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Eclogite xenoliths from Kimberley, South Africa — A case study of mantle metasomatism in eclogites

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ABSTRACT

Eclogite xenoliths from the Kimberley diamond mine dumps were studied for major, trace elements and oxygen isotopes. The suite consists of typical garnet and clinopyroxene rocks as well as kyanite-eclogites and olivine- or orthopyroxene-bearing samples. All samples have Al[6]/Al[4] ratios >2 which indicate high equilibration pressures, i.e. in the eclogite stability field as opposed to pyroxenites. Most samples are modally and cryptically metasomatized and contain up to 10 vol.% phlogopite plus ilmenite and rutile. Trace element geochemical characteristics of phlogopite and Ti-oxides are similar to those described for metasomatized peridotite xenoliths from the Kaapvaal craton, and show that the eclogite xenoliths experienced the same metasomatic event. Oxygen isotopic values of the phlogopites plot with those for pristine mantle, and are taken as evidence that the metasomatic agent did not have an exotic oxygen isotopic composition. In contrast, the eclogitic garnets are significantly lighter in oxygen isotopes than pristine mantle. These values cannot have been caused by the metasomatism that produced phlogopite, but are a preserved feature of the eclogite protoliths. The occurrence of kyanite is a strong indication for a low pressure origin of the protoliths, This, together with low oxygen isotopic values, a range of Mg-numbers of 59.5 to 88.8 and overall high trace element abundances compared to other eclogite xenolith suites, is taken as evidence that the protoliths of the Kimberley eclogites were seawater-altered oceanic cumulates which were metamorphosed in eclogite facies conditions and later overprinted by a mantle-derived metasomatic event.

1. Introduction

The Kimberley area in South Africa is known as the "type-locality" of mantle metasomatism (Dawson, 1984; Menzies and Hawkesworth, 1987). Here, fluid/melt metasomatism emanating from melts in veins in the lithosphere produced metasomatized peridotites and harzburgites in exceptionally high abundance which contain mineral parageneses that span a compositional range from almost pure metasomatic vein assemblages (e.g. MARID rocks, consisting of phlogopite + clinopyroxene + ilmenite/rutile ± K-richterite: Dawson and Smith, 1977) to only relatively weakly modally metasomatized wallrocks of phlogopite-bearing garnet peridotites (Erlank et al., 1987). Menzies et al. (1987) differentiated between a Fe–Ti rich, basanite-like silicate melt metasomatism and a hydrous, potassic, kimberlite-like fluid-rich metasomatism. The latter introduced highly Light Rare Earth Element (LREE) enriched signatures and, amongst other phases, low Ti-phlogopite, but lacked the high Ti signature of the former. Other authors proposed that the two styles of metasomatism may be related and suggested that the crystallising MARID dykes expelled alkali-rich fluids into the surrounding lithosphere, which metasomatized the enclosing peridotite wallrocks (Dawson and Smith, 1977; Jones et al., 1982; Waters et al., 1989). Radiogenic age information on the MARID assemblage as well as on the metasomatized peridotites shows that both styles of metasomatism occurred within the last 200 Ma (Kramers et al., 1983; Hawkesworth et al., 1990; Konzett et al., 1998, 2000) and, thus, could be related to the eruption of Group I and Group II kimberlites (Kinny and Dawson, 1992; Hamilton et al., 1998). This suggestion is supported by the overall kimberlitic–lamproitic chemistry of the metasomatic paragenesis. Compared to kimberlites, however, the MARID-metasomatism lacks the typical large quantities of CO_2 and the mineral chemistry of MARID phlogopites is more similar to lamproitic phlogopites crystallized under reducing conditions (Waters, 1987; Foley, 1989). Lamproitic melts may originate as the first melts caused by erosion of the lowermost cratonic lithosphere under the influence of a passing plume (Foley, 2008). While the metasomatic effects on the peridotitic suite of xenoliths are well studied, the effect on the less common eclogite xenoliths at this locality and the Kaapvaal craton in general is less well known. Eclogite xenoliths are rare, but integral parts of the cratonic lithosphere (Jacob et al., 1994; Jacob, 2004; Liu et

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al., 2009-this volume). They were incorporated upon stabilization of the Kaapvaal craton during the late Archaean (e.g. Coggon et al., 2009) and as such experienced most of the erosional and metasomatic events that affected the cratonic root. They can provide readily available sources of melts within the lithosphere due to their mostly lower solidi compared to peridotites (Irving, 1974) which can be lowered further by the introduction of hydrous metasomatic phases. Here, we describe the metasomatic effects on eclogite xenoliths from the Kimberley area, South Africa, to compare and evaluate their effects on a non-peridotitic paragenesis and assess the possibilities to see through it in order to ascertain the origin of this suite of eclogites.

2. Analytical methods

Major element concentrations were determined with a JEOL JXA 8900 RL microprobe at the Johannes Gutenberg-Universität Mainz, Germany using wavelength dispersive analysis and a range of natural and synthetic standards. The data were corrected using the CITZAF procedure (Armstrong, 1995). Detection limits were generally between 0.01 and 0.07 wt.% except for fluorine in phlogopite (0.17 wt.%). The operating accelerating voltage was 15 kV with a beam current of 20 nA for mica measurements and 20 kV and 12 nA for all other phases, the beam size was 2 µm. Trace elements in garnets, clinopyroxenes, phlogopites, olivine, orthopyroxene, kyanite and ilmenites were analysed *in situ* by Laser Ablation ICP-MS with an Agilent 7500ce quadrupol ICP-MS coupled with a New Wave Research UP213 Laser (213nm) at the Department of Geosciences, Johannes Gutenberg-Universität Mainz, Germany following methods described in Jacob (2006). Ablation was carried out at 6.6 J/cm^2 and 10 Hz, using He as carrier gas. All measurements were performed on polished thin sections using a spot size of 100 µm. The commercial software GLITTER 4.0 (Macquarie University) was used for data reduction with NIST SRM 612 (Jochum and Nehring, 2006) as the external standard and ^{43}Ca as the internal standard using values for CaO from the electron microprobe analyses for cpx and garnet, ^{29}Si (determined as SiO_2) for phlogopites, opx and olivine, and ^{47}Ti determined as TiO_2 for the rutiles and ilmenites. USGS BCR2-G was analysed as a secondary standard and values are given in Table 1c. Oxygen isotopic ratios were measured at Royal Holloway, University of London (RHUL), using a Laser Fluorination Prep system with a Synrad CO_2 Laser and BrF_5 reagent on line to a GV Instrument Optima dual inlet IRMS, described in Mattey (1997). Optically clean mineral separates were prepared for analysis, with sample weights for each analysis around 1.7 mg. The grains were rinsed with water and ethanol, but no acid leaching was applied. Values are reported relative to V-SMOW. Two working standards, an olivine SC OLII at +5.23‰ and a garnet G JAG at +5.42‰, and the international biotite NBS 30 at +5.06‰ were measured during the sample analytical run. Overall precision on standards and samples is better than ±0.1‰.

3. Petrography, major element chemistry and oxygen isotopic results

Twenty-one xenolith samples (eighteen thin sections and three xenoliths), collected over several years on the Boshof Road Dump and the Yacht Club Dump (also known as Bultfontein Floors) in Kimberley, South Africa were investigated in this study. Mantle material from these Diamond Mine dumps is thought to be derived mainly from the Bultfontein kimberlite. All samples consist of garnet and omphacite, and sometimes sulphides, rutile, ilmenite or magnetite are observed. One sample additionally contains 10 vol.% kyanite, one has 10 vol.% olivine (Fo_{89}) and two are orthopyroxene-bearing (supplementary Table S1). Most, but not all samples contain up to 10 vol.% phlogopite which occurs pervasively throughout the rocks in large brown books (up to ca. 500 µm). Some of the grains are euhedral and appear to be in textural equilibrium with the other phases (Fig. 1a), whereas others

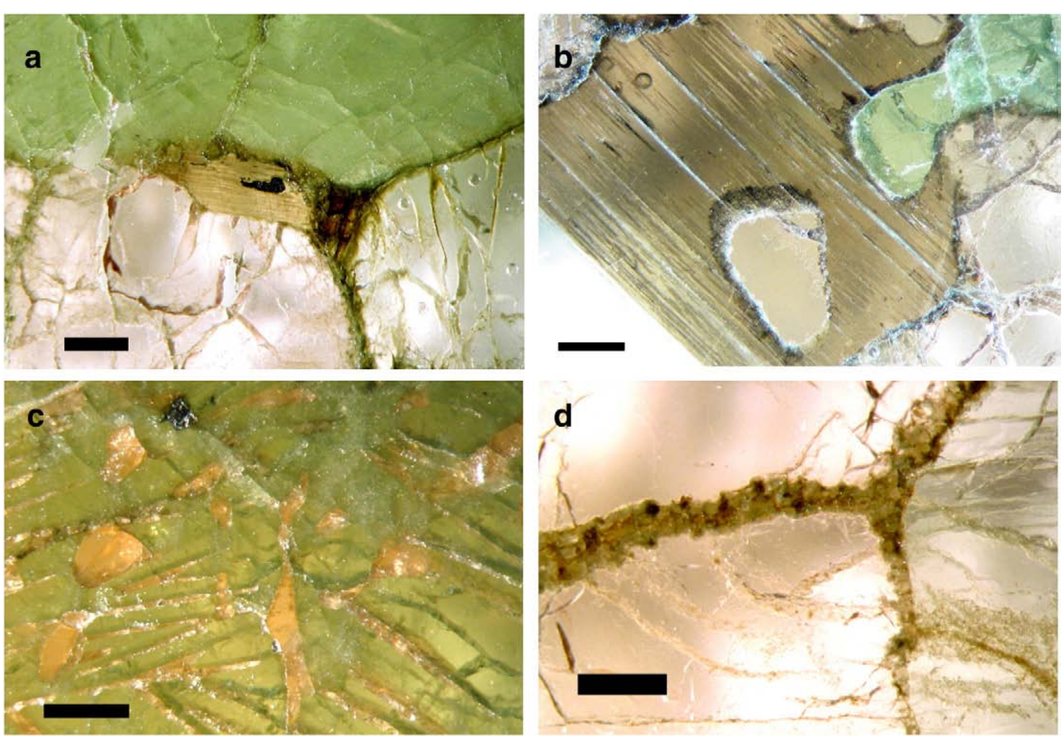

Fig. 1. Typical textures in the studied eclogite suite. Panel a shows a grain of phlogopites with an ilmenite inclusion on the grain boundaries of garnet (bottom), clinopyroxene (top) and olivine (right; sample XM1-727), panel b: phlogopite growing at the expense of garnet and cpx (sample XM1-677), panel c: garnet exsolutions in cpx in sample DJ0296, panel d: fine-grained secondary greenish mica along grain boundaries in sample KimE-1. Scale bars are 500 µm each.