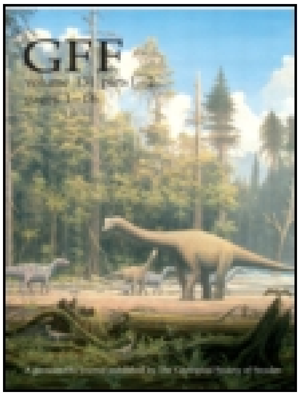

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Detrital zircon ages of Cambrian and Devonian sandstones from Estonia, central Baltica: a possible link to Avalonia during the Late Neoproterozoic

Anne Põldvere[a], Yukio Isozaki[b], Heikki Bauert[c], Juho Kirs[d], Kazumasa Aoki[b], Shuhei Sakata[e] & Takafumi Hirata[e]

[a] Geological Survey of Estonia, Kadaka tee 82, 12618 Tallinn, Estonia;

[b] Department of Earth Science & Astronomy, The University of Tokyo, Komaba, Meguro, 153-8902 Tokyo, Japan

[c] Institute of Geology, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

[d] Institute of Ecology and Earth Sciences, University of Tartu, Ravila 14a, 50411 Tartu, Estonia

[e] Department of Geology and Mineralogy, Kyoto University, 606-8502 Kyoto, Japan

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Note

Detrital zircon ages of Cambrian and Devonian sandstones from Estonia, central Baltica: a possible link to Avalonia during the Late Neoproterozoic

ANNE PÕLDVERE[1], YUKIO ISOZAKI[2], HEIKKI BAUERT[3], JUHO KIRS[4], KAZUMASA AOKI[2], SHUHEI SAKATA[5] and TAKAFUMI HIRATA[5]

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Abstract: Detrital zircon U–Pb ages of Lower Cambrian and Middle Devonian have been determined for sandstone in Estonia through LA-ICP-MS (Nu instruments, Wrexham, UK). Both sandstones have a similar zircon age spectrum with distinct age clusters that reflect the basement geology of Baltica, i.e. 2800–2700 Ma (Kola–Karelia), 1900–1700 Ma (Svecofennian), 1600–1500 Ma (Rapakivi) and 1200–1000 Ma (Sveconorwegian). Noteworthy is a cluster at 750–550 Ma, because rocks of such age are absent within the core of Baltica. The present results suggest a possible link between Baltica and Avalonia/Cadomia during the Late Neoproterozoic.

Keywords: Cambrian; Devonian; Baltica; detrital zircon; U–Pb age; Avalonia.

[1]*Geological Survey of Estonia, Kadaka tee 82, 12618 Tallinn, Estonia; anai@ut.ee*
[2]*Department of Earth Science & Astronomy, The University of Tokyo, Komaba, Meguro, 153-8902 Tokyo, Japan*
[3]*Institute of Geology, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia*
[4]*Institute of Ecology and Earth Sciences, University of Tartu, Ravila 14a, 50411 Tartu, Estonia*
[5]*Department of Geology and Mineralogy, Kyoto University, 606-8502 Kyoto, Japan*
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1. Introduction

During the Late Neoproterozoic and Early Paleozoic, Baltica formed an isolated continental block, and merged with Laurentia in the mid-Paleozoic through the Caledonian orogeny (e.g. Torsvik et al. 1996; Dalziel 1997). The geotectonic history of Baltica holds a significant key in explaining the Proterozoic–Paleozoic global tectonics, in particular, its tri-lateral relationships among Laurentia and Amazonia, and even with some detached continental fragments from Gondwana, such as Avalonian–Cadomian blocks (e.g. Cawood et al. 2007; Linnemann et al. 2012).

In addition to the conventional approaches of lithostratigraphy and biostratigraphy, as well as structural/metamorphic geology, detrital zircon chronology from terrigenous clastics provides information for deciphering assembly/dispersion history among multiple continental blocks. Concerning Baltica, detrital zircon analysis has been conducted mostly along its outer margins, but not much in the center, for identifying relevant tectonic links to surrounding continental blocks (e.g. Valverde-Vaquero et al. 2000; Bingen et al. 2005; Nawrocki & Poprawa 2006; Cawood et al. 2007; Kuznetsov et al. 2010; Miller et al. 2011).

For clarifying less revealed provenance evolution of the interior Baltica, this study includes age spectra of detrital zircon grains separated from the Lower and Middle Paleozoic sandstones in Estonia. Here we report the first result of detrital zircon chronology from central Baltica and preliminarily discuss relevant provenances of the Early–Middle Paleozoic sedimentary basins.

2. Geologic setting

The Precambrian basement of Baltica in the Fennoscandian part is composed of rocks with ages ranging from the Archean to Neoproterozoic (Fig. 1; Lehtinen et al. 2005). Several tectonothermal episodes have been identified, corresponding to particular tectono-magmatic units, i.e. the Kola–Karelia block (3500–2500 Ma), Svecofennian orogen (1950–1750 Ma), Transscandinavian igneous belt (TIB 1850–1750 Ma), Rapakivi granites (1650–1500 Ma) and Sveconorwegian orogen (SN 1200–900 Ma) in addition to the latest Neoproterozoic–Early Paleozoic orogenic belts along the four margins of Baltica. The Late Neoproterozoic to Paleozoic sedimentation history recorded in Baltica has been thoroughly reviewed by Nikishin et al. (1996) and Nielsen & Schovsbo (2011).

Estonia is located nearly in the center of Baltica (Fig. 1a) and its surface geology is entirely composed of the Ediacaran to Devonian shallow marine clastics and carbonates that were deposited directly upon the Precambrian basement as confirmed through deep-drilling investigation (Soesoo et al. 2004; Kirs et al. 2009).

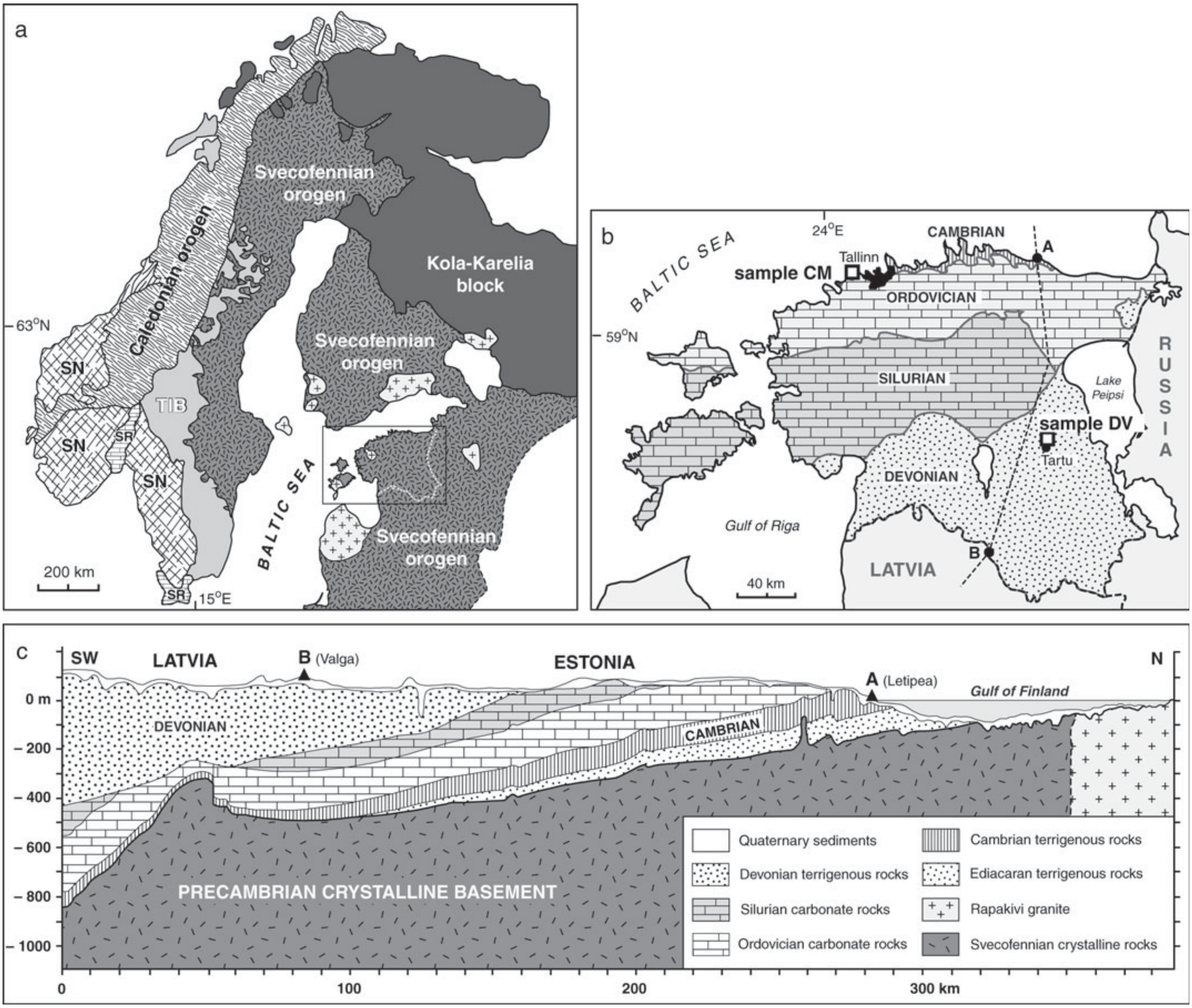

Fig. 1. Simplified geotectonic map of the Fennoscandian Shield (modified from Bogdanova et al. 2008; Rutanen et al. 2011). Samples (CM and DV), localities on bedrock map of Estonia (modified from Suuroja 1997) and geological cross section of Estonia (modified from Puura & Vaher 1997). Archean craton (Kola–Karelia block 3500–2500 Ma), Svecofennian orogen (1950–1750 Ma), TIB (1850–1750 Ma), Rapakivi granites (1650–1500 Ma), SN (1200–900 Ma), Caledonides (500–400 Ma) and Phanerozoic sedimentary rocks (SR).

According to the paleogeographic reconstruction by Nikishin et al. (1996) and Nielsen & Schovsbo (2011), which included the identification and mapping of distinct facies, Estonia was located in relatively stable shallow-water sedimentary settings, including alluvial, deltaic and shallow-marine settings during the late Ediacaran to Early Cambrian. The shallow-marine deposition of carbonate facies continued in Estonia during most of the Ordovician to Silurian (Nestor & Einasto 1997), whereas terrigenous clastics dominated the Devonian (e.g. Kleesment 1997; Marshall et al. 2007; Mark-Kurik & Põldvere 2012), analogous with the classic “Old Red Sandstone” in the UK.

The non-metamorphosed and scarcely deformed Cambrian–Silurian strata are exposed along the sea cliffs (klint) along the northern/western coasts of Estonia, whereas the distribution of Devonian rocks is limited to broad-outcrop areas of inland Estonia that continues southward into Latvia (Fig. 1b and c).

3. Samples

For clarifying the provenance evolution of the interior Baltica, ages were determined for detrital zircon grains separated from two samples collected from outcrops; i.e. Sample CM from the Lower Cambrian Kakumägi Member of the Tiskre Formation (Mens & Pirrus 1997) located at Tabasalu klint (59°27′6″ N, 24°29′18″ E) near Tallinn, northern Estonia, and Sample DV from the Middle Devonian Viljandi Member of the Aruküla Formation (Kleesment 1994) at the Kalmistu quarry (58°23′43″ N, 26°42′40″ E) in Tartu City, central Estonia.

Sample CM being light gray, weakly cemented, very fine quartz sandstone with ripple marks corresponds to the upper Dominopolian of upper Lower Cambrian, i.e. Atdabanian or Stage 3 of Series 2 (521–514 Ma, according to Peng et al. 2012). Paleocurrent data are not available from the outcrop but regional basin study (Nielsen & Schovsbo 2011) suggests the major terrigenous supply from the northern interior of Baltica.

Sample DV, consisting of reddish- and yellowish-brown, weakly cemented, very-fine to fine quartz sandstone with mica-rich levels and abundant fossil fish remains, corresponds to the lowermost part of the Givetian Stage (Aruküla Regional Stage; Mark-Kurik & Põldvere 2012; 387.7–382.7 Ma, according to Becker et al. 2012). Paleocurrent data are not available from the outcrop but regional basin study (Marshall et al. 2007) suggests major clastic supply from the northeastern interior of Baltica.

The zircon separation and dating procedures are described as "Analytical procedures" in the Supplementary material.

4. Results

Fig. 2 summarizes the $^{206}Pb/^{238}U$ age populations of the detrital zircon grains as probability age frequency curves using solely the ages on concordia, according to the Isoplot/Ex 3 program (Ludwig 2003). For the measurements of zircon grains and their concordia diagrams, refer to DD-Tables 1 and 2 and DD-Figs. 1 and 2 in the Supplementary material.

The two youngest zircon grains separated from Sample CM record ages of 540.5 ± 10.7 Ma and 541.9 ± 10.4 Ma (i.e. the base of the Cambrian). The remaining grains are roughly clustered into five age groups; i.e. 3000–2400 Ma, 1800–1600 Ma, 1600–1400 Ma, 1400–1000 Ma and 750–550 Ma.

The youngest zircon grain separated from Sample DV records an age of 453.6 ± 5.8 Ma (i.e. the middle of the Late Ordovician). The remaining grains are roughly clustered into six age groups: 2800–2700 Ma, 1800–1600 Ma, 1500–1400 Ma, 1350–1150 Ma, 1100–1000 Ma and 600–500 Ma.

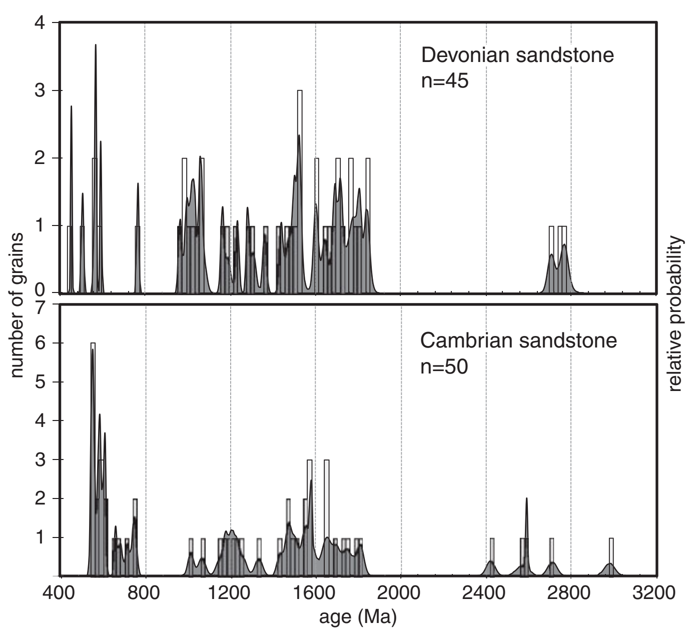

Fig. 2. U–Pb age spectra (in histogram and in probability age frequency curve) of detrital zircon grains from the Lower Cambrian (CM) and Middle Devonian (DV) sandstones in Estonia. One time bin for histogram is 20 million years; *n* – number of dated zircon grains.

5. Discussion

As per the youngest zircon grain, Sample CM (the Lower Cambrian; ca. 521–514 Ma) contains the youngest detrital zircon with slightly older age of 540 Ma, whereas Sample DV (the Middle Devonian; ca. 385 Ma) possesses Late Ordovician zircon grains (ca. 455 Ma) (DD-Tables 1 and 2, Supplementary Material). Thus no contradiction exists between the depositional age and ages of clastic grains for the two dated sandstones.

As per the older zircon grains, both samples have similar age spectra that range in the Precambrian (Fig. 2). This indicates that the Cambro-Devonian sedimentary basins of central Baltica shared essentially the same provenance composed of older Precambrian basement rocks. The Cambrian sandstone is characterized through detrital zircon grains of five distinct age groups, and the Devonian sandstone through six groups (Fig. 2). The oldest group, with ages ranging from 3000 Ma to 2400 Ma, evidently records a considerable amount of terrigenous clastics derived from the Archean basement, likely that of the Kola–Karelia block in northeast Baltoscandia (e.g. Saltykova & Koistinen 1996; Fig. 1a). Likewise, the two Mesoproterozoic age groups, with age ranging from 1800 Ma to 1600 Ma and 1600 Ma to 1400 Ma, record the derivation from the unique Svecofennian orogen and the Rapakivi granites in central Baltoscandia (e.g. Koistinen 1996; Laitakari et al. 1996). Furthermore, the group of zircon grains with age ranging from 1400 Ma to 1000 Ma indicates a terrigenous flux from the Sveconorwegian basement in the western Baltica. Such a distinct age clustering of detrital zircon grains of the Cambrian and Devonian sandstones in Estonia appears concordant with the Archean–Mesoproterozoic basement geology of Baltica, on which these sediments were deposited (Fig. 1c), although detrital zircon grains were likely involved in multiple sedimentary recyclings.

On the other hand, the reconstructed Early Cambrian basin geometry in Baltoscandia (Nielsen & Schovsbo 2011) shows the development of a NNE-trending narrow basin which opened to the south in southern Baltica (including the Tallinn area), receiving clastic supply mostly from the NE, i.e. the core of Baltica, rather than from the south.

In contrast, the group of detrital zircon grains with ages ranging from 750 Ma to 550 Ma is intriguing, simply because there is no possible provenance area expected within the Precambrian core Baltica (Fig. 1a). Noteworthy, lately reported was a similar age cluster of zircon grains separated from Cambrian sandstones from the neighboring St Petersburg area in western Russia (Miller et al. 2011). These relatively younger zircon grains were delivered obviously not from the core of Baltica but rather more likely from the peripheral orogenic belts around Baltica.

Baltica is bounded by four Late Neoproterozoic–Paleozoic orogenic margins; the Caledonian margin on the northwest, the Timanian margin in the northeast, the Tornquist margin on the southwest and the Variscan margin on the southeast. The Caledonian orogeny occurred along the modern western margin of Baltica during the Early–Middle Paleozoic (e.g. McKerrow et al. 2000); however, the orogeny was significantly younger than the zircon crystallization. Likewise, the Tornquist margin (the modern Polish side; e.g. Nawrocki & Poprawa 2006; Pease et al. 2008) and the Timanian orogen (Uralian side; e.g. Kuznetsov et al. 2010) of Baltica experienced tectono-thermal events no older than 650 Ma.

Instead, the occurrence of 750–650 Ma zircon grains from Estonia may suggest their possible origin from the Gondwana margin, because these ages apparently correspond to the so-called Pan-African (or Pan-Gondwanan) ages (e.g. Kröner & Stern 2004). Promising candidates around Baltica during the latest Neoproterozoic to earliest Cambrian time are the detached pieces of northern margin of Gondwanaland, such as the Avalonian–Cadomian blocks including the Brabant massif in Belgium (Linnemann et al. 2012). The crystallization age of the 750–650 Ma zircon grains from Estonia chronologically corresponds with that of the granitic magmatism, which occurred along the Avalonian magmatic arc (e.g. Nance et al. 2002). The tectonic interaction between Baltica and the Avalonian–Cadomian blocks along the Tornquist margin has been assumed to have taken place solely during the Early Paleozoic. Nonetheless the results reported here suggest a much earlier tectonic episode between the two during the Late Neoproterozoic, prior to the deposition of the Lower Cambrian in Estonia. As the present study reveals the preliminary results of detrital zircon chronology, further investigations are warranted for reconstructing the whole tectono-sedimentary history of the Neoproterozoic to Early Paleozoic Baltica.

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