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Detrital zircon age data from the conglomerates in the Upper Silesian and Małopolska blocks, and their implications for the pre-Variscan tectonic evolution (S Poland)

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Detrital zircon age of the conglomerates from the Upper Silesian (USB) and Małopolska (MB) (S Poland) have been investigated to compare their deposition age and possible provenience. The size and poor sorting of the lithoclasts reflect a short transportation, with deposition close to the sourceland. The Late Ediacaran conglomerate of the Potrójna IG 1 and Raciechowice 1 boreholes (USB) reveal a good match between the ages known from the local basement explored by boreholes. Detrital zircon clusters in a range of 579–585 Ma and 628–638 Ma and of 707 Ma are consistent with the distributions of Cadomian magmatism within the nearest orogenic belt or those identified elsewhere within the Brunovistulicum. In case of the conglomerate deposited in the Batowice 2 borehole (MB), the zircon clusters of 532, 551, 594 and 649 Ma, accompanied with a pre-Svecofennian group peaked at 2071 Ma, and the lack of Sveconorvegian population may document a tectono-sedimentary interaction between the Baltica's southern margin and the Gondwanan Cadomian and Late Cadomian basement during Early Paleozoic time. This conglomerate bed was deposited later, after the Early Ordovician, then docking of Małopolska Block – Baltica was probably completed.

Key words: Teisseyre-Tornquist Terrane Assemblage, maximum deposition age, proximal source, provenance, Cadomian orogen, Baltica.

INTRODUCTION

The U-Pb detrital zircon geochronology of sediments provides information about the age of clastic components and, in some cases, constrains a deposition time of sedimentary units.

Identifying specific age populations enables more regional and palaeogeographic comparisons between other units and matching them with potential sediment-source areas. Many of the provenance age determinations have been made on zircon grains extracted from sand-sized clastic rocks that are transported usually over thousands of kilometres (Pell et al., 1997; Sircombe, 1999; Bassett, 2000). However, coarse-grained deposits, including conglomerates, arise as a result of much shorter transport distances, e.g. tens to hundreds of kilometres (Kodama, 1994; Ferguson et al., 1996) and therefore may have a particular application for the provenance study of proximal sources.

In general, the conglomerates, as specific immature sediments, are deposited relatively close to the sourceland and typically associated with regions of high tectonic activity. The large size of the clasts and their poor sorting reflect short distances of transportation.

This aspect of detrital zircon geochronology has been explored by sampling conglomerate deposits from the Upper Silesia Block and the Małopolska Block. Both blocks are situated in the area between the western edge of ancient lithosphere of the East European Craton (EEC) and the younger lithosphere of the Paleozoic terranes of Central and Western Europe (Fig. 1A). At the end of the Neoproterozoic they formed the southernmost part of the Teisseyre-Tornquist Terrane Assemblage (Nawrocki and Poprawa, 2006; Żelaźniewicz et al., 2009), finally amalgamated in Early Paleozoic time (Buła, 2000; Belka et al., 2002), or as the proximal terranes detached from the cratonic margin and re-accreted after dextral translation (Dadlez et al., 2005).

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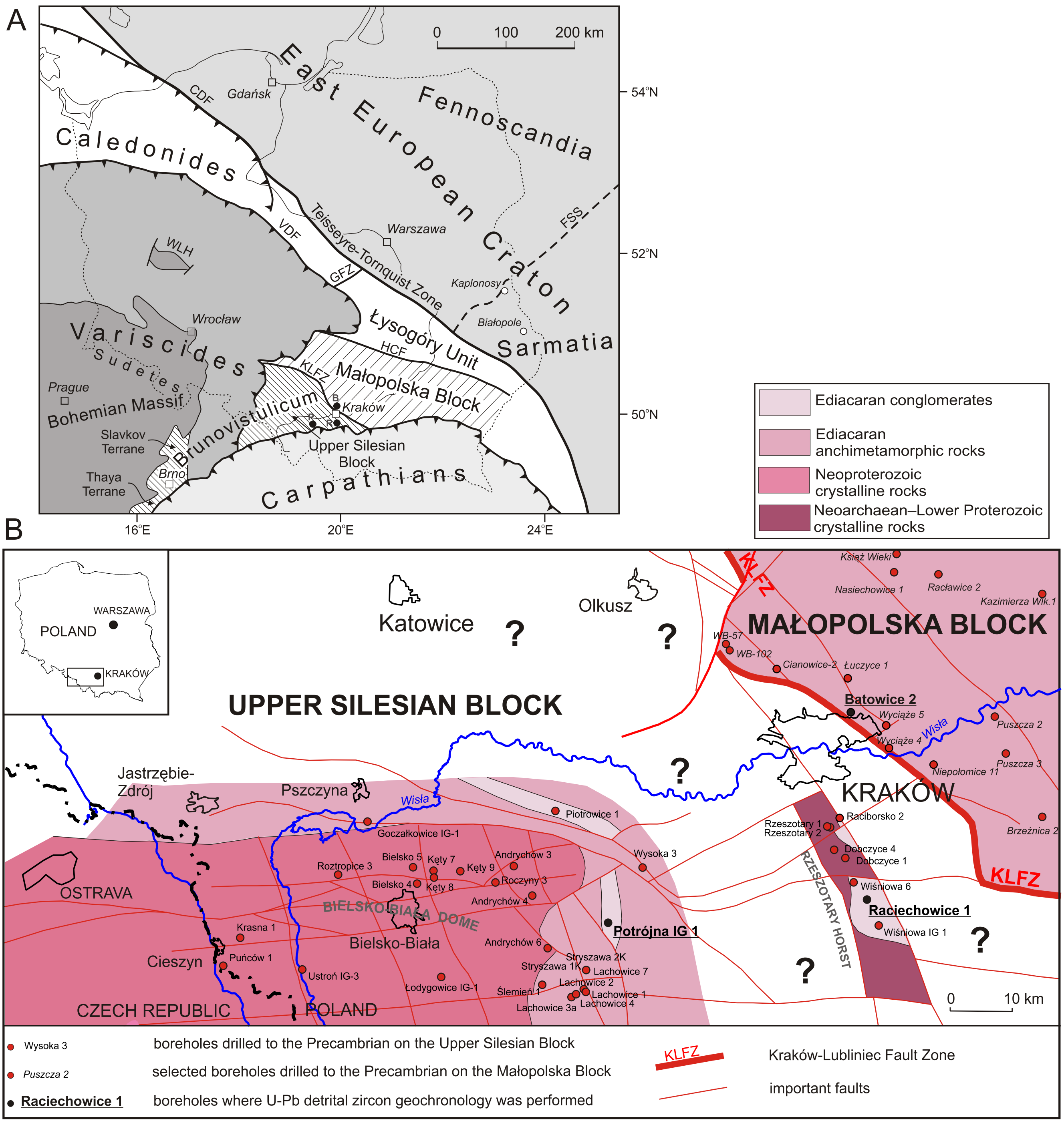


Fig. 1A – the position of the USB as a part of the Brunovistulian Terrane and the MB at the sub-Permian-Mesozoic palaeosurface on a tectonic sketch map of Central Europe (after Mazur and Jarosiński, 2006; Nawrocki and Poprawa, 2006); CDF – Caledonian Deformation Front, FSS – Fennoscandia-Sarmatia Suture, GFZ – Grójec Fault Zone, HCF – Holy Cross Fault, KLFZ – Kraków-Lubliniec Fault Zone, VDF – Variscan Deformation Front (after Pożaryski et al., 1992), WLH – Wolsztyn-Leszno High; the locations of drill holes are marked by black circles P – Potrójna IG 1, R – Raciechowice 1 (USB), B – Batowice 2 (MB); B – geological sketch map without formations younger than Precambrian in the area of the Upper Silesian Block and SE part of the Małopolska Block (after Buła and Żaba, 2005; Buła et al., 2015 modified), showing the location of the Potrójna IG 1, Raciechowice 1 and Batowice 2 boreholes and adjacent boreholes reaching Precambrian rocks

Their accretion process and particular paths of evolution that refer to Late Ediacaran and Early Paleozoic times are still a matter of debate (Dadlez et al., 1995, 2005; Pharaoh, 1999; Belka et al., 2000, 2002; Nawrocki and Poprawa, 2006; Narkiewicz et al., 2015; Walczak and Belka, 2017). Another widely discussed issue remains an affinity of these crustal units. The state of knowledge for both areas is not equivalent. Even incomplete data indicate a distinct palaeogeographical, facies and palaeotectonic development (Buła, 2000; Buła et al., 2008) of USB and MB during the Precambrian and Early Paleozoic.

The USB is commonly referred to as the exotic terranes with respect to the EEC (or Baltica). There is no close palaeogeographic relation of both the domains during the Early Cambrian (Nawrocki et al., 2001). Usually, USB is interpreted as having been derived from the Cadomian margin of Gondwana or Avalonia and finally docked to Baltica before the Early Devonian (Belka et al., 2000, 2002; Nawrocki and Poprawa, 2006).

In contrast, the MB is interpreted to be an integral part of Baltica margin, located in the present-day position during the whole Paleozoic (e.g., Dadlez, 2001; Jaworowski and Sikorska, 2006) or supposed to have been docked to Baltica in the Late Cambrian (Belka et al., 2000, 2002; Valverde-Vaquero et al., 2000; Winchester et al., 2002; Nawrocki and Poprawa, 2006; Nawrocki et al., 2007) or in the Silurian (Pożaryski, 1991; Narkiewicz, 2002; Verniers et al., 2008). It is pointed out that MB displays linkages to both the Baltica and Peri-Gondwana palaeocontinents (Belka et al., 2002; Nawrocki et al., 2007; Żelaźniewicz et al., 2009).

The evidence for the geotectonic origin of MB came from palaeomagnetic and isotopic provenance studies. The early geochronological analyses based on a low number of detrital mica and zircon measurements from fine-grained sediments (Belka et al., 2000, 2002) supported by model ages of clastic rocks from the northern part of MB and their Nd signatures (Walczak and Belka, 2017) allow concluding on their origin from Amazonian sources.

Significant arguments were provided after re-investigation of Cambrian fauna from the Kielce region of MB. The origin of Cambrian trilobites have been substantially revised (Żylińska and Masiak, 2007; Żylińska and Szczepanik, 2009; Żylińska, 2013) and then directly correlated with the Scandinavian successions, stating a Baltic biogeographic affinity. Part of the trilobite fauna, however, indicates strong similarity to the West Gondwana and Avalonia faunas. The presence of Avalonian and West Gondwanan trilobites in the succession, with the proliferation of single species over a large area, suggests that the MB margin belonged to a region with a mixed fauna. This led to the conclusion that MB must have also faced West Gondwana and Avalonia during the Cambrian epochs 2 and 3 (Żylińska, 2013).

In such an ambiguous geological context, detrital zircon age investigations focused on clastic material from eroded proximal sources, and deposited on margins of USB and MB (Fig. 1B) seems to be an appropriate tool to track the relationship between adjacent crustal blocks from the period when both the blocks might have remained independent.

The increase in U-Pb zircon data sets for crystalline and sedimentary source areas in the Baltica basement, USB and MB during the last decade allows for more specific comparisons between detrital zircon clusters and potential sediment source rocks than were previously possible.

Detrital zircon age data from conglomerates consisting of >100 dates acquired from each sample provide independent means to test for a tectonic relationship to the margin of EEC (Baltica) and the Precambrian/ Lower Paleozoic succession.

In the light of these advances, a detrital zircon geochronology of proximal deposits from the adjacent USB *versus* and MB, using the large-*n* methodology, is the main purpose of this contribution.

GEOLOGIC SETTING

UPPER SILESIAN BLOCK

The Upper Silesian Block forms a northern part of the composite Brunovistulicum Terrane (BVT) neighbouring the Bohemian Massif from the east (Dudek, 1980; Buła and Żaba, 2005, Kalvoda et al., 2007). Besides USB, the BVT includes also the Brno Massif (Block), and the Thaya and Slavkov units located on the territory of the Czech Republic, where several types of granitoids and gneisses have been documented (Friedl et al., 2004; Buła and Żaba, 2005, 2008; Kalvoda et al., 2008). The boundary between the USB and the Brno Block is determined by the Hána Fault developed on pre-Cambrian foundations (Buła et al., 2008, 2015). The western boundary of the BVT, at the contact with the Moldanubicum of the Bohemian Massif, is marked as the Moravo-Silesian Fault Zone (Buła et al., 2015).

The NE boundary with the Małopolska Block corresponds to the Kraków–Lubliniec Fault (Buła et al., 1997). Thus, the zone is interpreted as a pre-Devonian accretionary suture reactivated during the Variscan orogenic activity.

The basement of BVT, formed during the Cadomian Orogeny (Finger et al., 2000), is overlain by weakly metamorphosed Ediacaran flysch deposits. The total thickness of the Ediacaran to Cenozoic cover attains 8 km in the central and northern parts, decreasing to 2–3 km in the south and 1 km in the east.

In the southeastern part of BVT, in the area between Brno and Kraków, including USB, the basement rocks were identified by boreholes. The Precambrian and Lower Paleozoic rocks of USB were penetrated by ~450 boreholes, but not uniformly distributed over the area (Buła and Habryn, 2011; Buła et al., 2015). The Precambrian basement is represented by three rock complexes (Fig. 1B), different in terms of the origin and age (Buła and Żaba, 2008; Buła et al., 2008, 2015):

- Neoproterozoic (660–556 Ma) complex of igneous and metamorphic rocks of the Bielsko-Biała Dome, known from Cieszyn–Żywiec–Bielsko-Biała–Andrychów–Kęty area;
- Late Neoproterozoic (Ediacaran) complex of anchimetamorphic flysch-type deformed siliciclastics, recognized in a narrow belt stretching from Goczałkowice through Piotrowice–Wysoka–Potrójna to the Lachowice area.
- Paleoproterozoic (2.0 Ga), easternmost complex of the Rzeszotary Horst (south of Kraków), between Rzeszotary and Wiśniowa (Fig. 1B). It is a relatively narrow, elongated, NNW–SSE-trending structural element extending to the boundaries of the Kraków-Lubliniec Fault Zone, where mafic amphibolite-type rocks, with inherited Neoarchean protolith of 2.7 Ga age, have been recognized by drillings.

In the period preceding the development of the Cambrian sedimentary basin, the crystalline basement was subject to erosion resulting in locally occurring conglomerate beds, filling tectonic trench structures on the Late Ediacaran surface, mostly in the eastern part of USB. These coarse-grained deposits are composed of lithoclasts of plutonic, volcanic, with minor metamorphic and sedimentary clasts, and characterized by a thickness ranging from 4 to >150 m.

The Lower Paleozoic that covers the eastern part of USB is represented by unmetamorphosed Cambrian siliciclastic and Ordovician siliciclastic-carbonate rocks. The stratigraphic position of the Lower Cambrian, Middle Cambrian and Ordovician units is based on acritarch and trilobite fauna (Buła and Jachowicz, 1996; Moczydłowska, 1997). A more detailed description of each lithostratigraphic unit was provided by Buła et al. (2015).

MAŁOPOLSKA BLOCK

The Małopolska Block represents a tectonic unit of unidentified age of consolidation, because its crystalline basement has not been encountered. According to some authors, the MB is in fact composed of several sub-units of different geological developments, including the northern Kielce Block and southern Miechów-Rzeszów Block, while Belka et al. (2000) defined the eastern part of MB as the San Block.

In consequence, the present-day MB has in general a "mosaic" nature, expressed by the presence of block structures formed by Ediacaran anchimetamorphic rocks surrounded by various rocks of different Paleozoic ages, as a result of Variscan faults with high amplitudes (Buła and Habryn, 2008 and references therein).

In the westernmost part, the MB is separated from USB by the tectonically well-defined Kraków-Lubliniec Fault Zone (KLFZ), probably forming a part of the prominent Hamburg-Kraków transcontinental fault zone (Buła et al., 2008 and references therein), KLFZ which continues also into the basement of the Outer Carpathians to the south-east. From the south, the MB is covered by thick Carpathian flysch and limited by the Peri-Pieniny Zone. According to geophysical investigations, the MB basement may occur at depths exceeding 10 km (Malinowski et al., 2005).

A sequence of rocks recognized in MB consists of Late Neoproterozoic (Ediacaran) deposits covered by Lower Ordovician to Neogene clastic and carbonate rocks. At least five unconformities, including Ediacaran/ Cambrian and Cambrian/Ordovician, have been documented in this sequence. The oldest rocks of the MB, recognized so far, are mainly siltstones and mudstones, dated by palynological methodology as Ediacaran (Jachowicz-Zdanowska, 2014). They were discovered in the newly drilled Cianowice 2 borehole (Habryn et al., 2014). The Ediacaran sediments were covered directly by Middle Jurassic sandstones and conglomerates.

The Ediacaran clastic rocks, poorly sorted sandstone and conglomerate beds with planar bases and gradual, indistinct tops, indicate turbiditic deposition (Żelaźniewicz et al., 2009). For part of the flysch-type rocks, Ediacaran age was confirmed by acritarchs (Jachowicz-Zdanowska, 2011). There is also a tuff horizon recognized at a depth of 1388–1394 m in the Książ Wielki IG 1 borehole (for location see Fig. 1B), where a U-Pb age of 549 ±3 Ma (Compston et al., 1995) clearly supports the late Ediacaran age of the MB deposition.

In the southwestern part of MT, close to the contact with the USB, the Ediacaran siliciclastic rocks are covered uncomfortably by Ordovician-Lower Silurian carbonates and Upper Silurian shales (Buła et al., 1997; Buła and Habryn, 2008).

The exposures of Cambrian sedimentary succession of MB, composed of siliciclastic rocks, are known from the northern part, in the area of Holy Cross Mountains. The lowermost part of the Ordovician succession consists of glauconite-rich mudstones with abundant pyroclastic material (Salwa and Trela, 2019).

Several ash beds are preserved between the Upper Ordovician and Silurian dark shales and mudstones of the Holy Cross Mountains (Trela et al., 2018). The Silurian succession of MB has been compiled from discontinuous drill core profiles. It comprises Llandovery, Wenlock and Ludlow deposits correlated with a coeval sequence exposed in the Kielce Region of the Holy Cross Mountains (Verniers et al., 2008 and reference therein). In the southwestern part of MB (near Kraków), the Silurian deposits are divided into two parts. The older one is dominated by schists. The younger part is composed of mudstones, sandstones and conglomerates from Łapczyca (Heflik and Konior, 1972; Konior, 1974 and references therein). The thickness of these series varies from 10 m in the Wyciąże 1 borehole to over 217.1 m in the Batowice 2 borehole. These conglomerates were regarded as a Middle Ludlow molasse-type deposit of the Caledonian orogenic period (Łydka et al., 1963).

The important lithologic unit in the upper part of the sequence is greywackes (Niewachlów Beds) composed of sedimentary and volcanic rocks deposited during the mid-Ludlow (Kozłowski et al., 2014). A time frame of volcanic and subvolcanic activity at the end of the Ludlow was confirmed by diabase dykes of 432 ±2 Ma (Nawrocki et al., 2007) and abundance of volcanogenic zircon grains crystallized at 425–426 Ma, preserved as xenocrysts in the Kielce tuffs (Krzemińska and Krzemiński, 2019).

SUMMARY OF PUBLISHED U-Pb ZIRCON AGE DATA

Only a few geochronological reports have been published during last decades for the Precambrian rocks of USB and MB (Compston et al., 1995; Bylina et al., 2000; Żelaźniewicz et al., 2009; Żelaźniewicz and Fanning, 2020) or their xenoliths recognized between younger sediments (Burda et al., 2019; Gawęda et al., 2019). Nevertheless, they provide a significant support for the interpretation of the new outcome of detrital zircon age data in both areas.

The evidence of the oldest basement within USB derives from the unique Rzeszotary Horst (RzH) which is composed of high-grade migmatized orthoamphibolites and gneisses. The conventional U-Pb dating of zircons from the RzH amphibolites yielded the upper intercept age of 2732 +23/–21Ma (Bylina et al., 2000) interpreted as the age of igneous protolith, whereas the zircons from neosomes analysed by *SHRIMP* pointed to a prominent metamorphism or/and migmatization at ~2.0 Ga (Żelaźniewicz et al., 2001; Żelaźniewicz and Fanning, 2020).

The most common evidences of the igneous activity in USB and adjacent units within BVT are referred to Late Neoproterozoic time (Table 1). The zircon U-Pb dating documented a reliable age of several granitoid bodies of the Bielsko-Biała Dome (Żelaźniewicz et al., 2009), which crystallized at ~582.7 Ma (Roztropice) and 579 ±2.7 Ma (Kęty-8). Besides igneous rocks, the Neoproterozoic turbiditic successions in USB, fed largely from a former active margin of the recycled collisional orogen and its hinterland, provided a record of detrital zircon ages (Żelaźniewicz et al., 2009). The 90% of all analysed grains (n = 37), summarized from two samples, fall in a group of 680–550 Ma, accompanied by single grains of ~1.5 and ~1.9 Ga (Żelaźniewicz et al., 2009).

Among data obtained directly from USB, a similar U-Pb zircon age has been acquired from an exotic megablock (>100 m) known from the Western Outer Carpathians flysch (Burda et al., 2019). These orthogneisses occurred in Bugaj and Andrychów on the boundary between the Silesian and Subsilesian units. They crystallized at 580.1 ±6.0 Ma and 542 ±21 Ma, respectively, and were interpreted as olistoliths within the Silesian Nappe (Burda et al., 2019). Similar crystalline olistolithswere also collected from the Outer Carpathian basin flysch (Istebna, Osielec and Nowe Rybie exotics) covering the eastern prolongation of USB (Gawęda et al., 2019). These rocks provided directly a record of the hidden magmatic/metamorphic rocks formed at 566 ±3.1 Ma, 603.7 ±3.8 Ma, 613.3 ±2.6 Ma, and 617.5 ±5.2 Ma, most probably originated from the eastern BVT (USB). Thus, they are interpreted as an evidence of a Cadomian crystalline basement element.

The same type of coeval igneous activity (Table 1) was documented in the exposed westernmost part of BVT. Much more U-Pb zircon ages were obtained from the western part of BVT, close to the Brno Massif (Soejono et al., 2017; Hanžl et al.,

Table 1

The evidences of igneous activity from USB, MB and adjacent units

Area	Sample ID	U-Pb age [Ma]	Rock type	References
Brunovistulian terrane	Lody	629 ±6	granodiorite	Żelaźniewicz et al. (2009)
Upper Silesian Block	Rozt-2	583 ±6		Żelaźniewicz et al. (2009)
	Kety 8	579 ±2.7		Żelaźniewicz et al. (2009)
	Rocz	558 ±4		Żelaźniewicz et al. (2009)
(olistoliths)	Bugaj	580 ±6	granitoid	Burda et al. (2019)
exotic blocks	Andrychów	542 ±1	orthogneiss	Burda et al. (2019)
Fore-Sudetic Block	Strzelin	600 ±9	Gneiss	Oberc-Dziedzic et al. (2003)
	Velké Vrbno	568 ±9		Kröner et al. (2000)
	Keprnik Dome	570 ±6		Kröner et al. (2000)
Slavkov Unit	Ludvikov	684.5 ±0.9	orthogneiss	Kröner et al. (2000)
	Filipovice	612.7 ±1		Kröner et al. (2000)
	Jehnice	595 ±1	granodiorite	Timmerman et al. (2019)
	Blansko	597 ±2	tonalite	Timmerman et al. (2019)
	Lhota	606 ±2	granodiorite	Timmerman et al. (2019)
	Ždanice	601 ±2	diorite	Timmerman et al. (2019)
	Uhřice	594 ±2		Timmerman et al. (2019)
	Popice	590 ±8	leucogranite	Timmerman et al. (2019)
Thaya Unit	Gumping	595 ±1	granodiorite	Finger et al. (2000)
	DF-B (Derflice)	603 ±3.2		Svojtka et al. (2017)
	DF-C	603 ±5.2		Svojtka et al. (2017)
Central Basic Belt	Opalenka	725 ±15	metarhyolite	Finger et al. (2000)
	BM04	733 ±5		Hanžl et al. (2019)
	BM12-04	728 ±5		Hanžl et al. (2019)
Bittesch gneiss nappe	BIT-1	584 ±6	orthogneiss	Friedl et al. (2004)
	BTG-1	578 ±7		Friedl et al. (2004)
	UD2	568 ±3		Soejono et al. (2017)
	BM12-02	655 ±3		Hanžl et al. (2019)
	UD3 (Brno)	601 ±3		Hanžl et al. (2019)
	UD5 (Svratka)	634 ±6	granodiorite gneiss	Soejono et al. (2017)
	SPI1	614 ±10		Friedl et al. (2004)
	Eggenburg	583 ±11		Finger et al. (2000)
	Bittesch	578 ±7		Friedl et al. (2004)
Moldanubian terrane	Bayerischer Wald	555 ±12		Teipel et al. (2004)
		549 ±7		Teipel et al. (2004)
		549 ±6		Teipel et al. (2004)
Małopolska Block	Książ Wielki	549 ±3	tuff	Compston et al. (1995)
		(578 ±5)		Compston et al. (1995)
		(619 ±4)		Compston et al. (1995)

2019) which is separated from USB by the Hána Fault. In general, the Cadomian events identified in the BVT included: metamorphism and plutonism at ~650–620 Ma, widespread arc-type granitoid intrusions at ~590–580 Ma, and late bimodal magmatism at ~560–550 Ma. Recently, these time frames have been directly confirmed (Soejono et al., 2017) by U-Pb zircon ages of 634 ±6 Ma from the Svratka Dome, 601 ±3 Ma from the Brno Massif, and 568 ±3 Ma from the Bíteš orthogneiss (Table 1: sample UD2). A coeval igneous rocks protolith formation are known from the Moravian unit (Friedl et al., 2004).Their crystallization ages were obtained at 584 ±6 Ma (Bittesch gneiss), 578 ±7 Ma and 567 ±6 Ma (Eggenburg metagranite).

In contrast to the evidences from USB, the U-Pb age data of the MB rocks still remains poorly documented. In one borehole, Książ Wielki IG 1, however, the zircon U-Pb age determination (Compston et al., 1995) for a tuff layer confirmed the Ediacaran age of a volcanic event at ~549 ±3 Ma (72% of the total). The zircon collection contains also two older components of 578 ±4.5 Ma (13%) and 619 ±4 Ma (15%), as well as several detrital grains that have concordant and separate Early Proterozoic and Archaean ages.

The Neoproterozoic rocks of MB are represented mainly by a clastic, flysch-type series. In consequence, only detrital zircon age determination was conducted (Żelaźniewicz et al., 2009) on fine-grained sediments sampled from the area close to the Kraków-Lubliniec Fault Zone (five samples). Despite the statistically small number of archived single grain analyses (from n = 7 to n = 30) from each sample, these age data reveal the youngest population of detrital zircons have ages between ~670 and ~570 Ma. Also detrital zircon studies from the Lower Cambrian rocks from the northern part of MB (Kędziorka outcrop, Kielce Region) provided U-Pb ages of ~540, 557 and 592 Ma, and Pb-Pb ages of ~1.21.37, 1.5 and 2.0–2.1 Ga, 2.5 and 3.0 Ga (Belka et al., 2002).

SAMPLING

Sampling for the detrital zircon geochronology was performed on conglomerate beds cored in boreholes drilled a long time ago; hence, the core profiles were incomplete. New investigations of detrital zircon age were conducted on whole bulk conglomerate – rock samples, including clasts of various sizes up to fine-grained components and matrix. It was not possible to extract an individual groups of clasts, and the systematic clasts counting was not performed.

Conglomerate with clasts of various lithologies, described below, were collected from three boreholes: two from USB (Potrójna IG 1 and Raciechowice 1) and one from MB (Batowice 2) in the area near the boundary with the USB (Figs. 1B, 2 and 3).

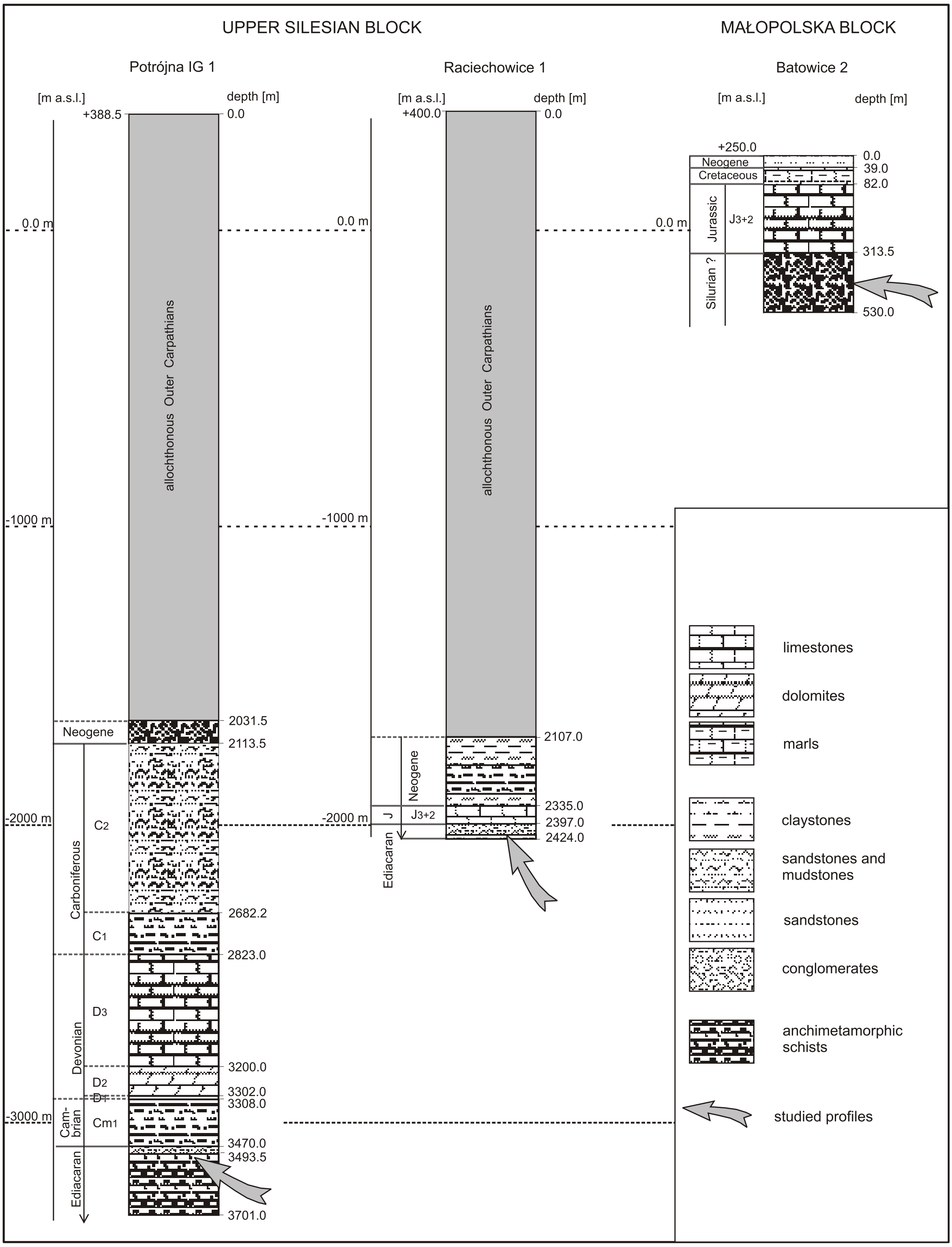


Fig. 2. Correlation of the Ediacaran/Lower Paleozoic sections of the Potrójna IG 1 and Raciechowice 1 boreholes from the Upper Silesian Block, and the Batowice 2 borehole from the Małopolska Block; intervals of sampled conglomerates are marked

Fig. 3. Photographs documenting conglomerate drill core samples and their assemblages of clasts (see the main text for explanations)

POTRÓJNA IG 1

The Potrójna IG 1 borehole represents a narrow area close to the Bielsko-Biała Dome elevated structure (Fig. 1B). This elevation is formed by Neoproterozoic crystalline rocks, mostly granitoids and meta-granitoids (Żelaźniewicz et al., 2009). The Potrójna IG 1 conglomerates (Fig. 2), covered by non-metamorphosed Lower Cambrian sediments, were interpreted as Eocambrian (Ślączka, 1985) and then as Ediacaran (Buła and Żaba, 2008). The reddish brown conglomerates occur between a depth of 3466 and 3493.5 m (Fig. 3). Two samples from depths of 3471–3472 m (Potrójna IG 1 – A) and 3472–3481 m (Potrójna IG 1 – B) were taken for detrital zircon age investigation. They represent intervals of ~1 and ~9 m in thickness, respectively, but there was no discernible lithological difference between these two samples. Thus, a division was made for checking of the results repeatability and as a control of the internal variability within one conglomerate layer. Both samples from the Potrójna IG 1 are represented by oligomictic conglomerate composed mainly of immature sedimentary and low-grade metasedimentary rocks (Fig. 3). The major components are fragments of immature greywacke, accompanied by marls, carbonates and altered pyroclastics. They not contain a clasts of igneous rocks. Feldspar grains are very scarce.

RACIECHOWICE 1

The Raciechowice 1 borehole is located on the Rzeszotary Horst (Fig. 1B) formed by a complex of Neoarchean-Paleoproterozoic crystalline rocks. The conglomerate beds were found at depths of 2399–2404 m and 2415–2424 m (Fig. 2) under Lower Jurassic deposits. No Paleozoic rocks have been preserved. Despite the lack of direct evidences, a Late Neoproterozoic age of the conglomerate was assumed based on comparisons with other deposits within USB (Buła, 2000). The available core fragments (Fig. 3) taken from depths of 2404 and 2415 m were compiled as one sample. The polymictic conglomerate consists of several different types of rocks. The pebbles derived from metasediments seem to be virtually dominated, but there are also numerous clasts of volcanic or pyroclastic rocks, and clasts of plutonic rocks and their metamorphic counterparts.

BATOWICE 2

The Batowice 2 borehole was located in the northern suburb of Kraków. Drilling was completed in 1958, thus, at the time of current sampling, the core material was fragmentary. The petrographic description was prepared by Cebulak (1958) These coarse grained sediment are covered by Jurasic strata. Under of incomplete layers of the Mesozoic sediments (Fig. 2). The conglomerate bed was drilled at a depth of 330 m, continuing down to the borehole bottom (~530 m) with a fewan arkosic sandstone and greywacke thin layers. The conglomerate consists of multi-coloured pebbles (Fig. 3): plutonic rocks including alkaline granites, pegmatite accompanied with red quartzites, black silica rocks, red-brown acid eruptive rocks (rhyolite, dacite, andesite), and some sedimentary rocks including shales, grey mudstones and greywackes. The clasts are poorly sorted and contain pebbles in range of 0.2–12 cm.

Because of a significant stratigraphic gap, there is no direct evidence of the age of conglomerate. Historically, a Devonian age was considered (Cebulak, 1958), but the rock from Batowice 2 closely resembles the conglomerate known from Łapczyca, which was assigned to the Middle Ludlow/Upper Silurian (Łydka et al., 1963).

All presented conglomerates are poorly sorted, and the pebbles show a wide range of composition, roundness and size, and contain various amounts of matrix that consists commonly of clay- or sand-sized particles or a mixture of clay and sand. The framework grains of conglomerates are composed mainly of rock fragments (lithoclasts) rather than of individual mineral grains. The rounding of the clasts indicates that they were transported over some distance from their original source and they have resided in a high-energy environment for some time.

ANALYTICAL PROCEDURES

The samples were processed by standard methods for separating zircons, including crushing, sieving, heavy liquid and *Frantz* isodynamic separator treatment, and the final hand-picking. The zircons together with chips of the *Temora-2* zircon ($^{206}Pb/^{238}U$ age of 416.8 ±0.3 Ma; Black et al., 2004) and 91500 zircon as a reference for U-content (U = 78 ppm, a $^{207}Pb/^{206}Pb$ age of 1065.4 ±0.3 Ma; Wiedenbeck et al., 1995) were mounted in epoxy and polished until quasi-central sections were reached. Cathodoluminescence (CL) technique was used to identify distinct zircon domains.

The U-Pb detrital zircons geochronology was conducted by *SHRIMP* at the PGI-NRI using analogous strategy as described by Williams et al. (2009). The analyses were performed using an O-primary beam focused onto the zircon surface with an elliptical spot size in a range of ~20–23 μm. Off-line data processing was accomplished using customized in-house software *SQUID2*. All U-Pb data are shown in Appendix 1*. Analyses were carried out on >100 spots in each sample, acquired on the core of each zircon grain, in a sequence consisting of one analysis of a *Temora-2* reference zircon measurement after every fourth unknown sample analysis.

For detrital grains >1000 Ma, the $^{206}Pb/^{207}Pb$ age is used in the cumulative probability plot, but for data <1000 Ma, the $^{206}Pb/^{238}U$ age is preferred because $^{206}Pb/^{238}U$ ages are generally more precise for younger ages, whereas $^{206}Pb/^{207}Pb$ ages are more precise for older ages (Gehrels, 2012).

To determine the maximum depositional age, the general methodology of Dickinson and Gehrels (2009) has been adopted. The only modification for the youngest cluster of zircons (n >3) that overlap in age at 2σ was the calculation of concordia age instead of weighted mean age.

Moreover, as part of the discussion, in order to compare and evaluate directly the origin of detrital zircon age, records from various clastic rocks from the EEC sedimentary cover were used.

They were collected from:

– coarse-grained sandstones and conglomerates of the Żuków Formation (Pacześna, 2014), composed of clasts de-

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1539

rived from eroded crystalline rocks deposited in gravel-bed braided river channels and on alluvial fans of the SW slope of EEC (Pacześna, 2014). They begin the Ediacaran clastic succession of the Lublin-Podlasie sedimentary basin. The results of detrital zircon age determinations, n = 80 (Appendix 2), from a polymictic conglomerate sample taken from the Kaplonosy IG 1 borehole (depth 1809 m), reflect a clastic material supplied from a relatively proximal source, most probably located on the TTZ margin of EEC in eastern and southeastern Poland;

– fine-grained sandstone of the Białopole borehole, depth 2870 m, of the Łopiennik Formation, using Pb-Pb zircon age data, n = 30, published by Żelaźniewicz et al. (2009). These clastic sediments of the Łopiennik Fm. are widespread in the central and southwestern parts of the sedimentary basin, representing the lowest part of the Ediacaran zone of *Vendotaenia–Sabellidites* in the central part of the Lublin-Podlasie sedimentary basin (Pacześna, 2014).

Due to lack of datable volcanic marker horizons or/and younger cross-cutting intrusives, diagenetic monazite grains were investigated to constrain the age of the diagenetic or/and metamorphic events (authigenic grains) or to characterize the ages of detrital monazite preserved in the matrix of conglomerates.

Chemical analyses of the monazite observed mostly within the matrix in samples from Potrójna A (USB) and Batowice (MB) were performed using a *Cameca SX 100* electron microprobe equipped with four wavelength dispersive spectrometers (WDS) at the PGI-NRI.

Monazite chemical composition was analysed using 15 kV accelerating voltage, 180 nA beam current, and ~3 μm size beam focused on a carbon-coated thin-section.

Moreover, chlorite chemical composition was analysed to obtain the temperature condition of this mineral formation, which may correspond to anchimetamorphism temperatures. Temperature was determined using solid solution thermometers that utilize a positive correlation between Al^{IV} content and temperature based on calibrated formulas proposed by Cathelineau and Nieva (1985) and Cathelineau (1988), and further modifications of those geothermometres and two further modifications of these geothermometres in which Fe/(Mg+Fe) ratio in chlorite has been employed to correct the Al^{IV} quantity (Kranidiotis and MacLean, 1987; Zang and Fyfe, 1995). All WDS analytical data are shown in Appendixes 2 and 3.

RESULTS OF DATING

DETRITAL ZIRCON GEOCHRONOLOGY

The number of single-grain analyses per sample ranges between 102 and 116. All U-Pb zircon age results obtained in this study are listed in Appendix 1, but summary of data including age characteristics of each sample are presented in Table 2.

A few results with high common lead (Pbc >1%) were excluded, but all accepted were used to construct Tera-Wasserburg and Wetherill concordia diagrams in Figure 4A–D.

POTRÓJNA IG 1 – A: DEPTH 3471–3472 m (USB)

The ages of detrital zircons from the uppermost part of the Potrójna IG 1 conglomerate range from Late Paleoproterozoic (1638 ±17 Ma) to Late Ediacaran (549 ±7 Ma). The youngest cluster is formed by six grains (Fig. 5A) with consistent U-Pb ratios and the concordia age at 554.5 ±6 Ma (MSWD = 1.3), that identify the youngest potential proto-source and may suggest the earliest possible age of deposition as the Late Ediacaran. The age spectrum has an unimodal distribution. The dominant group with a peak at ~602 Ma representing ~80% of all grains is Ediacaran (Table 2). There is also a sub-group 13.9% of Cryogenian age and two Tonian grains (Fig. 6A).

POTRÓJNA IG 1 – B: DEPTH 3472–3481 m (USB)

The ages of detrital zircons from the second sample of Potrójna IG 1 bed, range from Mesoproterozoic (1419 ±48 Ma) to Late Ediacaran (549 ±18 Ma). The youngest cluster is composed of four grains (Fig. 5B), with a concordia age at 552 ±13 Ma (MSWD = 0.073). The youngest detrital material and the dominant group of detritus represented by ~91% of grains is Ediacaran (Fig. 6B). The histogram (insert) documents at least three sub-peaks at ~585, 607 and 614 Ma. The grains older than 650 Ma are relatively rare.

RACIECHOWICE 1: DEPTH 2399–2404 m (USB)

The sample from Raciechowice 1 showed a distinct spectrum of detrital zircon ages (Fig. 4C), ranging from single Mesoarchean (3145 ±80 Ma) to Late Ediacaran (549 ±32 Ma) ages. It contains a major concentration of ages peaked at ~650 Ma and a minor concentration at ~2600 Ma. The youngest cluster is formed by four grains (Fig. 5C) that yielded a concordia age at 547.5 ±21 Ma (MSWD = 0.006), but a statistically dominant group (~39% of the analyses) has a Cryogenian age peaked at 650 Ma (Fig. 6C), with a minor Ediacaran subgroup (26.7%). There is also a prominent group of Neoarchean grains (17%), with peaks forming wider cluster around 2600 Ma.

BATOWICE 2: DEPTH 313–530 m (MB)

The age of detrital zircons from the Batowice 2 conglomerate (Fig. 4D) ranges from Paleoproterozoic (2153 ±18 Ma) to Ordovician (474 ±27 Ma). The youngest group consists of only two grains (Fig. 5D) with similar U-Pb ratios, yielding a concordia age at 482 ±27 Ma (MSWD = 0.14). The youngest single zircon grain (474 ±27 Ma) is concordant (the discordancy of +4%). The main group of ages peaked at ~590 Ma is formed by 42% of grains of Ediacaran age (Fig. 6D). The next population with a peak at ~2085 Ma is formed by 27.6% of grains of Paleoproterozoic age. The rest of the zircons show a Cambrian age (sub-group of 14.6%) and Cryogenian age (sub-group of 9.48%).

CHEMICAL GEOCHRONOLOGY OF MONAZITE

In contrast to the zircon geochronology, the monazite were analysed using grains exposed in thin-sections, thus the statistics of measurements is relatively low. The monazites from two conglomerate samples from the Potrójna IG 1 – A (USB) and Batowice 2 (MB) were studied. Chemical dating of monazites from the Potrójna sample USB (Appendix 2) revealed a limited number of small and relatively homogeneous grains, ~10 to 30 μm in size. They provide only Ediacaran ages between 590 ±44 Ma and 548 ±62 Ma.

About 20 monazite analyses from Batowice 2 (MB) document a wider age range between 658 ±44 Ma and 476 ±25 Ma.

Table 2

A summary of the U-Pb detrital zircon age results obtained from conglomerate samples

Area/Block	USB	USB	USB	MB
Subarea	Bielsko-Biała	Bielsko-Biała	Rzeszotary	westernmost part of MB
Sample ID	Potrójna IG 1	Potrójna IG 1	Raciechowice 1	Batowice 2
Depth interval [m]	3471–3472 (A)	3472–3481 (B)	2399–2424	>3000
Number of analyses	n = 108	n = 102	n = 116	n = 114
Youngest grain [Ma] (% discordancy)	549 ±7 (+1%)	549 ±18 (–10%)	549 ±32 (–10%)	474 ±27 (+4%)
Range [Ma] (from youngest accepted)	549 ±6 (+1%) 1638 ±17	549 ±18 (–10%) 1419 ±48	549 ±32(–10%) 3145 ±80	474 ± 27 (+4%) 2153±18
Age of youngest cluster (number of grains)	554 ±6.6 (6)	552 ±13 (4)	547 ±21 (4)	482 ±27 (2)
Number of subgroups	1	1	2–3	2–3
Dominated group (peak)	600	602	650 & ~2600	590 & 2085
Concordia ages of the coherent groups: (number of grains)	579 ±4 (20) 630 ±4 (31)	585 ±3 (65) 628 ±8 (13)	585 ±12(17) 638 ±8 (43) 707 ±14 (17) 2624 ±24 (10)	532 ±10 (17) 550 ±10 (7) 594 ±8 (34) 649 ±12 (17) 2071 ±9 (12)
Age spectrum % (number of grains)				
Silurian 416–444 Ma	–	–	–	–
Ordovician 444–488 Ma				1.7% (n = 2)
Cambrian 485–541 Ma				14.6% (n = 17)
Ediacaran 541–635 Ma	80.6% (n = 87)	91.2% (n = 93)	26.7% (n = 31)	42.2% (n = 49)
Cryogenian 635–720 Ma	13.9% (n = 15)	4.9% (n = 5)	38.8% (n = 45)	9.48% (n = 11)
Tonian 720–1000 Ma	1.85% (n = 2)	0.98% (n = 1)	4.3% (n = 5)	–
Mesoproterozoic 1000–1600 Ma	–	1.96% (n = 2)	1.7% (n = 1)	4.3% (n = 5)
Paleoproterozoic 1600–2500 Ma	0.92% (n = 1)	–	9.48% (n = 11)	27.6% (n = 32)
Archean >2500 Ma	–	–	17.2% (n = 20)	–

DISCUSSION

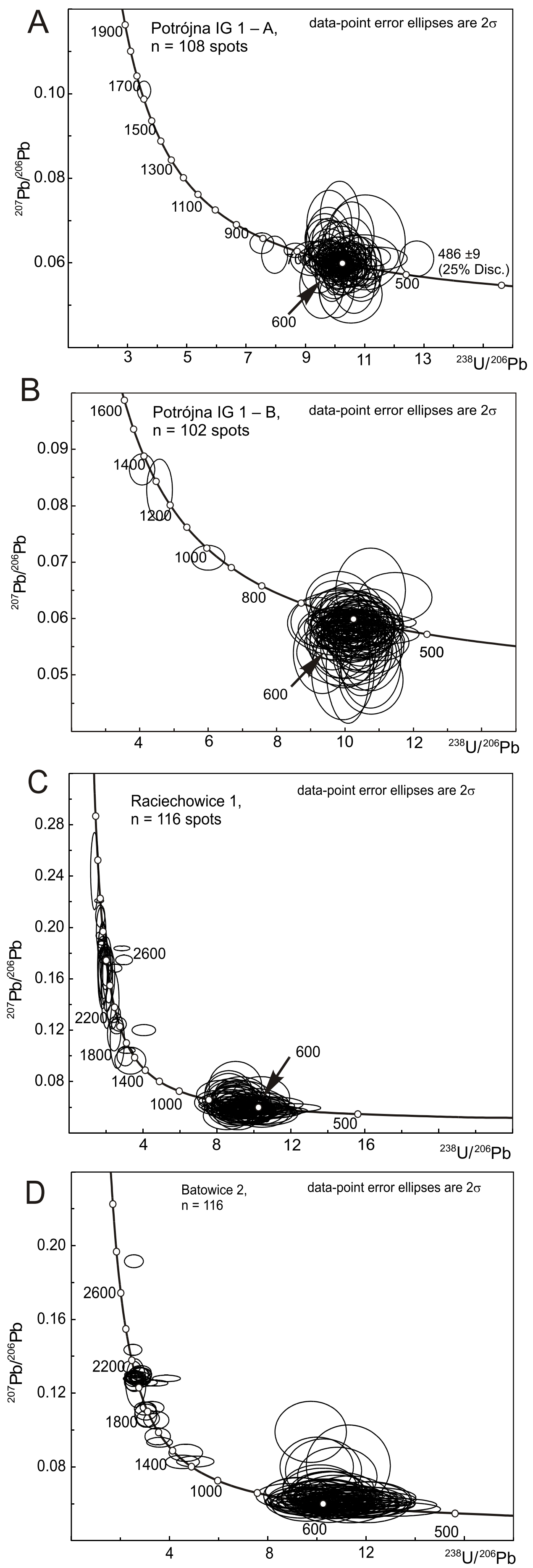
AGE OF DEPOSITION

The relationship between the youngest detrital zircon and deposition age depends strongly on the tectonic setting of sedimentary basin (Dickinson and Gehrels, 2009; Cawood et al., 2012; Spencer et al., 2016). Geochemical signature of Ediacaran sediments in USB (Żelaźniewicz et al., 2009) suggests an active tectonic setting controlled by Cadomian orogenic processes, with widespread intense magmatism and availability of abundant near-depositional-age grains, which is critical to the accuracy of calculated deposition age (Coutts et al., 2019). The effective indicator of the maximum deposition time seems to be a group of grains n >3 (Dickinson and Gehrels, 2009; Coutts et al., 2019); thus, this method was applied for the USB conglomerate, and the cluster of youngest grains from each conglomerate sample has been compared. The concordia ages from the upper and lower Potrójna IG 1 samples at 544 ±6.6 Ma (n = 6) and 552 ±13 Ma (n = 4), respectively, and Raciechowice 1 at 547 ±21 Ma (n = 4) confirm the maximum depositional age of the conglomerate unit to be Late Ediacaran (Fig. 5A–C). The same limit of 548 ±62 Ma of the youngest grains was obtained after a chemical study of monazite (sample Potrójna IG 1 – A).

The age of the youngest zircon clusters corresponds perfectly to the stratigraphic position of coarse-grained clastic beds in USB (Fig. 2), where conglomerates occur locally, filling depression structures on the eroded Ediacaran surface (Buła et al., 2015).

An example of passive tectonic setting is observed in the Batowice 2 conglomerate (MB), where the subsidence development, thermal history and crustal structure (including the Kielce Region), pointing to a stable cratonic setting during Ordovician-Silurian time (Narkiewicz, 2002). The passive tectonic setting is suggested independently on the basis a geochemical studies of mature quartz sandstones of the Cambrian and Ordovician sample set from MB (Nawrocki et al., 2007). Major and trace element contents document a passive continental margin by means of the Th-Co-(Zr/10) plots of the Bhatia and Crook (1986) discrimination diagram.

The passive tectonic setting is characterized by lack of magmatic activity. In consequence, sedimentary successions have no potential rocks that could be a source of near-depositional-age zircons; thus, the youngest grains could to be tens or hundreds of millions of years older than the real time of



sediment accumulation (Cawood et al., 2012), because the youngest detrital grain cluster defines the last igneous activity.

The conglomerate sample taken from MB (Batowice 2 borehole) contains Lower Paleozoic detrital material, including two Lower Ordovician grains (1.7%) accompanied with several Cambrian grains (14.6%), forming a cluster at 482 ±27 Ma. The same age range of the youngest detrital monazite population (476 ±25 Ma) was obtained by *in situ* chemical geochronology. These ages provided by detrital zircons and monazites do not represent the maximum deposition time, but reflect the age of the youngest igneous rocks that have contributed material to the sedimentary basin in Batowice 2. There is no record of volcanic activity from the end of the Ludlow ~432–425 Ma (Nawrocki et al., 2007; Krzemińska and Krzemiński, 2019).

DETRITAL ZIRCON GROUPS AND POTENTIAL SOURCES OF LITHOCLASTS

UPPER SILESIA BLOCK CONGLOMERATES

Two samples from the Potrójna IG 1 conglomerate contain mainly pebbles of eroded sediments or metasediments (Fig. 3). Thus, detrital material was supplied contributed to the sedimentary basin through recycling of older sedimentary rocks. A few groups of potential sources (Fig. 7) have been recognized. The zircon grains with similar U-Pb isotopic ratios correspond to the same or coeval source rocks. Most of detrital zircons, however, exhibit oscillatory zonings that reflect similar magmatic source rocks, which were rapidly reworked (Fig. 8A, B), and the age pattern shows an almost unimodal age distribution (Fig. 6A, B). In Potrójna IG 1 – A and Potrójna IG 1 – B, the majority (81% and 91%) of zircon ages fall within one broad Ediacaran range with the peaks at 600 Ma (Fig. 6A) and 602 Ma (Fig. 6B), respectively. This insignificant difference reflects a simple tendency of the accumulation of slightly younger detrital material in the uppermost part of the Potrójna IG 1 conglomerate bed.

The majority of clasts were supplied from two Cadomian sources, where the magmatism was cumulated at 580–585 and at 627–630 Ma. It suggests that the protolith may represent the same Cadomian orogenic setting. In such dynamic conditions, the recycling processes may proceed immediately during a relatively short time, which is obvious in case of immature greywacke-type deposits. Within a volcanic island-arc setting, isolated from continental input (e.g., fore-arc/back-arc), unimodal patterns of detrital zircon ages are prevalent and reflect the main time of magmatic activity (Cawood et al., 2012).

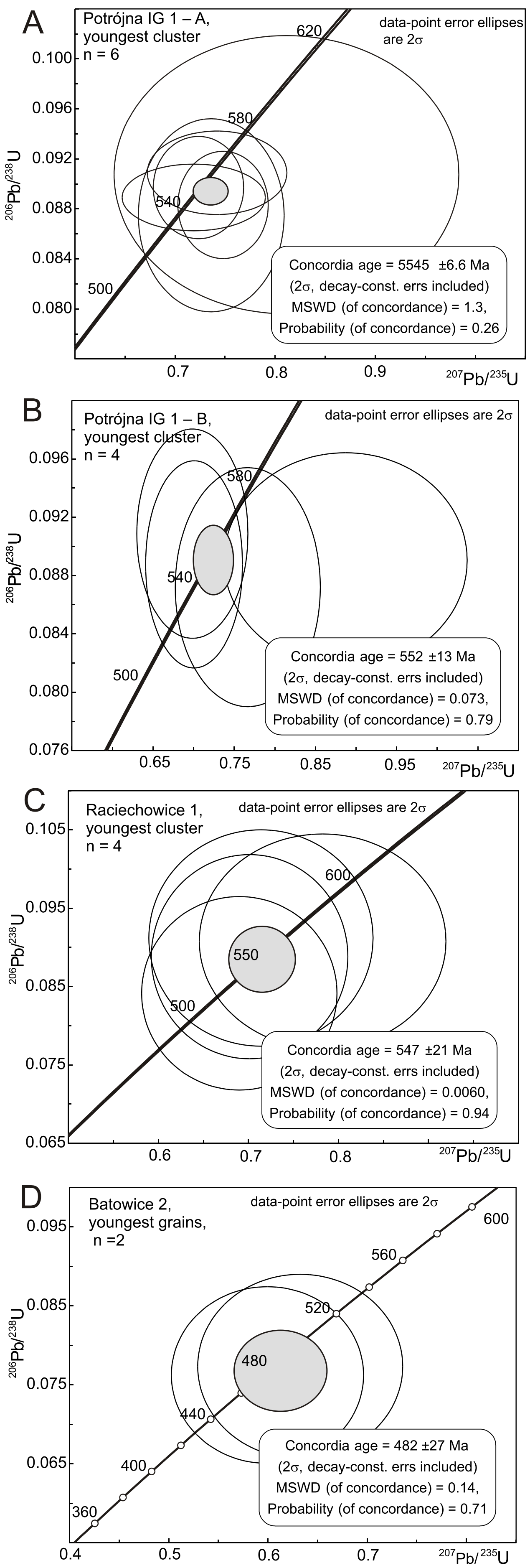
Similar unimodal detrital zircon age spectra for three sandstone samples with age maxima at 600 or ~650–660 and ~558 Ma (with lack of Paleozoic zircons) are currently reported from Basal Clastics close the Brno area of the western part of BVT (Timmerman et al., 2019).

A distinct age distribution was deciphered from the easternmost part of USB (Fig. 5C) in the Raciechowice 1 borehole (Table 2). The first two clusters (Fig. 7C), correspond to the groups identified in Potrójna, and they were supplied from relatively uniform Cadomian source rocks. The third one, with Cryogennian

←

Fig. 4. Tera-Wasserburg concordia diagrams of all accepted ages of detrital zircon grains from conglomerate sampled in the Potrójna IG 1, Raciechowice 1 and Batowice 2 boreholes

Uncertainties are shown at the 2σ level



zircon ages in a range of 740–704 Ma, probably reflect a more distal equivalent of the Central Basic Belt (CBB) with mafic and felsic volcanites in a range of 733 ±5 Ma – 728 ±5 Ma (Hanžl et al., 2019). The CBB was interpreted as a dismembered ophiolite with both plutonic and volcanic members. Apart from meta-tuffs of metadiabases, dykes of meta-rhyolite 725 ±15 Ma and meta-dolerite are most abundant in the eastern part of CBB (Finger et al., 2000).

The last prominent group is formed by Neoarchean grains (17%) which most probably reflect erosion of the rocks found in the Paleoproterozoic Rzeszotary Horst (RzH), where some zircons yielded $^{207}Pb/^{206}Pb$ ages in a range of 2.5–2.7 Ga (Bylina et al., 2000; Żelaźniewicz and Fanning, 2020). A few oldest detrital zircons (Fig. 8C) show a banded zoning, which is common for crystallization from a mafic melt.

The age spectra deciphered in the Raciechowice conglomerate are compatible with those identified in fine-grained sediments from the Cadomian Orogen in the NE Bohemian Massif (Linnemann et al., 2014), where the West African provenance was considered. This general suggestion may also have implications for the enigmatic origin of the RzH as an exotic component hosted in the juvenile Cadomian structure of USB.

The compilation of age data (Table 1) from several units within BVT, including the Brno Block of 600.9 ±2.8 Ma, Svratka Dome of 634 ±6 Ma, Thaya Unit of 603.3 ±5.2 Ma, and Slavkov Unit of 575 ±2 Ma, with granitoids emplaced at 606 ±2 Ma – 590 ±8 Ma (Friedl et al., 2004; Soejono et al., 2017 and references therein; Svojtka et al., 2017; Timmerman et al., 2019), supported by magmatic ages obtained from the hidden area of the Bielsko-Biała Dome (Fig. 1B), in Roztropice at 582.7 ±6 Ma and Kęty-8 at 579 ±2.7 Ma (Żelaźniewicz et al., 2009), shows the main pulses of igneous activity (Fig. 9) within the composite BVT. These stages well match to the age of clastic components deciphered from the Potrójna and Raciechowice 1 conglomerates, confirming that nearly all material was supplied from denudation of the local Cadomian source rocks.

MAŁOPOLSKA BLOCK CONGLOMERATE

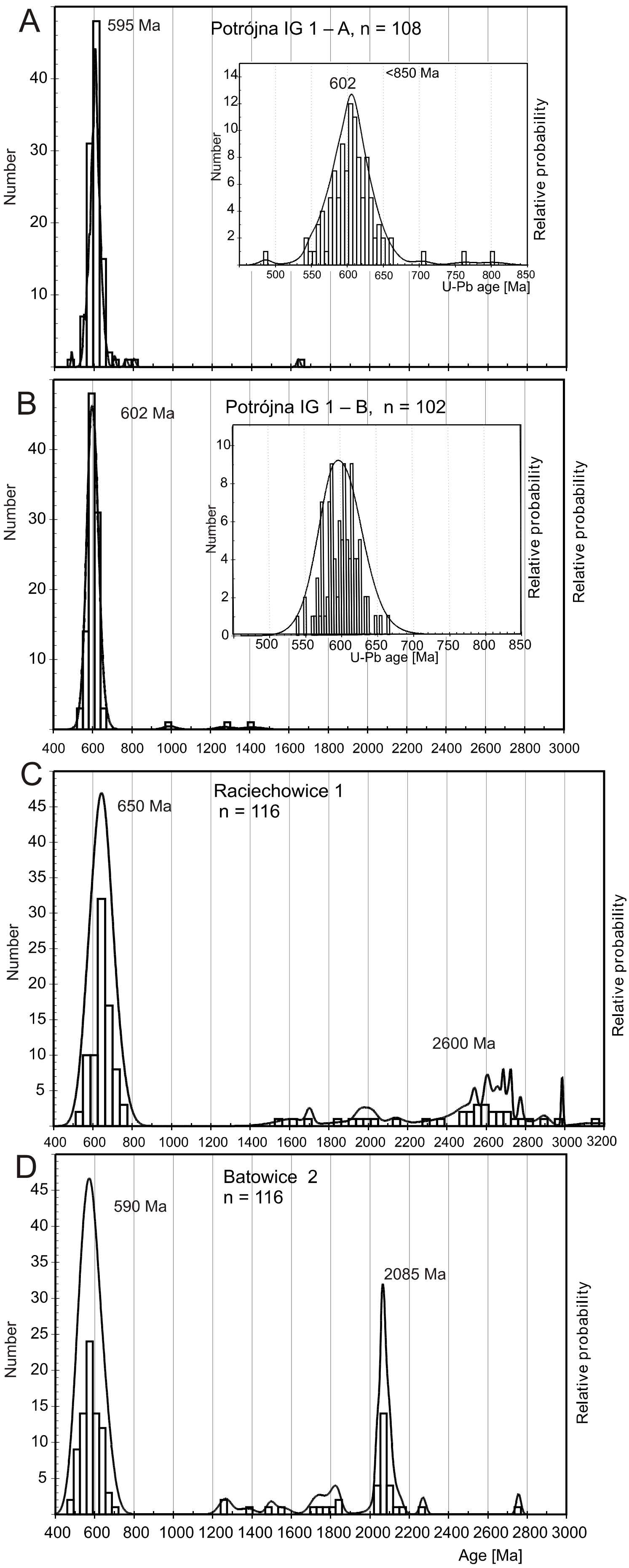
The clastic material in the Batowice 2 conglomerate represents eroded plutonic and volcanic rocks or their meta-equivalents. The youngest zircon group is composed of two Lower Ordovician grains (1.7%). Their form, limited amount, and age of 482 ±27 Ma (Fig. 8D, grain 103.1) suggest pyroclastic origin. The traces of Ordovician to Silurian volcanic pulses are widespread in MB of the Holy Cross Mountains (Trela et al., 2018) and represented by bentonite horizons with pyroclastic material derived by winds from Avalonian volcanoes. The distribution of pyroclastic flow in MB during Late Ordovician time was strongly controlled by SE trade winds (Trela et al., 2017).

The provenance of dominant pebblesderived from potentially proximal crystalline rocks seems to be more complex to decipher, because basement rocks of MB remain unknown.

The origin of MB and its relationship to the adjacent blocks is a subject of ongoing debate (Belka et al., 2000; Valverde-Vaquero et al., 2000; Narkiewicz, 2002; Żelaźniewicz et al., 2009; Narkiewicz et al., 2011; Walczak and Belka, 2017). The

Fig. 5. Wetherill concordia diagrams for the youngest detrital zircon grains (n >3) that overlap in age at 2σ

A – Potrójna IG 1– A, **B** – Potrójna IG 1 – B, **C** – Raciechowice 1, **D** – Batowice 2



proximity of MB and Baltica during Cambrian time was concluded on the basis of similarity of palaeomagnetic poles of MB *versus* EEC (Nawrocki et al., 2007). The close relationships to Amazonia were reported on the basis of Nd data of detrital sediments combined with detrital zircon ages (Belka, 2000; Walczak and Belka, 2017). Thus, it was accepted that, during Cambrian time, MB was supplied with clastic material from (I) Amazonian sources, being also progressively sourced from (II) the Baltica Svecofennian crust since the Middle Cambrian (Walczak and Belka, 2017).

The linkages from MB to Baltica and West Gondwana were considered after re-evaluation of Cambrian trilobite fauna from MB (Żylińska and Szczepanik, 2009; Żylińska, 2013). In consequence, the accrectionary history of MB constrained on these faunal records, completed by detrital mica signatures (Belka et al., 2000), point out that MB and Baltica were still not connected in the Early Cambrian, but a limited migration of faunal species was possible. In the Mid-Cambrian, the distance became smaller. Thus, the faunal record has been integrated and fine-grained clastic material from Baltica was successfully supplied to MB (Belka et al., 2000). At the end of the Ediacaran, the NW margin of Baltica changed its tectonic regime from extensional to active margin (Timanian Orogeny). Later, in Middle Cambrian to Middle Ordovician times, the Baltica underwent a substantial rotation of ~120°, with a maximum rate in Late Cambrian and Early Ordovician times (Cocks and Torsvik, 2005).

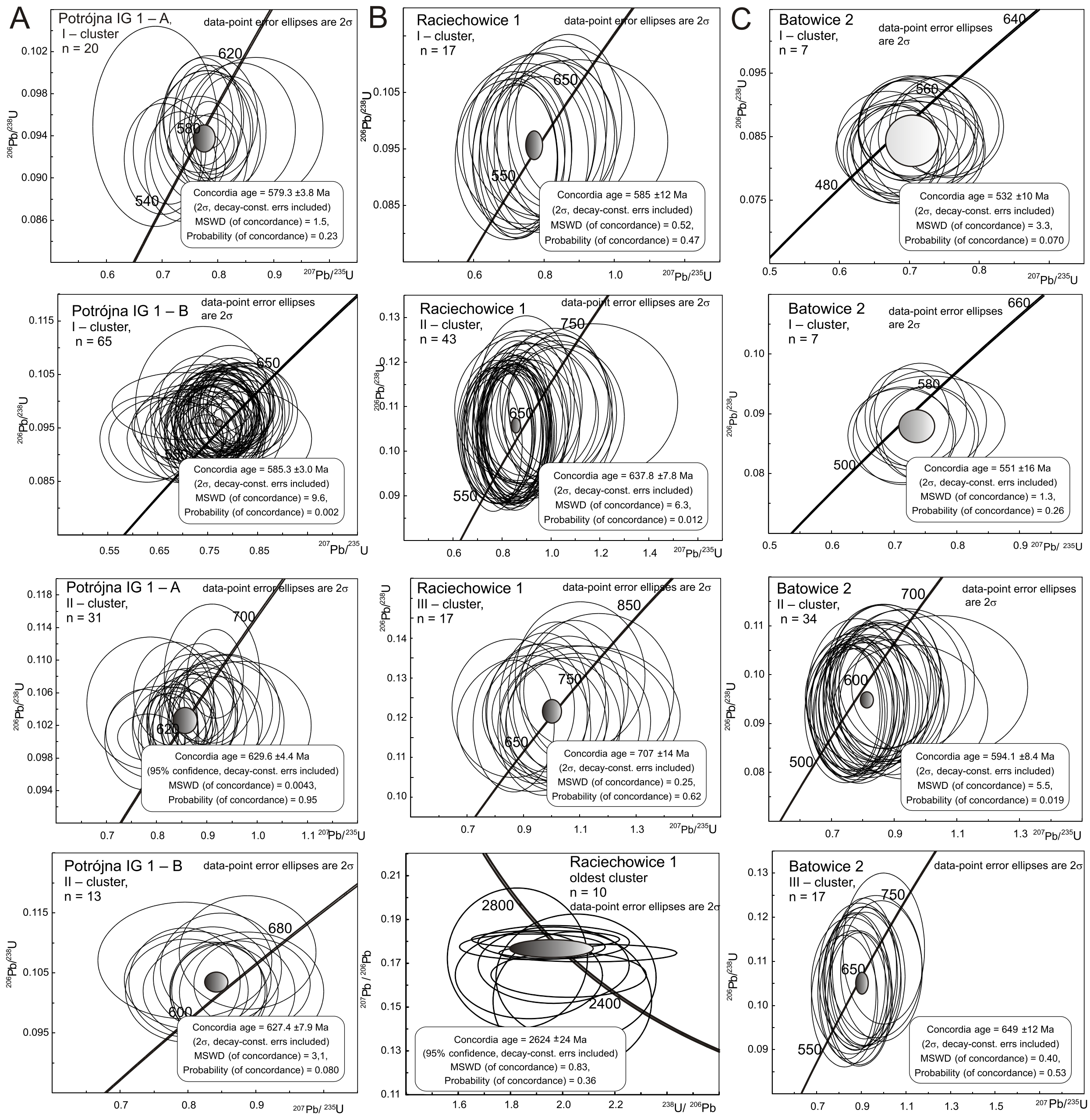
After the Late Ordovician, when the Batowice conglometare was deposited (the youngest detrital grain of 482 Ma), the MB margin must have been closer to the Baltica margin, but since Neoproterozoic time, Amazonia had been gradually separated from Baltica (Johansson, 2009). Because both blocks were previously closely combined to at least 0.8 G, the main crust formation stages recognized in Amazonia perfectly match the stages known from adequate belts of Baltica (Johansson, 2009).

One of the hypothesis assumes that MB must have docked to the Fennoscandian segment of Baltica, along the TTZ margin, being afterwards probably always located near its present position (Belka et al., 2002). As significant evidence the age of ~2.0 Ga known from Kędziorka, MB (Belka et al., 2002) or from Wymyślona 2037–2079 Ma (Valverde-Vaquero et al., 2000) are indicated. In both cases the detrital material was probably supplied from the Svecofennian part of Baltica up to in the Middle Cambrian (Walczak and Belka, 2017).

The detrital zircons in a range 2.1–2.0 Ga, observed in the Batowice conglomerate (Fig. 10A), but

Fig. 6. The comparison of detrital zircon age spectra from conglomerate samples, showing the distribution of dominant grains

The curves are probability plots accompanied with histograms, constrained on ^{206}Pb/^{238}U ages up to 1000 Ma and ^{206}Pb/^{207}Pb ages if the ^{206}Pb/^{238}U ages are older than 1000 Ma; the number of detrital zircon grains analysed is shown on the left; the scale of vertical and horizontal axes is normalized



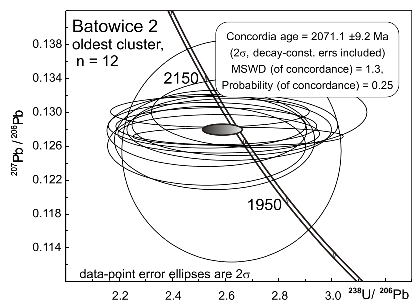


Fig. 7. Concordia diagrams showing well-defined detrital zircon clusters that may correspond to the age of potential source rocks

A – Potrójna IG1, **B** – Raciechowice 1, **C** – Batowice 2, including oldest components

described also in Cambrian sandstone of MB (Belka et al., 2002), could not have come from a Svecofeninan source, because the time of activity of this orogeny (Korja et al., 2006) was spanned between 1.9 and 1.8 Ga (1.92–1.88, 1.87–1.84, 1.87–1.79, and 1.79–1.77 Ga). Thus, the population of 2.1–2.0 Ga reflects undoubtedly an older source. Such a pre-Svecofennian crust was present only in northern Finland or in the Sarmatian part of Baltica and in the Volga Ural Block. In case of the fine-grained sediments, where a long distance transport is necessary, a number of possibilities for prevenance interpretation. The conglomerates as coarse-grained deposits are a result of short transport, e.g. tens to hundreds of kilometres, thus reflect mostly proximal sources.

As an example of a proximal deposition nearby source area the conglomerate from Kaplonosy IG 1 at a depth of 1809 m (Appendix 1) is presented. This coarse-grained clastic rock was

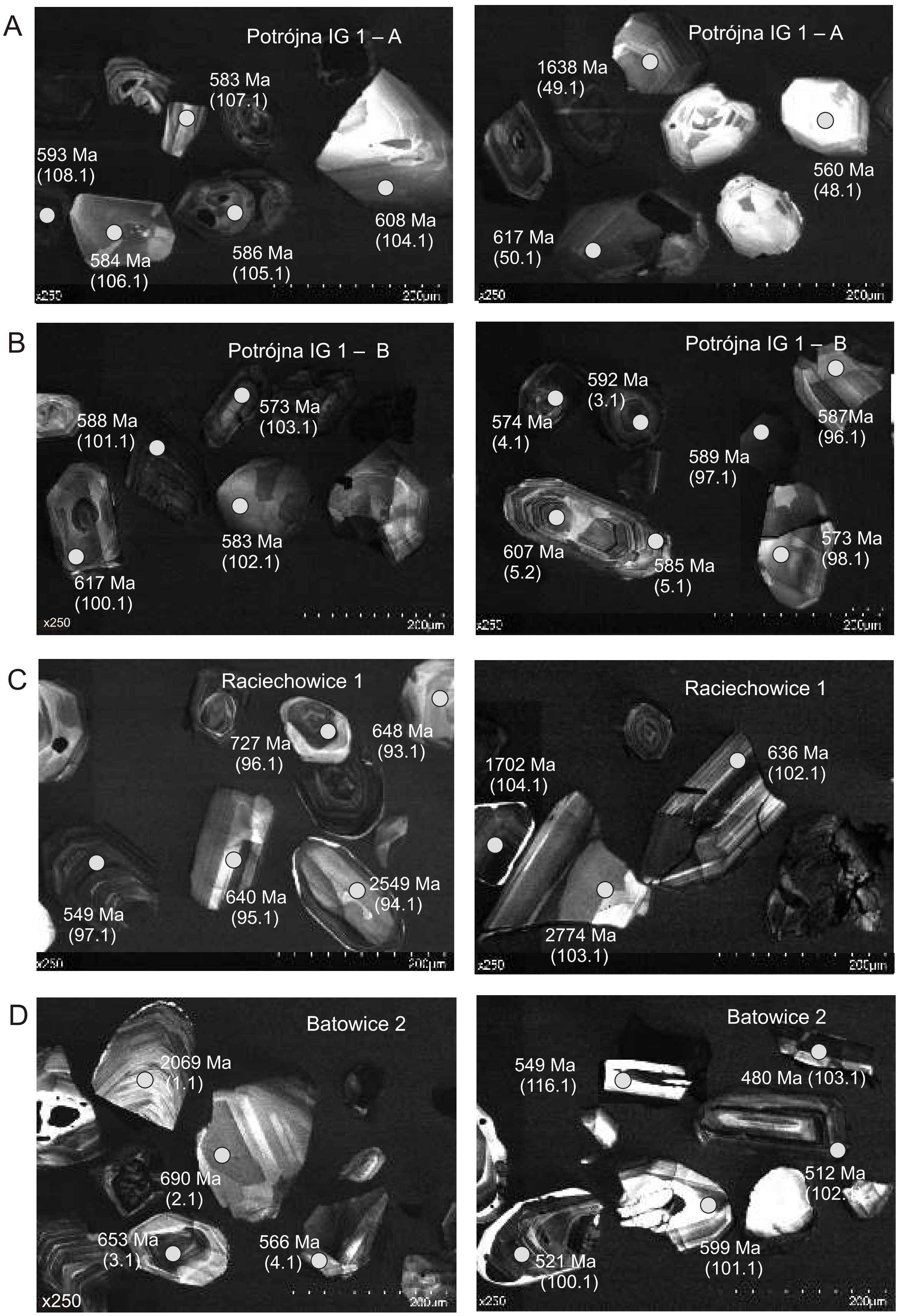


Fig. 8. Cathodoluminescence (CL) images of the collection of polished zircon grains in epoxy mount; images showing analysed detrital zircon grains from conglomerates of A – Potrójna IG 1 – A, B – Potrójna IG 1 – B, C – Raciechowice 1, D – Batowice 2

The age and ID of analysis are shown (for more details see Appendix 1); the CL images were acquired in the same magnification, brightness and contrast conditions to compare the internal features of individual grains and samples

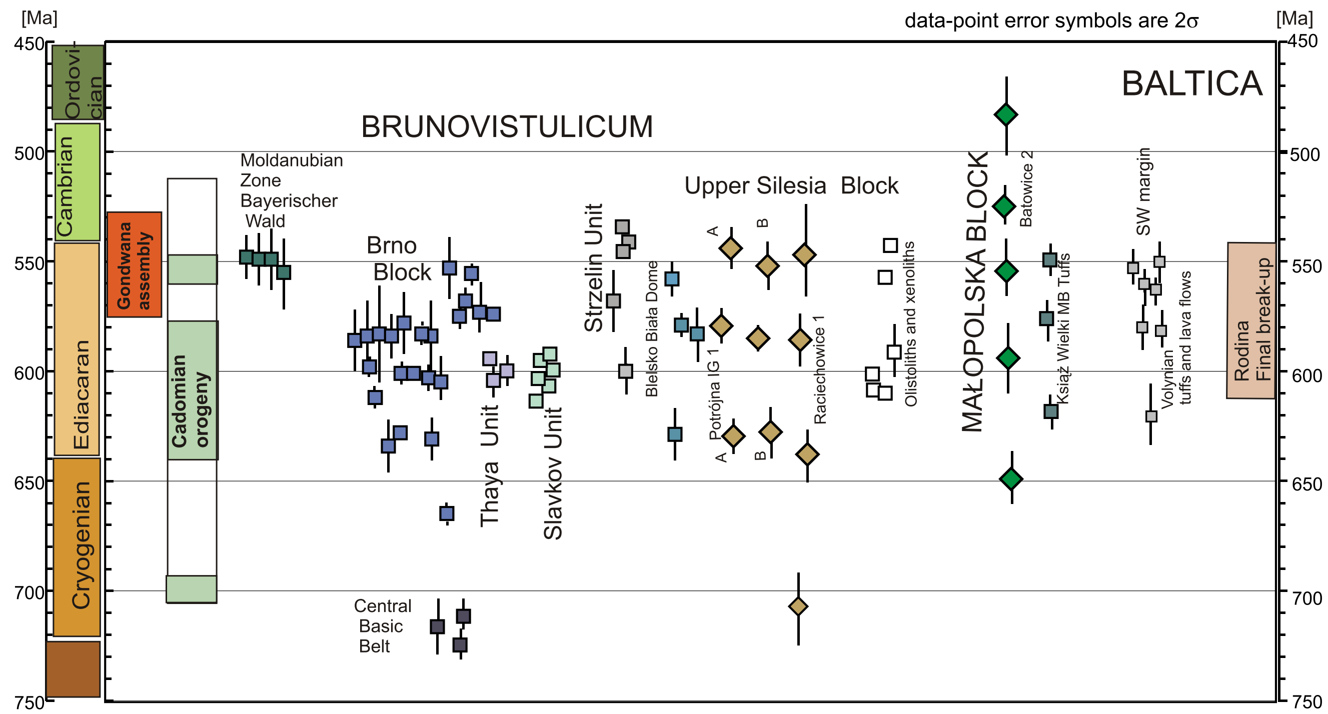


Fig. 9. The comparison of detrital zircon ages obtained as main clusters obtained from conglomerates of the Upper Silesia and Małopolska blocks (this study) and their potential sources

The U-Pb zircon concordia age compilation includes a Cadomian orogenic imprints in the Moldanubian Zone; moreover a proximal source rocks from the composite Brunovistulia Terrane, including the Upper Silesian and Brno blocks, Thaya, Slavkov and Strzelin units and volcanogenic record known from the Małopolska Block and from Baltica represented by Volyn-Orsha Aulacogen volcanic activity; ages obtained from xenoliths and olistoliths of the Outer Carpatian flysch are plotted separately. Detrital age record marked by diamond, in contrast to magmatic ages marked by square; data for comparison are taken from: Compston et al. (1995); Oberc-Dziedzic et al. (2003); Teipel et al. (2004); Linnemann et al. (2007); Żelaźniewicz et al. (2009), Shumlyanskyy et al. (2016), Soejono et al. (2017); Svojtka et al. (2017); Poprawa et al. (2018); Hajná et al. (2018); Burda et al. (2019); Gawęda et al. (2019); Timmerman et al. (2019)

deposited in Meso/Neoproterozoic time directly on the eroded basement of the Baltica passive margin near the Fennoscandia-Sarmatia suture. The dominant detrital zircons peaked at ~1535 Ma were delivered from AMCG or/and rapakivi-type rocks (Fig. 10C), which are widespread in the Mazury Complex. A minor Sveconennian group at ~1818 Ma may reflect an erosion event of the Svecofennian part of basement, including the nearest Mazowsze Domain (Krzemińska, 2010). Almost the same age pattern with a prominent rapakivi-derived signal (Fig. 10D) was recognized in the uppermost Ediacaran fine-grained sandstone from Białopole IG 1 (Żelaźniewicz et al., 2009) south of Kaplonosy IG 1 (Fig. 1A). These similarities suggest that the source area remained more or less unchanged over that time.

In case of the Batowice 2 conglomerate, the clasts must have been derived from a definitely distinct area, or different Baltica's margin, because the grains of 1.5 and 1.8 Ga are relatively rare (Fig. 10), in contrast to a significant zircon cluster of pre-Svecofennian grains of ~2.1–2.0 Ma. The potential Paleoproterozoic 2.1–2.0 Ga source rocks are known from the Sarmatian segment of EEC (Shumlyanskyy et al., 2015). They include granites of the Zhytomyr and Osnitsk complexes (northwestern part of Sarmatia) and o the Orekhiv-Pavlograd, Krivyy Rih and Golovanivsk sub-domains of the Ukrainian Shield, where the continental crust was formed during two orogenic events at ~2100–2050 Ma and 2000–1950 Ma (Shumlyanskyy et al., 2015). There is also the East-Sarmatian Orogen that formed through the collision between Sarmatia and Volgo-Uralia at ~2.1–2.0 Ga (Terentiev et al., 2016). Docking of MB at the southern, Sarmatian margin of Baltica was proposed by Lewandowski (1993) and Nawrocki et al. (2004, 2007). Therefore, the clastic material with pre-Svecofennian Paleoproterozoic (2.1–2.0 Ga) signature, widespread in the SW Sarmatian edge, may strengthen this hypothesis. In this model, the MB was developed near the present-day southern margin of Baltica and has been dextrally relocated along the TTZ edge of Baltica.

The absence of the ~1.0–1.2 Ga (Sveconorwegian) component in Batowice 2, which is known only from southern Scandinavia, reaffirms this interpretation.

Another prominent group is the population (Fig. 7) of Upper Ediacaran/Early Cambrian detritus formed by grains in a range of 534–506 Ma, which yielded a concordia age at 532 ±10 Ma. In general, during a time span of 570–530 Ma, a number of important manifestations of activity are widely noted as PanAfrican, Brazilian, Baikalian, Timanian and Cadomian orogenies. Thus, an important population with a maximum at 532 ±10 Ma can be considered as a Late Cadomian signature and input of eroded proximal Cadomian crust. Igneous rocks of this age reflect a late stage of continental arc magmatism along the northern margin of Gondwana and the onset of rifting and widespread magmatism (~530–500 Ma) that led to the opening of the Rheic Ocean (Linnemann et al., 2008).

A Gondwanan origin of the MB was concluded previously from detrital micas and zircon ages from Cambrian sediments and Cambrian brachiopods (Belka et al., 2002; Winchester et al., 2002). In a palaeoreconstruction proposed by Nawrocki et al. (2004), the MB was considered as a part of the Cadomian belt located near the present-day southeastern margin of Baltica, which must have been transferred to its present posi-

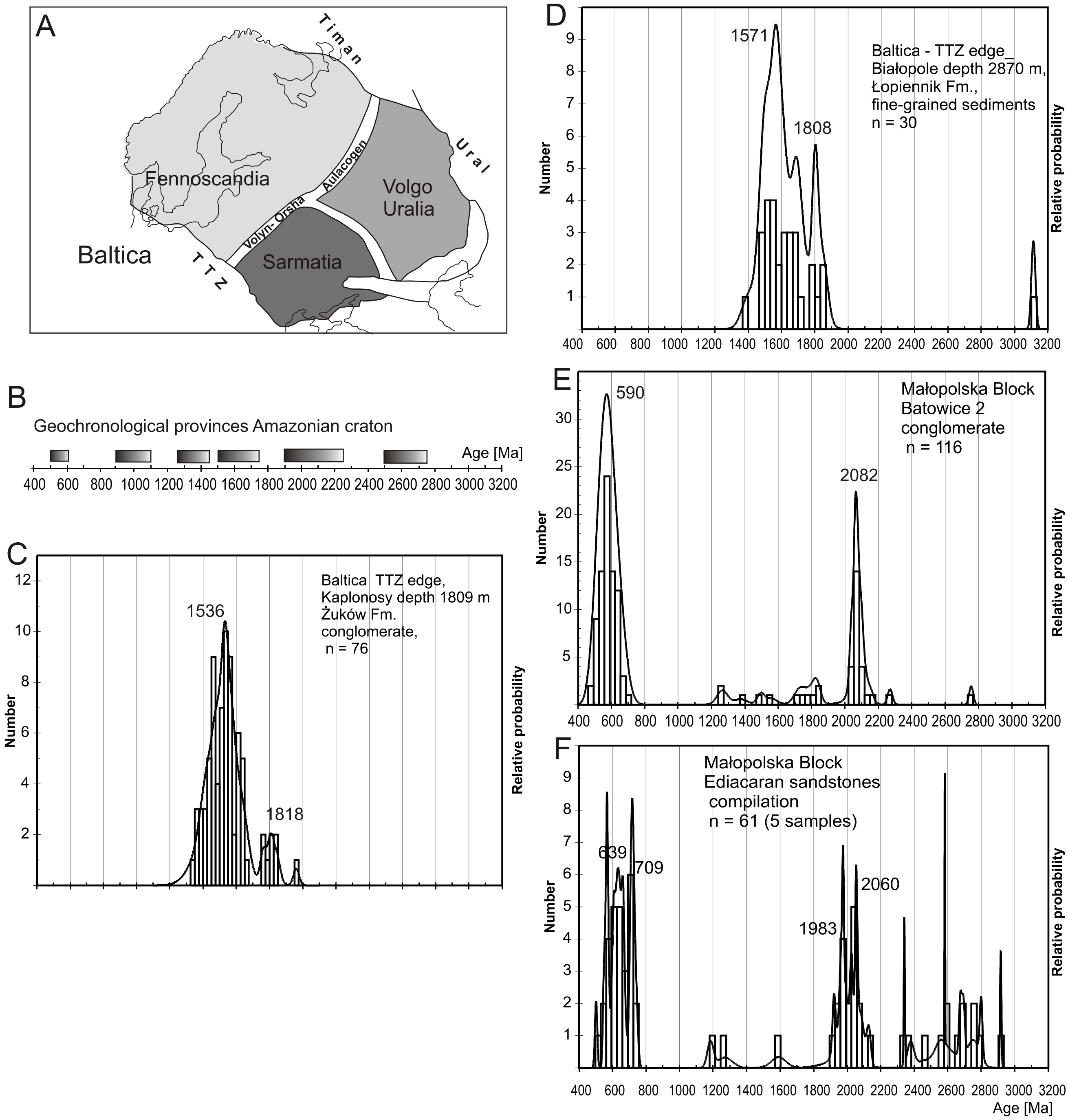


Fig. 10. The comparison using: A – schematic location of the Fennoscandia, Sarmatia and Volgo-Uralia blocks within the Baltica palaeocontinent (after Gorbatschev and Bogdanova, 1993); B – main crust formation events from the Amazon Craton (according to Nance and Murphy, 1996); C – detrital age spectrum of the Kaplonosy conglomerate (Żukow Fm.), which reflects the age of eroded basement near the TTZ Baltica margin; D – detrital age spectrum of Upper Ediacaran fine-grained sediments from Białopole, reflecting the age of detritus near the TTZ Baltica magin, data from Żelaźniewicz et al. (2009); E – detrital zircon age spectrum characteristic for the Batowice 2 conglomerate (MB); F – compilation of detrital age data collected from Late Ediacaran fine-grained sediments from the Małopolska Block margin, samples: Tuligłowy, Chałupki Dębiańskie, BN58, Zalasowa and Żarki, (data taken from Żelaźniewicz et al., 2009)

tion in latest Ediacaran to Late Cambrian times. Therefore, a detrital zircon pattern provided by the Batowice 2 conglomerate from the edge of MB may reflect a communication only between the margins of Gondwana (Late Cadomian clasts) and southern Baltica (pre-Svecofennian clasts). These evidences, provided by proximal deposits, indicate more directly the close spatial tectono-sedimentary interactions between both the blocks than those provided previously by investigation of fine-grained sediments (Fig. 10F). The age of main peaks is marked.

The diagrams were constrained on $^{206}Pb/^{238}U$ ages up to 1000 Ma, and $^{206}Pb/^{207}Pb$ ages if the $^{206}Pb/^{238}U$ ages are older than 1000 Ma.

CONCLUDING REMARKS

The first SHRIMP U-Pb detrital zircon age recognition of conglomerates from the Potrójna IG 1 (near the Bielsko-Biała Dome) and Raciechowice 1 (Rzeszotary Horst) boreholes in the Upper Silesia Block, and from the Batowice 2 borehole in the Małopolska Block (close to the Kraków-Lubliniec Fault Zone), using an adequate number of analyses (n >100) for each sample, points to as follows:

1 – the youngest zircon age of 549 Ma for both (Potrójna IG 1, Raciechowice 1) conglomerates in USB confirms their Latest Ediacaran age of deposition;

2 – the youngest zircon age of 482 Ma for Batowice 2 in MB does not allow for precise determination of deposition age, suggesting rather a lag time.

3 – the dominant clusters of zircon ages of 579 ±4, 585 ±3 and 628 ±8, 630 ±4 and 638 ±8 Ma from the Potrójna IG 1 and Raciechowice 1 (USB) boreholes are interpreted as an age of proximal source rocks, which is consistent with the distribution of Cadomian magmatism within the nearest orogenic belt, including those previously obtained in the Kęty-8 (579 ±2.7 Ma) and Roztropice (582.7 Ma) boreholes, and less common Early Cadomian episode of 707 ±14 Ma. All these plutonic-volcanic events were identified elsewhere within BVT;

4 – the age of older components of 2624 ±24 Ma (Neoarchean), reflecting erosion of the local basement (Raciechowice 1), unequivocally related to the Rzeszotary Horst;

5 – the ages of zircon grains derived from plutonic and volcanic lithoclasts of the Batowice 2 (MB) conglomerate of 532 ±10 Ma, 551 ±16 Ma, 594 ±8 Ma and 649 ±12Ma, accompanied with the characteristic pre-Svecofennian group peaked at 2071 ±10 Ma, may document a tectono-sedimentary interaction between the Gondwana and Baltica palaeocontinets during Early Paleozoic time.

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