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Mineral chemistry and geothermometry using relict primary minerals in the La Cocha ultramafic body: A slice of the upper mantle in the Sierra Chica of Córdoba, Sierras Pampeanas, Argentina

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ABSTRACT

The La Cocha ultramafic body, in the Sierra Chica of Córdoba (Sierras Pampeanas, Argentina), is formed by serpentinized spinel harzburgites, with lenses of spinel pyroxenites and hornblendites. The associated metamorphic rocks are garnet sillimanite gneisses, intercalated with tabular bodies of pyroxene amphibolites and forsterite marbles.

Mineral chemistry of relict primary phases (olivine, orthopyroxene and spinel) from samples of the spinel harzburgites and pyroxenites was determined, and several geothermometers were applied to estimate the temperature conditions under which these rocks may have been equilibrated.

In the spinel harzburgites, the primary spinel is Al–chromite [Cr# = Cr/(Cr + Al) = 0.48–0.57], which is replaced by ferrichromite and chlinoclore by metamorphism. Orthopyroxene is enstatite (En_{92}) and olivine is classified as forsterite (Fo_{92}); this last one shows a homogeneous and constant composition along the ultramafic body. Using geothermometric calibrations of the pair olivine–spinel, the highest temperature of 1157 °C would correspond to the primary conditions of formation of the harzburgites.

The spinel pyroxenites show a mineral composition defined by orthopyroxene (En_{85}, enstatite), olivine (Fo_{86}, chrysolite), spinel (*s. s.*) and magnetite. Serpentine and clinochlore were produced by metamorphism. Spinel has high concentrations in Al and very low in Cr, and is classified as spinel *sensu stricto*; magnetite replacement was produced by metamorphism. Orthopyroxene and olivine are depleted in MgO regarding these minerals in the harzburgites. Temperatures of 785–734 °C calculated using geothermometers with orthopyroxene are interpreted to be produced by metamorphism in amphibolite to granulite facies conditions.

Cumular textures were not observed in outcrops and thin sections of the studied rocks. The narrow composicional range and high forsterite content in olivine, the high Cr# in spinel, and the low concentrations of Ni and Cr in whole rock analyses indicate a mantle residual origin for these peridotites, which would exclude a cumular origin.

The association of peridotites with mafic bodies formed in an N-type MORB environment and a relict mantle fabric showed by the elongated crystals/aggregates of olivine (preserved in pseudomorphic replacements), indicating a high temperature flow, allow to interpret the La Cocha ultramafic body as a slice of oceanic mantle, belonging to basal tectonites of an ophiolite complex. This body shows similar petrological, geochemical and structural features than the other ultramafic bodies in the Sierras de Córdoba, therefore the origin proposed here could be applied to the other bodies.

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RESUMEN

El cuerpo ultramáfico de La Cocha, en la Sierra Chica de Córdoba (Sierras Pampeanas, Argentina), está formado por harzburgitas espinélicas serpentinizadas, con lentes de piroxenitas espinélicas y hornblenditas. Las rocas metamórficas asociadas son gneises granatíferos sillimaníticos, intercalados con cuerpos tabulares de anfibolitas piroxénicas y mármoles forsteríticos.

Se realizaron los primeros análisis de química mineral de muestras de las harzburgitas espinélicas, que contienen las fases primarias de las peridotitas (olivino, ortopiroxeno y espinelo), y de las piroxenitas espinélicas, y se aplicaron varios geotermómetros para estimar las condiciones de formación.

En las harzburgitas espinélicas, el espinelo primario es una cromita rica en Al [#Cr = Cr/(Cr + Al) = 0.48 − 0.57], que por metamorfismo es reemplazado por ferricromita y clinocloro. El ortopiroxeno es enstatita (En_{92}) y el olivino se clasifica como forsterita (Fo_{92}), este último con una composición homogénea y constante a lo largo del cuerpo. Usando el par olivino–espinelo como geotermómetro, la temperatura más alta calculada de 1157 °C correspondería a las condiciones primarias de formación de las harzburgitas.

Las piroxenitas espinélicas poseen una composición mineral definida por ortopiroxeno (En_{85}, enstatita), olivino (Fo_{86}, crisolita), espinelo (*s. s.*) y magnetita. Serpentina y clinocloro son producto del metamorfismo. El espinelo tiene concentraciones altas de Al y muy bajas de Cr, y se clasifica como espinelo *sensu stricto*; reemplazos por magnetita son producto del metamorfismo. El ortopiroxeno y el olivino están empobrecidos en MgO en relación con las harzburgitas. Temperaturas de 785–734 °C calculadas usando geotermómetros con ortopiroxeno son interpretadas como producto de metamorfismo en condiciones de facies de anfibolitas a granulitas.

No se observaron texturas cumulares en los afloramientos y secciones delgadas de las rocas estudiadas. El estrecho rango composicional y la elevada concentración en forsterita que posee el olivino, el alto #Cr del espinelo, y las bajas concentraciones de Ni y Cr en los análisis químicos de roca total serían indicadores de un origen residual del manto para las peridotitas, que descartarían un origen cumular para estas rocas.

La asociación de las peridotitas con cuerpos máficos formados en un ambiente tipo N-MORB y la fábrica mantélica relíctica de los cristales/agregados de olivino (preservada en los reemplazos pseudomórficos), indicando un flujo de alta temperatura, permiten interpretar al cuerpo ultramafico La Cocha como una escama de manto oceánico, correspondiente a tectonitas basales de un complejo ofiolítico. Dado que este cuerpo posee similares características petrológicas, geoquímicas y estructurales que los otros cuerpos ultramáficos de las Sierras de Córdoba, el origen propuesto aquí podría aplicarse a los otros cuerpos.

1. Introduction

Mineral chemistry of ultramafic rocks can provide useful information about the environment in which these rocks could be originated. In spite of the high degree of serpentinization and deformation, both by mantle flow and by orogenic processes, the compositions of the relict primary minerals in the peridotites, mainly spinel and olivine, are still preserved and provide important information about the physical conditions of its origin and in some cases of the tectonic environment (Dick and Bullen, 1984; Arai, 1994a; Roeder, 1994; Barnes and Roeder, 2001; Kamenetsky et al., 2001; Metzger et al., 2002; Coish and Gardner, 2004; Ahmed et al., 2005). Temperature conditions under which these rocks may have been equilibrated can be established by means of the application of a classic geothermometry, but they often lack pressure index minerals.

Mineral chemistry of spinel is particularly important: it is the most reliable petrogenetic indicator (Irvine, 1965, 1967) because in most cases it survives metamorphism, which allows to preserve the primary conditions. Mineral chemistry is sensitive to whole rock composition, mineral association, and conditions of pressure, temperature and oxygen fugacity (Irvine, 1965).

In upper mantle peridotites, the composition of spinel, mainly the Cr-number [Cr# = Cr/(Cr + Al)], can indicate the degree of partial melting and has been used as a guide to classify the peridotites in terms of tectonic environments (Dick and Bullen, 1984; Arai, 1994a). The degree of partial melting, including second-stage melting (Duncan and Green, 1980), enhances the Cr# of spinel in the peridotite restite (Dick and Bullen, 1984; Arai, 1994a). The melting style of the upper mantle is possibly different from a tectonic setting to another, with different degrees of melting in peridotites from arcs, plumes and mid-ocean ridges (Dick and Bullen, 1984; Arai, 1994a). Depleted peridotite with high Cr# (>0.7) in spinel can be produced either at the mantle wedge beneath arcs or at the plume-related within-plate mantle (Pearce et al., 1984; Arai, 1994b; Ishiwatari et al., 2003). The TiO_2 content of spinel varies depending on the tectonic place of generation: it is the lowest for the arc magmas, intermediate for MORB and the highest for intraplate magmas (Arai, 1992). For these properties, Cr, Fe and Ti are the main elements in the mineral chemistry of spinel that are used in the tectonic discrimination diagrams for peridotites.

Subsolidus equilibration during metamorphic or hydrothermal processes can significantly modify the primary composition of spinel (Abzalov, 1998; Mellini et al., 2005; Gervilla et al., 2012); therefore, the use of their chemical composition as a petrogenetic and geotectonic indicator needs a careful petrographic study.

The ultramafic rocks of the La Cocha body in the Sierra Chica of Córdoba (Sierras Pampeanas, Argentina) preserve relics of the original mineral assemblage, mainly spinel, olivine and orthopyroxene. These rocks has been studied in their petrological and whole rock geochemical features (Pugliese, 1995; Escayola et al., 1996; Pugliese and Villar, 2001, 2002, 2004; Anzil and Martino, 2009b), however the results reported here are the first studies of mineral chemistry and geothermometry using relict primary minerals carried out in these rocks.

The objectives of this contribution are the following ones: (a) to characterize the mineral chemistry of the La Cocha ultramafic rocks