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Development and inversion of Devonian and Carboniferous basins in the eastern part of the Variscan foreland (Poland)

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The Polish part of the Central European Variscan foreland includes several regional units that differ in crustal structure and are characterized by distinct Devonian to Carboniferous subsidence and depositional histories. These units responded differently to palaeostress changes along the southern margin of the Old Red Continent. During the Devonian to Namurian A, areas located to the south-west of the Teisseyre-Tornquist Zone (TTZ), including the Upper Silesian Coal Basin, Małopolska and Łysogóry–Radom blocks, were influenced by stress fields similar to those in the westward adjacent Rheno-Hercynian Zone, whilst the Lublin Basin, located to the north-east of the TTZ, shows a similar development to the Pripyat–Dniepr–Donets rift system. After the Namurian A, the entire southern Polish foreland started to respond in a more consistent way to the build-up of synorogenic compressional stresses, implying a more uniform development of the stress field. During the Namurian B to early Westphalian D, the Polish foreland was dominated by north-directed compressional stresses emanating from the Southeastern Variscan Belt. During the late Westphalian and early Stephanian, the entire foreland underwent compressional deformation and concomitant basin inversion under the influence of stresses propagating from the Moravian-Silesian Fold-and-Thrust Belt. In the Polish foreland, the development of Devonian-Carboniferous basins, as well as the architecture of Variscan structures, clearly reflect the reactivation of pre-existing crustal discontinuities, including specifically the TTZ, but also other major geophysically defined crustal boundaries. In general, thick-skinned tectonics controlled by the inherited structural grain of the basement prevailed, whereas structural decoupling, resulting in the development of minor thrusts and reverse faulting, was of local significance only. The distinct structural-depositional development of the Pomerania region reflects its distal location with respect to the evolving orogen. Orogenic compression influenced this area only indirectly, with the TTZ acting as a guide for the transmission of transtensional and transpressional stresses.

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INTRODUCTION

While the external parts of the Central European Variscan orogen consist of a stack of foreland-verging predominantly thin-skinned thrust sheets involving thick Devonian and Carboniferous, partly synorogenic successions (“Variscan Externides”), time-equivalent strata are disrupted in some parts of the Variscan foreland by basement-involving intraplate compressional structures (Ziegler, 1990; Ziegler *et al*., 2002). The boundary between these two fundamentally different deformation belts is placed along the Variscan (Thrust) Front (e.g. Jubitz *et al*., 1986), here referred to as the Variscan Orogen Boundary Zone (Fig. 1). This boundary may coincide with discrete frontal thrusts (e.g. the Midi and Aachen thrusts of the Ardennes) or with a more diffuse, wide zone of gradual fading out of folds-and-thrusts (northern Rhenish area; Behr *et al*., 1984). In Southern Poland, the Orlova Thrust marks the boundary between the Moravian-Silesian Fold-and-Thrust Belt of the Variscan Orogen and the much less deformed strata of the Upper Silesian Coal Basin in its foreland (Fig. 2). In contrast, the boundary between the thrusted and folded flysch succession of the Fore-Sudetic area and the foreland of Northern and Central Poland is poorly constrained (e.g. Dadlez *et al*., 1994; Mazur *et al*., 2006).

The sedimentary and tectonic development of the Moravian-Silesian segment of the Variscan Externides is now well-constrained owing to studies over many years, expanded and summarized during the last decade by Schulmann and Gayer (2000), Hartley and Otava (2001) and Żaba *et al*. (2005). The structural-palaeogeographic position of the Moravian-Silesian Belt within the general framework of the Central European Variscides is, however, still a matter of debate (e.g. Franke and Żelaźniewicz, 2002), although considerable progress has been made in placing this belt in the context of the Bohemian Massif, and particularly the Sudetic domain (Mazur *et al*., 2006). Moreover, there is still uncertainty about the dynamic relationship between the Variscan Orogen and the deformation of its distal foreland basin that is limited to the NE by the erosional edge of Carboniferous strata (Fig. 2). The list of unresolved or poorly re-

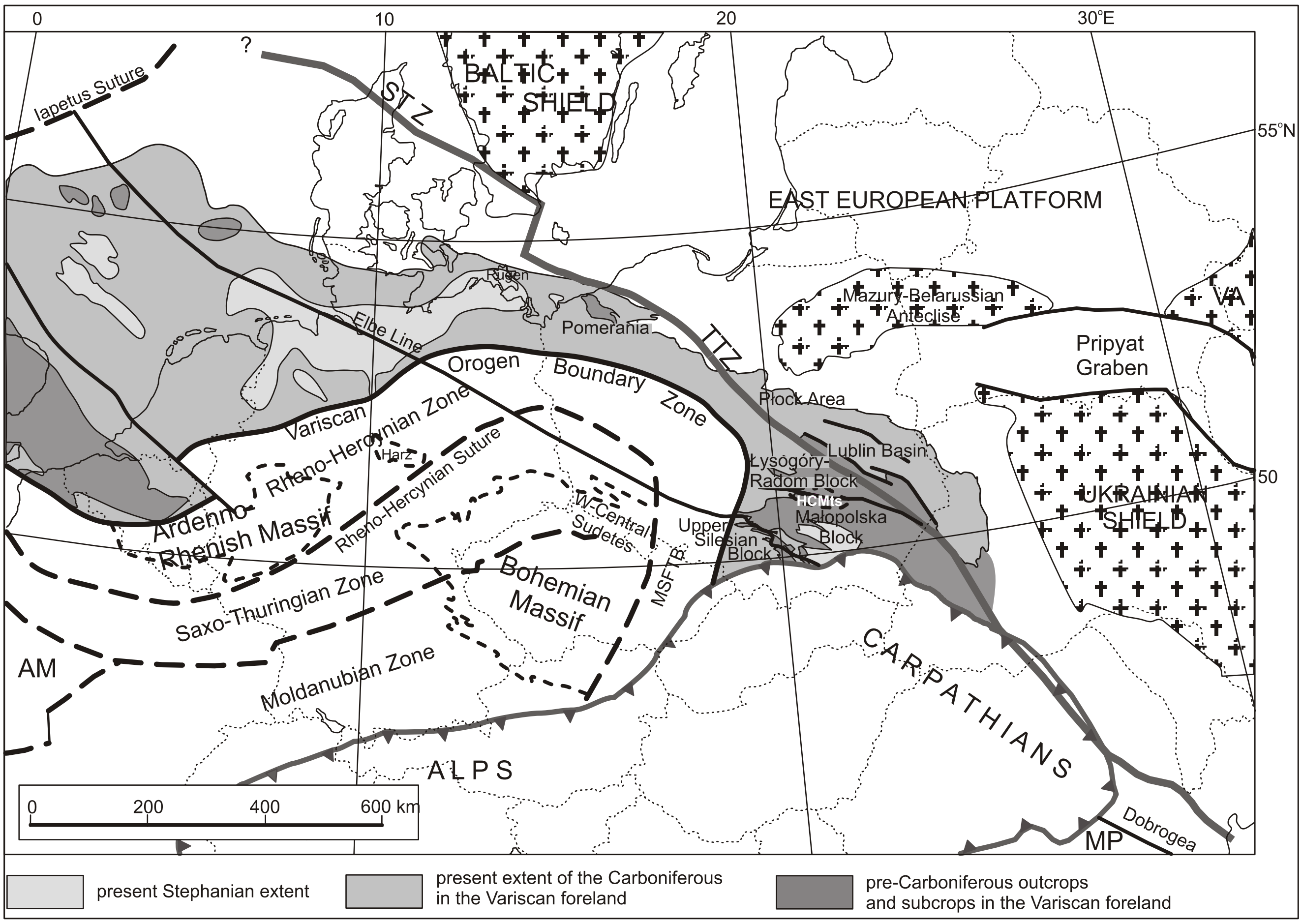


Fig. 1. Broader regional context of the Variscan foreland in Central Europe (compiled mainly after Pożaryski and Dembowski, 1983; Ziegler, 1990; Banka *et al*., 2002)

The trace of the Rheno-Hercynian suture corresponds roughly to that of the Rheic suture; cross pattern — elevations of the East European Platform; AM — Armorican Massif, HCMts — Holy Cross Mountains, MP — Moesian Platform, MSFTB — Moravian-Silesian Fold-and-Thrust Belt, STZ — Sorgenfrei-Tornquist Zone, TTZ — Teisseyre-Tornquist Zone, USCB — Upper Silesian Coal Basin, VA — Voronezh Anteclise

solved questions includes possible causal links between the different stages in the tectonic development of the orogenic belt and the foreland basin, palaeostress patterns, and the role played by pre-existing complex basement structure.

This paper synthesizes and integrates the available stratigraphic, palaeogeographic and structural data, and presents an updated interpretation of the Devonian to Carboniferous evolution of the Polish Variscan foreland as a whole. It partly builds and expands on an earlier synthesis by Narkiewicz *et al*. (1998*b*) that focused on the Pomerania and Lublin areas. An attempt will be made to identify and discuss far-field effects of tectonic stresses, that were transmitted both from the Western-Central European Variscan Orogen as well as from its southeastern branch into the foreland of Poland. Attention will be also paid to a mode in which regional stresses were partitioned by a pattern of reactivated crustal discontinuities.

REGIONAL DATABASE

Earlier regional stratigraphic and tectonic data was summarized and reviewed in the monographs edited by Marek (1983), Żelichowski (1983*a*), Raczyńska (1987), Zdanowski and Żakowa (1995), synthetic papers by Pożaryski (1986), Żelichowski (1987*a*), Pożaryski *et al*. (1992) and Narkiewicz *et al*. (1998*b*), and in a cartographic form by Pożaryski and Dembowski (1983), Żelichowski and Kozłowski (1983) and Pożaryski and Karnkowski (1992).

Since the late 1990s new important data and concepts have been reported in numerous publications. Buła and Żaba (2005) recently reviewed the structural-depositional development of the Upper Silesian Coal Basin in the context of the Moravian-Silesian Fold-and-Thrust Belt. Earlier, Buła *et al*. (1997) and Żaba (1999) documented the Palaeozoic structural evolution of the Kraków–Lubliniec Fault Zone. Based on structural field-data, Lamarche *et al*. (1999, 2003) presented a geodynamic interpretation of palaeostress patterns in the Holy Cross Mts. area. Antonowicz *et al*. (2003; see also Hooper *et al*., 2002) reinterpreted reflection seismic data from the Lublin Area and proposed a new structural model of a passive syncline above a major detachment surface. This in turn triggered a discussion on the tectonic controls on subsidence and inversion of the Lublin Basin (Dadlez, 2003; Narkiewicz, 2003; Krzywiec and Narkiewicz, 2003*a*).

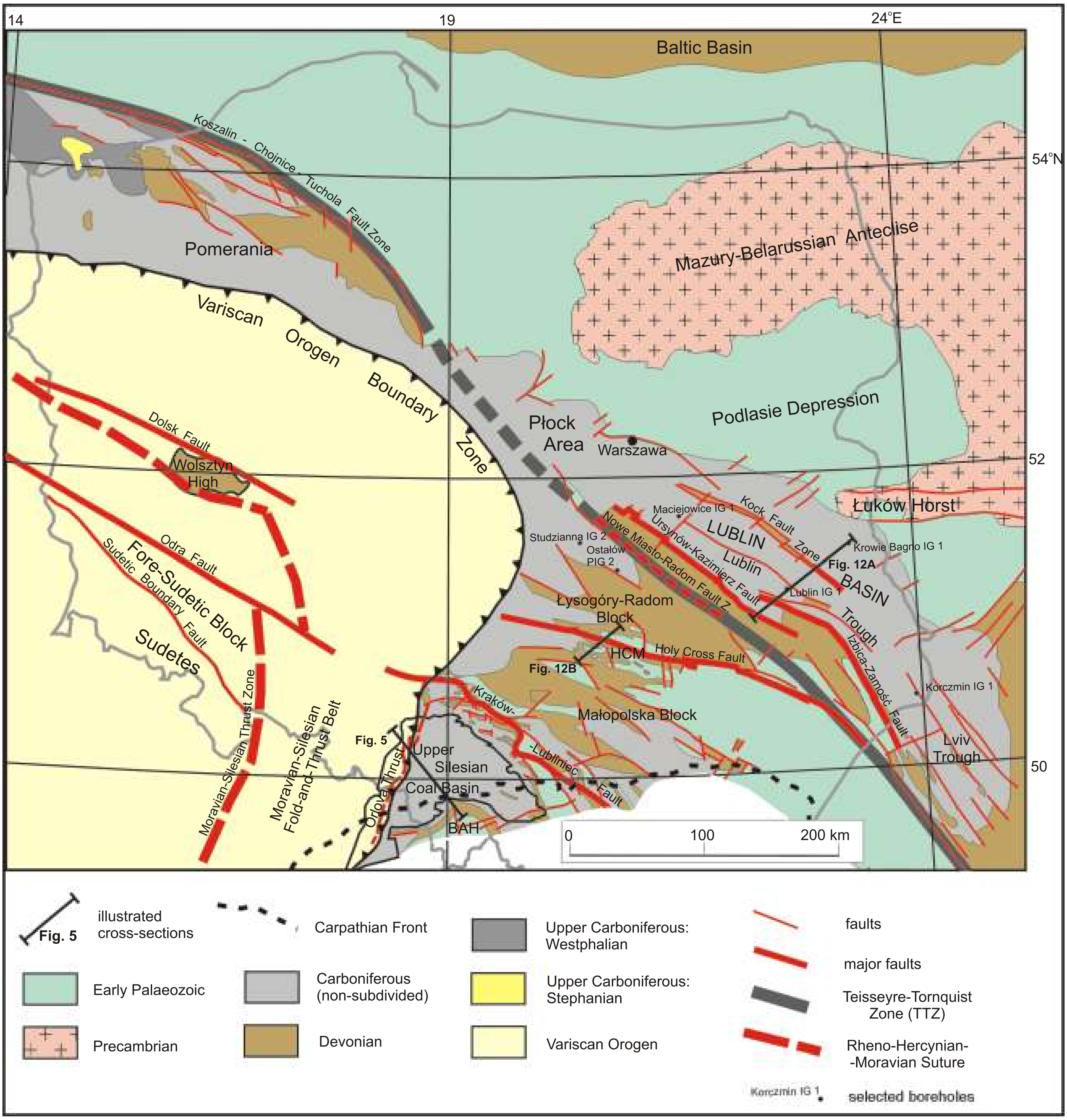


Fig. 2. Sub-Permian-Mesozoic map of Poland showing regional units of the Variscan foreland (partly based on Pożaryski and Dembowski, 1983)

BAH — Bielsko-Andrychów High; broken TTZ line marks its less firmly constrained segment

Several recent stratigraphic contributions have a direct bearing on the understanding of the Variscan foreland development in Poland. Of particular importance are papers discussing eustatic and tectonic controls on the Devonian and Early Carboniferous depositional systems (Narkiewicz, 1988; Szulczewski *et al*., 1996; Belka *et al*., 1996; Racki, 1997; Racki and Narkiewicz, 2000). New data on Carboniferous sediment accumulation and tectonics were reported by Skompski (1996, 1998), Lipiec and Matyja (1998), Waksmundzka (1998, 2005), Krzemiński (1999), Lipiec (2001), Jaworowski (2002) and Narkiewicz (2005).

The study presented here is based on a compilation, review and analysis of published and some unpublished data collected by the author. For basin analysis, the time scale of Gradstein *et al*. (2004) was adopted (Fig. 3). The results of earlier tectonic subsidence analyses carried out in different regions by Narkiewicz *et al*. (1998*b*), Racki and Narkiewicz, (2000) and Narkiewicz (2005) were amended using updated strati-

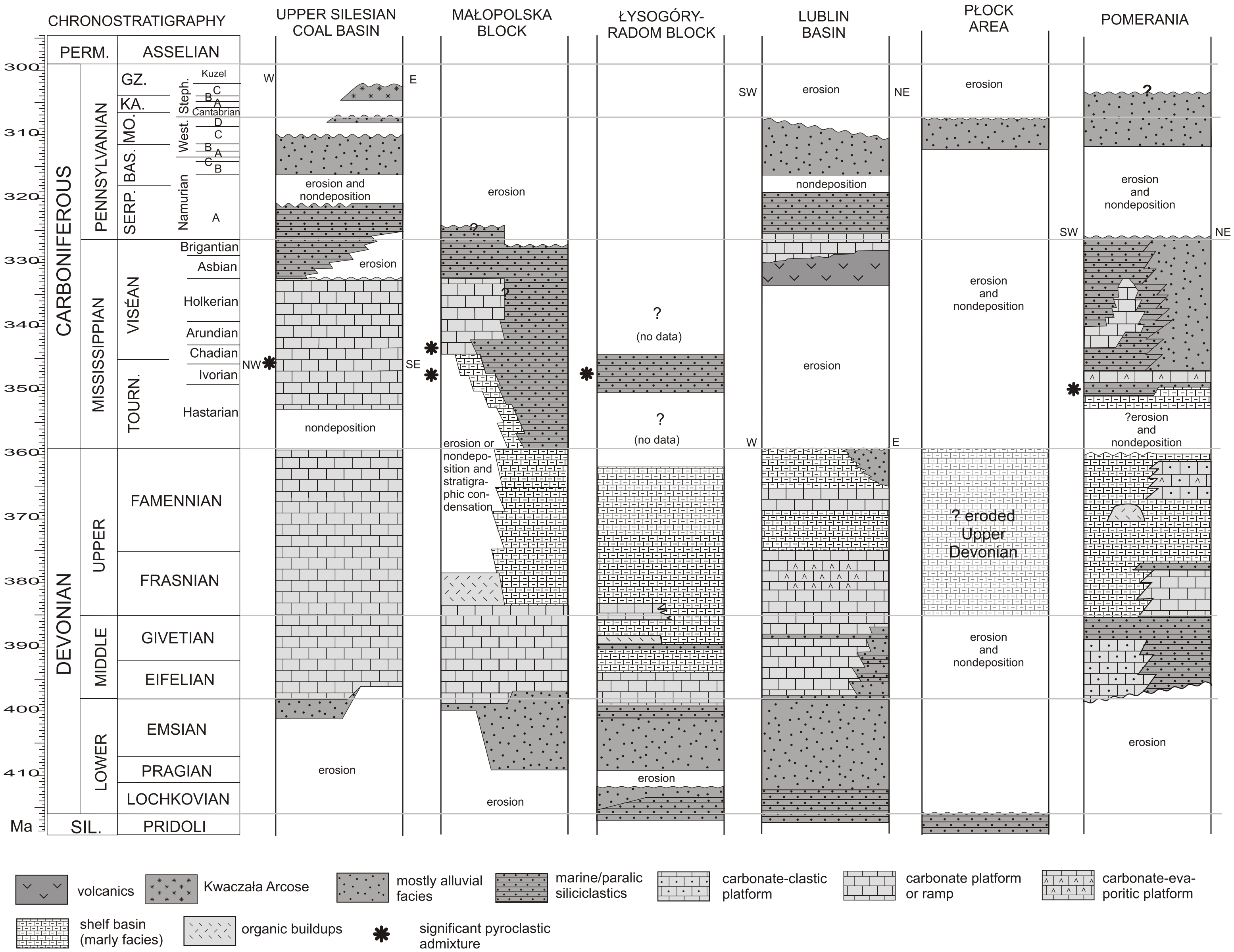


Fig. 3. Chronostratigraphic correlation of the Devonian-Carboniferous sections representative of six major regions of the Polish Variscan foreland (compiled from various sources mentioned in the text)

Chronostratigraphic scale after Gradstein *et al.* (2004); BAS. — Bashkirian; GZ. — Gzhelian; KA. — Kasimovian; MO. — Moscovian; SERP. — Serpukhovian; Steph. — Stephanian; West. — Westphalian graphic-structural observations and a consistent time scale (Fig. 4). Finally, disseminated palaeostress data were compiled and compared. The definition and outline of regional structural units is partly based on new interpretations of the deep crustal seismic sounding (DSS) data that were acquired in the context of the POLONAISE and CELEBRATION 2000 programs (see Guterch and Grad, 2006 for a recent review), and partly on an analysis of potential field data (Królikowski and Petecki, 1995; Grabowska and Bojdys, 2001; Królikowski, 2006).

STRUCTURAL AND PALAEOGEOGRAPHIC FRAMEWORK

The area addressed by this paper extends from the Variscan Orogen Boundary to the southwestern marginal zone of the East European Platform (EEP) and comprises the belt of the Devonian and Carboniferous subcrop and limited outcrops from Pomerania in the north-west to Central and south-eastern Poland (Fig. 1). The basement of this area consists of the cratonic crust of the EEP to the SW margin of which an array of crustal blocks or terranes and a hypothetical Caledonian thrust-and-fold-belt were accreted, mostly during the Early Palaeozoic, forming the Trans-European Suture Zone (TESZ) (e.g. Winchester *et al*., 2002; Dadlez *et al*., 2005; Nawrocki and Poprawa, 2006). This zone is separated from the craton by a first-order crustal discontinuity, referred to as the Teisseyre-Tornquist Zone (TTZ; Dadlez, 1997).

According to some authors, the TTZ acted as a strike-slip fault zone with a total displacement of the order of thousand kilometres during Devonian and Carboniferous times (Lewandowski, 1993; Franke and Żelaźniewicz, 2002). If so, the presently observed juxtaposition of structural units forming the TESZ against the East European Craton (EEC) would not reflect their actual spatial relationships during the time interval discussed, rendering the considerations advanced in this paper groundless. It is to be stressed, however, that recent palaeomagnetic data point to stability of the Małopolska and probably other TESZ blocks relative to the EEC from earliest Devonian time onwards (Nawrocki, 2000). Moreover, it will be shown that, although the TTZ was tectonically active during the Late Palaeozoic, it did not significantly disrupt the palaeogeographic configuration of the area addressed. In other words, based on the available data no large-scale displacements are required to explain the observed configuration of Devonian-Carboniferous basins and their structural evolution.

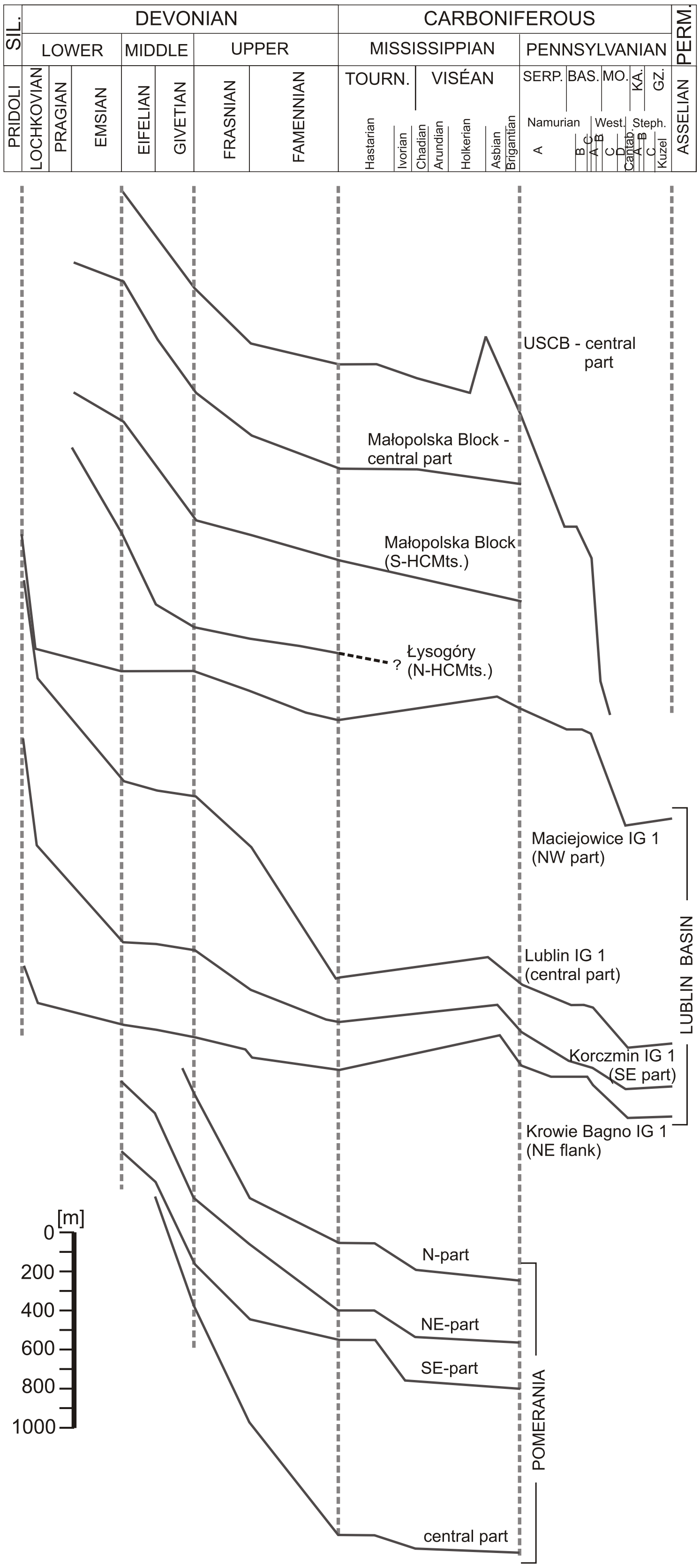


Fig. 4. Comparison of the Devonian-Carboniferous tectonic subsidence development of the Upper Silesian Coal Basin (USCB), Małopolska Block, Łysogóry–Radom Block, Lublin Basin and Pomerania (based mainly on McCann *et al*., 1997; Narkiewicz *et al*., 1998*b*; Narkiewicz, 2005)

Abbreviations of stratigraphic names as in Figure 3

The Polish part of the Variscan Orogen that crops out in the Sudetes Mts. is characterized by a complex structure that is still not fully understood. The Sudetes Mts. include possible counterparts of the Saxo-Thuringian and Moldanubian zones in their western and central parts, and the Moravian-Silesian Fold-and-Thrust Belt in their eastern part (Mazur *et al*., 2006). The latter is considered as a direct continuation of the Rheno-Hercynian Zone, though the concept of oroclinal bending around the NW margin of the Bohemian Arc is not accepted by all (e.g. Franke and Żelaźniewicz, 2002). The equivalent of the Rheno-Hercynian Suture is clearly recognized in the eastern Bohemian-Sudetic outcrop area (Staré Město Belt; Mazur *et al*., 2006). Its northward and north-westward trace, shown tentatively in Figure 2, is here based on the distribution of characteristic "Sudetic crust" as defined by the results of the DSS profiles LT-7, P4 and SUDETES (Dadlez, 2006; Majdański *et al*., 2006).

The external, Fore-Sudetic part of the orogen is concealed beneath thick Permian to Cenozoic sedimentary successions. In Figure 2 the outer boundary of the Variscan Orogen is shown in northwestern Poland essentially according to the interpretation of Pożaryski and Karnkowski (1992) whereas its position in Central Poland was adopted from Jubitz *et al*. (1986; see also discussion by Dadlez *et al*., 1994).

The recently proposed "passive syncline" model for the Lublin Basin (Hooper *et al*., 2002; Antonowicz *et al*., 2003) implies that thin-skinned Variscan thrusts had propagated from the currently assumed orogen boundary *ca*. 200 km eastward (*cf*. Fig. 2) and that all of southeastern Poland has to be included in the Variscan Externides. However, careful analysis of seismic and well data does not reveal any evidence for large-scale detachments in the basement of the Lublin Basin, or for associated triangle zones along its margins (Krzywiec and Narkiewicz, 2003*a*, *b*; Krzywiec, 2007). Moreover, the broader regional framework of this area is not compatible with "Appalachian-type" tectonics (Narkiewicz, 2003; Dadlez, 2003).

Towards the south, both the Bohemian part of the Variscan Orogen and its Polish-Ukrainian foreland plunge beneath the Carpathian nappes, thus rendering reconstructions of the Variscan Belt highly hypothetical. Nevertheless, based on the occurrence of exotic clasts in the Carpathian flysch, as well as on isolated outcrops in the Inner Carpathians, it is generally assumed that the Variscan orogenic belt extended into the area now occupied by the Carpathians (Ziegler, 1990; Znosko, 1992). The orogen continued along the southern EEC margin towards the Crimea and Caucasus in relationship with the north-dipping Palaeo-Tethys subduction system (Ziegler, 1990; Nikishin *et al*., 1996, 2001).

The Polish Variscan foreland basin can be subdivided into the six structural units, namely the Upper Silesian Coal Basin, the Małopolska and the Łysogóry–Radom blocks, the Lublin Basin, the Płock Area and Pomerania (Figs. 1 and 2). These units are characterized by a contrasting sedimentary record (Fig. 3) and subsidence pattern (Fig. 4) that reflect their structural independence and internal integrity during Devonian and Carboniferous times. It will be shown that these differences are mainly the effect of tectonic activity along crustal-scale discontinuities corresponding to the major faults or fault zones shown in Figures 1 and 2.

UPPER SILESIAN COAL BASIN

The Upper Silesian Coal Basin (USCB) occupies the NE corner of the Brunovistulicum Block or Terrane, the Neoproterozoic crystalline basement of which was consolidated during the Cadomian orogenic cycle (Finger *et al*., 2000). The derivation of this terrane and its accretion history are still problematic (see recent discussion in Nawrocki and Poprawa, 2006). The northern part of Brunovistulicum is defined as the Upper Silesian Block (Kotas, 1985; Buła and Żaba, 2005). The western part of Brunovistulicum extends beneath the Moravian-Silesian Fold-and-Thrust Belt (Fig. 2) that evolved in response to Carboniferous subduction of the Brunovistulian plate below the Bohemian Massif unit (e.g. Schulmann and Gayer, 2000; recently summarized by Buła and Żaba, 2005). The Moravian-Silesian Belt overrides the margin of the USCB along a system of thrusts rooted in the basement 10 km west of their present outcrop (Fig. 5). The NE boundary of the USCB is of mixed depositional-erosional character, running 10–20 km west of the Kraków–Lubliniec Fault (Fig. 2). The latter is a narrow tectonic zone (Żaba, 1999) that separates the Brunovistulicum and Małopolska blocks (Buła *et al*., 1997) which display contrasting crustal structures (Malinowski *et al*., 2005). The southern boundary of the USCB is erosional and extends across the northern slope of the Bielsko–Andrychów basement high that forms part of the Sub-Carpathian Arch (Narkiewicz, 2005).

MAŁOPOLSKA BLOCK

The Małopolska Block is bounded to the north by the WNW–ESE striking Holy Cross Fault that transects the Palaeozoic core of the Holy Cross Mts. According to gravity data (Królikowski and Petecki, 1995), this fault converges in its southeastern extension with the TTZ (Fig. 2). To the south, the Małopolska Block plunges deeply beneath the nappes of the Polish Carpathians and thus becomes inaccessible to boreholes. The crustal structure of the Małopolska Block differs from that of the adjacent Łysogóry–Radom Block, although the Holy Cross Fault is not marked by sharp contrasts in refraction-seismic P-wave velocity models (Malinowski *et al*., 2005; Guterch and Grad, 2006). The Early Palaeozoic history of the Małopolska Block is also distinct though its relation to adjacent units remains controversial (e.g. Nawrocki, 2000; Narkiewicz, 2002).

ŁYSOGÓRY–RADOM BLOCK

The pre-Permian Palaeozoic succession of the Łysogóry–Radom Block is poorly known from a few boreholes reaching Middle Devonian and uppermost Silurian strata below Mesozoic cover. The Upper Devonian and Carboniferous is mostly eroded. Consequently, the derivation of this block is subject to contradictory interpretations, including postulated close Baltica (EEC) affinities and an exotic terrane origin (see discussion in Dadlez *et al*., 1994; Belka *et al*., 2000). The NE boundary of the Łysogóry–Radom Block is particularly difficult to define. Traditionally it has been placed along the Ursynów–Kazimierz

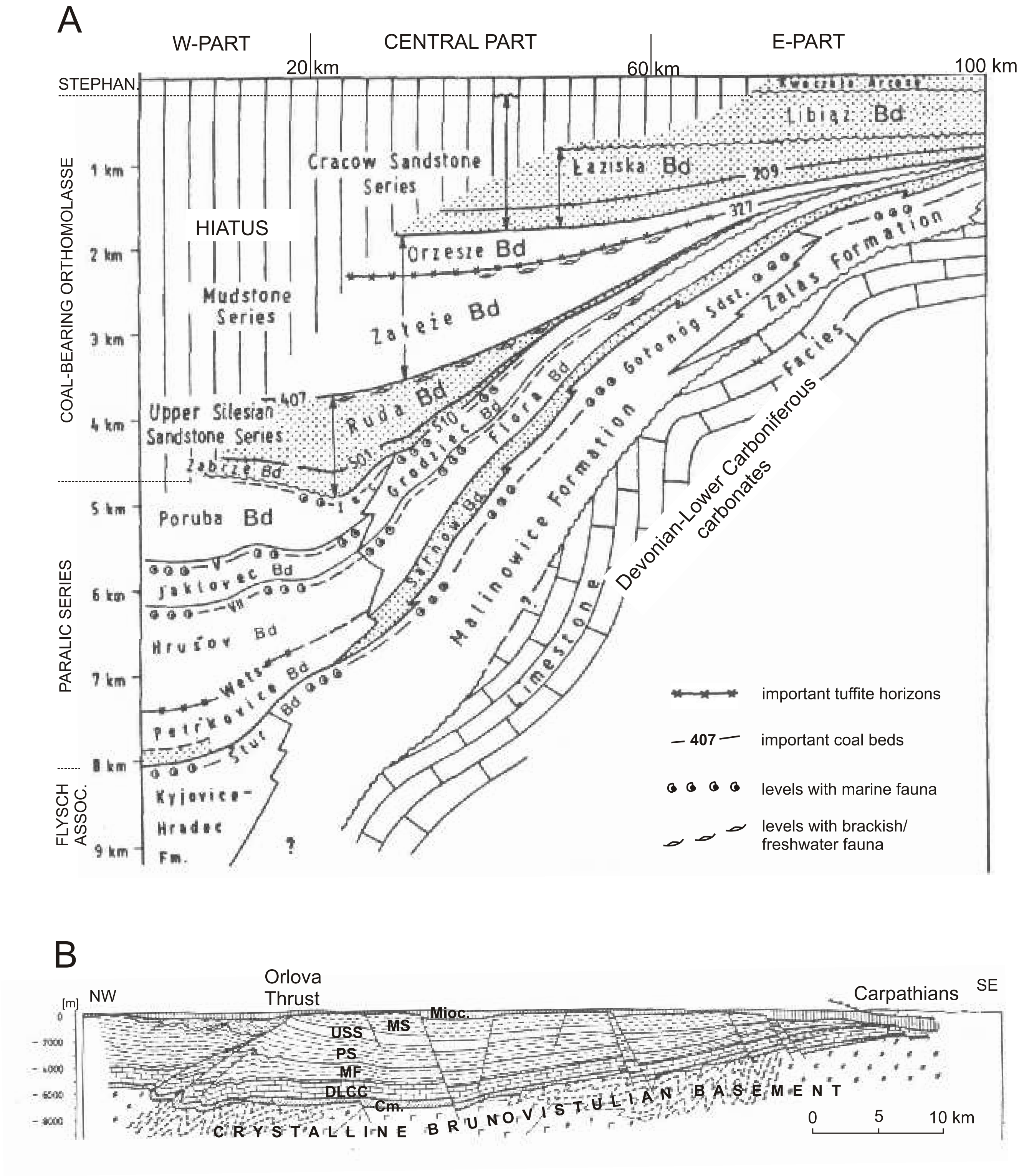


Fig. 5. A — lithostratigraphic framework of the Upper Silesian Coal Basin (stippled — important sandstone units); B — geological cross-section (see Fig. 2 for location; after Kotas, 1994, 1995)

Cm. — Cambrian, DLCC — Devonian-Lower Carboniferous carbonates, MF — Malinowice Fm., PS — Paralic Series, USS — Upper Silesian Sandstone Series, MS — Mudstone Series, Mioc. — Miocene

Fault that delimits the Lublin Trough to the SW (Fig. 2; e.g. recently Jaworowski and Sikorska, 2006). The latter fault, as well as the Izbica–Zamość Fault, owe, however, their present geometry to late Westphalian inversion (see below). Neither of these faults coincides with a geophysically documented major crustal discontinuity (Dadlez, 2001), and their role in controlling the development of depocentre, particularly during the Carboniferous, is equivocal (Narkiewicz, 2003).

By contrast, potential field and DSS data document the existence of an important crustal boundary — the TTZ — forming a narrow belt running from Nowe Miasto in the NW and continuing towards SE near Radom and Iłża (Grabowska and Bojdys, 2001; Dadlez, 2006). The Mesozoic expression of this zone is the Nowe Miasto-Iłża Fault documented by e.g. Hakenberg and Świdrowska (1997) and Pożaryski (1997). During the Devonian to Carboniferous the trace of the TTZ was offset by 10–20 km towards the east, particularly in the SE corner of the Radom–Łysogóry Block, as suggested by Mid Devonian depositional and subsidence patterns (unpubl. data). This tectonic boundary is here referred to as the Nowe Miasto–Radom Fault Zone (Fig. 2).

LUBLIN BASIN

The depocentre of the Lublin Basin corresponds to the Lublin Trough (Fig. 2). The latter unit owes its present geometry mainly to the latest Carboniferous inversion which led to a relative uplift of the SW and NE flanks (see below). Therefore, the previously used term "Lublin Graben" (Żelichowski, 1972; Narkiewicz *et al*., 1998*a*; Narkiewicz, 2003) is here replaced by a more descriptive "trough".

The Lublin Trough is flanked to the south-west by the elevated horst-like belt of the Lower and Middle Devonian subcrops (the Radom–Kraśnik High of Żelichowski, 1972) that is delimited by the TTZ and Ursynów–Kazimierz and Izbica–Zamość faults (Fig. 2). The deep-rooted Kock Fault Zone delimits the Lublin Trough to the north-east and is clearly outlined in the gravity field (Królikowski and Petecki, 1995). Beyond this fault zone, the Precambrian basement of the East European Platform ascends north-eastwards to depths of less than 4 km and has been reached by several deep boreholes.

The NW termination of the Lublin Trough is commonly drawn along the SW–NE striking Grójec Fault located south of Warszawa (e.g. Żelichowski, 1983). This fault, which coincides with a distinct gradient zone in the gravity field (Królikowski and Petecki, 1995), controlled the Permian to Mesozoic basin development and inversion (e.g. Dadlez, 1997) and can be traced as a strike-slip fault zone in the Permian-Mesozoic cover (Żelichowski, 1983). On the other hand, the significance of this fault during Devonian and Carboniferous times is questionable since limited borehole control provides no evidence that it affected the Devonian and Carboniferous facies pattern (Pożaryski *et al*., 1980, 1983; Miłaczewski, 1983; Miłaczewski *et al*., 1983). Conceivably, Late Carboniferous depositional gradients may have occurred across a rather broad SW–NE or W–E trending zone in the area located south of Warszawa. A W–E strike of this zone is compatible with the concepts of Pożaryski (1986) and Pożaryski *et al*. (1992) who interpreted a roughly W–E striking Łuków Fault along the S flank of the Podlasie Depression (Fig. 2). In earlier papers, Pożaryski *et al*. (1980, 1983) were unable to trace the Grójec Fault on their depth-to-basement map and argued that the Lublin Trough extended further to the WNW, with a gradual westerly deflection.

PŁOCK AREA

The pre-Permian stratigraphy of the Płock Area (Żelichowski, 1987*a*) is poorly known due to scarce borehole control. Its boundaries with the Lublin Basin to the SE (see above) and the Pomeranian area to the NW are only vaguely defined. According to earlier concepts, the Płock Area is underlain by the stable Warsaw (Warszawa) Block, which forms the western extension of the elevated Mazury–Belarussian Anteclise of the EEP (Pożaryski, 1975; Pożaryski *et al*., 1980). The SW boundary of the Płock Area coincides with the TTZ (Fig. 2), the location of which is constrained by the DSS lines LT-4, LT-5 and P4 (Dadlez, 2006; Guterch and Grad, 2006).

POMERANIA

In Pomerania, the NE subcrop edge of the Devonian strata coincides with the Koszalin–Chojnice–Tuchola Fault Zone that corresponds to the Pomeranian part of the TTZ, as constrained by DSS data (Fig. 2; Dadlez, 2006; Guterch and Grad, 2006). To the north-east of this line, Devonian and Carboniferous successions were eroded, presumably during latest Carboniferous–Early Permian times, resulting in the removal of the mainly proximal depositional systems of the basin margin. Based on facies patterns, however, it is postulated that Devonian and Early Carboniferous successions had originally extended over considerable distances north-eastwards, intermittently connecting the Pomeranian depositional area with the Baltic Basin (Żelichowski, 1987*b*). The Koszalin–Chojnice–Tuchola Fault Zone is interpreted as having acted during latest Carboniferous and Early Permian times as a crustal-scale strike-slip fault system (*op. cit*.). The SW boundary between the Pomeranian area and the Variscan orogenic front is poorly defined owing to deep burial of the pre-Permian strata (Dadlez *et al*., 1994).

STAGES OF BASIN DEVELOPMENT AND INVERSION

Based on the stratigraphic record of the Polish Variscan foreland and an analysis of its subsidence patterns and mechanisms, as summarized in Figures 3 and 4, six major stages can be distinguished in the development of its Devonian and Carboniferous sedimentary basins, including their latest Carboniferous inversion.

DEVONIAN — THERMALLY DRIVEN SUBSIDENCE AND REGIONAL EXTENSION

Following the end-Silurian final suturing of the TESZ terrane complex to the margin of the EEC, Lower Devonian

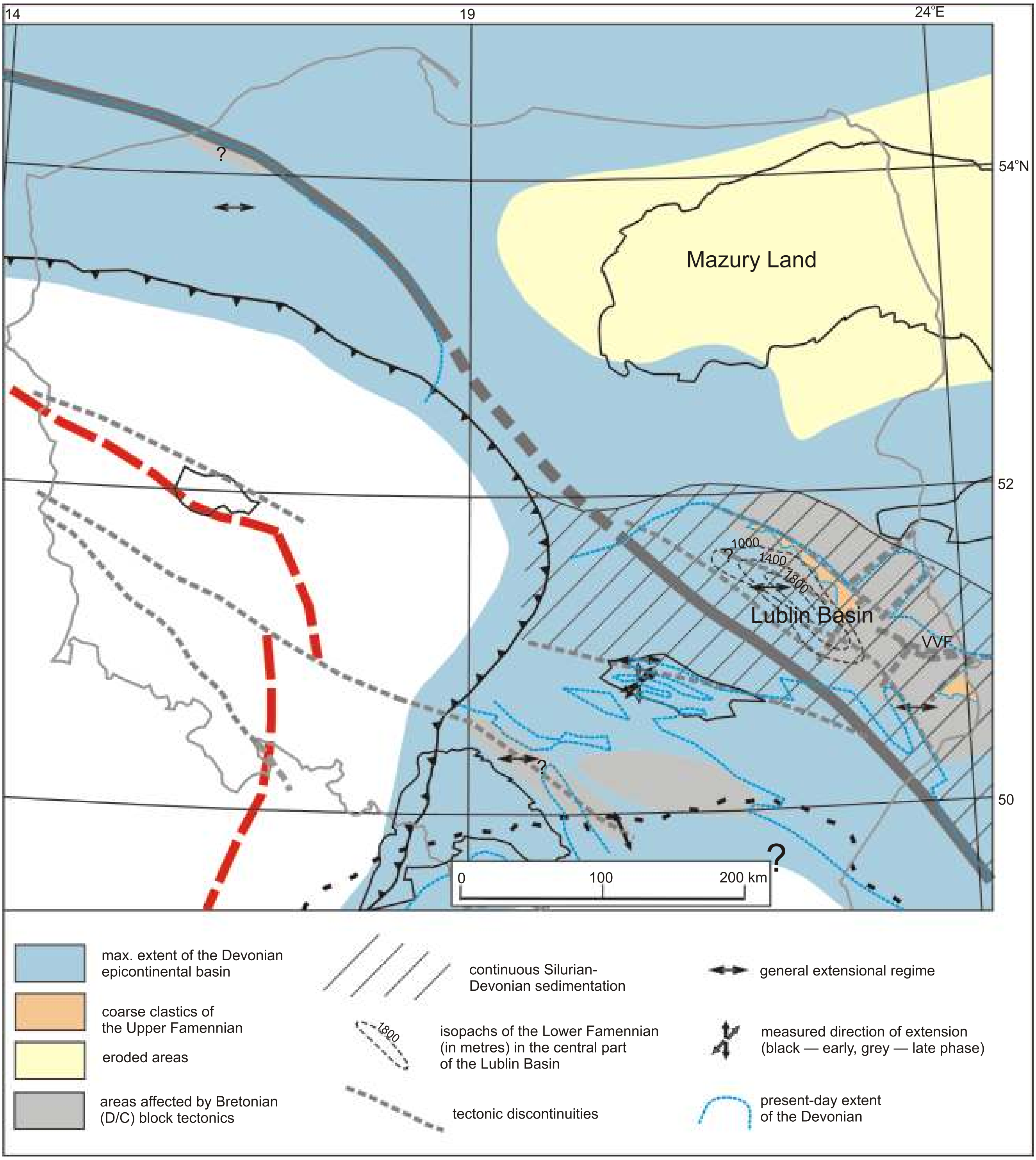
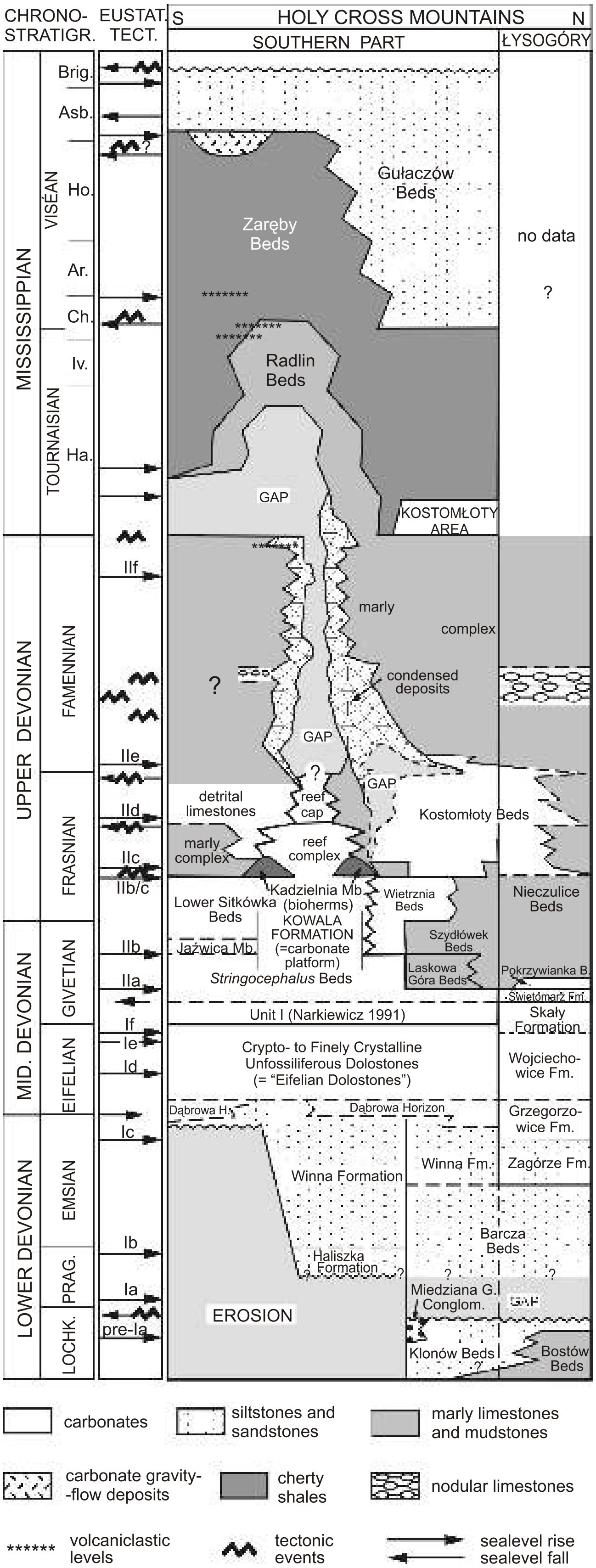


Fig. 6. Palaeogeographic map of the Polish Variscan foreland in the Devonian (based on various sources cited in the text)

VVF — Vladimir Volynski Fault; other explanations as in Figure 2

basal clastic rocks up to 200 m thick, onlapping various Proterozoic to Lower Palaeozoic rocks, were deposited in much of the study area. Only in the Łysogóry–Radom and Lublin regions did open marine sedimentation continue across the Silurian-Devonian boundary (Fig. 6). This area was also characterized by almost continuous Early Devonian accumulation of marginal marine to continental clastic deposits (Figs. 3 and 7) that reached a thickness of 1200–1500 m. Close to the Early-Mid Devonian boundary, a shallow-water carbonate platform was established across the entire Devonian basin except for its marginal parts in the Lublin and Pomeranian areas (Fig. 3). The Late Devonian depositional pattern comprises



shallow-water carbonate platforms, reefs and deeper-shelf systems. The thickness of these carbonate-marly sequences is generally close to 1 km except for the Lublin Basin where it may attain *ca*. 2.5 km, consisting mostly of Upper Devonian deposits. On the other hand, the Middle Devonian of the Łysogóry–Radom Block is exceptionally thick (more than 1 km) and is mainly composed of marly deposits of a shelf basin. No Devonian has so far been encountered in the Płock Area, either due to non-deposition or subsequent erosion. It appears plausible, however, that during the Late Devonian global high-stand in sea level, that is clearly reflected in adjacent regions, shallow-marine strata were deposited also in the Płock Area, and later eroded in pre-Westphalian times.

Previous studies have demonstrated the role of eustatic controls on cyclic deposition during the Mid and Late Devonian (Narkiewicz, 1988; Racki, 1997; Narkiewicz *et al*., 1998*a*; Racki and Narkiewicz, 2000; Fig. 7). The pattern of asymptotically decreasing tectonic subsidence (Fig. 4) is typical of thermal relaxation of the lithosphere after a rifting and/or thermal event (see e.g. Ziegler and Cloetingh, 2004 and the references given therein). On the other hand, field examples of Devonian syn-sedimentary faulting and palaeostress data consistently point to a generally extensional regime.

The tectonic boundary between the Upper Silesian and Małopolska blocks shows evidence for Late Devonian to Early Carboniferous vertical block movements and associated bimodal magmatism under conditions of subhorizontal extension (Żaba, 1999). NNW–SSE-directed extension was suggested by Jarosiński (2001) and Poprawa *et al*. (2001) for the Late Devonian-Tournaisian in the easternmost, sub-Carpathian part of the Upper Silesian Block. Well-documented transtension prevailed in the Holy Cross Mts. area during the late Emsian and Famennian while the most pronounced syn-sedimentary extensional tectonics are traceable in that area during the Late Devonian (Szulczewski *et al*., 1996; Racki and Narkiewicz, 2000; Lamarche *et al*., 2002, 2003; Figs. 6 and 7). Measured directions of a maximum extension range in the Holy Cross Mts. from W–E to SW–NE changing to N–S (Lamarche *et al*., 2003). The Holy Cross Fault clearly separated the Łysogóry–Radom Block, characterized by increased Lower and Middle Devonian subsidence, from the more stable Małopolska Block (Fig. 4).

Commencing in the mid-Frasnian, regional extension controlled strong subsidence in the Lublin Basin, as seen in the development of a distinct depocentre (Narkiewicz *et al*., 1998*a*). The geometry of this depocentre, as outlined by isopachs of the lower Famennian marine marly deposits (Fig. 7), confirms syn-sedimentary activity along the Ursynów–Kazimierz Fault in the SW and the Kock Fault Zone in the NE. Famennian deposits show evidence of syn-sedimentary deformation, such as

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Fig. 7. Devonian-Lower Carboniferous stratigraphy in the Holy Cross Mts. in the context of the most important eustatic and tectonic events (Devonian part based mainly on Racki and Narkiewicz, 2000, Carboniferous on Szulczewski *et al*., 1996)

Southern part of the HCMts. corresponds to the northern Małopolska Block, whereas the Łysogóry area to the northern Łysogóry–Radom Block; full names of the Mississippian chronostratigraphic units as in Figure 2 slumping and boudinage (unpublished core observations), both phenomena attributed here to seismic activity.

For Pomerania, Żaba and Poprawa (2006) postulated that Mid and Late Devonian basin development was controlled by a two-phase extensional regime, with the earlier pulse probably being of sinistral transtensional type and the late pulse, after a dextral transpressional phase, of extensional or dextral transtensional type.

Continuous marine sedimentation across the Devonian-Carboniferous boundary is documented only in the southern Holy Cross Mts. (Fig. 7; Malec, 1995). Condensed sequences or non-depositional gaps are recognized in the USCB (Bełka, 1985) and Pomerania (Matyja and Stempień-Sałek, 1994). The Devonian-Lower Carboniferous unconformity is known from boreholes in the southern part of the Małopolska Block (Jawor and Baran, 2004), whilst its presence in northern Pomerania remains problematic (Dadlez, 1978). Evidence for block faulting attributed to the Bretonian tectonic phase has also been reported for the Kraków–Lubliniec Fault (Żaba, 1999).

In the Lublin Basin, late Famennian syn-sedimentary activity along the Kock and Vladimir Volynski faults caused erosion on the blocks adjacent to the north and localized deposition of thick marginal marine clastic sediments to continental red-beds (Fig. 6). During the Tournaisian to early Viséan an erosional and non-depositional regime prevailed in the entire Lublin Basin, resulting in the removal locally of up to 1500 m of Devonian and (in part) Lower Palaeozoic successions.

TOURNAISIAN TO MID-VISÉAN — MOBILE SHELF AFFECTED BY VOLCANISM

During Tournaisian to mid-Viséan times, a widespread shelf basin extended from southern Poland to Pomerania (Fig. 8). Marine clastic deposition prevailed whilst carbonate platforms developed on elevated intra-shelf and coastal basement blocks (Żelichowski, 1987*b*; Belka *et al*., 1996). Clastic deposits, commonly containing a considerable volcaniclastic admixture, attain thicknesses of the order of several hundreds up to one thousand metres. Alluvial to near-shore marine clastic deposits grade basinwards into fine-grained offshore facies (Pomerania); the latter are dominated by dark siliceous shales and mudstones on the Małopolska Block and in the northern USCB area.

The Carboniferous of the Łysogóry–Radom Block is known only from a few boreholes in a tectonic graben of the Studzianna–Ostałów area (Fig. 2). Incomplete sections comprise several hundred metres of intercalated arkosic sandstones, siltstones and dark shaly mudstones yielding palynomorphs of late Tournaisian to (?) earliest Viséan age (Turnau in: Jaworowski, 2002). Coarser-grained beds contain, in addition to redeposited shallow-water carbonates, abundant trachytic and rhyolitic volcaniclastic material, suggestive of continental extension (Krzemiński, 1999). Jaworowski (2002) interpreted this succession as comprising gravitational mass flow deposits that were derived from a shallow shelf to the NE and that accumulated on a submarine slope. This near-shore clastic belt probably fringed the land area comprising most of the present Lublin region (Fig. 8). Thus, the Tournaisian to early Viséan basin margin appears to coincide approximately with the TTZ (Narkiewicz, 2003). Also in the Pomerania the basin margin apparently coincided roughly with the Koszalin–Chojnice–Tuchola Fault Zone, and was close to an area of acidic late Tournaisian volcanism (Muszyński *et al*., 1996; Lipiec, 2001).

During the Tournaisian to mid-Viséan, tectonic subsidence rates generally decreased and came locally to a standstill or were even reversed in response to Bretonian tectonics (Fig. 4). Regional extension triggered widespread magmatism that was particularly intense during the late Tournaisian and early Viséan along the NE basin margin; moreover, it controlled depositional patterns of carbonate platforms on elevated blocks. On the Małopolska Block (S Holy Cross Mts.) and the USCB the relationship between volcanic episodes and vertical movements of carbonate platforms can be demonstrated (Bełka, 1987; Belka *et al*., 1996). Magmatic activity was intense also in cratonic domains to the NE of the TTZ, as seen in the occurrence of diabase and syenite intrusions in the Płock Area (Żelichowski in: Marek, 1983) and of large mafic-alkaline intrusive bodies in NE Poland (Fig. 8; Krzemińska *et al*., 2006).

LATE VISÉAN — ONSET OF OROGENIC COMPRESSION

During the late Viséan, Carboniferous basins attained their maximum extent and encroached on all regions described except perhaps for the Płock Area (Fig. 9). A mobile clastic shelf, typical of the preceding stage, persisted in Pomerania and on the Małopolska Block and probably also on the Łysogóry–Radom Block. In Pomerania, prograding clastic facies mark a distinctive regression in the area of the TTZ, suggesting syn-sedimentary tectonic activity along the latter. Carbonate platforms that had thrived during the early Viséan were terminated in the southern USCB and in Pomerania roughly at the turn of the Holkerian and Asbian (Lipiec and Matyja, 1998; Lipiec, 2001; Narkiewicz, 2005), whereas on the Małopolska Block their development ceased during the early Asbian (Bełka *et al*., 1996).

Close to the Holkerian-Asbian boundary the westernmost part of the USCB carbonate platform began to subside rapidly whilst the remainder of this platform was uplifted, dissected into blocks and eroded. In the area of the Sub-Carpathian Arch, erosion locally removed more than 500 m of Lower Carboniferous and Upper Devonian carbonates (Narkiewicz, 2005). This erosional surface, which displays evidence of karstification, was onlapped and progressively overstepped from the west by late Viséan and earliest Namurian A clastic deposits that rest with a low-angular unconformity on their substrate (Fig. 3). This transgressive sequence consists in the west of marine shales, siltstones and sandstones up to 1500 m thick (Malinowice Fm.; Fig. 5) that thin eastward and grade into near-shore and continental clastic deposits containing a few coal beds (Zalas Fm.; Fig. 5). This sequence grades westwards into the Early Carboniferous flysch of the Moravian-Silesian Belt, and consequently it was interpreted by Kotas (1995) as its distal equivalent ("flysch association").

The general late Viséan-earliest Namurian depositional architecture of the USCB (Fig. 5), combined with the pattern of

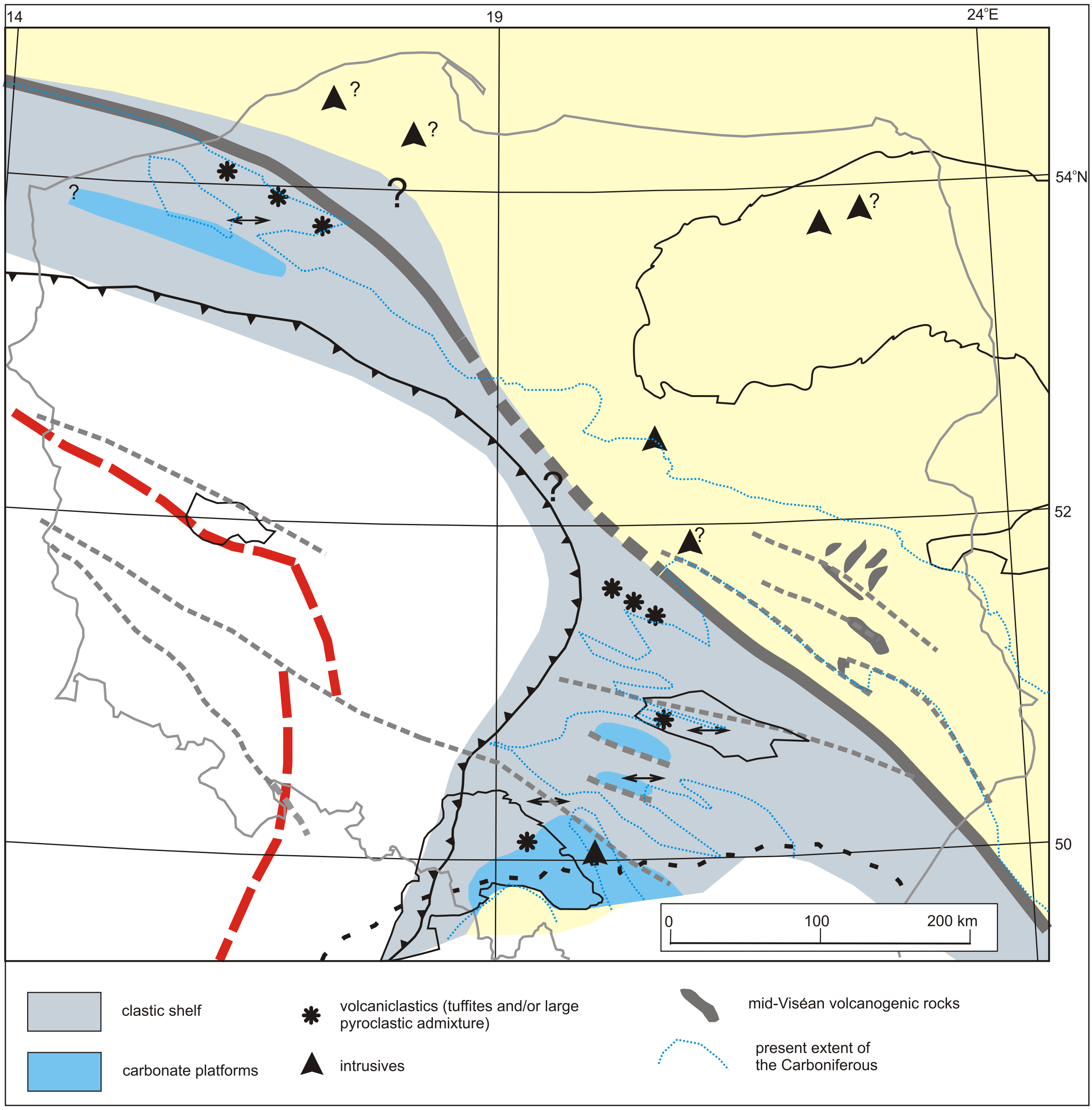

Fig. 8. Palaeogeographic map of the Polish Variscan foreland in the Tournaisian to mid-Viséan (based on various sources cited in the text)

Other explanations as in Figures 2 and 6

its subsidence (Fig. 4), reflect the development of a flexural foreland basin on the Brunovistulian lower plate in response to its tectonic loading by the Moravian-Silesian orogenic wedge (Buła and Żaba, 2005). This interpretation is compatible with a late Viséan rapid eastwards migration of the depocentre of this basin (Bełka, 1987) and a general western provenance of detrital material (Paszkowski *et al.*, 1995; Świerczewska, 1995, summarized by Gradziński *et al.*, 2005).

In the Lublin Basin, the late Viséan sedimentary-tectonic cycle was preceded by the extrusion of laterally discontinuous, locally up to 230 m thick volcanic rocks of basaltic composition that have yielded K-Ar ages of 339–325 Ma (Depciuch, 1974; Grocholski and Ryka, 1995). During the Asbian and early Brigantian, a late Viséan 50 to 200 m thick carbonate-clayey shelf sequence onlapped NE-wards the Bretonian unconformity (Skompski, 1998). During this time, the Kock Fault Zone marked the boundary between a more stable carbonate platforms to its NE, and a more rapidly subsiding carbonate-clayey shelf to the SW. The SW margin of the shelf is essentially unknown. Rather than corresponding to a discrete shelf edge, it could have formed a gentle slope transitional to a slightly deeper environment, characterized by dark mudstones and quartz arenites with

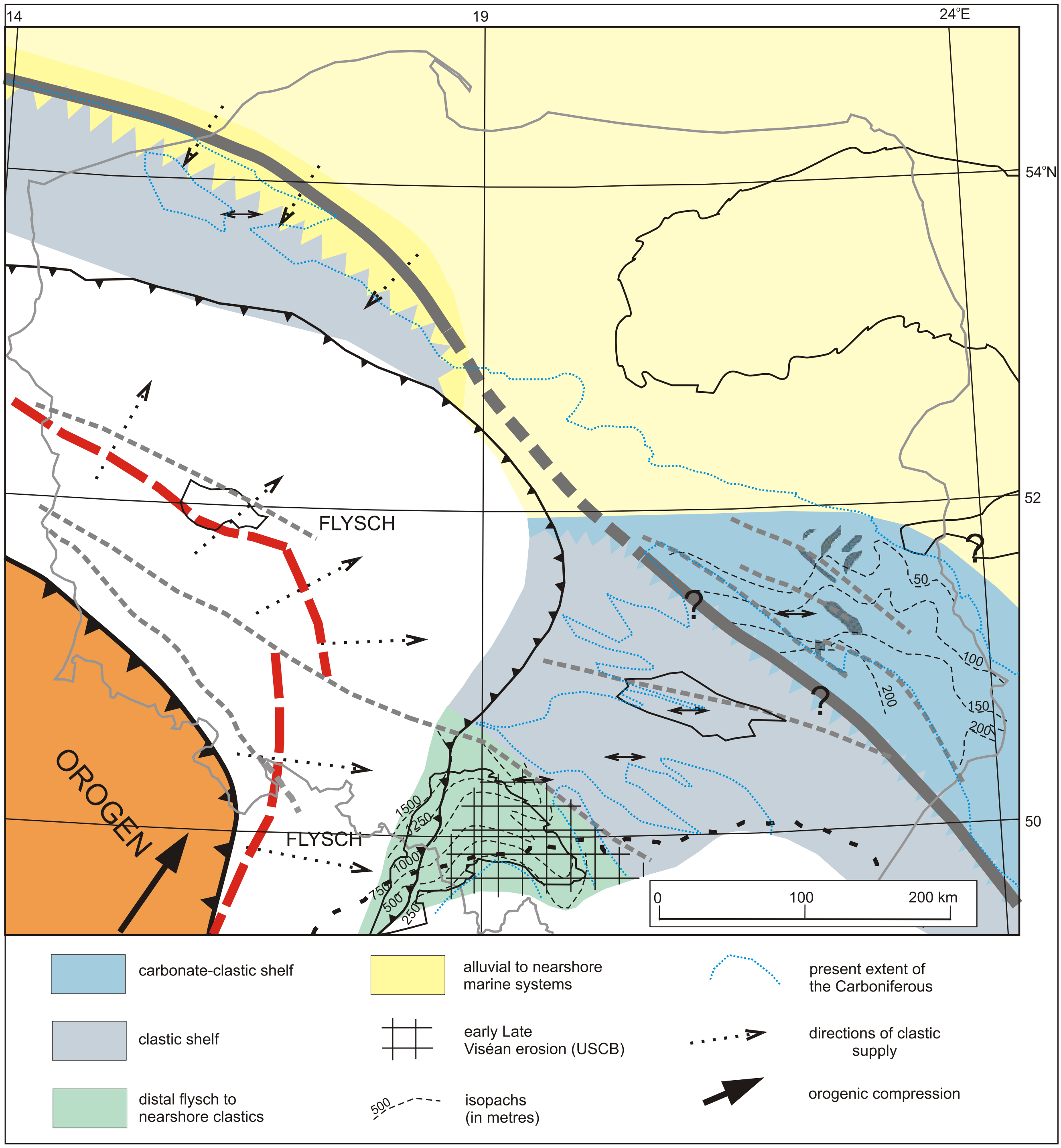

Fig. 9. Palaeogeographic map of the Polish Variscan foreland in the late Viséan (based on various sources cited in the text)

Other explanations as in Figures 2 and 6

greywacke intercalations, typical of the late Viséan of the Holy Cross Mts. (Żakowa and Migaszewski, 1995). A tentative position of this facies transition is shown in Figure 9, assuming that it was controlled by syn-depositional activity along the TTZ. The general late Viséan palaeogeography suggests that clastic material occurring on the Małopolska Block was derived from the rising Variscan Orogen in the west. Correspondingly, these deposits can be interpreted as probable distal equivalents of the synorogenic flysch, documented in the "Variscan Externides" (e.g. Krzemiński, 2005).

EARLY NAMURIAN A — EROSION AND PARALIC SEDIMENTATION

At the turn of the Early to Late Carboniferous the palaeogeographic setting of Poland underwent a major reorganization. Whilst during the Namurian A the Małopolska, Radom–Łysogóry (?), and Pomerania regions became exposed and subjected to erosion, the USCB and the Lublin Basin continued to subside, as seen in the accumulation of paralic coal-bearing sequences. In Southern Poland this change may be interpreted as reflecting NE-wards migration and aerial expan-

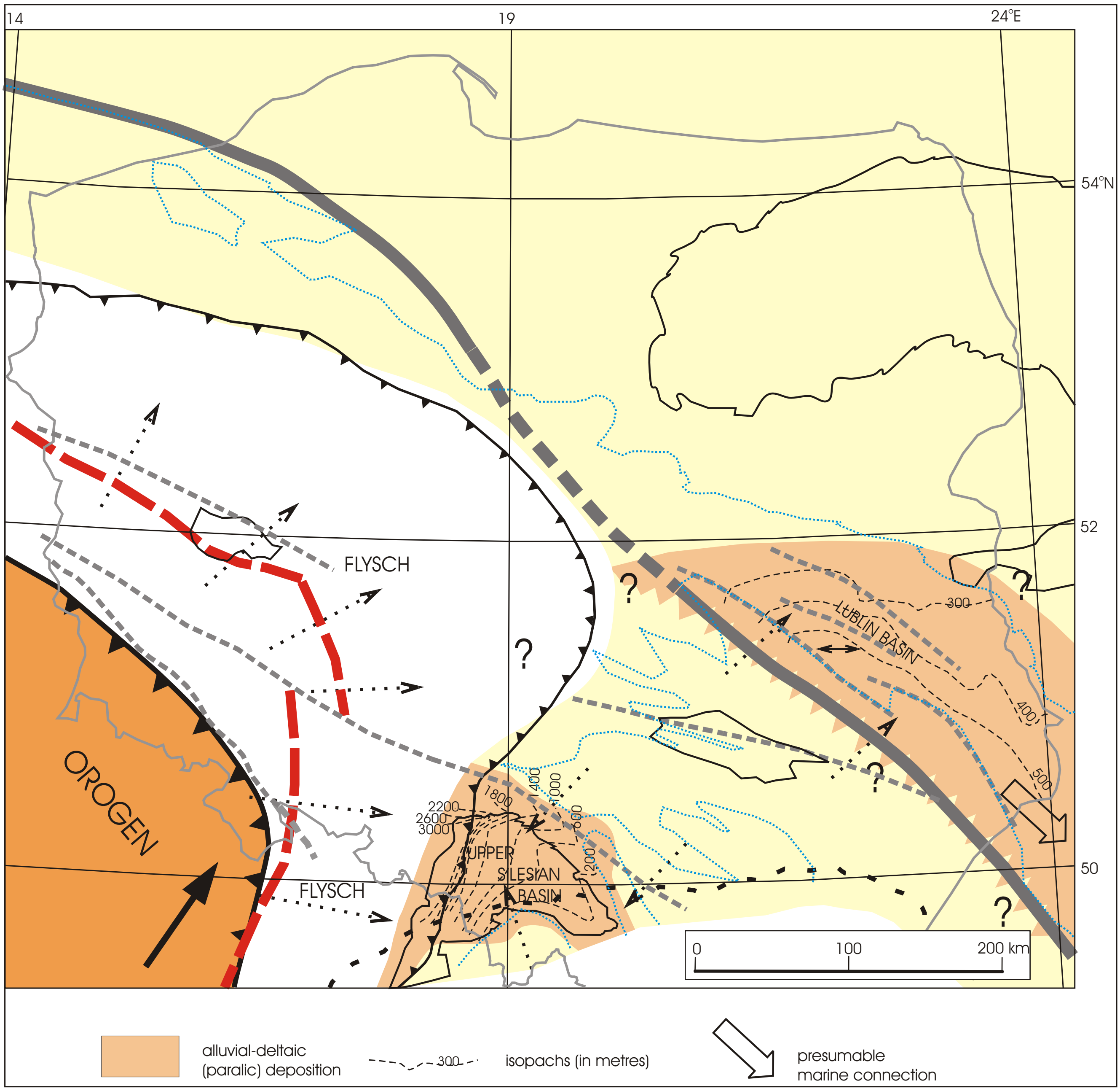

Fig. 10. Palaeogeographic map of the Polish Variscan foreland in the early Namurian A (based on various sources cited in the text)

Isopachs in the Lublin Basin refer to the Terebin Fm., in the Upper Silesian Basin to the Paralic Series (*cf.* Fig. 5); other explanations as in Figures 2, 6 and 9

sion of the forebulge that had developed during the late Viséan in the eastern USCB (Narkiewicz, 2005). An alternative explanation is a broad-scale lithospheric buckling in response to the build-up of collision-related intraplate compressional stresses (Fig. 10). The latter interpretation (suggested by P. A. Ziegler, 2007, pers. comm.) seems more probable given the considerable width and oblique orientation of the uplifted area relative to the hypothetical orogenic front.

In the USCB, the late Viséan deposits grade upwards into rhythmically bedded fluvial and, subordinately, marine coastal-deltaic deposits of the Paralic Series (Gradziński *et al.*, 2005). This "coal-bearing paramolasse" (Kotas, 1994) is up to 3500 m thick, thins progressively eastwards and ultimately pinches out (Figs. 5 and 10). Accumulation of this succession occurred during a cycle of increased tectonic subsidence of the flexural foreland basin that had commenced during the late Viséan and that reflects the progressive evolution of the Moravian-Silesian orogenic wedge. The Namurian A depositional regime of the USCB reflects a balance between subsidence rates and sediment supply from the eroded orogen as well as from the Sub-Carpathian Arch (Kotas, 1995). Sedimentation probably overstepped the Kraków–Lubliniec tectonic line, as indicated by occurrences of Namurian A deposits in the SW part of the Małopolska Block area reported by Żakowa and Jurkiewicz (1995) and Jawor and Baran (2004).

In the Lublin Basin, the predominantly clayey-carbonate succession gave way during the latest Viséan to paralic cyclothems comprising mostly siliciclastic shallow-marine to deltaic and fluvial facies containing subordinate limestone and coal horizons (Skompski, 1998; Waksmundzka, 1998, 2005). This succession attains a maximum thickness of 600 m near the SW margin of the Lublin Trough, particularly in its central and SE segment, whereas towards the NE it thins across the Kock Fault Zone and wedges out beyond it. The inferred SW margin of the basin was probably located beyond the present SW tectonic boundary of the Lublin Trough that apparently cross-cuts facies and palaeothickness patterns (Żelichowski and Kozłowski, 1983).

No Upper Carboniferous has been encountered so far on the Małopolska and Łysogóry-Radom blocks. Until more data can be obtained it is safe to assume that these areas were exposed and subjected to erosion starting from the Namurian A times. If so, the tectonically active SW margin of the Lublin Basin may have been controlled by the TTZ.

The direction of advance of marine incursions from the flexural Variscan foreland basin into the Lublin Basin is still uncertain. Available data suggest that the Namurian A deposits pinch out towards the west and north (Żelichowski and Kozłowski, 1983). At the same time this succession becomes thicker towards the SE where, however, it was eroded in the eastern Lviv area of Ukraine (Fig. 1). Nevertheless, it is conceivable that the Lublin Basin was connected in one way or another to the foreland flysch basin of the Southeastern Variscan Orogen.

NAMURIAN B-WESTPHALIAN — CONTINENTAL SEDIMENTATION

The end of the Namurian A corresponds to a regional break in sedimentation (Fig. 3) that apparently is not associated with significant tectonic deformation (Kotas, 1994; Narkiewicz *et al*., 1998*b*). This suggests a still-stand in tectonic subsidence or even a small uplift that is probably superimposed on an eustatic lowstand in sea level (mid-Carboniferous event; Saunders and Ramsbottom, 1986). During the Namurian B the depocentres of the Upper Silesian and Lublin basins were re-activated (Fig. 10), although with a considerable re-arrangement of subsidence patterns. This may point to structural controls on the late Namurian A hiatus.

In the USCB, sedimentation resumed under exclusively continental alluvial conditions while the depocentre shifted eastwards (Fig. 5). The main part of the “coal-bearing orthomolasse” (Kotas, 1994), comprising the Namurian B to lower Westphalian C, displays prominent thickness gradients, pinching out of particular depositional units and the occurrence of intra-formational erosional surfaces towards the eastern basin margin. The uppermost part of this succession is composed of late Westphalian D coarse-grained deposits. These are only known from the eastern part of the basin where their deposition was preceded by a sedimentary gap comprising late Westphalian C to early Westphalian D. Stephanian red beds of subordinate thickness unconformably overlie older Carboniferous rocks, clearly postdating basin inversion.

The subsidence pattern demonstrates (Figs. 4 and 5) that the post-Namurian A change in basin architecture was associated with a second orogenic phase and concomitant thrust-loading of the western margin of the Brunovistulian plate. Terrigeneous sediments, generally more coarse-grained than during the earlier phase, were supplied from the west but also from the southern Sub-Carpathian Arch (Kotas, 1995).

With the Namurian B resumption of subsidence of the USCB, the NE margin of the Upper Silesian Block underwent strong dextral transpressional deformation. High-angle thrusting of the western wall of the Kraków–Lubliniec Fault zone over the Małopolska Block was associated with secondary folding and reverse-faulting. This was followed in the late Namurian and Westphalian by sub-horizontal extension and block uplift (Żaba, 1999), accompanied in the Westphalian B by magmatism that peaked in the emplacement of calc-alkaline granitoids north-east of the Kraków–Lubliniec Fault (Fig. 11).

The Lublin Basin depocentre of the renewed subsidence shifted during the late Namurian slightly towards the NE (compare isopachs of the Dęblin Fm. in Fig. 11 with those of the Terebin Fm. in Fig. 10). During the Westphalian the depocentre was located in the NW part of the Lublin Basin and extended further NW-wards into the Płock Area (Fig. 11). The Namurian B to Westphalian C (D?) succession includes coal-bearing cyclothems composed of alluvial clastic deposits with an upwards decreasing proportion of deltaic marine facies. Its thickness decreases from up to 1500 m in the axial NW part of the basin to *ca*. 600 m in SE part (Żelichowski, 1972, 1983; Żelichowski and Kozłowski, 1983; Porzycki, 1984). In the Płock Area, Westphalian A to C (D?) deposits rest with a thick basal conglomerate containing rhyolitic clasts unconformably on the Silurian succession, and consist of continental clastic succession up to 1000 m thick that is correlative with the north-western Lublin region (Żelichowski, 1983, 1995) and wedges out to the NE. There is no direct proof of synsedimentary faults activity in the Lublin and Płock areas, although Upper Viséan to Namurian depositional architecture strongly suggests that the Kock Fault Zone controlled subsidence and sedimentation patterns (Waskmundzka, 2005; Narkiewicz *et al*., 2007*b*). This and other circumstantial evidence suggests a pull-apart depositional-subsidence regime (Żelichowski, 1983; Narkiewicz *et al*., 1998*b*). Particularly the NW-wards migration of the depocenter points to (dextral?) strike-slip movements along the TTZ. It is here assumed that the TTZ bounded the Lublin Basin to the SW.

In Pomerania, Westphalian B to Stephanian A–B continental clastic deposits unconformably overlie various Lower Carboniferous and Devonian rocks (Żelichowski, 1995) and fill WNW-trending grabens in the NW part of the area where they attain thicknesses of severals hundred metres. Żelichowski (1995) postulated that these grabens formed as pull-apart basins in response to strike-slip movements along the TTZ.

LATE WESTPHALIAN-EARLY STEPHANIAN INVERSION

During the late Westphalian D and early Stephanian (“Asturian tectonic phase”) the entire area of the Polish

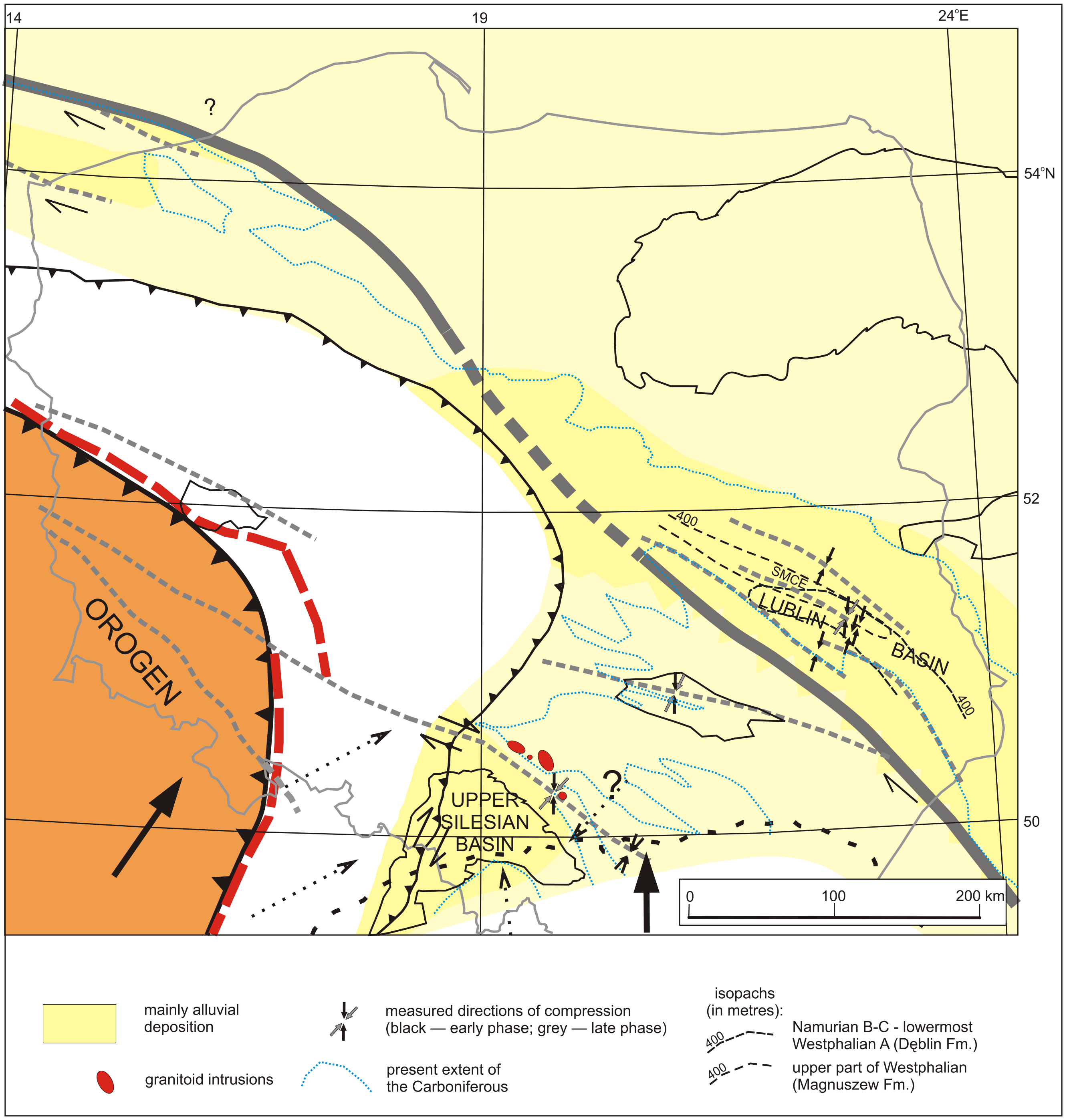

Fig. 11. Palaeogeographic map of the Polish Variscan foreland in the Namurian B to Westphalian

Measured directions of late Westphalian–early Stephanian compression after Jarosiński in Narkiewicz *et al*. (2007*b*), Lamarche *et al*. (2003) and Żaba (1999); SMCE — Stężyca-Mełgiew Central Elevation; other explanations as in Figures 2, 6 and 9

Variscan foreland was subjected to strong compression (Fig. 11). The age of the resulting structures is best constrained in the USCB where an angular unconformity between the Westphalian D and an indefinite part of the Stephanian is observed (Fig. 5). In the Lublin Basin, deformed Westphalian C (?D) strata are unconformably overlain by Permian and younger deposits, whereas in Pomerania the unconformity occurs between the Stephanian A–B and ?upper Stephanian-lowermost Permian deposits (Żelichowski, 1987*b*).

At the western margin of the USCB, the Orlova and related thrusts testify to E-directed compression with a dextral strike-slip component (Bogacz and Krokowski, 1981). The main part of this basin, adjacent to the E, is characterized by gentle folding with superimposed W–E trending faults of mixed dip-slip and dextral strike-slip character (Kotas, 1985, 1994; Fig. 5). These Variscan structures display amplitudes up to 2000 m and generally follow the E–W directed structural grain of the Proterozoic basement (Buła and Żaba, 2005). Coeval dextral transpressional deformation affected the NE margin of the Upper Silesian Block, although their magnitude was smaller than during the earlier post-Namurian A phase (Buła and Żaba, 1997; Żaba, 1999). Whereas Kotas (1985) and Buła and Żaba (2005) postulated N-directed compression, the horizontal compressional stress axis changed according to Żaba (1999) from N–S to NE–SW at the turn of the Westphalian to the Stephanian (Fig. 11). The related uplift and erosion of the western part of the USCB is estimated to amount to *ca*. 3–4 km, based on extrapolated sediment thicknesses from the east (Fig. 5). For the NE and central parts of this basin Belka (1993) estimated the magnitude of erosional unroofing at 1200 m and 2000–3000 m, respectively.

In the intraplate domain of SE Poland, late Variscan deformation resulted in the development of faulted folds with varying amplitudes and wavelengths (Fig. 12). In the Holy Cross Mts., such structures strike approximately normal to the N–S to NNE–SSW direction of the Variscan shortening (Lamarche *et al*., 2003). The most intense deformation, with amplitudes of up to 4 km is associated with the Holy Cross Fault Zone and involves a positive flower-like array of second-order faults suggestive of transpressional origin (Pożaryski, 1990; Pożaryski and Tomczyk, 1993; Lamarche *et al*., 2003). Mizerski (1995) and Lamarche *et al*. (2003) stressed the similarity of the Variscan structural development in both parts of the Holy Cross Mts., thus implying a common response of the Małopolska and Radom–Łysogóry blocks to the evolution of the palaeostress field. As post-Viséan strata have not been encountered so far on the Małopolska Block, its Variscan deformation was and still is commonly attributed to the "Sudetic tectonic phase" at the turn of the Viséan to the Namurian (e.g. Zdanowski, 1995; Jawor and Baran, 2004). However, consistent patterns of compressional stress field trajectories in the entire SE Polish Variscan foreland (Fig. 11) are suggestive of the common deformational phase which affected this area during the latest Westphalian to early Stephanian.

The cross-section of the Lublin Trough reveals the configuration of a truncated broad syncline, the uplifted flanks of which are associated with the deep-seated Ursynów–Kazimierz and Izbica–Zamość faults, and the Kock Fault Zone (Fig. 12). The Ursynów–Kazimierz Fault shows evidence for its pre-Permian transpressional reactivation that was accompanied by strong uplift of the southwestern block that is bounded to the SW by the Nowe Miasto–Radom Fault Zone. Seismic data reveal that this block, which is composed of deformed Devonian strata and unconformably overlain by Permian-Mesozoic sediments, is transected by NW–SE striking faults (Krzywiec, 2007). It probably represents a (sinistral?) transpressional inversion zone across which about 3 km of strata were eroded.

In the SE, the Izbica–Zamość Fault has a reverse throw of *ca*. 1 km (Żelichowski, 1972) whereas in the NE the Kock Fault Zone is a complex narrow zone of reverse faulting and folding, locally involving thin-skinned decoupling at the level of the Lower Palaeozoic shaly succession (Krzywiec and Narkiewicz, 2003*a*, *b*; Krzywiec, 2007).

Internally, the Lublin Trough is dissected by a system of roughly NW–SE striking, both SW and NE dipping reverse faults with associated anticlines, interpreted as positive flower structures (Pożaryski and Tomczyk, 1993). The most prominent of these is the Stężyca–Mełgiew Central Elevation (Fig. 12), probably a deeply rooted structure that was modified in its central segment by detachment at the mid-Frasnian evaporitic horizon (Narkiewicz *et al*., 2007). The anticlinal structures show evidence of rotation of the compression stress axis from SSW–NNE to WSW–ENE with a corresponding change from northeast-directed thrusting to sinistral transpression (Jarosiński, 2004, unpubl. report; Narkiewicz *et al*., 2007). In the central segment of the Lublin Trough, post-inversion erosion removed locally up to 1600 m of the Carboniferous strata, whilst east of the Kock Fault Zone 500 m or less strata were eroded.

Generally speaking, in areas to the NE of the USCB the strongest compressional deformation and the largest magnitudes of inversion are confined to narrow fault zones, including the Kraków–Lubliniec and Holy Cross faults, as well as to the major longitudinal faults of the Lublin Basin area. Structures that evolved along all of these discontinuities, which partly form the boundaries between crustal blocks, display a strike-slip component and are thick-skinned. The sense of the strike-slip displacement along the different faults may, however, differ (compare e.g. the Kraków–Lubliniec Fault and the Lublin Basin; Fig. 11).

In Pomerania, the style of late Variscan deformation is poorly known and is here tentatively attributed to strike-slip movements along the TTZ (Żelichowski, 1987*b*). Based on mesostructures observed in cores, Żaba and Poprawa (2006) postulated two Late Carboniferous-Early Permian phases of dextral transpression and thrusting that are separated by a transtensional phase.

REACTIVATION OF OLDER CRUSTAL DISCONTINUITIES

Data presented in this paper show that the "memory of the lithosphere" (Cloetingh *et al*., 2005) played an important role in the development and inversion of Devonian and Carboniferous sedimentary basins in the Polish Variscan foreland. This pertains specifically to the repeated reactivation of pre-existing crustal discontinuities corresponding to the boundaries between probable Caledonian terranes, such as the Kraków–Lubliniec and Holy Cross faults, as well as to the SW margin of the EEC that coincides with the Teisseyre-Tornquist Zone.

The Kraków–Lubliniec Fault was particularly active during the Carboniferous when it focused transtensional and mostly dextral transpressional deformation, as clearly documented by excellent mesostructural analyses (Żaba, 1999). Involvement of the deeper crust and probably of the mantle is evidenced by bimodal magmatism, including the emplacement of granites during the Westphalian. This crustal discontinuity affected ba-

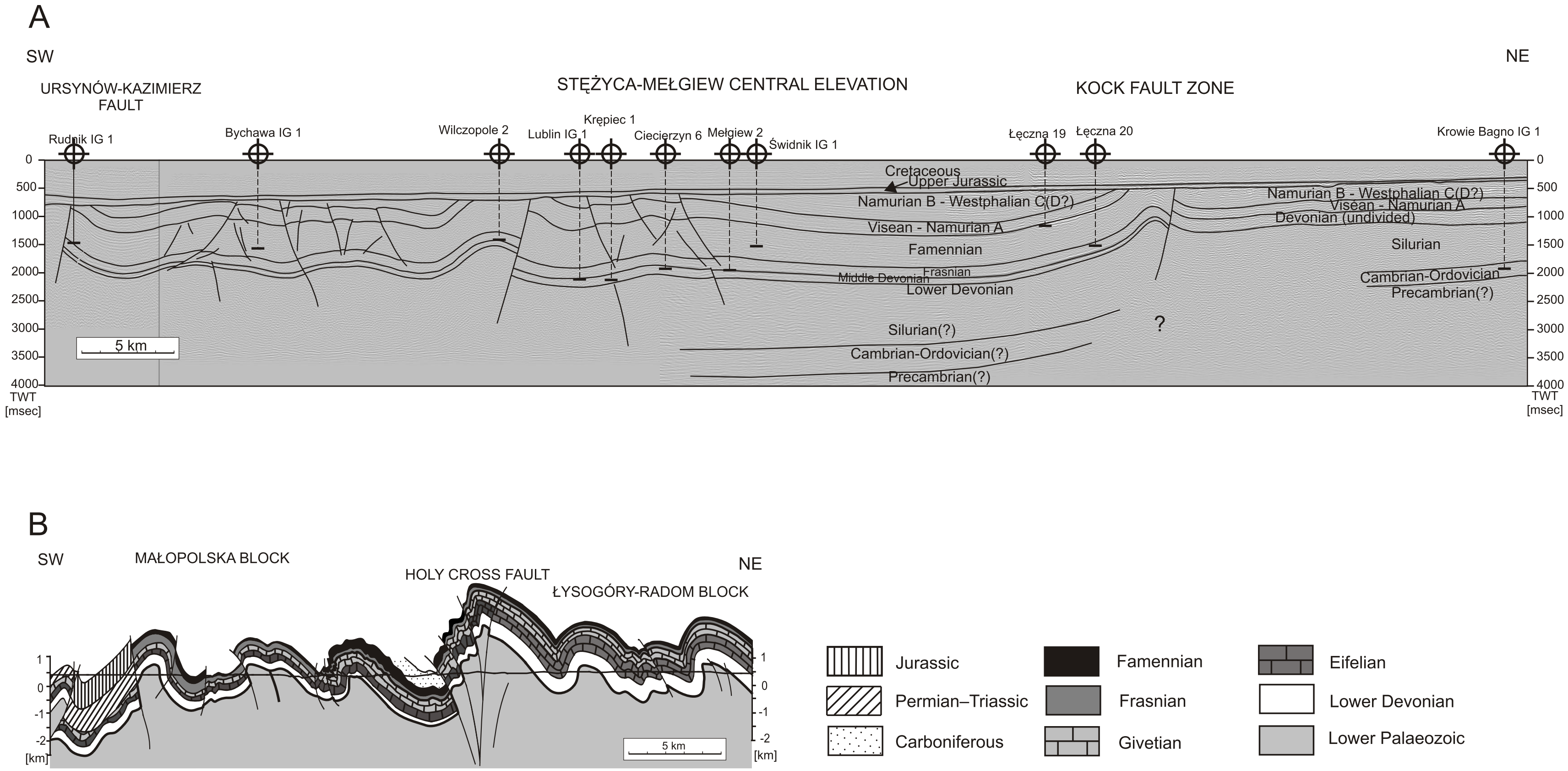

Fig. 12. Comparison of the Variscan structure of the Lublin Basin (A) and the western Holy Cross Mts. (B) as seen in cross-sections approximately perpendicular to the regional strike

A — regional seismic section interpreted by Piotr Krzywiec (fig. 6 in Narkiewicz *et al.*, 2007*b*),vertical scale is two-way travel-time (TWT) in miliseconds; **B** — modified figure 3 in Lamarche *et al.* (2003), mainly to adjust to approximately the same vertical and horizontal scales in both cross-sections; the cross-section shows the cumulative effect of both Variscan and Alpine (Cretaceous/Paleogene) deformation, although the latter are confined mainly to the south-westernmost part, whereas in remaining part they are insignificant (Lamarche *et al.*, 2003); for location of the cross-sections see Figure 2 sin evolution by controlling the location of facies gradients during the Early Carboniferous and the depositional margin in the Late Carboniferous.

The Holy Cross Fault separated two areas of differing Devonian depositional and subsidence development, with the Łysogóry–Radom Block displaying increased mobility, particularly in the Middle Devonian. During the Late Carboniferous phase of foreland compression, the Holy Cross Fault acted as a transpressional zone characterized by significant inversion amplitudes (Lamarche *et al*., 2003). Palaeogeographic reconstructions by Belka *et al*. (1996) suggest that WNW–ESE striking fault-controlled basement highs governed the development of Early Carboniferous carbonate platforms in the Małopolska area (Fig. 8).

The TTZ is here interpreted as having strongly influenced the architecture of the Devonian to Early Carboniferous strata in Pomerania, with areas of intermittent uplift and erosion located on the EEP (Figs. 8–11). It is likely that the basin margin was controlled by an array of down-stepping blocks along the craton margin rather than by a single fault. The late Tournaisian volcanism in Pomerania appears to be associated with activity along inland part of this fault system. During the Westphalian the TTZ and related WNW trending faults were responsible for development of transtensional grabens that in the mid-Stephanian were deformed under a transpressional regime.

The SE sector of the TTZ involves the Nowe Miasto–Radom Fault Zone and its SE extension converging with the Holy Cross Fault (Fig. 2). During the Mid Devonian this part of the TTZ clearly separated the more mobile block in SW from the stable area in NE. The subsequent history of this fault is hypothetical and is here mostly based on interpolations between the Lublin Trough in the NE and the poorly constrained evolution of the Łysogóry–Radom Block. It seems, however, conceivable that this fault controlled regional subsidence and facies gradients also during the Carboniferous (Figs. 8–11).

The Lublin Basin was dissected by an array of faults that roughly parallel the TTZ and that were transpressionally reactivated during the latest Westphalian. On the other hand, syn-sedimentary activity along these faults appears to vary in time and space. The Ursynów–Kazimierz Fault and the Kock Fault Zone controlled Late Devonian subsidence patterns (Fig. 6). The Kock Fault Zone was again active during the late Famennian-earliest Tournaisian Bretonian block movements and affected also depositional systems during the late Viséan and Namurian. Moreover, the fault systems of the Lublin area appear to be associated with mid-Viséan magmatic activity (Fig. 8). Conceivably the array of craton-margin parallel faults of the Lublin area represents reactivated hypothetical basement discontinuities that could had developed together with the TTZ during the Neoproterozoic break-up of Rodinia (*cf*. Nawrocki and Poprawa, 2006).

BROADER REGIONAL CONTROLS — DISCUSSION

The evolution of the Polish Variscan foreland reflects in general terms the main stages of the Devonian to Carboniferous structural-sedimentary development of the southern margin of the Old Red Continent that was controlled by the collision of Gondwana-derived microplates and ultimately of Gondwana (Ziegler, 1989, 1990). Several aspects of the evolution of the Polish Variscan foreland closely match that of the Rheno-Hercynian Zone in Germany and Belgium (e.g. Franke *et al*., 1978; Franke, 2000, 2006):

1. An extensional regime during the Devonian and Early Carboniferous (pre-late Viséan), the development of a carbonate-siliciclastic marginal shelf, and intense magmatic activity during the Tournaisian and early Viséan.

2. Intensifying syn-orogenic compression during the late Viséan and early Namurian A (“Sudetic phase”), and the development of Culm-equivalent flysch and paralic molasse in the USCB.

3. Gradual transition from paralic deposition during the Namurian to Westphalian coal-bearing molasse sedimentation.

4. Terminal Variscan deformation at the turn of the Westphalian and Stephanian (“Asturian phase”).

There are however some aspects of the Polish foreland evolution that do not readily fit into the geodynamic scenario of the Rheno-Hercynian Zone. These will be addressed in the following discussion.

DEVONIAN-EARLY (MID) VISÉAN EXTENSION

The beginning of Devonian sedimentation over large parts of Poland can be attributed to initial back-arc rifting preceding the Emsian onset of sea-floor spreading in the Rheno-Hercynian domain (Ziegler, 1990; Franke, 2000). This event is also recognized in the Moravian-Silesian area where syn-rift sedimentation and volcanism started during the Emsian (Schulmann and Gayer, 2000; Kalvoda, 2002). The regional thermal subsidence related to these events appears to have controlled also the Devonian evolution of the Polish Variscan foreland.

Phases of strong extension affected the Lublin Basin in mid-Frasnian and in Famennian times. The mid-Frasnian event is only weakly expressed in the Rheno-Hercynian Zone, but corresponds to the initial rifting stage of the Pripyat–Dniepr–Donets Graben (Narkiewicz *et al*., 1998*b*). Although exact stratigraphic correlations have not yet been established, it is likely that the Upper Frasnian Rechitsian to Evlanian horizons in the Pripyat Graben, marking its early syn-rift phase (Kusznir *et al*., 1996), correspond to the onset of accelerated subsidence of the Lublin Basin (Narkiewicz *et al*., 1998*a*; unpubl. data). In both basins the initiation of subsidence is marked by marine evaporites (much thinner in the Lublin area), and in both the maximum subsidence was attained during the Famennian. The lack of syn-rift volcanism in the Lublin Basin is, however, a significant difference that is consistent with its smaller subsidence rates and consequently weaker crustal extension as compared to the Pripyat–Dniepr–Donets Graben (Pożaryski, 1986).

The compressional (?) Bretonian pulse is reflected in the Lublin Basin by block tectonics of considerable magnitude whilst in the Pripyat Graben it may be tentatively related merely to the termination of the Late Devonian rifting stage.

The extensional reactivation of the Dniepr–Donets–Donbas system in the late early Viséan was associated with extrusive magmatic phenomena (Stephenson *et al*., 2006) — similar as in the contemporaneous Lublin Basin. The mid-Viséan magmatism of the Lublin Area is consistent with the general pattern of diachronous occurrence of rift-related magmatic activity in the southern parts of the EEC, peaking during the Givetian in the Peri-Caspian Depression, in the early Frasnian in the Donbas area, in the late Famennian-early Tournaisian in the Pripyat Graben, and finally, mid-Viséan in the Lublin Basin (Wilson and Lyashkevich, 1996; Stovba *et al*., 1996; Narkiewicz *et al*., 1998*b*; Fokin *et al*., 2001). This corresponds with westwards propagation of rifting activity in the southern EEC domain that was controlled by a common palaeostress regime dominated by NW–SE to N–S directed principal horizontal extensional stress trajectories (Fokin *et al*. 2001).

Kusznir *et al*. (1996) considered two alternative mechanisms of the Pripyat Graben rifting: (1) plume-induced uplift, and (2) remote plate-boundary stress combined with local plume uplift stress. The coeval rifting/extensional event in the Pripyat Graben and in the Lublin Basin areas within the framework of the consistent development of the entire Pripyat to Donbas system points to wide regional controls responsible for the common stress-field evolution, and thus favours the second mechanism. At the same time, widespread and prolonged magmatism suggests that thermal instability at the base of the lithosphere had a considerable regional and temporal range and is therefore difficult to explain in terms of a single mantle plume (*cf*. Stephenson *et al*., 2006).

LATE VISÉAN-EARLY NAMURIAN A

In response to increasing collisional coupling of the Old Red Continent and Gondwana, compressional stresses built up within the Variscan domain at the transition to the late Viséan (Ziegler, 1990). Late Viséan closure of the Rheno-Hercynian back-arc ocean, as postulated by Ziegler (1990), was accompanied by the development of the flexural Rheno-Hercynian foreland basin and the accumulation of the flysch-type "Kulm Grauwacke" that prograded rapidly towards the foreland (Franke *et al*., 1978; Ricken *et al*., 2000).

Following closure of the Moravian-Silesian Basin, dextral oblique subduction of the Brunovistulian plate under the Central Sudetic orogenic wedge commenced in the late Tournaisian (Schulmann and Gayer, 2000; Mazur *et al*., 2006). Although earliest greywackes are recorded during the Tournaisian, rapid flysch progradation started during the early Viséan and accelerated in the late Viséan (Kumpera and Martinec, 1995; Hartley and Otava, 2001). This can be related to increased uplift and exhumation rates of the Moldanubian internal parts of the orogen. Between 340–330 Ma (Holkerian-Asbian) the accretionary wedge underwent vertical extrusion with associated extension and eastwards thrusting towards the foreland (Schulmann and Gayer, 2000). According to Franke and Żelaźniewicz (2002) the present-day juxtaposition of the Central Sudetes and the Brunovistulian Block was essentially achieved by *ca*. 325 Ma (roughly the Viséan-Namurian boundary). A similar scenario is interpreted for the Polish part of the Moravian-Silesian Belt belt by Żaba *et al*. (2005).

In the USCB, the earliest equivalents of the syn-orogenic Culm succession are late Viséan in age, confirming that only by this time this area became incorporated into a flexural foreland basin in front of the NE-wards advancing orogen. Development of the distal flysch was predated by a distinct episode of uplift and erosion of the SE part of the USCB, probably reflecting syn-collisional compressional foreland deformation. This elevated area was progressively onlapped by upper Viséan and lower Namurian A deposits towards the east, during the main phase of flysch deposition in the Moravian-Silesian belt (Kumpera and Martinec, 1995; Schulmann and Gayer, 2000).

It is noteworthy that major late Viséan and early Namurian crustal shortening in the Variscan Orogen is not reflected in any significant compressional deformation in its foreland. Generally, an extensional regime prevailed probably until the end of the Viséan throughout the Małopolska and presumably the Łysogóry–Radom Block. In the Lublin area, mid- to late Viséan extension was particularly pronounced as indicated by basaltic magmatism followed by renewed subsidence. This agrees with the earlier concepts by Żelichowski (1987*a*, *b*) of the TTZ acting as a transtensional zone bounding the Lublin Basin to the SW, and at the same time controlling the NE erosional edge of the Pomeranian depositional area.

These events are contemporaneous with the accelerated late Viséan to Serpukhovian (=Namurian A) subsidence of the Dniepr–Donets rift system (Dvorjanin *et al*., 1996; Stovba *et al*., 1996). The evidence of late Viséan to Namurian A extension in the southern parts of the EEC may suggest that the back-arc extensional system was active longer in the southeastern part of the Old Red Continent than in the Rheno-Hercynian Zone of western Europe. Alternatively, Nikishin *et al*. (1996) and Fokin *et al*. (2001) proposed that the accelerated late Viséan-Namurian A subsidence of the Dniepr–Donets Graben was controlled by collision-related compressional forces transmitted from the southern continent margin (their Scythian Orogen).

NAMURIAN B-WESTPHALIAN C

According to Schulmann and Gayer (2000), the Moravian-Silesian accretionary wedge underwent continuous NE-directed dextral transpression after its emplacement on the Brunovistulian foreland around 330 Ma, accompanied by moderate shortening until *ca*. 310 Ma (Westphalian C). This is in agreement with the observations from the Polish part of the Moravian-Silesian Belt as well as from the USCB where a thick continental molasse-type sequence accumulated during the second phase of the foredeep subsidence. It is rather intriguing that pronounced dextral transpressional deformation occurred along the NE margin of the USCB after the Namurian A and not earlier during the preceding orogenic phase. Conceivably this may be attributed to the build-up of north-directed compressional stresses that were exerted by the SE Variscan Orogen on the Polish foreland where they interfered with the NE directed compressional stresses emanating from the Moravian-Silesian Belt. This stress regime may have been also responsible for the uplift of the Małopolska and Łysogóry–Radom blocks, as well as for the dextral strike-slip reactivation of the TTZ and associated fault systems that controlled the subsidence of the Lublin Basin. The latter basin was presumably connected with proximal foreland basins of the SE Variscan Belt. From the Namurian B onwards the Lublin and Płock areas, located on the marginal parts of the EEC, started to develop in concert with the remaining part of the Polish Variscan foreland. This indicates that the western and probably also the southern EEC margin became by that time dominated by a uniform palaeostress field and consistently responded to far-field compression emanating northwards from the SE Variscan Orogen. The inferred dextral sense of the Late Carboniferous strike-slip movements along the TTZ is consistent with the co-eval dextral transtension at its NW prolongation, i.e. in the area adjacent to the STZ (Fig. 1; Thybo, 1997).

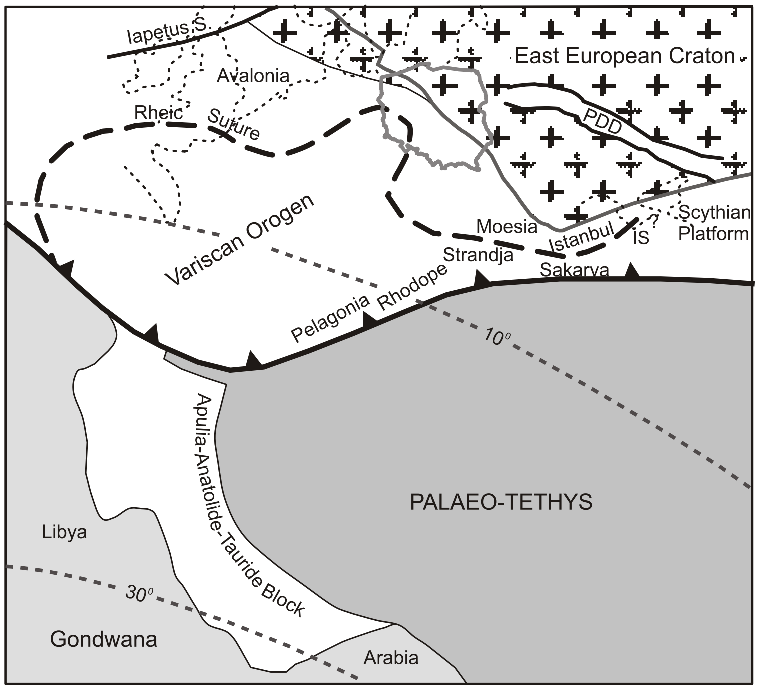

Fig. 13. Late Carboniferous palaeogeographic context of the Variscan Orogen of Western and Central Europe and its hypothetical eastern extension along the northwestern Palaeo-Tethys margin (after Okay *et al*., 2006, modified)

Outline of Poland is shown for a better comparison with Figures 1 and 2; IS — Intra-Pontide Suture; PDD — Pripyat–Dniepr–Donets–Donbas rift system

END WESTPHALIAN-EARLY STEPHANIAN INVERSION

The final compressional deformation of the Variscan foreland occurred in its different parts roughly simultaneously at the Westphalian-Stephanian transition, though the stratigraphic resolution of this event is variable. Palaeostress data indicate that during this time-span the trajectories of principal compressional horizontal stress axes rotated on a regional scale from nearly N–S to NE–SW. In all the regional units analyzed, the strike of resulting structures reflects the reactivation of pre-existing crustal discontinuities. Their common transpressional overprint is related to their oblique orientation with respect to the prevailing compressional stress trajectories. Observed permutations in the sense of transpression are probably related to variations in the strike of reactivated basement discontinuities.

Whereas the NE directed compression is consistent with the transport direction of the Moravian-Silesian Fold-and-Thrust-Belt (Schulmann and Gayer, 2000), the earlier north-directed compression points to stresses emanating from the SE Variscan Orogen. It is noteworthy that in the Moravian-Silesian Belt dextral late-stage transpression developed progressively during the Namurian B to end Westphalian interval (Schulmann and Gayer, 2000), whilst the distal foreland appears to record a single, apparently short deformation phase at the Westphalian-Stephanian transition.

According to the interpretation proposed in this paper the stress field of the Polish Variscan foreland was dominated during the late Namurian and early Westphalian by northerly directed compressional stresses propagating from the SE Variscan Orogen. Evidence of the Variscan orogenic development south of the EEC, in the present Black Sea area, was recently summarized by Okay *et al*. (2006). They included the Moesian Platform and westwards contiguous Istanbul Zone into the marginal part of the Old Red Continent, defining at the same time the south-adjacent Strandja Massif and Sakarya Zone as a separate Mid Palaeozoic microplate of a Gondwanan origin (Fig. 13). The Strandja–Sakarya arch accreted during the Late Carboniferous across the Intra-Pontide suture, probable continuation of the Rheic suture. The age of orogenic deformation is rather poorly constrained in the Istanbul Zone (Late Carboniferous-Early Permian) whereas it is confined to the Namurian in the Sakarya Zone (Okay *et al*., 2006). The interpreted northerly directed compression during the Late Carboniferous evolution of the Polish Variscan foreland may be thus conceived as a far-field effect of the coeval collision of the Strandja–Sakarya arch with the southern margin of Old Red Continent (*cf*. Fig. 13). The latter may also explain the development of dextral strike-slip movements along the TTZ with resulting Late Carboniferous development of the Lublin and Pomeranian basins in a pull-apart regime.

During the final orogenic phase, NE-directed stresses related to the dextrally NE-wards converging Moravian-Silesian Belt prevailed. It is postulated that, commencing in the late Viséan, the Bohemian Arc was moulded by the arcuate Rheno-Hercynian–Moravian-Silesian embayment of the Pomeranian and Fore-Sudetic margin of the ORC, involving the development of the dextral transpressional Moravian-Silesian Belt. It appears, however that it was not until the late Westphalian that collisional stresses projected from this belt became dominant in the SE Polish foreland.

Franke and Żelaźniewicz (2002) argued against oroclinal bending of the Bohemian Arc. They postulated a complex scenario of late Viséan dextral strike-slip displacement of the order of 1000 km along the Moldanubian Thrust (corresponding to the Moravian-Silesian Thrust Zone; Fig. 2) that was followed by similar displacements along the TTZ before the Stephanian. In view of the data presented here, this model cannot be supported, as there is no evidence for such enormous shearing neither along the EEC margin nor perpendicular to it. Furthermore, palaeomagnetic data do not support displacement of such magnitudes (Nawrocki, 2000). Moreover, this model apparently does not take into account the magnitude of Early Carboniferous shortening across the Moravian-Silesian Belt and fails to explain how and where the postulated shear displacements are accommodated within the EEC.

CONCLUSIONS

1. The sedimentary and structural record of the different crustal blocks that constitute the Polish Variscan foreland reflects their response to changing stress patterns during the Devonian and Carboniferous. From Devonian to Namurian A times the evolution of areas located SW of the TTZ, including the Upper Silesian Coal Basin and the Małopolska and Łysogóry–Radom blocks, was governed by a stress field that was akin to that of the westwards contiguous Rheno-Hercynian Zone. By contrast, the evolution of areas located to the NE of the TTZ, including the Lublin Basin, was then governed by the stress field that prevailed on the southern parts of the EEC, controlling i.a. the development of the Pripyat–Dniepr–Donets rift system (as noticed already by Pożaryski, 1986).

2. After the Namurian A, the entire southern Polish foreland started to respond in a consistent way to the build-up of syn-orogenic compressional intraplate stresses, thus implying a generally uniform stress field.

3. From Namurian B to early Westphalian times the southern Polish foreland was mainly controlled by N-directed compressional stresses emanating from the southeastern Variscan Orogen, developing along the Intra-Pontide suture south of Moesian Platform and Istanbul Zone. During that time the USCB underwent a second phase of flexural foredeep development in front of the NE-wards advancing Moravian-Silesian Belt.

4. During the late Westphalian and early Stephanian the entire area of the Polish Variscan foreland was subjected to compressional stresses changing from N- to NE-directed compression. The latter emanated from the Bohemian orocline and induced widespread basin inversion. This particularly strong compressional event marked the end of the Variscan Orogeny that was followed by a wrench-induced Stephanian-early Permian tectono-magmatic cycle (Ziegler, 1990).

5. The Devonian to Carboniferous evolution of the Variscan foreland of Poland reflects the repeated reactivation of pre-existing crustal discontinuities, such as the TTZ, the boundaries between the Upper Silesian, Małopolska and Łysogóry–Radom blocks and the fault systems within the marginal parts of the EEC in the Lublin Basin. In general, thick-skinned tectonics controlled by the inherited structural grain prevailed during the Westphalian-Stephanian inversion of the Polish Variscan foreland. Thin-skinned structural decoupling involving the development of minor thrusts and reverse faulting was of local significance.

6. The Devonian-Carboniferous evolution of Pomerania resembles in many respects that of the Rügen area (*cf.* McCann, 1999*a*, *b*) and presumably owes its distinct structural-depositional development to a distal position with respect to the evolving orogen. Late stage deformation of this area was mainly controlled by transtensional and transpressional stresses transmitted through the TTZ.

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REFERENCES

ANTONOWICZ L., HOOPER R. and IWANOWSKA E. (2003) — Lublin Syncline as a result of thin-skinned Variscan deformation (SE Poland) (in Polish with English summary). Prz. Geol., **51** (4): 344–350.

BANKA D., PHARAOH T. C., WILLIAMSON J. P. and the TESZ PROJECT POTENTIAL FIELD CORE GROUP (2002) — Potential field imaging of Palaeozoic orogenic structure in northern and central Europe. Tectonophysics, **360** (1–4): 23–45.

BEHR H.-J., ENGEL W., FRANKE W., GIESE P. and WEBER K. (1984) — The Variscan Belt in Central Europe: main structures, geodynamic implications, open questions. Tectonophysics, **109**: 15–40.

BELKA Z. (1993) — Thermal and burial history of the Cracow-Silesian region (southern Poland) assessed by conodont CAI analysis. Tectonophysics, **227**: 161–190.

BELKA Z., AHRENDT H., FRANKE W. and WEMMER K. (2000) — The Baltica-Gondwana suture in central Europe: evidence from K-Ar ages of detrital muscovites and biogeographical data. In: Orogenic Processes, Quantification and Modelling in the Variscan Belt (eds. W. Franke, V. Haak, O. Oncken and D. Tanner). Geol. Soc. London, Spec. Pub., **179**: 87–102.

BELKA Z., SKOMPSKI S. and SOBOŃ-PODGÓRSKA J. (1996) — Reconstruction of a lost carbonate platform on the shelf of Fennosarmatia: evidence from Viséan polymictic debrites, Holy Cross Mountains, Poland. In: Recent Advances in Lower Carboniferous Geology (eds. P. Strogen, I. D. Somerville and G.L. Jones). Geol. Soc. Spec. Publ., **107**: 315–329.

BELKA Z., VALVERDE-VAQUERO P., DÖRR W., AHRENDT H., WEMMER K., FRANKE W. and SCHÄFER J. (2002) — Accretion of first Gondwana-derived terranes at the margin of Baltica. In: Palaeozoic Amalgamation of Central Europe (eds. J. A. Winchester, T. C. Pharaoh and J. Verniers). Geol. Soc., London, Spec. Pub., **201**: 19–36.

BEŁKA Z. (1985) — Lower Carboniferous conodont biostratigraphy in the northeastern part of the Moravia-Silesia Basin. Acta Geol. Pol., **35** (1–2): 33–60.

BEŁKA Z. (1987) — The development and decline of a Dinantian carbonate platform: an example from the Moravia-Silesia Basin, Poland. In: European Dinantian Environments (eds. J. Miller, A. E. Adams and P. Wright): 177–188.

BOGACZ W. and KROKOWSKI J. (1981) — Rotation of the basement of the Upper Silesian Coal Basin. Ann. Soc. Pol. Geol., **50**: 183–208.

BUŁA Z., JACHOWICZ M. and ŻABA J. (1997) — Principal characteristics of the Upper Silesian Block and Małopolska Block border zone (southern Poland). Geol. Mag., **134** (5): 669–677

BUŁA Z. and ŻABA J. (2005) — Pozycja tektoniczna Górnośląskiego Zagłębia Węglowego na tle prekambryjskiego i dolnopaleozoicznego podłoża. Przew. 76 Zjazdu Pol. Tow. Geol.: 14–42.

CLOETINGH S., ZIEGLER P. A., BEEKMAN F., ANDRIESSEN P. A. M., MATENCO L., BADA G., GARCIA-CASTELLANOS D., HARDENBOL N., DÈZES P. and SOKOUTIS D. (2005) — Lithospheric memory, state of stress and rheology: neotectonic controls on Europe's intraplate continental topography. Quat. Sc. Rev., **24**: 241–304.

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

DADLEZ R. (1997) — Epicontinental basins in Poland: Devonian to Cretaceous — relationships between the crystalline basement and sedimentary infill. Geol. Quart., **41** (4): 419–432.

DADLEZ R. (2001) — Holy Cross Mts. area — crustal structure, geophysical data and general geology. Geol. Quart., **45** (2): 99–106.

DADLEZ R. (2003) — Synklina lubelska jako efekt cienkonaskórkowych deformacji waryscyjskich — dyskusja. Prz. Geol., **51** (9): 729–730.

DADLEZ R. (2006) — The Polish Basin — relationships between the crystalline, consolidated and sedimentary crust. Geol. Quart., **50** (1): 43–57.

DADLEZ R., GRAD M. and GUTERCH A. (2005) — Crustal structure below the Polish Basin: is it composed of proximal terranes derived from Baltica? Tectonophysics, **411**: 111–128.

DADLEZ R., KOWALCZEWSKI Z. and ZNOSKO J. (1994) — Some key problems of the pre-Permian tectonics of Poland. Geol. Quart., **38** (2): 169–189.

DEPCIUCH T. (1974) — Geochronological investigations of the magmatic rocks (in Polish with English summary). In: Rocks of the Precambrian Platform in Poland, 2. Sedimentary cover. Pr. Inst. Geol., **74**: 81–83.

DVORJANIN E. S., SAMOYLUK A. P., EGURNOVA M. G., ZAYKOVSKY N. Y., PODLADCHIKOV Y. Y., VAN DEN BELT F. J. G. and DE BOER P. L. (1996) — Sedimentary cycles and paleogeography of the Dnieper Donets Basin during the late Viséan-Serpukhovian based on multiscale analysis of well logs. Tectonophysics, **268** (1–4): 169–187.

FINGER F., HANZL P., PIN C., VON QUADT A. and STEYRER H. P. (2000) — The Brunovistulian: Avalonian Precambrian sequence at the eastern end of the Central European Variscides ? In: Orogenic Processes: Quantification and Modelling in the Variscan Belt (eds. W. Franke, V. Haak, O. Oncken and D. Tanner). Geol. Soc. London Spec. Publ., **179**: 103–112.

FOKIN P. A., NIKISHIN A. M. and ZIEGLER P. A. (2001) — Peri-Uralian and Peri-Palaeo-Tethyan Rift systems of the East European Craton. In: Peri-Tethyan Rift/Wrench Basins and Passive Margins (eds. P. A. Ziegler, W. Cavazza, A. H. F. Robertson and S. Crasquin-Soleau). Peri-Tethys Mem., **6**, Mém. Mus. Nat. Hist. Natur., **186**: 347–368.

FRANKE W., EDER W., ENGEL W. and LANGENSTRASSEN F. (1978) — Main aspects of geosynclinal sedimentation in the Rheno-Hercynian Zone. Z. Dt. Geol. Ges., **129**: 201–216.

FRANKE W. (2000) — The mid-European segment of the Variscides: tectonostratigraphic units, terrane boundaries and plate tectonic evolution. In: Orogenic Processes: Quantification and Modelling in the Variscan Belt (eds. W. Franke, V. Haak, O. Oncken and D. Tanner). Geol. Soc. London, Spec. Publ., **179**: 35–61.

FRANKE W. (2006) — The Variscan orogen in Central Europe: construction and collapse. In: European Lithosphere Dynamics (eds. D. G. Gee and R. A. Stephenson). Geol. Soc. London, Mem., **32**: 333–343.

FRANKE W. and ŻELAŹNIEWICZ A. (2002) — Structure and evolution of the Bohemian Arc. In: Palaeozoic Amalgamation of Central Europe (eds. J. A. Winchester, T. C. Pharaoh and J. Verniers). Geol. Soc., London, Spec. Publ., **201**: 279–293.

GRABOWSKA T. and BOJDYS G. (2001) — The border of the East-European Craton in south-eastern Poland based on gravity and magnetic data. Terra Nova, **13**: 92–98.

GRADSTEIN F. M., OGG J. G. and SMITH A. G. (2004) — A Geological Time Scale 2004. Cambridge Univ. Press.

GRADZIŃSKI R., DOKTOR M. and KĘDZIOR A. (2005) — Sedimentation of the coal-bearing succession in the Upper Silesia Coal Basin: research trends and the current state of knowledge (in Polish with English summary). Prz. Geol., **53** (9): 734–741.

GROCHOLSKI A. and RYKA W. (1995) — Carboniferous magmatism of Poland. Pr. Państw. Inst. Geol., **148**: 181–189.

GUTERCH A. and GRAD M. (2006) — Lithospheric structure of the TESZ in Poland based on modern seismic experiments. Geol. Quart., **50** (1): 23–32.

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

HARTLEY A. J. and OTAVA J. (2001) — Sediment provenance and dispersal in a deep marine foreland basin: the Lower Carboniferous Culm Basin, Czech Republic. J. Geol. Soc., London, **158**: 137–150.

HOOPER R. J., ANTONOWICZ L., IWANOWSKA E. and HATCHER R. jr. (2002) — The limit of Variscan deformation in southeastern Poland and the origin of the Lublin syncline. Geol. Soc. Am., Abstracts with Programs, **34**.

JAROSIŃSKI M. (2001) — Tectonic evolution of the upper Palaeozoic complex from structural analysis of the borehole core and acoustic scanner log from the Tarnawa 1 well (in Polish with English summary). Pr. Państw. Inst. Geol., **174**: 101–115.

JAROSIŃSKI M. (2004) — Opracowanie zmienności strukturalnej rdzeni w profilach wierceń z basenu lubelskiego i stref obrzeżających wraz z syntezą tektonicznej ewolucji obszaru. Centr. Geol. Arch. Państw. Inst. Geol. Warszawa.

JAWOR E. and BARAN U. (2004) — Geological setting and characteristics of Carboniferous strata in the southern part of the Małopolska block (in Polish with English summary). In: Hydrocarbon Generation Potential of Carboniferous Rocks in the Southern part of the Upper Silesian and Małopolska Blocks (ed. M. J. Kotarba): 25–48. Geosfera. Kraków.

JAWOROWSKI K. (2002) — Geotectonic significance of Carboniferous deposits NW of the Holy Cross Mts. (central Poland). Geol. Quart., **46** (3): 267–280.

JAWOROWSKI K. and SIKORSKA M. (2006) — Łysogóry Unit (central Poland) versus East European Craton — application of sedimentological data from Cambrian siliciclastic association. Geol. Quart., **50** (1): 77–88.

JUBITZ K.-B., ZNOSKO J., FRANKE D. and GARETSKY R. (1986) — Southwest border of the East European Platform. Tectonic Map 1:1 500 000. IGCP Project 86. Z.G.I. Berlin.

KALVODA J. (2002) — Late Devonian-Early Carboniferous foraminiferal fauna: zonations, evolutionary events, paleobiogeography and tectonic implications. Folia Facult. Sc. Nat. Univ. Masaryk. Brun., Geologia, **39**: 1–213.

KOTAS A. (1985) — Structural evolution of the Upper Silesian Coal Basin (Poland). X Congr. Int. Strat. Geol. Carb., Madrid 1983. Compte Rendu, **3**: 459–469.

KOTAS A. (1994) — Coal-bed methane potential of the Upper Silesian Coal Basin, Poland. Pr. Państw. Inst. Geol., **142**: 1–81.

KOTAS A. (1995) — Lithostratigraphy and sedimentologic-paleogeographic development. Moravia, Silesian, Cracovian region, Upper Silesian Coal Basin. In: The Carboniferous System in Poland (eds. A. Zdanowski and H. Żakowa). Pr. Państw. Inst. Geol., **148**: 124–134.

KRÓLIKOWSKI C. (2006) — Crustal-scale complexity of the contact zone between the Palaeozoic Platform and the East-European Craton in the NW Poland. Geol. Quart., **50** (1): 33–42.

KRÓLIKOWSKI C. and PETECKI Z. (1995) — Gravimetric Atlas of Poland. Pol. Geol. Inst. Warszawa.

KRZEMIŃSKA E., WISZNIEWSKA J. and WILLIAMS I. S. (2006) — Early Carboniferous age of the cratonic intrusions in the crystalline basement of NE Poland. Prz. Geol., **54** (12): 1093–1098.

KRZEMIŃSKI L. (1999) — Anorogenic Carboniferous sandstones from the northwestern border of the Holy Cross Mountains, central Poland (in Polish with English summary). Prz. Geol., **47** (11): 978–986.

KRZEMIŃSKI L. (2005) — Provenance of Carboniferous sandstones from the Variscan foreland basins in southwestern Poland and Moravia (in Polish with English abstract). Biul. Państw. Inst. Geol., **417**: 27–108.

KRZYWIEC P. (2007) — Tectonics of the Lublin area (SE Poland) — new views based on results of seismic data interpretation (in Polish with English summary). Biul. Państw. Inst. Geol., **422**: 1–18.

KRZYWIEC P. and NARKIEWICZ M. (2003*a*) — O stylu strukturalnym kompleksu dewońsko-karbońskiego Lubelszczyzny w oparciu o wyniki interpretacji danych sejsmicznych. Prz. Geol., **51** (9): 795–797.

KRZYWIEC P. and NARKIEWICZ M. (2003*b*) — Role of structural decoupling in Carboniferous evolution of the Lublin Trough (SE Poland). AAPG Int. Conf., Barcelona, Spain, Sept. 21–24, Abstracts.

KUMPERA O. and MARTINEC P. (1995) — The development of the Carbonifeous accretionary wedge in the Moravian-Silesian Paleozoic basin. J. Czech Geol. Soc., **40**: 47–64.

KUSZNIR N. J., KOVKHUTO A. and STEPHENSON R. A. (1996) — Syn-rift evolution of the Pripyat Trough: constraints from structural and stratigraphic modelling. Tectonophysics, **268** (1–4): 221–236.

LAMARCHE J., BERGERAT F., LEWANDOWSKI M., MANSY J. L., ŚWIDROWSKA J. and WIECZOREK J. (2002) — Variscan to Alpine heterogeneous palaeo-stress field above a major Palaeozoic suture in the Carpathian foreland (southeastern Poland). Tectonophysics, **357**: 55–80.

LAMARCHE J., LEWANDOWSKI M., MANSY J.-L. and SZULCZEWSKI M. (2003) — Partitioning pre-, syn- and post-Variscan deformation in the Holy Cross Mountains, eastern Variscan foreland. In: Tracing Tectonic Deformations Using Sediementary Record (eds. T. McCann and A. Saintot). Geol. Soc. Spec. Publ., **208**: 159–184.

LAMARCHE J., MANSY J. L., BERGERAT F., AVERBUCH O., HAKENBERG M., LEWANDOWSKI M., STUPNICKA E., ŚWIDROWSKA J., WAJSPRYCH B. and WIECZOREK J. (1999) — Variscan tectonics in the Holy Cross Mountains (Poland) and the role of structural inheritance during Alpine tectonics. Tectonophysics, **313** (1–2): 171–186.

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

LIPIEC M. (2001) — Systemy depozycyjne i diageneza utworów węglanowych dinantu na Pomorzu Zachodnim. Unpubl. Ph.D. thesis. Pol. Geol. Inst. Warszawa.

LIPIEC M. and MATYJA H. (1998) — Depositional architecture of the Lower Carboniferous sedimentary basin in Pomerania (in Polish with English summary). Pr. Państw. Inst. Geol., **165**: 101–111.

MAJDAŃSKI M., GRAD M., GUTERCH A. and SUDETES 2003 WORKING GROUP (2006) — 2-D seismic tomographic and ray tracing modelling of the crustal structure across the Sudetes Mountains basing on SUDETES 2003 experiment data. Tectonophysics, **413**: 249–269.

MALEC J. (1995) — Stop 1. Kowala. Devonian-Carboniferous boundary In: Development of the Variscan Basin and epi-Variscan Cover at the Margin of the East European Platform (Pomerania, Holy Cross Mts., Krakow Upland) (eds. M. Lipiec *et al*.). Guide to excursion A4. XIII Int. Congr. Carb.-Perm. Kraków.

MALINOWSKI M., ŻELAŹNIEWICZ A., GRAD M., GUTERCH A. and JANIK T. (2005) — Seismic and geological structure of the crust in the transition from Baltica to Palaeozoic Europe in SE Poland — CELEBRATION 2000 experiment, profile CEL02. Tectonophysics, **401**: 55–77.

MAREK S., ed. (1983) — The geological structure of the Warsaw (Płock) Trough and its basement (in Polish with English summary). Pr. Państw. Inst. Geol., **103**: 1–278.

MATYJA M. and STEMPIEŃ-SAŁEK M. (1994) — Devonian/Carboniferous boundary and the associated phenomena in Western Pomerania (NW Poland). Ann. Soc. Geol. Belg., **116**: 249–263.

MAZUR S., ALEKSANDROWSKI P., KRYZA R. and OBERC-DZIEDZIC T. (2006) — The Variscan Orogen in Poland. Geol. Quart., **50** (1): 89–118.

MCCANN T. (1999*a*) — Middle to Late Devonian basin evolution in the Rügen area, NE Germany. Geol. Mijnb., **78**: 57–71.

MCCANN T. (1999*b*) — The tectonosedimentary evolution of the northern margin of the Carboniferous foreland basin of NE Germany. Tectonophysics, **313**: 119–144.

MCCANN T., ŠLIAUPA S., POPRAWA P., NARKIEWICZ M., MATYJA H., LIPIEC M. and LAZAUSKIENĖ J. (1997) — The Devonian-Carboniferous tectonic evolution of selected intracratonic and passive margin basins from Central and Eastern Europe: constraints from subsidence analysis. Terra Nostra, 97/11: 85–89

MIŁACZEWSKI L. (1983) — Stratygrafia i paleogeografia. Dewon. In: The Geological Structure of the Warsaw (Płock) Trough and its Basement (ed. S. Marek). Pr. Inst. Geol., **103**: 77–78.

MIŁACZEWSKI L., RADLICZ K., NEHRING M. and HAJŁASZ B. (1983) — The Devonian deposits in the substrate of the north-western part of the Lublin sector of the Marginal Trough (in Polish with English summary). Biul. Inst. Geol., **344**: 23–56.

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

MUSZYŃSKI A., BIERNACKA J., LORENC S., PROTAS A., URBANEK Z. and WOJEWODA J. (1996) — Petrology and depositional environment of Lower Carboniferous rocks near Dygowo and Kłanino (the Koszlin-Chojnice zone) (in Polish with English summary). Geologos, **1**: 93–126.

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

NARKIEWICZ M. (1991) — Mesogenetic dolomitization processes: an example from the Givetian to Frasnian of the Holy Cross Mountains, Poland (in Polish with English summary). Pr. Państw. Inst. Geol., **132**:1–54.

NARKIEWICZ M. (2002) — Ordovician through earliest Devonian development of the Holy Cross Mts. (Poland): constraints from subsidence and thermal maturity data. Geol. Quart., **46** (3): 255–266.

NARKIEWICZ M. (2003) — Tectonic controls of the Lublin Graben (Late Devonian–Carboniferous) (in Polish with English summary). Prz. Geol., **51** (9): 771–776.

NARKIEWICZ M. (2005) — Devonian and Carboniferous carbonate complex in the southern part of the Upper Silesian Block (in Polish with English summary). Pr. Państw. Inst. Geol., **182**: 1–46.

NARKIEWICZ M., JAROSIŃSKI M. and KRZYWIEC P. (2007*a*) — Diagenetic and tectonic processes controlling reservoir properties of the Frasnian dolostones in the central part of the Lublin Graben (eastern Poland) (in Polish with English summary). Prz. Geol., **55** (1): 61–70.

NARKIEWICZ M., JAROSIŃSKI M., KRZYWIEC P. and WAKSMUNDZKA M. I. (2007*b*) — Regional controls on the Lublin Basin development and inversion in the Devonian and Carboniferous (in Polish with English summary). Biul. Państw. Inst. Geol., **422**: 19–33.

NARKIEWICZ M., MIŁACZEWSKI L., KRZYWIEC P. and SZEWCZYK J. (1998*a*) — Outline of the Devonian depositional architecture in the Radom-Lublin area (in Polish with English summary). Pr. Państw. Inst. Geol., **165**: 57–72.

NARKIEWICZ M., POPRAWA P., LIPIEC M., MATYJA H. and MIŁACZEWSKI L. (1998*b*) — Palaeogeographic and tectonic setting and the Carboniferous subsidence development of the Pomerania and Radom-Lublin areas (TESZ, Poland) (in Polish with English summary). Pr. Państw. Inst. Geol., **165**: 31–49.

NAWROCKI J. (2000) — Late Silurian paleomagnetic pole from the Holy Cross Mountains: constraints for the post-Caledonian tectonic activity at the Trans-European Suture Zone. Earth Planet. Sc. Let., **179**: 325–334.

NAWROCKI J. and POPRAWA P. (2006) — Development of Trans-European Suture Zone in Poland: from Ediacaran rifting to early Paleozoic accretion. Geol. Quart., **50** (1): 59–76.

NIKISHIN A. M., ZIEGLER P. A., PANOV D. I., NAZAREVICH B. P., BRUNET M.-F., STEPHENSON R. A., BOLOTOV S. N., KOROTAEV M. V. and TIKHOMIROV P. L. (2001) — Mesozoic and Cainozoic evolution of the Scythian Platform-Black Sea-Caucasus domain. In: Peri-Tethyan Rift/Wrench Basins and Passive Margins (eds.

P. A. Ziegler, W. Cavazza, A. H. F. Robertson and S. Crasquin-Soleau). Peri-Tethys Memoir, **6**, Mém. Mus. Nat. Hist. Natur., **186**: 295–346.

NIKISHIN A. M., ZIEGLER P. A., STEPHENSON R. A., CLOETINGH S. A. P. L., FURNE A. V., FOKIN P. A., ARSHOV A. V., BOLOTOV S. N., KOROTAEV M. V., ALEKSEEV A. S., GORBACHEV V. I., SHIPILOV E. V., LANKREIJER A., BEMBINOVA E. Yu. and SHALIMOV I. V. (1996) — Late Precambrian to Triassic history of the East European Craton: dynamics of sediimentary basin evolution. Tectonophysics, **268** (1–4): 23–63.

OKAY A. I., SATIR M. and SIEBEL W. (2006) — Pre-Alpide Palaeozoic and Mesozoic orogenic events in the Eastern Mediterranean region. In: European Lithosphere Dynamics (eds. D. G. Gee and R. A. Stephenson). Geol. Soc. London, Mem., **32**: 389–405.

PASZKOWSKI M., JACHOWICZ M., MICHALIK M., TELLER L., UCHMAN A. and URBANEK Z. (1995) — Composition, age and provenance of gravel-sized clast from the Upper Carboniferous of the Upper Silesia Coal Basin (Poland). Stud. Geol. Pol., **108**: 45–127.

POPRAWA P., JAROSIŃSKI M., PEPEL A., KIERSNOWSKI H. and JAWOR E. (2001) — Tectonic evolution of the Liplas-Tarnawa area — analysis of subsidence, mesostructures, seismic and gravimetric data (in Polish with English summary). Pr. Państw. Inst. Geol., **174**: 143–160.

PORZYCKI J. (1984) — Zarys geologii Lubelskiego Zagłębia Węglowego. Przew. 56 Zjazdu Pol. Tow. Geol.: 7–21.

POŻARYSKI W. (1975) — Structural development of the Polish Lowlands in the Variscan Epoch. Biul. Inst. Geol., **252**: 77–92.

POŻARYSKI W. (1986) — The Variscan stage of platform tectonical development of the Middle Europe (in Polish with English summary). Prz. Geol., **34** (3): 117–127.

POŻARYSKI W. (1990) — The Middle Europe Caledonides — wrenching orogen composed of terranes (in Polish with English summary). Prz. Geol., **38** (1): 1–9.

POŻARYSKI W. (1997) — Post-Variscan tectonics of the Holy Cross Mts — Lublin region (central Poland) and the substrate structure (in Polish with English summary). Prz. Geol., **45** (12): 1265–1270.

POŻARYSKI W. and DEMBOWSKI Z., eds. (1983) — Geological map of Poland and neighbouring countries without Cenozoic, Mesozoic and Permian deposits, 1:1 000 000. Inst. Geol. Warszawa.

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

POŻARYSKI W. and KARNKOWSKI P., eds. (1992) — Tectonic map of Poland during the Variscan time. Pol. Geol. Inst. Warszawa.

POŻARYSKI W., TOMCZYK H. and BROCHWICZ-LEWIŃSKI W. (1980) — The tectonics of sub-Permian Paleozoic in the Warsaw Basin (in Polish with English summary). Prz. Geol., **28** (2):73–81.

POŻARYSKI W., TOMCZYK H. and BROCHWICZ-LEWIŃSKI W. (1983) — Tektonika. Paleozoik przedpermski i jego podłoże. In: The Geological Structure of the Warsaw (Płock) Trough and its Basement (ed. S. Marek). Pr. Inst. Geol., **103**: 206–216.

POŻARYSKI W. and TOMCZYK H. (1993) — Geological cross section through SE Poland (in Polish with English summary). Prz. Geol., **41** (10): 687–695.

RACKI G. (1997) — Devonian eustatic fluctuations in Poland. Cour. Forsch.-Inst. Senckenberg, **199**: 1–12.

RACKI G. and NARKIEWICZ M. (2000) — Tectonic versus eustatic controls of sedimentary development of the Devonian in the Holy Cross Mts., Central Poland (in Polish with English summary). Prz. Geol., **48** (1): 65–76.

RACZYŃSKA A., ed. (1987) — Geological structure of the Pomeranian Swell and its basement (in Polish with English summary). Pr. Inst. Geol., **119**: 1–269.

RICKEN W., SCHRADER S., ONCKEN O. and PLESCH A. (2000) — Turbidite basin and mass dynamics related to orogenic wedge growth: the Rheno-Hercynian case. In: Orogenic Processes: Quantification and Modelling in the Variscan Belt (eds. W. Franke, V. Haak, O. Oncken and D. Tanner). Geol. Soc. London, Spec. Publ., **179**: 257–280.

SAUNDERS W. B. and RAMSBOTTOM W. H. C. (1986) — The mid-Carboniferous eustatic event. Geology, **14**: 208–212.

SCHULMANN K. and GAYER R. (2000) — A model for a continental accretionary wedge developed by oblique collision the NE Bohemian Massif. J. Geol. Soc., London, **157**: 401–416.

SKOMPSKI S. (1996) — Stratigraphic position and facies significance of the limestone bands in the subsurface Carboniferous succession of the Lublin Upland. Acta Geol. Pol., **46** (3–4): 171–268.

SKOMPSKI S. (1998) — Regional and global chronostratigraphic correlation levels in the late Viséan to Westphalian succession of the Lublin Basin (SE Poland). Geol. Quart., **42** (2): 121–130.

STOVBA S., STEPHENSON R. A. and KIVSHIK M. (1996) — Structural features and evolution of the Dniepr-Donets Basin, Ukraine, from regional seismic reflection profiles. Tectonophysics, **268** (1–4): 127–147.

STEPHENSON R. A., YEGOROVA T., BRUNET M.-F., STOVBA S., WILSON M., STAROSTENKO V., SAINTOT A. and KUSZNIR N. (2006) — Late Palaeozoic intra- and pericratonic basins on the East European Craton and its margins. In: European Lithosphere Dynamics (eds. D. G. Gee and R. A. Stephenson). Geol. Soc. London, Mem., **32**: 463–479.

SZULCZEWSKI M., BELKA Z. and SKOMPSKI S. (1996) — The drowning of a carbonate platform: an example from the Devonian-Carboniferous of the southwestern Holy Cross Mountains, Poland. Sed. Geol., **106**: 21–49.

ŚWIERCZEWSKA A. (1995) — Composition and provenance of Carboniferous sandstones from the Upper Silesia Coal Basin (Poland). Stud. Geol. Pol., **108**: 27–43.

THYBO H. (1997) — Geophysical characteristics of the Tornquist Fan area, north-west Trans-European Suture Zone: indcation of late Carboniferous to early Permian dextral transtension. Geol. Mag., **134** (5): 597–606.

WAKSMUNDZKA M. I. (1998) — Depositional architecture of the Carboniferous Lublin basin (in Polish with English summary). Pr. Państw. Inst. Geol., **165**: 89–100.

WAKSMUNDZKA M. I. (2005) — Ewolucja facjalna i analiza sekwencji w paralicznych utworach karbonu z północno-zachodniej i centralnej Lubelszczyzny. Unpubl. Ph.D. thesis. Pol. Geol. Inst. Warszawa.

WILSON M. and LYASHKEVICH Z. M. (1996) — Magmatism and the geodynamics of rifting of the Pripyat-Dnieper-Donets rift, East European Platform. Tectonophysics, **168** (1–4): 65–81.

WINCHESTER J. A. and THE PACE TMR NETWORK TEAM (2002) — Paleozoic amalgamation of Central Europe: new results from recent geological and geophysical investigations. Tectonophysics, **360**: 5–21.

ZDANOWSKI A. (1995) — Małopolska region. In: The Carboniferous System in Poland (eds. A. Zdanowski and H. Żakowa). Pr. Państw. Inst. Geol., **148**: 17.

ZDANOWSKI A. and ŻAKOWA H., eds. (1995) — The Carboniferous System in Poland. Pr. Państw. Inst. Geol., **148**: 1–215.

ZIEGLER P. A. (1989) — Evolution of Old Red Continent. A study in Palaeozoic plate tectonics. Kluwer Acad. Publ., Dordrecht.

ZIEGLER P. A. (1990) — Geological Atlas of Western and Central Europe, 2nd Ed. Shell Intern. Petrol. Mij., Geol. Soc., London, Publ. House, Bath.

ZIEGLER P. A., BERTOTTI G. and CLOETINGH S. (2002) — Dynamic processes controlling foreland development — the role of mechanical (de)coupling of orogenic wedges and forelands. In: Continental Collision and the Tectono-sedimentary Evolution of Forelands (eds. G. Bertotti, K. Schulmann and S. A. P. L. Cloetingh). EUG Stephan Mueller Spec. Publ. Ser., **1**: 17–56.

ZIEGLER P. A. and CLOETINGH S. (2004) — Dynamic processes controlling evolution of rifted basins. Earth Sc. Rev., **64**: 1–50.

ZNOSKO J. (1992) — Outline of post-Variscan geotectonic evolution of Poland. Bull. Pol. Acad. Sc., Earth Sc., **40** (4): 315–320

ŻABA J. (1999) — The structural evolution of Lower Palaeozoic succession in the Upper Silesia Block and Małopolska Block border zone (Southern Poland) (in Polish with English summary). Pr. Państw. Inst. Geol., **166**: 1–162

ŻABA J., CIESIELCZUK J., MALIK K. and STRZYŻEWSKA-KONIECZNA S. (2005) — Budowa oraz ewolucja strukturalna utworów dewońsko-karbońskich Gór Opawskich (strefa morawsko-śląska). Przew. 76 Zjazdu Pol. Tow. Geol.: 116–127.

ŻABA J. and POPRAWA P. (2006) — Deformation history of the Koszalin-Chojnice zone (Pomeranian segment of TESZ, NW Poland) constraints from structural analysis of Palaeozoic and Mesozoic successions in Polskie Łąki PIG 1 and Toruń 1 boreholes (in Polish with English summary). Pr. Państw. Inst. Geol., **186**: 225–252.

ŻAKOWA H. and JURKIEWICZ H. (1995) — Miechów Trough. In: The Carboniferous System in Poland (eds. A. Zdanowski and H. Żakowa). Pr. Państw. Inst. Geol., **148**: 115–119.

ŻAKOWA H. and MIGASZEWSKI Z. (1995) — Góry Świętokrzyskie Mts. In: The Carboniferous System in Poland (eds. A. Zdanowski and H. Żakowa). Pr. Państw. Inst. Geol., **148**: 109–115.

ŻELICHOWSKI A. M. (1972) — Evolution of the geological structure of the area between the Góry Świętokrzyskie and the river Bug (in Polish with English summary). Biul. Inst. Geol., **263**: 1–97.

ŻELICHOWSKI ed. (1983) — Geology of the Marginal Trough in the borderland of the Warsaw and Lublin regions (in Polish with English summary). Biul. Inst. Geol., **344**: 1–238.

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

ŻELICHOWSKI A. M. (1987*b*) — Zarys sedymentacji i paleotektoniki.Paleozoik podpermski. In: Geological Structure of the Pomeranian Swell and its Basement (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 152–155.

ŻELICHOWSKI M. and KOZŁOWSKI S., eds. (1983) — Atlas of geological structure and mineral deposits in the Lublin Region (in Polish with English summary). Inst. Geol. Warszawa.

ŻELICHOWSKI A. M. (1995) — Western Pomerania. Central Poland. In: The Carboniferous System in Poland (eds. A. Zdanowski and H. Żakowa). Pr. Państw. Inst. Geol., **148**: 97–102.