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More evidence on Neoproterozoic terranes in Southern Poland and southeastern Romania

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New geological, geochemical and U-Pb SHRIMP zircon age data brought more information about basement units in subsurface of Southern Poland and SE Romania, which allows to revise and refine some earlier models in the framework of the break-up of the Rodinia/Pannotia supercontinent. In the Brno Block, Moravia, and in the Upper Silesia Block, three different terranes formed the composite Brunovistulia Terrane. The Thaya Terrane (low $\varepsilon\mathrm{Nd}_{(T)}$) of Gondwana (Amazonia) descent collided obliquely at 640–620 Ma with the Slavkov Terrane (moderate $\varepsilon\mathrm{Nd}_{(T)}$) composed of amphibolite facies metasediments and arc-related, mostly unfoliated granitoids which intruded at 580–560 Ma. At that time, back-arc rifting separated the couple Thaya–Slavkov (inherited zircons: 1.01–1.2, 1.4–1.5, 1.65–1.8 Ga) that drifted away from Gondwana until collision around 560–550 Ma with the Rzeszotary Terrane, the Palaeoproterozoic (2.7–2.0 Ga) crustal sliver derived from Amazonia or West Africa. At least these three units composed Brunovistulia, which occurred at low latitudes in proximity to Baltica as shown by palaeomagnetic and palaeobiogeographic data. Then Brunovistulia was accreted to the thinned passive margin of Baltica around its Małopolska promontory/proximal terrane. A complex foreland flysch basin developed in front of the Slavkov–Rzeszotary suture and across the Rzeszotary–Baltica/Małopolska border. The further from the suture the less amount of the 640–550 Ma detrital zircons extracted from the Thaya–Slavkov hinterland and the smaller $\varepsilon\mathrm{Nd}_{(T)}$ values. In West Małopolska, the flysch contains mainly Neoproterozoic zircons (720–550 Ma), whereas in East Małopolska 1.8–2.1 Ga and 2.5 Ga zircons dominate, which resembles nearby Baltica. The basin infill was multiphase folded and sheared; in Upper Silesia prior to deposition of the pre-Holmia Cambrian overstep. In Małopolska, the folded flysch series formed a large-scale antiformal stack with thermal anticline in its core marked by low-grade metamorphic overprint. In Central Dobrogea, Moesia, Ediacaran flysch also contains mainly 700–575 Ma detrital zircons which link the source area, likely in South Dobrogea with *ca*. 560 Ma granitoids, rather close with Gondwana. However, fauna in Lower Cambrian overstep strata shows Baltican affinity. Such features resemble Upper Silesia, thus Brunovistulia might have extended beneath the Carpathians down to Moesia. The other part of South Dobrogea with Palaeoproterozoic ironstones resembles Ukrainian banded iron formation. If true, the Baltican sliver would be incorporated in Moesia. Such a possibility concurs with the provenance data from Ediacaran flysch of Central Dobrogea, which points to uplifted continental block as a source of detrital material. Our study supports an earlier proposition that at the end of the Neoproterozoic a group of small terranes that included Brunovistulia, Moesia and Małopolska formed the Teisseyre-Tornquist Terrane Assemblage (TTA). In our model, a characteristic feature of the TTA was a mixture of crustal elements that were derived from both Gondwana and Baltica, which gave rise to mutual collisions of the elements prior to and concurrent with the docking to Baltica in latest Ediacaran times. The presence of extensive younger covers and complex Phanerozoic evolution of individual members of the TTA impede the recognition of their Neoproterozoic history.

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INTRODUCTION

Recent studies and reinterpretations of tectonic units which intervene between the East European Craton (EEC = Baltica) and the Variscan orogen stress similarities shown by the regions spread between Southern Poland and northwestern Turkey, and possibly even further east (Pharaoh *et al*., 1997; Unrug *et al*., 1999; Kalvoda *et al*., 2002, 2003; Nawrocki *et al*., 2004*a*, *b*; Nawrocki and Poprawa, 2006). Correlations are however hampered as most of these regions are concealed beneath Permo-Mesozoic strata and tectonically overlain by the Carpathian Orogen. Thus provenence and palaeogeography of these units as well as time and mechanisms of their docking to

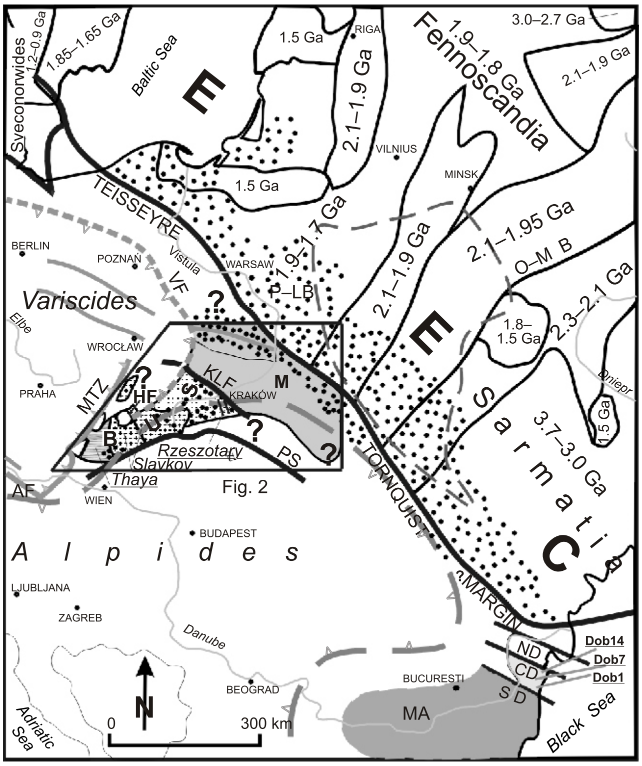

Fig. 1. Tectonic sketch showing the location of the Upper Silesia, Małopolska and Central Dobrogea blocks relative to the Teisseyre-Tornquist margin of the East European Craton (Baltica) and orogenic belts in Central Europe. Main lithotectonic units and their ages in Fennoscandian and Sarmatian parts of Baltica after Bogdanova *et al.* (2001). In Dobrogea, sampling sites for zircons are indicated with sample names

Ornamented and gray shaded areas outside the EEC — basement units with records of Neoproterozoic orogenic events; dots — Cambrian deposits: platform cover in the EEC, overstep in Brunovistulia and Małopolska; dashed outline — extent of the Volhyn basalts and associated pyroclastic rocks (Białowolska *et al.*, 2002); AF — Alpine Front; B — Brno Block; BUS — Brunovistulia; CD — Central Dobrogea; HF — Haná Fault; KLF — Kraków–Lubliniec Fault Zone; M — Małopolska Block; MA — Moesia; MTZ — Moldanubian Thrust Zone; ND — North Dobrogea; O–MB — Osnitsk–Mikashevichi Belt; P–LB — Podlasie–Lublin Basin; PS — Pieniny (Klippen Belt) Suture; SD — South Dobrogea; US — Upper Silesia Block; VF — Variscan Front; inset frame expanded to Figure 2

Baltica are still debated (Pożaryski and Kotański, 1979; Dudek, 1980; Brochwicz-Lewiński *et al.*, 1986; Pożaryski, 1991; Lewandowski, 1993, 1994; Haydutov and Yanev, 1995; Żelaźniewicz, 1998; Unrug *et al.*, 1999; Belka *et al.*, 2000; Nawrocki *et al.*, 2004*a*, *b*; Murphy *et al.*, 2000, 2004; Nance *et al.*, 2008). They are supposed to originate as crustal blocks detached from Gondwana and Baltica, however details of their derivation are more a matter of speculations rather than established facts. Isotopic ages (review in Finger *et al.*, 2000*a*, *b*; Dudek and Melkova, 1975; Dudek, 1995; Friedl *et al.*, 2000) and microfossil data (Kräutner *et al.*, 1988; Buła *et al.*, 1997; Seghedi, 1998; Moryc and Jachowicz, 2000; Jachowicz *et al.*, 2002) indicate that in Southern Poland (Upper Silesia, Małopolska), the Eastern Czech Republic (Brno region in South Moravia), and southeastern Romania (Central Dobrogea), Neoproterozoic rocks are extensively present (Fig. 1). They all seem to have been once involved in the Avalonian–Cadomian belt (*sensu* Nance and Murphy, 1994; Murphy *et al.*, 2004). In this study, the focus is on new data on Precambrian siliciclastic series and magmatic rocks from boreholes in Southern Poland, completed with the first SHRIMP II U-Pb ages for detrital and igneous zircons from Upper Silesia, Małopolska and Dobrogea. Combined with data on the provenance of detrital material and the ages of the youngest tectonothermal event in the source region(s), they allow for further refinement of Precambrian evolution of these regions and provide some new material for the ongoing discussions of late Neoproterozoic palaeogeography and geodynamics.

GEOLOGICAL DATA

There are numerous reports on late Neoproterozoic (Vendian = Ediacaran) sedimentary, magmatic, metamorphic and deformational events from Moravia (NE Czech Republic), Upper Silesia and Małopolska (S Poland), and Dobrogea (E Romania; Karnkowski *et al.*, 1977; Kowalski, 1983; Kräutner *et al.*, 1988; Kowalczewski, 1990; Dudek, 1995; Dallmeyer and Urban, 1998; Finger *et al.*, 2000*a*, *b*; Mikuláš *et al.*, 2008). Southern Poland and Dobrogea lie close to the Teisseyre-Tornquist (SW) margin of Baltica (Fig. 1). In this study, Southern Poland refers to a triangular region between the Variscan Bohemian Massif to the west, the Precambrian East European Craton to the east and the Alpine suture (Pieniny Klippen Belt) to the south (Figs. 1 and 2). It consists of the Upper Silesia Block in its western part and the Małopolska Block in its eastern part; the two units are separated by the NW-trending Kraków–Lubliniec Fault Zone (Buła *et al.*, 1997; Żaba, 1999). The Neoproterozoic and older basement of both blocks is concealed by Palaeozoic through Cenozoic cover, thus only known from unevenly distributed boreholes mainly drilled by the oil-industry (Fig. 2). Głowacki and Karnkowski (1963), Karnkowski (1977) and Kräutner *et al.* (1988) observed that the Precambrian (meta)sedimentary succession with Vendian acritarchs (Moryc and Jachowicz, 2000; Jachowicz *et al.*, 2002) in Małopolska is lithologically similar to the Histria Fm., Central Dobrogea (Fig. 1), which is well exposed, documented and interpreted as Vendian flysch (Seghedi and Oaie, 1994, 1999; Oaie, 1998, 1999) deposited in a Cadomian foreland basin (Seghedi *et al.*, 2000*a*, *b*, 2001; Seghedi and Oaie, 2004).

THE UPPER SILESIA BLOCK

The Upper Silesia Block (US), referred to as Vistulicum by Stille (1951), contacts across the Haná Fault Zone with the Brno Block (Fig. 2) further to the south-west and the two form Brunovistulicum (Dudek, 1980) which in the literature is also referred to as the Brunovistulian Block/Terrane, Brunovistulia, or Brunnia. The Brno Block, partly outcropped as the Brno Massif in Moravia, Czech Republic, is mainly composed of granodiorites to tonalites, quartz diorites and metabasites; the protolith of the latter was dated at 725 ±15 Ma (Pb-Pb single zircon; Finger *et al.*, 2000*a*, *b*). The metasediments, which are more abundant towards Upper Silesia, are ~640 to 610 Ma old and were intruded by unfoliated, post-tectonic, I-type (VAG)

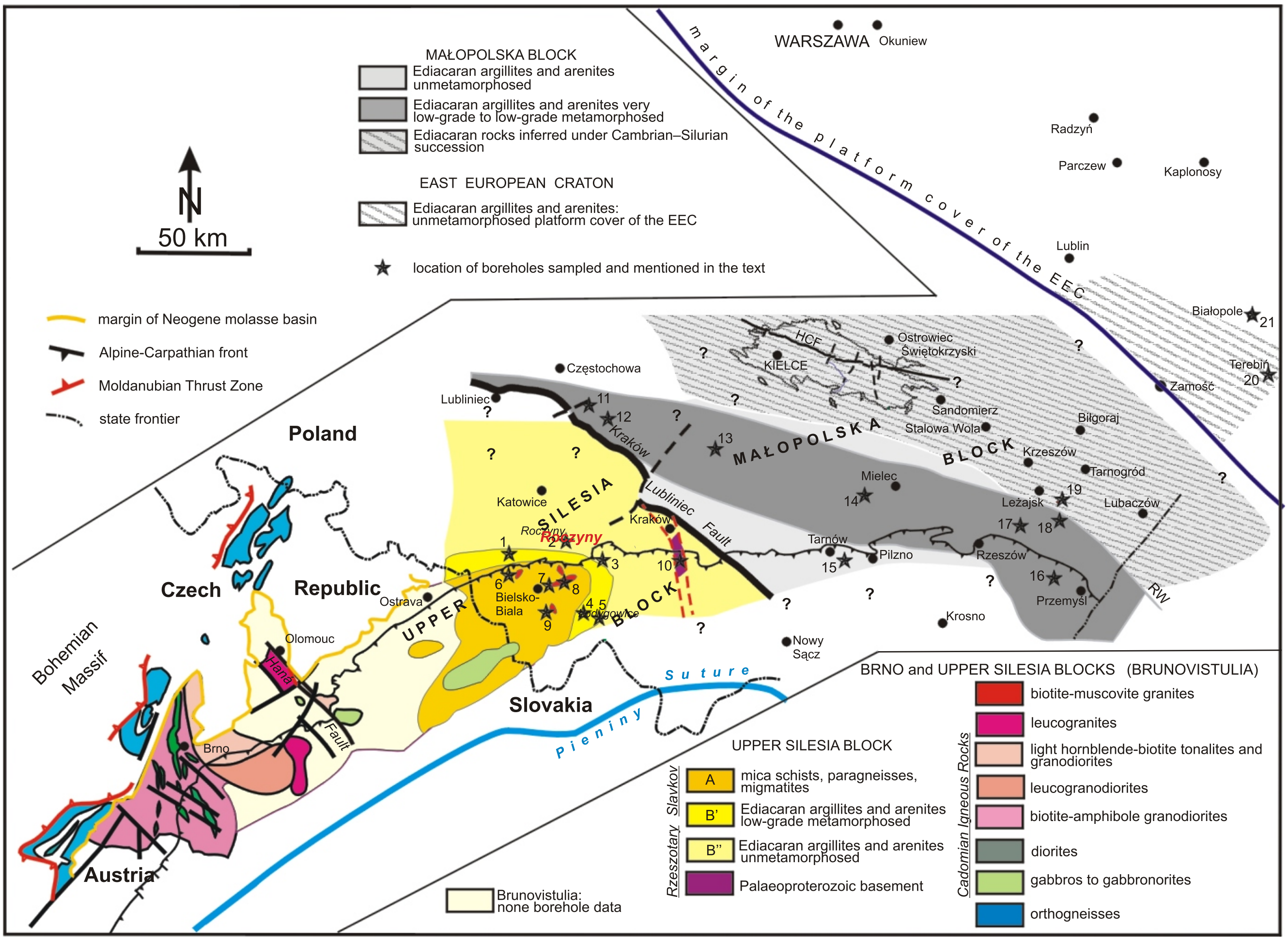

Fig. 2. Geological sketch of Precambrian basement rocks in Southern Poland and northeastern Czech Republic

Based on Dudek (1995), Finger *et al*. (2000*a*), Buła and Żaba (2005), Buła and Habryn (2008): modified; margin of the East European Platform after Znosko (1998); dotted contour — outline of outcrops of Palaeozoic rocks of the Holy Cross Mountains; HCF — Holy Cross Mountains Fault; RW — Ryszkowa Wola Fault. Boreholes: 1 — Goczałkowice, 2 — Piotrowice, 3 — Wysoka, 4 — Ślemień, 5 — Lachowice, 6 — Roztropice (Rozt-2), 7 — Kęty (Kety-8), 8 — Roczyny (Rocz-3), 9 — Łodygowice (Lody-1), 10 — Rzeszotary, 11 — Żarki Z-143, 12 — BN 58, 13 — Kostki Małe, 14 — Zgórsko, 15 — Zalasowa, 16 — Tuligłowy, 17 — Grzęska, 18 — Palikówka, 19 — Chałupki Dębniańskie, 20 — Terebiń, 21 — Białopole (Bial-3)

granitoids, gabbros and diorites at 596–550 Ma (for a review see Dudek and Melková, 1975; Dudek, 1980; Finger *et al.*, 1989, 2000*a*, *b*). In Poland, Neoproterozoic rocks of the Upper Silesia Block are known only from boreholes (Fig. 2).

The southwestern part of the Upper Silesia Block is composed of mica schists, paragneisses and migmatites (Heflik and Konior, 1974; Ślączka, 1976; Moryc and Heflik, 1998) dated (K-Ar on biotites; no isotopic control) at *ca*. 700–400 Ma (Borucki and Sałdan, 1965). The metamorphic grade of this metasedimentary-volcanogenic series ranges from middle to upper amphibolite facies. These rocks were intruded by several granitoid, diorite and gabbro bodies of various dimensions (Fig. 2). Our study shows that the granitoids are peraluminous, low-K to medium-K, calcic granodiorite to tonalite, which plot in the VAG or IAG/CAG fields, in the syn- to post-collisional setting (Table 1, Fig. 3). They display features of S/I-type (A/CNK ratio >1.1, SiO_2 >65%, but high-Na) granitoids which could have been derived from a lower(?) crustal source (low Th and U, K/Rb = 240–580) in a supra-subduction setting (negative Nb and Ti anomalies, positive Sr anomaly) of arc magmatism. With one exception, the Upper Silesian granitoids are unfoliated, which testifies to their inferred status of mainly late/post-tectonic intrusions.

In the US, further to the north and east, only low-grade metamorphosed to unmetamorphosed sediments were found in the drill cores and thus we distinguish two different lithologic/lithotectonic(?) domains referred in this paper as A and B, respectively (Fig. 2). The A (SW) domain is composed of the mentioned igneous and metamorphic rocks, whereas the B (NE) domain is composed of (meta)mudstones, sandstones and occasional conglomerates. The latter, weakly metamorphosed (Cebulak and Kotas, 1982) and unmetamorphosed (Ślączka, 1976, 1982), contain a variety of pebbles, including some of crystalline rocks akin to those of the former unit and thus likely derived from it (Fig. 4). This succession is assigned mainly or wholly to the Neoproterozoic because of the presence of a discordant, extensive cover of Lower Cambrian Holmia and sub-Holmia deposits (Buła and Jachowicz, 1996; Buła *et al.*, 1997; Moczydłowska, 1997; Buła, 2000). Earlier interpretations which assume its younger age (Kowalczewski, 1990) are unsup-

Table 1

Geochemistry of Neoproterozoic granitoids from the Upper Silesia Block

Sample	Lody-1	Rozt-2	Kety-8	Rocz-3
Depth	1777 m	2120.5 m	1456 m	1802 m
Rock	Granodiorite	Granodiorite	Granodiorite	Granodiorite
SiO_2	71.52	65.38	70.21	69.62
Al_2O_3	16.17	19.80	17.15	16.66
Fe_2O_3	1.79	1.51	0.98	0.73
MnO	0.04	0.040	0.020	0.022
MgO	0.73	1.16	0.89	0.46
CaO	2.22	3.74	2.57	2.43
Na_2O	4.94	6.02	6.23	6.08
K_2O	1.54	1.44	0.78	1.19
TiO_2	0.212	0.242	0.166	0.071
P_2O_5	0.09	0.11	0.08	0.08
LOI	0.91	0.93	1.10	1.17
Total	100.17	100.38	100.19	98.50
Ba	406	207	121	124
Co	85	52	79	35
Cr	–5	–20	–20	5
Cs	3	3.0	0.9	3.0
Ga	17	17	15	16
Hf	3	2.8	1.9	2.0
Nb	4	2.4	1.7	7.0
Pb	4	–5	–5	–5.0
Rb	52	44	11	24
Sc	2.4	3	3	1
Sr	437	712	503	314
Ta	0	0.15	0.13	0.10
Th	4	4.45	0.53	1.18
U	1	1.43	0.40	0.36
V	11	20	13	7
Zr	118	124	74	55
La	14	8.93	2.85	4.34
Ce	27	21.3	6.15	9.28
Pr	3	2.25	0.65	1.12
Nd	11	8.92	2.57	4.66
Sm	2	1.75	0.63	0.98
Eu	1	0.634	0.365	0.356
Gd	2	1.67	0.68	0.74
Tb	0	0.19	0.10	0.10
Dy	1	0.95	0.51	0.43
Ho	0	0.17	0.09	0.07
Er	1	0.48	0.27	0.21
Tm	0	0.063	0.036	0.030
Yb	1	0.46	0.24	0.20
Lu	0	0.077	0.037	0.028

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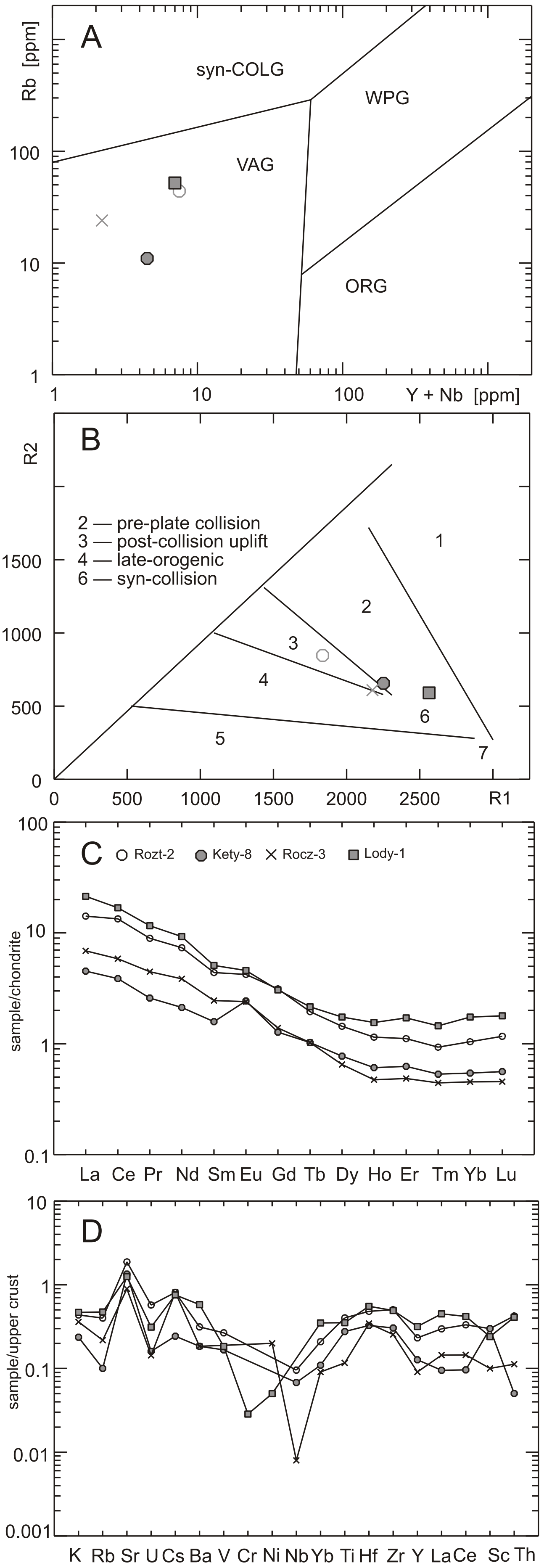

Fig. 3. Geochemistry of Neoproterozoic granitoids in the Upper Silesia Block

Geotectonic environment: **A** — Rb/Y+Nb plot (Pearce *et al.*, 1984), **B** — R1–R2 multicationic plot (Batchelor and Bowden, 1985); trace elements: **C** — normalized to chondrites (Nakamura, 1974), **D** — normalized to upper crust (Taylor and McLennan, 1985); legend of plot symbols as in C

Fig. 4. Conglomerate from basal part of Ediacaran flysch succession in northern domain of the Upper Silesia Block, borehole Goczałkowice IG 1, depth of 3270 m

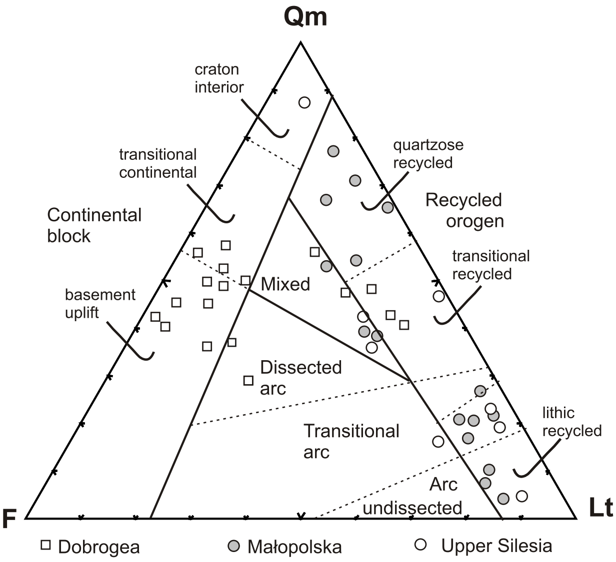

Fig. 5. Qm-F-Lt diagram (Dickinson *et al.*, 1983) for framework modes of sandstones and greywackes from Ediacaran flysch deposits in the discussed regions

ported. Although direct evidence is still scarce, the succession is (wholly?) underlain by a high-grade basement similar to that elevated and sampled in the Rzeszotary horst (Fig. 2). The protolith age of the metamorphosed (B') to unmetamorphosed (B") B domain sediments is bracketed by the granitoid intrusions of the domain A and the Lower Cambrian cover of alluvial/delta fans and shallow-marine deposits (Pacześna, 2005) with trilobite fauna of Baltican affinity at the genus level (Orłowski, 1975; Żylińska, 2002; Nawrocki *et al.*, 2004*b*; Nawrocki *et al.*, 2007).

Systematic analysis of the (meta)sedimentary rocks in the northeastern unit has been hampered by poor coring. A few petrographic descriptions have been published (Moryc and Heflik, 1998). Our examination of the drillcores that are still available shows that the more coarse-grained facies, which are represented by relatively shallow-water proximal conglomerates and sandstones occur closer to the domain A whereas more deep-water, more distal and more fine-grained sandstone-to-mudstone facies with turbiditic features occur further away (Fig. 2). The mode of distribution and greywacke composition of the sandstones, poor sorting, well-defined bases of the individual beds/layers, and evidence of graded and rythmical bedding are all suggestive of a flysch-type origin of the examined succession. The framework components of the greywacke sandstones on the Qm-F-Lt diagram (Dickinson and Suczek, 1979; Dickinson *et al.*, 1983) and similar diagrams plot mostly in the recycled orogen field (Fig. 5).

In the US, the sedimentary rocks occurring in a 15–20 km wide belt (B') next to the crystalline core (Fig. 2) underwent low-grade metamorphism, intense folding and zonal shearing parallel to the axial planes of asymmetric F_1 folds in bedding, accompanied by a steeply to moderately dipping (70–40°) cleavage (Fig. 6A, B). Its intersection with the bedding produces a subhorizontal intersection lineation. Up to three sets of thin quartz veinlets are observed. The oldest set is oblique to the bedding (at an angle of 40–70°) and involved in the crenulation folds F_2, while the other set, closely locally spaced, is parallel to the crenulation cleavage S_1 (Fig. 6B, C). These S_2 parallel quartz veins are often accompanied by concentrations of opaque constituents, which testifies to a pressure-solution component and active metamorphic fluids. Low-grade, greenschist facies metamorphism, locally up to the biotite zone, was pre- and syntectonic with respect to the F_2 deformation. Greenish-brown biotite neoblasts were associated with the pre-fold quartz set and grew parallel to the S_2 planes together with chlorite (Fig. 7). However, the metamorphic recrystallization was mainly limited to mimetic transformations of layer-silicates to new blasts of micas, while detrital quartz and feldspar grains were left intact rather and along with some lithic clasts only display a more or less advanced sericitization. The sub-Holmia Cambrian cover provides an upper age limit for the F_2 event which must have been older and assignable to a Neoproterozoic orogen. In the metagraywackes, superimposed open folds F_3 occur. Their shallowly dipping axial planes are often parallelled by the third set of quartz veins (Fig. 6B). This is an evidence of the repeated influx of fluids, but timing of the younger folding is uncertain. A subvertical maximum load is required for such folding. This might have been achieved in a late-orogenic collapse regime which terminated the Neoproterozoic orogeny. The third set of quartz veinlets would be then syndeformational, or developed still later, under the burden of the overlying Palaeozoic cover in which quartz veining is a common feature.

Generally in the domain B (B' + B"), Neoproterozoic metamorphism accompanying the F_1–F_2 deformation faded away further from the crystalline domain A, and at a distance of 10–20 km the flysch-type sediments remained unmetamorphosed (Fig. 2). This observation indicates a distinct polarization typical for an orogenic belt, with deformation and metamorphism dying outwards in a manner resembling fold-and-thrust belt, characteristic for orogenic forelands. Thus the A

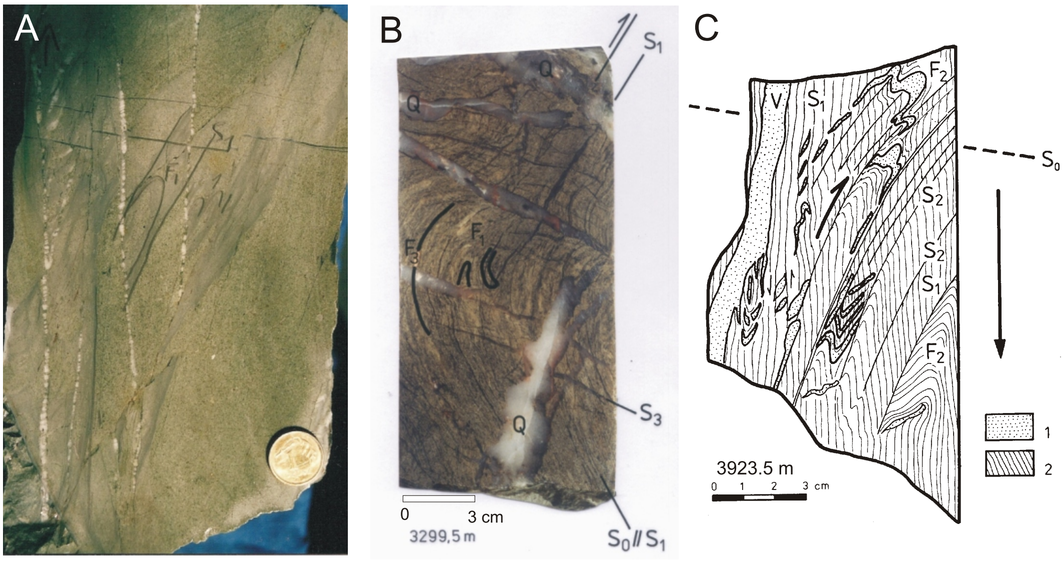

Fig. 6. S_1 crenulation cleavage and younger structures in low-grade metagreywackes in Upper Silesia

Upper Silesia: **A** — tight to isoclinal folds in bedding with S_1 axial planar cleavage cut by later quartz veinlets, borehole Goczałkowice IG 1, depth 3187 m; **B** — multiphase folding: S_0 — bedding, S_1 — axial planar foliation to F_1 folds, F_3 — open folds with shallowly dipping axial planes paralleled by quartz veins (Q), Ślemień IG 1, depth 3299.5 m; **C** — sketch from a photograph to show relation of structures, F_2 folds with S_2 axial planar cleavage, note shearing along S_1 and S_2 planes, 1— quartz, 2 — metagreywacke, borehole Lachowice 3a, depth of 3923.5 m

and B domains recognized in the US are interpreted as fragments of the inner (hinterland) and outer (foreland) parts of a Neoproterozoic orogen, respectively.

A deeper basement of the orogenic foreland in the US is represented by the Rzeszotary horst S of Kraków (Fig. 2) which exposed high-grade migmatized orthoamphibolites along with minor metasediments (I. Nowak *et al*., unpubl. data in prep.) at the Cambrian and Jurassic palaeosurfaces. Single grain U-Pb conventional dating of the abraded and non-abraded zircons from the amphibolites of the horst yielded the upper intercept age of 2732 +23/–21Ma (Bylina *et al.*, 2000) interpreted as a protolith age, whereas the zircons from neosomes analyzed with SHRIMP pointed to metamorphism and migmatization at ~2.0 Ga, with no younger overprint (Żelaźniewicz *et al*., 2001, unpubl. data in prep.; Jachowicz *et al*., 2002).

THE MAŁOPOLSKA BLOCK

The US and the Małopolska Block (MB) have a pronounced crustal boundary known as the Kraków–Lubliniec Fault Zone (Figs. 1 and 2). Seismic refraction data shows that the Vp wave velocity structure of the crust in Małopolska is practically the same like in the regions further NE, with the crustal layers similar to those of the EEC but markedly thinned south-westward as a passive margin (Malinowski *et al*., 2005). This suggests that they all belong to a single crustal block which has formed a promontory of the Baltica continent (= East European Craton) within such margin. Some differences in lithology and stratigraphy are restricted only to the 1–5 km thick uppermost layer of the crust, which allows the distinction of such upper crustal units as the Holy Cross Mts. Fold Belt, or the Radom–Kraśnik Horst. In

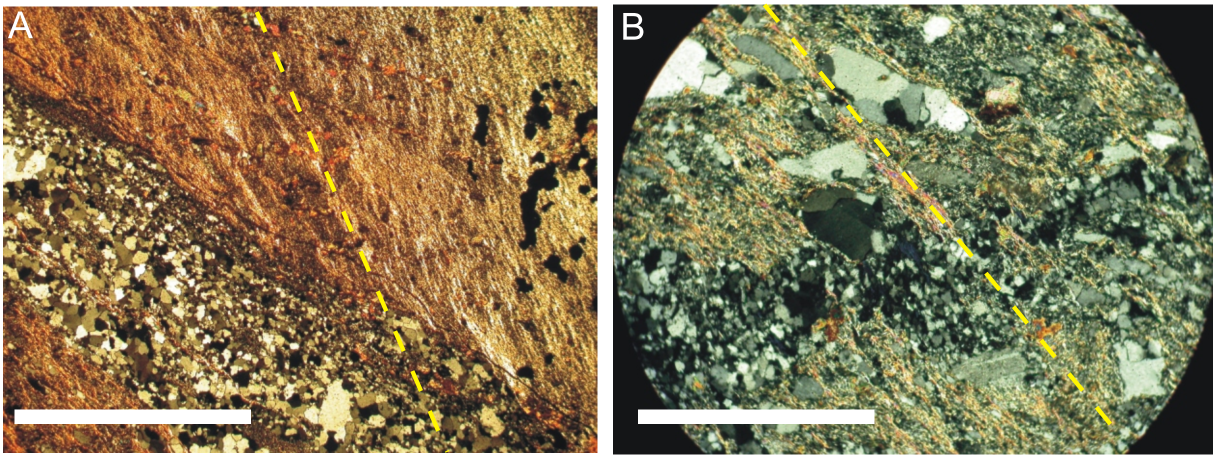

Fig. 7. Microphotographs of laminated turbidites with S_1 crenulation cleavage (yellow dashes) well developed in mica-rich layers, Upper Silesia

A — borehole Lachowice 7, depth of 3109 m, scale bar 1.5 mm long; **B** — borehole Ślemień, depth of 3300 m, scale bar 2.0 mm long view of this, the NE boundary of the MB taken as an independent crustal block is difficult to locate. At the Permo-Mesozoic surface, it can be paralleled with the Kazimierz–Ursynów Fault, which defines the SW border of the Mazovia–Lublin Graben, and identified with the marked down-thrown step in the EEC basement and its platform cover (Fig. 2). Such an option, consistent with the seismic refraction data (Malinowski *et al*., 2005), has been adopted in this paper and the MB includes herein the Kielce, Łysogóry and Radom–Kraśnik units which share the same type of Precambrian basement. Accordingly, the MB is considered a promonontory of the EEC/Baltica. Whether deeper segments of the Kazimierz–Ursynów Fault can actually represent a Neoproterozoic or younger terrane boundary remains a guess with no material data behind. Nevertheless, strike-slip displacements on this fault are well feasible at those times and thus the MB may also be considered a proximal terrane.

A lithostratigraphic column for the pre-Ordovician basement in western Małopolska is still uncertain (reviews in Kowalski, 1983; Kowalczewski, 1990; Buła, 2000). Acritarchs retrieved recently in 10 boreholes from the unmetamorphosed mudstones in the SW Małopolska Block (Moryc and Jachowicz, 2000; Jachowicz *et al*., 2002) document Ediacaran age for the succession, consistent with the U-Pb age of 549 ±3 Ma yielded by zircons from a tuff layer of intermediate composition (Compston *et al.*, 1995) drilled in one of the boreholes (Książ Wielki), and consistent with the earlier assignments of the top of the pre-Ordovician rocks in SW Małopolska (Fig. 2) to the Vendian (Jurkiewicz, 1975).

The Neoproterozoic succession of SW Małopolska, the topmost portion of which was penetrated by boreholes, is mainly represented by siltstones and mudstones, with subordinate sandstone and less frequent conglomerate interbeds. The rhythmic sedimentation of sandy to silty material, poorly sorted sandstone and conglomerate beds with planar bases and gradual, indistinct tops, the multiple fractional grading within coarse-grained beds and convolute bedding in fine-grained ones, and common lithic clasts are all indicative of turbiditic deposits which altogether seem to form an upward-fining succession. Turbidity currents of various degrees of concentration and cohesive flows carried material derived from a crystalline source or sources composed of granitoids, gabbros, and low-grade metamorphosed acid, intermediate and basic volcanogenic rocks, and from redeposited sediments, represented by abundant arenite pebbles accompanied by intraclasts of greywackes and tuffites; this is consistent with earlier observations of Moryc and Łydka (2000). Regional considerations point to a southerly location for an unidentified source area, possibly concealed under the Carpathians. All these features resemble the Neoproterozoic (meta)sediments in Upper Silesia, thus the Małopolska succession is also taken as syntectonic flysch-type sediments deposited in a foreland basin. This foreland was consituted by the thinned Baltica margin in which Małopolska presumably formed a distinct promontory.

The siliciclastic succession in Małopolska was partly affected by very low to low-grade metamorphism which, according to our study, gave rise to the WNW-trending, *ca*. 50 km wide belt flanked on either side by unmetamorphosed rocks (Fig. 2) with Vendian acritarchs (Moryc and Jachowicz, 2000; Jachowicz *et al*., 2002). Within the belt, up to the chlorite grade conditions were attained, with a maximum temperature of *ca*. 300°C shown by illite crystallinity studies (IC <0.42) (Kowalska, 2001). Minor folds accompanied by subvertical to subhorizontal axial planar cleavage, often of pressure solution type, are also confined to the belt and cease outwards (Fig. 8). The belt appears as an important thermal and tectonic zone of contractional deformation, possibly with large-scale listric thrusting as suggested by small-scale structures found in the drillcores (Fig. 8B). Unfortunately, kinematics throughout the zone is uncertain because the drillcores were not oriented. The asymmetric folds and steep to subvertical crenulation and pressure solution cleavage resemble similar (F_1S_1– F_2/S_2) features in Upper Silesia. In the MB, the folded and sheared flysch succession was probably detached from the underlying Neoproterozoic basement and displaced by thrusting toward the EEC craton, however this supposition cannot be proved as none of the drillholes numerous in the region pierced the flysch sediments. K-Ar ages of detrital micas (Belka *et al*., 2000; Nawrocki *et al*., 2007) from Cambrian rocks of the Holy Cross Mts. suggest that the discussed foreland deformation occurred at latest Ediacaran times.

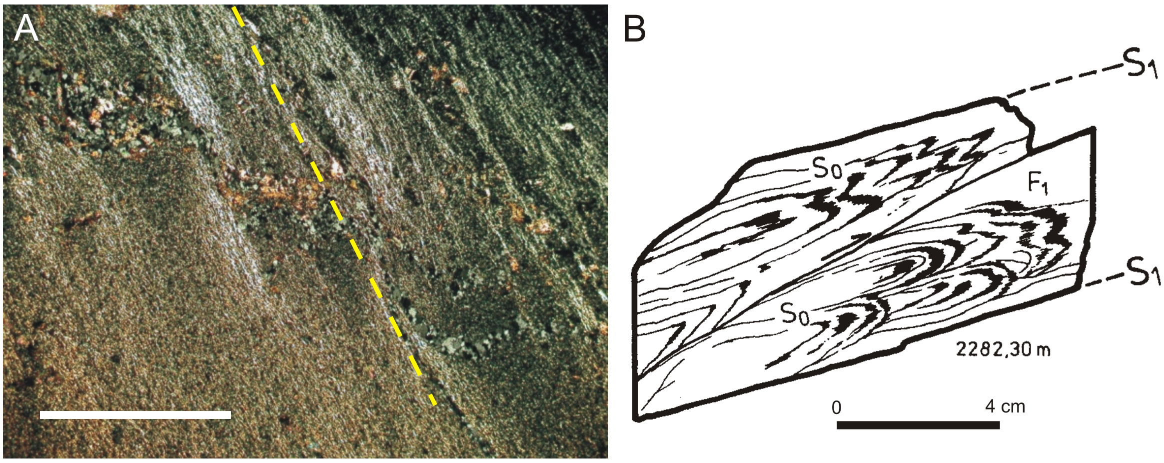

Fig. 8. Steep S_1 crenulation cleavage in very low-grade metamorphosed turbidite in Małopolska

A — bedding and metamorphic fabric seen as the axial planar foliation to small folds F_1, later rejuvenated in the normal regime, borehole Grzęska 1, depth of 1522 m, scale bar 1.5 mm long; **B** — sketch from photograph to show relation of structures, borehole Palikówka 6, depth of 2282.3 m; other explanations as in Figure 6

It is important for regional considerations that in the MB, the folded, low-grade metamorphosed and cleaved siliciclastic succession is overlain by patchily preserved overstep Ordovician (Arenigian) and Silurian deposits and concealed under the Carpathian accretionary wedge to the south (Kowalski, 1983; Kowalczewski, 1990; Buła, 2000). The presence of the lower (Holmia) Cambrian suggested by Pożaryski *et al.* (1981) and Kowalczewski (1990) has not been confirmed there (Buła, 2000; Buła and Żaba, 2005). A conglomerate-dominated series from south-westernmost Małopolska (Łapczyca Fm.) is not Cambrian but Late Silurian in age, occurring between the palaeontologically documented Ludlovian and the Lower Devonian (Buła *et al.*, 1997; Buła, 2000). In NE/E Małopolska, however, Cambrian rocks appear at the surface in the Holy Cross Mts. and they are known from subsurface in the Krzeszów–Lubaczów Zone to the SE but nowhere the Cambrian base has been observed. In the latter area, the low-grade metamorphosed (chlorite zone) Ediacaran rocks are in a tectonic contact with unmetamorphosed Lower Cambrian rocks along the SW border fault of the Ryszkowa Wola horst (Fig. 2; Buła and Habryn, 2008).

CENTRAL AND SOUTH DOBROGEA, ROMANIA

To the SE of Upper Silesia and Małopolska, Precambrian rocks are largely concealed under the Carpathians and appear in the Moesian Block, eastern Romania (Fig. 1). In Central Dobrogea (CD), close to the Black Sea coast, there is exposed a *ca*. 5000 m thick, greenish, turbiditic flysch sequence distinguished as the Histria Formation. Despite some very low-grade metamorphism, it contains relicts of an Ediacaran-type fauna, and palynologic evidence for its Vendian–Early Cambrian age (Seghedi and Oaie, 1994; Oaie, 1998). The Histria Fm. is subdivided into 3 members: lower and upper sandstone-dominated members of channelized midfan turbidites separated by a middle member of fine-grained, distal turbidites. In contrast to Małopolska with its likely fining upwards succession, an overall upward-coarsening facies association suggested a northward progradation of the southerly located source area of clastic material composed of igneous and metamorphic rocks including characteristic banded ironstones (Jipa, 1970; Seghedi and Oaie, 1999; Oaie, 1999). The Histria Fm. was deposited in a foreland basin that was floored by continental crust and formed in front of the thrust wedge preserved subsurface in South Dobrogea (Kräutner *et al.*, 1988; Seghedi *et al.*, 2000*a*, *b*). Then, it underwent very low-grade metamorphism and deformation around 570 Ma (K-Ar WR data; Seghedi *et al.*, 2001, 2005) which gave rise to N-vergent, upright to inclined folds with the slightly fanned subvertical axial planar slaty cleavage (Fig. 9) due to continued shortening and steady push from the south. To the west of the outcrop area, the Histria Fm. continues subsurface under a flat-lying platform of Ordovician and younger strata (Mirăuţă, 1969; Iordan, 1981). Although such features generally resemble Małopolska (Karnkowski, 1977), the direct linkage of the MB and CD (Kräutner *et al.*, 1988) cannot be tested because of the overlying Carpathians.

In Małopolska, the Vendian succession is underlain by unknown low-velocity rocks interpreted as metasediments of Neoproterozoic age, originally as rift and passive margin succession later included in the Trans-European Suture Zone (Malinowski *et al.*, 2005). In Central Dobrogea, the Histria Fm. probably overlies amphibolite facies metasediments and metatholeiites, locally exposed at the fault boundary with North Dobrogea (Fig. 1), with K-Ar mica ages of 696–643 Ma (Giuşcă *et al.*, 1967; Krautner *et al.*, 1988). The tholeiitic protoliths with arc signature must have been older. Magnetic anomalies which are produced by this basement may support such interpretation. However, the Proterozoic banded iron formation cannot be excluded as the cause of these anomalies.

In South Dobrogea (SD, Fig. 1), basement similar to that of CD contains the BIF rocks (the Palazu Mare Group) which are compared with the Krivoy Rog series of the adjacent East European Craton (Visarion *et al.*, 1979; Dimitriu, 2001). Together with underlying gneisses, the BIF rocks were thrust onto low-grade slates (Băltăgeşti Fm.) which represent the top of the flysch-type Ediacaran succession ("Greenschist Fm.") in Dobrogea (Kräutner *et al.*, 1988). Thrusting and contraction was

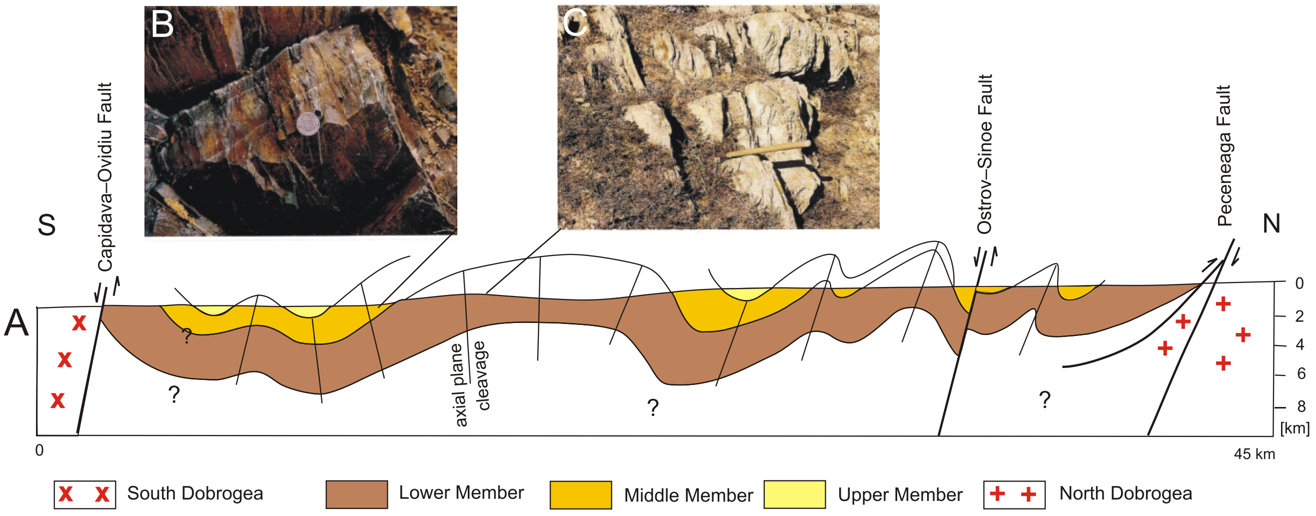

Fig. 9A — cross-section showing folds with fanned cleavage in metagreywackes of the Histria Fm. Central Dobrogea; B — field example of bedding/cleavage relation, Sibioara; C — field example of bedding/cleavage relation, west of Galibiari

likely coeval with deformation of the footwall slates. In turn, the Palazu Mare Group is unconformably overlain by the Cocoşu Group composed of Neoproterozoic mafic volcanogenic series passing upwards into clastic series (conglomerates, sandstones and siltstones) intensively folded and very gently metamorphosed at 547 Ma K-Ar, (Giuşcă *et al.*, 1967; Mirăuţă, 1969; Kräutner *et al.*, 1988). In the West Moesia basement, there are *ca*. 565 Ma granitoids that jointly with country paragneisses have been unconformably overlain by Cambrian cover with fauna of Baltican affinity (Seghedi *et al*., 2005).

PETROGRAPHIC AND GEOCHEMICAL DATA ON EDIACARAN (META)SEDIMENTARY ROCKS

To assess provenance major compositional framework of sandstones, greywackes and sandy mudstones was studied by standard point counting and results shown on the Dickinson-type plot (Dickinson and Suczek, 1979; Dickinson *et al*., 1983). This study was accompanied by heavy mineral analyses and completed with preliminary εNd data obtained via TIMS and ICP-MS analyses performed in ActLabs, Vancouver, Canada.

PROVENANCE

The clasts in turbiditic rocks from the three regions fall into three groups, with the proportions varying: (1) plutonic and volcanic rocks among which acid rocks overwhelm intermediate and mafic rocks (the latter being the least frequent, but it should be remembered that their preservation potential is lower); (2) metamorphic rocks (paragneisses, mica schists, quartzites and mylonites); and (3) diagenesed and low-grade metamorphosed siltstones, mudstones and sandstones. The heavy mineral assemblages vary in sampled sandstones, containing in varying proportions: zircon, garnet, micas, opaque minerals, apatite, titanite, rutile, tourmaline, and some amphibole and chlorite (J. Biernacka, unpubl. data). No systematic differences between the three regions occur, though mafic minerals are a bit more abundant in Małopolska and Dobrogea.

On the Fm-Q-Lt diagram for the unmetamorphosed and metamorphosed sandstones (framework grain modes) from the three regions (Fig. 5), the Vendian clastic rocks of Małopolska and Upper Silesia plot mostly in the recycled orogen field with minor mixed provenance. In contrast, the turbidites of the Histria Fm. in Central Dobrogea (somewhat richer in mafic constituents than those in Southern Poland) plot in the continental block provenance field and in the recycled orogen field. Characteristically, there is a very little overlap to a magmatic arc provenance in all three regions.

Our reconaissance analyses (Table 2) show that εNd values in Ediacaran sediments varies between the relatively highest for the Upper Silesia (–1.0), low for the E Małopolska (–8.5), and the lowest for East European Platform (–10.7). Sourcing of greywackes in Upper Silesia from rocks with much higher juvenile/mantle input and shorter crustal history than those in Małopolska and especially EEP is a corollary, although further confirmation of this notion by more systematic data is required.

GEOCHEMISTRY

Major element ratio diagrams show that siliciclastic rocks from the three regions plot relatively close to one another, forming elongate areas which distinctly overlap, and that the Małopolska samples are the most scattered (Table 3; Figs. 2 and 10). For these reason, the latter are subdivided into two more coherent groups of which one embraces samples from the western part of Małopolska and the other from its eastern part, further referred to as the western and eastern succession, respectively. For comparison, silicilastic rocks from Ediacaran platform cover of the East European Craton have also been taken into account and they all were compared to Neproterozoic rocks from Central Iberia (Fig. 10). Chemical classification of rocks from the US, MB and CD indicated that they are mostly immature (greywackes and pelitic greywackes (SiO_2/Al_2O_3–K_2O/Na_2O diagram from Wimmenauer, 1984) of acid to intermediate composition ((Hf/Yb) × 10 *vs.* La/Th and Ni *vs.* TiO_2 plots), with intermediate quartz contents. They display strongly variable K_2O/Na_2O ratios between 0.05 and 30.00, Al_2O_3/SiO_2 ratios between 0.12 and 0.33, and Fe_2O_3(= total Fe) + MgO contents between 2.18 to 12.58. The ternary Na_2O–K_2O–Fe_2O_3 + MgO diagram (Blatt *et al.*, 1980) classifies the studied rocks of the three regions as greywackes, lithic sandstones and arkoses.

On the SiO_2 *vs.* K_2O/Na_2O diagram, all samples from the CD, most samples from the MB and a half of samples from the US plot in the active continental margin field, while the remainder in the passive margin field. In Upper Silesia, the K/Rb ratios are uniformly around 210 which suggests that the metasediments derived from acid and intermediate magmatic precursors. In the MB and CD, the ratios are slightly higher (220–350), which may possibly be taken as an indication of some input from more mafic sources. The low La/Th and Eu/Eu* ratios indicate that the continental source was mostly composed of intermediate to acid (meta)igneous rocks with minor basic/ultrabasic lithologies. The relatively low $Al_2O_3/(CaO + Na_2O)$ ratios (Table 3) are indicative of synsedimentary vol-

Table 2

Sm-Nd isotopic composition of Ediacaran siliciclastic rocks from platform cover on the EEC (Białopole, 2870 m), East Małopolska (Kańczuga, 7501 m), Upper Silesia (Potrójna, 3480 m)

Sample	Sm [ppm]	Nd [ppm]	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	2s	Age [Ma]	$\varepsilon Nd_{(T)}$
Białopole	5.34	35.0	0.0923	0.511693	5	580	–10.7
Kańczuga	5.36	27.5	0.1177	0.511903	10	580	–8.5
Potrójna	3.79	18.71	0.1225	0.512306	8	580	–1.0

Geochemistry of Ediacaran siliciclastic rocks from exposures in Central

Exp./b-hole	D 1.8	D 1.10	D 3.2	D 5.1	D 6.1	D 6.2	D 8.1	D 14.3	D 15.1	Lach3	Lach4	Slem1
Depth [m]	0	0	0	0	0	0	0	0	0	3906	4015	3299
Rock	U.Mb./sd Sibioara	U.Mb./md Sibioara	L.Mb./sd Palazu	L.Mb./md Cheia	L.Mb./sd Cheia	L.Mb./md Cheia	M.Mb/md Raminicu	L.Mb./sd Istria	M.Mb./md Galibiori	US sand.	US grey.	US sand.
SiO_2 [%]	70.98	57.87	70.06	66.85	64.46	64.34	63.19	65.74	65.38	76.41	69.33	71.47
Al_2O_3	12.91	17.43	12.49	15.46	16.22	16.45	16.47	14.96	15.58	9.38	14.85	13.99
Fe_2O_3	4.38	7.99	5.02	5.32	6.05	6.40	7.16	5.59	6.88	3.72	4.53	2.99
MnO	0.079	0.124	0.072	0.116	0.109	0.126	0.141	0.116	0.105	0.049	0.09	0.064
MgO	1.81	3.21	1.87	1.51	2.14	2.07	2.06	1.43	2.05	1.00	1.66	1.00
CaO	0.89	0.82	1.16	1.48	0.49	0.98	0.75	2.08	0.27	1.58	2.13	1.65
Na_2O	4.31	3.04	2.76	3.42	1.63	3.80	3.04	3.59	2.54	1.68	4.20	4.12
K_2O	2.01	3.52	1.95	2.80	4.04	2.57	2.73	2.49	2.59	2.55	2.53	2.56
TiO_2	0.670	0.824	0.779	0.681	0.642	0.781	0.781	0.838	0.646	0.359	0.56	0.404
P_2O_5	0.11	0.16	0.12	0.40	0.09	0.14	0.12	0.12	0.09	0.10	0.12	0.11
LOI	1.63	3.34	2.72	2.22	3.11	2.62	2.85	2.62	2.91	3.32	2.5	1.61
Total	99.78	98.33	99.00	100.25	98.99	100.28	99.31	99.56	99.04	100.15	99.96	99.97
Ba [ppm]	522	462	392	637	790	551	496	551	407	366	559	510
Co	37	23	54	26	22	29	20	26	14	27	7.9	67
Cr	64	71	61	42	49	54	51	54	50	38	–	20
Cs	1.4	7.5	2.7	5.4	8.5	5.4	5.0	4.5	3.8	4.4	5.4	4.9
Ga	14	23	15	20	22	20	21	19	21	12	16.9	15
Hf	5.4	5.8	5.7	7.0	4.8	6.0	5.9	6.4	4.9	3.2	5.1	4.7
Nb	12.0	14.0	11.5	12.0	11.7	11.4	12.2	10.9	10.7	4.5	8.4	7.0
Pb	–	–	–	–	–	–	–	–	–	–	5.1	–
Rb	49	156	72	100	141	91	98	89	96	100	95.8	100
Sc	11	21	13	14	16	16	18	15	16	6	8	8
Sr	162	79	104	184	39	135	96	228	47	96	169.4	186
Ta	1.24	1.34	1.16	1.09	1.02	0.93	1.11	0.92	0.98	0.72	0.7	1.06
Th	9.20	10.9	8.66	9.80	9.57	9.55	10.1	9.06	9.00	7.20	9.9	11.9
U	1.40	2.51	1.61	2.65	2.27	2.36	2.17	2.23	1.88	1.74	2.9	3.82
V	80	126	86	68	88	93	99	104	91	51	62	44
Y	21	34	24	36	30	36	32	30	24	15	22.1	23
Zr	226	192	230	246	168	225	192	237	164	123	165.3	164
La	30.6	35.5	32.9	30.1	30.1	32.9	24.7	28.8	17.6	16.5	20.1	26.7
Ce	58.6	73.2	64.0	62.8	62.6	62.7	52.5	58.0	36.2	42.8	40.3	52.2
Pr	6.77	8.86	7.44	7.81	7.57	7.83	6.77	7.06	4.48	3.97	5.03	5.92
Nd	25.1	34.8	29.0	31.8	29.0	28.5	27.4	27.5	17.8	15.5	19.0	23.3
Sm	4.59	7.23	5.50	6.74	5.74	6.09	6.28	5.88	3.90	3.02	3.8	4.55
Eu	1.02	1.56	1.19	1.49	1.14	1.53	1.39	1.44	0.853	0.615	0.85	0.883
Gd	3.91	6.47	4.86	6.14	5.20	5.65	5.63	5.33	3.72	2.56	3.25	3.91
Tb	0.69	1.18	0.84	1.13	0.94	1.05	1.10	0.97	0.73	0.46	0.56	0.71
Dy	3.76	6.73	4.52	6.37	5.27	6.21	6.18	5.53	4.28	2.64	3.61	4.00
Ho	0.76	1.34	0.90	1.29	1.09	1.29	1.24	1.14	0.92	0.54	0.75	0.79
Er	2.41	4.28	2.89	4.28	3.51	3.85	3.99	3.56	3.05	1.75	1.99	2.62
Tm	0.345	0.632	0.403	0.635	0.509	0.563	0.596	0.531	0.450	0.258	0.41	0.403
Yb	2.25	3.98	2.51	4.01	3.33	3.50	3.74	3.38	2.97	1.68	2.10	2.54
Lu	0.359	0.624	0.394	0.624	0.505	0.510	0.563	0.508	0.486	0.263	0.37	0.404

EEC — East European Craton; MB — Małopolska Block; M.Mb. — Middle Member of the Histria Fm. (HF); L.Mb. — Lower Member of HF;

Table 3

Dobrogea and from boreholes in Upper Silesia and Małopolska

Stry2k	Piot1	Potr1	Rozt3	Zag1	Zalas1	Wary5	Kuź1	Kańc1	Herm1	Cha 1	Tul38	Zgór 2	Kury6	Tere5	Biał1
3321	3005	3490	2068	3921	4257	1929	7506	1656	5084	1346	2272	1991	946	8758	8847
US grey.	US silt.	US mud.	US sand.	MB mud.	MB mud.	MB mud.	MB mud.	MB sand.	MB mud.	MB sand.	MB sand.	MB mud.	MB mud.	EEC sand.	EEC mud.
70.86	70.95	59.46	73.73	67.25	74.73	62.76	63.04	82.77	61.63	64.39	82.70	53.50	70.34	84.05	74.66
15.42	14.48	18.39	13.22	18.29	11.53	17.83	17.60	8.29	20.06	20.09	8.75	28.79	16.13	8.57	14.70
3.97	4.46	9.13	4.42	5.04	3.53	8.28	9.09	3.37	8.16	4.58	1.80	5.76	6.17	3.28	4.51
0.06	0.06	0.11	0.06	0.06	0.045	0.11	0.23	0.05	0.13	0.017	0.014	0.10	0.02	0.03	0.02
1.88	1.74	4.74	1.91	2.16	1.32	3.05	3.49	0.96	2.58	0.83	0.38	2.59	1.66	0.76	1.17
1.63	1.03	0.51	0.39	0.38	0.38	0.59	0.91	0.45	0.57	0.10	0.31	0.33	0.13	0.60	0.25
0.24	4.11	0.17	4.03	0.63	3.21	2.75	2.30	3.04	2.21	0.40	4.14	1.48	0.49	0.61	0.92
5.35	2.44	6.17	1.60	5.58	2.62	3.63	2.40	0.56	3.72	3.85	0.36	6.32	4.11	1.53	2.88
0.46	0.63	1.05	0.52	0.51	0.559	0.88	0.83	0.36	0.84	0.989	0.597	0.99	0.92	0.54	0.85
0.12	0.09	0.27	0.12	0.08	0.11	0.13	0.12	0.15	0.09	0.03	0.21	0.14	0.04	0.02	0.04
6.2	1.8	5.8	2.0	4.5	1.71	4.7	4.3	2.1	4.0	5.17	1.02	5.8	5.1	2.2	4.0
99.85	99.98	99.86	99.81	99.86	99.73	99.82	99.82	99.84	99.98	100.47	100.27	99.82	99.81	99.83	99.86
469	495	272	294	628	503	310	666	74	574	611	57	1153	477	125	256
8.7	11.4	24.8	14.4	9.4	34	18.7	27.2	9.0	18.6	12	28	13.6	18.9	10.3	12.7
–	–	–	–	–	52	–	–	–	–	123	45	–	–	–	_
18.1	2.4	11.2	1.1	9.8	1.3	5.4	4.8	1.9	4.5	11.9	0.6	7.0	7.0	2.0	4.7
16.3	15.0	27.0	16.4	26.4	13	25.1	24.5	8.0	27.8	24	7	38.5	23.5	8.5	19.3
5.6	5.3	5.4	4.6	4.6	3.8	5.3	5.1	4.3	5.5	7.1	7.0	9.9	6.8	7.9	7.5
10.6	6.1	10.3	10.2	11.3	5.4	11.6	15.4	7.5	18.1	16.8	7.1	19.4	17.6	11.2	17.5
7.0	9.2	8.6	81.5	2.7	–	5.5	6.5	17.2	4.3	–	–	3.2	4.5	5.5	8.4
169.7	55.2	128.5	56.6	149.0	58	107.1	100.7	23.3	128.4	146	10	212.1	163.4	56.1	107.0
7	10	19	11	13	10	19	16	4	17	23	6	26	15	8	11
195.6	237.9	76.5	169.0	23.2	115	87.0	122.0	188.0	68.5	39	109	108.7	140.8	29.7	46.3
1.0	0.4	0.7	0.9	0.5	0.70	0.3	1.1	0.5	1.4	1.53	0.90	0.6	1.3	1.5	1.2
13.4	4.9	7.2	9.3	10.8	7.04	9.5	10.3	5.8	12.3	14.1	12.1	17.0	14.0	9.7	14.3
1.8	1.3	1.4	3.3	3.6	1.32	1.9	2.6	1.1	3.5	2.84	1.87	5.1	1.9	2.8	3.4
48	69	100	112	68	71	111	122	28	113	122	32	73	96	36	79
19.5	19.6	33.1	20.0	36.2	16	32.4	36.4	30.3	36.7	27	27	65.2	34.0	28.4	36.1
146.2	169.2	159.5	151.5	159.8	156	172.8	169.1	141.5	182.7	255	314	327.0	231.3	298.8	246.9
25.3	25.5	20.7	25.5	30.9	20.7	28.8	57.6	51.1	19.0	18.0	37.5	18.8	47.3	28.1	42.3
48.4	48.2	38.1	54.4	62.6	41.9	60.4	107.8	104.2	37.2	64.5	79.3	42.2	96.5	59.9	84.3
5.74	5.65	4.71	6.21	6.89	4.64	7.26	12.92	11.25	4.43	5.66	8.85	5.09	10.77	7.11	10.00
22.6	23.0	18.6	24.6	28.3	17.9	28.5	51.5	42.9	18.5	23.6	34.1	22.6	43.1	31.2	39.6
4.5	4.3	4.6	5.4	6.0	3.33	5.7	9.3	8.4	3.9	5.03	6.72	5.9	8.4	6.1	7.2
0.68	0.95	1.29	0.82	1.03	0.747	1.33	2.12	2.19	0.82	1.07	1.47	1.07	1.55	1.00	1.38
3.78	3.67	5.40	5.01	4.86	2.76	4.58	6.87	6.96	4.75	3.90	5.80	5.96	6.52	4.04	5.08
0.43	0.47	0.97	0.65	0.75	0.50	0.83	0.85	0.70	0.84	0.80	0.90	1.32	0.77	0.67	0.92
3.08	2.92	5.74	3.77	5.67	2.85	5.64	6.34	4.69	5.22	4.93	4.75	9.04	5.52	4.90	4.64
0.68	0.69	1.28	0.72	1.12	0.60	0.99	1.25	0.97	1.23	1.03	0.95	2.15	1.34	0.89	1.25
1.89	1.44	3.33	1.98	3.41	1.94	2.96	3.33	1.71	3.26	3.50	2.97	7.04	3.24	2.49	2.92
0.35	0.32	0.48	0.29	0.53	0.302	0.48	0.57	0.31	0.61	0.528	0.396	1.02	0.59	0.37	0.58
2.21	2.11	3.20	1.69	3.34	1.94	3.80	2.91	1.87	3.02	3.45	2.58	7.08	3.29	3.00	3.67
0.29	0.30	0.58	0.27	0.54	0.301	0.53	0.49	0.28	0.49	0.541	0.391	1.14	0.51	0.50	0.55

U.Mb — Upper Member of HF; US — Upper Silesia Block; grey. — greywackes; sd, sand. — sandstones; md, mud. — mudstones; silt. — siltstones

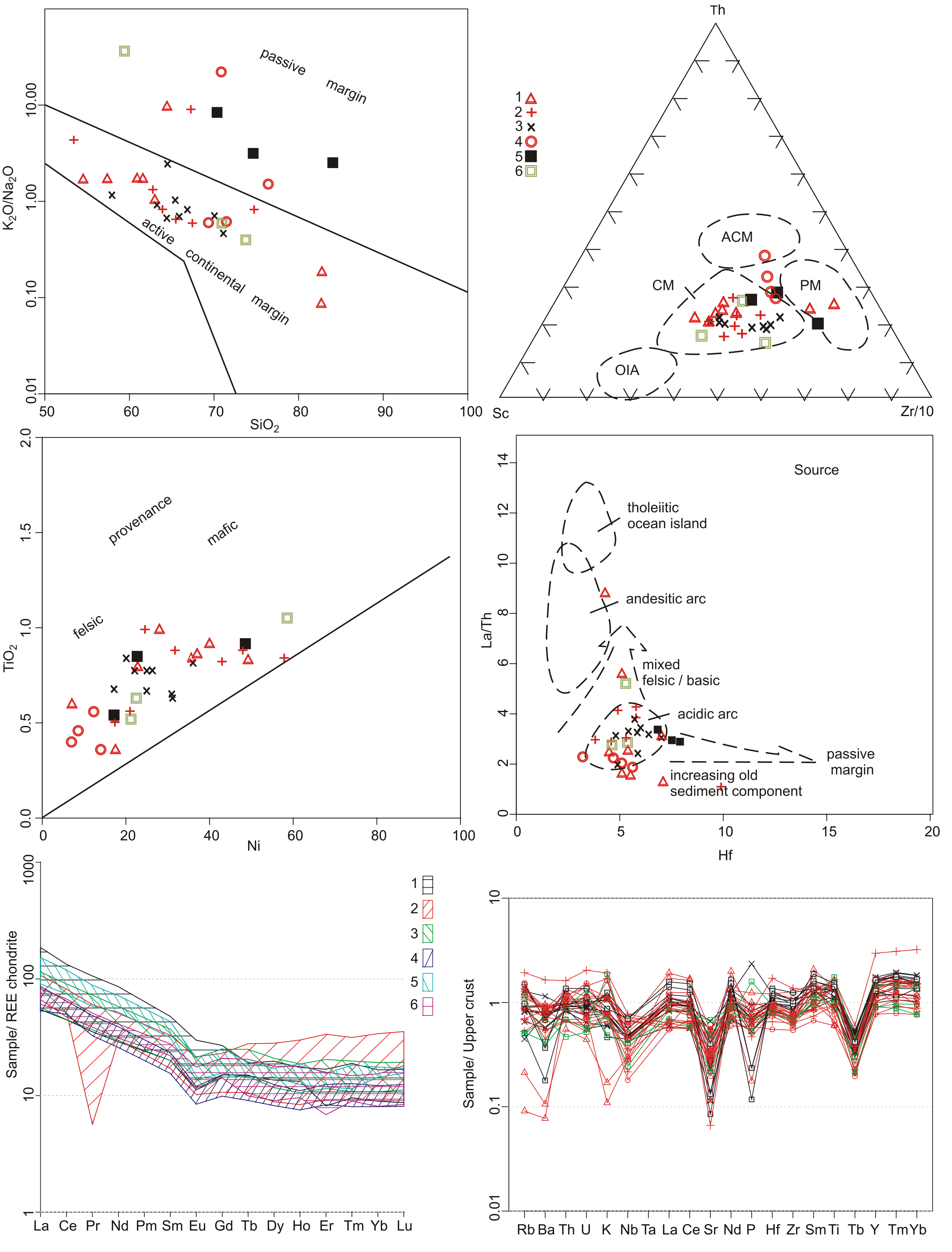

Fig. 10. Geochemistry of Ediacaran siliciclastic rocks from the studied regions

1 — East Małopolska; 2 — West Małopolska; 3 — Central Dobrogea; 4 — Upper Silesia; 5 — EEC platform cover; 6 — averages from 4 units in the Central Iberian Zone for comparison (Valladares *et al.*, 2000)

canic activity (*cf.*, Kukal, 1971). The relatively high degree of LREE/HREE fractionation is consistent with the rather low contribution of mafic/ultramafic material. The low amount of the latter in the source is also confirmed by the Hf *vs.* La/Th diagram (from Floyd and Leveridge, 1987), where most of the data points plot in the acidic arc source, with a few trending towards the passive margin field and to the mixed felsic/mafic source. This trend is reconfirmed on the Th/Sc *vs.* La/Sc plot (Floyd *et al.*, 1990, 1991). However, the low Th/Sc, La/Sc and Hf/Sc (higher Cr/Th) ratios are less indicative of a granitoidic source, and might suggest a higher input from a mafic source, or at least reflect complex lithologies at the source. The sum of Fe_2O_3 + MgO ranging between 4 and 11 also suggests the presence of some mafic rocks in the source area. On the multi-element diagram (Floyd *et al.*, 1991), normalized to upper continental crust (after Taylor and McLennan, 1985), anomalies >1 of abundances of V, Cr, Ni, Ti and Sc suggest mafic input, too. This is consistent with the CAAM setting determined for most of the samples as indicated by other diagrams (Th/Sc *vs.* La/Sc, *etc.*), whereas samples with passive margin affinity are rather sparse. On the other hand, most of the samples are characterized by strong negative Sr and Ba anomalies (Fig. 10), usually taken as an indication of a passive margin setting. Such indication is, however, inconsitent with the above data.

Inconsistencies of these types and the presence of samples that fall outside the identifying fields indicate that caution is needed when making immediate geotectonic discriminations based only on geochemical data. This problem has repeatedly been addressed in the literature (e.g., Rollinson, 1993; Mader and Neubauer, 2004), and explained via a variety of reasons, such as a high mica content, a low feldspar content, matrix compositions different from those in the reference samples (Bhatia,1983; Bhatia and Crook,1986), heavy mineral fractionation, or different sources. Lithological differences in the source(s) may also play a role. Two mudstones from the Vendian platform of the EEC were used in this study for comparative purposes; they were deposited in apparently similar facies conditions, yet differ significantly in their contents and elemental ratios. Thus, they often plot far from each other on various diagrams, despite consistently falling in the passive margin field on major element plots (Fig. 10). Although some differences may be difficult to explain, we believe that mudstones may represent a more regionally averaged provenance than sandstones.

Based on the low $Al_2O_3/(CaO + Na_2O)$ ratios, we assume that the composition of the studied siliciclastic rocks was not siginficantly influenced by weathering in the source areas, which allows us to compare the three regions under study. Despite general similarities, they are characterized by significant differences, and each of the regions has its own geochemical identity. Plots of the Dobrogea samples show the best cluster, while the Małopolska samples are relatively the most scattered (Fig. 10). This concurs with our distinction of two at least geochemically different successions (W/SW Małopolska and E/NE Małopolska). Their boundary is difficult to locate in boreholes, yet is obviously obliquely involved in the central belt of folded, cleaved and metamorphosed rocks (Fig. 2). The western succession appears rather consistent with Ediacaran rocks from Upper Silesia and Dobrogea, while samples of the eastern succession generally plot closer to the quartz-rich rocks of a passive margin (or fall outside the discriminating fields) and show some affinity to Ediacaran platform siliciclastics of the East European Craton (Figs. 1 and 2), also reflected by similar low $\varepsilon Nd_{(T)}$ values (Table 2). Most of the samples from the three studied regions occupy the same fields as Upper Neoproterozoic rocks from Central Iberia which came from a recycled orogen located on the N Gondwana margin and were deposited in slope and similar conclusion base-of-slope environment (Ugidos *et al.*, 1997; Valladares *et al.*, 2000). Likewise, our data show that flysch-type rocks in Upper Silesia and Małopolska (especially the western succession) were sourced from recycled orogens, whereas those in Central Dobrogea were mainly connected with basement uplift of more deeply eroded continental crust (Fig. 5).

RESULTS

Having integrated regional, sedimentological, geochemical and structural data we conclude that the Neoproterozoic flysch-type series were derived from the recycled magmatic precursors, mainly acid and intermediate, and scarcely mafic in composition. Low amount of volcanogenic admixtures and lack of igneous (lava flows, veins) component suggests that actual contribution to these series from magmatically active sources was insignificant and sedimentary basins had a continental floor. The flysch-type series were multiphase deformed in contractional regime, at least partly low-grade metamorphosed and eroded before the pre-Holmia Cambrian (US) or the Arenigian (MB) overstep covers were deposited. The data presented above rather preclude close or direct connections with active arc or back-arc rift settings. In consequence, either a retro-arc (continentally floored) or a foreland (pro-)basins can be assumed for the Neoproterozoic successions in the studied regions, and we find the second option more consistent with the collected data. Similar geochemical results were also obtained by Nawrocki *et al.* (2007) who moreover stressed the differences between the non-mature Ediacaran sediments and the matured Lower Cambrian sediments in East Małopolska. Such differences support the scenario proposed herein.

The Upper Silesia Block is the eastern part of the composite Brunovistulian Terrane, distinguished by Finger *et al.* (2000*a*) as the Slavkov Terrane encompassing Neoproterozoic igneous rocks dated at 725–580 Ma. They have $\varepsilon Nd_{(T)}$ values ranging from –1 to +3 (Finger *et al.*, 2000*a*), which are similar to the $\varepsilon Nd_{(T)}$ value of –1 obtained for the Upper Silesia turbidites (which was the highest value among the samples analyzed in our study). In hope that $\varepsilon Nd_{(T)}$ values represent the average of sources or lithologies in a source area, the Upper Silesia Foreland Basin, as inferred from the presented regional and sedimentological data, was most likely alimented from the SW part of the Upper Silesia Block (Slavkov Terrane) of the composite Brunovistulia Terrane. The foreland basins in West Małopolska and Dobrogea may have also been sourced from this terrane or another terrane(s) that displayed similar properties. The geochemical affinity (low $\varepsilon Nd_{(T)}$ values in particular) of the eastern Małopolska succession to the Ediacaran platform cover of the East European Craton (EEC) implies that the two regions received detritus from the craton. The implied proximity concurs with the conclusion about the thinned, Baltica-type crust in Małopolska, which was obtained from the analysis of the seismic refraction data (Malinowski *et al*., 2005), and is in line with the results of sedimentological studies of the Cambrian siliciclastic association from the EEC margin and the adjacent Holy Cross Mts., which indicates that Małopolska Block (including Łysogóry Unit) was not detached from Baltica (Jaworowski and Sikorska, 2006). However, significantly different age spectra of detrital zircons in platform rocks from the EEC margin (borehole Bial-3 = Białopole; Figs. 2 and 11) and from East Małopolska (boreholes Tuli = Tuligłowy and Chal = Chałupki Dębniańskie; Figs. 2 and 11) indicate supply from different sources on the craton (in Białopole, mainly from the 1.5 Ga A-type granite massifs; Fig. 1).

The Neoproterozoic turbiditic successions in Upper Silesia, West Małopolska and Central Dobrogea were deposited in marine basins which were largely fed from a former active continental margin of the recycled collisional orogen and its hinterland up to the continental interior, with the significant dominance of felsic over mafic rocks. A considerable amount of material was redeposited, which is attributed to a slope and base-of-slope environment. The relatively low volcanogenic input rather excludes an arc-trench slope setting (Belka *et al*., 2000) and suggests instead a scenario with foreland basins filled with flysch-type successions. This conclusion is further supported by the polarized deformation of the basin infill in a fold-and-thrust belt style, partly associated with very low grade to low grade metamorphism (chlorite zone, locally up to biotite zone). The deformation and metamorphism must have occurred before the pre-Holmia Cambrian in the US (concurrently with the youngest magmatism in the hinterland: see below), and before the Ordovician (Tremadocian to Arenigian) in the MB. Supposedly, the two successions envisaged in the MB probably merged in a way similar to that observed in the Variscan foreland succession in Poland (Jaworowski, 2002). The eastern succession was dominated by craton-related sediments, whereas the western one mostly comprised orogen-related sediments. Both successions were later involved in the WNW-trending central belt of intense deformation and metamorphism which was developed and elevated in an overall shortening regime. It likely formed an antiformal stack that collapsed and became zonally dissected in a normal regime which also allowed the rejuvenation of the former contractional cleavage as observed in drill cores (Fig. 8A). Based on the integrated data and reasons mentioned above, we propose that the domain B in the Upper Silesia Block is a fragment of the foreland and the domain A is a fragment of the hinterland (crystalline core) of a Neoproterozoic collisional orogen.

ISOTOPIC AGE DATA

To learn more about the source regions and to constrain the timing of the last zircon-forming event in the rocks prior to their uplift and denudation, a preliminary, reconnaissance series of isotopic datations was undertaken. The focus was on the rims and outgrowths on zircon grains. U-Pb SHRIMP analyses of selected detrital and magmatic zircon samples were done using SHRIMP II facilities at the Research School of Earth Sciences, the Australian National University, Canberra, and by Activation Laboratories Ltd., Ancaster, Canada, using SHRIMP II at the Geological Survey of Canada, Ottawa.

Zircon grains were hand-selected from the heavy mineral concentrates and mounted in epoxy resin together with chips of the FC1 (Duluth Gabbro) and SL13 (Sri Lankan gem) reference zircons. The grains were sectioned approximately in half and polished. Reflected and transmitted light photomicrographs and cathodoluminescence (CL) SEM images were prepared for all of the zircons. The CL images were used to decipher the internal structures of the sectioned grains and to target specific areas within the zircons.

The data was reduced in a manner similar to that described by Williams (1998, and references therein), using the *SQUID Excel Macro* of Ludwig (2000). The Pb/U ratios were normalised relative to a value of 0.1859 for the ^{206}Pb/^{238}U ratio of the FC1 reference zircons, equivalent to an age of 1099 Ma (Paces and Miller, 1993). The uncertainities given for individial analyses (ratios and ages) are at the one sigma level unless indicated otherwise. The Tera and Wasserburg (1972) concordia plots were prepared using *ISOPLOT/EX* (Ludwig, 1999).

SAMPLES

In Central Dobrogea, three members of the Histria Fm. (Dob1, Dob7, Dob14) were sampled (Fig. 1; Table 4). For the Małopolska Block, samples were taken from the metamorphic belt close to the Kraków–Lubliniec Fault Zone (BN-58, Z143) and from boreholes located to the south-west (Zalas) and north-east (Chal, Tuli) of this belt. In the Upper Silesia Block, sandstones of the domain B were sampled in 2 boreholes (Slem, Lach4), and granitoids from the domain A (Kety-8, Rozt-2, Rocz-3, Lody-1) were sampled in 4 boreholes (Fig. 2; Table 5). Sandstones of the Ediacaran platform of the EEC margin was sampled in 1 borehole (Bial-3; Fig. 2; Table 4).

DETRITAL ZIRCON SAMPLES

Dobrogea. The majority of the zircons from Dobrogea from the Histria Fm. (Table 4) are relatively clear subround to round elongate grains with pyramidal terminations. The CL images reveal igneous zoning and apparently older central components overgrown by later-formed zircon rims. Some are elongate euhedral crystals. Partial overgrowths with different contents of U and common Pb, homogeneous or simple zoned tips (some euhedral and darker), were analysed (Table 4). The Th/U ratios are commonly >0.2 suggesting a magmatic origin for most of the grains. Metamorphic grains or overgrowths are minor.

Małopolska. The zircons from Małopolska are more diversified between samples (Table 4). In East Małopolska, they are mostly short, subround and round (Tuli), round equant to elongate grains (Chal) of which most show igneous zoning under CL. In samples from West Małopolska, clear elongate to stubby euhedral grains with pyramidal terminations and rounded elongate to equant brown grains with pitted surfaces dominate. Their shapes suggest rather short period of surface transport. Many are simple zoned magmatic grains. Structured

Table 4

U-Th-Pb isotopic data for the analyzed zircon samples from siliclastic rocks of Central Dobrogea, Małopolska, Upper Silesia and marginal part of the East European Craton

Sample	U	Th/U	Pb*	^{204}Pb/^{206}Pb	f$_{206}$c	^{206}Pb/^{238}U	± 6/38	^{206}Pb/^{207}Pb	± 6/7	^{206}Pb/^{238}U		^{207}Pb/^{206}Pb	
Spot	[ppm]		[ppm]							Age [Ma]	±	Age [Ma]	±
Dob1													
1.1	504	0.2900	274	0.00006	0.00102	0.4944	0.0086	4.9021	0.1136	2589.9	37.4	2858.4	38.2
3.1	277	0.0452	26	0.00011	0.00191	0.1013	0.0008	16.3996	0.2608	622.0	4.5	638.4	34.6
5.1	92	0.7131	26	0.00001	0.00017	0.2786	0.0032	7.5399	0.1284	1584.4	15.9	2133.1	30.1
6.1	630	0.4702	175	0.00000	0.00006	0.2615	0.0017	10.6763	0.0477	1497.7	8.6	1501.4	8.5
7.1	589	1.1043	70	0.00004	0.00065	0.0982	0.0008	16.5136	0.1164	603.8	4.8	623.5	15.3
8.1	60	0.1548	6	0.00016	0.00272	0.0992	0.0012	16.0666	0.7328	609.4	7.2	682.4	100.5
9.1	63	0.7299	8	0.00001	0.00017	0.1061	0.0008	16.0185	0.2685	650.2	4.4	688.8	36.2
10.1	360	0.0488	37	0.00004	0.00062	0.1099	0.0008	16.3565	0.1763	672.3	4.6	644.1	23.3
Dob7													
1.1	113	0.3811	20	0.00004	0.00061	0.1768	0.0020	13.4834	0.1566	1049.6	10.9	1046.0	23.6
2.1	13	0.3295	1	0.00001	0.00017	0.1058	0.0020	14.7871	0.3166	648.5	11.8	857.1	45.1
4.1	515	0.1583	49	0.00000	0.00002	0.0992	0.0010	16.7025	0.0997	609.8	6.1	598.9	13.0
4.2	110	0.8228	12	0.00003	0.00044	0.0940	0.0012	16.7501	0.3290	579.0	7.0	592.8	43.2
Dob14													
2.1	178	0.54	17	0.000349	0.0061	0.1127	0.0017			688.0	10.		
2.2	151	0.82	13	0.000535	0.0095	0.0975	0.0013			600.0	8.0		
3.1	606	1.23	285	0.000010	0.0001	0.5468	0.0060	5.1282	0.0005	2812.0	25.0	2 785.0	4.0
3.2	606	1.24	285	0.000017	0.0002	0.5470	0.0046	5.1308	0.0005	2812.0	19.0	2 784.0	4.0
4.1	449	0.39	65	0.000071	0.0012	0.1669	0.0019	13.8696	0.0008	995.0	11.0	988.0	24.0
4.2	297	0.36	43	0.000028	0.0005	0.1695	0.0019	13.6799	0.0007	1009.0	10.0	1 017.0	19.0
6.1	155	0.42	13	0.000196	0.0035	0.1009	0.0012			620.0	7.0		
7.1	46	1.09	4	0.000430	0.0077	0.0941	0.0017			579.0	10.0		
8.1	40	1.00	3	–	<0.0001	0.0932	0.0017			574.0	10.0		
9.1	67	0.37	6	0.000423	0.0076	0.1013	0.0016			622.0	9.0		
10.1	136	1.00	12	–	<0.0001	0.1059	0.0013			649.0	7.0		
Tuli													
1.1	484	0.1500	234	0.00000	0.00006	0.4665	0.0060	5.8952	0.1033	2468.0	26.3	2554.0	29.7
2.1	80	0.4128	31	0.00012	0.00205	0.3625	0.0042	7.5586	0.0529	1994.1	19.7	2128.7	12.3
3.1	112	0.6124	12	0.00015	0.00255	0.0992	0.0012	17.0581	0.3009	609.6	7.1	553.1	39.0
4.1	199	0.4002	107	0.00001	0.00009	0.4856	0.0102	5.5902	0.2449	2551.8	44.3	2642.6	74.6
5.1	511	0.2158	203	0.00003	0.00060	0.3915	0.0048	6.5399	0.0735	2129.8	22.3	2378.7	19.3
6.1	38	0.8677	17	0.00005	0.00079	0.3913	0.0044	7.7374	0.0762	2128.8	20.4	2087.7	17.4
7.1	385	0.0714	185	0.00001	0.00016	0.4710	0.0065	5.7963	0.0061	2488.0	28.4	2582.3	1.7
8.1	451	0.0122	145	0.00005	0.00085	0.3323	0.0064	7.8784	0.1115	1849.7	31.0	2055.9	25.2
9.1	409	0.1988	178	0.00003	0.00053	0.4200	0.0094	6.1812	0.2272	2260.5	42.8	2474.4	63.4
11.1	143	0.4840	57	0.00001	0.00012	0.3671	0.0039	7.8641	0.0249	2015.8	18.5	2059.1	5.6
Chal													
1.1	869	0.1151	296	0.00011	0.00191	0.34697	0.0131	7.9232	0.1296	1920.1	63.0	2045.9	29.2
2.1	67	0.6514	7	0.00001	0.00017	0.09782	0.0021	16.1185	0.5079	601.6	12.1	675.5	68.8
3.1	53	0.6077	5	0.00001	0.00017	0.09373	0.0010	16.6863	0.5524	577.5	6.0	601.0	73.3
4.1	148	0.2646	29	0.00004	0.00066	0.19928	0.0019	12.5786	0.1154	1171.5	10.3	1184.6	18.2
5.1	646	0.1869	276	0.00002	0.00036	0.41291	0.0037	6.6862	0.0123	2228.2	16.9	2340.9	3.2
7.1	740	0.0985	248	0.00010	0.00181	0.33875	0.0022	7.8972	0.0206	1880.6	10.7	2051.7	4.6
8.1	471	0.1477	240	0.00002	0.00035	0.48757	0.0035	5.7180	0.1518	2560.2	15.4	2605.0	44.9
9.1	487	0.5395	128	0.00046	0.00797	0.25274	0.0134	8.4952	0.0411	1452.6	69.4	1921.8	8.7
10.1	720	0.7132	64	0.00002	0.00034	0.08101	0.0012	17.2342	0.1654	502.1	7.0	530.7	21.2

Tab. 4 cont.

Sample	U	Th/U	Pb*	^{204}Pb/^{206}Pb	f_{206}c	^{206}Pb/^{238}U	± 6/38	^{206}Pb/^{207}Pb	± 6/7	^{206}Pb/^{238}U		^{207}Pb/^{206}Pb	
Spot	[ppm]		[ppm]							Age [Ma]	±	Age [Ma]	±
BN-58													
3.1	39	0.7770	12	0.00102	0.00063	0.36536	0.0200	7.9176	0.0666	2000.0	35.4	1996.5	23.1
4.1	22	0.7014	7	0.00147	0.00042	0.37481	0.0164	7.4962	0.0476	2034.0	44.5	2034.6	33.8
4.2	75	0.6055	23	0.00030	0.00220	0.35261	0.0233	8.1103	0.0909	1939.3	25.7	1945.1	27.3
5.1	75	0.6422	7	0.00083	0.00130	0.10503	0.0061	14.8588	0.0666	639.1	10.8		
6.1	43	1.2113	4	0.00319	0.00033	0.11253	0.0050	11.5875	0.0385	668.0	15.0		
6.2	245	2.1638	25	0.00049	0.00130	0.11961	0.0093	14.3061	0.1250	723.0	9.1		
7.1	83	0.7842	9	0.00051	0.00280	0.12213	0.0075	14.9254	0.0769	740.3	11.7		
7.2	217	0.3273	22	0.00044	0.53095	8.462	0.1203	0.0676	0.0010	716.4	9.9		
8.1	124	0.6789	35	0.00022	0.32713	3.087	0.0457	0.1260	0.0050	1803.7	23.3	2002.2	73.8
8.2	177	0.6242	55	0.00004	0.06298	2.786	0.0359	0.1213	0.0008	1975.9	21.9	1966.8	12.0
9.1	54	0.5682	5	0.00083	0.00333	0.10235	0.0054	15.8479	0.0588	626.4	11.7		
10.1	50	0.4318	5	0.00156	0.00164	0.10750	0.0047	15.0376	0.0555	654.2	14.5		
10.2	91	0.5942	7	0.00144	0.00098	0.09220	0.0059	14.8809	0.0714	563.0	8.9		
11.2	229	0.2624	23	0.00041	0.00094	0.11811	0.0079	13.9276	0.0769	712.5	10.4		
13.1	80	0.7482	26	0.00037	0.00179	0.37439	0.0256	8.1169	0.0909	2047.2	28.5	1985.3	15.5
14.1	56	0.6450	5	0.00130	0.00083	0.10739	0.0059	14.0449	0.0500	650.0	11.6		
15.1	226	0.7090	45	0.00044	0.00143	0.23191	0.0170	9.1491	0.0555	1328.0	18.7	1591.4	43.6
15.2	182	0.2308	33	0.00025	0.00250	0.21168	0.0154	10.3627	0.1000	1219.7	16.1	1271.3	45.2
16.1	52	0.7282	5	0.00228	0.00078	0.10538	0.0049	14.0056	0.4545	638.1	13.5		
17.1	109	0.5399	9	0.00073	0.00213	0.10170	0.0068	15.5522	0.0909	621.7	9.1		
17.2	85	0.6042	7	0.00151	0.00084	0.09879	0.0062	14.4509	0.0666	600.8	9.5		
18.1	119	1.4837	12	0.00085	0.00149	0.11917	0.0082	14.5138	0.0909	721.2	10.2		
19.1	88	0.8677	9	0.00071	0.00131	0.12201	0.0079	14.2653	0.0833	736.8	11.1		
19.2	192	0.3372	19	0.00041	0.00138	0.11716	0.0083	14.5138	0.1250	709.4	9.8		
20.1	228	0.5289	68	0.00009	0.00714	0.12140	0.0286	8.1967	0.1666	1924.8	20.3	1966.5	11.9
21.1	87	1.2539	8	0.00107	0.00277	0.10328	0.0059	15.6250	0.1000	631.5	10.8		
Zalas													
1.1	226	1.1890	79	0.00018	0.00305	0.28534	0.0034	8.0149	0.0350	1618.2	17.0	2025.5	7.8
3.1	97	0.6349	58	0.00005	0.00082	0.50709	0.0042	5.4225	0.0277	2644.2	18.0	2693.0	8.5
4.1	215	0.3024	125	0.00001	0.00014	0.53170	0.0037	5.2257	0.1145	2748.6	15.6	2753.9	36.4
4.1	215	0.3024	125	0.00001	0.00014	0.53170	0.0037	5.2257	0.1145	2748.6	15.6	2753.9	36.4
5.1	375	0.1268	128	0.00001	0.00024	0.34281	0.0022	8.2421	0.0212	1900.2	10.5	1975.8	4.6
6.1	66	0.5109	26	0.00010	0.00166	0.37270	0.0181	8.3918	0.4427	2042.1	85.8	1943.7	97.5
7.1	56	0.8940	6	0.00011	0.00195	0.09070	0.0010	17.7372	0.8851	559.7	5.9	467.3	114.5
Z143													
1.1	74	0.35	47	–	<0.0001	0.1179	0.0017			718.0	10.0		
2.1	280	0.68	22	0.000014	0.0003	0.0920	0.0009			567.0	5.0		
2.2	216	0.66	16	0.000103	0.0018	0.0887	0.0011			548.0	6.0		
3.1	275	0.37	22	0.000058	0.0010	0.0924	0.0009			570.0	5.0		
4.1	306	0.45	146	0.000004	0.0001	0.5534	0.0049	5.0813	0.0010	2839.0	20.0	2799.0	8.0
5.1	218	0.58	81	0.000012	0.0002	0.4317	0.0055	5.4795	0.0008	2313.0	25.0	2675.0	8.0
6.1	145	0.41	14	0.000058	0.0010	0.1084	0.0013			664.0	7.0		
6.2	30	0.77	3	–	<0.0001	0.1088	0.0022			666.0	13.0		
7.1	543	0.54	261	0.000014	0.0002	0.5603	0.0049	4.7303	0.0005	2868.0	20.0	2916.0	4.0

Tab. 4 cont.

Sample	U	Th/U	Pb*	$^{204}Pb/^{206}Pb$	$f_{206}c$	$^{206}Pb/^{238}U$	± 6/38	$^{206}Pb/^{207}Pb$	± 6/7	$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$	
Spot	[ppm]		[ppm]							Age [Ma]	±	Age [Ma]	±
Bial-3													
1.1	56	0.00	12.6	–	<0.01	0.2606	0.0012	10.1522	0.0260	1500.9	29.2	1690.0	91.8
2.1	174	0.00	42.0	–	<0.01	0.2806	0.0019	10.8342	0.0769	1602.3	24.2	1566.0	26.6
3.1	368	0.00	85.1	0.000144	0.23	0.2689	0.0021	9.4697	0.0100	1532.2	17.8	1689.6	27.2
4.1	58	0.00	15.3	–	<0.01	0.3086	0.0015	9.3111	0.0417	1735.4	31.6	1772.2	40.5
5.1	477	0.00	106.4	0.000119	0.19	0.2597	0.0021	8.9206	0.1111	1485.7	16.3	1806.5	17.0
6.1	104	0.00	23.5	–	<0.01	0.2626	0.0015	10.7991	0.0555	1505.3	23.9	1511.2	44.8
7.1	739	0.00	89.1	0.000425	0.69	0.1404	0.0012	10.5708	0.1111	841.6	9.7	1398.0	40.3
8.1	38	0.00	9.4	0.000435	0.70	0.2876	0.0010	10.0100	0.0278	1629.4	48.4	1622.7	67.6
8.2	109	0.00	25.3	0.000035	0.06	0.2704	0.0016	10.4712	0.0555	1546.9	26.2	1583.4	33.8
9.1	120	0.00	27.7	–	<0.01	0.2689	0.0015	10.5485	0.0666	1538.4	23.9	1559.7	43.9
10.1	713	0.00	176.3	0.000058	0.09	0.2876	0.0024	9.0253	0.1250	1628.0	17.6	1799.3	17.0
11.1	83	0.00	18.1	–	<0.01	0.2533	0.0013	10.5708	0.0435	1455.5	26.2	1519.8	45.0
12.1	49	0.00	10.9	0.000193	0.31	0.2592	0.0011	10.4058	0.0370	1481.7	31.7	1496.4	62.6
13.1	220	0.00	47.1	–	<0.01	0.2492	0.0016	10.7875	0.0714	1435.7	19.4	1495.2	27.6
14.1	146	0.00	39.6	0.000113	0.18	0.3172	0.0017	8.7873	0.0588	1773.2	28.4	1836.9	35.1
15.1	75	0.00	17.1	–	<0.01	0.2649	0.0013	10.6157	0.0454	1526.8	28.3	1657.3	107.0
16.1	554	0.00	92.8	0.000216	0.34	0.1950	0.0016	9.4073	0.1111	1144.5	13.0	1685.3	26.1
17.1	183	0.00	40.9	0.000006	0.01	0.2602	0.0016	10.7411	0.0769	1490.7	21.4	1487.8	27.2
18.1	41	0.00	9.6	–	<0.01	0.2686	0.0010	10.1833	0.0370	1539.1	35.7	1654.7	50.5
19.1	69	0.00	15.6	0.000152	0.25	0.2627	0.0013	10.3413	0.0476	1500.4	26.4	1520.0	51.7
19.2	222	0.00	50.7	0.000091	0.15	0.2666	0.0019	10.5820	0.0909	1523.9	21.6	1568.6	22.4
20.1	84	0.00	19.1	–	<0.01	0.2642	0.0015	10.6044	0.0555	1511.7	24.0	1516.0	35.6
21.1	101	0.00	20.1	–	<0.01	0.2309	0.0012	10.2354	0.0476	1341.5	24.4	1612.4	45.5
22.1	75	0.00	16.8	0.000290	0.47	0.2600	0.0013	10.3627	0.0454	1490.1	32.0	1559.1	42.5
23.1	74	0.00	17.3	0.000087	0.14	0.2734	0.0014	11.3895	0.0454	1572.7	32.8	1559.0	47.1
24.1	147	0.00	80.1	0.000065	0.08	0.6325	0.0044	4.1719	0.0588	3157.4	36.0	3113.4	12.1
25.1	54	0.00	12.6	–	<0.01	0.2712	0.1260	10.3199	0.0303	1553.4	30.2	1643.5	85.4
26.1	351	0.00	86.1	0.000204	0.32	0.2856	0.0022	8.6281	0.0769	1614.9	18.3	1850.1	28.4
27.1	173	0.00	39.8	0.000153	0.25	0.2675	0.0185	10.4712	0.0769	1534.7	23.5	1614.9	25.8
28.1	304	0.00	72.6	0.000077	0.12	0.2784	0.0020	10.7066	0.1000	1603.6	25.6	1716.9	30.2
Slem													
1.1	819	0.3834	78	0.00024	0.00419	0.09383	0.00059	16.4564	0.1407	578.1	3.5	631.0	18.5
1.2	204	0.8000	23	0.00001	0.00017	0.10095	0.00079	16.7816	0.1151	620.0	4.6	588.7	15.0
2.1	685	0.1260	95	0.00045	0.00778	0.14601	0.00108	12.2493	0.1055	878.6	6.1	1236.8	17.0
2.2	235	0.6412	91	0.00001	0.00022	0.34583	0.00269	8.3300	0.0695	1914.7	12.9	1956.9	15.0
3.1	366	0.2508	39	0.00001	0.00021	0.10996	0.00082	16.0744	0.1219	672.5	4.8	681.4	16.3
3.2	506	0.3535	57	0.00003	0.00050	0.11232	0.00073	16.0162	0.1355	686.2	4.2	689.1	18.2
5.1	210	1.1422	25	0.00001	0.00017	0.09867	0.00088	16.7170	0.2176	606.6	5.1	597.0	28.5
6.1	122	0.9781	14	0.00008	0.00144	0.09746	0.00084	15.5972	0.5916	599.5	5.0	745.4	82.3
7.1	99	0.7726	11	0.00001	0.00017	0.09508	0.00219	16.4937	0.4179	585.5	12.9	626.1	55.6
8.1	237	0.6327	25	0.00000	0.00007	0.09962	0.00073	16.6488	0.2999	612.2	4.3	605.9	39.4

Tab. 4 cont.

Sample	U	Th/U	Pb*	^{204}Pb/^{206}Pb	f_{206}c	^{206}Pb/^{238}U	± 6/38	^{206}Pb/^{207}Pb	± 6/7	^{206}Pb/^{238}U		^{207}Pb/^{206}Pb	
Spot	[ppm]		[ppm]							Age [Ma]	±	Age [Ma]	±
Lach 4													
1.1	166	0.0013	15	–	<0.00001	0.10308	0.00130			1491.6	17.5		
2.1	144	0.0034	32	–	<0.00001	0.26034	0.00341			729.1	9.7		
3.1	302	0.0012	27	0.000039	0.06930	0.10272	0.00120			630.3	7.0		
4.1	116	0.0014	10	–	<0.00001	0.09955	0.00137			668.4	8.7		
5.1	136	0.0013	12	–	<0.00001	0.10098	0.00134			662.3	8.7		
6.1	163	0.0015	15	0.000033	0.00060	0.10925	0.00149			650.6	7.2		
7.1	214	0.0013	19	–	<0.00001	0.10237	0.00133			650.5	12.5		
8.1	404	0.0012	37	0.000042	0.00070	0.10619	0.00124			645.8	7.7		
9.1	568	0.0012	49	–	<0.0001	0.10020	0.00118			644.5	7.7		
10.1	295	0.0011	24	0.000025	0.00040	0.09299	0.00108			639.3	8.8		
11.1	341	0.0011	26	0.000014	0.00030	0.08903	0.00109			638.2	7.6		
12.1	351	0.0013	32	0.000018	0.00030	0.10515	0.00131			632.4	7.6		
13.1	106	0.0017	11	0.000007	0.00010	0.11974	0.00169			628.3	7.8		
14.1	27	0.0020	2	–	<0.00001	0.07857	0.00201			627.7	8.3		
15.1	105	0.0012	8	–	0.00010	0.08385	0.00122			621.8	11.6		
16.1	243	0.0011	18	–	<0.00001	0.08683	0.00109			620.1	7.9		
17.1	178	0.0012	14	–	<0.00001	0.09052	0.00120			615.6	6.9		
18.1	122	0.0014	10	–	<0.00001	0.09417	0.00136			611.8	8.0		
19.1	86	0.0022	8	0.000116	0.00210	0.10617	0.00215			604.1	6.7		
20.1	68	0.0020	6	–	<0.00001	0.10126	0.00198			580.1	8.0		
21.1	261	0.0013	24	0.000048	0.08585	0.10537	0.00132			573.2	6.4		
22.1	273	0.0013	24	0.000013	0.02392	0.10406	0.00130			565.4	8.2		
23.1	129	0.0014	10	–	0.00001	0.09166	0.00139			561.7	6.6		
24.1	322	0.0011	27	–	<0.00001	0.09824	0.00114			558.6	7.1		
25.1	163	0.0015	15	–	<0.00001	0.10821	0.00150			549.8	6.5		
26.1	215	0.0014	19	0.000108	0.19093	0.10227	0.00142			536.7	6.4		
26.1	215	0.0014	19	0.000108	0.19093	0.10227	0.00142			536.7	6.4		

Uncertainties reported at 1s and are calculated by numerical propagation of all known sources of error, and data corrected according to procedures outlined in Stern (1997); * — radiogenic Pb; f_{206}c — fractional ^{206}Pb contribution from common Pb

grains with various rim-core relationships are less common. Weakly zoned or homogeneous outgrowths are metamorphic, while weakly zoned euhedral outgrowths are of magmatic origin. The exteriors differ in their U and Pb contents. The Th/U ratios (Table 4) indicate dominance of magmatic grains.

Upper Silesia. The zircons are all nearly equant grains which are either clear, stubby prisms with pyramidal terminations and oscillatory igneous zoning, or round fragments of once larger grains preserving fragments of magmatic zoning. Far fewer grains are rounded, which generally points to a relatively short period of surface transport of the detrital material of both of the samples. The Th/U ratios (Table 4) indicate a magmatic origin for the zircons.

IGNEOUS ZIRCON SAMPLES

The zircons in sample Kety-8 are clear, with pyramidal terminations and aspect ratios ~1:3. Many grains are multiply oscillatory zoned, and some grains have igneous zoned outgrowths on simple structured cores. The Th/U ratios vary from 0.08 to 0.59. By contrast, the zircons in sample Rozt-2 are short and stubby, most with complex structured cores, occassionally embayed, with either simple igneous zoned or unzoned outgrowths. The Th/U ratios vary from 0.17 to 2.21. Almost all the zircons in sample Rocz-3 (Fig. 2; Table 5) are clear, stubby to long prismatic euhedral grains with oscillatory igneous zoning. The Th/U ratios (Table 5) vary between 0.03 and 0.9. The grain

Table 5

Results of SHRIMP U-Pb analyses of zircons from granitoids of the Upper Silesia Block

Sample									Total		Radiogenic		Age [Ma]	
Grain.	U	Th	Th/U	^{206}Pb*	^{204}Pb/^{206}Pb	f_{206}	^{238}U/^{206}Pb	±	^{207}Pb/^{206}Pb	±	^{206}Pb/^{238}U	±	^{206}Pb/^{238}U	±
Spot	[ppm]	[ppm]		[ppm]		[%]								
Kety-8														
1.1	213	57	0.27	16.6	0.000210	0.04	10.997	0.106	0.0592	0.0008	0.0909	0.0009	560.8	5.3
2.1	537	226	0.42	44.4	0.002370	4.04	10.399	0.087	0.0920	0.0022	0.0923	0.0010	569.0	5.7
3.1	304	69	0.23	24.3	0.000049	<0.01	10.772	0.097	0.0578	0.0006	0.0930	0.0009	573.2	5.0
4.1	261	40	0.15	21.1	0.000064	0.02	10.624	0.097	0.0595	0.0007	0.0941	0.0009	579.8	5.2
5.1	162	73	0.45	14.1	0.000167	0.14	9.865	0.137	0.0616	0.0008	0.1012	0.0014	621.6	8.5
6.1	544	190	0.35	44.4	0.000012	<0.01	10.527	0.104	0.0583	0.0004	0.0951	0.0010	585.8	5.7
7.1	291	54	0.19	23.8	–	<0.01	10.509	0.095	0.0591	0.0007	0.0952	0.0009	586.2	5.2
8.1	148	17	0.11	12.8	0.000183	<0.01	9.977	0.108	0.0590	0.0009	0.1004	0.0011	616.8	6.5
8.2	312	55	0.18	25.2	0.000059	<0.01	10.628	0.097	0.0574	0.0006	0.0943	0.0009	581.1	5.2
9.1	241	41	0.17	19.3	0.000079	0.17	10.749	0.100	0.0605	0.0007	0.0929	0.0009	572.5	5.2
10.1	224	54	0.24	18.0	0.000072	<0.01	10.717	0.102	0.0585	0.0007	0.0934	0.0009	575.6	5.4
11.1	253	20	0.08	20.1	–	0.10	10.806	0.100	0.0599	0.0007	0.0925	0.0009	570.0	5.2
12.1	122	23	0.19	9.9	0.000183	0.29	10.561	0.120	0.0618	0.0010	0.0944	0.0011	581.6	6.5
13.1	273	76	0.28	21.4	0.000003	0.17	10.951	0.104	0.0603	0.0007	0.0912	0.0009	562.4	5.2
13.2	221	36	0.16	17.8	0.000076	<0.01	10.684	0.102	0.0575	0.0007	0.0938	0.0009	578.0	5.4
14.1	623	366	0.59	99.4	0.000003	<0.01	5.385	0.047	0.0757	0.0004	0.1858	0.0017	1098.5	9.3
15.1	183	20	0.11	14.9	0.000060	<0.01	10.556	0.104	0.0582	0.0008	0.0949	0.0010	584.3	5.6
15.2	115	22	0.20	9.3	–	<0.01	10.546	0.117	0.0585	0.0010	0.0949	0.0011	584.6	6.3
16.1	631	226	0.36	51.5	0.000061	<0.01	10.522	0.100	0.0593	0.0004	0.0951	0.0009	585.4	5.4
17.1	136	27	0.20	10.5	0.000346	0.11	11.148	0.118	0.0595	0.0010	0.0896	0.0010	553.2	5.7
18.1	463	121	0.26	37.3	0.000057	<0.01	10.664	0.094	0.0590	0.0005	0.0938	0.0008	578.0	5.0
19.1	158	25	0.16	12.7	–	<0.01	10.695	0.108	0.0574	0.0008	0.0937	0.0010	577.5	5.7
20.1	135	17	0.12	10.8	0.000166	0.01	10.733	0.120	0.0593	0.0011	0.0932	0.0011	574.2	6.3
Rozt–2														
1.1	474	637	1.34	40.1	0.000104	0.19	10.146	0.102	0.0604	0.0005	0.0984	0.0010	604.9	5.8
2.1	222	93	0.42	18.5	0.003128	5.62	10.280	0.096	0.1019	0.0035	0.0918	0.0010	566.2	6.0
3.1	607	151	0.25	48.9	–	<0.01	10.657	0.091	0.0593	0.0008	0.0939	0.0008	578.4	4.7
4.1	26	14	0.52	2.7	0.000520	0.93	8.433	0.147	0.0648	0.0019	0.1185	0.0021	722.0	13.2
5.1	975	521	0.53	78.6	–	<0.01	10.649	0.085	0.0596	0.0003	0.0939	0.0008	578.7	4.4
6.1	130	74	0.57	11.5	0.000003	0.01	9.699	0.102	0.0602	0.0009	0.1031	0.0011	632.5	6.3
7.1	313	111	0.36	26.1	0.000185	0.33	10.320	0.093	0.0643	0.0006	0.0966	0.0009	594.4	5.1
8.1	121	87	0.72	10.9	0.000004	0.01	9.513	0.101	0.0601	0.0009	0.1055	0.0011	646.6	7.5
9.1	894	156	0.17	66.3	0.000520	0.92	11.597	0.094	0.0674	0.0004	0.0854	0.0007	528.4	4.2
10.1	278	221	0.80	24.5	0.000016	0.03	9.746	0.090	0.0589	0.0008	0.1026	0.0009	629.5	5.6
11.1	67	148	2.21	14.7	–	<0.01	3.932	0.046	0.0927	0.0010	0.2545	0.0030	1461.0	15
11.2	429	269	0.63	88.7	0.000088	0.14	4.154	0.039	0.0912	0.0004	0.2404	0.0023	1388.7	12
12.1	151	133	0.88	13.4	0.000065	0.12	9.703	0.100	0.0599	0.0009	0.1029	0.0011	631.6	6.2
12.1	1678	622	0.37	113.1	0.000115	0.21	12.743	0.102	0.0587	0.0003	0.0783	0.0006	486.1	3.8
13.1	392	198	0.50	33.8	0.000093	0.17	9.970	0.095	0.0617	0.0005	0.1001	0.0010	615.2	5.6
14.1	1053	560	0.53	78.2	0.000137	0.24	11.571	0.094	0.0606	0.0004	0.0862	0.0007	533.1	4.2
15.1	51	68	1.32	12.1	0.000108	0.17	3.645	0.059	0.0934	0.0013	0.2744	0.0045	1563	28
14.2	258	370	1.44	23.1	0.000043	0.08	9.606	0.116	0.0604	0.0009	0.1040	0.0013	638.0	7.4
16.1	560	267	0.48	46.7	0.000033	0.06	10.313	0.086	0.0608	0.0004	0.0969	0.0008	596.3	4.7
17.1	714	317	0.44	58.0	0.000079	0.14	10.562	0.087	0.0604	0.0006	0.0946	0.0008	582.7	4.9

Tab. 5 cont.

Sample									Total		Radiogenic		Age [Ma]	
Grain. Spot	U [ppm]	Th [ppm]	Th/U	^{206}Pb* [ppm]	^{204}Pb/^{206}Pb	f_{206} [%]	^{238}U/^{206}Pb	±	^{207}Pb/^{206}Pb	±	^{206}Pb/^{238}U	±	^{206}Pb/^{238}U	±
Rocz-3														
1.1	697	63	0.09	58	0.000039	0.07	11.3404	0.11110	0.0598	0.0011	0.0880	0.0090	544.8	5.3
2.1	612	31	0.05	50	0.000485	0.84	11.4012	0.09700	0.0595	0.0063	0.0876	0.0010	542.0	6.1
4.1	200	36	0.19	17	0.000010	0.02	11.0473	0.08840	0.0583	0.0044	0.0906	0.0011	558.6	6.7
5.1	186	30	0.17	16	0.000035	0.06	11.1794	0.10410	0.0591	0.0039	0.0894	0.0010	552.3	5.7
6.1	160	32	0.21	14	0.000045	0.08	11.3779	0.10300	0.0613	0.0038	0.8758	0.0010	543.0	5.8
6.2	95	69	0.75	11	0.000010	0.02	9.5584	0.05550	0.0603	0.0043	0.1047	0.0018	641.4	10.5
7.1	583	17	0.03	48	0.000010	0.02	11.1024	0.15870	0.0586	0.0066	0.0901	0.0006	556.0	3.7
8.1	429	14	0.03	35	0.000032	0.06	11.2145	0.16390	0.0604	0.0032	0.0890	0.0006	550.6	3.6
9.1	204	162	0.82	22	0.000077	0.13	10.3423	0.12650	0.0620	0.0050	0.0964	0.0008	595.0	4.7
10.1	690	2	0.00	57	0.000010	0.02	10.9853	0.16120	0.0593	0.0065	0.0910	0.0006	561.6	3.7
Lody-1														
1.1	361	87	0.24	30.4	0.003092	10.95	10.1920	0.0960	0.1475	0.0062	0.0874	0.0011	540.0	6.7
2.1	44	26	0.60	4.0	0.000189	0.87	9.4760	0.1670	0.0682	0.0035	0.1046	0.0019	641.4	11.3
2.2	2018	170	0.08	126	0.000902	4.50	13.7330	0.1140	0.0919	0.0020	0.0695	0.0006	433.4	3.7
3.1	383	48	0.12	31.2	0.000439	0.52	10.5400	0.0990	0.0636	0.0008	0.0944	0.0009	581.4	5.3
3.2	373	293	0.79	34.0	0.000052	0.03	9.4240	0.0880	0.0615	0.0006	0.1061	0.001	650.0	5.9
4.1	197	131	0.67	19.2	0.000291	0.41	8.7890	0.0920	0.0659	0.0008	0.1133	0.0012	691.9	7.1
5.1	185	228	1.23	15.8	–	<0.01	10.0380	0.1090	0.0599	0.0009	0.0997	0.0011	612.4	6.5

Notes: (1) Uncertainties given at the ones level. (2) Error in FC1 reference zircon calibration was 0.34% for the analytical session (not included in above but required when comparing data from different mounts). (3) f_{206} % denotes the percentage of ^{206}Pb that is common Pb. (4) Correction for common Pb made using the measured ^{238}U/^{206}Pb and ^{207}Pb/^{206}Pb ratios following Tera and Wasserburg (1972) as outlined in Williams (1998)

exteriors are usually richer in U. The zircon grains in sample Lody-1 (Fig. 2; Table 5) are subhedral to euhedral with pyramidal terminations. They are clearly structured, comprising inherited centres overgrown by igneous rims with euhedral outlines. The others are simply-zoned magmatic zircons. The high Th/U ratios confirm an igneous origin.

RESULTS

The obtained ages represent the first zircon U-Pb SHRIMP II geochronological data for Neoproterozoic rocks in Southern Poland and Dobrogea (Tables 4 and 5). Because of the reconnaissance character of our isotopic studies and the predominance of zircons younger than 1.0 Ga, the results for detrital grains are compared on histograms showing the ^{206}Pb/^{238}U ages (Fig. 11).

DETRITAL ZIRCON SAMPLES

In Dobrogea, a distinct age group between ~690 Ma and ~580 Ma is the most obvious, and another occurs at ~1–1.05 Ga, with indications of another two groups at ~1.4–1.5 Ga and at ~2.6–2.8 Ga (Fig. 11). Both the euhedral homogenous and truncating overgrowths of the 690–580 Ma group suggest that igneous and metamorphic events occurred in the source region in that time interval. In East Małopolska, most of the grain exteriors have ages between 2.56–1.8 Ga. However, an age group between ~610 Ma and ~575 Ma revealed by both igneous and metamorphic outgrowths is also significant (Fig. 11). By contrast, in West Małopolska, an age group of 670–570 Ma clearly dominates, with the remainder of the zircons spread between 1.2 and 2.9 Ga. In Upper Silesia, 90% of the analysed grains fall in a group of 680–550 Ma. The remaining single grains hint to minor ~1.5 and ~1.9 Ga components at the source. The EEC platform margin is dominated by ~1.6–1.5 Ga zircons with single Archean grain (3.1 Ga).

IGNEOUS ZIRCON SAMPLES

In Kety-8 sample, 20 analyses of 17 grains yielded a mean age of 579 ±2.7 Ma. Two grains have older cores of ~620 Ma, and there is one grain with core of ~1.1 Ga. The unfoliated granitoid intruded at ~580 Ma (Fig. 12).

In Rozt-2 sample, two subsets of analyses were discerned. A distinct subset of 6 analyses on 6 grains yielded the ^{206}Pb/^{238}U age domain of 582.7 Ma. The other subset of 7 analyses on 7 grains yielded an age domain of 628.3 Ma. The two age domains are consistent with the Kety-8 sample and are taken as a record of intrusion at ~580 Ma. One grain has an age of 722 ±13 Ma, and the three other grains have ages of ~1.4–1.5 Ga; they all reveal inheritance (Fig. 12).

In Rocz-3 sample, the analyses for the zoned core and for the weakly zoned truncating mantle of one grain gave ages of

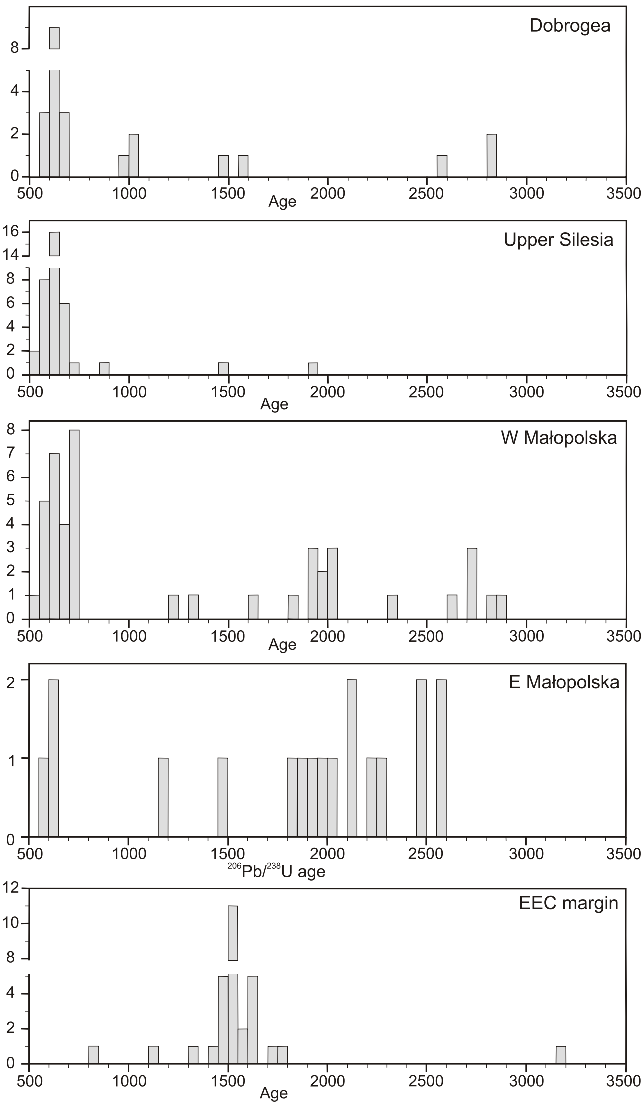

Fig. 11. Histograms showing U-Pb ages of detrital zircons from the EEC, Małopolska, Upper Silesia and Dobrogea

~642 and ~541 Ma, respectively. The mantles which truncate zoned cores in the remaining grains yielded $^{206}Pb/^{238}U$ ages between ~559 and ~541 Ma. Discarding two markedly older analyses, four concordant analyses yield an age of 558±4 Ma which is interpreted as the age of the (late syntectonic) intrusion, whereas the age of ~642 Ma represents inheritance (Fig. 12).

The analyses of zircons from the Lody-1 sample are poor and thus hard for interpretation. However, in view of the results yielded for the other three samples, the data may be taken to suggest that some of the zircon grains from the Łodygowice tonalite vein crystallized between ~690 and ~580 Ma, with the older age representing possibly inheritance and the younger probably referring to an intrusion time similar to that envisaged for other granitoids in Upper Silesia (Fig. 12).

DISCUSSION AND CONCLUSIONS

In recent palaeogeographic reconstructions which take into account Brunovistulia, this terrane is usually treated as a part of Avalonia (Nance and Murphy, 1994; Murphy *et al.*, 2004; Linnemann *et al.*, 2007). Małopolska or Dobrogea (Moesia) are considered less often and mostly regarded as parts of Baltica that were rifted off in the Neoproterozoic, then re-accreted to this continent still in Ediacaran or in Palaeozoic times, and Brunovistulia was to unite with Małopolska before the Devonian (Nawrocki *et al.*, 2004*a*; Nawrocki and Poprawa, 2006; Oczlon *et al.*, 2007). Some reconstructions assume that Dobrogea can be linked with the East Africa–Arabia sector of Gondwana and the Pan-African Orogen (Liégeois *et al.*, 1996; Linnemann, *et al.*, 2004). Winchester *et al.* (2002) envisaged the Brunosilesia–Moesia Terrane which included Dobrogea and acted as a bridge between peri-Gondwanan terranes and Baltica and already in the Neproterozoic was positioned next to this continent. The reconstructions are based on zircon ages, biogeographic and palaeomagnetic evidence. However, such data appear ambiguous and pay relatively little attention to internal geologic features of the terranes in question. Difficulties are enhanced by differences in the Ediacaran-Early Cambrian sections of the APW paths proposed for Baltica and its position with regard to other continents (Torsvik and Rehnström, 2001; Hartz and Torsvik, 2002; Popov *et al*., 2002; Lewandowski and Abrahamsen, 2003; Nawrocki *et al.*, 2004*a*). In this study, we prefer to utilize the model of Baltica and Brunovistulia proposed by Nawrocki *et al.* (2004*a*, *b*), especially that this conforms to the palaeobiogeographic data. The Early Cambrian trilobites (Orłowski, 1975; Nawrocki *et al.*, 2004*b*) and acritarchs (Buła *et al.*, 1997; Vavrdová, 2004; Mikuláš *et al.*, 2008) from Brunovistulia show close similarities to NW and SW Baltica. In the following section, we discuss both our and earlier data in hope of arriving at a more complete model of the evolution of the studied terranes.

GRANITOIDS

In the southern part of the Upper Silesia Block, unfoliated granites intruded metasedimentary rocks at *ca*. 580 Ma. Locally granitic magma was emplaced as late as *ca*. 560 Ma, probably into localized tectonic zone, because the 558 Ma old Roczyny granodiorite (Rocz-3) acquired fabric during intrusion. Rounded elongate feldspar augen set in a matrix of recrystallized quartz and biotite testify to a microstructural continuum of magmatic deformation to solid-state deformation at decreasing temperatures. This deformation shows that ductile strain locally operated in the basement of the block at the end of the Neoproterozoic, which is interpreted by us as a record of the Slavkov-Rzeszotary collision.

All the Upper Silesia granitoids developed at the expense of the older crust that underwent a tectonothermal event at *ca*. 640–620 Ma and included yet older, inherited components dated

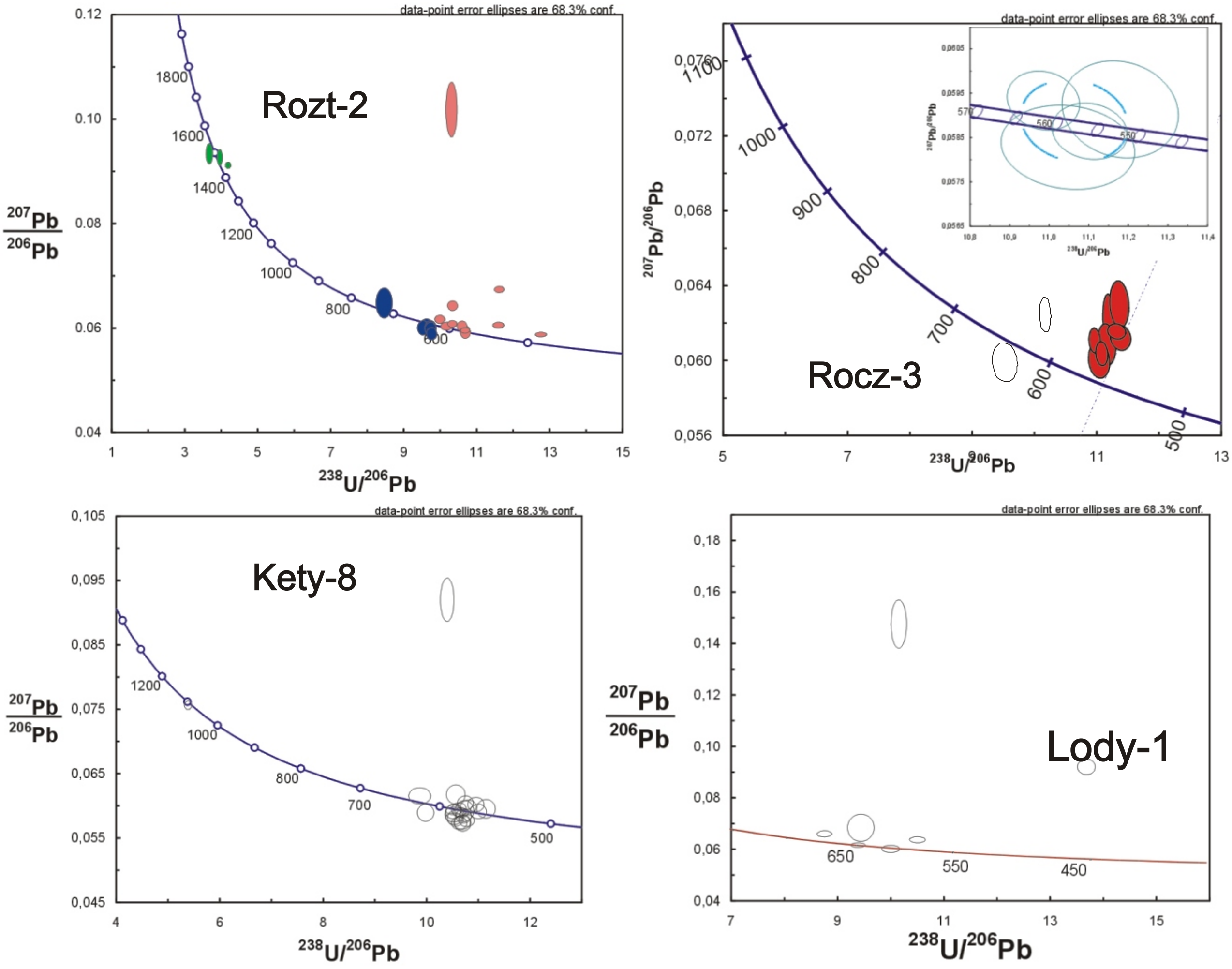

Fig. 12. U-Pb Tera-Wasserburg concordia plots for zircons from granitoids of the Upper Silesia Block

at ~720 Ma, 1.1 Ga and 1.4–1.5 Ga. Deformation and metamorphism of the country rocks must have generally occurred before granitic intrusions, probably during the *ca*. 640–620 Ma event. As the 558 Ma Roczyny granodiorite was disconformably covered with Lower Cambrian (pre-Holmia) shallow-water sandstones (Buła, 2000), a rapid orogenic-type uplift of the southern part of the Upper Silesia Block (domain A) in latest Neoproterozoic to earliest Cambrian times is a corollary.

In the Brno Block, intrusions of the ~590–580 Ma unfoliated granites evidently post-dated the collision between Thaya and Slavkov terranes (Fig. 13; Finger *et al.*, 2000*a*, *b*). Together with our new zircon data (~640–560 Ma and older age groups in the Upper Silesia granitoids: 1.0–1.2, ~1.5, 1.9–2.1 and 2.8–2.9 Ga), the isotopic ages support the notion that most of the Brunovistulian (Thaya and Slavkov terranes) crust is of Gondwanan descent and may have come from the Amazonian Craton.

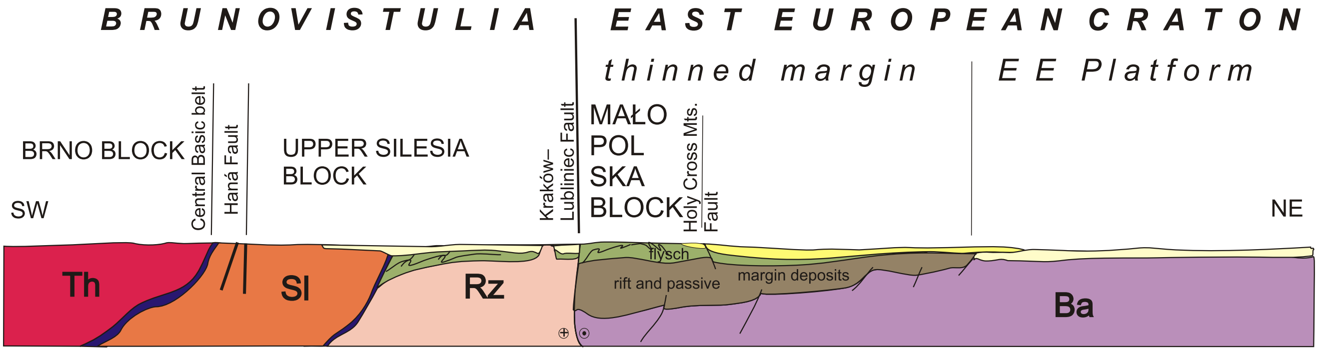

Fig. 13. Schematic model of the Neoproterozoic crustal structure in Southern Poland

Ba — Baltica continent; Rz — Rzeszotary Terrane; Sl — Slavkov Terrane; Th — Thaya Terrane; units marked with different shades of yellow — platform and overstep Palaeozoic deposits

In the Slavkov Terrane, single inherited zircons of ~1.1 Ga and ~1.5–1.4 Ga (2–4% discordant) age were found in granitoids that intruded into paragneisses and mica schists. Although scarce, they might indicate that the rocks evolved from the reworked Grenvillian orogen rather, than from a juvenile intraoceanic Avalonian crust (1.3–1.0 Ga age, Murphy *et al*., 2004). The granitoids in the eastern Slavkov (Upper Silesia) show affinity to I/S-type granites being probably derived from a lower crustal source in a supra-subduction setting of continental arc magmatism. This agrees with I-type signature reported by Finger *et al*. (2000*a*) from the western Slavkov Terrane. In the Thaya Terrane, gneisses also contain Meso- to Neoproterozoic zircons (1.6–0.9 Ma; Kröner *et al*., 2000) and are far better isotopically evolved (εNd$_{(T)}$ = –3 to –11) than the Slavkov ones (εNd$_{(T)}$ = –1 to +2), which justifies the distinction of the two terranes separated by a metabasite (ophiolite?) suture (Finger *et al.*, 2000*a*, *b*). The Nd isotopic signature and inherited zircons of 1.2, 1.5 and 1.65–1.8 Ga (Friedl *et al*., 2000) also are rather inconsistent with the provenance from a juvenile Avalonian arc. The Thaya granitoids developed via the recycling of an older continental crust and the process most likely occurred at the Amazonian sector of an active Gondwanan margin of the supercontinent Rodinia/Pannotia. The Slavkov Terrane was located more externally than Thaya and for the time being it faced a subducting oceanic crust. In its further history, the Slavkov Terrane got obliquely into contact with the Rzeszotary Terrane having Palaeoproterozoic basement (Fig. 13). This triggered (1) turbiditic, flysch-type sedimentation swallowing up the eroded products of the *ca*. 590–580 Ma magmatism as the detrital zircons of that age already occurred in the flysch, and (2) multiphase deformation and low-grade metamorphism of the flysch series. In this model, the Thaya–Slavkov couple represented the hinterland. K-Ar ages of detrital micas (Belka *et al*., 2000) from Lower Cambrian overstep rocks constrain the foreland deformation to latest Ediacaran times.

METASEDIMENTS

The age group of *ca*. 640–550 Ma, which characterizes the Upper Silesian/Brunovistulian granitoids, is remarkably consistent with the most distinct age groups identified in all the detrital zircon samples from the Neoproterozoic flysch-type successions in the Upper Silesia, Małopolska and Dobrogea regions. They were all fed from sources which in that time interval underwent tectonothermal events (arc magmatic, orogenic). In the present-day map view, there is a significant positive correlation between the percentage of zircons dated at 640–550 Ma in the Neoproterozoic clastic rocks and the distance to the southern, crystalline part of the Upper Silesia Block interpreted as the hinterland (Figs. 2 and 13). Zircons of this age group are most abundant in the proximal flysch deposited on this block, less frequent in the West Małopolska succession, still less in the distal flysch of the East Małopolska succession, and absent from the margin of the East European Platform (Fig. 11). The εNd$_{(T)}$ values for the flysch sediments also steadily decrease from the US domain B (εNd$_{(T)}$ = –1), where they are similar to those of the metasediments and igneous rocks in the eastern Slavkov Terrane and via the western to the eastern Małopolska succession (εNd$_{(T)}$ = –8 to –11) where they become identical to those of the Ediacaran platform covering the East European Craton. The closer to the craton the more zircons of the age groups known from the craton (1.5, 1.8, 2.0, 2.3–2.5 Ga; Figs. 1, 2 and 11) appear in late Neoproterozoic sediments (boreholes Tuligłowy and Chałupki). Such characteristics, combined with the sedimentological data which indicate the decreasing proximity of the flysch sediments away from the Slavkov Terrane (crystalline part of the US hinterland), suggest that probably also by latest Neoproterozoic–earliest Cambrian times, all these regions were already disposed close to one another and adjacent to the Teisseyre-Tornquist (T–T) margin of Baltica (Fig. 13) covered with Cambrian, matured, shallow-water deposits (Fig. 1), which is in line with palaeomagnetic (Nawrocki *et al*., 2004*a*, *b*) and biogeographical data (Orłowski, 1975; Buła *et al*., 1997; Vavrdová, 2004; Nawrocki *et al*., 2007; Mikuláš *et al*., 2008). Of particular importance is the finding by Żylińska (2002) that some trilobite species (e.g. *Schmidtiellus panowi* or *Kjerulfia orcina*), were endemic to US and MB only and that at the genus level the two regions shared the holmiid fauna with the continent of Baltica. Moreover, the matured Lower Cambrian sandstones in US, MB and the EEC margin all contain micas with Neoproterozoic (K-Ar >540 Ma) cooling ages (Belka *et al*., 2000; Nawrocki *et al*., 2007), which directly indicates that the detrital contents of these rocks must have been supplied from a nearby Neoproterozoic orogen whose thermal activity terminated shortly before the Cambrian. Palaeozoic evolution of the discussed regions is, however, beyond the scope of this paper and in terms of the provenance data will be featured separately.

Metasediments and unfoliated granitoids of the Slavkov Terrane have isotopic signatures (εNd$_{(T)}$ = –1 to +2) which indicate a relatively primitive crust. Such crust was a source for the flysch-type clastic rocks (εNd$_{(T)}$ = –1) deposited in the Rzeszotary foreland, designated in this study as the US domain B. All these features suggest that the US actually embraces fragments of the two mentioned terranes. In the Slavkov Terrane, magmatic avtivity continued till latest Neoproterozoic times as documented by the intrusion of the *ca*. 550 Ma Jablunkov gabbro (Finger *et al.*, 1989) and the 558 Ma Roczyny granodiorite. The ~560–550 Ma magmatism and localized shearing deformation seem to be a distinctive characteristic of the eastern part of this terrane which presumably developed during its oblique collision with the Rzeszotary Terrane (Archaean/Palaeoproterozoic basement without later overprint).

PALAEOGEOGRAPHIC AND TECTONIC EVOLUTION

Accepting the model of Finger *et al.* (2000*a*) for Brunovistulia, we suggest that the Thaya–Slavkov collision coincided with the *ca*. 640(650)–620 Ma tectonothermal event recorded by our zircon data, which was followed by granitoid intrusions at *ca*. 590–580 Ma in suprasubduction setting. Then the terrane couple obliquely collided with the Rzeszotary Terrane at ~560–550 Ma (prior to the pre-Holmia Cambrian) as suggested by localized deformation and shear-zone magmatism, and the three have since formed what is known as the composite terrane of Brunovistulia (Fig. 13). Concurrently, either Brunovistulia or another similar concealed fragments of Gondwana docked to the

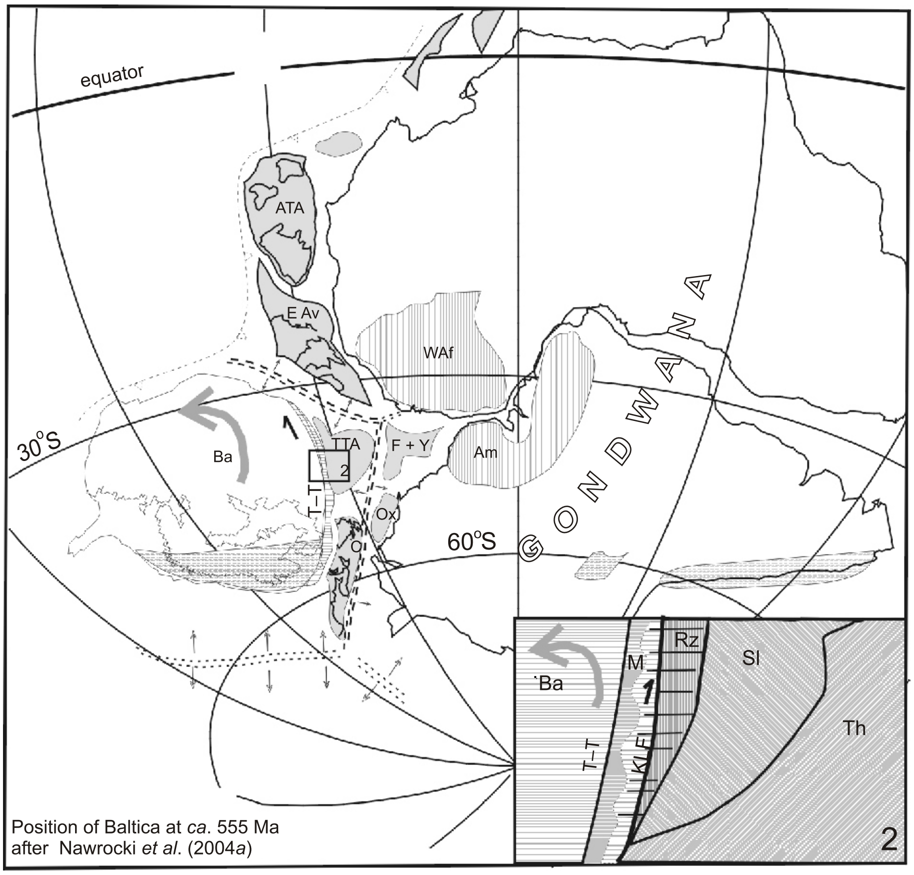

Fig. 14. Preferred palaeogeography based on Nawrocki *et al.* (2004*a*) and modified after Keppie *et al.* (2001), Torsvik and Rehnström (2001), Nance *et al.* (2002, 2008), Murphy *et al.* (2004)

Vertical ruling — Palaeoproterozoic unit in West Africa and South America; horizontal dashed ruling — fragments of the Grenville Belt; horizontal ruling — thinned, extended margin of Baltica (EEC); shaded units — terranes derived from West Gondwana. Am — Amazonia; ATA — Armorican Terrane Assemblage; C — Chortis; E Av — East Avalonia; F + Y — Florida and Yucatan; Ox — Oaxaquia; TTA — Teisseyre-Tornquist Terrane Assemblage; WAf — West Africa; Inset (2) schematically shows the members of the TTA after their collisions at the end of Neoproterozoic and unstable accretion to rotating Baltica. Sinuous dashed line — diffused border between the West and East Małopolska successions; horizontal ruling — dominance of the Brunovistulia (Gondwana) derived detritus; Ba — Baltica; KLF — future strike-slip of Kraków–Lubliniec Fault Zone; M — Małopolska; Rz — Rzeszotary; Sl — Slavkov; Th — Thaya; T–T — Teisseyre-Tornquist margin of Baltica

Małopolska sector of Baltica, which represented a part (promontory or proximal terrane) of the thinned, extended margin of the East European Craton (Figs. 13 and 14). This resulted in the formation of the foreland basin on the MB, the one in which the detritus from the 640–550 Ma terranes was merged eastward, in the MB eastern succession, with the detrital input from the Baltica continent (EEC). All the discussed terranes might have been parts of the Teisseyre Terrane Assemblage, proposed by Nawrocki and Poprawa (2006) and renamed to the Teisseyre-Tornquist Terrane Assemblage by Nawrocki *et al.* (2007), which occurred close to the present T–T margin of Baltica. Timing similar to that mentioned above is characteristic for events in the Avalonian–Cadomian belt (Murphy *et al.*, 2004; Nance *et al.*, 2008). The question is whether other features of these terranes, apparent connections to Baltica in particular, allow to include this assemblage into the belt and to what extent.

In general, the Avalonian–Cadomian belt is viewed as a peripheral orogen at the edge of Gondwana that developed in settings similar to those known from the East and West Pacific. It consists of two types of crustal elements. The Avalonian terranes originated from 1.3–1.0 Ga juvenile arc crust that accreted to Gondwana and underwent high-grade metamorphism at ~650 Ma, which was followed by *ca.* 640–570 Ma arc-related magmatism, then *ca.* 570–540 Ma wrench-related bimodal volcanism and sedimentation, and finally by Early Cambrian platformal succession (Murphy *et al.*, 2000, 2004). The Cadomian terranes originated above the ~3.0–2.0 Ga crust along the margin of the West African craton subjected diachronously to arc-type recycling during the late Neoproterozoic, with period of deformation and metamorphism at *ca.* 650–615 Ma that separated two phases of arc magmatism. The main, younger phase terminated at *ca.* 615–570 Ma and was followed by strike-slip tectonics till ~540 Ma (Nance and Murphy, 1994; Nance *et al.*, 2002, 2008). In Early Palaeozoic times, the Avalonian and Cadomian terranes were separated by the Rheic Ocean (Linnemann *et al.*, 2004, 2007).

As noted above, the Thaya Terrane presumably was a part of the Amazonian Craton once involved in the Grenvillian Orogen, then coupled with the Slavkov Terrane at 640–620 Ma, which produced an active Gondwanan margin and magmatic arc with the 580–550 Ma suprasubduction granites. An unspecified back-arc rifting, likely connected with the Pannotian stage of the Rodinia break-up (Dalziel, 1997), liberated from Gondwana the Thaya–Slavkov couple that (obliquely?) collided with the Rzeszotary Terrane around 560 Ma. The composite terrane of Brunovistulia was formed in that way by the collisions within Pannotia. The 2.7–2.0 Ga old Rzeszotary basement indicates linkage either with the West African Craton, tectonothermally inactive between 2.0 and 0.58 Ga (Murphy *et al.*, 2004), or possibly with the Maroni–Itacaiúnas Belt of the Amazonian Craton that also has similar age characteristics (Tassinari *et al.*, 1999). Baltican origin of the Rzeszotary Terrane seems rather improbable as the seismic velocity structure of its crust is quite different from that of Baltica (Malinowski *et al.*, 2005). This terrane carries magnetic anomalies (Buła and Żaba, 2008) which may be caused by basic rocks similar to those exposed in the Rzeszotary horst. However, the source of the anomalies cannot be verified by gravity studies because of the masking effect from widespread mineralization in carbonate rocks of Devonian cover, and the basites themselves are too old to represent an ophiolitic suture between the Slavkov and Rzeszotary terranes. Concluding, we suppose that Brunovistulia is clearly of Gondwanan descent, possibly derived from the sector where the Amazonian and West African Cratons were not far from each other. On the other hand, the palaeomagnetic and palaeobiostratigraphic data suggest that Brunovistulia must have been finally assembled in the proximity to Baltica.

In Romania, the South Dobrogea basement contains Proterozoic ironstones (BIF) similar to the Krivoy Rog series of the adjacent East European Craton (Visarion *et al.*, 1979; Dimitriu, 2001). This crustal element might have been a continental ribbon separated from Baltica by Neoproterozoic rifting which was probably recorded by the Cocoşu Group. The Central Dobrogea (CD) basement includes some arc/back arc metatholeiites with protoliths around 700 Ma or older. Metabasites of that age occur in the suture now welding the Thaya and Slavkov terranes in Brunovistulia, but it is unknown whether these fragments of supposedly oceanic crust are directly related. However, the detrital zircons retrieved from the Histria Fm. show that the Neoproterozoic flysch of CD was fed from the source with single grains of 1.5 and 1.0 Ga age, and dominated by grains dated at ~690–580 Ma (Fig. 11). Such age spectrum suggests the presence of the Gondwana-type crust concealed in the southern part of South Dobrogea. On the other hand, the continental block provenance of detrital material (Fig. 5) may indicate a source in the faulted cratonic crust. Accordingly the crustal fragments that contributed to the Moesian Block might have been derived from both Gondwana (Amazonia?, East Africa?) and Baltica.

In Małopolska, no basement underlying the Neoproterozoic flysch-type series is known from geological observations. Seismic refraction profiling revealed low velocity rocks down to 15–18 km that are interpreted as a thick succession of rift-related and passive margin metasediments deposited on the thinned Baltica margin (Malinowski *et al.*, 2005) in which Małopolska formed a distinct promontory. The folded and sheared flysch succession was probably detached from the underlying Neoproterozoic basement and displaced by thrusting landward over the Baltica margin, but the available drillholes were to shallow to prove or discard such a possibility. U-Pb ages of detrital zircons from Ediacaran rocks in Małopolska (this study) and K-Ar ages of detrital micas (Belka *et al.*, 2000; Nawrocki *et al.*, 2007) from Cambrian rocks of the Holy Cross Mts. suggest that the flysch succession was deformed at the end of the Ediacaran.

In West Małopolska, an age group of 670–570 Ma dominates among detrital zircons in the flysch series.This age group is less significant in East Małopolska and virtually absent from the EEC margin (Fig. 11). In Upper Silesia (domain B), most analysed zircon grains fall in a group of 650–550 Ma and directly reflect the composition of the adjacent crystalline source area (domain A). The two came into contact after the Thaya–Slavkov and Rzeszotary terranes obliquely collided.

The revealed pattern of the detrital zircon distribution is consistent with our results of regional, sedimentological, geochemical and structural observations which all support the notion that the extensive Neoproterozoic flysch-type deposits in Brunovistulia, Małopolska and Central Dobrogea developed in a foreland system which accumulated clastic sediments derived by erosion from the crystalline hinterland that evolved between ~690 and 550 Ma. The US domain B was nearest to this hinterland. The West Małopolska succession might have also occupied rather proximal position to Brunovistulia or to another terrane with similar evolution and properties (e.g. alike zircon ages, Fig. 11) as suggested by the high contents of the 680–550 Ma detrital zircon grains that underwent relatively short surface transport. Such interpretation concurs with the presence of the 2.7–2.0 Ga old zircons in borehole Zalasowa (Zalas; Fig. 2), similar in age to the Rzeszotary basement nearby. On the other hand, the East Małopolska and Central Dobrogea clastic series which contain more zircons of other age groups were evidently more distant and/or fed from another portion of the hinterland, now unknown (hidden below the Carpathians), and from the nearest craton, i.e. from Baltica. Characteristically, the Ediacaran platform sandstones (Białopole, Figs. 2 and 11) from the EEC margin do not contain Neoproterozoic zircons although such zircons already occur in overlying Lower Cambrian and younger sandstones of this margin (Valverde-Vaquero *et al.*, 2000; Jachowicz *et al.*, 2002), which testifies to the appearance of Brunovistulia and related terranes at the Precambrian/Cambrian boundary. For Małopolska and Baltica, the proposed interpretation is consistent with the U-Pb zircon age spectra, provenance characteristics, similar low $\varepsilon Nd_{(T)}$ values, similar with seismic velocity structure of the crust (Malinowski *et al.*, 2005) and sedimentological data from the Cambrian siliclastic rocks of the EEC margin and adjacent units (Jaworowski and Sikorska, 2006). Accordingly, the

Neoproterozoic foreland basin of Małopolska was floored by the Baltican crust.

The multiphase folding and localized metamorphism of the foreland basin infill, dying out toward the craton, is fully consistent with such scenario. However, the obliquity of the Małopolska structural grain to the EEC margin suggests transpressional regime and dextral strike-slip movement effective on crustal faults in the basement to the Trans-European Suture Zone (TESZ). The folding and shearing as interpreted from the observations in drill cores led likely to a large-scale antiformal stack with metamorphosed belt in the core. It may have resulted in a positive topographic relief which probably prevented the region from being covered with Cambrian overstep deposits. In Małopolska, a platform cover started to accumulate in the Arenigian with limestones in its western part and sandstones to mudstones in more central part. In its eastern part, mostly shales and sands of Arenigian age were laid over shallow-water Cambrian clastics (Jaworowski and Sikorska, 2006; Fig. 1).

In Dobrogea, the Ediacaran flysch of the Histria Fm. and Băltăgeşti Fm. also underwent very low-grade metamorphism and N-vergent folding around 570 Ma (Kräutner *et al.,* 1988; Seghedi *et al*., 2001), associated with stacking and thrusting of the Proterozoic basement over the flysch, with uplift dated at ~547 Ma. The deformation could only be due to the continued shortening and pushing of the Dobrogean units from the south onto the adjacent margin and the East European Craton was apparently the only candidate (Seghedi and Oaie, 2004). A passive role of the southern margin of this craton, the Scythian Platform, postulated in older Russian literature was recently recalled by Saintot *et al*. (2006). Chen *et al*. (2002) dated at 590–560 Ma (meta)granitoids from the Istanbul Zone and found that together with the country rocks they were cooled and uplifted at 548–545 Ma, with no later overprint. Although now displaced to the south due to the Black Sea opening in the Late Cretaceous, in latest Neproterozoic times, the Istanbul Zone was likely attached to the Scythian margin of Baltica and may be regarded as one of the Gondwana-derived terranes which became accreted to Baltica in the Ediacaran. Transpressional accretion of terranes at that time was also envisaged along the southern Baltica margin by Oczlon *et al*. (2007). These events are still poorly constrainted because of extensive Phanerozoic overprints.

The crucial issue for explaining the geodynamic situation of the studied terranes in Neoproterozoic times is the commonly accepted neighbourhood of Baltica and West Gondwana in Rodinia. After the break-up of this supercontinent, they still were close to one another forming the transient supercontinent Pannotia, a purported short-lived successor to Rodinia which evolved at 580–540 Ma from the collisions between parts of fragmented Rodinia (Dalziel, 1997). Baltica, Laurentia, Siberia, Gondwana were accompanied by microcontinents liberated during this reconstitution. Relocations gave rise to various collisions between those large and small crustal pieces. It was the very process that allowed Brunovistulia to assemble and then to dock transpressionally with Baltica along its S/SW (Małopolska, T–T) passive margin. Palaeomagnetic data show that Baltica experienced rotation and fast transfer to the equatorial position in late Ediacaran times (Popow *et al*., 2002; Lewandowski and Abrahamsen, 2003; Nawrocki *et al*., 2004*a*, *b*; Nawrocki and Poprawa, 2006). Brunovistulia was in the equatorial position at *ca*. 540 Ma (Nawrocki *et al*., 2004*a*, *b*) and remained close to this continent through the whole Phanerozoic, which does not preclude its later rotation and strike-slip movements on the Kraków–Lubliniec Fault Zone (Żaba, 1999). Such later events are beyond the scope of this paper.

A mechanism which detached continental fragments from Gondwana was an overall rifting coupled with some back-arc extension during Rodinia break-up which started around 750–700 Ma and especially during the subsequent Pannotian reorganization of the supercontinent caused by the activity of a mantle plume. Baltica and Gondwana disparted leaving behind some continental ribbons which with time became transformed into microcontinents/terranes. Baltica remained rimmed by passive margins whereas an oceanic subduction below West Gondwana made its margin active. Convergent regime brought about the accretion of some terranes and led locally to back-arc rifting which eventually separated several continental fragments from the Gondwana mainland already in the Neoproterozoic. The oceanic ridge spreading promoted their outward drifting. Some of them might collide with still nearby continents and/or microcontinents.

The terranes featured in this study could be parts of the above scenario (Fig. 14). Ophiolite relics of the Central Basic Belt between the Thaya and Slavkov terranes (Fig. 13), dated at *ca*. 725 Ma represent fragments of an ocean (Iapetus) opened between Laurentia, Gondwana and Baltica when Rodinia started to break-up. Thaya was part of Amazonia when it was coupled with Slavkov at *ca*. 640–620 Ma. The coupling was associated and followed by deformation and amphibolite facies metamorphism (pre-580 Ma) in the newly formed magmatic arc. Continued subduction led to the back-arc opening and effective drifting of the Thaya–Slavkov couple between 620 and 580 Ma, possibly during the Pannotian reorganization. Probably, the Rzeszotary Terrane was detached from West Africa or Amazonia (Maroni–Itacaiúnas) roughly coevally. Having drifted an unknown distance, the two collided at *ca*. 560 Ma and formed Brunovistulia. This occurred at low latitudes and in the proximity to Baltica with which it started soon to share fauna and microflora. A significant part of the Baltican thinned passive margin (Figs. 2 and 13) was the Małopolska promontory that became transformed into the foreland in front of the hinterland composed largely of Gondwana derived terranes. The two were transpressionally juxtaposed.

Brunovistulia either also embraced the Carpathian basement fragments (Zemplin massif in Slovakia, Apuseni Mts. and South Danubia in Romania) and the West Moesia (Seghedi *et al*., 2005), or these units formed another terrane(s) in proximity to Baltica too. The other parts of Moesia (South/Central Dobrogea) were likely of Baltican descent. The western and eastern parts of Moesia might have assembled, like the Slavkov and Rzeszotary terranes, at the time of granite intrusions (565 Ma) and then the Moesian Block re-accreted to S/SW Baltica apparently at 570–547 Ma. Baltica drifted away and rotated anticlockwise (Fig. 14). While rotating, Baltica could also intercept other crustal fragments which had earlier been detached from Gondwana or

Baltica itself. The rotation might have also allowed for dextral strike-slip movements of these fragments relative to the continent and between one another. Their further redistribution at the Baltica margin, though in various ways and at various distances, occurred during the Phanerozoic. This topic is, however, beyond the scope of this paper.

Notably, our study supports the existence of the Teisseyre-Tornquist Terrane Assemblage (TTA, Nawrocki and Poprawa, 2006; Nawrocki *et al*., 2007) which in Neoproterozoic times comprised a group of small continental terranes including Brunovistulia, Moesia, and Małopolska. The latter formed a promontory of Baltica that may have been displaced and thus may have also acted as a proximal terrane. In our model, a characteristic feature of the TTA was a mixture of crustal elements that were derived from both Gondwana and Baltica, which led to mutual (Pannotian) collisions of the elements prior to and concurrent with the docking to Baltica in latest Ediacaran times. The presence of extensive younger covers and complex Phanerozoic evolution of individual members of the TTA impede the recognition of their Neoproterozoic history.

The onset of separation of Baltica from Gondwana within Rodinia is poorly constrained. Dynamic stratigraphy of the crust at the T–T Baltica margin and palaeogeographic reconstructions suggest that effective thinning and rifting must have occurred in pre-Ediacaran and Ediacaran times and cannot be assigned to the Cambrian (Malinowski *et al*., 2005; Li *et al*., 2008; Johansson, 2008). Basaltic volcanism of the LIP-type Volhyn Flood Basalt Province (continental alkaline basalts to quartz tholeiites) might be a part of this event but it was limited to one area only and missing in evidence at the T–T craton margin along strike (Fig. 1). Up to *ca*. 500 m thick traps and pyroclastic deposits (625–550 Ma, K-Ar and U-Pb ages), although at the surface spread parallel to the Teisseyre-Tornquist margin of the EEC (Fig. 1; Emetz *et al*., 2004; Elming *et al*., 2007), were actually fed from the NE–SW oriented crustal fractures that coincided with the Fennoscandia–Sarmatia boundary which was perpendicular to the T–T margin (Białowolska *et al*., 2002). Subsidence curves for Palaeozoic deposits in the local Podlasie–Lublin Basin (Fig. 1; Poprawa and Pacześna, 2002; Pacześna and Poprawa, 2005) located at the southwestern tip of the 1.3–1.0 Ga Volhyn–Orsha aulacogen covering this boundary, in their Cambrian segments reflect both the fault tectonics and thermal subsidence connected with the cooling of the crust that followed when the trap construction halted. Such mechanism seems to explain the continued accumulation of sediments in this basin in post-rift times, especially that the trap volcanism did not influence Cambrian sedimentation along the T–T unstable margin. K-Ar ages of micas reported by Nawrocki *et al*. (2007) from Cambrian sandstones in the Holy Cross Mts. (E Małopolska) yield a cluster at 740–720 Ma which probably reflects the onset of rifting within Rodinia and is coeval with the *ca*. 725 Ma metabasite belt trapped between the Thaya and Slavkov terranes in Brunovistulia. In the matured Cambrian siliciclastics of East Małopolska, the micas with K-Ar ages older than *ca*. 640 Ma up to *ca*. 1 Ga likely represent reworked components derived from earlier rift-related and subsequent passive margin sediments once deposited on the thinned Baltica margin.

The Ediacaran/Cambrian configuration was not final, however and some sectors of the SW/S margin of Baltica and adjacent terranes were later subjected to rifting and further reorganization during the Palaeozoic and Mesozoic. This was achieved by strike-slip tectonics. One of the examples is the KLZ along which Brunovistulia was sinistrally transported with respect to Małopolska for unknown distance in the late Silurian and dextrally in the latest Carboniferous (Żaba, 1999), in the latter case affecting the Devonian platform cover which spread across the terrane boundary (Buła, 2000). Another example is North Dobrogea, intervening between Baltica and Central Dobrogea, with the record of Palaeozoic rifting and deposition and subsequent Cimmerian orogenic overprint (Săndulescu, 1984), and likewise the Scythian and Istanbul-Zonguldak terranes further east. Owing to such events, other Gondwana derived terranes are now found dispersed along the SW/S margin of the East European Craton between Poland and Kazakhstan.

Comparing our data with the aforementioned characteristics of the Avalonian–Cadomian belt, similarities in the timing of events are evident. In Brunovistulia, these are: (1) ~640–620 Ma — terrane collision with deformation, metamorphism and plutonism, (2) ~590–580 Ma — arc-type granitoid intrusions, (3) ~560–550 Ma — late bimodal magmatism and strike-slip deformation, followed by an overstep lower Cambrian platform. Such clear sequence of events strongly supports the connection of Brunovistulia with the Avalonian–Cadomian belt in Neoproterozoic times. However, its further history was largely independent of the belt from which the terrane had already been detached in the Ediacaran and docked with Baltica and Baltica-derived slivers around the Precambrian/Cambrian boundary. Actually, it heralded there the Avalonian–Cadomian belt that in a similar way approached first Baltica and then Laurussia in consecutive steps between Late Ordovician and Late Carboniferous times. Further studies are necessary to test the proposed interpretations.

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