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Oxidation of lithospheric mantle beneath Tanzania by melt reaction

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Introduction

The oxidation state of the mantle is a key parameter in controlling the speciation of fluids and melt and can influence the mantle solidus and resulting melt properties. The variation of mantle oygen fugacity has important influence on magma genesis, magmga degassing, mantle metasomatic processes and the production of diamonds.

The existing data shows that most of the spinel peridotites at the top of the upper mantle yield oxygen fugacity within ±2 log units relative FMQ buffer. The garnet peridotites from cratonic lithosphere reveal a general decrease in fo2 with depth, which appears to result from the effect of pressure on the controlling Fe3+/Fe2+ equilibria. This has been confirmed by a series of studies (e.g., McCammon and Kopylova, 2004; Lazarov et al., 2009; Stagno et al., 2013). On the other hand, the oxidation state of cratonic mantle is readily to be modified by fluid infiltration and melt reaction (e.g., Creighton et al., 2009; 2010). Both geophysical and geochemical evidence shows that the base of the Tazania Craton has been modified by mantle plume. To understand how the oxygen fugacity of cratonic mantle has been affected by mantle plumes, we collected some garnet and spinel peridotites from the Tanzania Craton to study their oxidation state. The peridotite xenoliths were collected from the Labait volcano, which lies on the border between the Archean Tanzanian Craton and the Neoproterozoic Mozambique Belt.

Mineral chemistry and P-T calibration

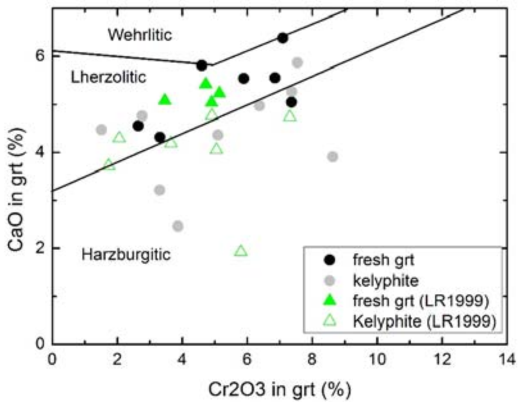

Fig. 1 CaO versus Cr_2O_3 in fresh garnet and kelyphite of peridotites from Labait, Tazania.

There are both lhzerlite and harzburgite in the collected xenolith peridotites. Many peridotites preserve the evidence of melt reaction or fluid infiltration: coarsening of clinopyroxene, reaction rims around clinopyroxene, veins with spinel or phologpite, small patches enriched in clinopyroxene, phologpite and/or rutile. Among the xenoliths, seven contain fresh garnet and another four contain kelyphite or completedly decomposed garnet. Most of the fresh garnet grains are homogeneous in composition. Some garnet is replaced by kelyphite, fine-grained symplectic corona consists of spinel and orthopyroxene. The kelyphite rims around the fresh garnet has identical compositions with the fresh garnet except a few kelyphites have higher MgO and Cr_2O_3 but lower CaO. All the fresh garnet have high CaO contents of 4.32-6.39 and high Cr_2O_3 contents of 2.64-7.36. They mainly fall into the lherzolitic garnet area (Fig. 1) although most of the host periodite are actually harzburgite. The Mg# of fresh garnet range from 83.1 to 87.0. The Fo number of olivines from the garnet-bearing peridotites range from 89.2 to 92.0. The Mg numbers of orthopyroxene and clinopyroxene from the garnet-bearing peridotites are 89.9-92.4 and 88.5-91.4, respectively. Some olivines have rims with lower Mg# than the cores and adjacent orthopyroxene.

The six spinel-bearing peridotites have generally heterogenous spinel with Cr# ranging from 46.8 to 90.1. The orthopyroxenes in the spinel peridotites have lower CaO and Al_2O_3 than those in the garnet peridotites. The Mg numbers of orthopyroxene and clinopyroxene from the spinel peridotites are 90.8-93.3 and 90.4-93.2, respectively.The Fo number of olivines from the spinel peridotites range from 90.4 to 92.7.

The 11 garnet peridotites have equililbration temperatures of 1270-1400 ^{o}C and pressures of 4.1-5.8 GPa according to the barometer and thermometer of Brey and Kohler (1990). Most of the P-T data are similar with previous results of Lee and Rudnick (1999) except two samples with significantly higher pressure at 5.8 GPa (Fig. 2). They form an adiabatic decompossing trend. The 9 spinel peridotites gave Ca-in-opx temperatures (Brey and Kohler, 1990) of 930-1170 ^{o}C assuming a pressure of 4.5 GPa.

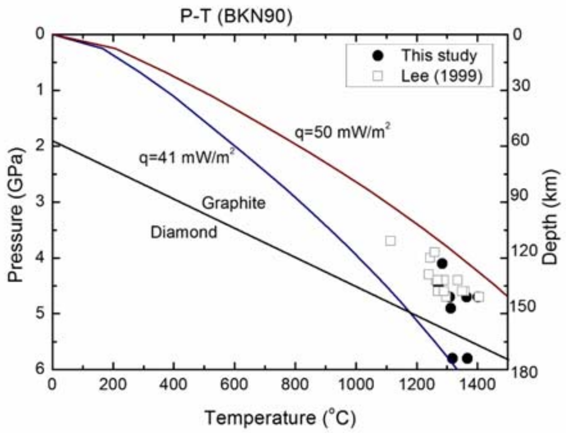

Fig. 2 Pressure and temperature estimates of Labait garnet-bearing peridotites calcualated from barometer and thermometer of Brey and Kohler (1990). The results of Lee and Rudnick (1999) are also shown for comparison.

Garnet and spinel fO_2

Nine fresh garnets (six from this study and three from Lee and Rudnick, 1999) were analyzed by Mössbauer spectroscopy, yielding Fe^{3+}/total Fe of 0.08±0.02 to 0.16±0.02. The corresponding oxygen fugacity range is -2.1±0.5 to -0.2±0.2 relative to the FMQ buffer, using the calibration of Stagno et al. (2013). Five spinels/chromites (one from this study and four from Lee and Rudnick, 1999) gave Fe^{3+}/total Fe values of 0.32±0.04 to 0.9±0.04. The fO_2s obtained from these spinels are -1.8 to -0.2 relative to the FMQ buffer according O'Neill and Wall (1987), or -0.5 to 0.4 relative to the FMQ buffer according to the calibration of Ballhaus et al. (1991). Generally, the spinel peridotites have oxygen fugacities that are consistent with those from the garnet peridotites. As shown in Fig. 3, these data show that the mantle lithosphere of the Tanzania craton is significantly more oxidized than that of the Kaapvaal craton and the Siberian craton at similar pressure (Stagno et al. 2013 and references therein). However, the Labait samples have similar oxygen fugacity to those of metasomatised xenoliths from the Slave craton (Creighton et al. 2010).

Garnet trace elements

LA-ICPMS trace element analyses on the garnets show variable REE patterns. Some are characterized by depletion in LREE, slow enrichment from MREE to HREE, which is similar to normal garnet REE patterns equilibrated with melt. Some garnets are depleted in LREE and flat from Sm to Lu. Some garnets have sinusoidal or humped sinusoidal REE patterns with humps at Nd, Sm or Eu, following by a decreasing in MREE with or without a concurv up in Yb and Lu. This can be interpreted by reaction of peridotites with melt with different compositions, or in different degrees (Stachel et al., 2004; le Roex and Class, 2016). We hypothesize that the oxidation of the Labait peridotites may result from melt reaction, where the melt is likely derived from the plume of the East African Rift. Although the cratonic mantle has not (yet) been destroyed by the mantle plume, the oxidation state of the entire lithospheric mantle beneath the Tanzania craton may have been reset by the plume-derived magmatism.

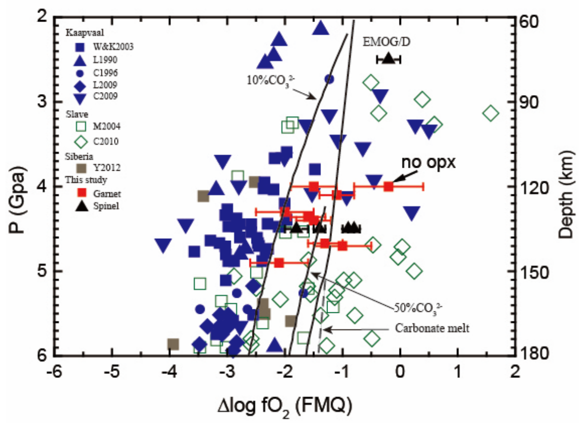

Fig. 3 Log(f_{O2}) (relative to the FMQ buffer) calculated for garnet-bearing and spinel-bearing peridotites from Labait according to the calibration of Stagno et al. (2013). The results from Kaapvaal, Slave and Siberia are shown for comparison.

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