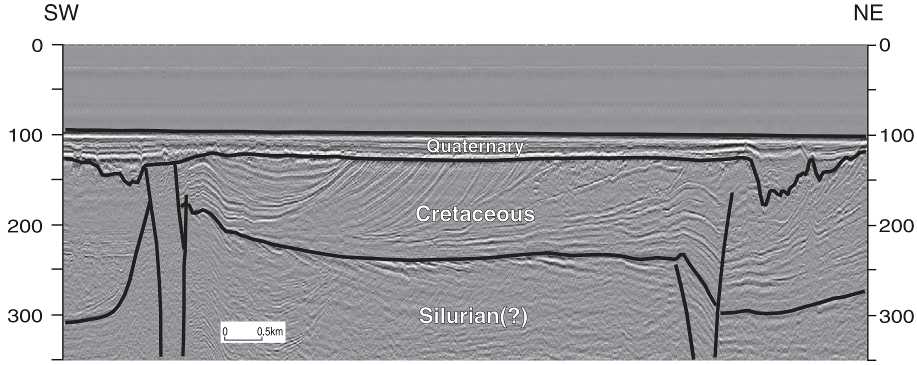

Fig. 5. Seismic example of the Upper Cretaceous depositonal and tectonic architecture related to the inversion and strike-slip movements within the Bornholm–Darłowo Fault Zone. See Fig. 2 for location. Vertical scale—millisecond, two-way traveltime.

highly complex deformation within the sedimentary cover (cf. Christie-Blick and Biddle, 1985). Analogue modelling has shown that basement wrench faulting often results in the development of strongly localised fault-and-fold zones, especially when previously extensional features are reactivated as strike-slip faults (Richard and Krantz, 1991; Richard et al., 1991).

Within the NE part of the Bornholm–Darłowo Fault Zone, closer to the Christiansø Block, strike-slip movements were minor, and Late Cretaceous inversion-related tectonic activity resulted in the formation of reverse faults and associated folds (Figs. 4 and 6). These faults define the Bornholm Block and the SE extension of the Svaneke Trough (comp. Vejbæk et al., 1994 and their Figs. 1 and 2). Here we propose that, due to their planar complexity, they should be regarded as a part of the wide Bornholm–Darłowo Fault Zone defined in this paper. Within the central segment of this part of the Bornholm–Darłowo Fault Zone, a thicker Palaeozoic cover is present, while in immediate vicinity of the Christiansø Block, beneath the Svaneke Trough, Palaeozoic cover is considerable thinner (Vejbæk et al., 1994). This proves that faults bordering particular blocks were active during earlier (pre-Permian–Silurian?) extensional phases (Vejbæk et al., 1994). They were reactivated during Late Cretaceous inversion of the Danish–Polish basin system, with minor wrenching. Detailed seismic stratigraphic analysis of the Upper Cretaceous sedimentary succession shows that inversion processes in this part of the Bornholm–Darłowo Fault Zone may to some extent be regarded as syn-depositional. Above reverse fault responsible for a local uplift of basement blocks, a subtle thickness reduction can be observed within the hinge zone of a fault-related fold (Fig. 6). They can be regarded as

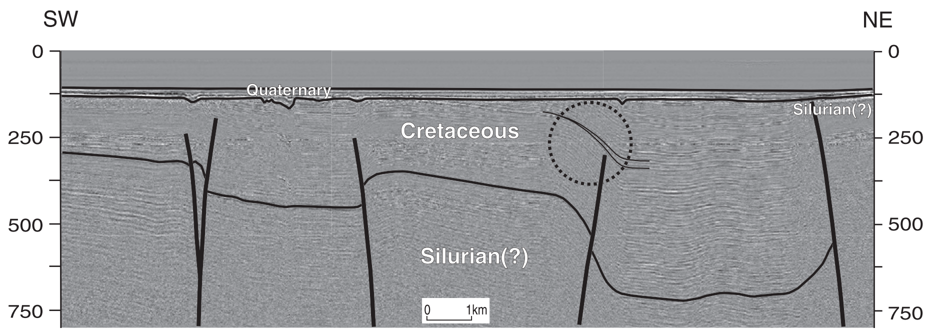

Fig. 6. Seismic example of the Upper Cretaceous depositonal and tectonic architecture related to inversion and strike-slip movements within the Bornholm–Darłowo Fault Zone. See Fig. 2 for location. Vertical scale—millisecond, two-way traveltime. Circle: area where subtle thickness change occur above inversion-related reverse fault, indicating syn-kinematic (i.e. syn-inversion) deposition.

indicators of the tectonic activity and uplift of such inverted fault (cf. Cartwright, 1989).

NW–SE-oriented seismic line provides another example of the Upper Cretaceous tectonic and depositional pattern from the Bornholm–Darłowo Fault Zone (Fig. 7). This line is crossed by the most SW part of the line B10A belonging to the multichannel seismic reflection survey completed in 1989 (comp. Sviridov et al., 1995 and their Fig. I.2.6a). However, detailed location data for line B10A of Sviridov et al. (1995) were not available, hence precise correlation of this line with the seismic line shown in Fig. 7 was not possible. Therefore, only general correlation of depositional units identified on both seismic lines was completed. Due to significantly smaller spatial coverage of the seismic experiment completed within the Polish territorial waters, it was not possible to distinguish all the depositional units described by Sviridov et al. (1995), and therefore some of the described depositional units include two units of Sviridov et al. (1995).

Along the line shown in Fig. 7, the very prominent progradational character of the Upper Cretaceous deposits can be observed. Within the entire Cretaceous sedimentary succession, five depositonal units delineated by the angular unconformities and their correlative conformities were distinguished. Seismic reflectors are generally high-amplitude, high-continuity events, and can be easily traced within the particular sequences. Due to significant—mostly post-depositional—uplift of pop-up structure formed above basement strike-slip fault and observed in the central part of Fig. 7, it was only partly possible to correlate particular seismic units across this structure.

Oldest depositional unit A (approximately equivalent to units 1 and 2 of Sviridov et al., 1995) identified along the seismic line presented in Fig. 7 rests directly on the Palaeozoic (Silurian?) basement. Within the NW part of this line (Fig. 7) its upper boundary is related to the prominent erosional unconformity developed below the base of the Quaternary. Unit B (approximately equivalent to unit 3 of Sviridov et al., 1995) is characterised by clearly progradational seismic pattern, with oblique clinoforms developed above unit A. Its upper boundary is also related to erosional unconformity below the base of the Quaternary. Unit B is onlapped by unit C (equivalent of units 4 and 5 distinguished by Sviridov et al., 1995) that is characterised by rather parallel and concordant reflectors. Erosional unconformity below the Quaternary succession is observed at the top of this unit. Youngest units D and E (equivalent

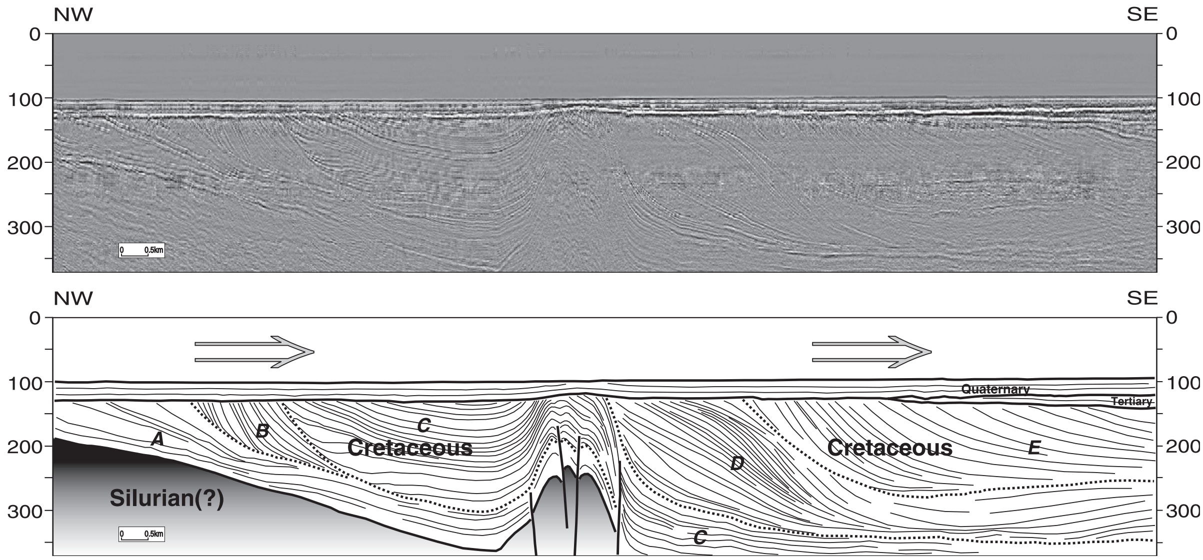

Fig. 7. Seismic example of Upper Cretaceous depositonal and tectonic architecture related to inversion and strike-slip movements within the Bornholm–Darłowo Fault Zone. See Fig. 2 for location. Dotted lines: boundaries of identified depositional units A, B, C, D, and E. Note prominent progradational pattern developed within the syn-inversion Upper Cretaceous succession. Arrows—general direction of progradation for the entire Upper Cretaceous inversion-related complex. See text for further explanations.

to units 6 and 7 of Sviridov et al., 1995, respectively) exhibit prominent progradational character, with upwards convex and concave tangential seismic pattern, becoming horizontal and aggradational towards the basin centre. Dips of progradation-related reflectors are in the order of 10–15°. Upper boundaries of these units are also defined by erosional unconformity beneath the Cenozoic (Tertiary and Quaternary) series. Observed progradational pattern points to the source area located generally towards N. It can be correlated with uplifted Bornholm Block, its erosion and deposition of syn-uplift (= syn-inversion) sediments. Internal depositional architecture described by five distinguished depositional units (A–E) reflects cyclic development of the Upper Cretaceous succession. Units A and C might represent two basin-fill stages under lower energy conditions, without significant sediment progradation. Units B, D and E formed under higher energy conditions, with more significant sediment supply and development of high-angle progradational sedimentary succession (comp. Sviridov et al., 1995). Prominent erosional unconformity between the Upper Cretaceous and Cenozoic successions indicates next stage of more regional uplift and erosion that was followed by rather uniform Cenozoic deposition.

Wrenching within the basement might have created additional accommodation space by relative downfaulting of the SW part of this strike-slip fault system (right part of seismic profile in Fig. 7). The added accommodation space could then be filled by rapidly prograding sedimentary bodies outbuilding from the uplifted Bornholm area. Sequence boundaries and other clearly visible key surfaces of the Upper Cretaceous succession are significantly deformed by pop-up structure related to strike-slip movements (Figs. 4, 5 and 7). Topmost part of the Cretaceous succession within the S Baltic Sea is dated as Maastrichtian (comp. Pożaryski and Witkowski, 1990); it can therefore be inferred that part of the NW–SE wrenching within the Bornholm–Darłowo Fault Zone took place also either during the latest Late Cretaceous, and/or in post-Cretaceous times.

Development of the Upper Cretaceous sedimentary succession imaged on high-resolution seismic data could have also been influenced by the Late Cretaceous third-order eustatic sea-level changes. During Late Cretaceous times, global sea-level was high, but numerous short-term variations are reported and are partly interpreted as a global features (Hardenbol and Robaszynski, 1998). Due to lack of wells penetrating Upper Cretaceous succession of the Bornholm–Darłowo Fault Zone it was, however, not possible to precisely date the sedimentary sequences observed on shallow high-resolution data and analyse them in a context of sea-level changes.

5. Discussion

Strike-slip movements are often associated with inversion tectonics, especially when compressional stresses driving the inversion are obliquely oriented to the tectonic zones present within the sedimentary basin undergoing inversion. Within the onshore part of the Mid-Polish Trough, both NW–SE (e.g. along the Koszalin–Chojnice zone) and SW–NE (e.g. along the Grójec fault zone) strike-slip movements have been documented (Dadlez, 1994; Krzywiec, 2000, 2002a). Its most north-western offshore part was inverted mostly without significant wrenching. However, as it was described in this paper, important strike-slip faulting took place within a wide zone located between Bornholm and the Polish coast, i.e. outside the Mid-Polish Trough proper (comp. Fig. 2). Strike-slip movements were associated also with inversion of other parts of the Danish–Polish Mesozoic basin system. For example, inversion of the Danish Central Graben was associated with important strike-slip movements that resulted in creation of positive flower structures (Mogensen and Jensen, 1994; Vejbæk and Andersen, 1987). In this area inversion tectonics was at least partly associated with syn-tectonic sedimentation, enhanced by uplift of basement blocks along reverse faults and their subsequent erosion (Cartwright, 1989), similarly to the Bornholm–Darłowo Fault Zone described in this paper. During Late Cretaceous inversion of these areas, older inherited faults were reactivated. The reactivated faults included both Caledonian and Variscan faults and faults related to the initiation and development of Permian–Mesozoic Peri-Tethyan basin system. Within the Bornholm–Darłowo Fault Zone, lack of well data necessary for stratigraphic calibration of seismic data did not allow for precise dating of tectonic movements along particular faults.

Tectonosedimentary pattern observed within the Bornholm–Darłowo Fault Zone suggests that uplift of the Bornholm realm rather then uplift of the Mid-Polish Trough was of much higher significance for development of its Upper Cretaceous sedimentary cover. Syn-tectonic deposits were clearly supplied generally from the north and north-west (i.e. from the area of the Bornholm Block), and no significant sedimentary input from the south-west (i.e. from the inverted and uplifted Mid-Polish Trough) can be observed on available seismic data. This suggests that in this part of the Mid-Polish Trough, the so-called marginal trough did not develop. Marginal troughs are related to sediment accumulation along the flanks of inverted basins, during erosion and redeposition of sediments from their uplifted axial parts. Development of marginal troughs was documented in various onshore parts of the Mid-Polish Trough (see Dadlez, 2001; Krzywiec, 2000, 2002a,b for detailed discussion and further references). Within the offshore part of this inverted sedimentary basin, apparently, uplift of its axial part was less significant in comparison to the uplift and erosion within the nearby-located Bornholm Block, whose erosion provided bulk of sediments for the Upper Cretaceous succession.

6. Conclusions

High-resolution seismic data acquired within the wide area between Bornholm and the Polish coast provide new information on a structural style of the Late Cretaceous tectonic activity related to inversion of the Mid-Polish Trough. The major features of the described tectono-sedimentary system include strike-slip and reverse faults within the Bornholm–Darłowo Fault Zone, in the area between the Koszalin Fault and the Christiansø Block. This wrench-dominated faulting was related to reactivation of the pre-Permian fault system caused by Late Cretaceous inversion of the Danish–Polish Mesozoic basin system. The main source area for syn-inversion sedimentation was provided by uplifted basement blocks, in particular by the Bornholm Block. Major sediment progradation within the Bornholm–Darłowo Fault Zone, especially in its central part, was generally towards the south–southeast. Late Cretaceous sediment progradation was enhanced by downfaulting along a strike-slip fault system and related expansion of accommodation space. Within the NE part of the Bornholm–Darłowo Fault Zone, close to the Christiansø Block, some syntectonic deposition also took place resulting in subtle thickness changes within the hinge zone of the inversion-related folds. NW–SE wrenching within the Bornholm–Darłowo Fault Zone took place also during the latest Late Cretaceous or post-Cretaceous times. It was followed by more regional uplift and erosion, responsible for formation of regional erosional unconformity between the Upper Cretaceous and the Cenozoic (Tertiary and Quaternary) successions. Lack of significant sediment supply from the inverted and uplifted offshore part of the Mid-Polish Trough suggests that in this area NW–SE-located marginal trough did not form, and instead uplifted Bornholm Block played by far more prominent role for development of syn-inversion depositional successions.

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