

THE SPINEL- TO PLAGIOCLASE-FACIES TRANSITION IN MANTLE PERIDOTITES: NATURAL AND EXPERIMENTAL CONSTRAINTS

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Plagioclase-bearing peridotites are diffuse (up to 30%) in passive continental margin and mid-ocean ridge settings and constitute an important geodynamic marker. Their origin can be related either to i) impregnation of melts produced by asthenosphere upwelling, or ii) metamorphic recrystallization *via* subsolidus tectonic exhumation of the lithospheric mantle from spinel- to plagioclase-facies conditions. The two processes can be concomitant and sometimes difficult to distinguish because detailed petrologic criteria are not yet available to properly define the metamorphic origin. Impregnation by melts is widely documented in most of plagioclase peridotites and its structural and chemical effects were widely investigated. So far, few studies have documented the spinel-plagioclase transition in mantle peridotites from both on-land and oceanic settings. Experimental data on the subsolidus spinel- to plagioclase-facies transition are scarce and they refer only to fertile mantle compositions in simplified chemical systems (CaO-MgO-Al₂O₃-SiO₂, CMAS, CMAS + NaO₂, CMAS + FeO; Presnall *et al.*, 2002). In complex chemical systems (pyrolite-type compositions), the spinel-plagioclase transition was investigated exclusively at near-solidus temperature (T = 1200-1300°C; Green & Ringwood, 1970; Green & Falloon, 1998). These studies have evidenced that the spinel-plagioclase transition is isobar and occurs at pressures between 0.8 and 1.5 GPa, but the transition behaviour at lower temperature (600-1100°C) is only defined by thermodynamic calculations. At present, no experimental data are available for compositions really representative of mantle peridotites at extensional setting (*i.e.* compositions more depleted than a pyrolite), in complex chemical system, at subsolidus conditions. Moreover, compositional variations in aluminous phases (plagioclase and spinel), at proceeding of metamorphic reaction, are completely absent.

The major aim of this study was therefore to locate the spinel to plagioclase transition as a function of the compositional variability of mantle peridotites, thus providing insights on the subsolidus exhumation of the lithospheric mantle at extensional settings. Moreover, this work was focused to define the compositional and modal variations in minerals (in particular spinel and plagioclase) in response to the spinel-plagioclase transition. The research was based on a combined methodological approach including studies on Ligurian ophiolitic peridotites (Northern Apennine, Italy) coupled to experimental investigations. In the Suvero lherzolites (External Liguride Unit, Northern Apennine), the subsolidus plagioclase-facies recrystallization is recorded by i) fine-grained granoblastic aggregates of plagioclase + olivine + pyroxenes, and ii) plagioclase + olivine intergrowths around brown Al-rich spinels. The study of ophiolitic peridotites provided major and trace element compositional variations related to facies transition and bulk-rock compositional end-members suitable for experimental investigations.

High pressure experiments were performed on peridotite compositions modelled in complex systems (*e.g.*, CMAS + NaO₂ + FeO + Cr₂O₃ + TiO₂) at P from 0.27 to 1.0 GPa and T from 900 to 1200°C, using both piston cylinder and autoclave. They were carried out on synthetic gels reproducing bulk compositions ranging from fertile lherzolite (FLZ, similar to pyrolite) to depleted lherzolite (DLZ) to harzburgite (HZ), in order to cover the compositional variability recorded by abyssal and ophiolitic peridotites. Reasonable grain size (up to 50-70 µm) and coherent element partitioning in minerals (*e.g.*

X_{Mg} in olivine and pyroxenes) support approach to equilibrium. Experimental results indicate that the spinel-plagioclase transition in the fertile lherzolite occurs between 0.8-0.9 GPa at 1100°C, and between 0.7-0.8 GPa at 1000°C, thus showing a positive dP/dT slope. In the depleted peridotite (DLZ) the transition is shifted towards lower P (about 0.1 GPa) relative to the fertile lherzolite (FLZ), indicating that the spinel-plagioclase reaction is moved at lower P as a result of increasing bulk depletion. Experimental results on harzburgite were invalidated by diffuse crystallization of amphibole. The spinel-plagioclase transition curves for the different compositions (FLZ, DLZ, HZ) were calculated using Perple_X package (Connolly, 1990; Connolly & Pettrini, 2002) in the system Cr-NCFMAS. Calculated transitions are in disagreement with the experimentally-derived transitions, indicating that thermodynamic modeling fails to predict reliably the P-T location of the spinel-plagioclase transition, because mineral solution models adopted in theoretical computations are only approximated in a complex chemical system.

In experiments, plagioclase crystallizes as thin rim around seed relicts or as small anhedral crystals associated with olivine and pyroxenes; a Cr-rich spinel is stable within the plagioclase stability field up to low pressure (~ 0.3 GPa). The spinel-plagioclase reaction is therefore continuous within the plagioclase stability field, and is accompanied by systematic compositional variations in plagioclase, spinel and pyroxenes as a function of pressure (and in minor extent temperature). Such compositional variations in minerals are consistent with those documented in the studied EL peridotites. Pyroxenes record a significant Al content (and Na in clinopyroxene) decrease at decreasing pressure across the transition and progressively within the plagioclase stability field, confirming previous thermodynamic predictions in the CMAS (Gasparik, 1984). Plagioclase records a marked An content increase within a rather narrow range of pressure, from 0.8 to 0.31 GPa. At given P-T conditions, the difference in bulk depletion (fertile FLZ vs. depleted DLZ) results in different plagioclase modal abundance, lower in the DLZ, rather than different An content in plagioclase. Therefore, the composition of plagioclase represents a potential geobarometer for the low-pressure recrystallization of mantle peridotites. In spinel X_{Cr} and TiO_2 increase at decreasing pressure up to relatively high values, similar to those documented in many impregnated plagioclase peridotites.

Mass balance calculations indicate that at decreasing P, the increase in plagioclase modal amount is coupled to increase in modal olivine and overall decrease in modal pyroxenes reflecting the continuous reaction $Al\text{-rich } sp + Al\text{-rich } px_1 = plag + ol + Al\text{-poor } px_2 + Cr\text{-rich } sp$. Highest plagioclase modal amounts are observed in experiments at the lowest pressures (~ 0.3 GPa), 8.97 and 4.89 wt.%, respectively, in the FLZ and DLZ. These values represent the maximum plagioclase abundances produced by metamorphic recrystallization in peridotite compositions, and can represent a modal constraint to discriminate the origin of plagioclase peridotites.

Experimental data on compositional variations in minerals can be used to constrain the pressure conditions at which mantle peridotites recrystallized within the plagioclase-facies stability field. Experimentally-derived covariation trends in minerals compared to compositional data from the External Liguride peridotites evidenced a multi-stage low-P recrystallization of this mantle sector, from $P > 1$ GPa to 0.8 up to 0.5 GPa.

REFERENCES

- Connolly, J.A.D. (1990): Calculation of multivariable phase diagrams: an algorithm based on generalized thermodynamics. *Am. J. Sci.*, **290**, 666-718.
- Connolly, J.A.D. & Pettrini, K. (2002): An automated strategy for calculation of phase diagram sections and retrieval of rock properties as a function of physical conditions. *J. Metam. Geol.*, **20**, 697-708.

- Gasparik, T. (1984): Two-pyroxene thermobarometry with new experimental data in the system CaO-MgO-Al₂O₃-SiO₂. *Contrib. Mineral. Petrol.*, **87**, 87-97.
- Green, D.H. & Falloon, T.J. (1998): Pyrolite: a Ringwood concept and its current expression. *In*: "The Earth's Mantle", I. Jackson, ed. Cambridge University Press, Cambridge, 311-378.
- Green, D.H. & Ringwood, A.E. (1970): Mineralogy of peridotitic compositions under upper mantle conditions. *Phys. Earth Planet. Interiors*, **3**, 359-371.
- Presnall, D.C., Gudfinnsson, G.H., Walter, M.J. (2002): Generation of mid-ocean ridge basalt at pressure from 1 to 7 GPa. *Geochim. Cosmochim. Acta*, **66**, 2073-2090.