Geochronology and noble gas isotope signatures of kimberlites and lamproites of the Baltic Shield

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Alkaline igneous rocks like kimberlites and lamproites, generated in the deep mantle, are important tracers of magma genesis and the interaction between mantle and crust. These usually gas-rich rocks and included mantle xenoliths, e.g. diamonds, are a potential source of information about the thermal conditions, the fluid behaviour and the oxidation level in the mantle. The volatile-rich nature of the magmas causes their rapid ascent through the crust which, coupled with high incompatible-element concentrations, renders them very resistant to crustal contamination. Within the scope of a DFG-RFFI project we investigate the genesis and formation of kimberlites and lamproites of the eastern Baltic Shield. Noble gas isotopic data represent a powerful tool for such studies because of their usefulness as tracers for fluid behaviour and their ability to discriminate between mantle and crustal components.

In Table 1 we report noble gas abundances and characteristic isotope ratios for one kimberlite and three lamproites from the locations Kostamuksha (Karelian block) and Poria Guba (Kola block). The most striking observation from these data is the extremely radiogenic signature of all noble gases and, by consequence, the very high concentrations particulary of ^{4}He and ^{40}Ar. To appreciate these data we shall first discuss the geochronology of the samples.

Table 1. Noble gas abundances (in cm^3 STP/g), isotopic ratios, and ratio $CO_2/^{36}Ar$ for kimberlite 12a and three lamproites from the eastern Baltic Shield. Sample locations: P = Poria Guba, K = Kostamuksha. Error limits are 2σ

Sample	^{4}He [10^{-8}]	^{20}Ne [10^{-12}]	^{40}Ar [10^{-8}]	^{84}Kr [10^{-12}]	^{132}Xe [10^{-12}]	$CO_2/^{36}Ar$ [10^9]*
P 12 a	3280 ± 260	5950 ± 200	4800 ± 420	520 ± 27	28.4 ± 1.3	9.89 ± 0.97
P 12-2	15600 ± 1000	2680± 640	86700 ± 7500	145 ± 11	32.1 ± 2.0	11.4 ± 7.52
K D-21	13100 ± 1300	4920 ± 250	40600 ± 4200	5520 ± 850	2350 ± 200	0.052 ± 0.005
K D-26	4830 ± 180	460 ± 38	33200 ± 2200	146 ± 11	43.4 ± 2.7	2.02 ± 0.49

*For reference:
$CO_2/^{36}Ar$ ratios of atmosphere = 10.5, continental crust $<10^7$, depleted mantle = $10^9 - 10^{10}$

Sample	^{3}He/^{4}He [10^{-6}]	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{40}Ar/^{36}Ar [10^3]	^{136}Xe/^{132}Xe [10^{-2}]
P12 a	0.278 ± 0.021	9.499 ± 0.056	0.0363 ± 0.0160	2.52 ± 0.11	33.91 ± 0.79
P12a (cr)	0.51 ± 0.09	9.72 ± 0.34	0.0294 ± 0.0025	0.601 ± 0.015	32.1 ± 2.8
P 12-2	0.0067 ± 0.0028	5.2 ± 1.2	0.102 ± 0.012	260 ± 170	40.1 ± 1.1
K D-21	0.0263 ± 0.0052	8.53 ± 0.17	0.1224 ± 0.0049	4.66 ± 0.10	32.95 ± 0.18
K D-26	0.0259 ± 0.0057	8.19 ± 0.59	0.0496 ± 0.0086	19.9 ± 4.6	35.9 ± 1.7

cr = crushed sample

The ^{87}Rb-^{87}Sr and ^{147}Sm-^{143}Nd methods, yield an age of 1231 ± 9 Ma or 1241 ± 41 Ma, respectively, for lamproites from Kostamuksha, whereas for lamproite 12-2 from Poria Guba an age of 1719 ± 9 Ma is calculated. In comparison, K-Ar dating of separated micas from Kostamuksha yields a somewhat higher value of 1290 ± 21 Ma, whereas the K and radiogenic ^{40}Ar concentrations of whole rock samples would even imply an age of ~ 2000 Ma. The obvious excess of radiogenic ^{40}Ar is most likely due to an interaction of the rock material with a gas-rich fluid phase within the crust.

U/Th-^{4}He dating is not feasible because of ^{4}He diffusion loss. Instead the nucleogenic component of ^{21}Ne ($^{21}Ne_n$), mainly produced by the reaction $^{18}O(\alpha,n)^{21}Ne$ (e. g. Kennedy *et al.*, 1990), might be used as a dating tool, owing to the constant production ratio $^{21}Ne_n/^{4}He = 4.5 \times 10^{-8}$ (Yatsevich and Honda, 1997).

Furthermore, we have observed excesses of ^{132}Xe, ^{134}Xe and ^{136}Xe generated by spontaneous fission reactions of ^{238}U, which could be used for dating purposes also. However, first results of U/Th-^{21}Ne and U-Xe dating are not consistent, probably as a consequence of inhomogenous rock samples. Further investigations on mineral separates will reveal whether besides ^{40}Ar other noble gas isotopes produced in nuclear processes are present in higher concentrations than what in-situ production can explain.

The neon isotopic compositions in stepwise heating fractions of 1 kimberlite and 3 lamproites are graphically displayed in a neon three-isotope plot (Fig. 1). The ratios $(^{21}Ne/^{22}Ne)_n$ vary among samples and extraction temperatures; in most fractions both $^{21}Ne/^{22}Ne$ and $^{20}Ne/^{22}Ne$ are clearly different from atmospheric ratios, obviously due to the presence of nucleogenic ^{21}Ne and ^{22}Ne, the latter being produced by the reaction $^{19}F(\alpha,n)^{22}Na(\beta^+)^{22}Ne$.

Except for one (D-21, 600°C), all data points are consistent with one of two linear fits (solid lines in Fig. 1), representing simple two component mixtures between atmospheric Ne and two nucleogenic components with distinct $(^{21}Ne/^{22}Ne)_n$ ratios. This indicates that two minerals with distinct O/F ratios are the main carriers of nucleogenic Ne. Using the empirical correlation between the $(^{21}Ne/^{22}Ne)_n$ production ratio and the $^{18}O/^{19}F$ ratio (cf. Kennedy *et al.*, 1990), total O/F volume ratios of ~33 for $(^{21}Ne/^{22}Ne)_n = 0.16$ and ~ 81 for $(^{21}Ne/^{22}Ne)_n = 0.40$ are calculated.

In the kimberlite 12a from Poria Guba we have found a $^{3}He/^{4}He$ ratio of 0.28×10^{-6} (Table 1), which is clearly higher than the crustal ratio ($\sim 2 \times 10^{-8}$). Another split of that sample was crushed mechanically, releasing only gases stored in fluid inclusions but not those sited within the crystal lattice. In that experiment the ratio was still higher ($\sim 0.5 \times 10^{-6}$). This is clear evidence that the excess ^{3}He (with respect to crustal abundance), has not been produced by cosmic ray irradiation, as cosmogenic ^{3}He should not be concentrated in inclusions. Contamination by atmospheric ^{3}He is negligible, because the $^{3}He/^{20}Ne$ ratio is a factor of 3000 higher than in air. Therefore, the only explanation for the increased $^{3}He/^{4}He$ ratio is a mantle component in kimberlite 12a. Additionally the $CO_2/^{36}Ar$ ratios of some samples including 12a suggest a mantle origin (Table 1; cf. Lokhov and Levsky, 1994).

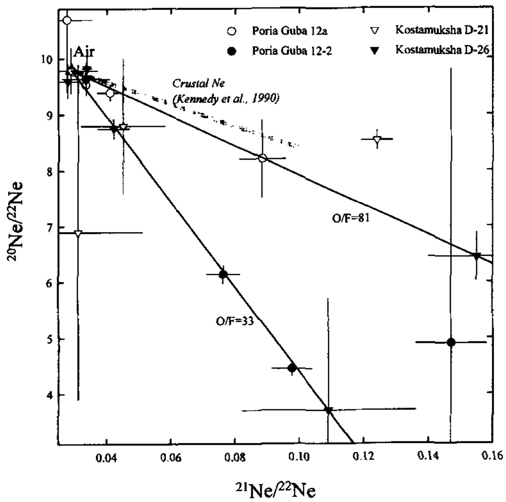

FIG. 1. Neon three-isotope plot for stepwise heating fractions of one kimberlite and three lamproites.

Future studies are aimed at more clearly elaborating the mantle and crustal contributions to the formation of these rocks and, possibly, developing an extended mantle model taking into account the existence of a subcontinental mantle which is enriched in lithophile elements.

References

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