Journal of the Geological Society

Proterozoic zircon ages from lower crustal granulite xenoliths, Kola Peninsula, Russia: evidence for crustal growth and reworking

H. DOWNES, P. PELTONEN, I. MÄNTTÄRI and E.V. SHARKOV

Journal of the Geological Society 2002; v. 159; p. 485-488
doi:10.1144/0016-764901-162

Notes

Journal of the Geological Society, London, Vol. **159**, 2002, pp. 485–488. Printed in Great Britain.

SPECIAL

Proterozoic zircon ages from lower crustal granulite xenoliths, Kola Peninsula, Russia: evidence for crustal growth and reworking

H. DOWNES[1], P. PELTONEN[2],
I. MÄNTTÄRI[2] & E. V. SHARKOV[3]

[1] *School of Earth Sciences, Birkbeck College, University of London, Malet Street, London, WC1E 7HX, UK (e-mail: h.downes@ucl.ac. uk)*
[2] *Geological Survey of Finland, PO Box 96, Espoo, FIN-02151 Finland*
[3] *Institute of Ore Deposits Geology, Petrology, Mineralogy and Geochemistry (IGEM) RAS, Staromonetny per. 35, Moscow, Russia*

Lower crustal garnet granulite xenoliths from beneath the Kola–Karelian domain of the Fennoscandian Shield (Russia) were brought to the surface in Devonian lamprophyre diatremes. To establish the relationships between processes in the lower crust and geological events recorded in the upper crust, zircons from two of these xenoliths were dated by ion microprobe. One xenolith contains mainly primary magmatic zircon grains that yielded an average age of 2.47 Ga. The Kola–Karelia domain formed part of a large basaltic igneous province in the earliest Proterozoic (*c.* 2.45 Ga); thus, such xenoliths probably represent deep-seated equivalents of this magmatism. A second garnet granulite xenolith contained only internally featureless zircons. Most of these yielded concordant ages between 1.77–1.61 Ga. This age distribution indicates that at *c.* 1.7 Ga the protolith was migmatized during an event that may be related to emplacement of granites and pegmatites in the region. However, two zircon grains in the second xenolith gave much younger ages of 1.47 and 1.45 Ga. This spread in the ages is related to an unknown younger event around 1.4 Ga (or perhaps later) when the *c.* 1.7 Ga 'migmatite' zircons were reset to variable degrees. These zircon ages are evidence for the complex evolution of the lower crust, recording multiple events, some of which are not currently expressed on the surface.

Keywords: Fennoscandian Shield, xenoliths, lower crust, zircon.

This paper attempts to determine the relationships between ages recorded within the lower crust and major events known from the upper crust of the Fennoscandian (Baltic) Shield (Fig. 1). In order to clarify the age of events in the lower crust, garnet granulite xenoliths from the Kola–Karelian domain (Kempton *et al.* 1995, 2001) have been investigated. Following the method of Rudnick & Williams (1987), Chen *et al.* (1994) and Hölttä *et al.* (2000), zircons have been separated from lower crustal xenoliths and ages determined on individual crystals using an ion microprobe (NORDSIM) technique.

Nature of the lower crustal xenoliths. Granulite-facies xenoliths from a Devonian lamprophyric diatreme on Elovy Island off the south coast of the Kola Peninsula (Russia) represent the lower crust of the Kola–Karelian domain of the Fennoscandian shield (Kempton *et al.* 1995; 2001). They are mostly mafic meta-igneous garnet granulites in which crystallization occurred at 750–930 °C and 12–15 kbar, equivalent to depths of 30–50 km. Previous age constraints on the xenoliths suggest that they are Proterozoic, but the results are somewhat contradictory. Conventional U–Pb dating of zircons from the xenoliths yielded discordant results suggesting an age >1.72 Ga (Kempton *et al.* 1995). Internal Sm–Nd isochrons for clinopyroxenes and garnets gave values of 1.5 Ga (Neymark *et al.* 1993), which Kempton *et al.* (2001) interpreted to represent cooling through the Sm–Nd blocking temperature for these minerals. Internal Pb–Pb whole rock–mineral isochrons yielded ages of 2.4 and 1.8 Ga (Neymark *et al. 1993). Ar/Ar determinations of phlogopite from a strongly metasomatized xenolith gave an age of 2.0–2.1 Ga (Kelley & Wartho, 2000). Nd depleted mantle model ages for the xenoliths are also commonly in the region of 2.4 Ga (Kempton et al. 2001).*

Analytical techniques and results. For ion probe analyses, small pieces of xenoliths were crushed in a shatter box, the crushed pieces were then sieved using disposable sieve cloth and the heavy mineral fractions were extracted using heavy liquids. Particular care was taken to avoid contamination at all stages. Two samples (N39, N27-21) yielded zircons that were handpicked from the concentrate, mounted in epoxy, polished and coated with carbon for SEM study and with gold for SIMS analyses. Back scattered electron images were obtained and inclusion phases identified by JEOL Scanning Electron Microscope at the Geological Survey of Finland (GTK). U–Pb analyses were run using the Nordic SIMS (NORDSIM) Cameca IMS 1270 at the Swedish Museum of Natural History, Stockholm. The spot-diameter for the 4 nA primary O_{2-} ion beam was *c.* 30 µm, and oxygen flooding in the sample chamber was used to increase the transmission of Pb. Zr, Pb, Th and U species were measured in each spot. The mass resolution (M/DM) was 5400 (10%). The raw data were calibrated against a zircon standard (91500) and corrected for background (204.2) and modern common lead ($T = 0$; Stacey & Kramers' model). For a detailed description of the analytical procedure, see Whitehouse *et al.* (1999). Zircon age determinations are presented in Table 1.

Sample N39 is a medium-grained non-foliated feldspar-rich garnet granulite composed of feldspars (84%), garnet + kelyphite (10%), clinopyroxene (5%) and accessory phases (Kempton *et al.* 1995). It yielded prismatic zircon grains or their fragments in the size range of 50–100 µm. Most of them are growth-zoned, magmatic-looking grains with no significant overgrowths or recrystallization. Unfortunately, the recovered zircons were small relative to the beam size of the ion probe and so details of the zoning could not be studied. Most of them yielded concordant ages with an average of 2.47 Ga (Table 1; Fig. 2). Two faintly zoned crystals (04a, 08a) gave slightly younger ages of 2.41 Ga, indicative of partial resetting of some of the 2.47 Ga grains. One large prismatic zircon grain gave an older (Archaean) concordant age of 2.84 Ga.

In contrast, xenolith N27-21 has a gneissose texture with lenses of clinopyroxene and garnet alternating with bands of plagioclase and quartz. It has a more mafic bulk composition than N39 and contains 30% garnet, 30% clinopyroxene and 30% feldspar, together with minor quartz (5%) and accessories (Kempton *et al.* 1995). The zircons from N27-21 are also different from those of

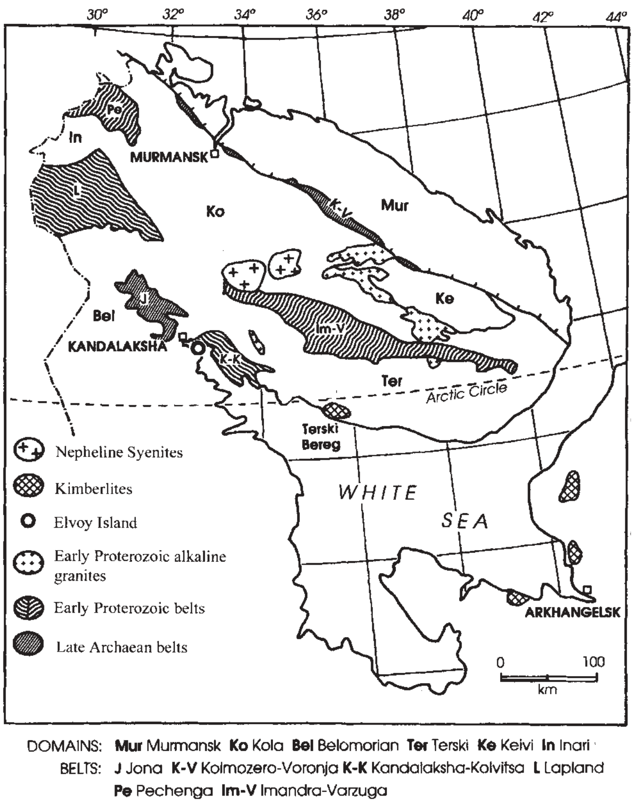

Fig. 1. Figure1. Sketch map of the Kola–Karelia domain of the northeastern Fennoscandian Shield (after Kempton *et al.* 1995). Location of Elovy Island (source of xenolith samples) is also shown.

N39, being slightly larger and more irregular in shape. They are non-prismatic and completely devoid of any magmatic growth-zonation, similar to the featureless zircons found in high-grade metamorphic rocks. Therefore only one analysis was made from each grain. Most of these grains yielded concordant ages within the range 1.77–1.61 Ga while two grains gave much younger $^{207}Pb/^{206}Pb$ ages of 1.45 and 1.47 Ga (Table 1; Fig. 2).

Discussion. The oldest age found in the Kola xenoliths (2.84 Ga) was obtained from a single zircon grain in N39. This could represent a xenocryst derived from Archaean basement rocks of the region. However, most of the ages of the zircons in N39 are in the region of 2.47 Ga, i.e. early Palaeoproterozoic. At this time, the Kola–Karelian domain was dominated by eruptions of rift-related low-Ti picrites and basalts (Puchtel *et al.* 1997; Lobach-Zhuchenko *et al.* 1998). Mafic dyke swarms, large layered basic–ultrabasic intrusions and gabbro–anorthosites were also emplaced in the period 2.50–2.43 Ga (Alapieti *et al.* 1990; Balashov *et al.* 1993; Amelin *et al.* 1995; Sharkov *et al.* 1997; Balagansky *et al.* 2001). This magmatism formed part of a large igneous province that occupied much of the northern Fennoscandian Shield (Sharkov *et al.* 1999). This was the main episode of mantle-derived magmatic activity within the area and Kempton *et al.* (2001) suggested that the granulite xenoliths represent the underplated lower crust of this Palaeoproterozoic large igneous province. The new zircon age data strongly support this interpretation. It is probable that much of the lower crust of the Kola–Karelia region is formed of 2.4–2.5 Ga mafic granulites that are the high-grade metamorphic equivalents of the magmatic rocks seen in surface exposures.

Table 1. *Ion probe zircon data, analysed at NORDSIM facility, Stockholm*

	Zircon morphology,	Derived ages						Calibrated ratios						Elemental data					
Sample/Spot#	inner structure	$^{207}Pb/^{206}Pb$	±s	$^{207}Pb/^{235}U$	±s	$^{206}Pb/^{238}U$	±s	$^{207}Pb/^{206}Pb$	±s %	$^{207}Pb/^{235}U$	±s%	$^{206}Pb/^{235}U$	±s%	Rho	Disc.%	[U] ppm	[Th] ppm	[Pb] ppm	$^{206}Pb/^{204}Pb$
N39 garnet granulite																			
n895-01a	Fragment, clear zoning	2470	7	2481	18	2495	39	0.1614	0.42	10.517	1.91	0.4727	1.87	0.98		160	99	101	3.86×10^4
n895-02a	Prismatic, clear zoning	2844	5	2853	18	2867	43	0.2022	0.29	15.612	1.89	0.5600	1.86	0.99		242	175	190	3.86×10^4
n895-03a	Fragment, clear zoning	2462	8	2488	18	2521	39	0.1606	0.45	10.597	1.92	0.4785	1.86	0.97		117	68	74	2.58×10^4
n895-04a	Elongated, undulous zoning	2408	8	2385	18	2359	37	0.1555	0.45	9.475	1.91	0.4418	1.86	0.97		148	86	86	2.77×10^4
n895-05a	Oval, quite homogeneous	2474	11	2484	17	2497	35	0.1618	0.63	10.551	1.78	0.4730	1.66	0.94		94	94	65	3.09×10^4
n895-06a	Fragment, clear zoning	2464	5	2428	16	2385	33	0.1608	0.32	9.924	1.69	0.4476	1.66	0.98	0.4	239	169	146	3.21×10^4
n895-07a	Fragment, straight zoning	2476	7	2470	16	2463	34	0.1619	0.41	10.389	1.71	0.4654	1.66	0.97		143	100	91	4.47×10^4
n895-08a	Oval, undulous zoning	2413	7	2382	16	2346	33	0.1560	0.42	9.443	1.71	0.4391	1.66	0.97		141	94	84	5.93×10^4
N27-21 garnet granulite																			
n896-01a	Roundish, homogeneous	1466	30	1412	19	1377	23	0.0919	1.59	3.017	2.47	0.2381	1.89	0.76		25	34	9	$>1 \times 10^6$
n896-02a	Fragment, homogeneous	1669	15	1677	17	1684	28	0.1024	0.84	4.217	2.05	0.2986	1.87	0.91		73	54	29	3.77×10^4
n896-03a	Oval, homogeneous	1767	19	1762	19	1757	30	0.1081	1.07	4.669	2.21	0.3133	1.93	0.87		38	21	15	4.01×10^4
n896-04a	Fragment, homogeneous	1446	40	1404	22	1376	23	0.0910	2.15	2.985	2.85	0.2380	1.88	0.66		19	11	6	8.76×10^3
n896-05a	Fragment, homogeneous	1610	29	1657	21	1695	29	0.0993	1.59	4.115	2.49	0.3007	1.93	0.77		23	13	9	1.20×10^4
n896-06a	Fragment, homogeneous	1702	52	1710	29	1717	29	0.1043	2.87	4.387	3.46	0.3051	1.93	0.56		23	14	9	1.23×10^4
n896-07a	Fragment, homogeneous	1680	37	1620	23	1575	27	0.1030	2.01	3.932	2.77	0.2767	1.90	0.69		33	35	13	4.21×10^3
n896-08a	Fragment, homogeneous	1757	34	1783	22	1804	29	0.1075	1.88	4.787	2.64	0.3230	1.86	0.70		22	13	9	1×10^6

Degree of discordance is calculated at the closest 2s limit. All other errors are a 1s level.

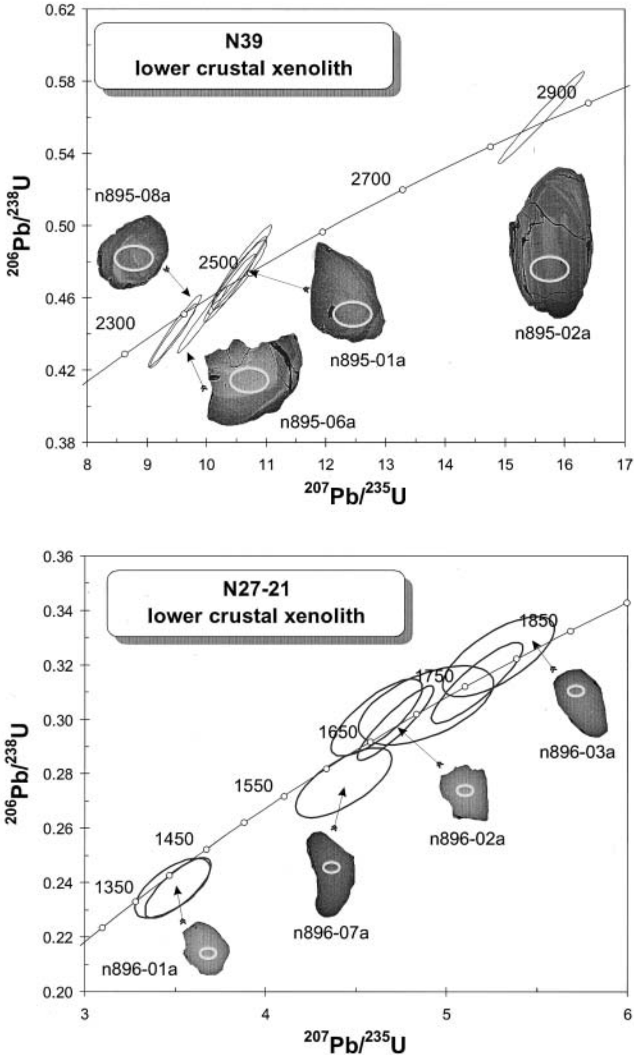

Fig. 2. U–Pb concordia diagrams for zircons from lower crustal garnet granulite xenoliths from Kola Peninsula. Errors are plotted at 2 sigma.

Magmatic activity in the northern Fennoscandian Shield also occurred between 2.2 and 2.0 Ga. This consisted of rift-related picrite and basalt lavas, dyke swarms and large Ti-rich layered intrusions (Sharkov & Smolkin 1997; Puchtel *et al.* 1998). In the Pechenga–Varzuga volcanosedimentary belt, alkali basalts eruptions about 2.2 Ga in age gradually gave way to tholeiite pillow lavas, Fe-picrite flows and Ti-rich basalts with ages around 1.98 Ga (Melezhik & Sturt 1994). This major event is not recorded in the lower crustal zircons yet analysed, but Ar–Ar analyses of phlogopite from a Kola granulite xenolith yielded an age of metasomatism of *c.* 2.0 Ga (Kelley & Wartho 2000).

Late Palaeoproterozoic magmatic activity of the area ended around 1.81–1.75 Ga, with intrusion of potassic granites, granodiorites and micaceous pegmatites. The lower crustal analogue of these processes may have been anatexis of the granulites, recognized within the xenoliths as felsic veins which contain relics of the melanocratic matrix (Kempton *et al.* 1995). At this stage, the internally featureless zircon grains of the gneissose xenolith N27-21 were probably formed. Previous U-Pb dating of zircons from another Kola granulite xenolith (Vetrin & Nemchin 1998) yielded similar ages of 1.71–1.82 Ga. The new zircon data for N27-21 with ages of 1.77–1.61 Ga imply that this age was a major episode of metamorphism and migmatization in the lower crust. Rejuvenation of tectonic–magmatic processes in the Fennoscandian Shield occurred about 1.75 Ga ago, with small-scale rifting and basaltic magmatism; lamproites and lamprophyres of 1.71–1.72 Ga age were intruded. Some of these events may also be related to the 1.77–1.61 Ga ages recorded by xenolith N27-21. The ages of N27-21 zircons are also very similar to those reported from a lower crustal xenoliths and zircon xenocrysts recovered from kimberlites of eastern Finland, 500 km SSW from the Kola locality (Hölttä *et al.* 2000;Peltonen & Mänttäri 2001). This suggests that the 1.7 Ga thermal event affected most of the lower crust of the Fennoscandian shield and coincides with the age of the Svekofennian granites emplaced further west. However, the 1.47–1.45 Ga ages of some zirc ons are anomalous and may record an additional Mesoproterozoic thermal episode, which is not recorded in the upper crust of the area.

In conclusion, zircons from lower crustal xenoliths in the Kola–Karelia region record several distinct magmatic and metamorphic events. The first major episode was underplating of basic magmas at 2.4–2.5 Ga, during a period of widespread mantle-derived magmatic activity clearly observed in the surface geology. A second event in the lower crust was migmatization at *c.* 1.7 Ga, coincident with emplacement of granitic magmas in the upper crust. A thermal disturbance in the lower crust at *c.* 1.4 Ga, however, has not yet been directly identified on the surface, indicating that events in the lower crust are not necessarily recorded in the upper crust. Conversely, a major magmatic event at 2.0–2.2 Ga, widely recorded in the surface geology, has also not yet been found in the zircon age distribution from the lower crust of the Kola region.

Discussions with Pamela Kempton, Andy Markwick, Valery Vetrin, Svetlana Bogdanova, Victor Balagansky and many colleagues at the annual SVEKALAPKO meetings, sponsored by the ESF EUROPROBE project, have been very valuable. Comments by Alfred Kröner and Fernando Corfu helped to focus our ideas. The work of PP and IM was supported by grant 40553 from the Academy of Finland.

References

Alapieti, T.T., Filen, B.A., Lavrov, M.M., Smolkin, V.F. & Voitsekhovsky, S.N. 1990. Early Proterozoic layered intrusions in the north-eastern part of the Fennoscandian Shield. *Mineralogy and Petrology*, **42**, 1–12.

Amelin, Yu.V., Heaman, L.M. & Semenov, V.S. 1995. U-Pb geochronology of layered intrusions in the eastern Baltic Shield: implications for the timing and duration of Paleoproterozoic continental rifting. *Precambrian Research*, **75**, 31–46.

Balagansky, V.V., Timmerman, M.J., Kozlova, N.Ye. & Kislitsyn, R.V. 2001. A 2.44 Ga syn-tectonic mafic dyke swarm in the Kolvitsa Belt, Kola Peninsula, Russia: implications for early Palaeoproterozoic tectonics in the northeastern Fennoscandian Shield. *Precambrian Research*, **105**, 269–287.

Balashov, Yu.A., Bayanova, T.B. & Mitrofanov, F.P. 1993. Isotope data on the age and genesis of layered intrusions in the Kola peninsula and Northern Karelia, north-eastern Baltic Shield. *Precambrian Research*, **64**, 197–205.

Chen, Y.D., O'Reilly, S.Y., Kinny, P.D. & Griffin, W.L. 1994. Dating lower crustal and upper mantle events: an ion microprobe study of xenoliths from kimberlite pipes, South Australia. *Lithos*, **32**, 77–94.

Hölttä, P., Huhma, H., Mänttäri, I., Peltonen, P. & Juhanoja, J. 2000. Petrology and geochemistry of mafic granulite xenoliths from the Lahtojoki kimberlite pipe, eastern Finland. *Lithos*, **51**, 109–133.

Kelley, S.P. & Wartho, J.-A. 2000. Rapid kimberlite ascent and the significance of Ar-Ar ages in xenolith phlogopites. *Science*, **289**, 609–611.

Kempton, P.D., Downes, H., Sharkov, E.V., Vetrin, V.R., Ionov, D.A., Carswell, D.A. & Beard, A. 1995. Petrology and geochemistry of xenoliths from the Northern Baltic Shield: Evidence for partial melting and metasomatism in the lower crust beneath an Archaean terrane. *Lithos*, **36**, 157–184.

Kempton, P.D., Downes, H., Neymark, L.A., Wartho, J.A., Zartman, R.E. & Sharkov, E.V. 2001. Garnet granulite xenoliths from the northern Baltic Shield - the underplated lower crust of a Palaeoproterozoic Large Igneous Province? *Journal of Petrology*, **42**, 731–763.

Lobach-Zhuchenko, S.B., Arestova, N.A., Chekulaev, V.P., Levsky, L.K., Bogomolov, E.S. & Krylov, I.N. 1998. Geochemistry and petrology of 2.40-2.45 Ga magmatic rocks in the north-western Belomorian Belt, Fennoscandian Shield, Russia. *Precambrian Research*, **92**, 223–250.

Melezhik, V.A. & Sturt, B.A. 1994. General geology and evolutionary history of the early Proterozoic Polmak-Pasvik-Pechenga-Imandra/Varzuga-Ust'Ponoy Greenstone Belt in the northeastern Baltic Shield. *Earth Science Reviews*, **36**, 205–241.

Neymark, L.A., Nemchin, A.A., Vetrin, V.R. & Salnikova, E.V. 1993. Sm-Nd and Pb-Pb isotope systematics in deep crustal xenoliths from dikes and explosive pipes of the southern part of the Kola Peninsula. *Doklady Akademii Nauk*, **329**, 781–784.

Peltonen, P. & Mänttäri, I. 2001. An ion microprobe U-Th-Pb study of zircon xenocrysts from the Lahtojoki kimberlite pipe, eastern Finland. *Bulletin of the Geological Survey of Finland*, **73**, 47–58.

Puchtel, I.S., Haase, K.M., Hofmann, A.W., Chauvel, C., Kulikov, V.S., Garbe-Schonberg, C.D. & Nemchin, A.A. 1997. Petrology and geochemistry of crustally contaminated komatiitic basalts from the Vetreny Belt, southeastern Baltic Shield: Evidence for an early Proterozoic mantle plume beneath rifted Archean continental lithosphere. *Geochimica et Cosmochimica Acta*, **61**, 1205–1222.

Puchtel, I.S., Arndt, N.T., Hofmann, A.W., Haase, K.M., Kroner, A.M., Kulikov, V.S., Kulikova, V.V., Garbe-Schonberg, C.D. & Nemchin, A.A. 1998. Petrology of mafic lavas within the Onega plateau, central Karelia: evidence for 2.0 Ga plume-related continental crustal growth in the Baltic Shield. *Contributions to Mineralogy and Petrology*, **130**, 134–153.

Rudnick, R.L. & Williams, I.S. 1987. Dating the lower crust by ion microprobe. *Earth and Planetary Science Letters*, **85**, 145–161.

Sharkov, E.V. & Smolkin, V.F. 1997. The early Proterozoic Pechenga-Varzuga Belt: a case of Precambrian back-arc spreading. *Precambrian Research*, **82**, 133–151.

Sharkov, E.V., Smolkin, V.F. & Krassivskaya, I.S. 1997. Early Proterozoic magmatic province of siliceous high-Mg boninite-like series in the eastern Baltic Shield. *Petrology*, **5**, 448–465.

Sharkov, E.V., Snyder, G.A., Taylor, L.A. & Zinger, T.F. 1999. An early Proterozoic large igneous province in the eastern Baltic Shield: Evidence from the Mafic Drusite Complex, Belomorian Mobile Belt, Russia. *International Geological Review*, **41**, 73–93.

Vetrin, V.R. & Nemchin, A.A. 1998. [U-Pb age of zircons from xenolith of granulite in explosive pipe of the Elovy Island (southern Kola Peninsula)]. *Doklady Akademii Nauk*, **359**, 808–810 [in Russian].

Whitehouse, M.J., Kamber, B. & Moorbath, S. 1999. Age significance of U-Th-Pb zircon data from early Archaean rocks of west Greenland - a reassessment based on combined ion-microprobe and imaging studies. *Chemical Geology*, **160**, 201–224.

Received 7 December 2001; revised typescript accepted 28 March 2002.
Scientific editing by Richard England