A Tonian age for the Visingsö Group in Sweden constrained by detrital zircon dating and biochronology: implications for evolutionary events

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Online Supplementary Material

Appendix S1. Details of analytical methods

Analytical methods follow those described in Zhang et al. (2015a,b). Zircons were analyzed for U, Th and Pb isotopes using an ESI NWR-193 excimer laser coupled to a Thermo XSeries2 quadrupole ICP-MS at the PetroTectonics Analytical Facility, Department of Geological Sciences, Stockholm University. Analytical conditions and parameters are summarized in Table S1. Each analysis consisted of 30 seconds background acquisition followed by 40 seconds of data acquisition and 15 seconds wash-out using a 25 µm spot size. He was used as the ablation carrier gas to minimize sample redeposition from the aerosol and stabilize signal intensities (Eggins et al. 1998; Günther & Heinrich, 1999; Horn et al. 2001). The instrument was tuned for maximum sensitivity of Pb and U while keeping ThO/Th below 0.5 %. The tubing from the ablation chamber to the ICP source was equipped with a signal smoothing device consisting of several Tygon® tubes to split the stream and recombine it. External standardization was performed using Plešovice zircon (Sláma et al. 2008), analyzed at the start and end of the analytical sequence and bracketing a maximum of 10 analyses by two measurements of standard zircon. Zircon FC-5z from the Duluth Gabbro (Paces & Miller Jr, 1993) was treated as a known-unknown to control data accuracy.

Table S1. Analytical conditions and parameters

<table>
<thead>
<tr>
<th>Laser ablation:</th>
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<tbody>
<tr>
<td>Laser</td>
<td>ESI New Wave ArF 193 nm</td>
</tr>
<tr>
<td>Energy density</td>
<td>7 J cm⁻²</td>
</tr>
<tr>
<td>Frequency</td>
<td>10 Hz</td>
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<tr>
<td>Beam diameter</td>
<td>25 µm</td>
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<tr>
<th>ICP-MS:</th>
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<tbody>
<tr>
<td>Instrument</td>
<td>Thermo XSeries2 quadrupole</td>
</tr>
<tr>
<td>Plasma power [W]</td>
<td>1400</td>
</tr>
<tr>
<td>Sample gas [l/min]</td>
<td>500</td>
</tr>
<tr>
<td>Auxiliary gas [l/min]</td>
<td>0.72</td>
</tr>
<tr>
<td>Cooling gas [l/min]</td>
<td>13</td>
</tr>
<tr>
<td>Nebulizer gas [l/min]</td>
<td>0.94</td>
</tr>
<tr>
<td>Acquisition mode</td>
<td>pulse</td>
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<tr>
<td>Dwell times (ms)</td>
<td>200Hg (20), 201Hg (20), 202Hg (40), 204Pb (50), 206Pb (50), 208Pb (50), 232Th (40), 235U (50), 238U (50), 248ThO (20)</td>
</tr>
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<tr>
<th>Standards:</th>
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<tr>
<td>External</td>
<td>Plesovice (Slama et al., 2008)</td>
</tr>
<tr>
<td>Secondary FC-5z</td>
<td>(Paces and Miller, Jr., 1993)</td>
</tr>
</tbody>
</table>
Data reduction and calculation of ratios and ages were performed off-line using the software Iolite (Hellstrom et al. 2008; Paton et al. 2011) and the VizualAge data reduction scheme of Petrus and Kamber (2012). The down-hole isotopic fractionation correction follows Paton et al. (2011) and common Pb is monitored on mass 204 (204Pb + 204Hg).

Analytical results are presented in Table S2, and Figures S1, S2, and S3. Errors are reported at the 2-sigma level. For zircon ages younger than 1.2 Ga the 206Pb/238U ages were used for the final analysis and for ages older than 1.2 Ga the 207Pb/206Pb ages were selected for the final analysis. Analyses with high common Pb as well as those with >10% discordance or >10% uncertainties, were excluded from the final data synthesis. Concordia diagrams and probability density distribution plots were made using ISOPLOT/Ex 4.15 (Ludwig, 2008) (Figs. S1, S2, S3). Excluded analyses are marked by an asterisk in online Supplementary Material Table S2 (U–Pb data Excel file) available at http://journals.cambridge.org/geo.

Provenance of the Visingsö Group. The provenance of the Visingsö zircons is consistent with derivation from the Sveconorwegian orogenic belt and sources within it. These include igneous, metamorphic and recycled sedimentary rocks exposed in the region at the time of deposition, i.e. Svecofennidian rocks (c. 2.0–1.75 Ga), TIB (c. 1.86–1.66 Ga plutonic and volcanic rocks), and metamorphic and igneous rocks associated with the Gothian (1.66–1.52 Ga), Hallandian (c. 1.47–1.38 Ga), and Sveconorwegian (c. 1.14–0.90 Ga) orogens (Lundmark and Lamminen, 2016; Möller et al. 2015). Swarms of 1.6–0.95 Ga dolerite dikes also intrude Fennoscandian basement (Söderlund et al. 2005).

Meso- to Neoproterozoic sediments now only locally preserved across the shield are also potential sources (Fig. 1A). These ‘Jotnian’ sandstones, broadly 1.6–0.9 Ga in age, are red continental siliciclastic rocks associated with local marine ingressions (Morad & Al-Aasm, 1994) and include the Almesåkra Group and the Dala Sandstone Formation in Sweden, the Trysil sandstone in Norway, and the Muhos and Hailuoto formations in Finland (see Bingen et al. 2011; Lundmark & Lamminen, 2016). The Dala Sandstone Formation has a maximum age of 1.59–1.58 Ga with prominent zircon peaks between c. 1.61–1.88 Ga (Lundmark & Lamminen, 2016). The sandstones and schists of the allochthonous Sparagmite basins in the Caledonides have zircon ages that range from 1990–860 Ma with peaks at 1645, 1600, 1490, 1280, 1155, 965, and 930 Ma, are inferred to have been mostly derived locally – this includes sources within the Sveconorwegian belt that may include a far-traveled Laurentian component, as well as sources from east of the belt in Fennoscandia (Bingen et al. 2011).

Similar sources are recognized for the first time in the Visingsö Group, though the provenance of its lower formation is distinct from its middle formation. The lower formation sample V15-Lem is dominated by late Mesoproterozoic to early Neoproterozoic peaks at c. 1026, 945, and 900 Ma, with lesser peaks at c. 1600, 1446, 1268 and 1100 Ma. The middle formation sample V15-9 is dominated by Mesoproterozoic zircon (age peaks at c. 1640, 1580, and 1439 Ma), while older (c. 1780 Ma) and younger ages (c. 1260–1045 Ma) are lesser contributors. Sample V15-10 is dominated by Palaeoproterozoic to Mesoproterozoic zircon, with age peaks at c. 1751, 1625, and 1450 Ma, a spread of ages at c. 1300–990 Ma, and a minor peak at c. 992 Ma. The notable dominance of Sveconorwegian-aged detritus in the lower formation dramatically decreases up-section where Hallandian, Gothian, and Svecofennidian sources dominate. This suggests a changing source region/drainage pattern for these sediments, likely due to burial or re-routing of Sveconorwegian sources. Sediment provenance is generally consistent with local derivation, however sources for the small (8–14%) c. 1.2–1.3 Ga component require voluminous and persistent northwards transport across the Panthalassa margin of Rodinia (e.g. Bingen et al. 2011). This is also in agreement with
combined sediment provenance and paleocurrent data from clastic rocks of Finnmark, which indicate sources from the south (Zhang et al. 2015a, b).

References.

**APPENDIX S2. List of species of organic-walled microfossils in the Visingsö Group**

Eukaryotic unicellular taxa:

*Cerebrosphaera globosa* (Ogurtsova and Sergeev, 1989) Sergeev and Schopf, 2010  
*Chuaria circularis* (Walcott, 1899) Vidal and Ford, 1985  
*Germinosphaera bispinosa* (Mikhailova, 1986) Butterfield, 1994  
*Leiosphaeridia div.sp.*  
*Macroptycha uniplicata* Timofeev, 1976  
*Navifusa majensis* Pyatiletov, 1980  
*Octoedryxium truncatum* Rydavskaya, 1973  
*Schizofusa* sp.  
*Simia simica* (Jankauskas, 1980) Jankuskas, 1989  
*Squamosphaera colonialica* (Jankauskas, 1979) Tang et al., 2015  
*Tasmanites* sp.  
*Valeria lophostrata* (Jankauskas, 1979) Jankauskas, 1982  

Eukaryotic multicellular taxa

*Ostiana microcystis* Hermann, 1976  
*Synsphaeridium* sp.

Cyanobacterial taxa

*Eoschizothryx composita* Seng-Joo and Golubic, 1998  
*Eosynechococcus moorei* Hofmann, 1976  
*Oscillatoriopsis* sp.  
*Palaeolyngbya catenata* Hermann, 1974  
*Polytrichoides lineatus* (Hermann, 1974) Hofmann, 1976  
*Sphaerocongregus variabilis* Moorman, 1974  
*Siphonophycus* div.sp.
Figure S1.
Figure S2.
Figure S3.

**Fig. A3**

- **Filtered Data**: Data-point error ellipses are 2σ.
- **All Data**: Data-point error ellipses are 2σ.

**V15-9, sandstone** (n=117/154)

Max Age ≤ 1050 ± 15 Ma (95%)

(n=2, MSWD=0.57, P=0.45)