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Outline of the lithology and depositional features of the lower Paleozoic strata in the Polish part of the Baltic region

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Lower Paleozoic deposits have been noted in the western part of the Baltic Depression belonging to the Precambrian platform as well as in the Koszalin–Chojnice Zone that represents a hypothetical fragment of the Caledonian fold and thrust belt. Generally, the boundary between these regions is considered to run along faults belonging to the Teisseyre-Tornquist Zone. The deposits have been widely recognized in the East European Craton, and their entire lithological column has been drilled through in on- and offshore boreholes. New constructed lithofacies-thickness maps have updated the lithofacies diversity and thickness changes of the Ediacaran–lower Paleozoic deposits. The sedimentary infill of the Baltic Basin begins with deposits of the Żarnowiec Formation ascribed to the uppermost Ediacaran and lowermost Cambrian. The upper part of the Lower Cambrian comprises sandstones and mudstones and the Middle Cambrian is made of sandstones, mudstones and claystones. Upper Cambrian to Tremadocian strata are represented by dark bituminous shales. Arenigian to Ashgillian deposits are developed as thin calcareous-muddy deposits. Silurian strata represent a thick (over 3000 m) succession of siltstones and shales with subordinate calcareous intercalations in the upper part of the succession (Pridoli). In the Koszalin–Chojnice Zone only, fragments of tectonically disturbed Ordovician and Silurian shales and siltstones have been recognized.

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INTRODUCTION

In the Polish Exclusive Economic Zone of the Baltic Sea and the nearby onshore area, lower Paleozoic deposits have been recognized on both sides of the Teisseyre-Tornquist Tectonic Zone (TTZ), commonly accepted as the boundary of the East European Craton (EEC; Znosko, 1962, 1998; Dadlez, 2000; Fig. 1). The lower Paleozoic strata in the marginal part of the EEC represent a fragment of a more extended sedimentary cover deposited on a Precambrian basement. This area represented a pericratonic marine basin developed on a crystalline peneplain, slightly tilted to the south-west. The western part of the Baltic Depression, the attraction of which has increased owing to the discovery of oil fields in the Cambrian deposits, is located directly on the craton slope, abutting from the east to faults linked within the TTZ, whereas the lower Paleozoic in the Koszalin–Chojnice Zone, situated within the Trans-European Suture Zone (TESZ) is considered to represent a hypothetical fragment of the Caledonian fold and thrust belt *sensu* Znosko (1962, 1998).

Knowledge of the lower Paleozoic strata in both regions varies significantly; they have been well-documented on the EEC in numerous boreholes drilled on- and offshore, whereas to the west of the TTZ Cambrian deposits have not been discovered at all, and Ordovician to Silurian strata have been observed only fragmentarily in less than twenty boreholes (Fig. 1).

In order to compare the development of the lower Paleozoic deposits of the western part of the East European Craton and of the Koszalin–Chojnice Zone a stratigraphic and facial analysis has been carried out. The results combined with previous lithological, biostratigraphical and sedimentological studies have revealed the general outline of the stratigraphy and depositional features of these deposits in both regions.

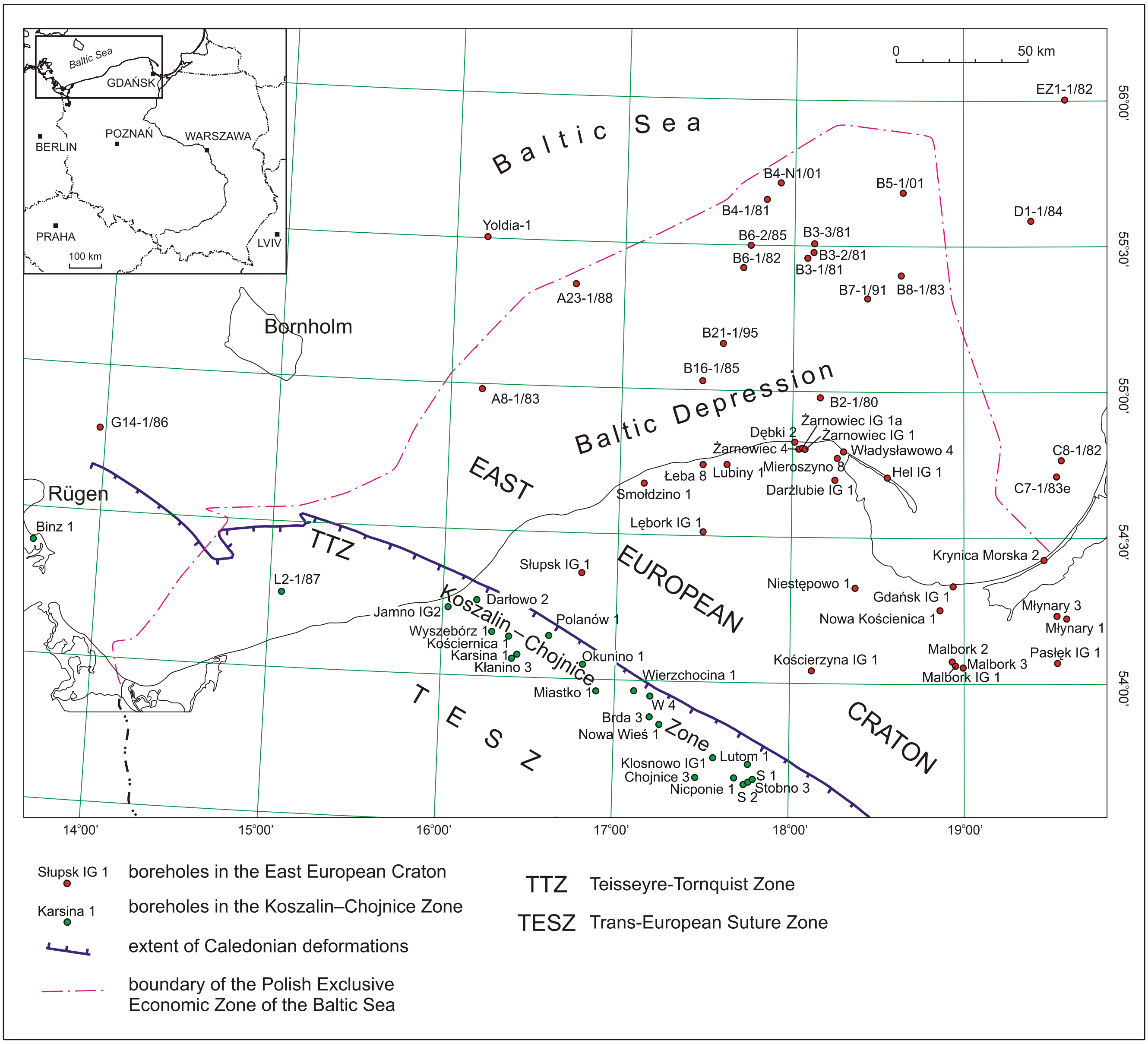

Fig. 1. Location of selected boreholes with Ediacaran–lower Paleozoic deposits in the Polish part of the Baltic region

DATA USED

Characterization of the stratigraphy and development of sedimentary infill of the early Paleozoic Baltic region as well as of the Koszalin–Chojnice Zone is based on systematization and updating of earlier studies conducted on the key borehole sections located on both sides of the Teisseyre-Tornquist Zone (i.a., Modliński and Szymański, 1997; Jaworowski, 1999, 2000*a*, Modliński *et al.*, 2006; Podhalańska and Modliński 2006; Podhalańska, 2007, 2009). Previous research has been complemented by recent stratigraphical, palaeontological and sedimentological data provided by the authors. A number of lithostratigraphical units distinguished in the Ediacaran–lower Paleozoic succession of the EEC, and their general depositional environments, are described in relation to craton margin depositional sequences determined by Jaworowski (1999). Interpretation of the depositional environments of the succession is based on the results of previous studies (i.a., Jaworowski, 1998, 2000*a*; Jaworowski and Sikorska, 2003; Podhalańska and Modliński, 2006; Podhalańska, 2007, 2009) as well as on a new stratigraphical and facies analysis. Lithofacies-thickness maps showing the general lithofacies trends have been constructed on the basis of analysis of key boreholes selected from among several tens of boreholes drilled on both sides of the TTZ (Fig. 1).

DEPOSITIONAL HISTORY

WESTERN PART OF THE EAST EUROPEAN CRATON

The sedimentary cover of the East European Craton in North Poland begins with Ediacaran and Cambrian deposits. There is no data on their presence to the west of the TTZ in the

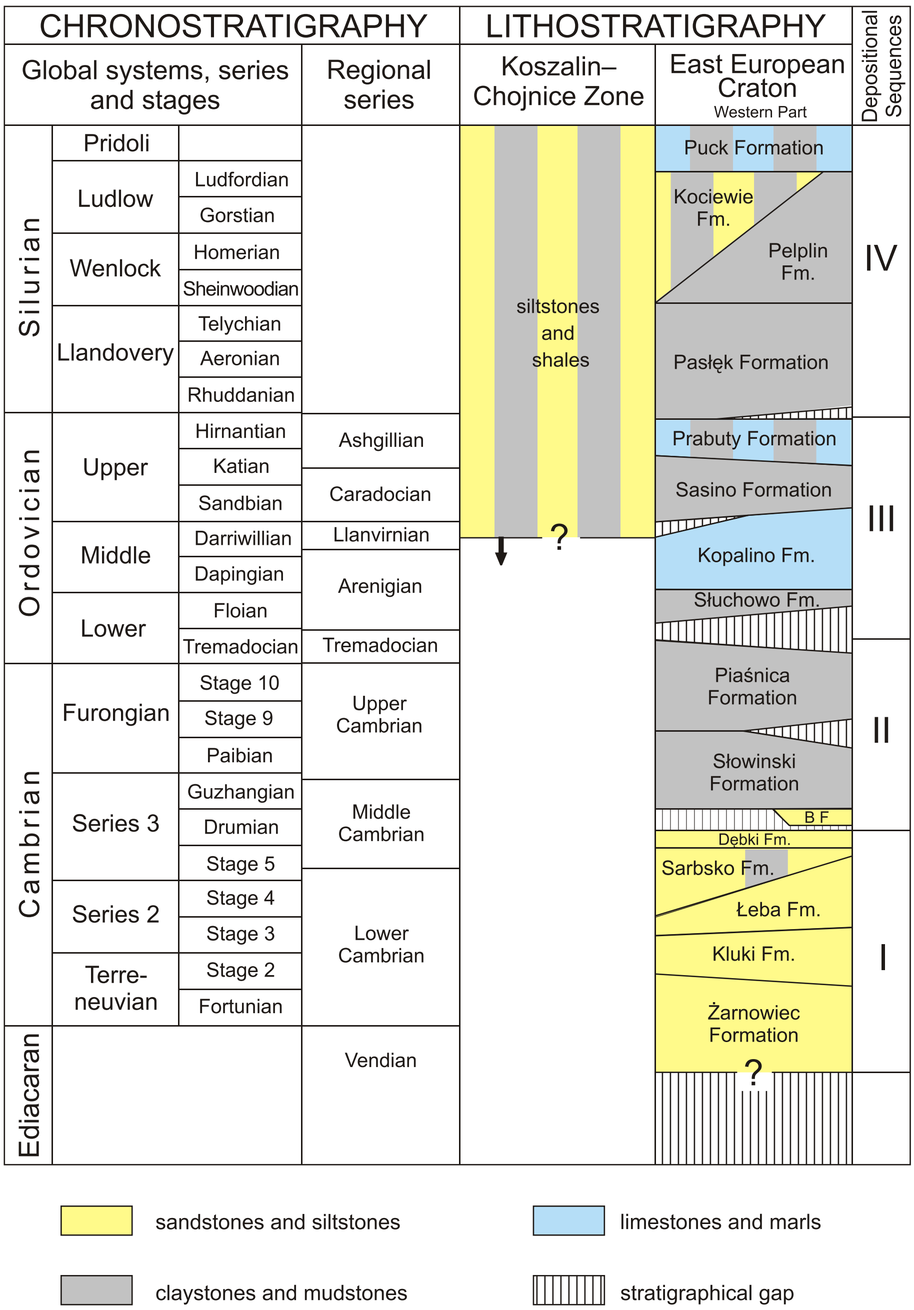

Fig. 2. Stratigraphic chart of the Ediacaran–lower Paleozoic in the Polish part of the Baltic region: Koszalin–Chojnice Zone and the western part of the Baltic Depression; depositional sequences after Jaworowski (1999)

BF – Białogóra Formation

Koszalin–Chojnice Zone. In the part of the Baltic Depression studied, deposits of this age have been noted in numerous boreholes located onshore, as well as in about twenty offshore boreholes within the Polish Exclusive Economic Zone in the Baltic Sea and in the offshore borehole G14-1/86 in the German Economic Zone (Franke *et al.*, 1994).

The lower Paleozoic strata on the EEC, subdivided by Jaworowski (1999, 2002) into four depositional sequences, represent a fragment of a more extended sedimentary cover deposited on a Precambrian basement. According to this subdivision, depositional sequence I includes the upper Ediacaran to Middle Cambrian deposits (without the uppermost part). Depositional sequence II is composed of the deposits of upper Middle Cambrian to lower Tremadocian; sequence III is represented by the Arenigian to Ashgillian deposits without the uppermost part and sequence IV consists of the Llandovery to Pridoli deposits (Fig. 2).

Depositional sequence I begins with the deposits of the Żarnowiec Formation (Lendzion, 1970; Jaworowski and Sikorska, 2003), lying directly on crystalline rocks and as-

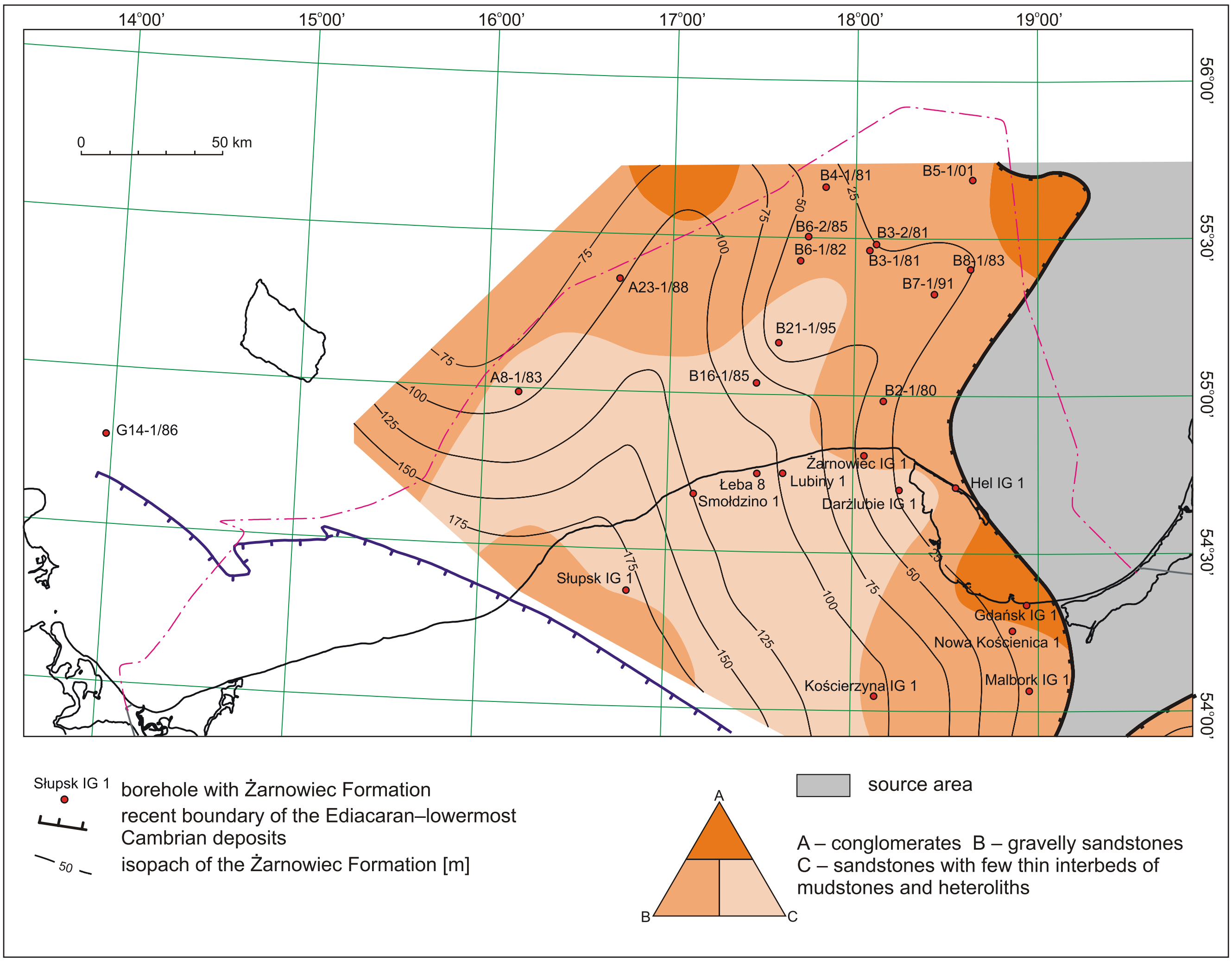

Fig. 3. Lithofacies-thickness map of Ediacaran–lowermost Lower Cambrian deposits (Żarnowiec Formation) after Jaworowski and Sikorska (2010)

Other explanations as in Figure 1

signed to the Ediacaran–lowermost Lower Cambrian. The upper boundary of the sequence is situated at the erosional unconformity at the base of the Białogóra Formation (Fig. 2). Sedimentary infill of the Baltic Basin began with terrestrial deposits of the Żarnowiec Formation represented by poorly sorted sandstones (quartz and arkozic wackes) and conglomerates, pink-grey to cherry-red in colour. The strata were deposited in terrestrial conditions in alluvial fan and braided river plain settings (Jaworowski and Sikorska, 2003). Higher up they pass into continental-marine deposits within deposits of fan-deltas and braided deltas. The thickness of this formation increases to the south-west and varies from about 10 m in the Hel IG 1 section to over 150 m in the Słupsk IG 1 borehole (Fig. 3). Equivalents of the Żarnowiec Formation are probably the Nexø sandstones on Bornholm and the Adlergrund Sandstein Formation in the G14-1/86 borehole.

Deposits of the Żarnowiec Formation pass continuously into the Lower Cambrian Kluki Formation. This formation is represented by fine-grained sandstones, siltstones and sandstone-mudstone heterolithic deposits. The deposits were formed in a marine setting; the sandstones represent tidal shore sands, and the mudstons and heterolithic deposits represents the transition zone between tidal shore sands and shelf muds (Jaworowski, 1998). The maximal thickness of the Kluki Formation reaches about 200 m.

The succeeding unit is the Łeba Formation, represented mainly by sandstones with glauconite and phosphoritic concretions and by sandstone-mudstone heterolithic deposits. These deposits belong to the Lower Cambrian *Holmia* and *Protolenus* zones. They were formed mainly in the transition zone between tidal shore sands and shelf muds (Jaworowski, 1998). Their thickness reaches from tens of metres to maximally 185 m.

The overlying Sarbsko Formation (Bednarczyk and Turnau-Morawska, 1975) comprises black claystones, dark grey mudstones and mudstone-sandstone heterolithic deposits. The deposits are commonly assigned to the uppermost part of the Lower Cambrian *Protolenus* Zone and to the Middle Cambrian *Acadoparadoxides oelandicus* and lower part of the *Paradoxides paradoxissimus* zones. They represent shelf muds, locally with storm beds (Jaworowski, 1998). The thickness of the formation exceeds 200 m.

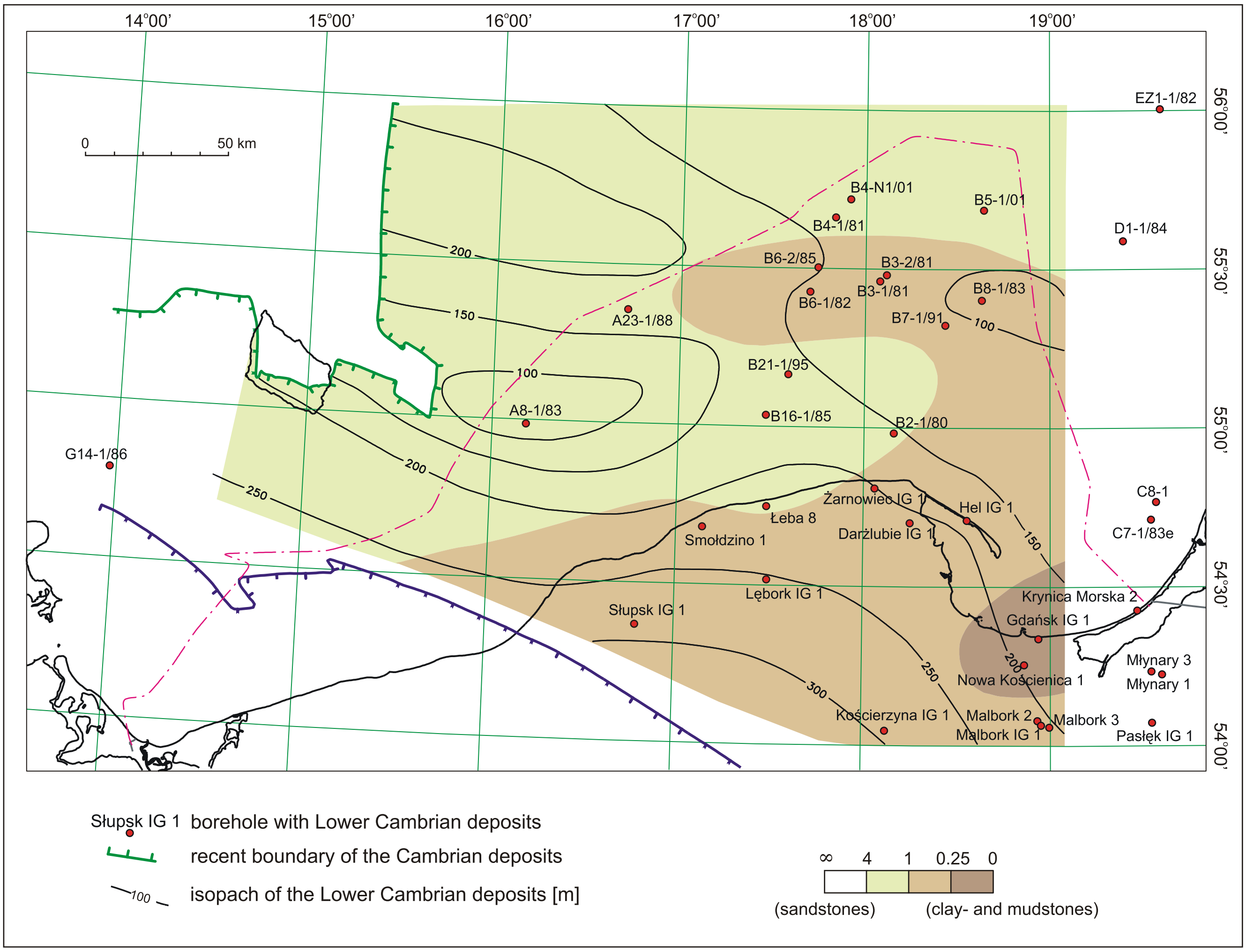

Fig. 4. Lithofacies-thickness map of Lower Cambrian deposits after Lendzion (1998) supplemented by Modliński

Other explanations as in Figure 1

The total thickness of the Lower Cambrian varies from about 100 m (A8-1/83 borehole) to about 300 m near the Kościerzyna IG 1 borehole (Fig. 4).

Above the Sarbsko Formation occurs the Dębki Formation assigned to the lower part of the Middle Cambrian – the *Paradoxides paradoxissimus* Zone. It is developed as light-grey, fine- to medium-grained quartz sandstones with rare interbeds of sandstone-mudstone heterolithic deposits. These deposits were formed as tidal shore sands whereas the rare sandy-muddy interbeds represent the transition zone to shelf muds (Jaworowski, 1998). The Middle Cambrian deposits (Dębki Fm.) are the main potential hydrocarbons reservoir rocks in the lower Paleozoic succession. The thickness of this formation reaches 80 m.

Locally, the Dębki Formation is overlain by the Osiek Formation comprising mudstones and mudstone-sandstone heterolithic deposits. These deposits are assigned to the upper part of the Middle Cambrian *Paradoxides paradoxissimus* Zone. The formation indicates sedimentation of shelf muds and the transition zone between shelf muds and tidal sands (Jaworowski, 2000*b*). The thickness of this formation is small and does not exceed 30 m. The thickness of the Middle Cambrian deposits reaches 300 m in the Łeba Block (Fig. 5).

Depositional sequence II begins with a distinct erosional unconformity at the base of the Białogóra Formation (Fig. 2). The upper sequence boundary is determined at the erosional unconformity between the Piaśnica Black Bituminous Shale Formation (Piaśnica Fm.) and the Słuchowo Shale with Glauconite Formation (Słuchowo Fm.; Fig. 2). The Białogóra Formation is represented by poorly-sorted quartz sandstones with glauconite and numerous phosphoritic clasts. This unit is assigned to the Middle Cambrian *Paradoxides forchhammeri* Zone. The deposits developed in the nearshore part of a shallow sea and represent the basal member of the succeeding marine transgression (Jaworowski, 2000*b*). The formation occurs only locally and its thickness does not exceed 4 m.

The maximum thickness of the Middle Cambrian strata reaches about 300 m in the zone between the B2-1/80 borehole and the Kościerzyna IG 1 borehole (Fig. 5).

The uppermost units of the Cambrian are the Słowiński and Piaśnica formations (Bednarczyk and Turnau-Morawska, 1975), represented by bituminous shales with thin interbeds

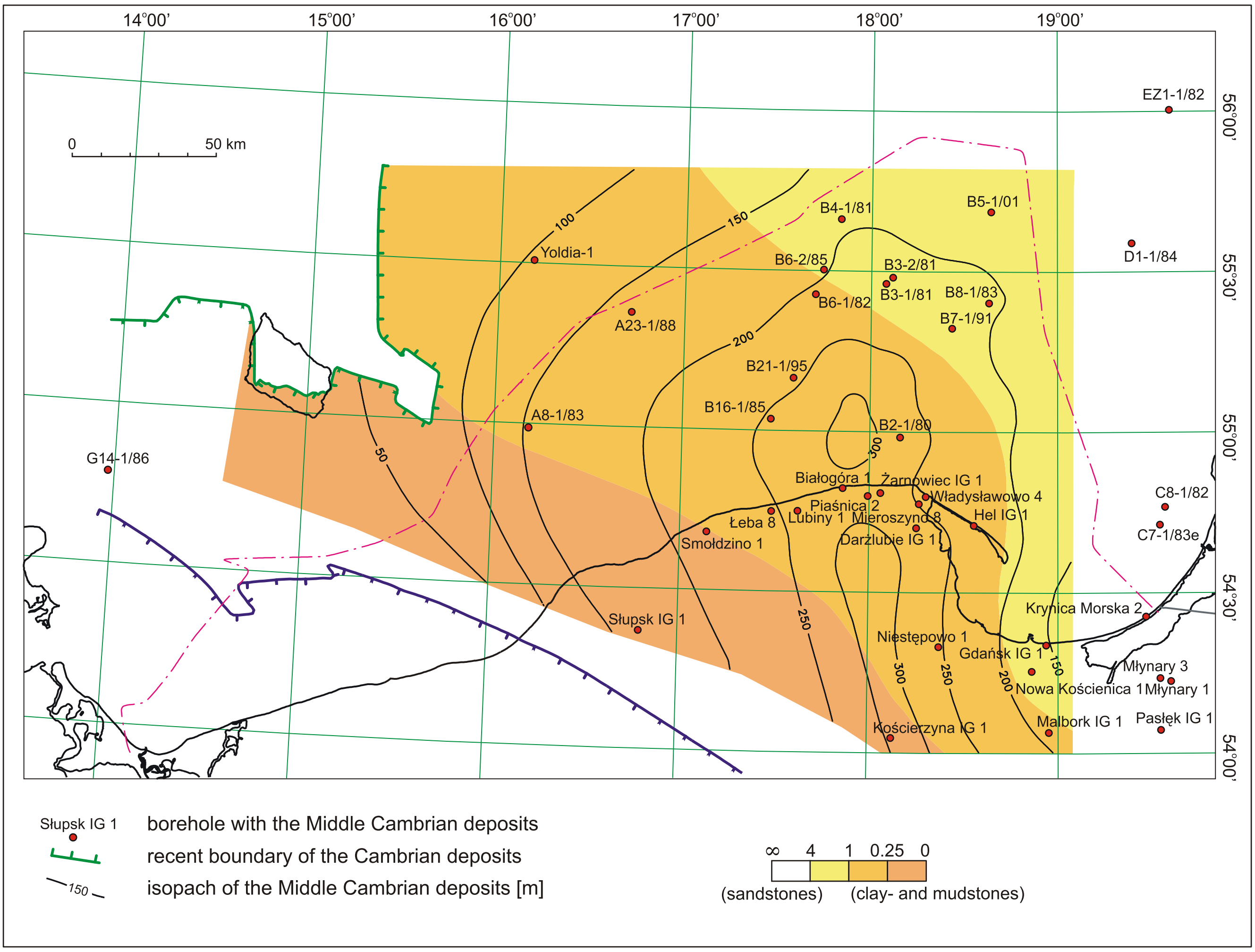

Fig. 5. Lithofacies-thickness map of Middle Cambrian deposits after Lendzion (1998) supplemented by Modliński

Other explanations as in Figure 1

and lenses of dark, often bioclastic limestones. These highstand system tract (HST) deposits belong to the uppermost part of the Middle Cambrian and the Upper Cambrian (*Agnostus pisiformis–Acerocare* zones). The uppermost part of the Piaśnica Formation terminates the lithological column of the depositional sequence II and reaches to the lower Tremadocian. These deposits represent shelf muds deposited in anoxic conditions. They correspond to the alum shales of Scandinavia (Jaworowski, 1998). The Upper Cambrian–Tremadocian claystones of the Piaśnica Formation represent the main potential horizon of the oil source rocks. According to lithofacies-thickness analysis the maximum thickness of these deposits reaches about 35 m (Fig. 6).

Ordovician strata have been noted on both sides of the TTZ, i.e. in the western part of the Baltic Depression and in the Koszalin–Chojnice Zone.

In the offshore and onshore part of the Baltic Depression Ordovician strata were recognized in numerous boreholes, of which several were fully cored. This allowed precise determination of the boundaries between the lithostratigraphical units distinguished as well as the location of boundaries between Ordovician regional British series and Baltic stages (Modliński and Topulos, 1974; Modliński and Szymański, 1997) as well as some global stages (Fig. 2).

The lithological column of the lowermost Tremadocian occurs in stratigraphic and sedimentary continuity with the Upper Cambrian strata and is represented by the topmost part of black bituminous shales of the Piaśnica Formation. The present-day range of these deposits is restricted by erosion, covers only a small fragment of the Polish part of the Baltic Sea and its thickness varies between 0 to 8.5 m. Its equivalents in Bornholm, Scania and Öland are lower Tremadocian bituminous shales traditionally referred to the "*Dictyonema* Shale" (Hede, 1951; Bergström, 1982).

Depositional sequence III in the Baltic region begins with the washed-out top of the Piaśnica Formation, overlain by transgressive shales with glauconite of the lowermost Słuchowo Formation. The upper sequence boundary corresponds to the erosional surface on the top of the Prabuty Marl and Shale Formation (Prabuty Fm.). The Słuchowo Formation comprises dark grey and black shales with intercalations and horizons of grey-green shales with a basal conglomerate. In the vicinity of Żarnowiec and Łeba and in offshore boreholes, the thin (0–0.7 m) Odargowo Limestone Member is recognized within this formation. The age of the

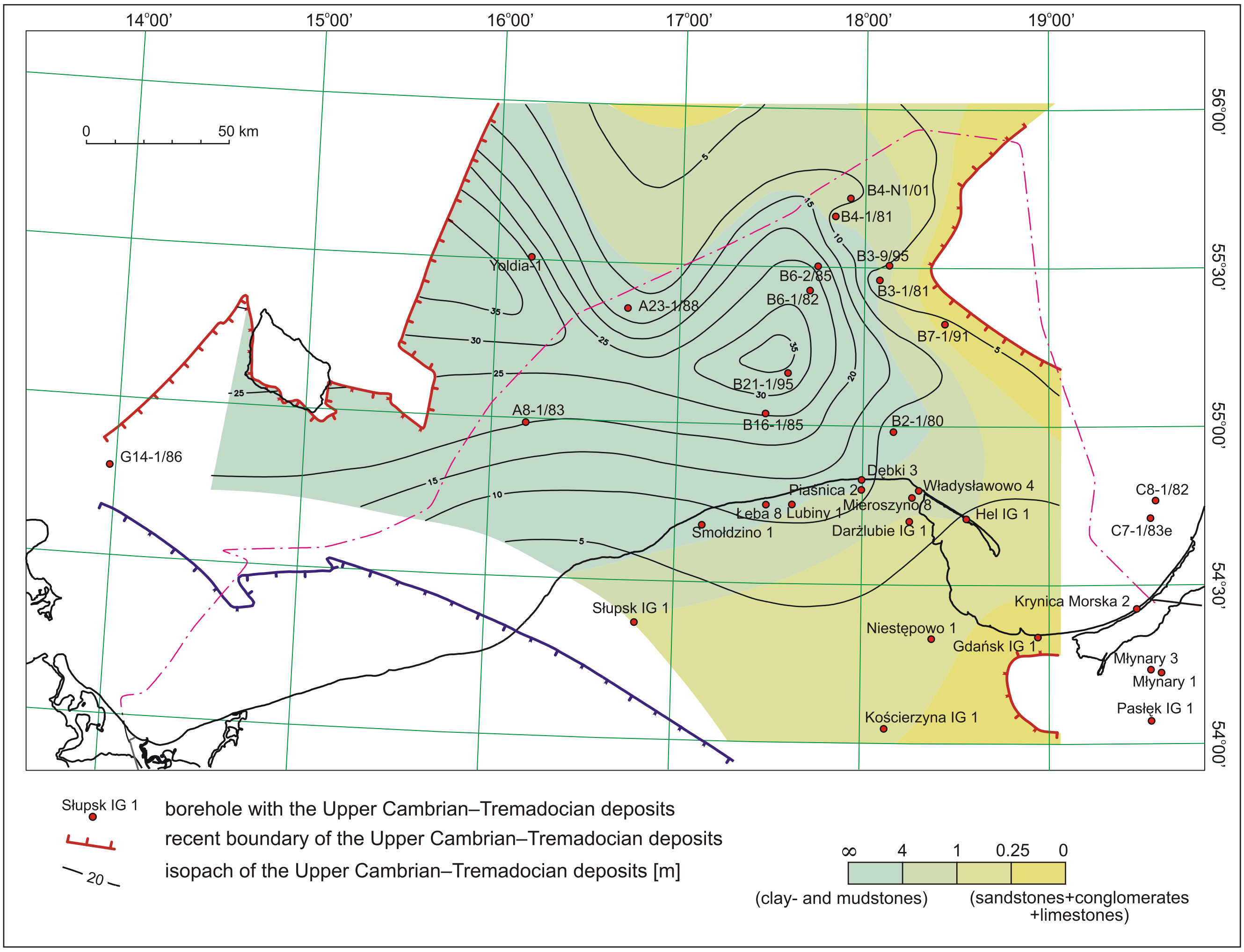

Fig. 6. Lithofacies-thickness map of Upper Cambrian to Tremadocian deposits based on archival data of Lendzion (1998)

Other explanations as in Figure 1

formation was determined as Arenigian (Latorp Stage in the Baltic subdivision). The shales were formed in the shallower part of a muddy plain or at the boundary between the deeper and shallower part of the open shelf, characterized by temporarily dysoxic or anoxic waters. These rocks mostly represent HST deposits. The thickness of the formation varies from 3 to 20 m. Its lithostratigraphic equivalents in Scania are the lower *Didymograptus* Shales, recently known as the Tøyen Shale (Bergström, 1982; Jaanusson, 1982).

Above the Słuchowo Formation the Kopalino Limestone Formation (Kopalino Fm.) occurs, mainly represented by marly limestones with numerous bioclasts; subordinate limestones and organodetritic limestones are also present. The faunal assemblage identified documents the upper Arenigian–lower Llanvirnian, corresponding to the Volkhov–Aseri strata in the Baltic Depression. The deposits were formed in a deeper part of a vast carbonate ramp within the range of storm wave base. The thickness of the formation varies from *ca*. 5 to 20 m in onshore sections and from below 1 to about 30 m in offshore sections. The lithological equivalent of this unit on Bornholm and in Scania is the Komstad Limestone Formation (Bergström, 1982).

This unit is overlain by the Sasino Shale Formation (Sasino Fm.), representing the highstand deposits in depositional sequence III. It is represented by black, dark grey and green-grey shales, often bituminous, in some cases calcareous and/or silicified. These shales contain intercalations and laminae of tuffites and bentonites. The Sasino Formation comprises strata from the upper Llanvirnian to the uppermost Caradocian, which correspond to the Lasnamägi to Vormsi Baltic stages representing the upper Llanvirnian–Caradocian HST deposits in the Baltic area (Nielsen, 2004). The depositional environment was referred to the distal part of the shelf and upper slope, periodically being under the influence of storm wave base. The thickness of this unit reaches up to 35 m in onshore sections and about 70 m in offshore sections. Its equivalents in Scania and Bornholm are the *Dicellograptus* Shales (Bergström, 1982).

The uppermost part of the Ordovician succession is assigned to the Prabuty Marl and Shale Formation (Prabuty Fm.). The unit is composed of marls and shaly marls, as well as mudstones and calcareous shales, grey to dark grey. In some sections, the uppermost part of the succession comprises quartz sandstone or sandy

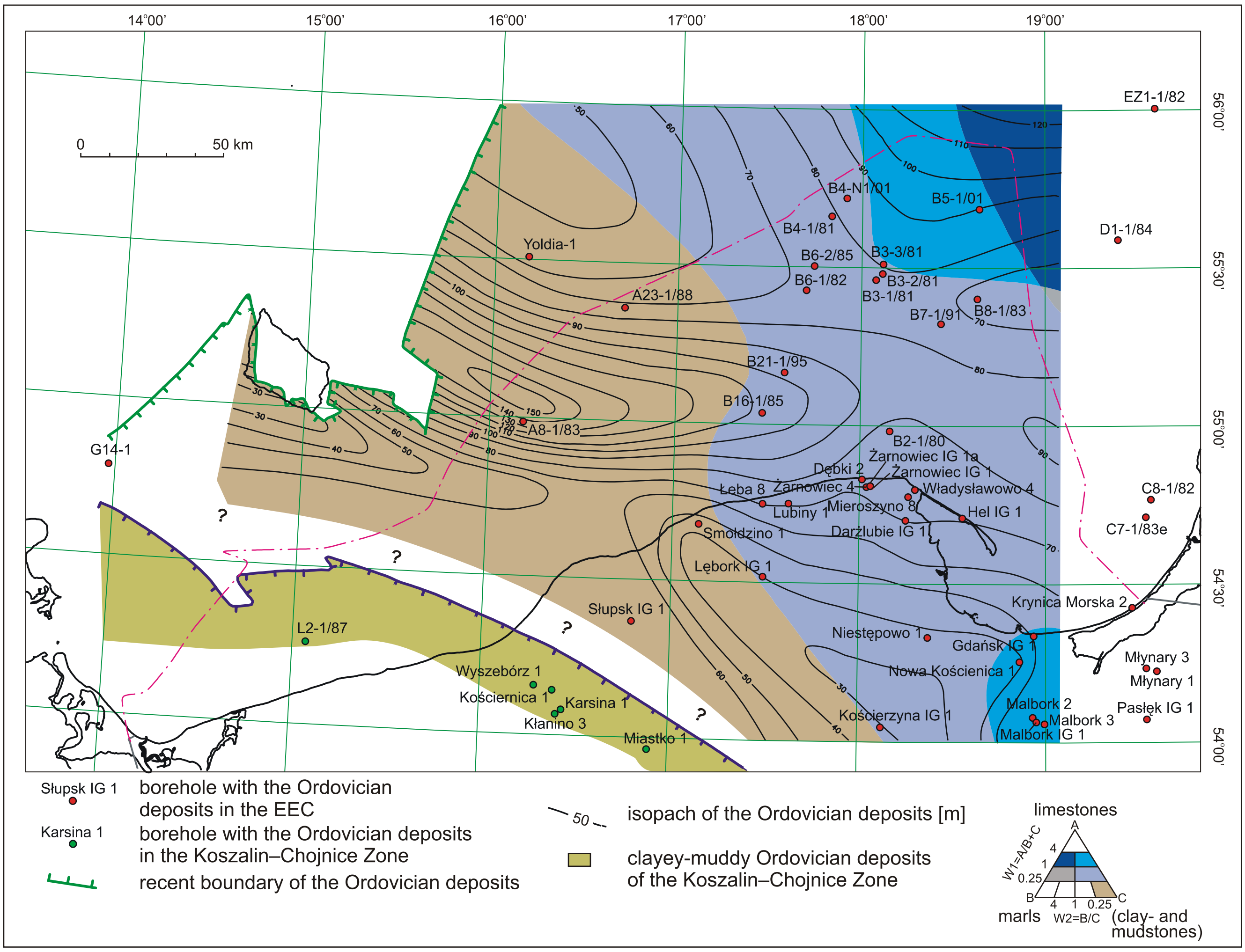

Fig. 7. Lithofacies-thickness map of Ordovician (Arenigian–Ashgillian) deposits

Other explanations as in Figure 1

mudstones beds. The deposits have been assigned to the Ashgillian, corresponding to the Baltic Pirgu and Porkuni stages, representing lowstand system tract (LST) deposits in the Upper Ordovician succession (Nielsen, 2004). The sedimentary setting, as for the Sasino Formation, represented an outer shelf. The thickness of the formation varies from 3 to 20 m. In Scania and Bornholm the lithostratigraphic equivalents of the lower part of the formation are the Jerrestad Shales, and of the upper – the Tommarp Shales (Bergström, 1982). The total thickness of depositional sequence III (Ordovician strata from Arenigian to Ashgillian) varies from about 30 m in the Kościerzyna IG 1 borehole to about 150 m in the A8-1/83 borehole, and the general lithofacies trend is related to the southwesterly increase of the shaly content in deposits (Fig. 7).

Lithofacies studies have indicated the regressive character of the Upper Ordovician depositional succession. The peak of regression, expressed by the deposition of sandstones in the upper part of the Prabuty Formation, took place in the late early Hirnantian (Hirnantian regressive event). The regression in the Polish part of the Baltic region , as in other parts of the Baltic region corresponds to the eustatic sea level fall linked with climatic cooling and Gondwana glaciation (Podhalańska, 2009).

A profound sea level rise started during the graptolite *Normalograptus persculptus* Chron. The drowning event extended into the Silurian is recorded by the bituminous claystones and mudstones of the lower part of the Pasłęk Formation (Jantar Member; Podhalańska, *op. cit.*).

Depositional sequence IV begins with an erosional unconformity at the top of the Prabuty Formation and includes the Llandovery to Pridoli deposits and probably the uppermost Ashgillian in the deepest part of the basin. The upper sequence boundary is determined at the top of the Puck Formation (Fig. 2).

In the offshore and onshore part of the Baltic Depression, Silurian deposits have been drilled by a large number of boreholes, and the uppermost part of the succession was also noted in numerous boreholes in the Puck Bay area. Notable is the Lębork IG 1 core, in which Silurian deposits, 2245.2 m thick, were observed. These were almost completly cored allowing precise location of all stage boundaries and determination of their ranges using index data for standard biostratigraphic zones (Tomczyk, 1968, 1976; Szymański and Modliński, 2003).

The Silurian succession forming depositional sequence IV in the lower Paleozoic cover of the EEC, is represented by a thick,

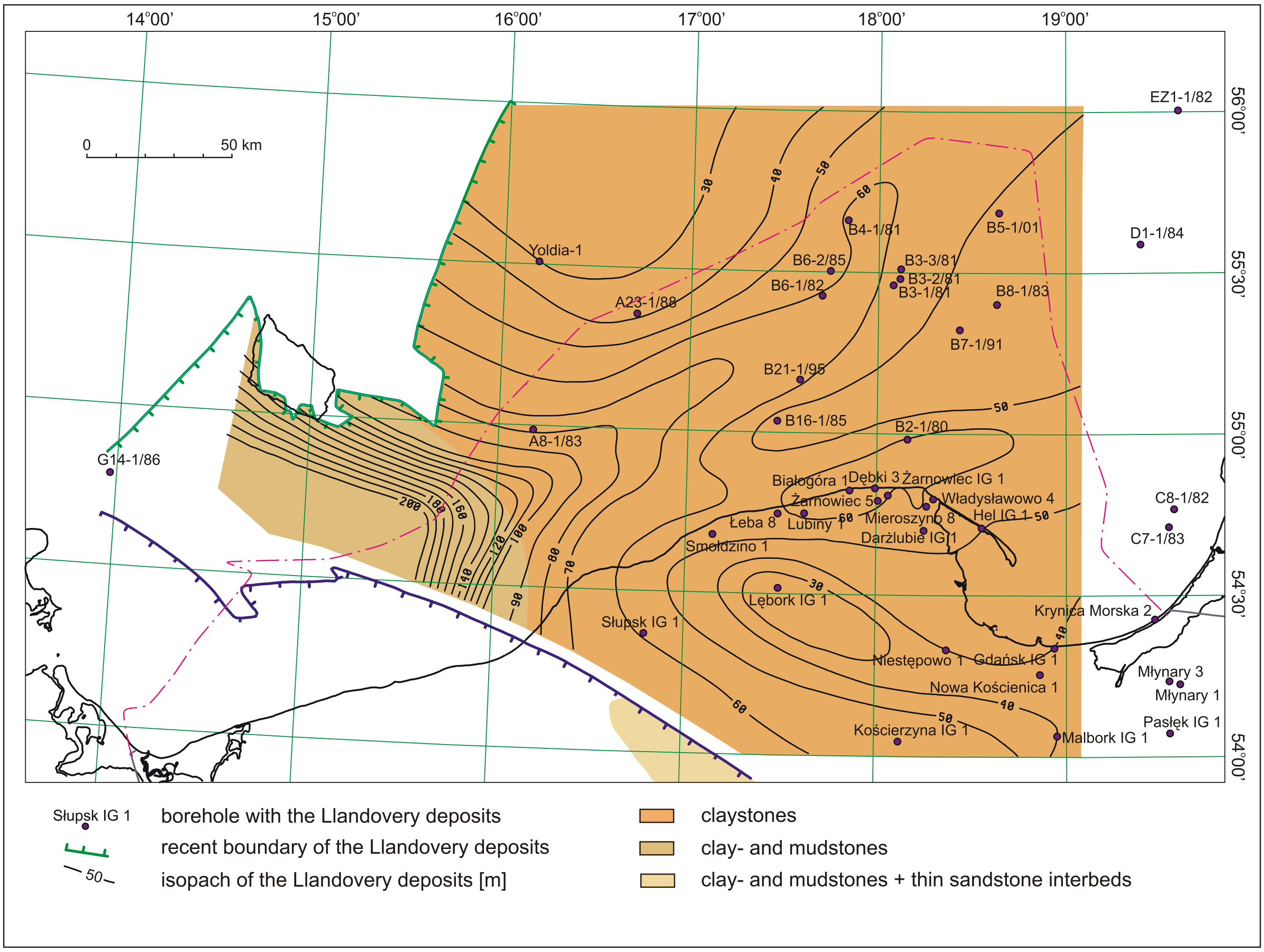

Fig. 8. Lithofacies-thickness map of Llandovery deposits

Other explanations as in Figure 1

monotonous siliciclastic succession (Tomczyk, 1962, 1968; Jaworowski, 2000*a*; Szymański and Modliński, 2003; Podhalańska and Modliński, 2006). The succession is dominated by claystons and mudstones, with thin interbeds of fine-grained quartz sandstone. Other deposits occur subordinately and include thin interbeds of pyroclastic (bentonites, tuffites) and carbonaceous rocks (marls, marly and organodetritic limestones), the occurrence of which is linked with the uppermost part of the Silurian succession – Pridoli. The Silurian sequence does not contain intraformational sedimentary gaps, which results in a continuous sedimentary record. Silurian deposits in the western part of the Baltic region were considered by Jaworowski (2000*a*) to represent exoflysch accumulated in a Caledonian foreland basin on the edge of EEC.

The uppermost Ordovician Prabuty Formation, partly eroded away at the top, is usually unconformably covered by the Pasłęk Shale Formation (Modliński *et al.*, 2006), representing the lower part of depositional sequence IV in the lower Paleozoic cover of the East European Craton (Fig. 2). In the lower part the unit is represented by black bituminous transgressive shales (Jantar Bituminous Shales Member), passing upwards into dark grey and grey shales interlaminated with green, grey-green and black shales. Subordinate interbeds of brown-red and brown calcareous shales occur in some sections. Rare thin marl and marly limestone beds as well as bentonite laminae have been observed. This formation is assigned to the Llandovery; some sections, e.g. the Białogóra 2 or Lębork IG 1 boreholes, may also encompass the uppermost Ashgillian *Normalograptus persculptus* Zone (Tomczykowa and Tomczyk, 1976; Podhalańska, 2003, 2009). The depositional environment can be compared with the medial part of an open or periodically isolated (?) epicontinental shelf with a dominance of settings with low coarse material supply. The rocks indicate deposition of material within an open siliciclastic shelf with relatively calm hydrodynamic conditions, in dysoxic or periodically anoxic conditions (Jaworowski, 2000*a*, *b*, 2002; Podhalańska, 2009). The formation occurs over the entire area of the Polish part of the Baltic region, and its thickness varies from about 15 to 100 m to the west (Fig. 8).

The following unit is the Pelplin Shale Formation (Pelplin Fm.; Modliński *et al.*, 2006). Its lower part is dominated by dark grey and grey, rarely black shales, in some cases calcareous with thin interbeds and lenses of marly limestones. The upper part is composed of grey and grey-green laminated shales,

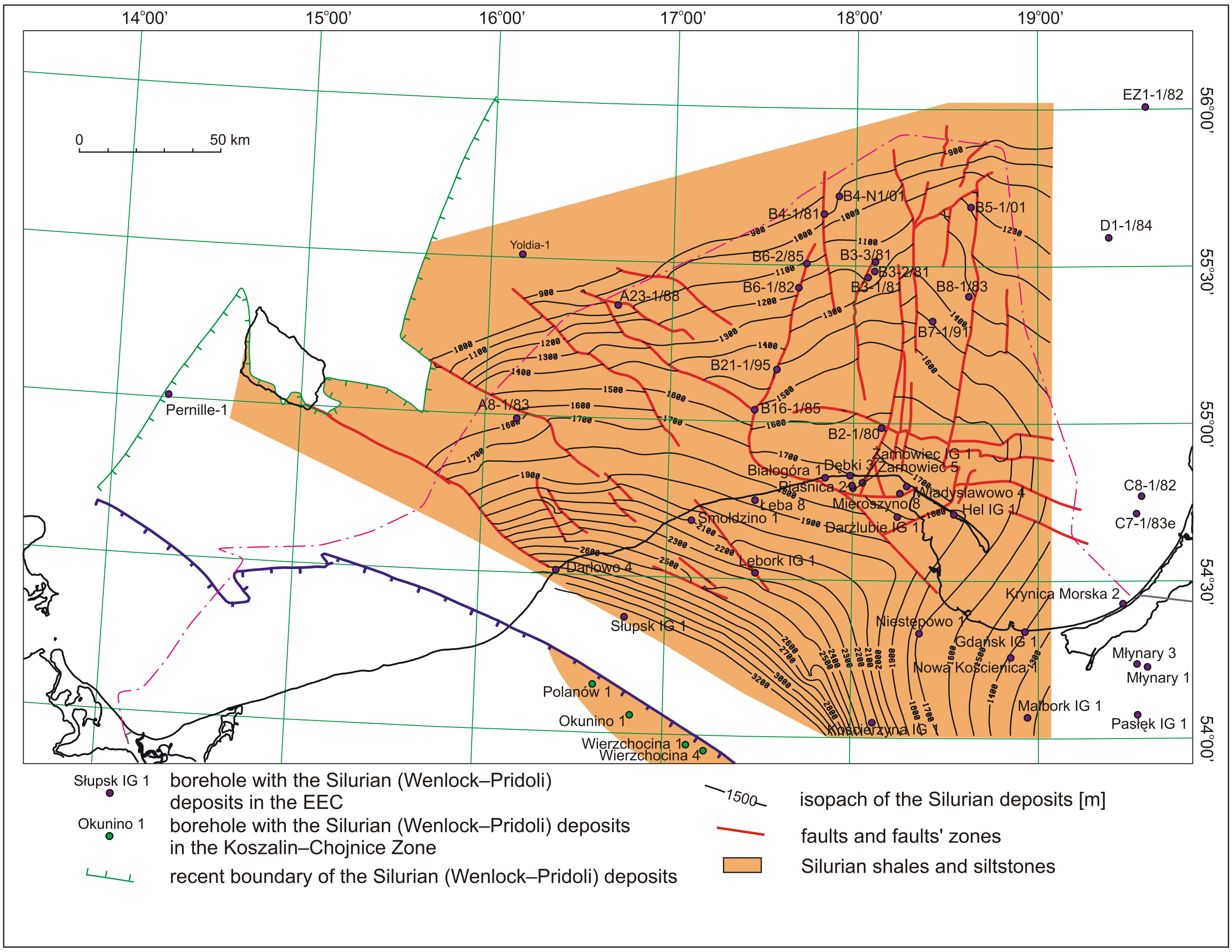

Fig. 9. Lithofacies-thickness map of Wenlock–Pridoli deposits

Other explanations as in Figure 1

often calcareous. Subordinate bentonite laminae occur within the shales. The lower boundary of the formation roughly corresponds to the base of the Wenlock, whereas the upper boundary is diachronous within various zones of the Wenlock and Ludlow. Deposits of this formation may be compared with the muds of the distal part of an outer siliciclastic shelf and slope, the hemipelagic depositional settings of which were depleted as regards the supply of coarse terrigenous material. The bottom zone was characterized by periodically restricted circulation and poor oxygenation of the water, leading to reducing conditions. The formation is distributed over almost the entire Polish part of the Baltic region; it is lacking near Słupsk where it thins out completely. The maximum thickness reaches about 400 m (Żarnowiec IG 1 and Prabuty IG 1 boreholes).

Deposits of the Pelplin Formation gradually pass into the Kociewie Shales and Siltstones Formation (Kociewie Fm.). This unit comprises grey and dark grey shales and calcareous shales, commonly intercalated with light grey and grey siltstones and calcareous siltstones. Sporadic thin intercalations and bentonite laminae occur. Siltstone intercalations yield numerous sedimentary structures with many sole marks, horizontal and ripple lamination and graded bedding (Jaworowski, 1971, 2000*a*). The Kociewie Formation is assigned to an interval from the lower Wenlock to the upper Ludlow, and the sequence is most complete in the western part of the area in the Słupsk IG 1 borehole.

Shales and siltstones were deposited in a hemipelagic environment. The generally slow sedimentation from suspension was interrupted by numerous submarine gravity flows supplying silty material to the basin. Following Jaworowski (2000*a*, *b*, 2002) some siltstone deposits can be considered as the products of deposition from cohesive flows, akin to clast-poor debrites. Massive siltstone beds passing gradually into shales reflect in turn two sedimentary processes linked together – cohesive flow of silty material and turbidity currents. Siltstone beds with sharp basal surfaces, numerous current hieroglyphs, gradually passing at their tops into shales, undoubtedly represent deposits of turbidity currents.

The source area for the silty material in the shale-siltstone succession of the formation was a Caledonian accretionary prism located along the collision zone between Baltica and East Avalonia (Jaworowski, 2000*a*, 2002). The thickness of this formation varies from 300–400 m near Pasłęk, Gdańsk and Żarnowiec to over 3000 m in the Słupsk IG 1 borehole.

Lithological equivalents of the Kociewie Formation are the “Silur Skiefer” on Bornholm in the western part of the Baltic Depression (Nielsen, 1993).

The Reda Calcareous Siltstone Member is distinguished in the upper part of the Pelplin Formation, comprising an upper Ludfordian isochronous horizon (Urbanek and Teller, 1997; Szymański and Modliński, 2003). The member comprises calcareous siltstones with shale laminae and interbeds, from 10 to 30 m thick. This is the most characteristic lithostratigraphic and geophysical horizon within the monotonous upper Silurian succession.

The terminal unit in the Silurian succession is represented by the Puck Shales and Calcareous Shales Formation (Puck Fm.; Modliński *et al.*, 2006). In the lower part it comprises shales and calcareous laminated grey to green shales, sporadically with bentonite laminae, passing upwards into laminated, grey-green calcareous shales, with interbeds and lenses of marly and organodetrital light grey limestones and marls. The formation encompasses the uppermost Ludlow *Hemsiella hemsiensis* Zone and the Pridoli.

Shales and siltstones of this unit were, as in the case of the Kociewie Formation, formed within the distal part of a shelf and slope. The most complete successions of the Puck Fm. are preserved in two areas: in the offshore B8-1/83 borehole, where its thickness exceeds 900 m, and in the vicinity of Władysławowo and the Hel Peninsula, where it reaches almost 1300 m; further to the south the thickness decreases to 300 m in the Słupsk IG 1 borehole.

The total thickness of the upper Silurian (Wenlock–Pridoli) in the study area varies from about 1000 m to the north to over 3000 m in the vicinity of Słupsk (Fig. 9).

KOSZALIN–CHOJNICE ZONE

Ordovician. There is no data on Cambrian deposits to the west of the TTZ in the Koszalin–Chojnice Zone. Ordovician deposits have been recognized in at least ten sections in the vicinity of Koszalin and Chojnice (Bednarczyk, 1974; Modliński, 1968; Podhalańska and Modliński, 2006; Fig. 1); however, they were not drilled through in any of these boreholes, with only fragments discovered (from several metres to about 1000 m in thickness) of a tectonically disturbed succession. Additionally, Ordovician deposits have been drilled in the Polish Exclusive Economic Zone in the Baltic Sea in the L2-1/87 borehole, in several boreholes on Rügen Island and in some boreholes in the German Economic Zone of the Baltic Sea (Jaeger, 1967; Giese *et al.*, 1994).

Ordovician deposits of the Koszalin–Chojnice Zone, like those on Rügen Island, are developed as siliciclastics and show a considerable thickness, usually steep and variable stratal dips, and the presence of slickensides indicating substantial tectonic deformation. But due to partial stratigraphic incompatibility of the Ordovician succession between Koszalin–Chojnice Zone and Rügen Island the possibility of correlation between the two regions is limited.

On Rügen Island only the lower part of the Ordovician succession (Tremadocian–Llanvirnian) has been recognized. The oldest unit determined as the Wittow Gruppe (Stratigraphischen Tabelle von Deutschland, 2002) comprises sandstones, shales and greywackes of the upper Tremadocian and black and grey shales with siltstone interbeds assigned to the lower Llanvirnian. The upper Llanvirnian deposits are grey-green shales with thick packets of greywackes (Jaeger, 1967; Servais, 1994). The total thickness of the Ordovician deposits in Rügen area reaches about 1500–2000 m.

The oldest deposits known from the Koszalin–Chojnice Zone are upper Llanvirnian and Caradocian strata (Bednarczyk, 1974; Modliński, 1987; Podhalańska and Modliński, 2006), where fragments of a monotonous siltstone and shale succession, dark grey and grey-green in colour, with rare sandstone, dolomite and siderite intercalations have been recognized. Intercalations of pyroclastic deposits – tuffites or admixtures of pyroclastic material represented by numerous mica flakes have been noted in some boreholes e.g. in the Brda 3 or Nowa Wieś 1 boreholes (Modliński, 1978).

The uppermost Ordovician – Ashgillian deposits have not been registered in any of the cores in this area; they are probably developed similarly as the uppermost Ordovician deposits in the Toruń 1 borehole (Podhalańska and Modliński, 2006).

Comparing the facies characteristics of coeval Ordovician deposits in the Koszalin–Chojnice Zone and the western part of the EEC on the base of old and new facts, it may be said that fine-grained siliciclastic deposits with subordinate carbonates predominated in both these areas during the late Llanvirnian and Caradocian. The difference relies on much greater thicknesses in the Koszalin–Chojnice Zone as well as a higher contribution of coarser-grained terrigenous material and the presence of structures indicating the activity of the bottom and distal turbidity currents as compared to the craton area.

Silurian deposits have been noted on both sides of the TTZ, i.e. in the western part of the Baltic Depression and in the south-eastern part of the Koszalin–Chojnice Zone (Figs. 8 and 9). In both areas the degree of recognition of Silurian deposits varies significantly.

Silurian deposits in the Koszalin–Chojnice Zone have been recognized in several boreholes (Teller and Korejwo, 1968; Tomczyk, 1987; Podhalańska and Modliński, 2006). As in the case of the Ordovician, the Silurian lacks formal or informal lithostratigraphic subdivisions.

The oldest documented Silurian deposits belong to the upper Llandovery and have been distinguished in the Lutom 1 borehole near Chojnice (Teller and Korejwo, 1968). The 500 m thick core of tectonically disturbed deposits comprises siltstones and shales with thin sandstone interbeds. The deposits are composed of structureless siltstones or, more frequently, of shale-siltstone laminites, formed in a calm setting, as well as siltstones to fine-grained sandstones deposited under weak currents, including traction and turbidity currents (Podhalańska and Modliński, 2006). The true thickness of this fragment of the succession can be estimated at about 200 m.

The Wenlock is represented by dark grey shales and siltstones fragmentarily recognized in the Klosnowo IG 1 and Wierzchocina 4 cores (Tomczyk, 1987).

In some cores fragments of the Ludlow succession have also been distinguished (Tomczyk, *op. cit.*). The lower Ludlow represented by siltstones and shales was noted in the Darłowo 2, Okunino 1 and Polanów 1 cores, whereas the upper Ludlow – in the Nicponie 1 core (shales and siltstones) as well as in the Stobno 1 and Stobno 3 cores (shales). The uppermost Silurian – Pridoli developed as shales was probably encountered in the Chojnice 3 and Stobno 2 cores.

The fragments of the Silurian succession recovered do not permit evaluating its total thickness in the Koszalin–Chojnice Zone, or determining the thickness of its particular units.

Summarizing, siliciclastic sedimentation continued in the Silurian (Podhalańska and Modliński, 2006) and, as in the Ordovician, it is devoid of coarse grained deposits. However, more siltstones and fine-grained sandstones are present in the Silurian succession than in the Ordovician. The most numerous interbeds of fine-grained sandstones occur in the Llandovery. For example, within the Llandovery deposits in the Lutom 1 borehole there occur numerous sedimentary structures pointing to current activity. Some fragments of the succession may suggest deposition from distal turbidity currents. The content of siltstones is quite high in the Wenlock. Towards the top of the Silurian succession, the sediments become very monotonous, the basin undergoes filling and shallow marine deposits appear.

CONCLUSIONS

Newly constructed lithofacies-thickness maps have allowed updating of the lithofacies diversity and thickness variability of the Ediacaran–lower Paleozoic deposits as well as demonstration of the general lithofacies trends within the stratigraphical units.The Ediacaran and oldest lower Paleozoic deposits are known only from the East European Craton. The depositional history of the Baltic region begins with the alluvial and shallow marine siliciclastics of the Ediacaran to lowermost Cambrian, with southwesterly increase of the deposit thickness. Sandstones of the Lower and Middle Cambrian and fine siliciclastics of the Upper Cambrian and Tremadocian represent the next units of the lower Paleozoic sedimentary succession.

Ordovician and Silurian deposits of Northern Poland are observed on both sides of the Teisseyre-Tornquist Tectonic Zone: in the Koszalin–Chojnice Zone in the west and the East European Craton in the east. The characteristics of the Ordovician rocks from the Koszalin–Chojnice Zone and marginal part of the East European Craton indicate that they show features of sediments deposited in various facies zones. The Ordovician facies of the Koszalin–Chojnice Zone is represented mainly by hemipelagic sediments deposited from suspension. Some of the sediments show evidence of being deposited by weak sea currents, including decelerating turbidity currents.

The sedimentary pattern of the Ordovician of the Polish part of the EEC margin is consistent with the depositional pattern across the Oslo–Scania–Bornholm area. The general lithofacies trend is related to the southwesterly increase of the shaly content in deposits. The depositional succession observed in the Ordovician of the Baltic region seems to have been strongly controlled by sea level variation, probably of eustatic nature. It was represented mainly by the siliciclastic and carbonate-siliciclastic deposits of an outer shelf and upper continental slope, deposited in variable redox conditions: mainly anoxic in the Tremadocian and Caradocian, dysoxic in the lower Ashgillian and oxic in the Arenigian, Llanvirnian and upper Ashgillian. The sedimentary succession of the Upper Ordovician and the lowermost Silurian in the Baltic region has been influenced largely by glacieustatic fall and rise of sea level related to climatic fluctuation: first the end-Ordovician glaciation and regression and subsequently the warming and transgression.

The Silurian lithofacies of the Koszalin–Chojnice Zone show similarity to distal siliciclastic facies distinguished within the Baltic region, deposited in the foreland of the Pomeranian Caledonides. In the Koszalin–Chojnice Zone rocks of such origin, unlike their counterparts of similar age from the marginal part of the East European Craton, are tectonically deformed, although to a lesser extent than the Ordovician rocks. The upper Silurian deposits of both the Koszalin–Chojnice Zone and the marginal part of the East European Craton provide evidence for a shallowing of the sedimentary basin in the Pridoli and the development of shallow-marine deposits with a benthic fauna.

Due to the facies differences in the both regions characterized, especially in the Ordovician, and the incomplete stratigraphical record in the Koszalin–Chojnice Zone, the correlation between the lower Paleozoic craton margin depositional sequences and the Ordovician–Silurian depositional succession in the Koszalin–Chojnice Zone is not yet possible.

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