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PRECAMBRIAN AND PALAEOZOIC BASEMENT OF THE CARPATHIAN FOREDEEP AND THE ADJACENT OUTER CARPATHIANS (SE POLAND AND WESTERN UKRAINE)

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Abstract: In south-eastern Poland and western Ukraine, the Outer Carpathian orogen and the Carpathian Foredeep developed in the foreland of the East-European Platform (Baltica). The area consists of a number of tectonic units included in the Trans-European Suture Zone (TESZ): the Łysogóry–Radom and Małopolska blocks in the territory of Poland, and the Rava Rus'ka Zone, Kokhanivka Zone and Leżajsk Massif in the Ukraine. The development of the TESZ began in the (?Middle) Late Neoproterozoic and was associated with rifting processes taking place along the western edge of the East-European Craton (Baltica) during the break-up of the Rodinia/Pannotia supercontinent. The passive margin of Baltica evolved into the TESZ during collisional and/or strike-slip movements. In the TESZ (Małopolska Block and Leżajsk Massif), Ediacaran flysch-type siliciclastics were affected by weak metamorphism and folding during the Cadomian orogeny. The development of Cambrian deposits in the East-European Craton, Łysogóry–Radom Block, northeastern part of the Małopolska Block (Kielce Fold Belt) and in the Rava Rus'ka and Kokhanivka zones was associated with the post-rift thermal subsidence. Tectonic movements (so-called Sandomierz phase), which occurred probably due to an oblique collision of the Małopolska Block (included into the passive margin of Baltica) and the East-European Craton during late Middle Cambrian to Late Cambrian (possibly also Early Ordovician) times, resulted in the following: (1) development of stratigraphical (?erosional) gaps in the Middle and Upper Cambrian sections of the Lublin–Podlasie slope of the East-European Craton and the Kielce Fold Belt in the Małopolska Block; (2) intense tectonic subsidence of the Łysogóry–Radom Block during the deposition of Middle and Upper Cambrian sediments; (3) development of compressional folds in the Lower Cambrian to lower Middle Cambrian deposits of the Kielce Fold Belt on the Małopolska Block. Ordovician–Silurian series were deposited in a typical flexural foredeep basin, in which subsidence and deposition rates accelerated during Late Silurian (Ludlow–Pridoli) and Early Devonian (Lochkovian) times. It is postulated that the present position of the Małopolska Block relative to the Łysogóry–Radom Block and East-European Craton resulted from post-Silurian dextral movements between the Małopolska Block and the East-European Craton. Devonian–Carboniferous deposits occur only in the Małopolska Block located in the Variscan foreland. The Middle-Late Devonian and Early Carboniferous shallow-marine carbonate platforms developed under an extensional regime. The siliciclastic Upper Visean–Lower Namurian A Culm series were deposited in the flexural Variscan foreland basin. During the Late Namurian A, the Małopolska Block was uplifted in response to the build-up of compressional foreland stresses. During post-Carboniferous times, the Precambrian and Palaeozoic deposits were subject to erosion and restructuring during the Alpine orogeny.

Key words: basement, Carpathians, Carpathian Foredeep, East-European Platform, Trans-European Suture Zone, south-eastern Poland, western Ukraine.

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INTRODUCTION

In the flexural Carpathian foreland basin and under the Outer Carpathians of south-eastern Poland and western Ukraine, deep boreholes provide control on the distribution of variable thicknesses of Palaeozoic sediments (Cambrian to Carboniferous) and the Precambrian basement beneath the Permian and Mesozoic series (Fig. 1). Palaeozoic deposits are only exposed in the Holy Cross Mts. area, to the north of the Carpathian Foredeep.

The Precambrian and Palaeozoic (excluding Permian) series of this area form part of the Małopolska and Łysogóry–Radom blocks (terranes) of Poland and the Leżajsk Massif and Kokhanivka and Rava Rus'ka zones of the Ukraine. These tectono-sedimentary units form part of the Trans-European Suture Zone (TESZ) that extends along the south-western margin of the East-European Craton (Baltica), and which are commonly treated as parts of the Pala-

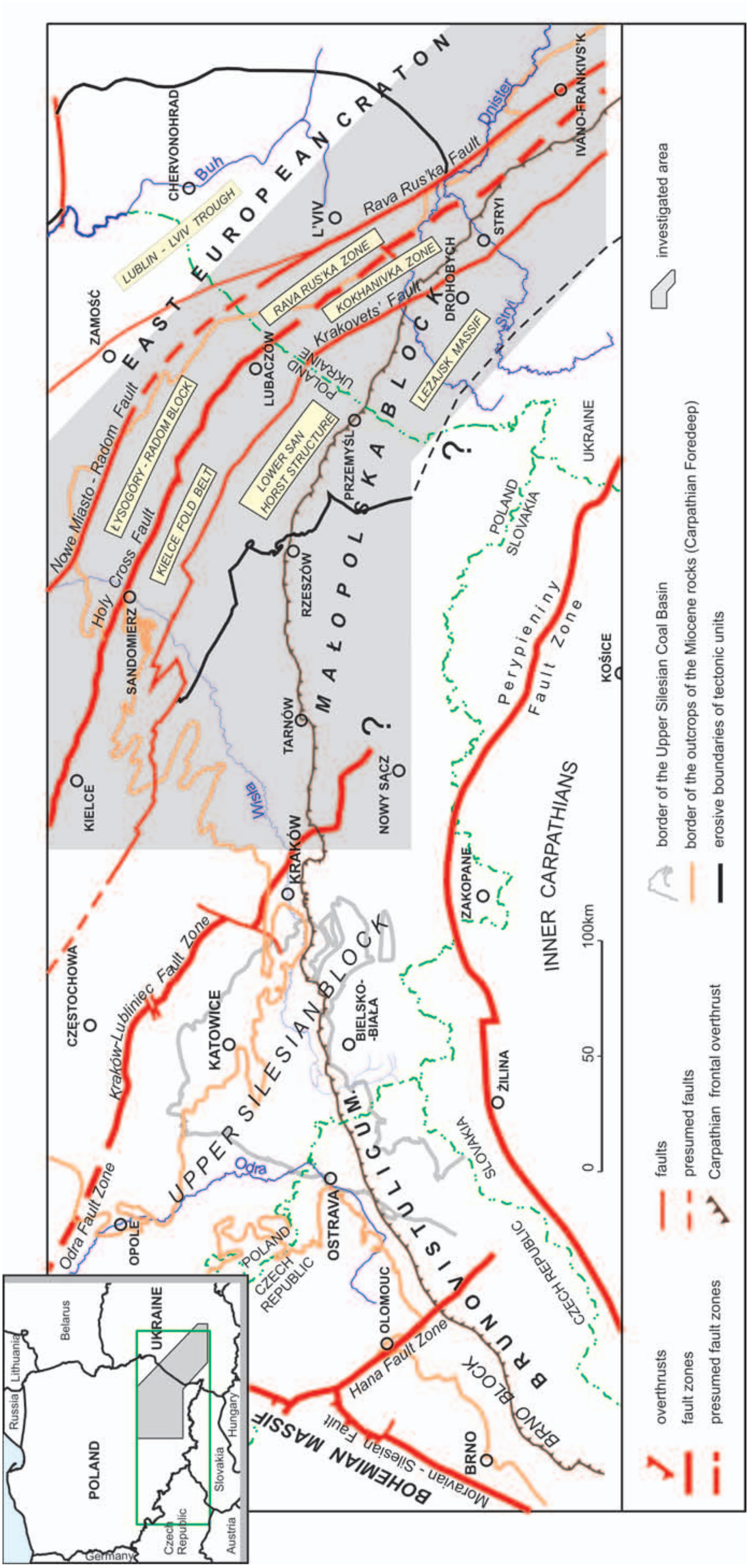

Fig. 1. Tectonic regional subdivision of the south-eastern part of Poland and western Ukraine at the sub-Permian–Mesozoic palaeosurface (central and western parts of the map after Buła *et al.*, 2008)

eozoic (epi-Variscan) Platform of central and western Europe, also referred to as the West-European Platform (*e.g.*, Kruglov & Tsypko, *eds*, 1988; Mizerski & Stupka, 2005; Oszczypko *et al.*, 2006).

Sedimentary-diastrophic processes, occurring at different times (from Precambrian to Carboniferous) and with different intensity within each of the above-mentioned tectonic units, which should be treated as separate lithospheric units, resulted in the observed differences in their geological structure. The boundaries between these units are marked by regional, repeatedly reactivated fault zones, generally of a strike-slip nature.

Limited control on the stratigraphical position and lithlogical characteristics of Precambrian and Palaeozoic series occurring in this area render it difficult to decipher the tectonic development of the different units, giving rise to quite significant differences in views concerning their palaeotectonic and palaeogeographical evolution and the age of their consolidation. Discrepancies also concern the course of boundaries between the individual tectonic units.

This paper attempts to clarify some of the controversies regarding the above-mentioned problems on the tectonic position and palaeogeographical and tectonic development of the Precambrian and Palaeozoic succession in the basement of the Carpathian Foredeep and in the marginal part of the Outer Carpathians in SE Poland and western Ukraine, and to develop a coherent model of the geological structure in the area. For this purpose, published results of lithologic, stratigraphic, tectonic and mapping were used and supplemented by the results of lithological, sedimentary, petrographic and palynological studies on drill cores acquired from several boreholes. Of particular importance are the results of palynological studies carried out on rock samples previously considered Precambrian or Early Palaeozoic in age, which permitted to verify their stratigraphical position (Jachowicz-Zdanowska, 2011).

TECTONIC POSITION OF THE PRECAMBRIAN AND PALAEOZOIC ROCKS

In SE Poland, the basement of the marginal part of the Outer Carpathians and Carpathian Foredeep is represented by Precambrian and Palaeozoic rocks of the southeastern part of the Małopolska Block and the south-western part of the Łysogóry–Radom Block (Fig. 1).

Małopolska Block

This unit, which includes the Kielce region of the Holy Cross Mts. (Pożaryski *et al.*, 1992; Pożaryski & Tomczyk 1993), is flanked to the southwest by the Upper Silesian Block (Brunovistulicum), from which it is separated by the well-defined Kraków-Lubliniec Fault Zone (Fig. 1; Buła *et al.*, 1997; Żaba, 1999; Buła & Żaba, 2005; Buła & Habryn, eds., 2008), probably forming part of the prominent Hamburg–Kraków transcontinental fault zone (Brochwicz-Lewiński *et al.*, 1983; Oberc 1993; Buła & Żaba, 2005; Buła *et al.*, 2008). According to Pietsch *et al.* (2010), this fault zone continues in the basement of the Outer Carpathian to the southeast from Kraków in the direction of Smilno in Slovakia. The northeastern boundary of the Małopolska Block, at the contact with the Łysogóry–Radom Block, is marked by the Holy Cross Fault, which is well defined in the Holy Cross Mts. in the area between Kielce and Sandomierz (Fig. 1).

Various interpretations have been advanced for the south-eastward continuation of the Holy Cross Fault (*e.g.*, Tomczyk, 2000; Modliński & Szymański, 2005; Poprawa, 2006b; Narkiewicz, 2007; Narkiewicz *et al.*, 2007) into the area where Palaeozoic rocks occur at large depths beneath the Neogene cover of the Carpathian Foredeep and where this area is delineated on the basis of both geophysical and geological investigations. In this paper we adhere to the course of the Holy Cross Fault as shown in the geological and structural maps of the Precambrian and Palaeozoic basement of the Outer Carpathians and Carpathian Foredeep (Buła & Habryn, *eds*, 2008) and with reference to the views of Tomczyk (2000) and Modliński and Szymański (2005), suggesting that it runs from Sandomierz towards Lubaczów, where it approaches the border with the Ukraine (Figs 1, 2).

In that area of the Małopolska Block that coincides with the marginal part of the Outer Carpathians and Carpathian Foredeep, Precambrian (Ediacaran) rocks and various in age Palaeozoic deposits subcrop at the sub-Permian–Mesozoic or sub-Cainozoic (Miocene) unconformity (Fig. 2). The Palaeozoic sediments of this area were repeatedly subject to tectonic deformation and erosion, resulting in the development of a "mosaic" pattern of horsts upheld by Ediacaran deposits and older rocks within the Devonian–Carboniferous cover series (Fig. 2).

There is a clear variability in the structural style of the Palaeozoic sedimentary cover of the Małopolska Block. In its north-eastern part adjacent to the Holy Cross Fault Zone, encompassing the Kielce region of the Holy Cross Mts. and the area between Sandomierz and Lubaczów, the Palaeozoic succession (represented by the Cambrian, locally Ordovician and Silurian deposits and Devonian–Carboniferous rocks of the Kielce region – Fig. 2) shows fold or fold-and-block style of the geological structure. A zone of such structures observed in this part of the Małopolska Block has been distinguished by Buła *et al.* (2008) as a separate tectonic unit called the Kielce Fold Belt (Fig. 1). In the remaining area of the Małopolska Block, grabens, half-grabens, horsts and half-horsts predominate, involving Ediacaran and Palaeozoic (Ordovician to Carboniferous) rocks. A prominent structure is a vast horst extending between Baranów Sandomierski and Przemyśl, composed of Ediacaran rocks, referred to as the Lower San Anticlinorium or Lower San Elevation (Figs 1, 2) (Karnkowski & Ołtuszyk, 1968; Pożaryski & Tomczyk, 1968).

Łysogóry–Radom Block

This unit is flanked to the SW by the Małopolska Block and to the NE by the East-European Craton. On the margin of the latter the Devonian–Carboniferous Lublin Basin developed that extends into the territory of Ukraine as the L'viv Trough (Fig. 1). The south-western boundary of the Lublin Basin, of which the Lublin Trough forms the axial part, is usually identified in Poland with the Ursynów-Kazimierz and Izbica–Zamość faults (*e.g.*, Jaworowski & Sikorska, 2006; Żelaźniewicz *et al.*, 2009). Narkiewicz *et al.* (2007) suggest, however, that the Nowe Miasto–Radom Fault Zone forms the boundary between the Łysogóry–Radom Block and Lublin Basin. According to Narkiewicz *et al.* (2007), the trend of this fault zone was constrained by "the existence of a crustal discontinuity in the basement – the Teysseire–Tornquist Zone (TTZ), equivalent to the edge of the East European Platform".

On the Łysogóry–Radom Block, boreholes provided information on Cambrian (mainly Upper and Middle), Ordovician, Silurian and Devonian deposits, which show a characteristic zonal pattern (Fig. 2). At the top of the Palaeozoic unconformity (sub-Jurassic and sub-Tertiary surface), Cambrian deposits subcrop only in the south-western part of this tectonic unit, adjacent to the Holy Cross Fault. Farther to the north and northeast, Ordovician, Silurian and Devonian series subcrop. Drilling data provided no clear evidence for the timing and nature of tectonic deformation of these series. A significant role of Caledonian movements and strong folding of the Cambrian deposits in the Łysogóry–Radom Block were postulated by Dadlez *et al.* (1994). Alternatively, Mizerski (2000) postulates that these deformations involved exclusively block faulting, and that only during the Variscan orogeny, Palaeozoic (Cambrian to Devonian) deposits were probably folded as a whole.

In the basement of the Ukrainian marginal part of the Outer Carpathians, the Carpathian Foredeep and in the foreland area three tectonic units composed of Precambrian and mainly Lower Palaeozoic rocks were identified. These are, from the southwest to the northeast, the Leżajsk Massif, Kokhanivka Zone and Rava Rus'ka Zone (Fig. 1; Kruglov & Tsypko, *eds*, 1988; Stupka, 1991, 1993; Mizerski & Stupka, 2005 and references cited therein).

Leżajsk Massif

The Leżajsk Massif forms the south-eastern continuation of the Lower San Horst, mapped in Poland as part of the Małopolska Block (Figs 1, 2; Buła & Habryn, *eds*, 2008). Although both of them consist of similar Precambrian siliciclastic rocks, there are different views on their age. The results of palynological and radiometric investigations of Precambrian rocks from the Małopolska Block suggest that they are Ediacaran in age (Żelaźniewicz, *et al.*, 2009 and references therein). On the other hand, Precambrian rocks of the Leżajsk Massif were previously regarded as Riphean in age, corresponding to the Polesie Series developed in the marginal zone of the East-European Craton; therefore, the Leżajsk Massif was considered as having been consolidated during the Baikalian tectonogenesis (Kruglov & Tsypko, *eds*, 1988; Stupka, 1993; Mizerski & Stupka, 2005).

Kokhanivka Zone

This tectonic unit, which is separated from the Leżajsk Massif by the Krakovets Fault Zone (thrust?) (Fig. 1), consists of deformed Cambrian mudstone-sandstones (Fig. 2) of possibly latest Neoproterozoic age, as suggested by Kruglov and Tsypko, *eds*, (1988) and Stupka (1991) (*cf.* Mizerski & Stupka, 2005). Locally – in the Verchany–Derzhiv region – Ordovician and Silurian clastic deposits occur (Fig. 2; Kruglov & Tsypko, *eds*, 1988), which, according to Stupka (1991, 2002), are folded and involved in thrust and reverse faults.

Rava Rus'ka Zone

Within this tectonic unit, Silurian calcareous mudstones and sandstones and Lower Devonian sandstone-shale deposits subcrop at the base-Jurassic unconformity (Figs 1, 2; Stupka, 1991, 2002; Mizerski & Stupka, 2005). These rocks are strongly tectonized, steeply dipping, and involved in folds as suggested by Cambrian series occurring in the core of anticlines outlined by Silurian strata (Kruglov & Tsypko, *eds*,, 1988; Stupka, 1991, 2002). Mizerski and Stupka (2005) did not clearly express their views on the boundary between the Kokhanivka and Rava-Rus'ka zones. Different ages of the Palaeozoic deposits in these units suggest that a fault separates them, as shown in the geological map (Fig. 2). To the northeast, the Rava Rus'ka Zone borders the L'viv Foredeep (Figs 1, 2) along the regional Rava Rus'ka Fault Zone (thrust?). This tectonic zone is commonly considered to represent both the south-western limit of the L'viv Foredeep and the south-western edge of the East-European Platform (*cf.* Mizerski & Stupka, 2005).

The framework of the geological structure of Precambrian and Palaeozoic succession from the Poland/Ukraine borderland, illustrated in Figure 2 and developed based on the latest geological and partly geophysical data, shows that the Palaeozoic structures of the Kielce Fold Belt (in the north-eastern part of the Małopolska Block) and the Łysogóry–Radom Block in the territory of Poland are equivalents of the Ukrainian Kokhanivka and Rava Rus'ka zones, respectively (Figs 1 and 2).

STRATIGRAPHY AND LITHOLOGY OF THE PRECAMBRIAN AND PALAEOZOIC DEPOSITS

The Precambrian

Precambrian rocks of the Małopolska Block, composing the basement of the marginal part of the Carpathians and Carpathian Foredeep in south-eastern Poland, were encountered in several hundred wells drilled in the area located west of the Tarnobrzeg–Leżajsk–Jarosław–Przemyśl line (Buła & Habryn, *eds*, 2008). Only short Precambrian sections of different lengths (up to 750 m in the Zalasowa 2 borehole) were examined by drilling. These rocks occur beneath Palaeozoic (Ordovician to Permian), Mesozoic (Triassic and Jurassic) and Miocene series and are represented by weakly metamorphosed (anchimetamorphic) siliciclastics (*e.g.*, Samsonowicz, 1955; Głowacki & Karnkowski, 1963; Pożaryski & Tomczyk, 1968; Jawor, 1970; Karnkowski, 1977; Moryc & Łydka, 2000; Buła & Habryn, *eds*, 2008; Żelaźniewicz *et al.*, 2009), consisting of mudstones, sandstones, sandy gravelstones and polymictic conglomerates, variously coloured, mostly cherry-brownish, grey-green, olive-green or grey, occasionally accompanied by tuffite interbeds. These deposits are characterized by rhythmic sedimentation and graded bedding, indicating that they were deposited by density currents and thus are flysch-type sediments. They often exhibit signs of chloritization and sericitization, and locally of phyllitization. The rocks are characterized by a very strong degree of tectonic deformation, commonly dip at 45–90° and include cataclastic rocks and tectonic breccias.

These rocks used to be considered to be Precambrian (Riphean, Vendian) or Early Cambrian in age (Samsonowicz, 1955; Głowacki & Karnkowski, 1963; Pożaryski & Tomczyk, 1968; Jurkiewicz, 1975; Karnkowski, 1977; Kowalski, 1983; Kowalczewski, 1990; Buła, 2000; Moryc & Łydka, 2000). Their Neoproterozoic–Ediacaran (Vendian) age was proved in the Małopolska Block, based on palynological studies (acritarchs) from the following boreholes (Fig. 2): Radlna 2, Stawiska 1, Zalasowa 1 (Tarnów region); Lipnica 7, 10, 16, 17 and Tryńcza 2 (Leżajsk region) (Moryc & Jachowicz, 2000; Jachowicz *et al.*, 2002; Jachowicz, 2008). The Late Proterozoic–Ediacaran age of the sub-Ordovician siliciclastics found in the Książ Wielki IG1 borehole (Miechów region) was proved by the isotopic analysis of zircons (U-Pb method) from tuffite interbeds in these rocks (age 549 ± 3 Ma) (Compston *et al.*, 1995). The results of isotopic studies (U-Pb SHRIMP II method) of single zircon grains from fossil-dated or presumed Ediacaran rocks from the Zalasowa 1, Tuligłowy 38, Chałupki Dębniańskie 1 (Fig. 2), Ż 141 and BN 58 boreholes show a significant proportion of zircon grains, which grew in parent rocks as whole crystals (or their rims) between 720 and 550 Ma (Żelaźniewicz *et al.*, 2009). These data clearly confirm the Late Ediacaran age of the Małopolska Block flysch deposits.

Rocks of undefined age, forming the Leżajsk Massif in western Ukraine, which are similar to those above described from the Małopolska Block, were to date considered to be Riphean in age (Fig. 1; Kruglov & Tsypko, *eds*, 1988; Stupka, 1993; Mizerski & Stupka, 2005). They show features of siliciclastic flysch that either underwent weak epizonal metamorphism or was subjected to strong epidiagenetic metamorphic processes. In western Ukraine, they were encountered – according to Stupka (1993) – in about 20 boreholes, including several wells located in the Chyzhky and Mostys'ka regions near the Ukrainian-Polish border.

Palynological studies on drill cores of presumed Riphean age in the Chyzhky 1 and 2 boreholes (Jachowicz-Zdanowska, 2011), yielded the following results:

– the Chyzhky 1 section represents rocks younger than Palaeozoic;

– the Chyzhky 2 section consists down to 3,600 m of rocks younger than Palaeozoic, below – (interval 3885–3940 m), grey and greenish mudstones with faint lamination dipping at 40° were recovered in four cored intervals of low core yield.

These rocks, which are weakly chloritized and sericitized contain no determinable micro- and macrofossils and are probably Precambrian in age. It should be noted that the geological literature provides no detailed data from individual boreholes that reached Riphean flysch rocks in this part of the Ukraine. Hence, we do not know the criteria for distinguishing the rocks in those boreholes.

In view of the results of palynological and radiometric studies of the Precambrian flysch in the Małopolska Block, indicating its Ediacaran age (Compston *et al.*, 1995; Moryc & Jachowicz, 2000; Jachowicz *et al.*, 2002; Jachowicz, 2008; Żelaźniewicz *et al.*, 2009), it can be assumed that similar Precambrian rocks of the Leżajsk Massif in the Ukraine (which forms an integral part of the Małopolska Block) and primarily those of its prominent Lower San Horst (Figs 1, 2), are also Ediacaran in age, rather than Riphean as previously assumed.

Żelaźniewicz *et al.* (2009) postulated that the Ediacaran flysch succession of the Małopolska Block was folded and underwent weak and variable metamorphism during the Cadomian tectonic movements at the end of the Ediacaran, as suggested by the results of radiometric age determinations of detrital zircons (U-Pb) from the Ediacaran flysch of the Małopolska Block and of detrital mica (K-Ar) from Cambrian rocks of the Holy Cross Mts. (Bełka *et al.*, 2000; Nawrocki *et al.*, 2007).

The Palaeozoic

Cambrian

In south-eastern Poland, Cambrian clastic rocks occur on the north-eastern flank of the Lower San Horst where they subcrop at the sub-Miocene or sub-Jurassic unconformity along a belt extending from the Holy Cross Mts. through Stalowa Wola towards Lubaczów and the border with the Ukraine (Figs 2, 3). Farther to the northeast, Cambrian rocks are gradually onlapped by Ordovician and Silurian rocks (Janów Lubelski–Biłgoraj–Narol region; Figs 2, 3). In this area, Cambrian rocks were encountered in more than 300 boreholes. In some of them their stratigraphic position was determined based primarily on palynological studies (Dziadzio & Jachowicz, 1996; Kowalska *et al.*, 2000; Jaworowski & Sikorska, 2006; Jachowicz-Zdanowska, 2011). Results presented in these papers indicate that only fragments of the Lower, Middle and Upper Cambrian sections varying in length from a few metres to several hundred metres (over 650 m in Narol IG2) have been identified in individual boreholes.

Drilling data also indicate a clear zoning of the lateral distribution of these deposits (Kowalska *et al.*, 2000). For instance, the oldest, Lower Cambrian rocks occur in the south-western zone of the outcrop belt directly adjacent to the Lower San Horst, while farther to the northeast, Middle to Upper Cambrian deposits subcrop at the sub-Miocene, sub-Jurassic and sub-Ordovician unconformities. The Cambrian series are represented by black, grey or grey-green claystones and mudstones, usually sandy, and light grey, fine-grained (rarely medium-grained) quartz sandstones, commonly interbeded or laminated with mudstones and claystones (heteroliths), occurring in different proportions. There are also rare thin conglomerate layers. These rocks contain a variety of sedimentary structures and numerous trace fossils. According to Dziadzio and Probulski (1997) and Jaworowski and Sikorska (2006), Cambrian deposits of

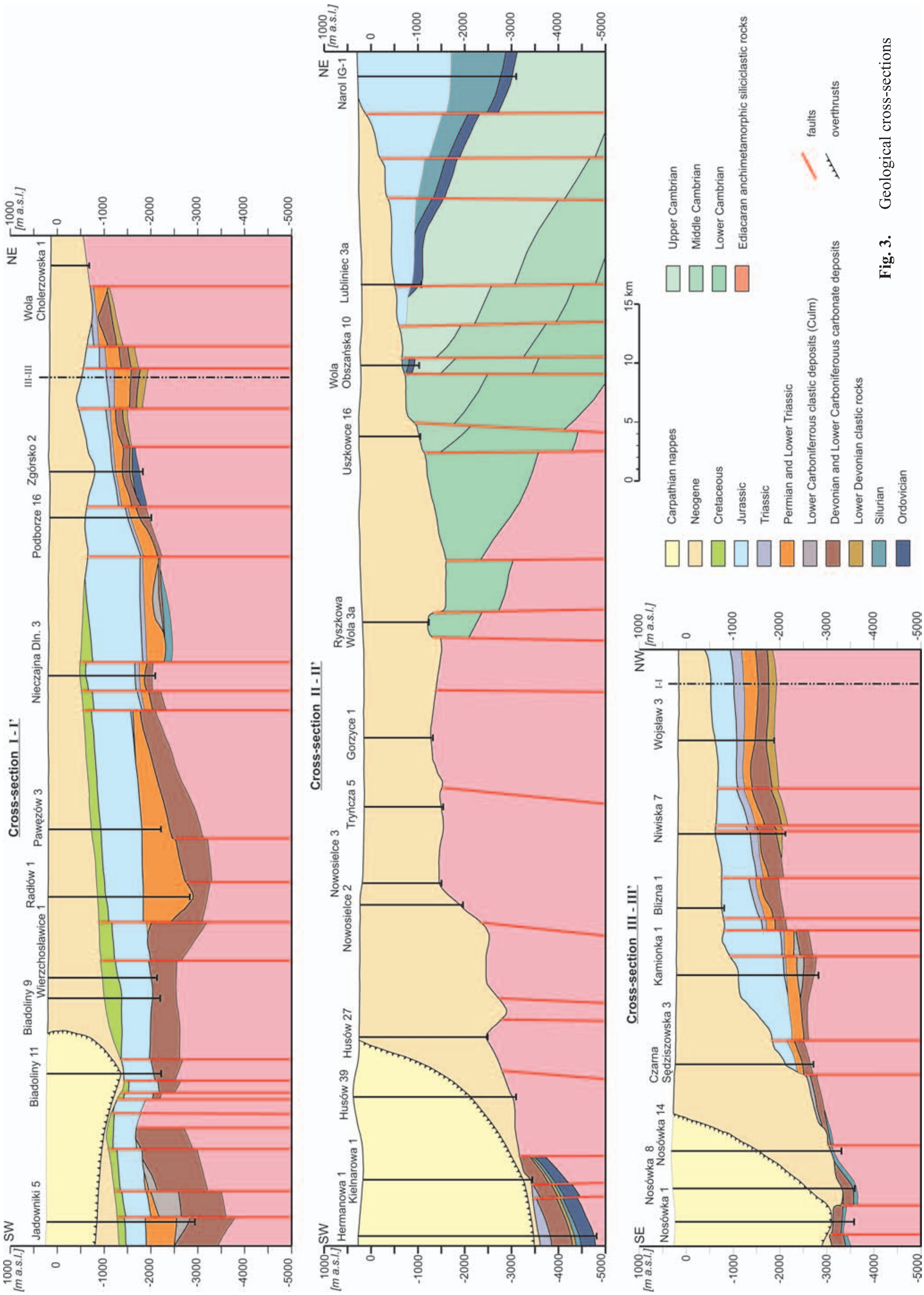

Fig. 3. Geological cross-sections

this area developed on an extensive shelf, dominated by tides and storms.

Stratal dips recorded in the Cambrian sections are highly variable, from low-angle to steep and even vertical. Steep dips prevail in the Lower and Middle Cambrian sections, whereas the Upper Cambrian strata often lie in a horizontal position (Kowalska *et al.*, 2000; Jaworowski & Sikorska, 2006). Fragmentary data available on the Cambrian deposits and their variable stratal dips make it impossible to determine their total thickness (Fig. 4), which probably exceeds 1,000 m in this region.

Cambrian rocks of the study area occur within two tectonic units distinguished in the sub-Permian–Mesozoic basement of south-eastern Poland, *i.e.* the Kielce Fold Belt covering the north-eastern part of the Małopolska Block and the Łysogóry–Radom Block. These tectonic units extend to the border with the Ukraine in the southeast (Figs 1, 2).

Drygant (2000) proposed a lithostratigraphic scheme for the Palaeozoic rocks occurring beneath the marginal parts of the Outer Carpathians and Carpathian Foredeep in the western Ukraine based mainly on lithological criteria and the results of well log analyses in several boreholes, including: Dobromyl' Stril'bychi 33, Dubliany 1, Bortiatyn 1, Chornokuntsi 1, Podilsti 1, and Rudky 300 (Fig. 2), suggesting the presence of Ordovician and Cambrian rocks. It should be stressed that these rocks contain no fossils in most boreholes, and their stratigraphic position has been proved on the basis of single faunal evidence or acritarchs found only in some of them.

Drygant (2000) distinguished Cambrian rocks mostly under fossil-free Ordovician clastic deposits. The Cambrian succession is represented by mudstones-claystones and quartz sandstones (quartzites) that are interbeded in different proportions. These rocks locally contain trace fossils. Drygant (2000) subdivided the Cambrian section into three lithostratigraphic units, namely: the Lower Cambrian Baltic Series attaining the thickness of 132 m; the Lower Cambrian Berezhtsi Series attaining the thickness of 306 m, and the Middle to Upper Cambrian Stryvigor Series, which does not exceed 98 m in thickness. These series were primarily subdivided into 14 secondary lithostratigraphic units ranked as beds.

The occurrence of the complete Cambrian section and the lithostratigraphic scheme, as proposed by Drygant (2000) for the Ukrainian Carpathian Foredeep is, however, questioned for several reasons. In most boreholes, Cambrian and Ordovician sections are exclusively distinguished on the basis of lithological criteria, and there are clastic rocks that are Palaeozoic and even Jurassic in age of similar lithologic characteristics in the investigated boreholes (Dulub *et al.,* 2003). Distinguishing between the differently aged and lithologically similar deposits based exclusively on lithological criteria can lead to serious errors in the assessment of their stratigraphic position. Based on palaeontologic studies, Dulub *et al.* (2003) indicate that indeed part of the section penetrated by the Chornokuntsi 1 and Podil'tsi 1 boreholes is probably Jurassic in age rather than Palaeozoic (Cambrian and Ordovician), as envisaged by Drygant (2000). The results of palynological studies carried out by Jachowicz-Zdanowska (2011) on rock samples from the lower portions of the Dobromyl'–Stril'bychi 33 and Dubliany 1 sections also negate their Cambrian or Ordovician age. Samples taken from these rocks contain palynomorphs, which are characteristic of rocks younger than the Palaeozoic. Early Cambrian acritarch assemblages have been identified by Jachowicz-Zdanowska (2011) in the following boreholes: Korolyn 2 (depth 4,423.0–4,565.0 m), Bortiatyn 1 (depth 3,986.0–4,297.0 m) and Rudky 300 (depth 3,176.0–4,501.9 m).

It should be noted that the Lower Cambrian rocks, containing acritarchs found in the Bortiatyn 1 borehole, were included by Drygant (2000) into the lower part of the Baltic Series (tentatively interpreted as Lower Cambrian) and into the Precambrian–Vendian, whereas in the Rudky 300 borehole – into the Jurassic, Ordovician, Cambrian and Vendian. In the Verchany 1 borehole (Figs 2, 5), Jachowicz-Zdanowska (2011) found Late Cambrian acritarch assemblages in rock samples from depths between 1,996.0 and 2,056.8 m, whilst the overlying rocks (1,967.0–1,975.4 m) contain characteristic Ordovician acritarch assemblages. By contrast, Drygant (2000) assigned in the same borehole deposits of the depth interval of 1,961.0–2,104.0 m entirety to the Ordovician.

This casts serious doubts on the validity of the Palaeozoic lithostratigraphic scheme offered by Drygant (2000) for this part of the Ukraine. Moreover, it is questionable that most of the boreholes listed by this author penetrated complete Cambrian sections of almost equal thicknesses, covered with a continuous Ordovician cover, also of nearly constant thickness. Such an assumption is contradicted by, among others, strong variation of the stratal dip angle observed in both the Palaeozoic and Jurassic rocks, as pointed out by Kruglov and Tsypko, *eds*, (1988), Stupka (1991) and Dulub *et al.* (2003). It is, therefore, expected that coeval Palaeozoic rocks identified in the individual boreholes vary in thicknesses. The above-mentioned boreholes and others described by Drygant (2000), where Cambrian rocks were identified, are located in the Kokhanivka Zone, which is an extension of the Kielce Fold Belt in Poland (Figs 1–4). Thus, it should be assumed that Cambrian deposits of these tectonic units developed under similar sedimentary-diastrophic conditions.

Ordovician

In the Polish part of the study area, Ordovician rocks occur in both the Małopolska Block and the Łysogóry–Radom Block (Figs 1–5). Ordovician rocks of the Małopolska Block do not form a continuous cover, but were preserved in several regions (Figs 3, 5) in tectonic structures, such as fold, fold-and-block or block structures (Buła & Habryn, *eds*, 2008). Ordovician strata unconformably overlie Ediacaran or Cambrian series and are in turn overlain by Silurian sediments and locally by Devonian, Carboniferous, Mesozoic or even Miocene deposits.

In the basement of the Carpathian Foredeep and the marginal part of the Outer Carpathians, Ordovician deposits of the Małopolska Block were penetrated by 20 wells located in the following regions: Busko-Zdrój–Dąbrowa Tarnowska (boreholes: Strożyska 5, Niwki 3, Lubasz 2, Zalesie 1 and Zgórsko 2); Pilzno–Rzeszów (boreholes: Pilzno 40,

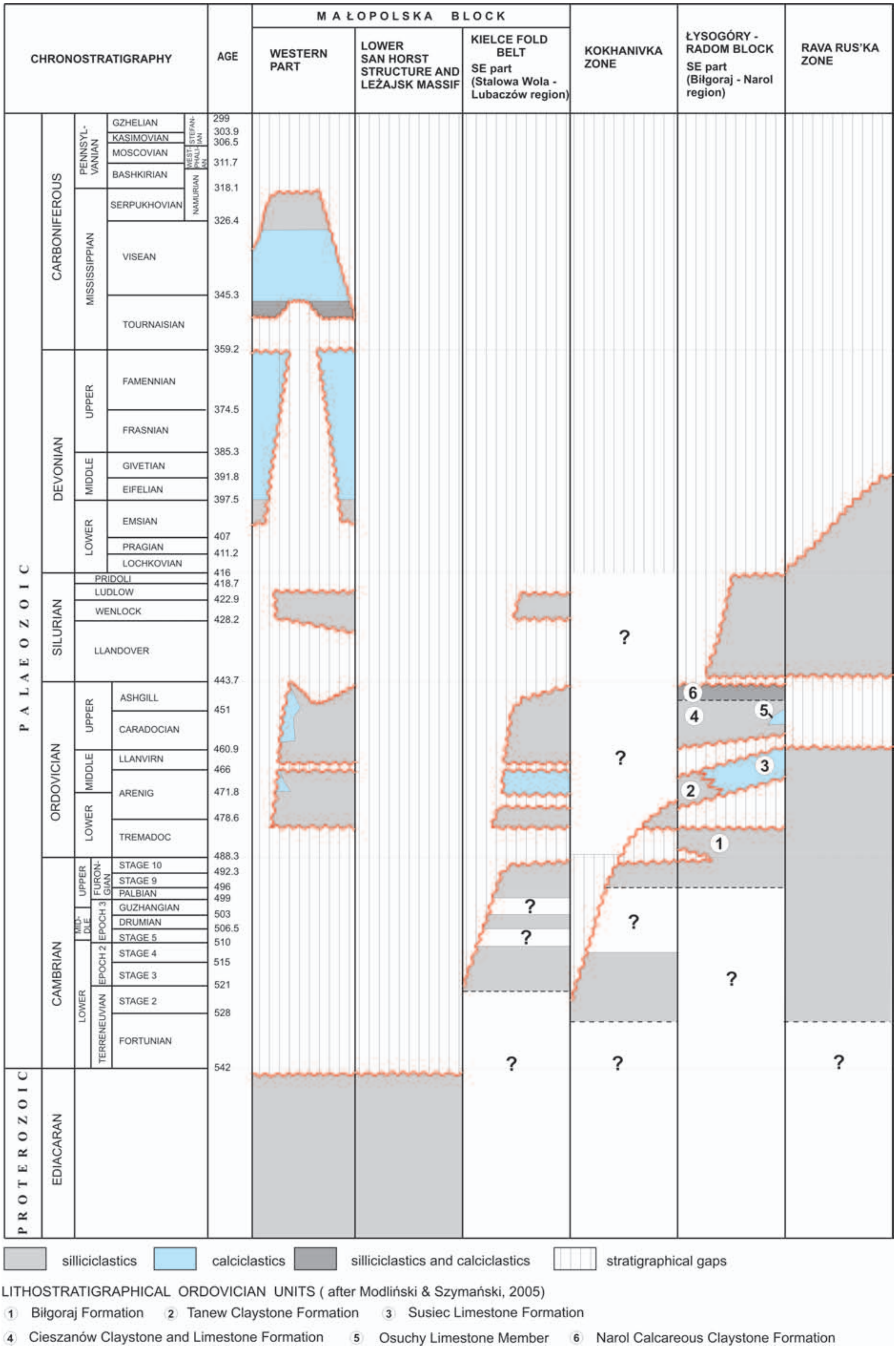

Fig. 4. Precambrian and Palaeozoic schematic stratigraphical sections of south-eastern Poland and western Ukraine

Nosówka 1, 2, 5, 6, 7, 8, 9, 12, Podgórze 1, Zagorzyce 1, Będziemyśl 3 and Hermanowa 1); Tarnogród–Lubaczów (boreholes: Wola Obszańska 8, 9, 10, Uszkowce 1, 4 and Lubaczów 14) (Fig. 5) (Tomczyk, 1963; Kwiatkowski *et al.*, 1966; Bednarczyk *et al.*, 1968; Moryc, 1974, 1992, 1996, 2006; Moryc & Nehring-Lefeld, 1997; Kowalska *et al.*, 2000; Maksym *et al.*, 2003; Buła & Habryn, *eds*, 2008).

The stratigraphy of the Ordovician, represented in these areas by clastic (claystones and siltstones, and rare sandstones and conglomerates) and carbonate (limestone and dolomite) rocks, was established on the basis of graptolite, conodonts and acritarch determinations. In individual boreholes, evidence for the stratigraphical position of penetrated Ordovician series is, however, variable and essentially depends on the quantity of available drill core material. In some boreholes, Ordovician sediments were identified exclusively on the basis of well logging analysis. The existing data indicate the presence of stratigraphic gaps spanning different parts and even the entire Ordovician (Fig. 4). These data also establish the occurrence of lateral lithological changes, such as the replacement of carbonates by clastics.

A characteristic feature of the Ordovician succession in the Małopolska Block is the presence of a distinct, probably synchronous (?Upper Tremadoc–Lower Arenig) glauconitic sandstone of varying thickness (from several metres to 70 m), which occurs at its base. Up in the Ordovician sections (Upper Arenig through the Ashgill), there is a remarkable lithological and facies variability. Carbonates (sandy and nodular bioclastic limestones, bioclastic and crystalline dolomites) are the prevalent or significant lithological components in the western parts of the Busko- Zdrój–Dąbrowa Tarnowska, Pilzno–Rzeszów and Tarnogród–Lubaczów regions. Clastic rocks (claystones, marly claystones and mudstones with graptolites) predominate in the Ordovician sections of the eastern parts of the Busko-Zdrój–Dąbrowa Tarnowska and Pilzno–Rzeszów regions.

Ordovician rocks of the Małopolska Block are characterized by a small, but variable thickness, mostly below 100 m. The greatest thickness is observed in the south of the Pilzno–Rzeszów region in the Hermanowa 1 borehole – 336 m. The only partially penetrated Ordovician section of the Pilzno 40 borehole is 140 m thick. The dips of the Ordovician strata in the above-mentioned three regions of the Małopolska Block usually do not exceed 20°, and are only locally steeper in tectonic deformation zones.

Palaeontologically dated (graptolites, conodonts) Ordovician rocks of the Łysogóry–Radom Block have been found in the following boreholes of the Biłgoraj–Narol region (Figs 4, 5): Narol IG1 and IG2, Dyle IG1, Kozaki 1, Osuchy 1, and Doliny 1 (Modliński & Szymański, 2005; Drygant *et al.*, 2006). The Ordovician succession is underlain in this area by Upper Cambrian deposits, and overlain by Silurian, Jurassic or Miocene rocks.

The Ordovician section starts with Lower Tremadoc quartz sandstones, claystones and mudstones (varying in thickness from 63 m to about 93 m), included by Modliński and Szymański (2005) into the Biłgoraj Sandstones and Claystones Formation. This formation is subdivided into the Frampol Sandstones Member (lower) and Goraj Claystones and Mudstones Member (upper). The Biłgoraj Formation is overlain by two laterally equivalent lithostratigraphic units: the Tanew Claystones Formation and the Susiec Limestones Formation, which is subdivided into the Psary Limestone Member (lower) and Rebizanty Limestone Member (upper). The Tanew Claystones Formation is represented in its basal part by a glauconite layer (0.1–3.0 m) or a claystone layer with abundant glauconite, and in its upper part by a complex of claystones and mudstones (up to about 85 m in thickness).

The Susiec Limestones Formation is composed of marly limestones with abundant bioclasts, and marls, locally dolomitic, up to 3 m in thickness. According to Modliński and Szymański (2005), the Tanew Claystones Formation was deposited during the Early to Late Arenig. The Susiec Limestones Formation, in turn, was deposited during the Late Arenig and Early Llanvirn. These formations are separated from the Lower Tremadoc Biłgoraj Formation by a stratigraphic gap spanning the Upper Tremadoc. In the northwest of the region, the Susiec Formation also spans the lower Lower Arenig, whereas in the southeast, it represents the Lower and Middle Arenig.

In this region, the upper portion of the Ordovician sequence is represented by 130–180 m thick calcareous claystones, locally with bentonite interbeds, and lenses of marly limestones and limestones, referred to the Cieszanów Limestones and Claystones Formation by Modliński and Szymański (2005). Its lower part consists of up to 6 m thick marly and organodetritic limestones, which were distinguished as the Osuchy Limestone Member. The stratigraphical range of this formation covers the Upper Llanwirn and the entire Caradoc. It rests with a sedimentary discontinuity surface on the Tanew Claystones Formation or the Susiec Limestone Formation deposits. This stratigraphic gap spans the Lower and Middle Llanvirn in the northwest of the region, and the Middle Llanvirn in the southeast.

In the Biłgoraj–Narol area, Ordovician sedimentation ends with calcareous claystones and mudstones included by Modliński and Szymański (2005) into the 19–25 m thick Narol Calcareous Claystones Formation of Ashgill age.

The thickness of the Ordovician deposits in the Biłgoraj–Narol area ranges from 184.6 m (Doliny 1 borehole) to 380.1 m (Dyle IG1 borehole), and stratal dips vary between 5 and 45°. Presenting the characteristics of the Ordovician deposits identified in the Biłgoraj–Narol area, Modliński and Szymański (2005) (*vide* Drygant *et al.*, 2006) suggest that they show a close palaeogeographical relationship and far-reaching analogies of the geological events with Ordovician deposits from the Łysogóry region of the Holy Cross Mts. For this reason, the Biłgoraj–Narol area is included in the Radom–Łysogóry Block.

In the marginal part of the Outer Carpathians and the Carpathian Foredeep in western Ukraine, palaeontologically dated Ordovician rocks were encountered in only two boreholes: Dobromyl'–Stril'bychi 33 and Verchany 1 (Fig. 5; Drygant, 2000, Jachowicz-Zdanowska, 2011).

In the Dobromyl'–Stril'bychi 33 borehole, Ordovician rocks were penetrated at a depth of 5,001–5,132 m and consist of graptolitic claystones and mudstones, locally interbedded and laminated by fine-grained quartz sandstones (Drygant, 2000). Based on graptolites, these rocks were included into the Lower, Middle and lower Upper Ordovician (from the Tremadoc through lower Caradoc). For this section, Drygant (2000) (*vide* Drygant *et al.*, 2006) established the Stril'bychi Series, subdivided (from the bottom) into the Verchany, Vyrva, Nahuievychi and Skelivka beds.

The Ordovician section of the Dobromyl'–Stril'bychi 33 borehole was defined by Drygant (2000) as the stratotype for western Ukraine. Palaeontologically barren Ordovician rocks from other boreholes, mentioned in the chapter on the Cambrian rocks, were distinguished by Drygant (2000) in relation to this stratotype section. However, it should be noted that Ordovician rocks of the Dobromyl'– Stril'bychi 33 borehole were treated, according to earlier views (Drygant, 2000 and references therein), as a detached block within the Outer Carpathian flysch units. Drygant (2000), assuming their autochthonous ("root") position in this borehole and suggesting a Cambrian age for the underlying rocks, did not provide credible evidence for his hypothesis.

Results of palynological studies carried out by Jachowicz-Zdanowska (2011) on samples of sub-Ordovician basement rocks from the Dobromyl'–Stril'bychi 33 borehole indicate that they are younger than the Palaeozoic. This shows – as previously assumed – an allochthonous position of the Ordovician rocks in this borehole. Therefore, the section cannot be a stratotype for the Ordovician rocks that occupy an autochthonous position in the Palaeozoic sections throughout western Ukraine. In the light of the foregoing considerations, the lithostratigraphic scheme of Ordovician rocks in this area, as proposed by Drygant (2000), requires a revision based on more complete palaeontological evidence. Presently, it is difficult to justify the author's view that, in the basement of the marginal part of the Outer Carpathians and the Carpathian Foredeep of the Ukraine, there is a massive (continuous) cover of Ordovician clastic rocks ranging in thickness between 30 and 130 m, which rests conformably on Cambrian deposits and is unconformably overlain by Jurassic deposits, as shown in Fig. 5.

Ordovician (and possibly Silurian) rocks, which were originally deposited in the Kokhanivka Zone in the Ukraine, were probably eroded – as it is the case in the Małopolska Block of Poland – probably prior to the Jurassic transgression. In the Kokhanivka Zone erosional processes reached the Cambrian. The Verchany 1 borehole (Fig. 2; Drygant, 2000; Jachowicz-Zdanowska, 2011), which penetrated about 30 m of Ordovician mudstones and sandstones interbedded with fine-grained quartz sandstones (overlying the Upper Cambrian and underlying the Jurassic), proves that Ordovician deposits were locally preserved in this tectonic unit. In the Rava Rus'ka Zone, palaeontologically barren Ordovician claystone-mudstone deposits were found in the Ivano-Frankivs'k 1 borehole below Silurian at a depth of 3,592–3,693 m (after Drygant, 2000).

Silurian

Similar to Ordovician strata, Silurian series are only locally developed in the basement of the Outer Carpathians and Carpathian Foredeep and on the Małopolska and Łysogóry–Radom Blocks of Poland (Figs 2–5).

In the Małopolska Block, the extent of Ordovician sediments partially overlaps the extent of Silurian deposits (Figs 3, 5). Palaeontologically dated (by graptolites and acritarchs) Silurian rocks were found beneath Devonian, Carboniferous, Triassic, Jurassic and Miocene formations in several wells located in the following regions: Busko Zdrój–Dąbrowa Tarnowska (Strożyska 5, Niwki 3, Mędrzechów 1 and Lubasz 2 boreholes); Pilzno–Rzeszów (Zawada 8K, Czarna Pilzno 3, Żukowice 38, Pilzno 40, Zagorzyce 1 and 6, Nawsie 1 and Hermanowa 1 boreholes); and Tarnogród–Lubaczów (Uszkowice 1, Wola Obszańska 6, 8 and 10) (Fig. 5) (Tomczyk, 1963; Bednarczyk *et al.*, 1968; Moryc, 1974, 1992, 1996, 2006; Moryc & Nehring-Lefeld, 1997; Kowalska *et al.*, 2000; Maksym *et al.*, 2003; Buła & Habryn, *eds*, 2008).

In this area, the Silurian is represented by mudstones and claystones, often marly, with graptolites, that locally contain intercalations of fine-grained quartz sandstones, occasional limestone lenses and interlayers of radiolarites and tuffogenic rocks. Biostratigraphic studies indicate the occurrence of stratigraphic gaps in the top and basal parts of the Silurian sections (Fig. 4). Silurian rocks representing the upper Llandovery occur only to the south of the Pilzno–Rzeszów region (Hermanowa 1 and Nawsie 1 boreholes). In its northern part and in the Busko Zdrój–Dąbrowa Tarnowska and Tarnogród–Lubaczów regions, Silurian sedimentation started in Wenlock or only in Early Ludlow times (*e.g.*, Niwki Strożyska 5 and 3 boreholes).

In the Małopolska Block, no Pridoli deposits have been proved so far, presumably due to end-Silurian and Early Devonian erosion. As a result, Silurian rocks of variable thicknesses are preserved only locally as summarized in the following regions: Busko Zdrój–Dąbrowa Tarnowska – 36–264.3 m; Pilzno–Rzeszów – 28–206 m; and Tarnogród–Lubaczów – 7.5–165 m. Stratal dips of Silurian deposits commonly range from a few to between ten and twenty degrees, rarely exceeding 30°.

In the Łysogóry–Radom Block, Silurian series subcrop the basal Jurassic and Tertiary unconformities in a belt extending from the Janów Lubelski region, through Narol towards the border with the Ukraine (Figs 2, 5) where the were penetrated in several boreholes, including Narol IG1 and IG2 and Dyle IG1. A partial section of the Silurian succession was drilled, among others, in the Potok IG1 borehole (Figs 3, 4; Modliński *et al.*, 1993; Tomczyk, 2000; Buła & Habryn, *eds*, 2008). The lowest part of the Silurian section is represented here by about 50 m thick black bituminous claystones with numerous graptolites proving their Llandovery age. The Wenlock is represented by 50–70 m thick dark claystones with graptolites, locally containing limestone lenses. The lower part of the Ludlow section is composed mainly of graptolitic claystones, containing limestone lenses or interbeds of marly limestones, tuffites and bentonites. Its upper part is dominated by mudstones, sandy mudstones and fine-grained sandstones, which become more important up section. The Ludlow succession is 580–620 m thick. The lower part of the Pridoli succession is composed of claystones and mudstones, whereas its upper part is dominated by claystones with limestone lenses, containing graptolites. The Pridoli deposits, preserved under

Jurassic rocks, attain a thickness of over 400 m (Narol IG1 and Potok IG1 boreholes); in the Narol IG2 borehole it is 112 m. The stratigraphically most complete Silurian section of the greatest thickness (1,094.5 m) was encountered in the Narol IG1 borehole. The Potok IG1 borehole encountered an 832.5 m thick Silurian section while the Dyle IG1 borehole penetrated 200 m of Silurian sediments. In these boreholes the stratal dip of the Silurian deposits varies between a few and about 40°.

Beneath the Carpathian Foredeep of the western Ukraine, Silurian sediments were found under Jurassic or Lower Devonian deposits in the Rava Rus'ka Zone (Figs 2, 4, 5; Kruglov & Tsypko, *eds*, 1988; Stupka, 1991, 2002; Drygant, 2000). Silurian sections, poorly dated by fossils, were among others encountered in the Rava Rus'ka 1 and Ivano-Frankivs'k 1 boreholes (Fig. 5). In the latter, Silurian strata occur between Lower Devonian and Ordovician sediments at a depth of 3,148–3,592 m (Drygant, 2000) and consist of marly claystones interbedded with marly or clayey limestones, rarely with mudstones and fine-grained sandstones, attributed by Drygant (2000) to the upper Llandovery, Wenlock, Ludlow and Pridoli. There are no data on the thickness distribution of Silurian rocks in the Rava Rus'ka Zone. Strong tectonic deformation of the Palaeozoic succession in this tectonic unit (dip angles from 70 to 90°) is suggested by Kruglov and Tsypko, *eds*, (1988) and Stupka (1991, 2002) (*vide* Mizerski & Stupka, 2005).

Devonian

Devonian series, occurring in the basement of the marginal part of the Carpathians and Carpathian Foredeep of south-eastern Poland, were examined by wells in the western part of the Małopolska Block (Figs 2, 3). Lower Devonian sediments subcropping Jurassic series occur in the northern part of the Carpathian Foredeep on the Łysogóry–Radom Block (north of Sandomierz) and at the edge of the East-European Platform in the Kraśnik region (Fig. 2). Similarly, Lower Devonian series subcropping Jurassic sediments, occur beneath the Ukrainian Carpathian Foredeep in the Rava Rus'ka Zone and at the edge of the East-European Platform in the Ivano-Frankivs'k region (Fig. 2).

In the western part of the Małopolska Block, west of the Lower San horst structure (Figs 2, 3), Devonian series were encountered in over 40 boreholes in the marginal part of the Carpathians and Carpathian Foredeep (Jawor, 1970; Jurkiewicz & Żakowa, 1972; Kicuła & Żakowa, 1972; Zając, 1981, 1984; Moryc, 1987, 1992, 1996, 2006; Buła & Habryn, *eds*, 2008) where they occur beneath Carboniferous, Mesozoic and Tertiary deposits and rest unconformably on Ediacaran, Ordovician and Silurian rocks.

The lower part of the Devonian sections is represented by Emsian clastic rocks (Old Red facies). These are usually mottled quartz sandstones (quartzites), mudstones and claystones. The proportion of these rock types varies in the individual Lower Devonian sections, the thickness of which ranges between 15 m and 150 m.

The Middle and Upper Devonian succession is represented by carbonates. Dolomites, accompanied by dolomitic limestones, and locally marls and limestones dominate in the Eifelian. The occurrence of anhydrite and gypsum testifies to locally restricted marine conditions. The Givetian section consists of dolomites and limestones, predominantly stromatoporoidal ones. The Famennian is represented by detrital and nodular, bituminous and marly limestones. Rhythmic deposition of clayey-marly or calcareous-detrital sediments dominated in the Famennian. The thickness of the Middle and Upper Devonian carbonates, preserved in this part of the Małopolska Block under the Carboniferous succession, varies greatly from 87 m to over 1,000 m.

No Devonian deposits are encountered in the Dębica region and farther northwards as far as Dąbrowa Tarnowska, where the Carboniferous (Visean) rests unconformably on Silurian, Ordovician or Ediacaran rocks.

This suggests that this region formed a high during the Devonian and possibly Early Carboniferous times, referred to as the "Dębica Peninsula" (Zając, 1987) or the "Mędrzechów–Brzozów Land" (Narkiewicz *et al.*, 1998b).

In the Łysogóry–Radom Block and along the margin of the East-European Platform, the Lower Devonian sediments were penetrated below the Jurassic series between Sandomierz and Kraśnik by the following boreholes: Rachów 1, Stróża IG1, and Zakrzew IG2 and IG3 (Fig. 2; Miłaczewski, 1981; Pożaryski & Tomczyk, 1993; Tomczyk, 2000). Their thicknesses vary between 170 m to over 1,400 m. In the boundary area between the Radom–Łysogóry Block and the East-European Platform (at the edge of which the Devonian–Carboniferous Lublin Basin developed), the following three Lower Devonian lithostratigraphic units are recognized (Miłaczewski, 1981; Narkiewicz *et al.*, 1998a, 2007):

– Sycyna Formation – dark-grey claystones and mudstones with rare limestone interbeds, interpreted as deeper shelf deposits of the lower Lower Lochkovian age;

– Czarnolas Formation – dark-grey claystones, mudstones and fine-grained quartz sandstones, deposited in a shallow-marine near-shore zone, attributed to the upper Lower Lochkovian;

– Zwoleń Formation – fine-grained sandstones and mostly mottled claystones and mudstones, rarely accompanied by conglomerate layers with quartz pebbles. These are alluvial deposits (Old Red facies) of the Late Lochkovian to end-Emsian age.

Similar Lower Devonian rocks, in terms of lithology and facies types, occur in the Rava Rus'ka Zone and along the south-western edge of the East-European Platform in the Ukraine. They are assigned to two lithostratigraphic units, namely the Tyver Series (Lochkovian–lowermost Pragian) and the Dnister Series (upper Pragian–?Lower Eifelian) (Drygant, 2000). Equivalent lithostratigraphic units were encountered below the Jurassic succession in the Rava Rus'ka Zone in the Rava Rus'ka 1 (depth 1,225–2,587 m) and Ivano-Frankivs'k 1 (depth 880–3,148 m) boreholes (after Drygant, 2000).

The Lower Devonian series of the East-European Platform, Radom–Łysogóry Block and Rava Rus'ka Zone overlie Silurian deposits conformably and in depositional continuity.

Carboniferous

Carboniferous rocks, occurring beneath the marginal part of the Outer Carpathians and Carpathian Foredeep, were encountered in the Małopolska Block only (Figs 2–4). Like the Devonian rocks, they occur in the western part of this tectonic unit (west of the Lower San Horst). In the Outer Carpathians and Carpathian Foredeep, Carboniferous rocks have been reported from over 60 boreholes under the Permian, Mesozoic and Tertiary formations. They commonly overlie Devonian rocks, whereas in the Dąbrowa Tarnowska–Dębica–Rzeszów region they rest directly upon Silurian, Ordovician or Ediacaran rocks. The following three Carboniferous lithostratigraphic units have been identified by Moryc (1987, 1992, 1996, 2006) and Jawor and Baran (2004):

– Carbonate-Clastic Complex ”A“ , attributed to the Upper Tournaisian, composed of red and grey-green, variously grained sandstones, locally conglomeratic, and variegated claystones and mudstones, containing interbeds of carbonates , mainly pelitic dolomites, marly claystones and pelitic limestones. Deposits of this complex occur only in a narrow strip along the western, northern and eastern margin of the so-called ”Dębica Peninsula“ (Zając, 1981) or the ”Mędrzechów–Brzozów Land“ (Narkiewicz *et al.*, 1998b), where pre-Devonian series are directly overlain by Visean deposits. The thickness of the complex attains 76 m;

– Carbonate Complex ”B“, also referred to as the ”Carboniferous Limestone“, is early Visean in age and overlies complex “A” in depositional continuity. It is represented by crystalline, cryptocrystalline and micritic limestones and dolomites. The limestones contain thin intercalations of variegated claystones or mudstones. These deposits are much more widespread than those of complex ”A“. They were removed by erosion over a large area. In places where they are overlain by younger Carboniferous clastics (below described complex ”C“), they range in thicknesses between 80 m and 590 m;

– Clastic (terrigenous) Complex ”C”, which spans the ?Middle Visean through Lower Namurian (lower Namurian A), is composed of claystones, grey mudstones and fine-to medium-grained sandstones (Culm facies). These clastics attain in this part of the Małopolska Block thicknesses of up to 500 m.

PALAEOGEOGRAPHY AND TECTONIC EVOLUTION OF THE PRECAMBRIAN AND PALAEOZOIC

In south-eastern Poland and western Ukraine, the Outer Carpathians and Carpathian Foredeep developed on the margin of the East-European Platform (Baltica) and the adjacent Łysogóry–Radom and Małopolska blocks in Poland and the Rava Rus'ka Zone, Kokhanivka Zone and Leżajsk Massif in the Ukraine (Figs 1, 2). These units, together with the Brunovistulicum that adjoins the Małopolska Block in the southwest (Fig. 1), form parts of the Trans-European Suture Zone (TESZ). The evolution of this zone during Proterozoic and Palaeozoic times is in many respects still not fully resolved, owing to limited control on its Palaeozoic successions and the lack of data on the basement structure of the individual tectonic units (Fig. 4; Dadlez, 2006; Nawrocki & Poprawa, 2006; Jaworowski & Sikorska, 2006).

Present information on the geological structure of the Precambrian and Palaeozoic succession in this area of the TESZ and the margin of the East-European Platform does not permit to establish discrete boundaries between the different tectonic units that are presumably bounded by regional or super-regional fault zones. Their course has been delineated with varying accuracy (Fig. 1) in the geological map (Fig. 2), depending on the availability of geophysical and geological control on the Precambrian and Palaeozoic structure of different parts of the study area.

The problems of palaeogeography and tectonic processes affecting the development of the south-western edge of the East-European Craton and tectonic blocks (terranes) involved in the formation of the TESZ during Neoproterozoic and Early Palaeozoic times (especially Małopolska Block and Brunovistulicum) have been summarized by Malinowski *et al.* (2005), Jaworowski and Sikorska (2006), Nawrocki and Poprawa (2006), Poprawa (2006a, b), Narkiewicz (2007), Nawrocki *et al.* (2007) and Żelaźniewicz *et al.* (2009). These authors expressed in general a consistent opinion that the development of the TESZ began in (?Middle) Late Neoproterozoic times and was associated with rifting processes taking place along the western edge of the East-European Craton during the breakup of the Precambrian Rodinia/Pannotia supercontinent (*vide* Golonka 2009, Golonka *et al.* 2009). According to Poprawa (2006a), the rifting process led to ”the development of Baltica passive margin, which evolved into the TESZ during Palaeozoic collisions and/or strike-slip movements”.

Deposition of siliciclastic rocks of the Polesie Formation, overlying the Palaeo- or Mesoproterozoic crystalline basement, is related to an early rifting phase on the south-western slope of the East-European Craton. These rocks were deposited about 770–700 Ma ago (?Early-Middle Neoproterozoic) (Poprawa, 2006a). The main rifting event in this part of the East-European Craton is proved by the development of widespread basaltic traps, including those known from south-eastern Poland and western Ukraine (Nikishin *et al.*, 1996). The related Sławatycze Formation (represented in its bottom portion by coarse-clastic alluvial deposits, conglomerates and coarse-grained sandstones, and in its upper portion by volcanogenic rocks – basalts interbedded with tuffs and agglomerates) is the record of this event in the Lublin–Podlasie region (Poprawa & Pacześna, 2002; Pacześna & Poprawa, 2005). Based on radiometric data, the age of these rocks was estimated at about 650–550 Ma (Nawrocki & Poprawa, 2006; Poprawa, 2006a).

The basalt lavas and volcaniclastic rocks of the Sławatycze Formation and Ediacaran clastic deposits of the Białopole and Siematycze formations, whose depocentres developed probably under an extensional regime, are considered by Poprawa and Pacześna (2002) and Poprawa (2006a) as Late Proterozoic synrift deposits of the Lublin–Podlasie Basin. However, the uppermost Ediacaran rocks of the Lublin and the Włodawa formations in the Lublin–Podlasie Basin record, according to Poprawa and Pacześna (2002), represent the transition from the syn-rift to the post-rift phase.

The Ediacaran series, represented by weakly metamorphosed (anchimetamorphic) and strongly tectonically deformed flysch-like siliciclastics, occur in the TESZ in the

Małopolska Block (Żelaźniewicz *et al.*, 2009). Lithologically similar rocks of the Leżajsk Massif located in the Ukraine, which forms undoubtedly an integral part of the Małopolska Block (Figs 1, 2), should be considered to be of the same age. According to Żelaźniewicz *et al.* (2009), these rocks were folded and underwent weak metamorphism at the Ediacaran/Cambrian transition during the Cadomian orogeny and represent the outer part of the Cadomian orogenic belt.

Refraction seismic data presented by Malinowski *et al.* (2005) from the profile CEL 02 point out the following:

– wave propagation velocity Vp within the crust of the Małopolska and Łysogóry blocks is almost identical to that within the crust of the south-western edge of the East-European Platform in the Lublin–Podlasie region;

– Ediacaran flysch deposits of the Małopolska Block are underlain by rocks characterized by low wave propagation velocity, which are interpreted as Neoproterozoic metasediments representing a rift succession of a passive margin subsequently incorporated into the TESZ.

Based on these data, Malinowski *et al.* (2005) and Żelaźniewicz *et al.* (2009) consider the Łysogóry–Radom and Małopolska blocks as the most south-westerly parts of the East-European Craton (Baltica), which, since the Late Ediacaran, occupied a similar position as today. However, they do not exclude strike-slip movements during the Phanerozoic along the faults that bounded the individual tectonic units of the TESZ.

An alternative view on the position of the Małopolska Block relative to Baltica during the Ediacaran was advanced by Nawrocki and Poprawa (2006) and Poprawa (2006a), who assumed that its present position with respect to the East-European Craton was not representative for Neoproterozoic times. The rationale for this hypothesis was the great contrast between the lithologic-facies development of Neoproterozoic (Ediacaran) rocks in the Małopolska Block and those observed along the margin of the East-European Craton in the Lublin–Podlasie Basin. In addition, the Małopolska Block rocks are intensely tectonically deformed and weakly metamorphosed due to Cadomian orogenic processes, whilst coeval rocks of the Lublin–Podlasie Basin show no signs of metamorphism and compressional deformation. Therefore, these authors assumed that the Małopolska Block was docked to the East-European Craton during the Cambrian in response to convergence processes and strike-slip movements.

The Cambrian rocks occur on the south-western slope of the East-European Platform, in the Łysogóry–Radom Block, in the north-eastern part of the Małopolska Block (Kielce Fold Belt), and in the Rava Rus'ka and Kokhanivka zones (Figs 1, 2). According to our interpretation, the lack of Cambrian deposits in the western part of the Małopolska Block (west and south of the Kielce Fold Belt) and in the Leżajsk Massif (Figs 2–4) is due to the uplift during Cadomian tectonic movements. As a result, this part of the Małopolska Block and the Leżajsk Massif probably formed emergent areas during the Cambrian. This hypothesis is supported by the fact that in the western part of the Małopolska Block (west and south of the Lower San Horst structure) Ordovician and younger series directly overlie Ediacaran rocks (Fig. 4). It is very unlikely that Cambrian sediments were deposited in this area and were completely eroded during a relatively short time prior to the Ordovician.

According to Jaworowski and Sikorska (2006), the Middle and Upper Cambrian rocks of the Łysogóry–Radom tectonic unit and the Lower and Middle Cambrian deposits on the western margin of the East-European Platform form part of a siliciclastic passive margin prism that developed on a broad shelf dominated by tides and storms. These authors assumed that the Łysogóry–Radom unit formed the proximal part of the Cambrian passive margin of the East-European Craton, while the Kielce Zone (Kielce Fold Belt) included in the Małopolska Block was situated in its distal part. Jaworowski and Sikorska (2006) claimed that a characteristic feature in the Cambrian palaeogeographical record of the Holy Cross Mts. is the presence of narrow zones of sand deposition, which are separated by areas dominated by sandstone-mudstone heteroliths, mudstones and claystones. According to these authors, the zones of sand deposition correspond to shallows located on the elevated edges of tilted blocks controlled by large-scale normal listric faults. These faults were especially active during the Ediacaran breakup of the Rodinia supercontinent. As a result of related tensional faulting in the Łysogóry–Radom unit and the Małopolska Block, the margin of the East-European Craton subsided (Jaworowski & Sikorska, 2006). The Łysogóry–Radom and Małopolska blocks were, however, not separated from Baltica during the breakup of the Rodinia supercontinent, but were an integral part of its passive margin. Thus, deformation of Cambrian sediments occurring during the Middle Cambrian and at the Late Cambrian/Ordovician transition may be related to the reactivation of rotational movements on pre-existing normal listric faults in response to strike-slip movements (Jaworowski & Sikorska, 2006; Nawrocki & Poprawa, 2006).

Poprawa and Pacześna (2002), Pacześna and Poprawa (2005), and Poprawa (2006a) suggested that the Cambrian and Early Ordovician sedimentation on the Baltica passive margin in the area of the Lublin–Podlasie, Łysogóry–Radom and Małopolska blocks (Kielce Fold Belt) was controlled by post-rift thermal subsidence, typical of both passive margins and rift basins. The upper Middle-Upper Cambrian and Lower Ordovician sections of the Lublin–Podlasie slope and the Kielce Fold Belt of the Małopolska Block contain stratigraphic gaps. Nawrocki and Poprawa (2006) and Poprawa (2006a) suggested that these gaps developed during the docking of the Małopolska Block (treated as a proximal terrane) to Baltica. Accretion of tectonic units at the end of the Middle Cambrian and during the Late Cambrian is thought to involve their oblique convergence that might have been related to the sinistral rotation of Baltica. Poprawa (2006a, b) suggested that, in the latest Cambrian, the Małopolska Block was located farther to the southeast with respect to its present location.

A model of oblique collision of the Małopolska Block with Baltica during the period of late Middle Cambrian through Late Cambrian (and possibly Early Ordovician), postulated by Nawrocki and Poprawa (2006) and Poprawa (2006a, b), permits to explain the development of compressional fold structures in the Lower and lower Middle Cambrian deposits of the Kielce Fold Belt in the Małopolska Block. Deformation of these rocks and stratigraphical gaps observed in this area in the upper Middle-Upper Cambrian succession were associated with the so-called Sandomierz tectonic phase (*e.g*., Kowalczewski *et al.*, 2006).

Strong tectonic subsidence during deposition of the Middle-Upper Cambrian and Lower Ordovician (Lower Tremadocian) series of the Łysogóry–Radom Block is – according to Poprawa (2006a) – the result of flexural bending of the crust in this block in response to its tectonic loading by the Małopolska Block during its Middle and Late Cambrian docking to Baltica. However, Poprawa (2006a) did not exclude a possibility that the Łysogóry–Radom Block was at that time not yet firmly welded to Baltica as evidenced by "zones activated in the late history of this part of the TESZ".

As there is no tectonic unconformity between the Ordovician and Silurian sequences in the Małopolska Block, Łysogóry–Radom Block and on the southern slope of Baltica (Lublin–Podlasie region), they are included in a single tectono-stratigraphic unit. Ordovician series are characterized by a great lithological and facies variability, which is particularly evident in the Małopolska Block, where carbonate platform facies are replaced laterally by graptolitic shale facies (basinal facies) (Trela, 2006; Buła & Habryn, *eds*, 2008).

Stratigraphical gaps evident in the Lower and lower Middle Ordovician (Tremadoc–Arenig) sections of the area under consideration reflect tectonic movements that started in the Middle and Late Cambrian and continued even in the Early Ordovician. These Late Cambrian–Ordovician tectonic movements led to the uplift and erosion of older rocks in the Małopolska Block and the continental slope of Baltica. Stratigraphical gaps observed at the Ordovician/Silurian boundary probably relate to a global eustatic sea-level drop (Poprawa, 2006b; Trela, 2006). The Silurian clastic succession is clearly dominated by graptolitic shales. Characteristic for these basins is the Ludlow episode of large-scale coarse-grained clastic supply.

In the Małopolska Block, Silurian sedimentation came to its end probably during the Ludlow (*e.g*., Narkiewicz, 2002; Malec, 2006; Poprawa, 2006b; Buła & Habryn, *eds*, 2008; Kozłowski, 2008). The Ludlow or older deposits are overlain in this area by either Lower Devonian (Emsian, Old Red facies) clastics or Middle Devonian carbonates and locally by post-Devonian rocks. The angular unconformity between the Devonian and Silurian (amounting 10–15 degrees) indicate the Caledonian deformations on the Małopolska Block (Żaba, 1999). The discontinuous, patchy distribution of Ordovician and Silurian deposits in this block (Fig. 5) shows that they were subjected, even before the Emsian or Middle Devonian, to intense erosion that in places reached the older rocks (Buła & Habryn, *eds*, 2008).

In the Biłgoraj–Narol region of the Łysogóry–Radom Block, variably thick Silurian sections, including Pridoli and Ludlow rocks, occur beneath the Jurassic cover. Their thicknesses are many times greater than those of the older Silurian stages (Narol IG1 and Ruda Lubycka 1 boreholes; Modliński *et al.*, 1993; Tomczyk, 2000).

In the Łysogóry region of the Holy Cross Mts., Pridoli marine deposits pass without a sedimentary break into Lochkovian marine deposits (Malec, 2006, Kozłowski, 2008). They are separated from the unconformably overlying Emsian rocks by a stratigraphical gap spanning the Pragian (and maybe also the upper Lochkovian). In both the Biłgoraj–Narol region and the Łysogóry region, the thickness of the Ludlow and Pridoli deposits is several times greater than that of the older Silurian rocks.

Subsidence analyses of the Silurian–Ordovician section in the Lublin–Podlasie Basin (Poprawa, 2006b) indicate from the ?Middle-Late Ordovician onward a gradual increase in subsidence and deposition rate culminating in the Ludlow and Pridoli. Like in the Łysogóry Radom Block, there is depositional continuity between the Silurian and Lower Devonian (Lochkovian) series. The Silurian/Devonian transition deposits of the L'viv Foredeep and Rava Rus'ka Zone show similar features to those observed in the Lublin–Podlasie Basin and the Łysogóry–Radom Block (Kruglov & Tsypko, *eds*, 1988; Drygant, 2000).

Processes controlling the Middle Ordovician to Late Silurian/Early Devonian subsidence and sedimentation on the south-western margin of Baltica and on the Małopolska and Łysogóry–Radom blocks were associated with the development of the Caledonian orogen (Poprawa, 2006b). This orogen extends from the Arctic-North Atlantic domain, the Scandian collision zone between Laurentia-Greenland and Baltica, through northern Germany into Poland where it marks the collision zone between the Gondwana-derived East-Avalonia terrane and the south-western margin of Baltica (Ziegler & Dèzes, 2006; Pharaoh *et al.*, 2006; Golonka, 2009). Development of the North German-Polish Caledonides was associated with the subsidence of a broad flexural foreland basin on the western margin of Baltica, commencing in Silurian times (Nawrocki & Poprawa, 2006, Šliaupa *et al.*, 2006).

Poprawa *et al.* (1997), Narkiewicz (2002) and Poprawa (2006b) suggest that the Ordovician and Silurian tectonic subsidence of the Małopolska and Łysogóry–Radom blocks (defined for the Holy Cross Mts. area only) was similar to the Ordovician–Silurian basin developed along the western margin of Baltica, especially the Lublin–Podlasie Basin, and it was driven by load-induced flexural deflection of the lithosphere. The Ordovician–Silurian subsidence curves, determined for these basins (Narkiewicz, 2002; Poprawa, 2006b), show the characteristic "knee" shape that is attributed to the deflexion of a foreland plate under the weight of an encroaching orogenic wedge, as seen, for instance, in the Carpathian Foredeep (Oszczypko, 2006).

In the area under consideration, the Upper Silurian (Ludlow–Pridoli) and Lower Devonian (Lochkovian) series reflect a substantial increase in the tectonic subsidence and deposition rate. No Upper Silurian (Pridoli) and Lower Devonian (Lochkovian–Pragian) sediments have been found on the Małopolska Block. It suggests that this block occupied at that time a different palaeogeographic position with respect to the Łysogóry–Radom Block and the Baltica margin than it presently does. The post-Silurian dextral displacement of the Małopolska Block (or the Małopolska and Łysogóry–Radom blocks) relative to the East-European Craton is postulated by, *e.g*., Lewandowski (1993), Dadlez *et al.* (1994), Narkiewicz (2002) and Poprawa (2006b). The latter – referring to the conclusions of Nawrocki (2000) who pointed out the lack of palaeomagnetic evidence for the post-Silurian displacement of the Małopolska Block with respect to the East-European Craton – suggested small-scale displacements, which were within the limits of methodical error and the palaeomagnetic resolution.

The role of the Caledonian diastrophism in shaping the structure of the Ordovician–Silurian succession in this area is unclear (*vide* Mizerski & Stupka, 2005). The post-Ludlow uplift of the Małopolska Block resulted in intense erosion of the Ordovician–Silurian rocks. These rocks, occurring locally in the southwest of the block (Fig. 5), form a pattern of block-faulted structures. However, in the Kielce Fold Belt that forms part of the Małopolska Block, they occur within fold or fold-and-fault block structures. The resolution of the Ordovician and Silurian succession in the Łysogóry–Radom Block (in the Biłgoraj–Narol region) and Rava Rus'ka Zone is, however, too poor to reliably define their structural style. Folded style of the succession in the Rava Rus'ka Zone is attributed by Kruglov and Tsypko, *eds* (1988) to Caledonian movements. It is, however, unknown to what extend this area was overprinted by Variscan deformations (Fig. 1).

The Devonian–Carboniferous carbonate and clastic rocks, representing the Variscan tectono-stratigraphic unit, occur in the western part of the Małopolska Block only (Figs 2–4). Narkiewicz (2007) assumed a much greater original extent of the Devonian (from Middle Devonian) and Carboniferous (up to Upper Namurian A) sequences and postulated that they occurred almost throughout the entire Małopolska Block, except in its southern part that formed land in Devonian times (Mędrzechów–Brzozów land; Narkiewicz *et al.*, 1998b). The present lack of these Devonian and Carboniferous sediments in the north-eastern part of the Małopolska Block is attributed by Narkiewicz (2007) to Permo-Carboniferous(?) erosion. It should be also noted that he assumed a different course of the Holy Cross Fault, marking the boundary between the Małopolska and Łysogóry–Radom blocks, from that adopted in the present work.

According to Narkiewicz (2007), this fault merges in the area north of Lubaczów with the Nowe Miasto–Radom Fault Zone that continues from the northeast and represents the south-western border of the East-European Craton. In this context, the Małopolska Block is bordered to the north by the Łysogóry–Radom Block, and to the northeast – directly by the East-European Craton. Narkiewicz (2007) provides no justification for the adopted version of the Holy Cross Fault trend. At present, it is difficult to determine and to justify the development of the Devonian–Carboniferous succession in south-eastern Poland and western Ukraine, in the area situated southwest of the East-European Craton.

Narkiewicz (2007) includes the Małopolska Block into a mosaic of crustal blocks located in the Variscan foreland. These blocks, separated by deep-rooted and repeatedly reactivated fault zones, reacted differently to changing lithospheric stress pattern in Devonian and Carboniferous times. In accordance with the Narkiewicz's (2007) view, Devonian and Carboniferous deposits (up to Namurian A) of the Małopolska Block accumulated under the stress field similar to that of the Variscan externides, *i.e*. in the Rhenohercynian Zone and the Moravo-Silesian fold-and-thrust belt. The Middle-Upper Devonian shallow-marine carbonate platform deposits of the Małopolska Block were deposited under an extensional regime, locally in continuity with lithologically similar Lower Carboniferous facies. A remarkable change in sedimentation, interpreted by Narkiewicz (2007) as resulting from orogenic compression and erosion of the Variscan orogenic wedge, provided the Late Visean and Early Namurian A deposition of the siliciclastic Culm facies on the Małopolska Block. In the Late Namurian A, the Małopolska Block was uplifted, probably as a result of south-to-north directed orogenic stress.

In post-Carboniferous times, the Precambrian and Palaeozoic rocks occurring presently in the basement of the Outer Carpathians and Carpathian Foredeep were subjected repeatedly to erosion during Late Carboniferous–Permian, Mesozoic and Cainozoic times. The geological structure of these rocks changed as a result of the development and inversion of the Mesozoic basin and Alpine tectonic movements leading to the formation of the Outer Carpathian orogen and the Carpathian Foredeep (Golonka *et al.*, 2000, 2006; Oszczypko *et al.*, 2006; Kuśmierek, 2010). This restructuring was associated primarily with either reactivation of older (Variscan and pre-Variscan) fault zones or the formation of new (post-Variscan) faults, displacing Precambrian and Palaeozoic rocks in the study area (*e.g*., Buła & Habryn, *eds*, 2008).

CONCLUSIONS

In south-eastern Poland and western Ukraine, the Outer Carpathian orogen and its foredeep developed on the margin of the East-European Platform (Baltica). The area consists of a number of tectonic units, including the Łysogóry–Radom Block and Małopolska Block in Poland, and the Rava Rus'ka Zone, Kokhanivka Zone and Leżajsk Massif in the Ukraine (Fig. 1). These tectonic units, located within the Trans-European Suture Zone (TESZ), are composed of the Precambrian and Palaeozoic (Cambrian to Carboniferous) rocks and are separated by regional fault zones (Fig. 2).

In the study area, fragmentary control on Palaeozoic sections and the lack of data on the structure of the Precambrian basement in some of these tectonic units (Fig. 4) inhibits a comprehensive and unambiguous assessment of the Late Precambrian and Palaeozoic evolution of the TESZ.

Development of the TESZ began in the Late Proterozoic rifting processes along the present-day western margin of the East-European Craton (Baltica) during the breakup of the Rodinia/Pannotia supercontinent (*e.g*., Poprawa & Pacześna, 2002, Malinowski *et al.*, 2005; Nawrocki & Poprawa, 2006; Poprawa, 2006a; Golonka, 2009; Golonka *et al.*, 2009; Żelaźniewicz *et al.*, 2009). The rifting culminated in the earliest Cambrian development of the Baltica passive margin, which includes the Łysogóry–Radom and Małopolska blocks, where the Earth's crust is characterized by similar geophysical features as the crust in the south-western edge of the East-European Craton in the Lublin–Podlasie segment (Malinowski *et al.*, 2005; Żelaźniewicz *et* *al.*, 2009). The complete record of the rifting phases and post-rift Neoproterozoic and Early Palaeozoic (Cambrian and Early Ordovician) thermal subsidence of the basin was recognised only in the geologically well-explored Lublin–Podlasie slope of the East-European Platform (Poprawa & Pacześna, 2002; Poprawa, 2006a).

In the Małopolska Block and its integral part, the Leżajsk Massif (Figs 1, 2), there occur Ediacaran flysch-like siliciclastics that underwent weak metamorphism and fold deformation at the Ediacaran/Cambrian transition as a result of Cadomian tectonic movements. They represent the outer part of the Cadomian orogenic belt (Żelaźniewicz *et al.*, 2009). In terms of lithological and facies development, metamorphic transformations and the nature of tectonic deformation, they differ from the coeval platform deposits observed in the south-western edge of the East-European Platform.

Significant differences in the palaeogeographical and tectonic development of the Ediacaran rocks between the Małopolska Block and the East-European Craton show that the position they presently occupy relative to each other is not representative of Neoproterozoic times (Nawrocki & Poprawa, 2006; Poprawa, 2006a).

The development of Cambrian deposits in the East-European Craton, the Łysogóry–Radom Block, the north-eastern part of the Małopolska Block (Poprawa, 2006a) and in the Rava Rus'ka and Kokhanivka zones is associated with the post-rift thermal subsidence.

Stratigraphical (?erosional) gaps observed in the Middle and Upper Cambrian sections in the Lublin–Podlasie slope of the East-European Craton and in the Kielce Fold Belt (Małopolska Block) as well as compressional fold structures found in the Lower Cambrian and lower Middle Cambrian deposits of the Kielce Fold Belt formed as a result of tectonic movements (so-called Sandomierz tectonic phase), probably caused by an oblique collision of the Małopolska Block and the East-European Craton during the period spanning the late Middle to Late Cambrian (maybe also the Early Ordovician) (Nawrocki & Poprawa, 2006; Poprawa, 2006a). The likely results of this collision were also flexural bending of the Earth's crust in the Łysogóry–Radom Block and intense tectonic subsidence during the Middle-Late Cambrian and Early Ordovician (Early Tremadoc) deposition (Poprawa, 2006a).

Tectonic constraints on the Middle Ordovician to Late Silurian/Early Devonian deposition in this part of the TESZ (Figs 3, 4) can be associated with the then-forming collision zone along the south-western margin of Baltica, referred to as the "North-German-Polish zone of the Baltica-Avalonia collision" (Poprawa, 2006b).

The Ordovician–Silurian deposits of this area show the characteristics of foredeep basins developing as a result of flexural bending of lithospheric plates (Narkiewicz, 2002; Poprawa, 2006b). It particularly refers to the Ordovician–Silurian deposits occurring on the slope of the East-European Craton: in the Łysogóry–Radom Block and Rava Rus'ka Zone. A characteristic feature of the Silurian deposits is a clear increase in tectonic subsidence and deposition rates during the Late Silurian (Ludlow–Pridoli) and Early Devonian (Lochkovian). In the Małopolska Block, there are no Upper Silurian (Pridoli) and Lower Devonian (Lochkovian) rocks. This suggests that the block occupied a different palaeogeographic position at that time in relation to the East-European Craton: to the Łysogóry–Radom Block and Rava Rus'ka Zone. Therefore, its post-Silurian dextral movement relative to the East-European Craton is inferred (Lewandowski, 1993; Dadlez *et al.*, 1994; Narkiewicz, 2002; Poprawa, 2006b).

The Devonian–Carboniferous carbonate and clastic rocks of the Variscan structural complex occur in the western part of the Małopolska Block only (Fig. 2). The position of the Małopolska Block within the Variscan foreland area suggests that the Devonian–Carboniferous deposition occurred under the influence of a stress field that was similar to that observed in the Variscan externides, *i.e.* in the Rhenohercynian Zone and Moravo-Silesian fold-and-thrust belt (Narkiewicz, 2007). The Middle-Upper Devonian and Lower Carboniferous shallow-marine carbonate platform deposits developed in an extensional regime, while the deposition of the Culm siliciclastic rocks (Late Visean–Early Namurian A) occurred under orogenic compression. In the Late Namurian A, the Małopolska Block was uplifted as a result of orogenic stresses.

During post-Carboniferous times, Precambrian and Palaeozoic deposits of the basement of the Outer Carpathians and Carpathian Foredeep were subject in this area to erosional processes and restructuring during Alpine orogenic movements (Golonka *et al.*, 2000, 2006; Oszczypko *et al.*, 2006; Kuśmierek, 2010).

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