

Carbonatite metasomatism and melting of the Arabian lithosphere: evidence from oxygen isotopes and trace element composition of spinel lherzolites

G. Chazot
M.A. Menzies
B. Harte

*Department of Geology, Royal Holloway University of London,
Egham Surrey TW20 0EX, UK.*

*Department of Geology and Geophysics, University of Edinburgh,
Grant Institute, West Mains Road, Edinburgh EH9 3JW, U.K.*

D. Matthey

*Department of Geology, Royal Holloway University of London,
Egham Surrey TW20 0EX, UK.*

Introduction

The mineralogy and chemistry of many mantle xenoliths provide evidence for fluid-peridotite interaction leading to modification of the composition of primary minerals or crystallization of new metasomatic minerals. The isotopic and chemical composition of the different peridotite minerals can be used to study the nature and composition of the fluid circulating in the mantle and the nature of the interactions between these fluids and the peridotitic matrix. We have undertaken an integrated study of mantle xenoliths from Yemen, Arabian Peninsula, in order to constrain fluid-peridotite interaction using the oxygen isotope composition as well as the major and trace element composition of the constituent minerals.

Samples

The mantle samples have been selected from two localities in the south-eastern part of Yemen. At Bir Ali, the xenoliths are anhydrous spinel lherzolites and some samples show evidence of melting of clinopyroxene (cpx) and/or spinel with formation of new spinel, cpx and glass. At Ataq, the xenoliths are amphibole-bearing spinel lherzolites or spinel lherzolites free of hydrous phases and containing occasional melt pockets, with residual spinel and cpx surrounded by silicate-glass and new olivine, cpx and spinel. In the hydrous lherzolites, the amphibole (amp) is disseminated in the peridotite and always associated with the spinel. In addition two lherzolites contain large grains of apatite disseminated in the peridotitic matrix. In all the samples, amphibole and spinel are contained in melt pockets and are surrounded by glass containing new olivine, cpx and spinel. These samples also show evidence of melting of orthopyroxene or

replacement by clinopyroxene and amphibole.

Analytical techniques

The oxygen isotopic composition of the different phases has been analyzed using the laser-fluorination technique described by Matthey and Macpherson (1993) to extract the oxygen and convert it into CO₂ gas. The isotope ratios were measured on a VG Prism mass spectrometer. The internal mass spectrometer precision on more than 150 analyses averages $\pm 0.02\%$ and the sample reproducibility averages $\pm 0.07\%$. It is important to stress that the oxygen yields obtained for all the phases reported here were always around 100%.

A suite of 21 trace elements was determined using the Camea ims-4f ionprobe at Edinburgh, with a 8 nA primary beam of O⁻. These elements were measured using secondary ions with energy filtering by an offset of 70 to 80 volts from the nominal 4.5 kV for clinopyroxene, amphibole and glass, and with an offset of 120 volts for apatite in order to reduce oxide interference from this enriched mineral. All the elements are reported relative to Si and ion yields measured in repeated analyses of NBS610 standard.

Results

The range of $\delta^{18}\text{O}$ values is very restricted for all the phases in the lherzolites and varied from 5.12 to 5.37‰ for the olivine, from 5.68 to 5.98‰ for the orthopyroxene, from 5.53 to 5.77‰ for the clinopyroxene and from 5.35 to 5.53‰ for the amphibole. The main observation from these data is the lack of any systematic differences in the oxygen isotope composition of co-existing olivine, cpx and orthopyroxene in hydrous or anhydrous lherzolites. This contrasts with previously published data where hydrous lherzolites exhibit much more variation in oxygen isotope ratio than

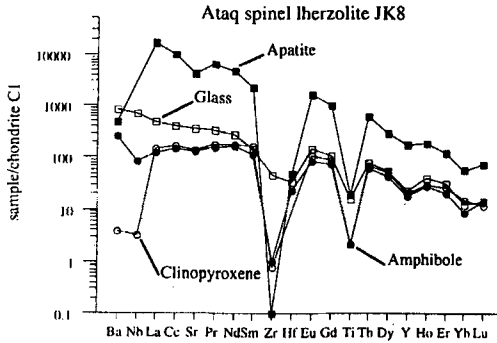


FIG. 1.

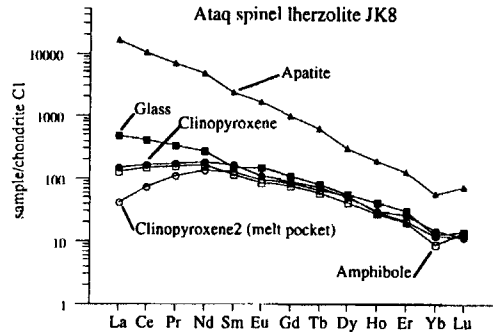


FIG. 2.

anhydrous lherzolites (Harmon *et al.*, 1986/87; Kempton *et al.*, 1988) and indicates that the metasomatic fluid from which the amphibole and the cpx were formed was in isotopic equilibrium with mantle olivine and orthopyroxene or had been buffered by mantle olivine during percolation through the peridotite.

The trace element results confirm that the different phases of the lherzolites are in chemical equilibrium. In all the amphibole-bearing lherzolites from Ataq, clinopyroxene, amphibole and apatite (when present) are in equilibrium and show the same shape of chondrite-normalized trace element patterns (Fig. 1) with important REE enrichments and large Zr, Ti, and (to a lesser extent) Hf negative anomalies. On the other hand, clinopyroxenes in anhydrous samples from Bir Ali have light-REE depleted patterns without large depletion in Zr, Hf and Ti. According to these results, clinopyroxene, amphibole and apatite seem to be cogenetic phases in the hydrous lherzolites, and were formed during reaction of orthopyroxene with a fluid largely depleted in Zr, Hf and Ti. The similarity of the trace element content of the cpx and amp (Fig. 1) implies that the $K_{d_{cpx/amp}}$ are near 1 for all the analyzed elements except for Nb, Ba and Rb during the formation of these minerals in mantle conditions. Newly formed olivine, spinel, cpx and glass have also been analyzed in the melt pockets formed by breakdown of amphibole, spinel and clinopyroxene. The new olivine is enriched in Ca and the glass in the melt pockets is Mg-poor and Al-rich, and its major element composition is directly related to the composition of the amphibole. The glass and the new cpx show no fractionation of the middle and heavy rare earth elements relative to the amphibole and the primary clinopyroxene. However, the glass is enriched in light REE (La-Nd) and the new cpx shows a complementary depletion of these elements (Fig. 2). The composition of the apatite,

primary clinopyroxene, amphibole, new clinopyroxene and glass indicates that the melting occurred in a closed system, without fluid infiltration, and was essentially isochemical.

These results indicate that some of the peridotites from Yemen have been modified initially by reaction of a fluid phase with orthopyroxene and maybe primary cpx, with subsequent crystallization of clinopyroxene, amphibole and sometimes apatite. All these minerals are in chemical equilibrium and show large Zr, Hf and Ti negative anomalies. Such chemical characteristics are not found in the associated plio-Quaternary basalts erupted at the surface and so are not directly related to volcanism in this area. This was followed by melting that occurred mainly around amphibole and spinel, with formation of glass, new cpx, olivine and spinel. The chemical composition of all the metasomatic minerals implies equilibration with a fluid depleted in Zr, Hf and Ti. This fluid has the composition of a carbonatitic melt formed in the garnet stability field, where Zr and Ti behave as compatible elements in the garnet (Sweeney *et al.*, 1992). Therefore the observed trace element patterns (Fig. 1) indicate that the initial fluid phase was a carbonate melt. Reaction of such a melt with peridotite has produced textural relationships in these natural peridotites that compare favourably with textures observed in experiments where carbonatitic melts are reacted with peridotite (Wallace and Green, 1988; Dalton and Wood, 1993). In the natural peridotites these reactions are accompanied by extreme enrichment in REE and Ba, Sr, Th, U, Pb, with important implications for the isotopic evolution of the lithospheric mantle and the contamination of basaltic magmas. Thus, the Yemen lherzolites provide petrological and chemical evidence for interaction between peridotite and a fluid of carbonatitic composition followed by isochemical melting of amphibole and spinel before or during entrainment of the xenoliths.