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# Isotopic ages of Lentiira – Kuhmo – Kostomuksha olivine lamproite - Group II kimberlites

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**Abstract**

The Lentiira-Kuhmo-Kostomuksha triangle, along the Finland – Russian border and within the central part of the Archean Karelian craton, contains numerous examples of phlogopite-rich, ultramafic, mantle-xenocryst-bearing and, in some cases, diamond-bearing dike rocks. Laser probe Ar-Ar data on phlogopite from 3 dike rocks on the Finnish side (Lentiira, Kuhmo) all gave ages within error of each other, 1202 ± 3 Ma (2σ), 1199 ± 3 Ma (2σ) and 1204 ± 4 Ma (2σ) while a fourth sample produced mixed ages. Published Rb-Sr dates on mineralogically and chemically similar dikes from the Russian side (Kostomuksha) are 1232 ± 5 Ma. The question remains open whether these represent two distinct age populations or whether differences in isotopic system behavior are the reason for the 30 m.y. age difference.

**Key words:** kimberlite, lamproite, phlogopite, biotite, absolute age, Ar-40/Ar-39, Proterozoic, Lentiira, Seitaperä, Kuhmo, Finland, Kostomuksha, Russian Federation

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## 1. Introduction

Kimberlites are ultramafic, volatile-charged, incompatible element-rich magmas that represent a mixture of liquid, mantle peridotite and eclogite detritus carried from depth, and typically megacryst suite minerals such as Ti-pyrope, Mg-ilmenite and Cr-diopside. There are two end-member kimberlite types, based on examples from South Africa: Group I with abundant large, rounded grains (macrocrysts) of olivine, in a matrix of euhderal olivine, monticellite, perovskite, magnesian ulvöspinel-magnetite, Ba-rich phlogopite-kinoshitalite mica, calcite and serpentine, and Group II typically with abundant phlogopite ± olivine in a matrix of phlogopite, K-richterite and other diagnostic minerals (Table 1). Olivine lamproites show some similarities to Group II kimberlites but exist, for example, in W. Australia (Argyle diamond mine), Montana and Wyoming USA, and southern Spain, whereas no rocks absolutely identical to Group II kimberlites have been found outside of southern Africa.

In the area of Lentiira and Kuhmo, in eastern Finland (Fig. 1), occur a series of rocks with characteristics of both olivine lamproites and Group II kimber-

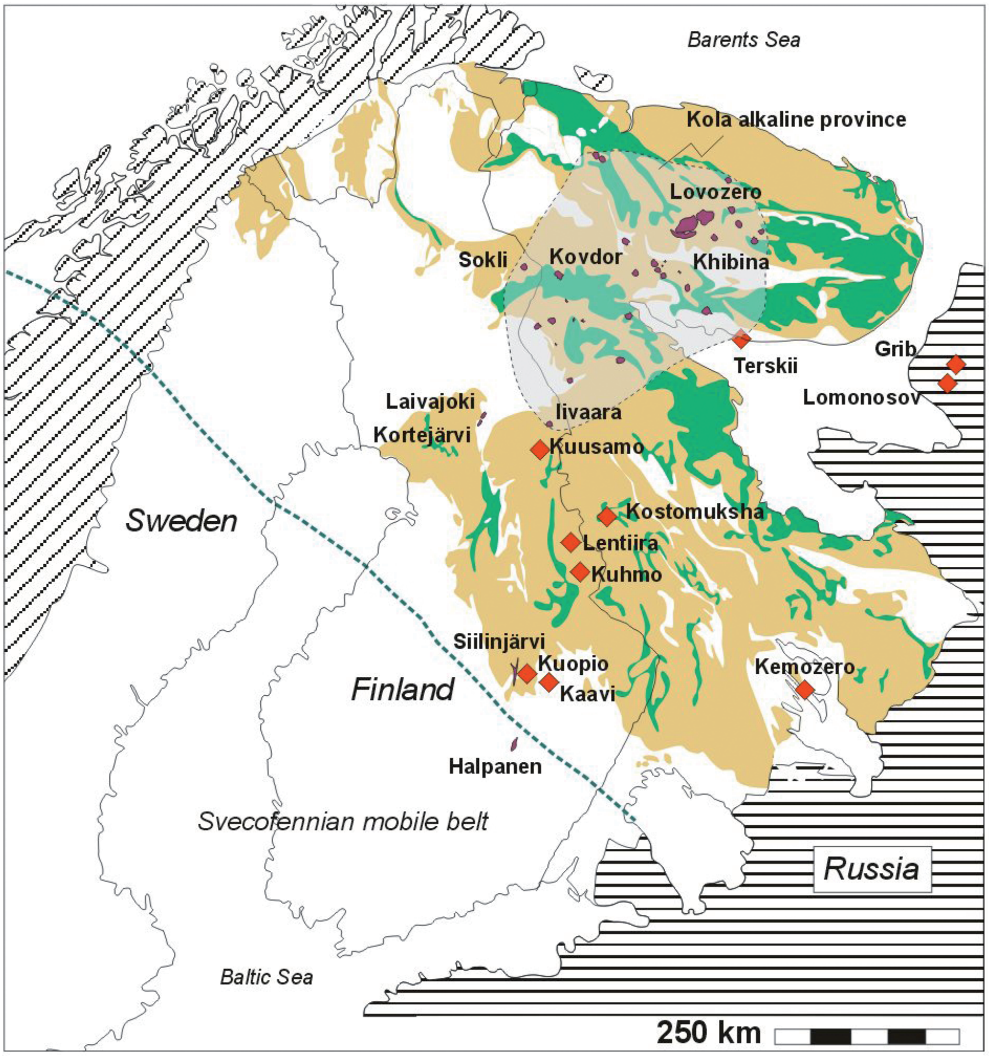



Fig. 1. Map showing the Lentiira-Kuhmo-Kostomuksha kimberlite/lamproite locations (black diamonds) within the Archean Karelian craton (SW margin marked by dashed line) along with other kimberlitic occurrences in the Fennoscandian shield.

lites (O'Brien & Tyni, 1999), although in fact they share more characteristics with the latter. The most notable feature of these ultramafic rocks is that they contain abundant phlogopite as phenocrysts, and more rarely as macrocrysts. Additionally, they range from being olivine macrocryst-poor to extremely olivine macrocryst-rich, and in some cases contain abundant microxenoliths of mantle peridotite. Additional minerals include K-richterite, Mn-rich ilmenite, Cr-rich spinel zoned to Ti-magnetite, apatite and perovskite in a calcite + serpentine matrix.

In the Kostomuksha region of Russian Karelia, about 40 km NE of the Finnish occurrences (Fig. 1), a suite of rocks ranging from leucite lamproite to olivine lamproite to Group II kimberlites has been identified and studied. These rocks have been termed K2L by Mahotkin (1998), in reference to their intermediate mineralogies between Group II kimberlite and olivine lamproite. The occurrence of leucite (now pseudoleucite), priderite and the lack of matrix serpentine in many of these rocks indicate that they are closer to true lamproites, yet many contain groundmass carbonate, rare to absent in typical lamproites.

All of the rocks discussed here are phlogopite-rich, but differ in that those from the Finnish side of the border contain groundmass carbonate and serpentine and have perovskite rather than priderite, all characteristics more typical of Group II kimberlite. Detailed research into whether there is a true E-W variation in magma types is the topic of another study, but here we report age evidence that may indicate a temporal separation of the Kostomuksha and Lentiira-Kuhmo kimberlite/lamproite dike fields by a few tens of millions of years. However, it is also important to note that regardless of distinct age populations and detailed mineralogical differences, on a broader scale there is a general mineralogical, geochemical and isotopic similarity among the lamproite and Group II magmas from Lentiira-Kuhmo-Kostomuksha and with the diamondiferous kimberlites of the Arkhangelsk area of Russia; all linked by the fact that they occur within the same Karelian-Kola-Kuloi mega-craton.

## 2. Previous Age Data

Only limited age-dates of the rocks discussed here have so far been published, and it is the goal of this short communication to update the situation with the latest geochronological results on these rocks. Rather imprecise perovskite U-Pb data by ion microprobe from Seitaperä, near Kuhmo can be interpreted to represent an age of around 1.2 Ga (O'Brien et al., 2005) although there is very large scatter in the data. From the Kostomuksha field, a Rb-Sr mineral isochron age of 1232 ± 4.5 Ma was reported for 4 selected mineral fractions (2 phlogopites and 2 pyroxenes) from 2 different dike hand samples (Belyatsii et al., 1997; Nikitina et. al, 1999). Although the data from the entire set of 11 analyses (mineral separates and whole rocks) from 5 different samples show considerably more scatter, recalculating using the entire dataset does not change the outcome significantly because of the very radiogenic Sr in the two phlogopite fractions. The full dataset gives 1232 ± 10 Ma with an MSWD of 35 using 0.5% and 0.05% std errors for $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$, respectively. The same two papers (op. cit.) also report a Sm-Nd isochron from these samples, 1234 ± 80, but the large errors do not help narrow down the time of dike emplacement.

As part of a study of noble gases on the Kostomuksha lamproitic dike rocks, Wiersberg (2001) obtained K-Ar ages from what is apparently the same sample suite as studied by Belyatsky et al., 1997 and Nikitina et. al, 1999. Wiersberg (2001) reports K-Ar ages ranging from 1150 to 1246 Ma and an overall age of 1193 ± 20 Ma (although Isoplot [Ludwig, 2000] suggests 1193 ± 42 Ma at a 95% confidence level). Earlier statements about a $^{40}Ar/^{36}Ar$ – $^{40}K/^{36}Ar$ correlation for 6 of these same K-feldspar/phlogopite separates giving an age of 1223 ± 13 Ma (Wiersberg et al., 1999; 2000) was apparently reinterpreted as mixing with atmospheric components (Wiersberg, 2001).

## 3. Samples and analytical procedures

Two samples each from the Kuhmo and Lentiira areas (Table 1) were submitted for $^{40}Ar/^{39}Ar$ laser probe analyses of phlogopite to the Noble Gas Laboratory at the University of Melbourne.

The Kuhmo samples comprise: 1. Sample **16.12 27 m** is a reddish brown rock, composed of approximately 60 % phlogopite (Fig. 2), taken from the original Malmikaivos drill core from hole 12, at 27 m depth. A full mineralogical description and microprobe data for this rock are given in O'Brien & Tyni (1999). 2. Sample **6501-B-2** was taken by trenching where the till is relatively thin at the NW corner of the Seitaperä intrusion as part of a Ph. D. thesis project (Lehtonen, 2005). The sample is considerably

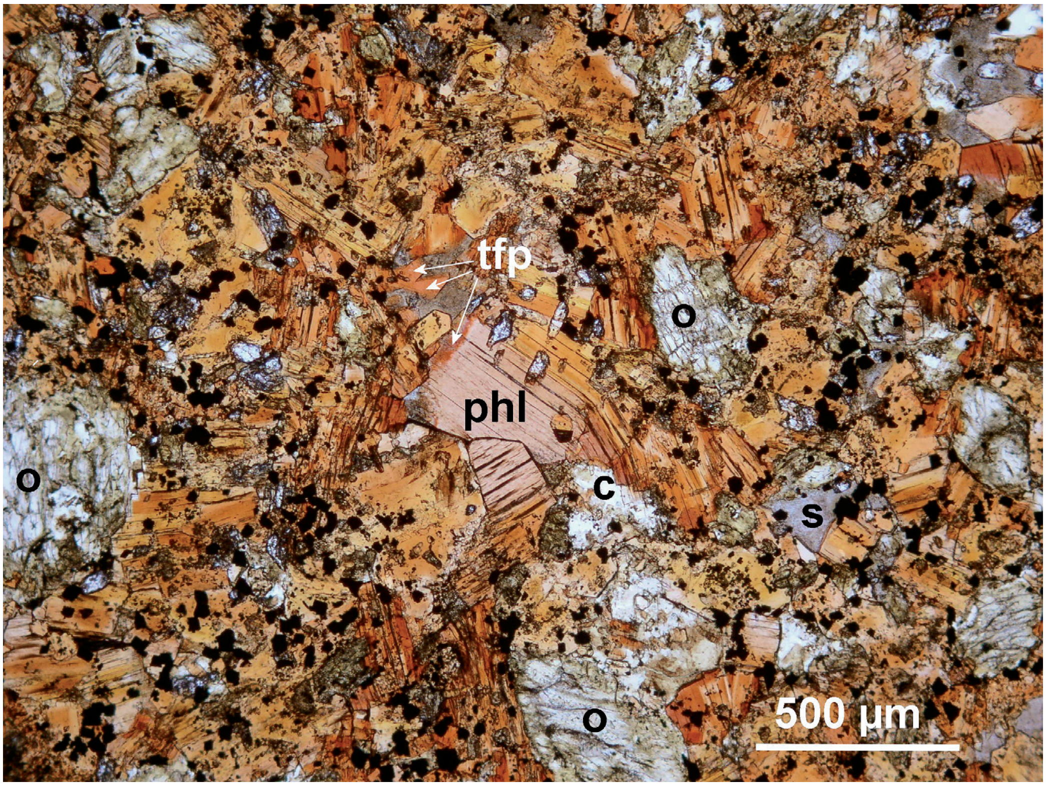



Fig. 2. Photomicrograph of Seitaperä sample 16.12, 27 m. Rock is dominantly phlogopite (phl), zoned at margins to tetraferriphlogopite (tfp), olivine pseudomorphs (o), small black cubes of perovskite & oxides, carbonate (c), and serpentine (s). Plane polarized light.

coarser than 16.12 27 m, yet contains a similar modal percentage of fresh, red-brown phlogopite, making it an ideal sample for Ar-Ar dating.

The Lentiira samples comprise: 1. Sample **Lent-W1** is from a roughly 1m wide dike at the western extent of the Lentiira Group II kimberlite field. The sample was slightly more altered than the Seitaperä samples, and some alteration of phlogopite is apparent. The main reason for choosing the sample is the abundance of mantle xenocrysts (particularly pyrope) that it contains. 2. Sample **DC401** represents a mixed sample containing crushed material from a somewhat altered kimberlitic rock and the surrounding country rocks. Many of the grains in the sample were dark brown to black representing biotite flakes from the granitic bedrock so a mixed age for this sample was anticipated.

Phlogopite mineral separates were prepared from each sample using standard crushing, sieving, desliming and electromagnetic methods. Approximately 20 – 30 phlogopite grains were handpicked from each sample and washed in deionized water and acetone prior to being shipped for irradiation. The grains were wrapped in aluminum packets and placed into an aluminum irradiation canister together with aliquots of the flux monitor GA1550 (Age = 98.8 ± 0.5 Ma; Renne et al., 1998). Packets containing $K_2SO_4$ were placed at either end of the canister to monitor $^{40}Ar$ production from potassium. The irradiation canister was irradiated in position 5C of the McMaster reactor, Hamilton, Ontario, Canada.

After irradiation, the samples were removed from their packaging and individual phlogopite grains were loaded into a copper sample holder. The sam-

**Table 1.** Lentiira and Kuhmo samples submitted for 40Ar/39Ar dating

| Sample Number | Locality | Sample Type TS | TS chip | mica con | Map Sheet | Latitude deg | min | sec | Longitude deg | min. | sec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16.12 27 m | Seitäperä, Kuhmo | | x | | 4413-12 | 64 | 14 | 44.30 | 29 | 47 | 56.35 |
| 6501-B-2 | Seitäperä, Kuhmo | x | | | 4413-12 | 64 | 14 | 43.63 | 29 | 47 | 48.93 |
| Lent-W1 | West Lentiira dike | x | | | 4414-06 | 64 | 31 | 48.39 | 29 | 33 | 52.64 |
| DC 401 308-328 | East Lentiira dike/ CR | | | x | 4414-09 | 64 | 31 | 23.55 | 29 | 47 | 22.75 |

ples were then individually step-heated using a CW Nd:YAG laser. $^{40}Ar/^{39}Ar$ analyses were carried out on a MM5400 mass spectrometer using a Daly detector. Mass discrimination was monitored by analyses of standard air volumes. Correction factors for interfering reactions are as follows: $(^{36}Ar/^{37}Ar)Ca = 2.63$ (± 0.01) x 10-4; $(^{39}Ar/^{37}Ar)Ca = 6.86$ (± 0.03) x 10-4; $(^{40}Ar/^{39}Ar)K = 0.0015$ (± 0.007). Ca/K ratios were calculated as follows: Ca/K = 1.9 x $^{39}Ar/^{37}Ar$. The reported data have been corrected for system backgrounds, mass discrimination, fluence gradients and atmospheric contamination. Unless otherwise stated, errors associated with the age determinations are one-sigma uncertainties and exclude uncertainties in the J-value, age of the fluence monitor GA1550 and the decay constants. Decay constants are those of Steiger & Jager (1977). The $^{40}Ar/^{39}Ar$ dating technique is described in detail by McDougall and Harrison (1999).

## 4. Results

For sample **16.12 27 m** a total of five single grains were step-heated in 2 – 4 increments (Table 2). Most grains are characterized by slightly elevated low temperature ages, possibly caused by release of excess argon from inclusions and/or minor alteration-induced recoil loss of $^{39}Ar_K$ (Fig. 3a). However, the highest temperature steps are concordant, with a weighted mean age of 1202 ± 3 Ma (2σ, incl. J-error) (Fig. 3b). This result is also within error of the plateau age determined for grain #5 (1200 ± 7 Ma; 2σ, incl. J-error) (Fig. 3a).

Five mica grains from Sample **6501-B-2** were each step-heated in four increments (Table 2). Grains #1 and #2 produced somewhat discordant age spectra, but with similar high temperature ages of ~1200 Ma (Table 2). The other three grains are characterized by age plateaus with weighted mean ages of 1209 ± 8 Ma (2σ; incl. J-error), 1200 ± 6 Ma (2σ; incl. J-error) and 1199 ± 8 Ma (2σ; incl. J-error) (Figs. 4a-c). The weighted mean result for the high temperature steps from all five grains is 1199 ± 3 Ma (2σ; incl. J-error) (Fig. 4d).

Six grains from sample **Lent-W1** were individually step-heated in two to three increments (Table 2). Five grains are characterized by younger low temperature steps, presumably due to minor $^{40}Ar$ loss. Grain #1 exhibits an elevated low temperature age, possibly caused by release of excess argon from inclusions and/or alteration-induced recoil loss of $^{39}Ar_K$. The high temperature results are, however, concordant, with a weighted mean age of 1204 ± 4 Ma (2σ, incl. J-error; MSWD = 0.96) (Fig. 5).

A total of eight grains were step-heated from sample **DC401**. Low temperature apparent ages range from 1173 ± 11 Ma to 2001 ± 24 Ma, whereas the highest temperature steps are mostly older at 1384 ± 7 Ma to 2443 ± 57 Ma (Table 2; Fig. 6). As this sample represents a mixture of kimberlitic material and country rock, the spread in ages likely comes from micas from the surrounding rocks that have been variably reset by injection of the dike magma. In this case the youngest ages may represent the closest ap-

**Table 2.** $^{40}Ar/^{39}Ar$ Step-Heating Analytical Results

| Grain No | Step No | Cum $\%^{39}Ar$ | $^{40}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{36}Ar/^{39}Ar$ | Vol. $^{39}Ar$ $x10^{-14}$mol | %Rad. $^{40}Ar$ | Ca/K | $^{40}Ar^{*}/^{39}Ar$ | Age (Ma) | ± 1s.d. (Ma) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Seitaperä (Body 16) (16.12/27m) | | | | | | | | | | | |
| J-value = 0.0071985 ± 0.0000072 | | | | | | | | | | | |
| 1 | 1 | 20.0 | 135.4 | 0.0708 | 0.0053 | 2.276 | 98.8 | 0.135 | 133.8 | 1217.3 | 4.3 |
| | 2 | 100.0 | 131.6 | 0.0258 | 0.0013 | 9.336 | 99.7 | 0.049 | 131.3 | 1200.1 | 5.1 |
| 2 | 1 | 41.6 | 132.9 | 0.1570 | 0.0032 | 2.883 | 99.3 | 0.298 | 132.0 | 1204.8 | 3.9 |
| | 2 | 88.3 | 132.7 | 0.0902 | 0.0017 | 3.246 | 99.6 | 0.171 | 132.2 | 1206.2 | 5.1 |
| | 3 | 100.0 | 133.0 | 0.3210 | 0.0043 | 0.810 | 99.1 | 0.610 | 131.8 | 1203.9 | 8.9 |
| 3 | 1 | 24.4 | 140.1 | 0.5411 | 0.0080 | 1.789 | 98.3 | 1.030 | 137.8 | 1243.4 | 6.5 |
| | 2 | 43.6 | 133.7 | 0.0109 | 0.0023 | 1.479 | 99.5 | 0.021 | 132.9 | 1211.3 | 7.9 |
| | 3 | 100.0 | 132.2 | 0.0804 | 0.0007 | 4.380 | 99.8 | 0.153 | 132.0 | 1204.9 | 7.1 |
| 4 | 1 | 36.8 | 134.1 | 0.0425 | 0.0052 | 2.388 | 98.9 | 0.081 | 132.5 | 1208.4 | 4.1 |
| | 2 | 84.4 | 131.7 | 0.0230 | 0.0008 | 3.135 | 99.8 | 0.044 | 131.5 | 1201.6 | 5.4 |
| | 3 | 100.0 | 130.7 | 0.0154 | 0.0002 | 1.040 | 100 | 0.029 | 130.6 | 1195.4 | 5.8 |
| 5 | 1 | 35.6 | 134.4 | 0.0945 | 0.0040 | 3.666 | 99.1 | 0.180 | 133.3 | 1213.5 | 3.6 |
| | 2 | 72.5 | 131.1 | 0.0198 | 0.0005 | 3.894 | 99.9 | 0.038 | 130.9 | 1197.8 | 3.5 |
| | 3 | 98.2 | 132.7 | 0.0486 | 0.0014 | 2.685 | 99.7 | 0.092 | 132.3 | 1206.7 | 6.7 |
| | 4 | 100.0 | 138.4 | 0.1714 | 0.0015 | 0.176 | 99.7 | 0.326 | 138.0 | 1244.5 | 41.1 |
| Seitaperä (Body 16) (6501-B-2) | | | | | | | | | | | |
| J-value = 0.0071985 ± 0.0000072 | | | | | | | | | | | |
| 1 | 1 | 35.37 | 130.6 | 0.0078 | 0.0074 | 4.154 | 98.3 | 0.015 | 128.4 | 1180.8 | 3.8 |
| | 2 | 53.14 | 134.2 | 0.0089 | 0.0026 | 2.087 | 99.4 | 0.017 | 133.4 | 1214.4 | 4.9 |
| | 3 | 67.32 | 137.5 | 0.0088 | 0.0064 | 1.665 | 98.6 | 0.017 | 135.6 | 1228.8 | 8.2 |
| | 4 | 100.0 | 132.7 | 0.0154 | 0.0045 | 3.838 | 99.0 | 0.029 | 131.4 | 1200.7 | 4.7 |
| 2 | 1 | 16.52 | 128.2 | 0.1760 | 0.0055 | 2.221 | 98.7 | 0.334 | 126.6 | 1168.9 | 5.8 |
| | 2 | 40.34 | 133.5 | 0.0196 | 0.0023 | 3.201 | 99.5 | 0.037 | 132.9 | 1210.7 | 7.2 |
| | 3 | 73.94 | 130.9 | 0.0231 | 0.0018 | 4.517 | 99.6 | 0.044 | 130.4 | 1194.1 | 3.3 |
| | 4 | 100.0 | 131.6 | 0.0091 | 0.0020 | 3.503 | 99.6 | 0.017 | 131.0 | 1198.3 | 4.7 |
| 3 | 1 | 17.47 | 133.5 | 0.0230 | 0.0010 | 1.994 | 99.8 | 0.044 | 133.2 | 1212.9 | 7.4 |
| | 2 | 48.76 | 132.6 | 0.0067 | 0.0016 | 3.573 | 99.6 | 0.013 | 132.1 | 1205.6 | 6.7 |
| | 3 | 82.30 | 132.9 | 0.0099 | 0.0012 | 3.828 | 99.7 | 0.019 | 132.6 | 1208.9 | 6.0 |
| | 4 | 100.0 | 131.6 | 0.0069 | 0.0076 | 2.021 | 98.3 | 0.013 | 129.4 | 1187.3 | 6.9 |
| 4 | 1 | 4.20 | 52.1 | 0.1393 | 0.0084 | 0.543 | 95.2 | 0.265 | 49.6 | 550.6 | 9.4 |
| | 2 | 29.26 | 132.6 | 0.0296 | 0.0006 | 3.240 | 99.9 | 0.056 | 132.5 | 1208.0 | 4.9 |
| | 3 | 37.31 | 130.7 | 0.0154 | 0.0002 | 1.040 | 100.0 | 0.029 | 130.6 | 1195.4 | 5.8 |
| | 4 | 100.0 | 131.0 | 0.0378 | 0.0021 | 8.106 | 99.5 | 0.072 | 130.3 | 1193.9 | 4.9 |
| 5 | 1 | 12.33 | 127.8 | 0.0455 | 0.0093 | 2.002 | 97.9 | 0.087 | 125.0 | 1158.1 | 7.9 |
| | 2 | 28.83 | 133.7 | 0.0068 | 0.0036 | 2.678 | 99.2 | 0.013 | 132.6 | 1209.1 | 12.5 |
| | 3 | 76.79 | 131.9 | 0.0217 | 0.0016 | 7.786 | 99.6 | 0.041 | 131.4 | 1201.0 | 5.4 |
| | 4 | 100.0 | 130.9 | 0.0166 | 0.0016 | 3.768 | 99.6 | 0.032 | 130.4 | 1194.4 | 5.6 |

**Table 2. cont.** $^{40}Ar/^{39}Ar$ Step-Heating Analytical Results

| Grain No | Step No | Cum $\%^{39}Ar$ | $^{40}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{36}Ar/^{39}Ar$ | Vol. $^{39}Ar$ $x10^{-14}mol$ | %Rad. $^{40}Ar$ | Ca/K | $^{40}Ar^{*}/^{39}Ar$ | Age (Ma) | ± 1s.d. (Ma) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kuhmo (Lent-W1) | | | | | | | | | | | |
| J-value = 0.0071985 ± 0.0000072 | | | | | | | | | | | |
| 1 | 1 | 35.37 | 135.6 | 0.1530 | 0.0053 | 2.604 | 98.9 | 0.291 | 134.0 | 1218.6 | 3.8 |
| | 2 | 53.14 | 136.5 | 0.0127 | 0.0153 | 3.737 | 96.7 | 0.024 | 132.0 | 1205.0 | 4.3 |
| 2 | 1 | 67.32 | 131.4 | 0.1437 | 0.0036 | 2.851 | 99.2 | 0.273 | 130.4 | 1194.4 | 4.2 |
| | 2 | 100.0 | 133.3 | 0.0116 | 0.0017 | 4.037 | 99.6 | 0.022 | 132.8 | 1210.2 | 3.6 |
| 3 | 1 | 16.52 | 129.2 | 0.0368 | 0.0062 | 1.676 | 98.6 | 0.070 | 127.4 | 1174.3 | 2.9 |
| | 2 | 40.34 | 135.5 | 0.0060 | 0.0027 | 2.009 | 99.4 | 0.011 | 134.6 | 1222.5 | 8.6 |
| | 3 | 73.94 | 133.2 | 0.0088 | 0.0024 | 0.941 | 99.5 | 0.017 | 132.4 | 1207.9 | 11.6 |
| 4 | 1 | 100.0 | 134.4 | 0.0947 | 0.0130 | 1.327 | 97.2 | 0.180 | 130.6 | 1195.6 | 5.9 |
| | 2 | 17.47 | 132.0 | 0.0116 | 0.0013 | 3.757 | 99.7 | 0.022 | 131.6 | 1202.6 | 5.9 |
| | 3 | 48.76 | 132.2 | 0.0365 | 0.0021 | 3.040 | 99.5 | 0.070 | 131.6 | 1202.1 | 3.9 |
| 5 | 1 | 82.30 | 127.8 | 0.0173 | 0.0030 | 0.358 | 99.3 | 0.033 | 126.9 | 1170.7 | 24.4 |
| | 2 | 100.0 | 131.4 | 0.0022 | 0.0001 | 3.924 | 100.0 | 0.004 | 131.4 | 1201.0 | 7.5 |
| 6 | 1 | 4.20 | 131.4 | 0.0289 | 0.0037 | 2.205 | 99.2 | 0.055 | 130.3 | 1193.9 | 6.4 |
| | 2 | 29.26 | 131.8 | 0.0031 | 0.0011 | 1.990 | 99.8 | 0.006 | 131.5 | 1201.5 | 5.1 |
| | 3 | 37.31 | 130.3 | 0.0031 | 0.0002 | 2.563 | 100.0 | 0.006 | 130.3 | 1193.5 | 6.1 |
| Kuhmo (DC401 308-328) | | | | | | | | | | | |
| J-value = 0.0071985 ± 0.0000072 | | | | | | | | | | | |
| 1 | 1 | 42.41 | 289.1 | 0.4241 | 0.3219 | 0.869 | 67.1 | 0.806 | 194.0 | 1577.0 | 10.0 |
| | 2 | 67.35 | 244.0 | 0.5428 | 0.0543 | 0.511 | 93.4 | 1.030 | 228.1 | 1752.9 | 20.0 |
| | 3 | 100.00 | 255.6 | 4.8588 | 0.0428 | 0.669 | 95.2 | 9.260 | 244.2 | 1830.1 | 17.2 |
| 2 | 1 | 43.13 | 348.5 | 2.5045 | 0.4696 | 0.088 | 60.2 | 4.770 | 210.3 | 1662.9 | 67.4 |
| | 2 | 92.92 | 330.0 | 0.6833 | 0.0943 | 0.102 | 91.6 | 1.300 | 302.1 | 2084.2 | 91.5 |
| | 3 | 100.00 | 229.0 | 1.4828 | 0.0592 | 0.015 | 92.4 | 2.820 | 211.9 | 1671.0 | 332.5 |
| 3 | 1 | 79.99 | 414.6 | 1.6426 | 0.5008 | 0.081 | 64.3 | 3.120 | 267.1 | 1934.9 | 74.3 |
| | 2 | 98.59 | 390.9 | 1.4451 | 0.0822 | 0.019 | 93.8 | 2.750 | 367.2 | 2332.4 | 308.9 |
| | 3 | 100.00 | 486.4 | 3.5962 | 0.6550 | 0.001 | 60.3 | 6.850 | 293.9 | 2050.4 | 2212.7 |
| 4 | 1 | 69.45 | 315.2 | 1.3051 | 0.2050 | 0.272 | 80.8 | 2.480 | 255.0 | 1880.2 | 39.3 |
| | 2 | 100.00 | 383.2 | 6.9105 | 0.0601 | 0.120 | 95.5 | 13.200 | 367.6 | 2334.1 | 33.5 |
| 5 | 1 | 70.43 | 280.9 | 0.1149 | 0.1244 | 4.001 | 86.9 | 0.218 | 244.3 | 1830.6 | 5.6 |
| | 2 | 98.31 | 311.1 | 0.0789 | 0.0376 | 1.584 | 96.4 | 0.150 | 300.0 | 2075.5 | 9.1 |
| | 3 | 100.00 | 280.2 | 0.1036 | 0.0414 | 0.096 | 95.6 | 0.197 | 268.1 | 1939.2 | 39.0 |
| 6 | 1 | 15.52 | 131.2 | 0.1338 | 0.0139 | 1.111 | 96.9 | 0.254 | 127.2 | 1172.6 | 11.0 |
| | 2 | 61.27 | 163.2 | 0.1664 | 0.0009 | 3.275 | 99.8 | 0.316 | 163.0 | 1400.4 | 5.8 |
| | 3 | 100.00 | 160.4 | 0.2372 | 0.0007 | 2.772 | 99.9 | 0.451 | 160.2 | 1383.9 | 7.2 |
| 7 | 1 | 75.83 | 361.6 | 0.9819 | 0.2697 | 0.248 | 78.0 | 1.870 | 282.2 | 2000.8 | 23.5 |
| | 2 | 98.62 | 424.3 | 0.0934 | 0.0848 | 0.075 | 94.1 | 0.177 | 399.2 | 2443.2 | 57.0 |
| | 3 | 100.00 | 820.1 | 4.2059 | 0.5002 | 0.005 | 82.0 | 8.020 | 674.5 | 3188.6 | 2095.9 |
| 8 | 1 | 29.94 | 231.0 | 0.0280 | 0.0123 | 2.056 | 98.4 | 0.053 | 227.4 | 1749.3 | 8.8 |
| | 2 | 64.28 | 246.6 | 0.0150 | 0.0035 | 2.358 | 99.6 | 0.028 | 245.5 | 1836.3 | 11.0 |
| | 3 | 100.00 | 243.5 | 0.0197 | 0.0027 | 2.453 | 99.7 | 0.037 | 242.7 | 1823.0 | 8.0 |

i) Errors are one sigma uncertainties and exclude uncertainties in the J-value.

ii) Data are corrected for mass spectrometer backgrounds, discrimination and radioactive decay.

iii) Interference corrections: $(^{36}Ar/^{37}Ar)Ca = 2.83E-4$; $(^{39}Ar/^{37}Ar)Ca = 6.86E-4$; $(^{40}Ar/^{39}Ar)K = 1.5E-3$

iv) J-value is based on an age of 98.8 Ma for GA-1550 biotite.

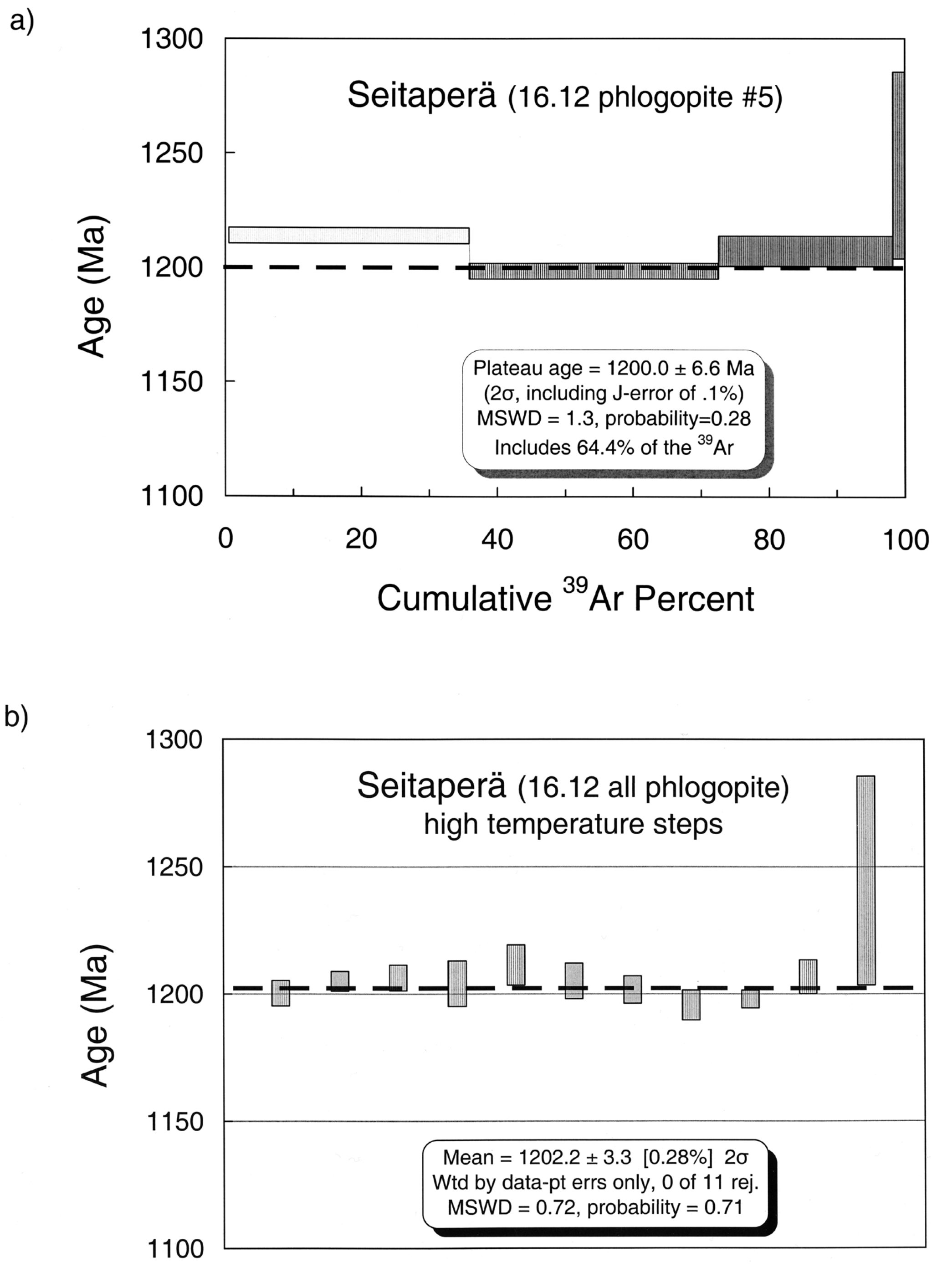



Fig. 3. $^{40}Ar/^{39}Ar$ plots for sample 16.12, Seitaperä. a) $^{40}Ar/^{39}Ar$ step-heating age spectrum for phlogopite grain #1 from sample 16.12. b) Histogram showing $^{40}Ar/^{39}Ar$ ages obtained from the high temperature heating steps for five phlogopite grains, sample 16.12. Error boxes are one-sigma uncertainties. Uncertainties in the weighted mean ages are two-sigma.

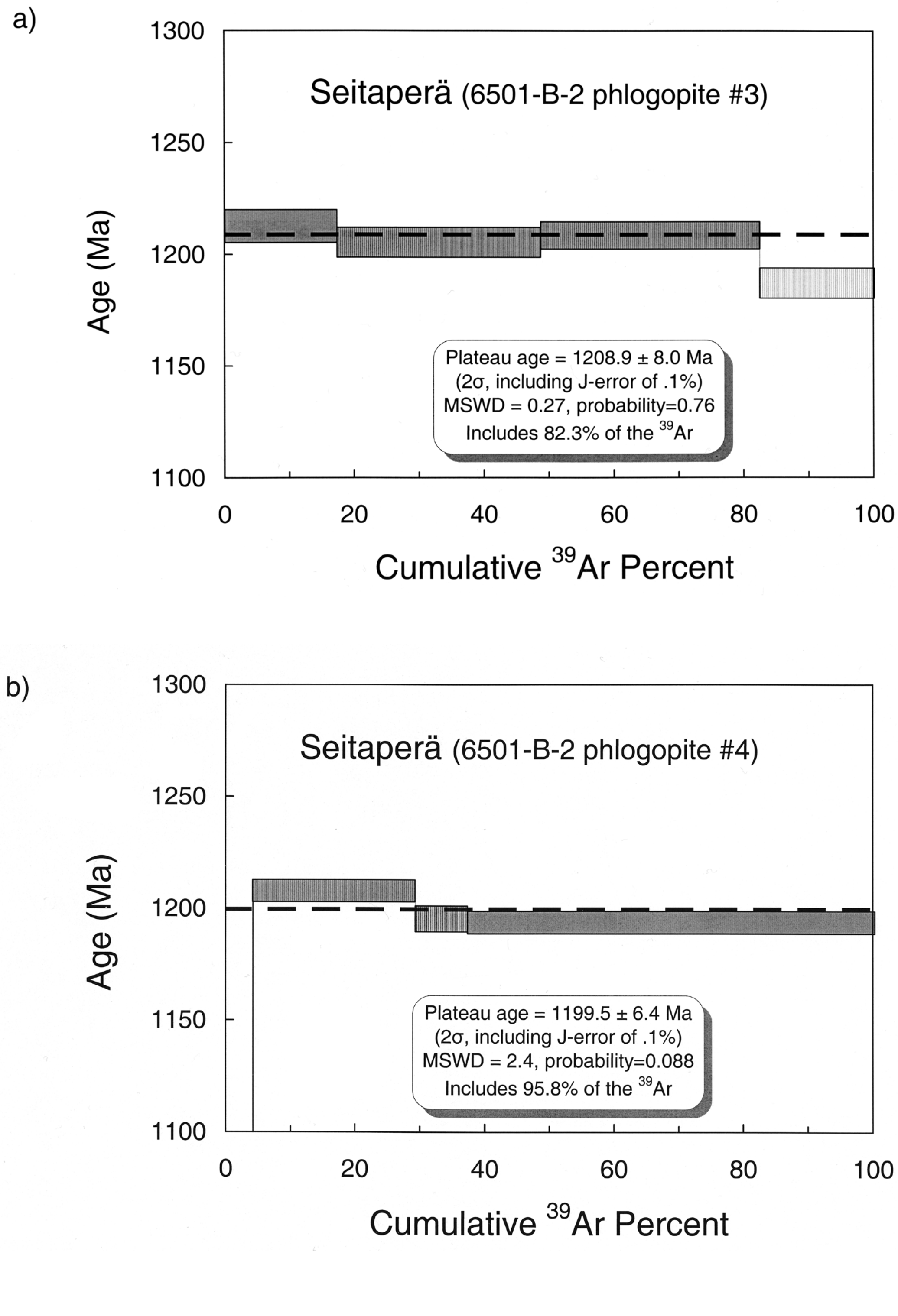
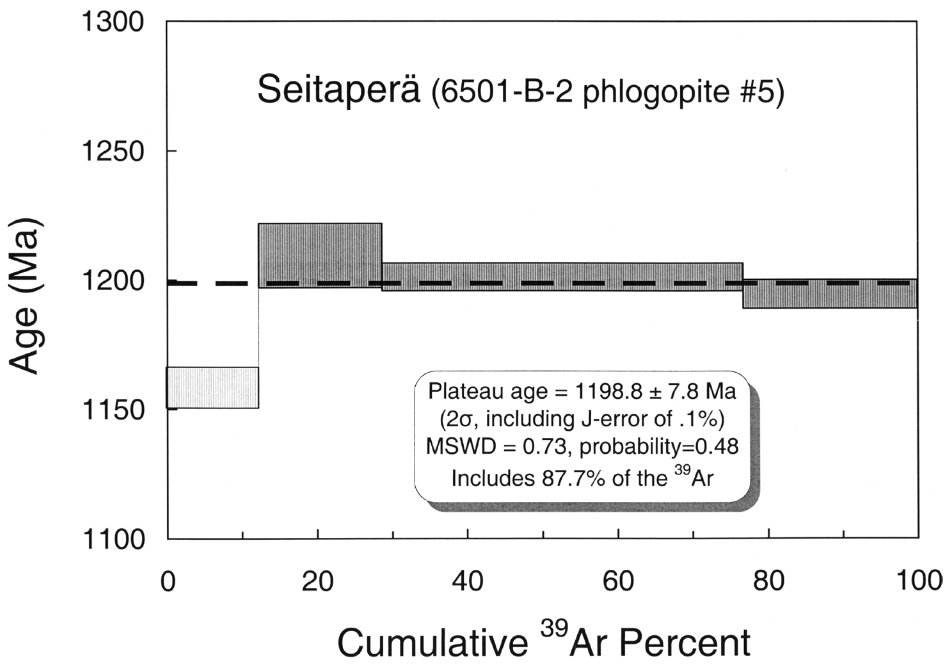



Fig. 4. $^{40}Ar/^{39}Ar$ plots for sample 6501-B-2, Seitaperä. a) $^{40}Ar/^{39}Ar$ step-heating age spectrum for phlogopite grain #3 from sample 6501-B-2. b) $^{40}Ar/^{39}Ar$ step-heating age spectrum for phlogopite grain #4 from sample 6501-B-2.

c)




d)

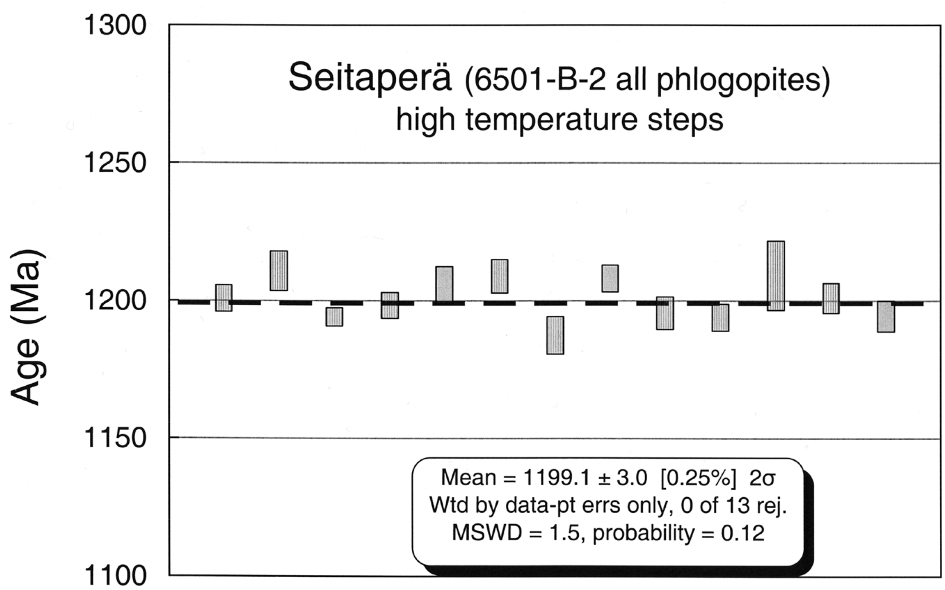



Fig. 4. continued. c) $^{40}Ar/^{39}Ar$ step-heating age spectrum for phlogopite grain #5 from sample 6501-B-2. d) Histogram showing high temperature $^{40}Ar/^{39}Ar$ ages obtained from five phlogopite grains, sample 6501-B-2. Error boxes are one-sigma uncertainties. Uncertainties in the weighted mean ages are two-sigma errors.

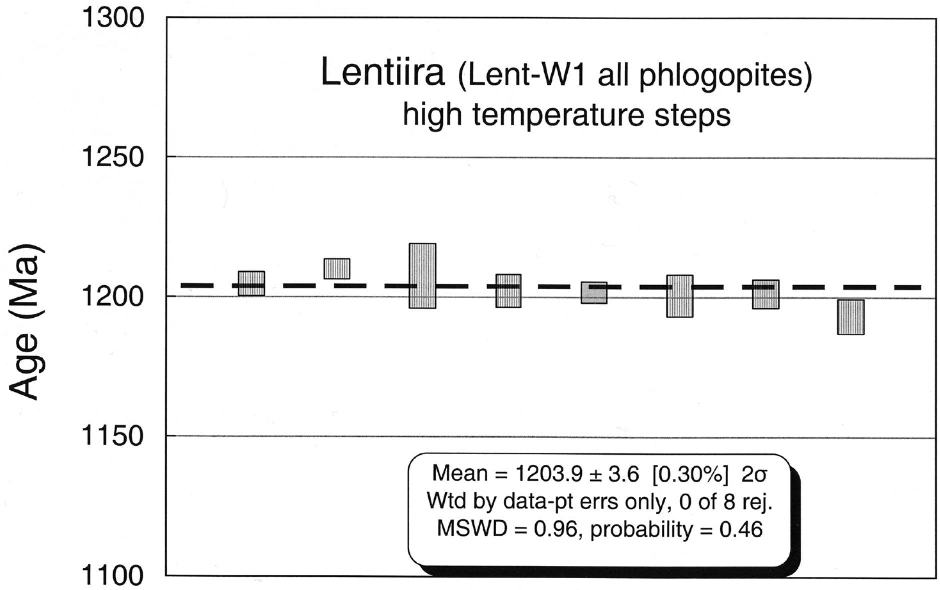



Fig. 5. Histogram showing high temperature $^{40}Ar/^{39}Ar$ ages obtained from six phlogopite grains, sample Lent-W1, Lentiira. Error boxes are one-sigma uncertainties. Uncertainties in the weighted mean age are two-sigma errors.

proximation to the time of dike emplacement (~1.2 Ga), consistent with results from Lent-W1.

## 5. Discussion

As a group the Ar-Ar age data from samples 16.12 27 m, 6501-B-2 and Lent-W1 produced ages that are all within error of each other, 1202 ± 3 Ma (2σ), 1199 ± 3 Ma (2σ) and 1204 ± 4 Ma (2σ), respectively. The consistency of the step-heating results suggests that these ages represent precise determinations of the dike emplacement times at these localities. The fact that they overlap in time, combined with their mineralogical and geochemical similarities, suggest that these dikes represent a cogenetic suite of magmas.

The question arises however, are the kimberlitic rocks on the Finnish side of the border time correlative to those in the Kostomuksha area in Russian Karelia? As noted earlier, the Rb-Sr data would suggest not, the Kostomuksha dikes would seem to be roughly 30 ± 10 m.y. older than their Finnish counterparts. Yet the data of Wiersburg (2001), although producing rather scattered K-Ar ages, nevertheless center on 1193 Ma, and consequently would suggest just the opposite, that the two groups are indeed time correlative. The answer to this question can only come from further age determinations on rocks from both sides of the border. Particularly useful would be laser Ar-Ar dating, as was conducted in this study, on a selected suite of fresh samples from the Kostomuksha dikes.

Interestingly, 1200 Ma marks a significant worldwide kimberlite/lamproite intrusive event. The best known include: 1. the major diamond producing Argyle olivine lamproite at 1178 ± 47 Ma (Pidgeon et al., 1988; Sun et al., 1986), 2. the Krishna lamproites at 1224 ± 14 Ma (Kumar et al., 2001) thought to be the source rocks of the most famous Indian diamonds, 3. the Premier kimberlite in South Africa at 1198 ± 14 Ma (Phillips et al., 1989) known for producing some of the largest diamonds ever mined. Although not yet proven to contain significant diamonds, the olivine lamproites – Group II kimberlites of Lentiira-Kuhmo-Kostomuksha may still prove to be economically interesting, as the Archean mantle they have ascended through has all of the hallmarks for good diamond potential (e.g. O'Brien et al., 2003).

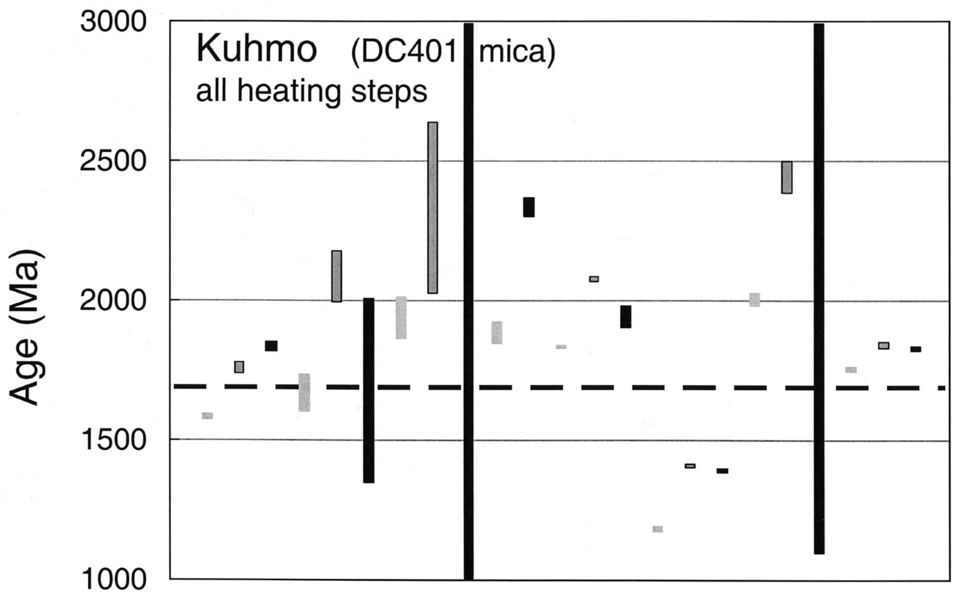



Fig. 6. Histogram showing $^{40}Ar/^{39}Ar$ results for eight biotite grains from sample DC401, Lentiira. Light grey = low temperature step; medium grey = intermediate temperature step; black = high temperature step. Error boxes are one-sigma uncertainties.

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