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Title: AGES OF DETRITAL ZIRCONS (U/Pb, LA-ICP-MS) FROM THE LATEST NEOPROTEROZOIC - MIDDLE CAMBRIAN(?) ASHA GROUP AND EARLY DEVONIAN TAKATY FORMATION, THE SOUTH-WESTERN URALS: A TEST OF AN AUSTRALIA-BALTICA CONNECTION WITHIN RODINIA

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Abstract: Results from U/Pb-dating of detrital zircons (dZr) from sandstones of the Basu and Kukkarauk Fms. (Asha Group) of Ediacaran-Middle Cambrian(?) age along with the results obtained from the Early Devonian Takaty Fm. are presented. The age of the Asha Group is traditionally labeled as Upper Vendian in the Russian stratigraphic chart that overlaps with the Ediacaran in the International stratigraphic chart. The dZr whose ages fall within the age-interval of (500-750 Ma) are common in the Basu and Kukkarauk Fm. These ages are typical for crystalline complexes in the Pre-Uralides-Timanides orogen. The identification of zircons with this age range agrees with commonly adopted interpretations for the depositional origin of the Asha Group as a molasse resulting from the erosion of that orogenic belt. Based on the estimates of the youngest ages of dZr along with the tentative identification of inarticulate brachiopods in the Kukkarauk Fm., it appears that the upper part of the Asha Group may extend into the Middle Cambrian.

There is a dominant population of Mesoproterozoic zircons (~900-1750 Ma) in the sandstones of the Asha Group. Potential source regions for this range of zircon ages can be identified within the East European Platform (EEP) and include the Svecofennian and Sveconorwegian orogens in the present-day western and northwestern sections of Baltica. While these may be considered 'obvious' source regions, the dZr spectra are unusual in that these distal source zircons dominate over near source regions. In addition, paleotopography strongly indicates numerous barriers to cross-Baltic transport. We explored other potential sources for the dZr in the Asha Group. One intriguing hypothesis places the Uralian margin of Baltica near Australia in Rodinia. This so-called "Australia Upside Down" (AUD) model was posited as an alternative 'exit strategy' for the tectonic transition from Rodinia to Gondwana. We compared (via the Kolomogorov-Smirnov test) the cumulative age distributions of the Asha Group rocks with those from several Ediacaran-Cambrian sequences in Australia and found a high degree of similarity between the two populations. This indirectly supports the AUD contention with Baltica in Rodinia time; however, the upper part of the Asha Group may be as young as Middle Cambrian in age and paleogeographies that tie the Uralian margin of Baltica to Australia are problematic. One potential solution to the paleogeographic conundrum placing Baltica in connection with Australia in the Late Ediacaran is to posit that the dZr population in the Asha Group represents re-worked material originally deposited in Riphean-aged sediments during Rodinia time.

A limited study of dZr in the early Devonian Takaty Formation showed an absence of any dZr younger than Paleoproterozoic. The absence of young zircons would suggest that the Takaty Formation was

accumulated from high-standing regions within Volgo-Uralia that are composed of Archean and Paleoproterozoic crystalline complexes.

Although sedimentary strata of the south-western Urals including Basu, Kukkarauk and Takaty Fms. form a continuous-like section, the spectrum of dZr ages from those formations indicates major changes in basinal source and structure. The basin was most likely intracontinental (intra-Rodinia) during the Tonian/Cryogenian interval and perhaps into the Ediacaran. Accumulation of strata within the Asha Group (Late Neoproterozoic-Middle Cambrian) contains detritus that may have originated from an easterly source (Australia?). Later, during accumulation of Takaty Fm. (Early Devonian), the basin formed along a passive margin with main input from the western side (EEP).

ABSTRACT

Results from U/Pb-dating of detrital zircons (***dZr***) from sandstones of the Basu and Kukkarauk Fms. (Asha Group) of Ediacaran-Middle Cambrian(?) age along with the results obtained from the Early Devonian Takaty Fm. are presented. The age of the Asha Group is traditionally labeled as Upper Vendian in the Russian stratigraphic chart that overlaps with the Ediacaran in the International stratigraphic chart. The ***dZr*** whose ages fall within the age-interval of (500-750 Ma) are common in the Basu and Kukkarauk Fm. These ages are typical for crystalline complexes in the Pre-Uralides-Timanides orogen. The identification of zircons with this age range agrees with commonly adopted interpretations for the depositional origin of the Asha Group as a molasse resulting from the erosion of that orogenic belt. Based on the estimates of the youngest ages of ***dZr*** along with the tentative identification of inarticulate brachiopods in the Kukkarauk Fm., it appears that the upper part of the Asha Group may extend into the Middle Cambrian.

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Baltica in Rodinia time; however, the upper part of the Asha Group may be as young as Middle Cambrian in age and paleogeographies that tie the Uralian margin of Baltica to Australia are problematic. One potential solution to the paleogeographic conundrum placing Baltica in connection with Australia in the Late Ediacaran is to posit that the ***dZr*** population in the Asha Group represents re-worked material originally deposited in Riphean-aged sediments during Rodinia time.

A limited study of ***dZr*** in the early Devonian Takaty Formation showed an absence of any ***dZr*** younger than Paleoproterozoic. The absence of young zircons would suggest that the Takaty Formation was accumulated from high-standing regions within Volgo-Uralia that are composed of Archean and Paleoproterozoic crystalline complexes.

Although sedimentary strata of the south-western Urals including Basu, Kukkarauk and Takaty Fms. form a continuous-like section, the spectrum of ***dZr*** ages from those formations indicates major changes in basinal source and structure. The basin was most likely intracontinental (intra-Rodinia) during the Tonian/Cryogenian interval and perhaps into the Ediacaran. Accumulation of strata within the Asha Group (Late Neoproterozoic-Middle Cambrian) contains detritus that may have originated from an easterly source (Australia?). Later, during accumulation of Takaty Fm. (Early Devonian), the basin formed along a passive margin with main input from the western side (EEP).

Highlights (for review)

U/Pb-isotope dating (LA-ICP MS) of dZr zircons from sandstones of Basu and Kukkarauk Fm. from Asha Gr. and Takaty Fm of the western flank of the BU (Southern Urals) were carried out.

Ages of dZr from Basu Fm. fall within the time interval ~(705 – 2869) Ma, ages from Kukkarauk Fm. ~(617 – 3188) Ma and Takaty Fm. ~(1858 – 3054) Ma.

KS-test have shown a high similarity of spectrum of the ages of detrital zircons from quartzite Cape River (Queensland) and Marino Arkose and Bonney Sandstone (Adelaida) Formation of the Eastern Australian with age near the Ediacaran-Cambrian boundary with those from similar age Basu and Kukkarauk Formation Western part of the Southern Urals.

Although sedimentary strata of the Western part of the Southern Urals including Basu, Kukkarauk and Takaty Fms. form a continuous-like section, the spectrum of dZr ages from those Fms indicates major changes in basinal source and structure.

The basin was most likely an intracontinental (intra-Rodinia) basin during the Tonian/Cryogenian interval and perhaps into the Ediacaran.

Accumulation of strata within the Asha Group (Late Neoproterozoic-Middle Cambrian) contains detritus that may have originated from an easterly source (Australia?).
Later, during accumulation of Takaty Fm. (Early Devonian), the basin formed along a passive margin with main input from the western side (East European Platform).

1. Introduction

The eastern boundary of East European Platform (EEP) is the present-day N-S trending Ural Mountains (the Urals) (Fig. 1). The Uralide Orogen is a part of Paleozoic fold-thrust belt that was formed during the final stages of northern Pangea. During this orogenic cycle, the Uralian Ocean closed between Arctida-Baltica-Laurentia (Arct-Laurussia) and Siberia-Kazakhstania-Kyrgyzia along the Uralian suture (or Main Uralian Fault; Hamilton, 1970; Zonenshain *et al*. 1990, Sengör *et al*. 1993; Puchkov, 2000, 2002, 2009, 2010; Kuznetsov *et al*., 2010a; Görz and Hielscher, 2010).

The Uralian orogeny has exposed Late Cambrian to Late Paleozoic rocks that collectively form the Uralides. In contrast, older rock complexes in and west of the Urals are collectively named the Pre-Uralides-Timanides. The Pre-Uralides-Timanides are clearly separated from the Uralides by a stratigraphic contact or sometimes a clear structural unconformity. The subdivision between the two was firstly made by Kheraskov (1948).

Along strike, the Urals are subdivided into the ***Eastern-Uralian*** and ***Western-Uralian*** (~western slope of the Urals) megazones separated by the ***Main Uralian Fault***. The eastern Uralides are mostly covered by younger sediments, but are generally thought to be allochthonous with respect to the Uralian edge of the Arct-Laurussia. The Western-Uralian megazone contains both the Uralides and the Pre-Uralides-Timanides.

Many geological aspects of the Uralides (*e.g.*, relations of individual sequences of different scale, their biostratigraphic and isotopic-geochronological characteristics) are presently well understood and led to a reasonably coherent geodynamical history of the Uralide Orogeny (see the most recent review-articles Brown *et al*. 2006; Fershtater *et al*. 2007, 2010; Puchkov 2002, 2009, 2010; Ryazantsev *et al*. 2008, 2012). Even so, many key questions regarding the Pre-Uralian history (recorded and partially preserved in Pre-Uralides–Timanides complexes) remain to be answered or are still very much under discussion. For example: how long did the Uralian ocean exist? Was there a Paleo-Uralian Ocean that closed ahead of the Uralian Ocean?

Some researchers argue that Uralian Ocean opened in the Ordovician (Ivanov *et al*., 1986, Puchkov 2002, 2010; and others), whereas others believe that this "Pre-Uralian" ocean existed deeper in time beginning in the Late Precambrian (Samygin and Leites, 1986; Samygin and Ruzhentsev, 2003; Samygin and Kheraskova, 2005; Kuznetsov, 2009 etc.). The late Precambrian to Cambrian sedimentary basins now occupying the western Uralian megazone may hold key clues that can help trace the pre-Ordovician history of the Uralian margin.

Our examination of the early evolution of the Uralian margin is inextricably tied to the tectonic history of the EEP and its relationship to the assembly and dispersal of the Columbia (Meert, 2012) and Rodinia (Li *et al*., 2008) supercontinents. It was recently proposed that the Paleoproterozoic basement of the EEP was formed between ca. 2.1–1.8 Ga as a part of Paleoproterozoic supercontinent Columbia (Rogers and Santosh, 2002; Zhao *et al*., 2004). As Columbia broke apart, Proto-Baltica became isolated and later incorporated into the Rodinia supercontinent. Alternatively, it is possible that Proto-Baltica remained attached to Laurentia throughout the Columbia-Rodinia supercontinents and only became a separate block (Baltica) during the opening of the Ediacaran Iapetus Ocean (Meert and Powell, 2001; Hartz and Torsvik, 2002; Bogdanova *et al.*, 2008; Li *et al.*, 2008, Evans, 2009; Piper, 2000, 2007, Swanson-Hysell *et al.*, 2012). Although there is a general consensus that Proterozoic supercontinents assembled and dispersed, the exact configuration of those supercontinents is strongly debated (Swanson-Hysell *et al.*, 2012; Meert, 2012; Meert and Torsvik, 2003; Evans, 2009). The existence or absence of a Late Neoproterozoic – Cambrian Paleo-Uralian ocean is a strong constraint for positioning Proto-Baltica within Rodinia. Was the Uralian edge of Proto-Baltica a passive margin or it was juxtaposed with a continent?

In this paper we examine the stratigraphy and detrital zircon record of a sequence of thick and expansive clastic sedimentary sequence in the southern part of the Western Urals. These sediments accumulated during the Neoproterozoic-Paleozoic. These sediments were thought to have formed during the initial rift phases of the Uralian Ocean during the early Paleozoic

(Ivanov *et al.*, 1986).

2. Pre-Uralides–Timanides of the Bashkir Uplift (southern part of the Western Urals)

The Central Uralian uplift is composed of a range of sub-meridional rises extending along the entire Urals. Structurally, it is made up of large uplifts and anticlinoriums of Pre-Uralides–Timanides complexes lying among the Uralian and Neo-Uralian complexes of the West Uralian megazone (Kuznetsov *et al.*, 2006, 2007, 2010a; Kuznetsov, 2009; Puchkov, 2000, 2003, 2010). The Bashkirian uplift (BU) is the largest structural element of the southern part of the Central Uralian uplift. In the north, west, and south, the BU borders structures composed of Paleozoic deposits of the Western-Uralian megazone. In the east, the BU borders the non-uniformly deformed and metamorphosed Paleozoic and Precambrian complexes of the Uraltau uplift (Fig. 2).

The lower horizons in the BU are represented by an Archean and Paleoproterozoic gneiss-amphibolite complex with granulitic relics known as the Taratash metamorphic complex (TMC). The TMC is exposed in the northern part of the BU and reside in the core of Taratash anticline (Lennykh *et al.*, 1978; Sindern *et al.*, 2005; Puchkov, 2010 and references therein). The upper structural element of Pre-Uralides–Timanides in the BU is represented by a sequence composed of terrigenous, terrigenous-carbonate, carbonate and rare volcanogenic and volcanogenic-sedimentary rocks up to 10-12 kilometers in thickness (Puchkov, 2010; Maslov, 2004). The upper sequence lies stratigraphically over the TMC, with structural unconformity. The sedimentary section is divided into two parts. The lower (and thicker) part of the sequence is the Riphean Supergroup (Stratotype..., 1983; Kozlov, 1982; Kozlov *et al.*, 1989; Maslov, 2004). The upper part of the sedimentary sequence is up to 1500 meters thick and is composed of interlayered siltstones, sandstones, and conglomerates of arkosic and polymictic composition known as the Asha Group. The age of the Asha Group is debated and estimates range from

Upper Neoproterozoic to Middle Cambrian (Kozlov, 1982; Bekker, 1968, 1992, 1996; Kuznetsov and Shazillo, 2011).

Based on the lithological characteristics of different parts of the sequence, the Asha Group is subdivided into several lithostratigraphic units (Formations) known as (from oldest to youngest) the Bakeevo, Uryuk, Basu, Kukkarauk, and Zigan Formations (Fig. 2; Stratotype..., 1983; Kozlov, 1982; Bekker, 1996; Puchkov, 2010; Maslov, 2004). Age constraints for the Asha Group are based on a combination of recent geochronological work, paleontological evidence and correlation with other units in the northern and central Urals (Grazhdankin *et al.*, 2011). Ediacaran biota have been reported from multiple units within the Asha Group (Bekker, 1968, 1992, 1996), the age of these deposits was therefore assumed to be Ediacaran (Puchkov, 2010, Maslov, 2004). Recent geochronological data support this contention (Grazhdhankin *et al*., 2011) along with additional fossil discoveries (Kolesnikov *et al*., 2012). U-Pb ages from the Zigan Formation in the northern part of the BU yielded a weighted mean $^{206}Pb/^{238}U$ age of 548 Ma (Levashova *et al*., in press). Lithological and stratigraphic equivalents of Asha Group within the Northern Urals are known as the Sylva Group. Recently, several very thin and rare tuff layers were found inside Chernykamen Formation of the Sylva Group. Magmatic zircons from these tuff layers were dated (U-Pb, SHRIMP) as 557±13 Ma (Maslov *et al*., 2006). The Asha Group rests upon the upper units of Riphean Supergroup with stratigraphic unconformity and is unconformably overlain by Paleozoic deposits. The oldest sedimentary units overlying the Asha Group are thought to be Lower Devonian in age (Takaty Formation) in the western part of the BU and of Middle Ordovician age in the south (Puchkov, 2000, 2009, 2010). The Takaty Formation can be found along the western slope of the Southern, Middle and Northern Urals. Its stratotype locality is found along the Takaty River (South Urals) where the Late Emsian (~400 Ma) age is paleontologically constrained (Ivanuskin *et al*., 2009). The Takaty Formation is underlain by an erosional unconformity on older strata and is conformably overlain by carbonate units that are nearly continuous from the Middle Devonian to Lower Permian. The Takaty

Formation is dominated by monomictic or oligomictic quartz sandstones that show very little (if any) regional differences in lithology suggesting that source material for sandstones was the same along the western slope of the Southern, Middle and Northern Urals.

3. Sampling and Dating of the detrital Zircons

3.1. Sampling of the rocks

The samples 09-027 and 09-041 for detrital zircons were taken along the stratotype section of the Asha Group, from Kukkarauk Creek. Sample 09-027 (Basu Formation) was taken (53°35'50,3"N; 56°46'25,0"E) on the eastern side of a small roadside open pit located 50 m south of Sterlitamak–Makarovo–Kulgunino highway. The Basu Formation here is composed of dirty green, fine- and mid-grained polymictic sandstones with a significant admixture of white mica flakes at the surfaces of beds. A slump (a gravity slide fold) is sometimes observed in the outcrop (Fig. 3). Sample 09-041 (Kukkarauk Fm.) was taken (53°36'04,6"N; 56°41'06,2"E) from a coarse-grained red sandstone found as a lens within conglomerates of the Kukkarauk Formation along the bank of Kukkarauk Creek (Fig. 4). Sample (09-025) was taken from a quartz sandstone of the Takaty Formation near the confluence of the Sikaza River and Kukkarauk Creek (53°36'41"N, 56°39'28"E).

Each sampled weighed approximately one kilogram. Care was taken to prevent contamination (or cross-contamination) during manual disintegration in a cast iron mortar. Samples were pulverized to a size less than 0.16 mm and then density filtered on a water table. Heavier fractions were further isolated using variable density liquids. Individual zircon grains were then hand-picked and mounted in epoxy for analysis

Gross morphologies of the zircons from sample 09-027 sample included rounded to subrounded bi-pyramidal crystals. The typical crystals are yellowish pink, light pink or pink in color, transparent, to semi-transparent (a few more opaque grains were also present) and about 100 μm or less in size.

Zircons from sample 09-041 are represented by semi-rounded and occasional well to very well rounded pink grains. Many grains are characterized by a quite intense luster, and more rarely grains with a dull surface can be found. The size of grains is 50–100 μm.

Zircons from sample 09-025 are mostly represented by fragments of rounded crystals. There are small yellowish to transparent grains that commonly preserve a crystalline form (weakly rounded) and larger colorless to light pink transparent grains.

The dating of all zircons was carried out by U/Pb-isotopic method (LA-ICP-MS) at the Isotope Center, University of Florida. Analytical details can be found in Malone *et al*. (2008). Samples that yielded $^{206}Pb/^{238}U$ ages that are more than 10% discordant from their $^{207}Pb/^{206}Pb$ ages were not used in the analysis. For grains older than 1000 Ma, $^{207}Pb/^{206}Pb$ ages were used and for grains <1000 Ma, $^{206}Pb/^{238}U$ ages are used.

3.2. Dating of Detrital Zircons

For the Basu Formation (sample 09-027), 78 analyses have yielded useful ages ranging from 755-2869 Ma (Fig. 5). Three rather distinct populations are observed in the Meso to Paleoproterozoic time spans from 1105-1338 Ma (23 grains); 1454-1593 Ma (23 grains) and 1652-2095 Ma (24 grains). Both Mesoproterozoic populations are unimodal with clear age peaks (maximum density probability – ***MDP***) at 1213 Ma and 1501 Ma. The Paleoproterozoic population has two ***MDP*** at 1907 and 2000 Ma. Less dominant populations (4 ***dZr*** or 5% and 3 ***dZr*** or 4%) had ages that fell within the 959-1060 Ma and 2704-2869 Ma intervals.

For Kukkarauk Formation (sample 09-041) 57 analyses have yielded concordant ages that range from 617-3188 Ma (Fig. 5). The dominant population (20 zircons) range in age from ~1300 Ma to ~1700 Ma with an ***MDP*** of 1465 Ma. A somewhat smaller Late Mesoproterozoic population (11 grains) ranges between 1099-1231 Ma with an ***MDP*** of 1195 Ma. The remaining zircons (15 grains) are of Paleoproterozoic to Neoarchean age ranging from 1923-2097 Ma (***MDP*** at 1987 Ma) and from 2644-2850 Ma with no well-defined ***MDP***.

The sample from the Takaty Formation yielded 44 concordant ages that fall between ~1860-3050 Ma (Fig. 5). Within this range, it is possible to discern at least 3 distinct populations. The youngest (Paleoproterozoic) population is represented by 19 grains with an ***MDP*** of 1920 and a rather narrow age span of 1860-2150 Ma. The remaining two zircon populations are mostly Archean in age with an older grouping at 3042 Ma (***MDP*** 8 grains) and a younger grouping with two ***MDP*** peaks at 2640 Ma and 2424 Ma (early Paleoproterozoic). We note a very large (nearly 1.5 Ga!) "gap" between the sedimentary age of sandstones from Takaty Formation (~400 Ma) and the age of the youngest of dated ***dZr*** (~1.86 Ga).

4. Tectonic nature of Asha Group and constraints for its age

Traditionally, the age of Asha Gr. is estimated as Ediacaran (Upper Vendian in Russian stratigraphic chart; Bekker, 1968, 1992, 1996; Sokolov and Zhamoida, 2002). More recently, Kuznetsov and Shazillo (2011) report the discovery of numerous fine fragments of inarticulate brachiopods within the Kukkarauk Fm. These fragments are very small (ranging from 1 mm to several hundred μm) thought to belong to the Obolidae Family. The first appearance datum (FAD) for the Obilidae takes place in the Botomian (~515 Ma). There is some disagreement about the significance of these 'fossils' as well as their identification. For example, Puchkov (2012) has argued that the fossils are more diagnostic of Nemakit-Daldyn biota (~542-525 Ma). Additional support for a Cambrian-age of the Kukkarauk Formation comes from early detrital zircon (and Ar-Ar) work reported by Wilner *et al*. (2003) and Glasmacher *et al*. (1999) where ages ~515 Ma appear in the detrital record. In contrast, Levashova *et al*. (in press) report U-Pb ages on zircon of 548 Ma for the Zigan Formation that would relegate the bulk of the Asha Group to the Ediacaran. While the significance of these finds must await further verification, it seems clear that the age of the Kukkarauk and Zigan Formations should be placed near the Ediacaran-Cambrian boundary (see also Grazhdankin *et al*., 2011).

5. Source Comparison Analyses

To compare the obtained dates for ***dZr*** from samples 09-027 (Basu Formation) and 09-041 (Kukkarauk Formation), we applied the Kolmogorov–Smirnov test (KS-test) to their cumulative age distributions. The comparison of the derived set of ages (Table 1, Fig. 6) has shown a high degree of similarity between the samples (p = 0.529). In spite of the different lithologies sampled (i.e. polymict sandstones versus arkosic sandstones), there are no substantial differences in the age distributions of the detrital zircons. Given that both sequences appear to have sourced similar regions, we combine both data sets as an integrated database for the Asha Group and conclude that both received input from the same source regions.

We then take the combined “Asha Group” detrital zircon profile and compare the results to those obtained from the Devonian-aged Takaty Formation. In general, the EEP is considered to be the most likely source (western-derived in present-day coordinates) for clastic material in both the Takaty Formation and the Asha Group. A second possibility is that these sediments entered the basins from nearby local sources or from hypothetical ‘eastern’ sources that are not part of the EEP.

Potential source regions in the immediate vicinity of the basinal sediments include Precambrian basement complexes (both igneous and metamorphic) including the following units:

(1) Taratash metamorphic complex: The Taratash includes granulites and amphibolites. The oldest known material in the Taratash is derived from relic zircons dated to between 3.5-2.6 Ga (Krosnobaev, 1986; Sindern *et al*., 2005; Ronkin *et al*. (2007). Metamorphic ages within the Taratash range from 2.1-1.8 Ga.

(2) Ai Formation: This formation includes subalkaline basalts (~1.64 Ga) of the Navysh volcanic unit at the base of the Riphean Supergroup (Stratotype, 1983; Kozlov *et al*., 1989).

(3) Mashak Suite: This unit is composed of bimodal volcanic rocks dated to 1.38 Ga (Ernst *et al*., 2006; Puchkov *et al*., 2009; Puchkov, 2010; Ronkin *et al*., 2005a).

(4) Berdyaush Massif: Includes granitoids, syenites and nepheline syenites (~1.38 Ga; Krasnobaev *et al*., 1984; Ronkin *et al*., 2005b).

(5) Kusa-Kopan, Akhmerovo and Gubensky Complexes: Composed of gabbro-norites, granitic gneisses, granitoids and granites rangind in age from 1.33-1.39 Ga (Krasnobaev *et al*., 2006, 2008; Kholodnov *et al*., 2006; Puchkov, 2010).

(6) Mazara Massif: Includes granitoids and gabbros with ages of ~665-680 Ma and 705-710 Ma (Kuznetsov, 2009).

Potential source regions from within the EEP are located in four large crustal blocks in Karelia, Kola (Baltic/Fennoscandian shield), Sarmatia (Ukrainian Shield) and Volga-Uralia. These four regions all contain significant tracts of Archaean-age crust (Mints *et al*., 2010). Within the Baltic/Fennoscandian shield, the main events associated with the assembly of the platform occurred between 2.1-2.6 Ga (Bayanova, 2004; Bibikova *et al*., 2005; Glebovitskii, 2005; Hölttä *et al*., 2008, Chaschin *et al*., 2008; Slabunov *et al*., 2006; Slabunov, 2008).

Vast exposures of the Sarmatia crustal province outcrop on the Ukrainian shield and are found in the Voronezh basement uplift that is covered by very thin (10-100 m) layer of sediments. The study of these exposures reveals several distinctive events in Sarmatia. They include crustal fragments with ages 3.8–2.9, 3.2–3.0 and ~2.7 Ga, sutured by orogenic belts with ages 2.3–2.1 Ga (Samsonov *et al*., 1996; Shchipansky, Bogdanova, 1996; Chernyshov *et al*., 1997, 2001; Shcherbak *et al*., 1984; 2003, 2008; Bibikova, *et al*., 2003, 2008a, 2010; Kirilyuk *et al*, 2002; Claesson *et al*., 2000, 2001, 2006; Gornostayev *et al*., 2004; Bogdanova, 2005; Shchipansky *et al*., 2007; Bogdanova *et al*., 2008, Lobach-Zhuchenko *et al*., 2005, 2010).

Volgo-Uralia is a large crustal domain that is entirely (excluding Taratsh uplift in the Urals) covered by a thick sediment cover. Nevertheless, many deep boreholes were drilled into basement crystalline rocks. Geochronological studies on these core samples allow us to identify the age characteristics of the Volgo-Uralian complexes that range from 3.5 Ga (the oldest complexes exposed in the Taratash uplift) to 1.9 Ga. Within that range, there is a predominance of ages between 2.6-2.8 Ga (Sindern *et al*., 2005; Ronkin *et al*., 2007; Bogdanova *et al*., 2008; Krasnobaev and Cherednichenko, 2005; Bibikova *et al*, 2008b, 2009).

It is worth emphasizing that ages between 2.4–2.2 Ga are not known in the northern part of EEP (Baltic/Fennoscandian shield) and they are extremely rare for the Volgo-Uralia and Sarmatia crustal blocks. Thus although the global LAME event (2.6–2.8 Ga; e.g. Condie, 2004) is widely observed across the EEP, the time interval 2.4–2.2 Ga is a time of tectonic and magmatic quiescence in the EEP.

The younger history of EEP is much better known on account of a more extensive geochronological data base. At ~ 2.1 Ga, the collision of Sarmatia and Volga-Uralia occurred and resulted in the Volgo-Sarmatian orogeny. As a result of this event, the Volga-Sarmatia (Sarmatia + Volga-Uralia) proto-craton was formed by ~2.00 Ga (Shchipansky *et al*., 2007; Bibikova *et al*., 2009; and references therein).

During post-collisional collapse of Volgo-Sarmatian orogen, voluminous production of 1.82-1.74 Ga plutons occurred including the Korosten (Amelin *et al*., 1994; Bogdanova *et al*, 2004; Shumlyanskyy *et al*., 2006) and Korsun'-Novomyrgorod (Kalinin, 2008, Starostenko *et al*., 2008) and Novoukrainskiy plutons consisting of gabbro-anorthosites-granites (Rapakivi-like granites). A large supra-subduction orogen of the accretionary type with supra-subduction magmatism and metamorphism formed along the northwestern edge of Volgo-Sarmatia – the Osnitsk-Mikashevichi Igneous Belt (Aksamentova, 2002, Shchipansky *et al*., 2007; Bogdanova *et al*., 2008 and references therein). It was a precursor of the Volgo-Sarmatia and Fennoscandia collision zone.

At ~1.98-1.91 Ga, the Kola and Karelia blocks collided, forming the Kola-Karelian proto-craton and Lapland-Kola (sometimes named as Kola-Karelian) collisional orogen (Daly *et al*., 2006, Slabunov, 2008). Further crustal growth of Kola-Karelia is marked by the Fennian orogeny at ~ 1.89–1.87 Ga, the Svecobaltic orogeny at 1.84–1.80 Ga and the Nordic orogeny at 1.82–1.79 Ga, each of which accreted the older domains to each other and added juvenile crustal material so that the bulk of the Sveco-Fennian region was cratonised at 1.79–1.78 Ga (Lahtinen *et al*., 2005). All tectonic/magmatic events from the Kola-Karelian collision up to the Nordic orogeny resulted in the formation of Sveco-Fennia, and are collectively referred to as the Svecofennian orogeny. The Svecofennian orogeny evolved in stages, involving not only continent-continent collision and microcontinent accretion, but also large-scale extension of accreted crust and post-collisional gravitational collapse (Korja *et al*., 2006).

At ~1.8–1.75 Ga, Volgo-Sarmatia collided with Fennoscandia (Volyn–Middle-Russian collisional orogen; Bogdanova, 2005; Bogdanova *et al*., 2008 and references therein) to form Proto-Baltica. During collisional and post-collisional collapse of the Volyn–Middle-Russian collisional orogen, the emplacement of 1.45-1.7 Ga Rapakivi granite plutons and associated gabbro-anorthosites intrusions took place. The largest are the Salmi, Vyborg, Riga, Bornholm bodies (Neymark *et al*., 1994; Åhäll *et al*., 2000; Andersson *et al*., 2002; Bogdanova *et al*, 2008).

Proximal to the western margin of Proto-Baltica, numerous accretionary processes occurred intermittently between 1.7-0.9 Ga. These include the Gothian (1.73-1.55 Ga), the Telemarkian (1.52-1.48 Ga), the Danopolonian (1.47-1.42 Ga) and the Sveconorwegian (1.14-0.9 Ga). The latter Sveconorwegian orogeny is thought to be associated with global events in that same age range resulting in the formation of the supercontinent Rodinia (Bingen *et al*., 2008a,b; Bogdanova, 2005; Bogdanova *et al*., 2008; Meert and Torsvik, 2003; Pesonen *et al*., 2003).

Source regions for the younger Neoproterozoic-Cambrian zircons (750-500 Ma) on the EEP exist along the north-eastern periphery of the platform where relicts of the Pre-Uralides-

Timanides orogeny compose the basement of the Pechora basin (Timan hills), western Polar Urals, the Kanin Peninsula and neighboring regions (Kuznetsov *et al*., 2006, 2007, 2010a). Analagous age ranges in the Cadomides are thought to be represented in the Pre-Caspian depression (Leonov *et al*., 2010).

Bimodal complexes of Volynia Large Igneous Province (western Ukraine, southern Belorussia and eastern Poland) are characterized by ages 550-555 Ma (Shumlyanskyy *et al*., 2009; Shumlyanskyy and Nosova, 2008; Elming *et al*., 2007; Nawrocki *et al*., 2004). Recently, rhyolites from the Volynia area were dated (zircons, U-Pb, SHRIMP) as 557 ± 9 Ma (Nosova *et al*., 2010). The short-lived Volynia event produced thin (~several cm thick) tuffaceous layers which are traced by boreholes penetrating Ediacaran strata over the whole EEP from the Volynia region up to the Urals and White Sea region. In the western Middle Urals, the tuffaceous layers from the lowermost Chernykamen Fm. were dated (zircons, U-Pb, SHRIMP) as 557±13 Ma (Maslov *et al*., 2006). The same tuffaceous layers from the ZimnieGory Fm. and Zimniy Bereg near the White Sea were dated as 555.4 ± 1.7 Ma (Martin *et al*., 2000) and 550 ± 4.4 Ma (Iglesia-Llanos *et al*., 2005). This narrow time interval ~(550-557) Ma characterizes Baltica's Volynia LIP event and distinguishes it from the broad 750-500 Ma zircon populations that characterize the Pre-Uralides – Timanides (Kuznetsov *et al*, 2010a; Orlov *et al*., 2011; Soboleva *et al*., 2012).

Detrital zircons with ages of ~ (400-490) Ma (Bingen and Solli, 2009; Bingen *et al*., 2009) can be sourced from complexes of Scandinavian Caledonides located in the most north-western part of EEP.

6. Provenance for the Asha Group Sedimentary Rocks

The sedimentary complexes located along the south Uralian periphery of the EEP are considered to be autochthonous or para-authochthonous with the EEP (i.e. Baltica or Proto-Baltica; Puchkov, 2000; 2010; Levashova *et al*., 2013). Given that relationship, it seems reasonable to conclude that the principle source of clastic material into the Asha Group was from the Volga-Uralian region of the EEP that is located immediately west of the Asha Group outcrops. This fragment of the basement comprises the Paleoproterozoic and Archean complexes spanning the range of about 1750–3500 Ma (Fig. 1 and 5). If this region is the source for the Asha Group, then it might be expected that the erosional products of crystalline complexes of Volgo-Uralia and relicts of orogens from its frame – Volgo-Sarmatian and Volyn-Middle-Russian (collectively called as "Volgo-Uralian provenance signal") should dominate. In contrast, the Asha Group sedimentary sequences reported in this study only about one third (32%) of the ***dZr*** have ages reflecting Volgo-Uralia (2100-3500 Ma), complexes of Volgo-Sarmatian orogen (2000-2100 Ma) and Volyn-Middle-Russian orogen (1750-2000 Ma). Thus, the so-called “Volgo-Uralian” signature in the Asha Group rocks does not dominate the signal and indicates that alternative (and perhaps more distal) sources should also be considered.

The primary signal in the Asha Group gives ages ranging from 900-1750 Ma (66% of the grains studied). Sources adjacent to the Asha Group sediments with ages in this range are not known from the adjacent regions of Volgo-Uralia, but are known elsewhere in the EEP. Specifically, ages in this range are fairly common in the Sveconorwegian and Svecofennian areas some 2500 kilometers from the Asha Group sedimentary basins. In principle, long-distant transport and reworking of ***dZr*** is not unusual in modern settings. Therefore this north-western Baltica signal implies the presence of a lengthy riverine system to deliver material to the peri-Baltic region where the Asha Group now resides. Although possible, the weak Volgo-Uralia (32%) signal compared to the dominant northwestern Baltic signal (66%) requires a river system eroding the Svecofennian and Sveconorwegian regions with limited input or tributaries along the Volgo-Uralian margin.

Although there are modern analogues that might explain such a distribution, the paleotectonic setting in the region of the Asha Group during the Neoproterozoic seems at odds with a lengthy and mature river system. During the Neoproterozoic a series of SW-NE trending aulocogens in the Volhyn-Orsha region served as a paleo-depression separating north western Baltica (i.e. Svecofennian and Sveconorwegian sources) from the region of the Asha Group (Kheraskova *et al*., 2001; Chamov, 2005; Chamov *et al*., 2010; Garetsky and Nagorniy, 2006; Bogdanova *et al*., 2008; Nikishin *et al*., 1996). Figure 7 (Tracks 1, 2 and 3) show potential riverine systems that drained Baltica and delivered sediments to the southwest (Track 1), northeast (Track 2) and towards the Caspian region (track 3).

Kuznetsov *et al*. (2010a,b) provided detrital zircon evidence that Svecofennian and Sveconorwegian areas were being diverted towards the Timanian margin of Baltica (Track 2, Fig. 7). Zircon ages from clastic rocks of the Djejim Formation (southern Timan) vary from ~ 1175 to 2972 Ma with a predominance of Paleoproterozoic ages. Kuznetsov *et al*. (2010a,b) argued that the majority of sediments in the Djejim Formation were derived from crystalline complexes located in the present-day central and north-eastern parts of Baltica and to a lesser extent from north-western Baltica. The proportions of far and weak ‘north-western Baltic’ and near and strong ‘central Baltica’ signals in the Djejim detritus supports the presence of a physical barrier to transport.

Given the presence of these physical barriers to north-western Baltic detritus into the Asha basin, it is possible that other modes of transport may have delivered this material into the Asha basin. One potential delivery mechanism is along-coast migration from the mouth areas of Volhyn-Orsha, Middle-Russian or Pachelma aulocogens that is difficult to test. A second possibility is that the so-called Svecofennian and Sveconorwegian detritus did not come from Baltica, but rather from another region that contains crustal elements of similar-age. This region may have been located adjacent to the Asha basin or from an ‘unknown’ easterly source with age characteristics similar to Sveconorwegian or Svecofennian rocks.

We examine the possibility of an alternate (or ‘easterly’ source) by examining the precursory paleogeography that ultimately culminated in the development of the Asha Basin. It is widely believed that a supercontinent called Rodinia persisted from ~1.1 Ga until 0.75 Ga, but the exact paleogeography of that supercontinent is contentious (Meert and Torsvik, 2003; Evans, 2009; Piper, 2007). In some reconstructions (Meert and Powell, 2001; Li *et al*., 2008), the Uralian margin of Baltica is depicted as a passive margin. Given the barriers to sedimentation discussed above, we argue that other models should be considered in order to explain the ***dZr*** distribution in the Asha Group.

There are several alternatives to a Svecofennian/Sveconorwegian source for the Asha sediments that have appeared in the literature. Tohver *et al*. (2006) place the Amazonian craton along strike from Baltica and adjacent to eastern Laurentia in the Rodinia configuration and the West African craton along the Sarmatian margin of Baltica (Johansson, 2009). A somewhat unconventional option is the Australia Upside Down (AUD option) proposed by Evans (2009). In the AUD configuration, the Queensland margin of Australia was juxtaposed with the South-Uralian edge of Baltica at the beginning of the Neoproterozoic (Fig. 8a). A more recent discussion by Swanson-Hysell *et al*. (2012) showed that the AUD option does not contradict new paleomagnetic data from Neoproterozoic rocks in the Amadeus basin, Australia.

7. Australia Upside Down (AUD) and other options

In an effort to test the AUD configuration, we used the KS-test to compare the spectrum of ***dZr*** ages from the Basu and Kukkarauk Formations to those from age-equivalent (Late Neoproterozoic) sedimentary rocks from eastern Australia. Ferguson *et al*. (2007) provide ***dZr*** ages from the Cape River metamorphic complex in Queensland and Ireland *et al*. (1998) report ***dZr*** data from the Bonney sandstone and Marino quartzite from the Adelaide region of southeastern Australia.

The Australian samples are dominated by Mesoproterozoic-Late Paleoproterozoic ages with minor Neoproterozoic and Early Paleoproterozoic ages (Fig. 9). All three samples show peaks between 1.1-1.2 Ga, but vary somewhat in their Late Paleoproterozoic distributions. The

KS-test showed cross-“p” values of 0.106, 0.884 and 0.363 (Table 1, Fig. 6) indicating that they all sourced the same regions. The main difference between the Australian dataset and the Asha Group spectra is the lack of any Archean ages in the Australian samples. The Asha-Australia KS-test demonstrates a strong similarity between the two groups (Table 1). For example, for Cape River sample cross-"***p***" values rather, both for ***dZr*** from Basu Formation (09-207, ***p*** = 0.654), and Kukkarauk Formation (09-041, ***p*** = 0.567), and also for summary age set ***dZr*** (09-207+09-041, ***p*** = 0.573).

The relatively strong correlation between the two datasets provides some independent evidence that Australia and the eastern margin of Baltica were juxtaposed during the Neoproterozoic and the sediments were sourced from the same regions. Potential source regions include the central part of Australia (relicts of Musgrave orogeny 1100-1400 Ma), parts of the Northern Australia (relicts of Georgetown orogeny, 1400-1750 Ma; Giles *et al*., 2004; Betts, Giles, 2006) and/or more western parts of Australia.

If this conjecture is correct, then the Uralian margin of Baltica and the eastern margin of Neoproterozoic of Australia were juxtaposed into Late Ediacaran time. The modified paleogeography would also require significant changes to Rodinia paleogeography and conjugates for the western margin of Laurentia (Evans, 2009). It should be noted that the ‘connection’ between Australia and Baltica in the Evans (2009) model was considered valid at ~750 Ma. Breakup along the eastern margin of Laurentia is thought to have taken place between 615-550 Ma (Puffer, 2002). Furthermore, Meert (2003) argued that Gondwana assembly was nearly complete by ~550 Ma and any scenario incorporating the AUD hypothesis requires complex Neoproterozoic-Cambrian gyrations (Fig. 8b). Given the problematic nature of the Neoproterozoic database for Laurentia and Baltica (summarized in Meert, in press; Abrajevitch and Van der Voo, 2010), we feel that this connection should be evaluated further by examining a larger database from both Australia and the Uralian sediments. One additional possible source for the Asha Group sediments is that they were derived from the Amazonian-West African region. Detrital zircon records from modern West

African rivers and the Amazon (Rino *et al*., 2008) have not been statistically evaluated with those of the Asha Group, but given the strong similarities between Baltica and Amazonia noted by Johansson (2009) we feel it is premature to reject a more 'traditional' Rodinia setting in favor of the AUD hypothesis.

8. Provenance of the Devonian Takaty Formation

Deposition of the Takaty Formation in the Early Devonian occurred in a sedimentary basin along the Uralian margin of Arct-Laurussia (Fig. 10a, Kuznetsov *et al*., 2010a). Evaluation of potential source regions for the Takaty Formation is complicated by the lack of any detritus younger than 1.86 Ga. This distribution would seemingly preclude both continental local sources as well as any arc-related complexes of Paleozoic age. Given the limited sample size (44 grains), we are cautious about making any definitive arguments about the source region for these clastic sediments. The following discussion is based solely on the idea that further data support the observation made in our study.

Assuming that the only available source for zircon supply in the Takaty Formation is a crustal region with ages older than 1.86 Ga, we presume a source composed exclusively of Paleoproterozoic to Archean crust that was eroded during Devonian time. This would preclude source regions from north-western Baltica because both the Svecofennian and Sveconorwegian regions contain crustal sources younger than 1.86 Ga.

There is a strong similarity between the Takaty Formation and complexes that comprise the central regions of the Volga-Ural area. We consider the Volga-Ural region as the most likely source for ***dZr*** in the Takaty Formation due to the fact that the most structurally elevated section of the EEP is in the Volga-Ural anticiline. Several uplifts of crystalline basement – Tatar, Tokmov and others are specified from seismic reflection data. Drilling of oil-bearing sedimentary strata showed that the basal levels of sedimentary cover are Eifelian in age, and are Frasnian in age some places. The basal

Devonian strata rest on the deeply eroded Archean and Paleoproterozoic magmatic and metamorphic complexes with pronounced unconformity. In accordance with these observations, the Volga-Uralian part of EEP is interpreted on paleogeographic reconstructions (Nikishin *et al*., 1996) as a high standing landmass during the Early Devonian. Its erosional products were transported to the Uralian margin of Arctic-Laurussia and accumulated here as Takaty sandstone (Fig. 10B). The uplift created a barrier that prevented the erosional products of remote parts of EEP (Sveco-Norway, Caledonian etc) from reaching the Uralian margin.

9. Conclusions

U/Pb-isotope dating (LA-ICP MS) of ***dZr*** zircons from sandstones of Basu and Kukkarauk Fm. from Asha Gr. and Takaty Fm of the western flank of the BU (Southern Urals) were carried out. Ages of ***dZr*** from Basu Fm. fall within the time interval ~(705 – 2869) Ma, ages from Kukkarauk Fm. ~ (617 – 3188) Ma and Takaty Fm. ~(1858 – 3054) Ma.

Application of KS-test showed that the detrital zircon ages sets of Basu and Kukkarauk Fms. have a statistical degree of similarity, although the samples were selected from different types - polymictic and arkosic sandstones of different levels of Asha Gr. This suggests that the total volume of the two sandstone formations formed by the accumulation of erosional products from same source regions and can therefore be used as a single dataset. There are no similarities between the source regions of the Asha Group and the Takaty Formation despite their proximity. The Asha Group, along with many Neoproterozoic to Upper Paleozoic sediments along the southern Uralian margin are autochthonous or para-autochthonous to Baltica/Proto-Baltica. Source regions to the west of the Asha Group (Volga-Uralian region of the EEP) are composed primarily of Proterozoic and Archean aged complexes ranging in age from 1750-3500 Ma. Very few zircons of this age were discovered in the Asha Group and therefore the Volga-Uralian signal is muted whereas the Early Neoproterozoic-Late Paleoproterozoic (900-1750 Ma) signal is dominant. Although source rocks of this age are common in the distal regions of Baltica, their prevalence in the Asha rocks demands an explanation.

We believe that one potential explanation for this dichotomy (i.e. near-source signal muted and distal source signal amplified) is that the clastic rocks of the Asha Group had a non-Baltic source. We attempt to identify that source using our detrital zircon record. There are several potential explanations for the 'signal' in the Asha Group rocks. (1) A complex fluvial system was in-place across Baltica that delivered mature 'distal' zircons (900-1750 Ma) preferentially over near-source zircons. (2) The Asha basin was essentially closed to westerly sources from Baltica, but was open to sources to the eastern or southern side. (3) Non-Baltic sediments were sourced along the Uralian margin during the Riphean and were re-worked into the Asha Group during the Ediacaran-Cambrian interval.

In an effort to answer this question, we looked at potential 'out of Baltica' sources. Evans (2009) proposed a new Rodinia configuration by placing northern Australia adjacent to the Uralian margin of Baltica (Fig. 10a). This configuration is nicknamed the "Australia upside down" hypothesis (see also Swanson-Hysell *et al.*, 2012). We examined the detrital zircon record from several Australian sandstone samples from the Cape River (CR190) quartz sandstone in Queensland (Late Cambrian age) along with the Marino arkosic sandstone (AFB123136) and Bonney sandstone (AFB123140) from the Adelaide region. The Bonney sandstone (Wilpena Group) is Late Ediacaran in age and the Marino arkosic sandstone is thought to be of Marinoan age. We compared detrital zircon suites from the Australian samples to those found in the Asha Group. The KS-test between the samples show a high degree of similarity (see Fig. 6) and indicates that Australian sources may have provided detritus to all of these rocks. Although the detrital zircon suites provide some evidence for an Australia-Baltica connection during the Neoproterozoic and/or Cambrian, there are issues related to the paleogeographic reconstructions that make the Australia-Baltica connection. Assuming that Australia was the source of detritus for the Asha group sediments, then Australia (or parts of it) must have occupied space proximal to the Uralian margin of Baltica. The AUD hypothesis (Evans, 2009; Swanson-Hysell, 2012) is permissible using the extant Neoproterozoic paleomagnetic database (~750 Ma). This unusual proposal is discussed in some detail by both Evans (2009) and Swanson-Hysell *et al*. (2012), but neither publication offered a complete ‘exit-strategy’ for Australia into Gondwana that would be required by the AUD hypothesis. The Ediacaran paleogeography is no less problematic-- especially for Baltica (Meert, 2013). Figure 8b shows a possible reconstruction between Baltica at ~550 Ma using poles from the Winter Coast (Iglesia-Llanos *et al*., 2005; Popov *et al*., 2002), Laurentia (Meert, 2013) and Gondwana (Meert, 2003). As with any paleomagnetic reconstruction, there are degrees of freedom in choice of polarity (i.e. north or south poles) and in longitude. In Fig 8b, Baltica-T is positioned to the south of the present-day eastern margin of Laurentia and to the north of the African-South America join in Gondwana. This position is consistent with models that posit the opening of the Iapetus Ocean between Baltica and Laurentia beginning at ~615 Ma (Kamo *et al*., 1989; Puffer, 2002; Cawood and Nemchin, 2001; O’Brien and van der Pluijm, 2012). The position also results in relatively simple geometries and plate motions required to close the Iapetus, Theic and Rheic oceans between Baltica, Gondwana and Laurentia in the Paleozoic. In contrast, the Baltica-U option assumes the opposite polarity for the Baltica data and moves it longitudinally into a position adjacent to western Australia. This reconstruction allows for detrital input from Australia to the Uralian margin and supports the similarities in ***dZr*** populations, but demands a very complex drift and rotation history for Baltica in the early Paleozoic that is not easily remedied with the degrees of freedom allowed by paleomagnetic data.

There is an alternative solution to the paleogeographic conundrum discussed above. If the AUD hypothesis is correct, then a significant amount of detrital input into the late Riphean-Early Vendian sequences of the Urals (from Australia) may have occurred before Australia began its journey towards Gondwana (i.e. early in the exit strategy). In this scenario, the ***dZr*** populations observed in the Asha Group result from erosion, along-shore transport and re-working of the older sedimentary rocks along the Uralian margin rather than an Ediacaran-Cambrian juxtaposition of the Baltica and Australia. This hypothesis would require a detailed accounting of global paleogeographies from ~750 Ma to about 550 Ma that are currently lacking (Swanson-Hysell *et al*., 2012). A further test would be to examine ***dZr*** populations of Riphean-Early Vendian rocks in the Urals to see if they contain the same ***dZr*** populations as the Asha Group.

The accumulation of the Early Devonian Takaty Formation occurred in a lengthy sedimentary basin along the Uralian margin of Arct-Laurussia. The absence of ***dZr*** younger than 1.86 Ga excludes local (Uralian sources) and Paleozoic volcanic arc products as sources for these rocks. It would appear that the Takaty Formation sourced regions from uplifted blocks of the EEP composed of Archean and Paleoproterozoic rocks. We also note that a more detailed study of the Takaty Fm. is required before making any detailed conclusions about a single source as we have a sample of only 44 grains taken from a relatively small region.

Although sedimentary strata of the south-western Urals including Basu, Kukkarauk and Takaty Fms. form a continuous-like section, the spectrum of ***dZr*** ages from those Fms indicates major changes in basinal source and structure. The basin was most likely an intracontinental (intra-Rodinia) basin during the Tonian/Cryogenian interval and perhaps into the Ediacaran. Accumulation of strata within the Asha Group (Late Neoproterozoic-Middle Cambrian) contains detritus that may have originated from an easterly source (Australia?). Later, during accumulation of Takaty Fm. (Early Devonian), the basin formed along a passive margin with main input from the western side (EEP).

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Figure Legends

Figure 1: Map of the main basement complexes and structures of the East European Platform (EEP) and its periphery, including blocks of consolidated basement, rift structures, and Neoproterozoic and Paleozoic fold-thrust belts (modified from Kuznetsov *et al*., 2010a). Late Paleoproterozoic–early Neoproterozoic complexes of the EEP from Bogdanova *et al*. (2008). Neoproterozoic–Middle Cambrian complexes at the eastern and northeastern periphery of the EEP after Kuznetsov *et al*. (2007a); (Kuznetsov, (2009). Configuration of the White Sea Rift System after Baluev, (2006). Insert: Contours of EEP proto-cratons Fennoscandia, Sarmatia and Volga-Uralia simplified from Bogdanova *et al*. (2008). Plutons: K - Korosten, KN - Korsun'-Novomyrgorod, Nu - Novoukrainskiy, Vy - Vyborg, R - Riga, S - Salmi, B - Bornholm.

Figure 2: Map of the geological structural setting and stratigraphic subdivisions within the region of the Bashkirian Uplift.

Figure 3: Photo of sandstones of Basu Fm. A slump among subgraywacke sandstones.

Figure 4: Photo of conglomerates of Kukkarauk Formation with lenses and thin layers of red sandstones.

Figure 5: Histograms and density probability plots for detrital zircon ages obtained from the Basu (09-027) Formation and the Kukkarauk Formation (09-041) of the Asha Group along with results from the Devonian-aged Takaty Formation (09-025). The upper section of the figure shows the major time intervals bracketing the main tectonic events within the EEP and surrounding regions.

Figure 6: Cumulative probability density plots for Australian Ediacaran-Cambrian age rocks, Ediacaran-Cambrian age samples from the Bashkirian Uplift and the Devonian Takaty Formation, Southern Urals.

Figure 7: Sediment transport and paleotopographical scheme for Baltica in the Ediacaran-Cambrian interval. Track 1 shows SW-transport directions, Track 2 shows transport directions towards the NE and Track 3 represents transport directions towards the present-day Caspian Sea.

Figure 8: (a) Adaptation of the paleotectonic reconstruction for Rodinia illustrating the so-called Australia Upside Down (AUD) hypothesis (after Evans, 2009; Swanson-Hysell *et al*., 2012). (b) Ediacaran reconstruction showing Baltica, Gondwana and Laurentia. Baltica is positioned between Laurentia and Gondwana (Baltica-T) using one polarity option and adjacent to Australia (Baltica-U) using the opposite polarity option.

Sample locations: 1- Southern Urals, this paper; 2 - Djejim Parma, Timan Hills (Kuznetsov et al., 2010a,b).

Figure 9: Histogram for detrital zircon populations from the Bonney Sandstones, Marino Arkose (both Adelaide, south-eastern Australia; Ireland *et al*, 1998), the Cape River quartzite (Queensland, eastern Australia; Fergusson *et al*., 2007) and the Asha Group (09-027 + 09-041; this paper).

Figure 10: (a) Conceptual tectonic setting of the Paleozoic-aged Arct-Laurussia (modified after Kuznetsov *et al*., 2010a). TTL=Teisseyre-Tornquist Line, A=Arctida, B=Baltica, L=Laurentia. Latitude lines drawn every 30 degrees. (b) Paleogeographic setting for the EEP during the Early Devonian.

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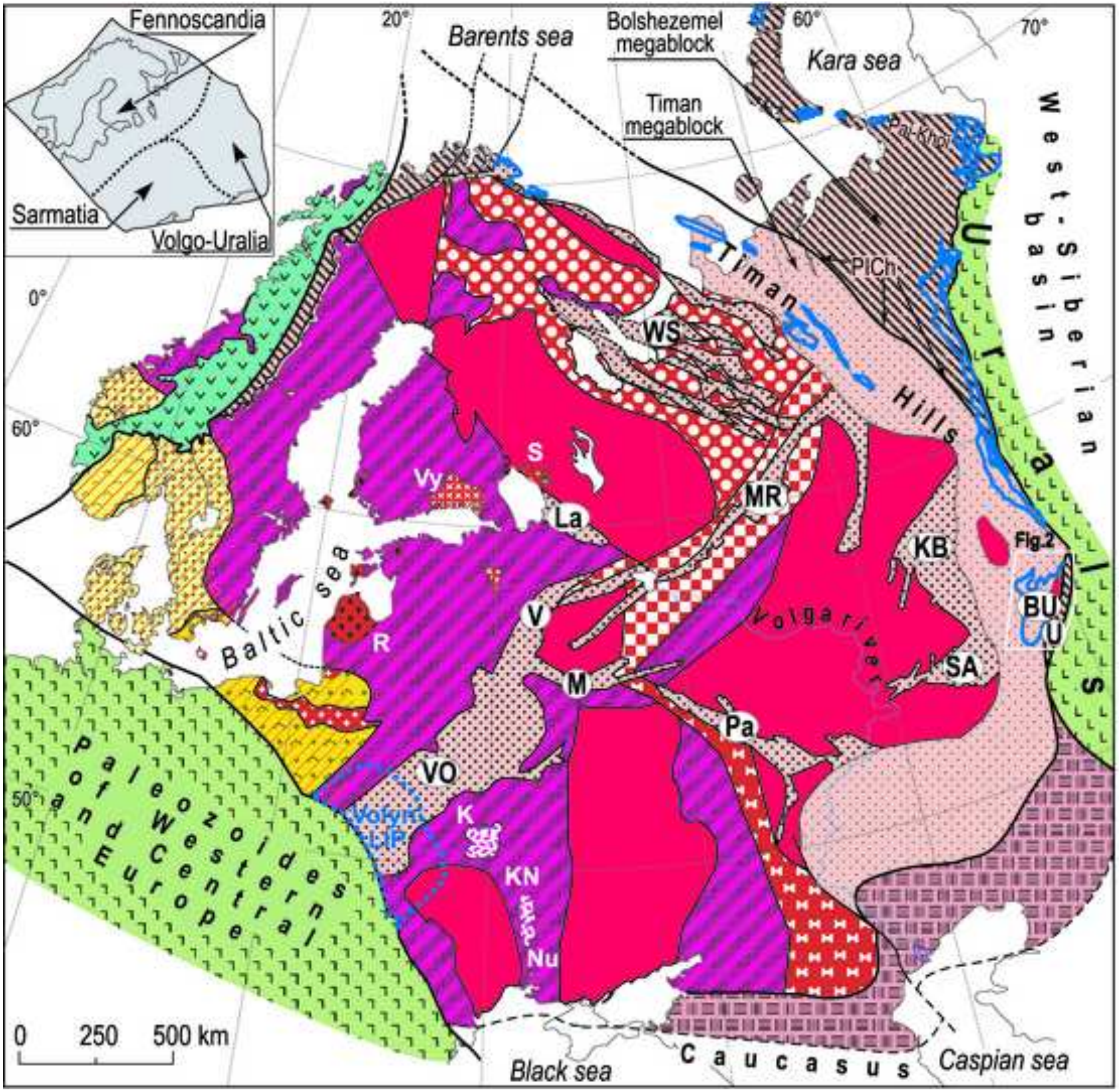

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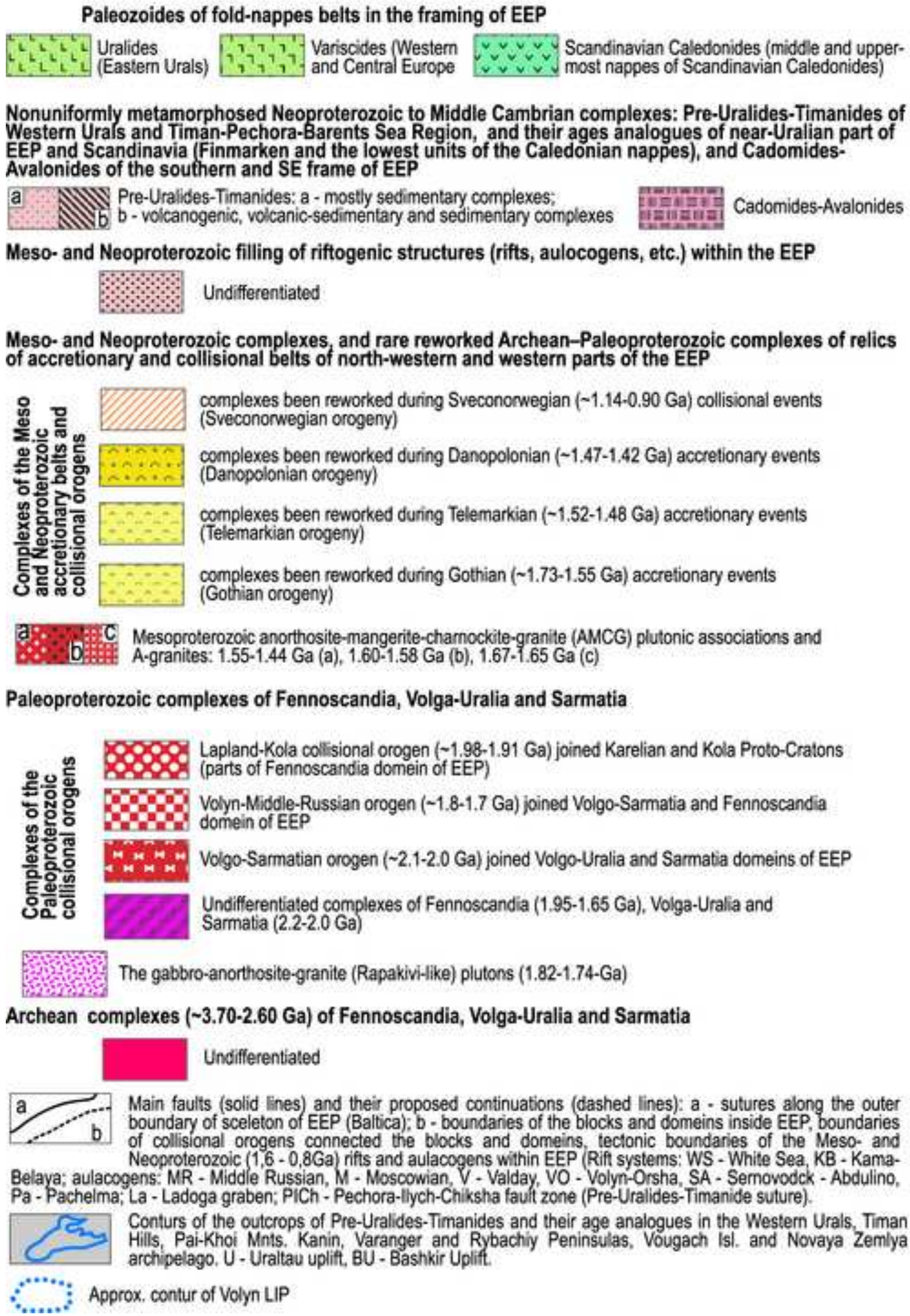

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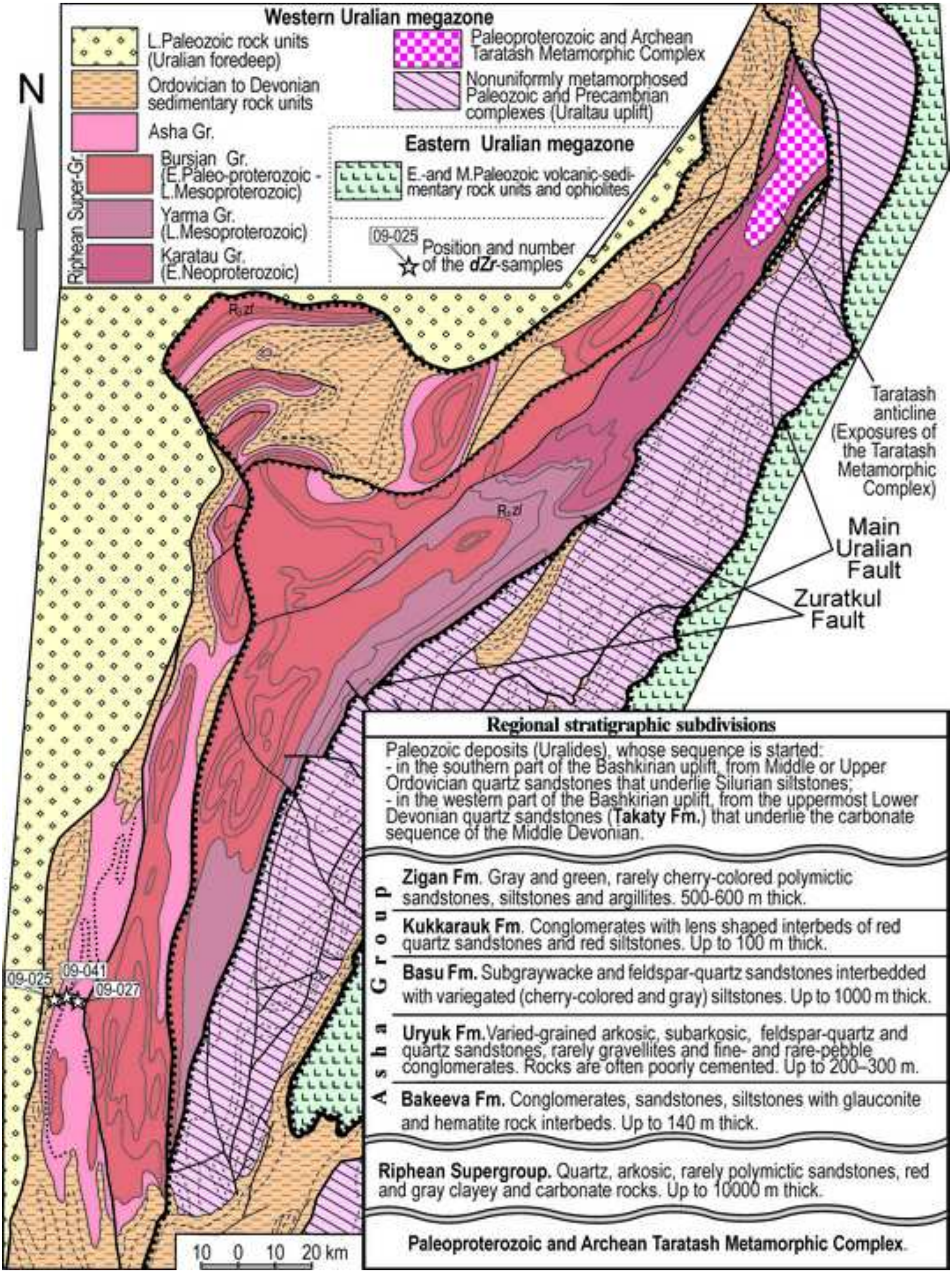

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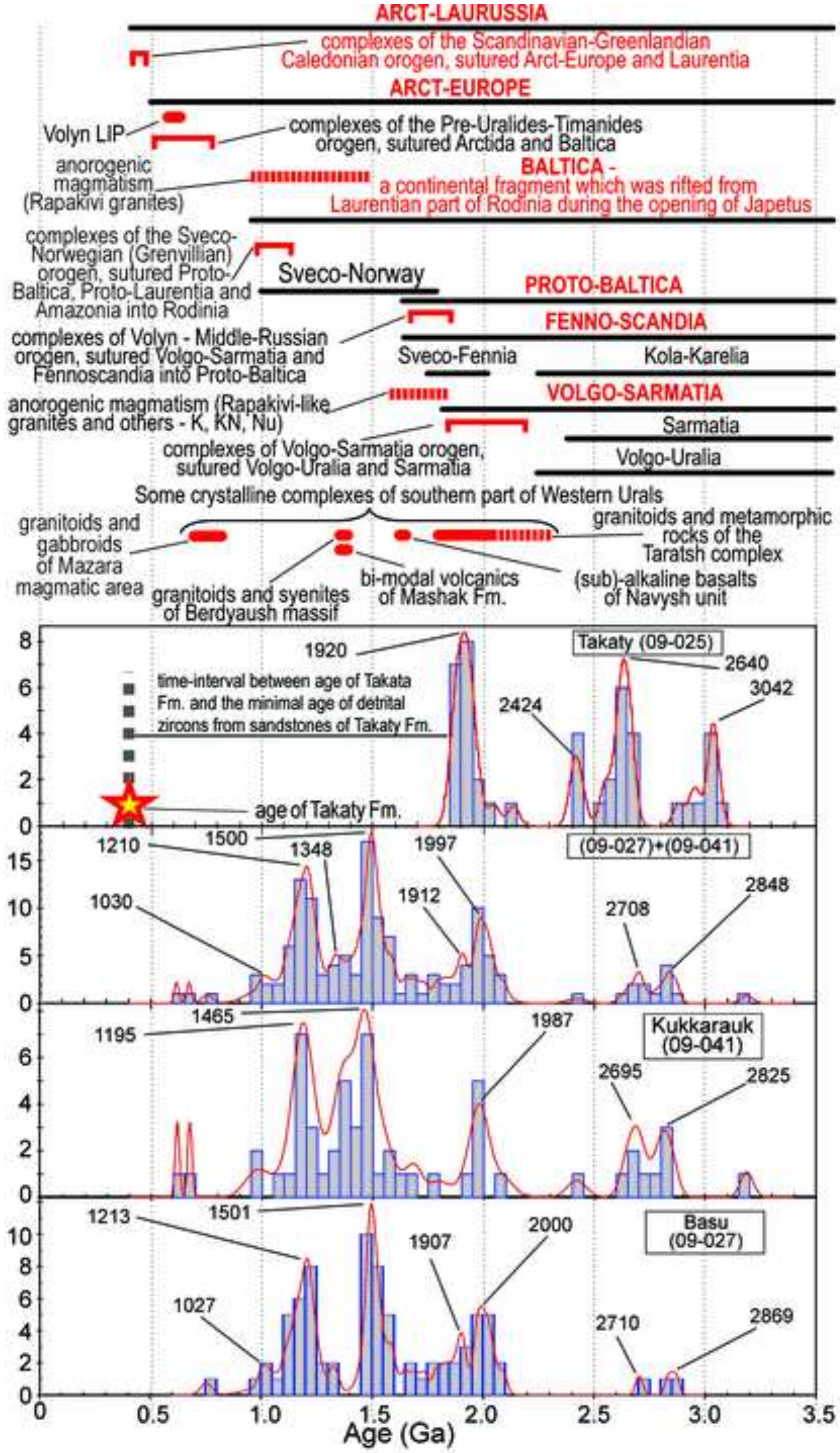

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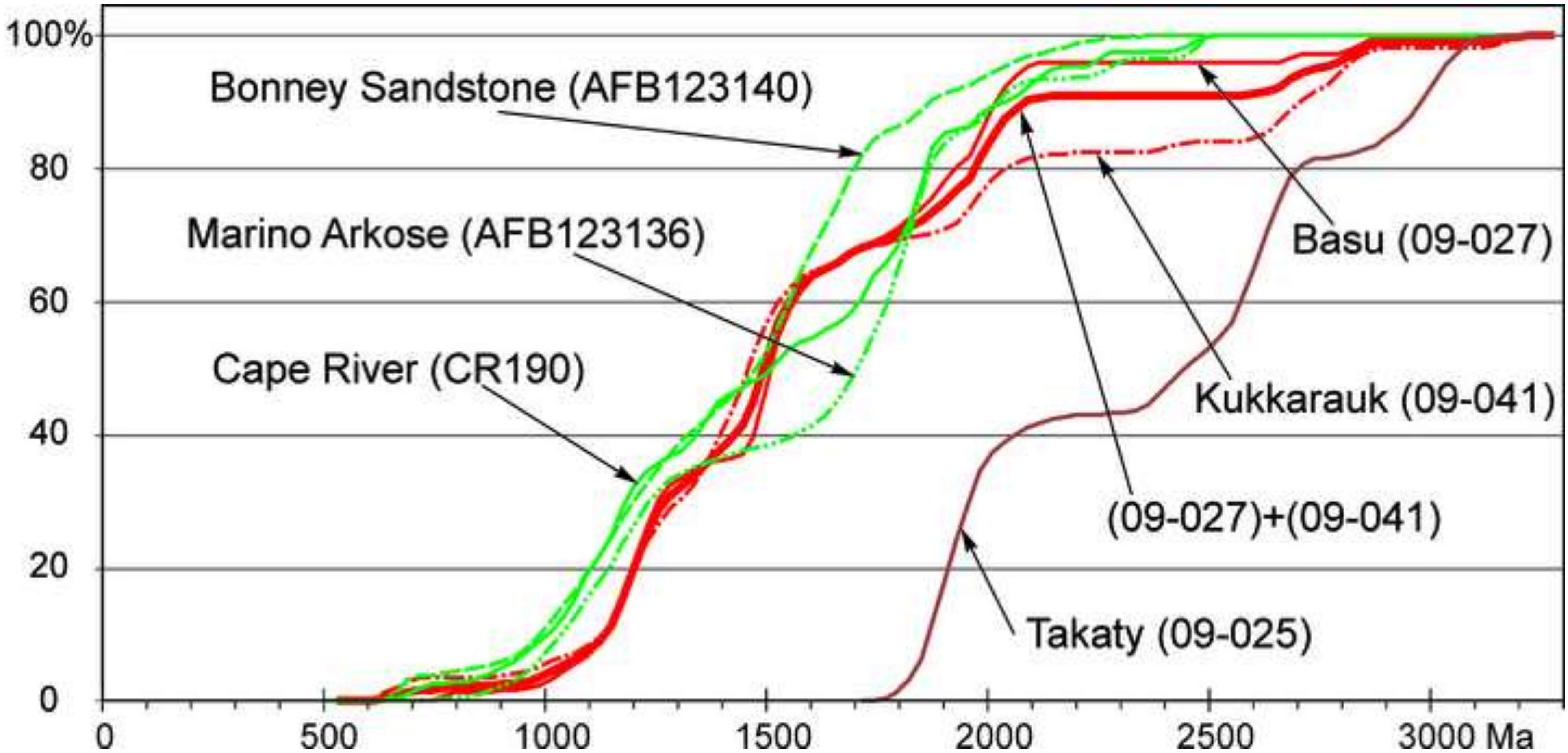

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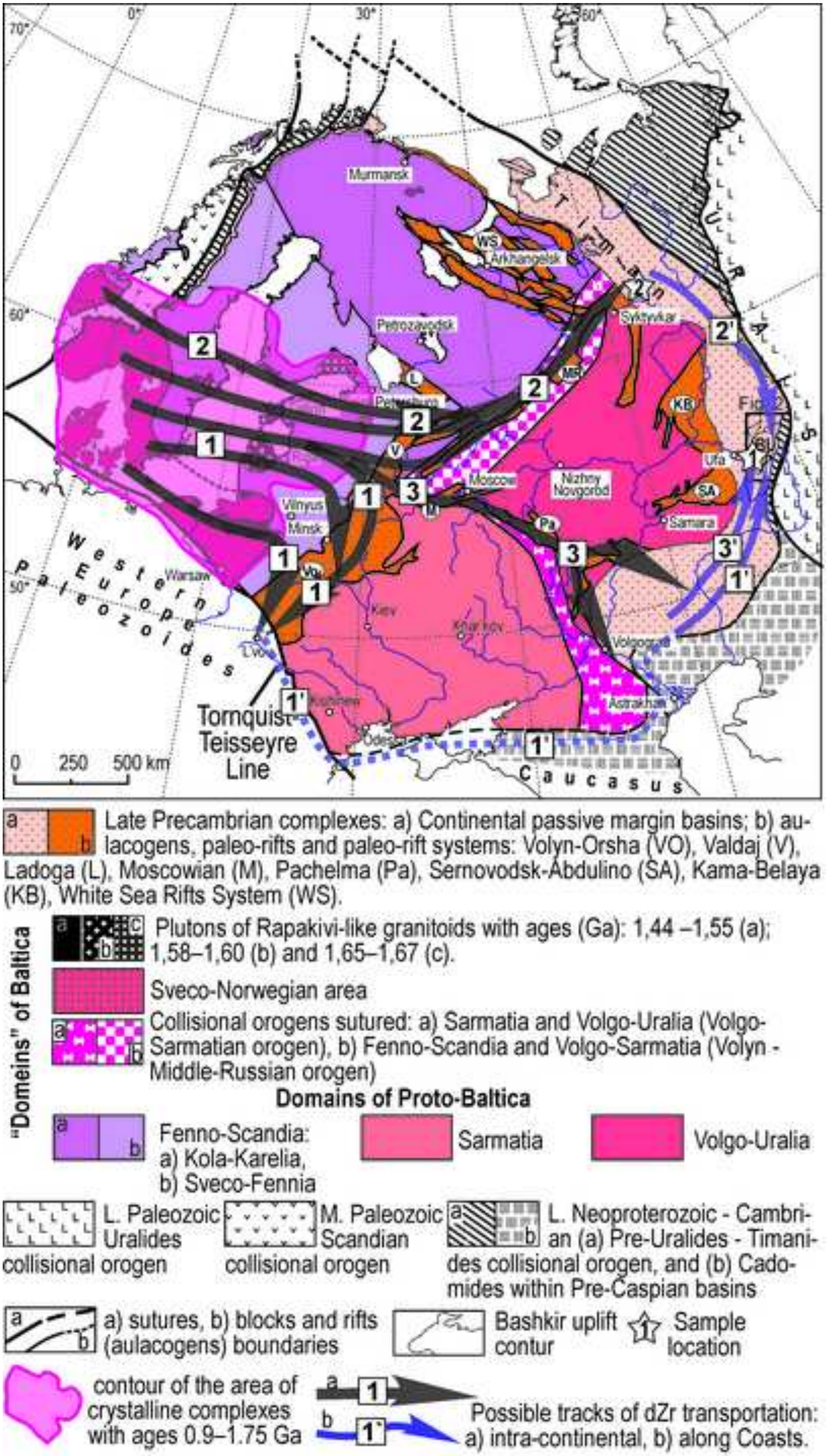

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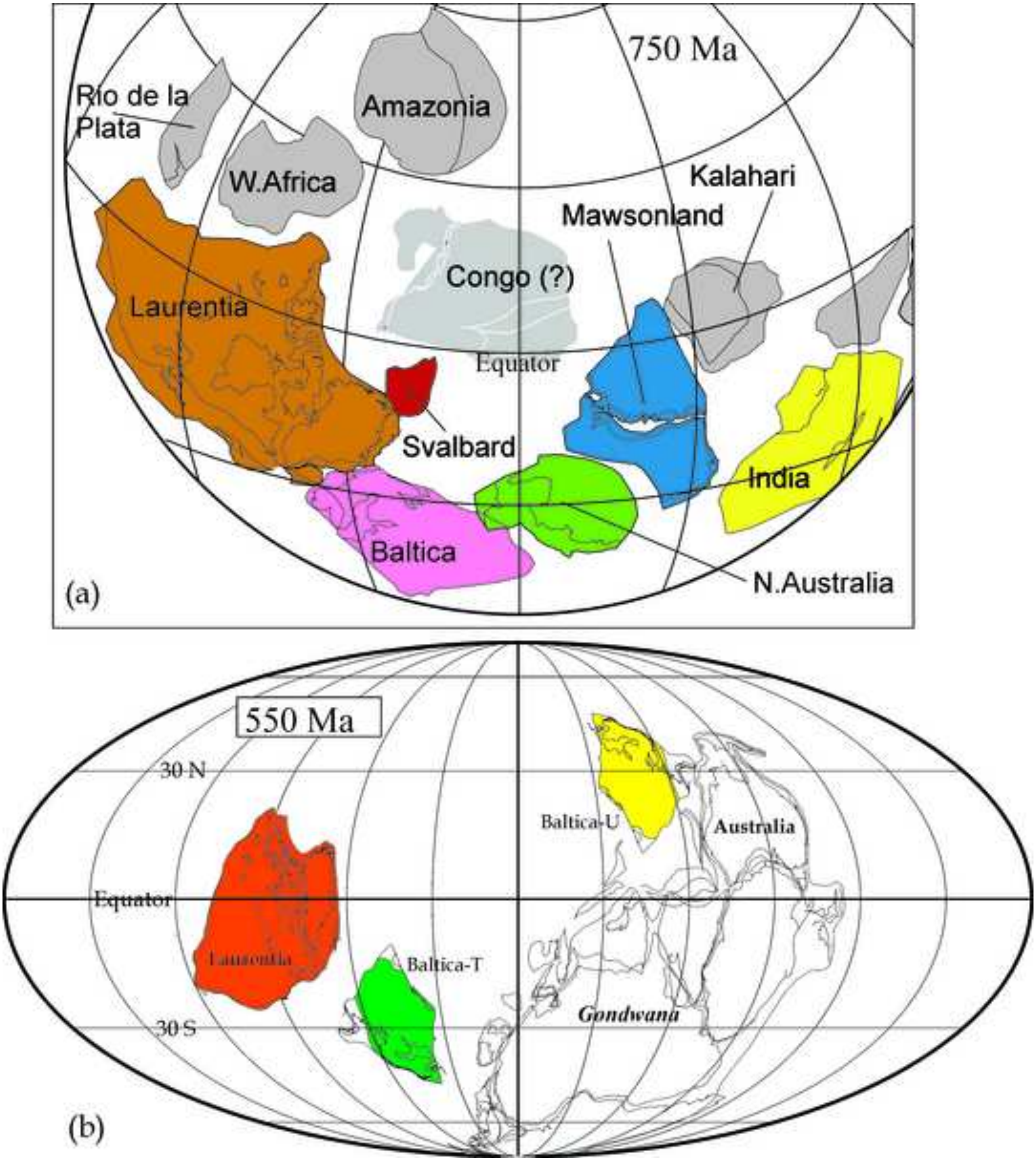

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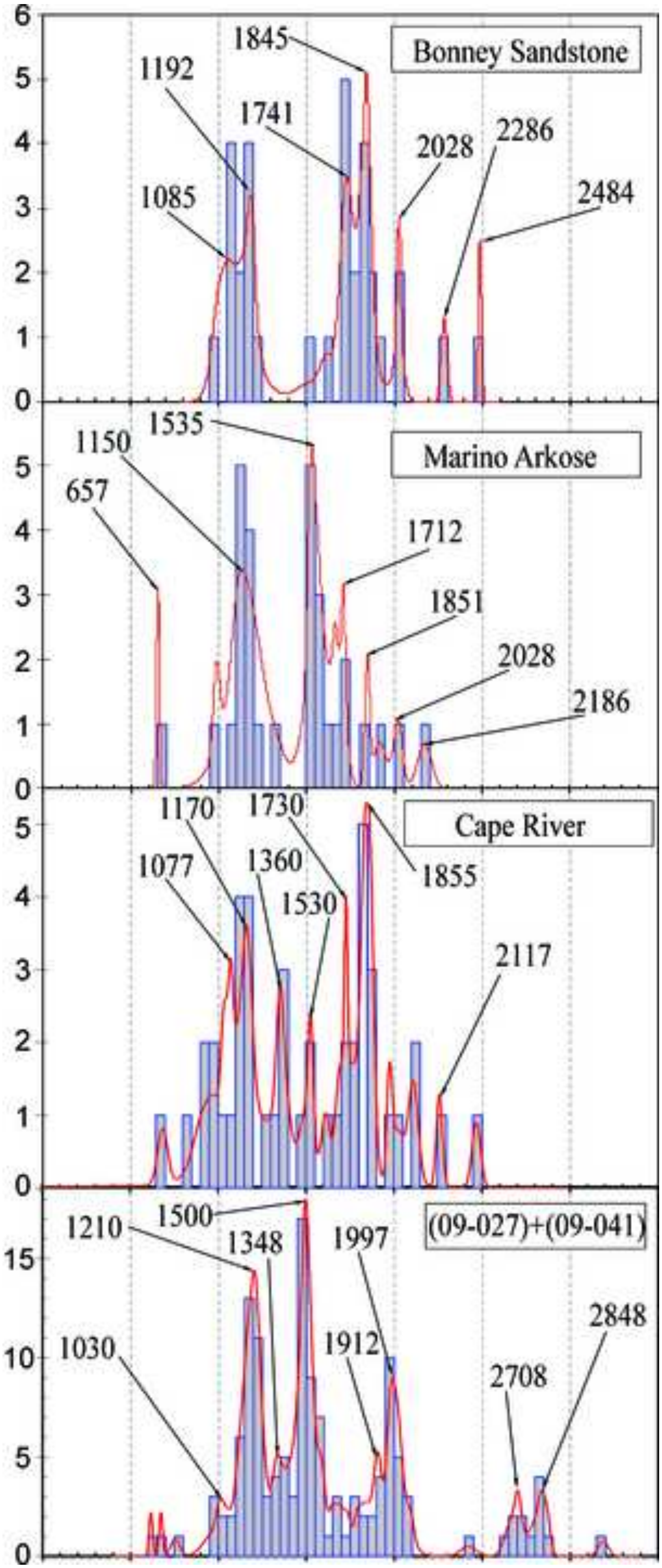

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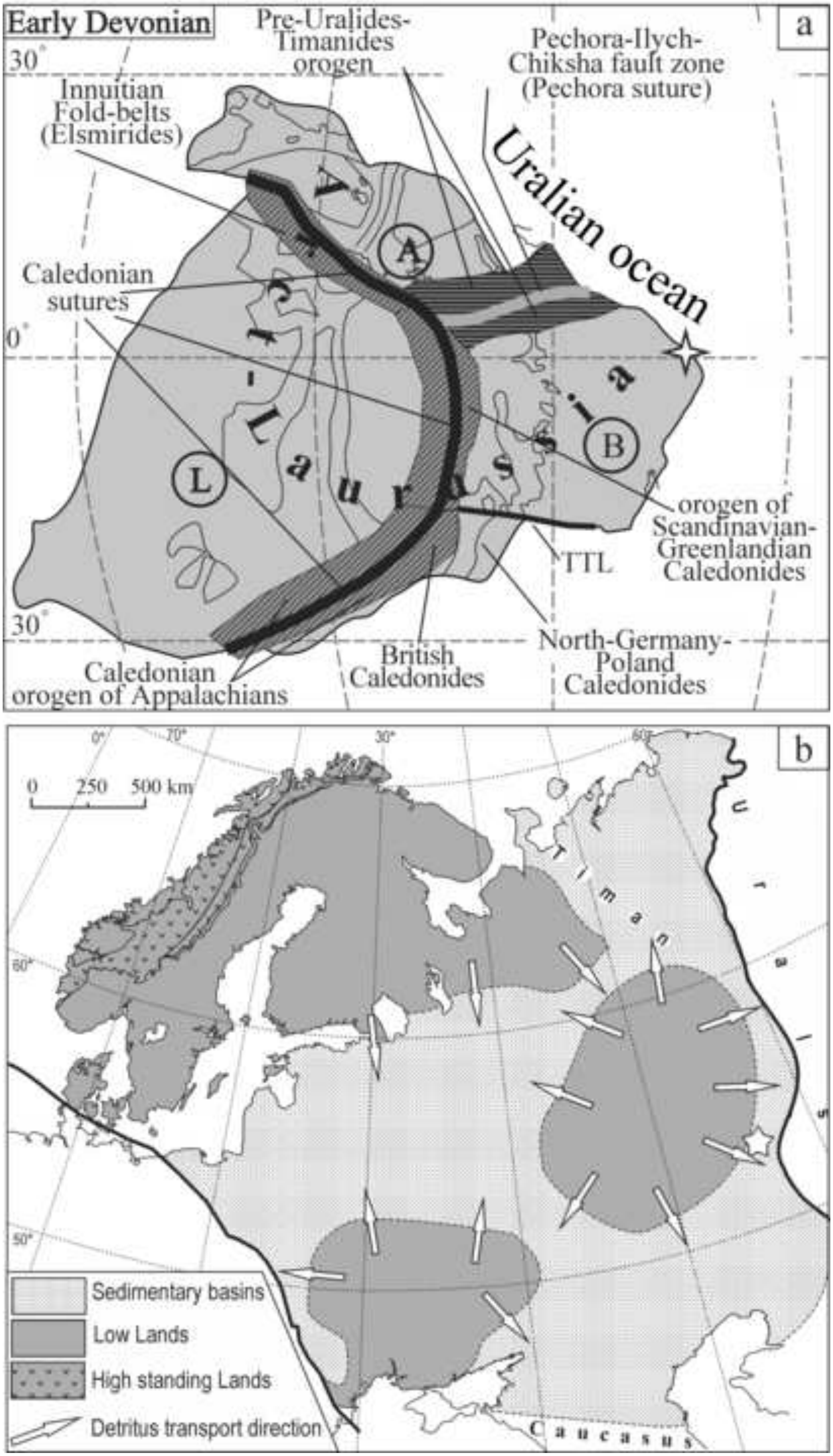

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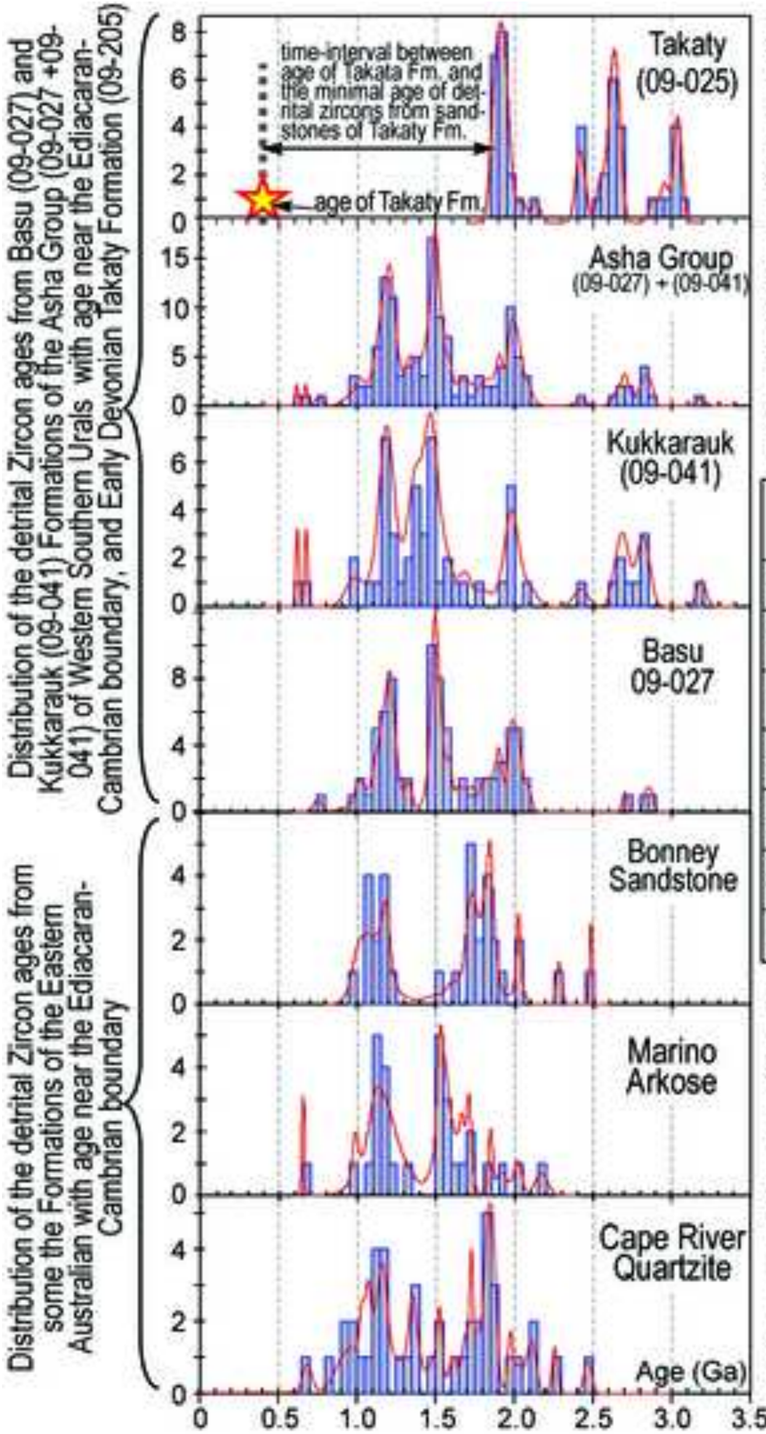

U/Pb-isotope dating (LA-ICP MS) of dZr zircons from sandstones of Basu and Kukkarauk Fm. from Asha Gr. and Takaty Fm of the western flank of the BU (Southern Urals) were carried out.
Ages of dZr from Basu Fm. fall within the time interval ~(705 – 2869) Ma, ages from Kukkarauk Fm. ~(617 – 3188) Ma and Takaty Fm. ~(1858 – 3054) Ma.

KS-test have shown a high similarity of spectrum of the ages of detrital zircons from quartzite Cape River (Queensland) and Marino Arkose and Bonney Sandstone (Adelaida) Formation of the Eastern Australian with age near the Ediacaran-Cambrian boundary with those from similar age Basu and Kukkarauk Formation Western part of the Southern Urals.

	Basu (09-027)	Kukkarauk (09-041)	(09-027) + (09-041)	Cape River Quartzite (CR190)	Marino Arkose (AFB123136)	Bonney Sandstone (AFB123140)	Takaty (09-025)
Basu (09_027)		0.529	0.999	0.654	0.663	0.212	0.000
Kukkarauk (09-041)	0.529		0.909	0.567	0.387	0.217	0.000
(09-027) + (09-041)	0.999	0.909		0.573	0.474	0.142	0.000
Cape River Quartzite (CR190)	0.654	0.567	0.573		0.363	0.884	0.000
Marino Arkose (AFB123136)	0.663	0.387	0.474	0.363		0.106	0.000
Bonney Sandstone (AFB123140)	0.212	0.217	0.142	0.884	0.106		0.000
Takaty (09-025)	0.000	0.000	0.000	0.000	0.000	0.000	

Although sedimentary strata of the Western part of the Southern Urals including Basu, Kukkarauk and Takaty Fms. form a continuous-like section, the spectrum of dZr ages from those Fms indicates major changes in basinal source and structure. The basin was most likely an intracontinental (intra-Rodinia) basin during the Tonian/Cryogenian interval and perhaps into the Ediacaran. Accumulation of strata within the Asha Group (Late Neoproterozoic-Middle Cambrian) contains detritus that may have originated from an easterly source (Australia?). Later, during accumulation of Takaty Fm. (Early Devonian), the basin formed along a passive margin with main input from the western side (East European Platform).

Tabl. 1. P value results from the Kolmogorov–Smirnov statistical test (using error in the CDF) for all samples discussed. White, P values less than 0.05; yellow, P values greater than 0.05. For discussion, see text.

	Basu (09-027)	Kukkarauk (09-041)	(09-027) + (09-041)	Cape River Quartzite (CR190)	Marino Arkose (AFB123136)	Bonney Sandstone (AFB123140)	Takaty (09-025)
Basu (09_027)		**0.529**	**0.999**	**0.654**	**0.663**	**0.212**	0.000
Kukkarauk (09-041)	**0.529**		**0.909**	**0.567**	**0.387**	**0.217**	0.000
(09-027) + (09-041)	**0.999**	**0.909**		**0.573**	**0.474**	**0.142**	0.000
Cape River Quartzite (CR190)	**0.654**	**0.567**	**0.573**		**0.363**	**0.884**	0.000
Marino Arkose (AFB123136)	**0.663**	**0.387**	**0.474**	**0.363**		**0.106**	0.000
Bonney Sandstone (AFB123140)	**0.212**	**0.217**	**0.142**	**0.884**	**0.106**		0.000
Takaty (09-025)	0.000	0.000	0.000	0.000	0.000	0.000	

Note: Plotting of the graphs (Fig. 6) and KS-test implementation were made in the MS Excel program using the macros developed by G. Gehrels and J. Guynn (Department of Geosciences, University of Arizona, Tucson,United States), https://sites.google.com/a/laserchron.org/laserchron/home/

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