^{40}Ar-^{39}Ar age constraints for a metasomatic imprint of the Kaapvaal Craton mantle lithosphere ca. 1 Ga ago

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Mantle xenoliths exhumed during eruption of kimberlite magmas provide information on mantle compositions of cratonic mantle lithosphere. It appears that depleted residues of large ancient melt depletion events and products of refertilization processes are both visible in the rock record (e.g. Pearson et al., 2003). The latter is associated with introduction of incompatible elements into the lithospheric mantle. In part this can be attributed to late interaction between xenolith and kimberlite host (e.g. Simon et al., 2007). However, reported radioisotope ages also agree with major metasomatic enrichment events prior to kimberlite emplacement. Unfortunately, the resulting age distributions are often not compelling enough to establish a link between metasomatic and geotectonic events.

Excess ^{40}Ar versus in-situ radiogenic ^{40}Ar*

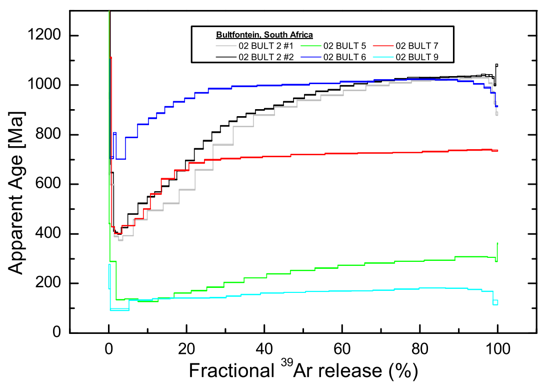
Phlogopite is a major and relatively abundant metasomatic mineral phase which can be found in mantle xenoliths. In addition, it is well suited for dating via the K-Ar or Ar-Ar dating method. The nominal closure temperature of argon in phlogopite is <500 °C and hence, we would expect to date the time of kimberlite emplacement. However, frequently ages exceeding the kimberlite age were found. This discrepancy had been attributed to the presence of excess (= mantle) ^{40}Ar that is unsupported by K and thus increases observed ages (Phillips and Onstott, 1988; Johnson and Phillips, 2003).

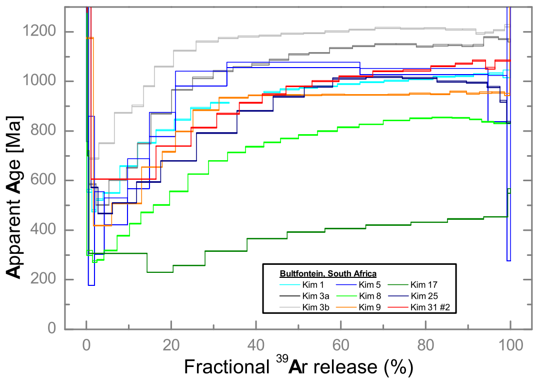
More recently however, it was shown that Ar might be retained in phlogopite at much higher temperatures and during extended periods of time (Kelley and Wartho, 2000). It was argued that the solubility of argon in phlogopite is significantly higher compared with coexisting mineral phases, i.e. the solid/solid partitioning is in strong favour of phlogopite. In this view Ar-Ar ages of mantle phlogopites could date ancient metasomatic enrichment processes in the lithospheric mantle (Wartho and Kelley, 2003).

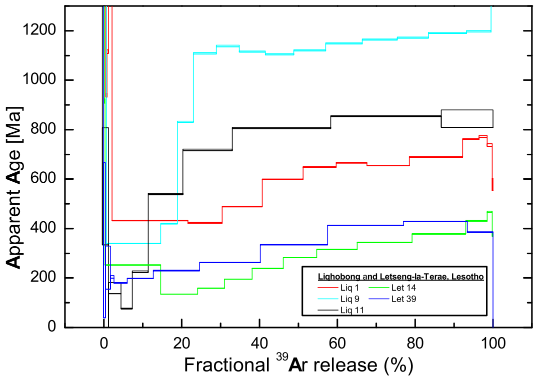
Ar-Ar dating of mantle phlogopites

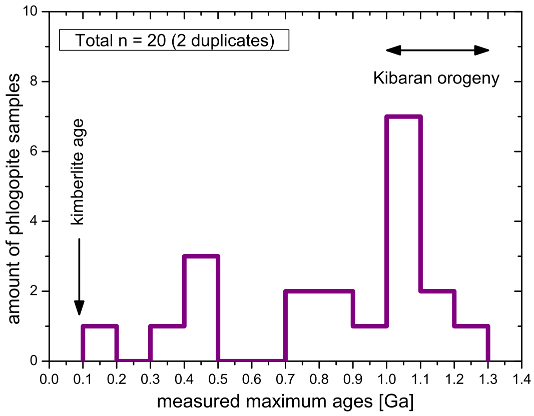
We analysed a suite of phlogopites hosted in 17 mantle xenoliths (garnet and spinel peridotites) and one diopside megacryst from the kimberlites of Bultfontein (South Africa), Letseng-la-Terae and Liqhobong (both Lesotho) via the conventional ^{40}Ar-^{39}Ar dating method. A second group of phlogopites hosted in another six mantle xenoliths from Bultfontein and Letseng-la-Terae had been dated with incremental laser heating and laser spot analysis.

All samples which were measured with the conventional high resolution step-heating method show age spectra (displayed below) typical of partial ^{40}Ar* loss related to kimberlite intrusion 80 - 90 Ma ago, but never resulted in total resetting of the K-Ar system. Apparent ages increased monotonically with increasing release temperature and reached maximum ages of up to 1220 Ma. This agrees with phlogopite ages reported in literature which also do not exceed 1200 Ma.



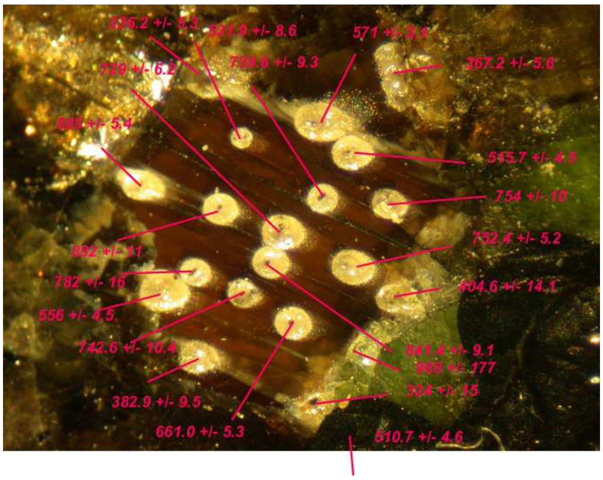






Several phlogopite separates from different xenoliths displayed similar maximum ages of 1.0 - 1.2 Ga, an age range that is further supported by application of diffusion theory and correction for ^{40}Ar*-loss. We can visualize this apparent clustering of ages plotting the distribution of maximum ages in a histogram (resolution 0.1 Ga).

Apparent ages obtained with the laser method encompass a similar range as for the conventional dating method with a slightly lower maximum apparent age of 1029 ± 19 Ma. Core ages tend to be higher than rim ages, pointing to a preferred ^{40}Ar*-loss from the outer layers of phlogopite grains.



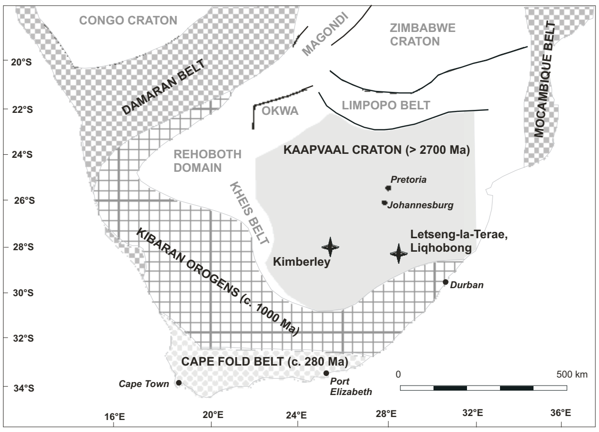
An example of a laser spot age map for a typical phlogopite grain (Let 64) is shown above (2σ-error).

The clustering of ages around 1.0 - 1.2 Ga, the differences in modal abundances of phlogopite in their respective host peridotites and the different extent of ^{40}Ar*-loss make contributions of an excess ^{40}Ar component unlikely. The only detected possible excess ^{40}Ar contribution was observed in five phlogopite separates at highest release temperatures which is attributed to degassing of argon trapped in fluid or melt inclusions hosted in minor impurities of pyroxenes or olivine. However, the concentrations of this ^{40}Ar contribution are negligible relative to the total ^{40}Ar* concentrations observed in the phlogopites.

The *P-T* equilibrium conditions of the host peridotites encompass 800-1200°C and 2.9-4.6 GPa, respectively. The temperatures are far in excess to accepted closure temperatures for argon in phlogopite (<500°C). This supports models which propose that argon partitioning is in strong favour of the phlogopite lattice in a typical mantle mineral assemblage. Alternatively, diffusion of argon in mantle minerals like olivine might be too slow relative to phlogopite to allow for a significant loss of argon from the phlogopite lattice. We conclude that the ages point to formation of new phlogopites in course of a metasomatic addition of melts and fluids carrying the necessary amount of K and water.

Dating metasomatism

We associate the age of this metasomatic event with the Kibaran orogenic cycle (1.00 - 1.25 Ga ago) that led to formation of the Namaquan-Natal fold belt at the southern border of the Kaapvaal craton (see map below). Subduction of oceanic crust below the cratonic keel would be accompanied by dewatering of the slab and production of melts that could penetrate into the lithospheric mantle. Beside water these melts would also carry other incompatible elements. Since subduction is not a discrete event but may have continued for several hundreds of million years this might explain why we observe an age distribution instead of a clear time mark. In addition, subduction below the craton can influence the mantle lithosphere even in some distance to the geotectonic border between Archean crust and the crustal units of the Namaqua-Natal fold belt (e.g. at Kimberley, 250 km distant).



We found no age constraint corresponding to other major geotectonic or magmatic events. Only one phlogopite sample from Bultfontein yielded an age of 750 Ma (corrected for ^{40}Ar*-loss) significantly outside the range of the Kibaran orogeny but more closely corresponding to the break-up of Rodinia. Of course, this remains still speculative but underlines the ability of the conventional ^{40}Ar-^{39}Ar dating method to detect other major metasomatic events by analysing phlogopites hosted in mantle xenoliths with a statistically sufficient number.

References

Johnson L., Phillips, D., 2003. ^{40}Ar/^{39}Ar dating of mantle metasomatism: A noble approach or all hot air? 8th Int. Kimb. Conf. Long Abstract.

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

Pearson, D.G., Canil, D., Shirey, S.B., 2003. Mantle samples included in volcanic rocks: xenoliths and diamonds. In: Carlson, R.W., (ed.) The mantle and core. Treatise on geochemistry. Amsterdam: Elsevier, pp. 171-275.

Phillips, D., Onstott, T.C., 1988. Argon isotopic zoning in mantle phlogopites. Geology 16, 542-546.

Simon, N.S.C., Carlson, R.W., Pearson, D.G., Davies, G.R., 2007. The origin and evolution of the Kaapvaal cratonic lithospheric mantle. J. Petrol. 48, 589-625.

Wartho, J.-A., Kelley, S.P., 2003. ^{40}Ar/^{39}Ar ages in mantle xenolith phlogopites: determining the ages of multiple lithospheric mantle events and diatreme ascent rates in southern Africa and Malaita, Solomon Islands. In: Vance, D., Müller, W., Villa, I., (Eds.), Geochronology: Linking the isotope record with petrology and textures. Geol. Soc., London, Spec. Publ. 220, 231-248.