

SIGNIFICANCE OF PHOSPHORUS CONTENT OF OLIVINE, PYROXENE, AMPHIBOLE AND GLASS IN SPINEL LHERZOLITES FROM YEMEN

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ABSTRACT

INTRODUCTION

In rock-forming silicates, phosphorus can substitute to a small extent for silicon in SiO_4 tetrahedra. Phosphorous contents of 100 ppmw or more are not unusual in garnets, pyroxenes, feldspars, olivines or amphiboles (Koritnig, 1965). In the Earth's upper-mantle where phosphorus is believed to amount to around 200 ppmw (Watson, 1980), silicates may represent a major phosphorus reservoir (*e.g.* Thompson, 1975). The Yemen lherzolites nodules recovered in the Plio-Quaternary alkali basalts of the Ataq and Bir Ali volcanoes appear to be outstanding samples to understand the phosphorus behaviour in peridotites. Subsequently to a metasomatic event that enriched these lherzolites with incompatible elements (including phosphorus) and induced crystallisation of apatite, amphibole and clinopyroxene, incongruent melting of amphibole has occurred that produced a silicate liquid recovered as glassy pockets containing newly formed euhedral crystals: olivines, clinopyroxenes and spinels (Chazot *et al.*, 1996a). In these samples, Chazot *et al.* (1996b) have measured partition coefficients between apatite, clinopyroxene, amphibole, and melt for several elements. Their results, in good agreement with literature data, indicate that equilibrium between crystal and melt was achieved for these elements. In some samples, the phosphorus content of the glass reaches 1 wt% P_2O_5 . According to the phosphorus partition-coefficients of up to 0.05 measured by Anderson and Greenland (1969) between olivine phenocrysts and coexisting basaltic groundmass in Hawaiian basalts, we would expect P_2O_5 -contents of up to 500 ppmw for the olivines in the glassy pockets. We have therefore undertaken systematic analyses of the phosphorus content of the phases in the melt pockets using the electron microprobe (EMPB).

ANALYTICAL CONDITIONS

High beam current of 100 nA (15 kV) was chosen in order to increase the electron microprobe analysis precision (EMPB). The accuracy of the EMPB analyses was tested out on two synthetic garnet-glasses containing 100 and 500 ppmw P_2O_5 (as determined independently using a colorimetric method).

Results: Most of the microprobe analyses presented here were performed on the JK3 sample (see Chazot *et al.*, 1996a) but similar results have been obtained in other samples. The silica content of the solidified melt is comprised between 50.5 and 54.9 wt%, alumina content is closed to 23-24 wt%. The sum $\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ represents 15 wt% whereas $\text{FeO} + \text{MgO}$ only accounts for 6 wt%. The P_2O_5 content of the JK3 melt varies from 0.750 to 1.300 wt%. With a P_2O_5 -content of 1000 ppmw, euhedral olivines are

by one order of magnitude richer than those of the matrix. Orthopyroxene crystals are absent from the melt pockets and only occur in the matrix. They are characterized by a very low P_2O_5 content of around 100 ppmw or less (*i.e.* close to the EMPB detection limit). Clinopyroxenes occur in both matrix and melt pockets. Out of 25 clinopyroxene analyses in the melt pockets, we found a P_2O_5 content comprised between 140 and 600 ppmw (mean value = 440 ppmw, $1\sigma = 100$ ppmw). Matrix clinopyroxenes display P_2O_5 compositions of around 200 ppmw. Amphibole occurs within the melt pockets as a residual mineral. Phosphorus content is found to range between 350 and 730 ppmw with a mean value (out of 16 analyses) of 540 ppmw ($1\sigma = 100$ ppmw). A few EMPB analyses (10 nA, 15 kV) have also been performed on JK3 apatites. They are chlorapatites with a remarkably high REE-content ($\text{Ce}_2\text{O}_3 + \text{La}_2\text{O}_3 = 3-4$ wt% and $\text{Ce}_2\text{O}_3 > \text{La}_2\text{O}_3$) and a very high strontium-content (7-8 wt% SrO). No phosphorus was detected in the numerous tiny euhedral spinels of the melt pockets.

CONCLUSIONS

Our EMPB analyses of the melt-pocket phases indicate that a significant amount of phosphorus can be incorporated in silicates. The most striking result is the P_2O_5 content of olivine which reaches 1000 ppmw P_2O_5 . It is to be noted that olivines containing several wt% P_2O_5 (so-called phosphoran olivines) have already been described in skarns and meteorites (Agrell *et al.*, 1998 and Buseck, 1977, respectively). Using the data obtained in the melt pockets, we can calculate partition coefficients for phosphorus between minerals and basaltic melt: K_d olivine/melt = 0.10, K_d cpx/melt = 0.04.

From these results, it can be shown that, at least for the MOR basalts, and assuming a batch melting model, no phosphate mineral is required at the source to account for the phosphorus content of the basaltic melt. In any case, in the light of the present work and previous study on phosphorus incorporation in garnets (*e.g.* Thompson, 1975; Hagerty *et al.*, 1994), it can be inferred that silicates must represent a major repository for phosphorus in the Earth's upper-mantle.

REFERENCES

- Agrell S.O., Charnley N.R. and Chinner G.A., 1998. Phosphoran olivine from Pine Canyon, Piute Co., Utah. *Mineral. Mag.*, 62: 265-269.
- Anderson A.T. and Greenland L.P., 1969. Phosphorus fractionation diagram as a quantitative indicator of crystallization differentiation of basaltic liquids. *Geochim. Cosmochim. Acta*,

- 33: 493-505.
- Buseck P., 1977. Pallasite meteorites—mineralogy, petrology and geochemistry. *Geochim. Cosmochim. Acta*, 41: 711-740.
- Chazot G., Menzies, M.A. and Harte B., 1996a. Silicate glasses in spinel lherzolites from Yemen: origin and chemical composition. *Chem. Geol.*, 134: 159-179.
- Chazot G., Menzies M.A. and Harte B., 1996b. Determination of partition coeff. between apatite, clinopyroxene, amphibole, and melt in natural spinel lherzolites from Yemen: Implications for wet melting of the lithospheric mantle. *Geochim. Cosmochim. Acta*, 60: 423-437.
- Haggerty S.E., Fung A.T. and Burt D.M., 1994. Apatite, phosphorus and titanium in eclogitic garnet from the upper mantle. *Geophys. Res. Lett.*, 21: 1699-1702.
- Koritnig S., 1965. Geochemistry of phosphorus—I. The replacement of Si^{4+} by P^{5+} in rock-forming silicate minerals. *Geochim. Cosmochim. Acta*, 29: 361-371.
- Thompson R.N., 1975. Is upper mantle phosphorus contained in sodic garnet? *Earth Planet. Sci. Lett.*, 26: 417-424.
- Watson E.B., 1980. Apatite and phosphorus in the mantle source regions: an experimental study of apatite/melt equilibria at pressures to 25 kbar. *Earth Planet. Sci. Lett.*, 51: 322-335.