

## Pre- and post-accretionary carbonates in the Renazzo CR chondrite

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Although Renazzo and other CR chondrites have experienced extensive aqueous alteration [1], these meteorites also contain primitive organic matter [2]. We describe a reaction front boundary between pristine and aqueously altered matrix in a focused ion beam (FIB) extracted section by transmission electron microscopy (TEM) and synchrotron-based X-ray absorption near-edge structure spectroscopy (XANES). The altered portion of the section contains phyllosilicates, Fe-depleted pentlandite, and abundant elongated polycrystalline sulfide “slivers”, while the pristine portion of the section contains well-rounded, discrete sulfides with no phyllosilicates. Organic matter and Ca-rich carbonates [3] are present throughout the section.

Combining Ca- and C-XANES with electron diffraction in the TEM, the carbonates are tentatively identified as aragonite (CaCO<sub>3</sub>) and whewellite (CaC<sub>2</sub>O<sub>2</sub>·H<sub>2</sub>O), which are difficult to distinguish based solely on composition. Ca-XANES is sensitive to changes in coordination (6-fold in calcite, 7-fold in whewellite, and 9-fold in aragonite). Whewellite spectra also include contributions from nearest-neighbor interactions with structural water.

Whewellite in the altered portion of the section is associated with organic matter and Fe-oxide, suggesting hydrous oxidation of organic matter and sulfide generation by parent body fluids. Carbonate in the pristine portion of the section, with no apparent interactions with surrounding matrix, may have formed by preaccretionary oxidation of primitive organic matter. Organic matter in the aqueously altered portion of the section appears to contain more oxidized moieties and less aromatic moieties than that in the pristine portion.

[1] Weisberg *et al.* (1993) *GCA* **57**, 1567-1586. [2] Busemann *et al.* (2006) *Science* **312**, 727-730. [3] Fredriksson *et al.* (1981) *Meteoritics* **16**, 316.

## Geochemistry of mantle olivine and application to geothermometry

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Trace element compositions of olivines from 72 mantle rocks (xenoliths from kimberlites and basalts, orogenic peridotites) were analyzed to study systematic variations between mantle lithologies and rock compositions, partitioning mechanisms, and potential for geothermobarometry. Forsterite contents of the olivines fall between 89 and 93, whereas equilibrium *P* and *T* range from 800 to 1500°C and 15 to 75 kbar.

Trace elements in olivine can be divided into three groups. *Group I elements* (Ni, Mn, Co, Cu, Zn, Li) show a narrow range of concentrations and correlate with Fo content. Olivine is the major host for these elements. Except for Li, these are divalent elements with ionic radii close to that of Mg. *Group II elements* (Cr, Al, V, Sc, Ca, Na) show a large range of concentrations, mainly controlled by the equilibration temperature of the rock. They are strongly concentrated in co-existing mantle minerals (garnet, cpx, spinel) and have a narrow concentration range in the bulk rock. They fit less comfortably in the olivine lattice than Group I elements because of their charge or size. Differences between garnet and spinel-facies rocks are apparent for Al, V, and Sc. *Group III elements* (Ti, Zr, Nb, REE) show the largest range of concentrations, controlled mostly by bulk rock contents, and can thus be used to reconstruct melt depletion and metasomatic history of the host rock. They are strongly incompatible in olivine and other mantle minerals because of their charge and often size. Olivines from garnet, garnet-spinel and spinel-facies rocks can be distinguished using a Zr-Sc diagram.

Uptake of Al and Cr is charge-balanced by Na in *garnet-facies* olivine, with Al and Cr in about equal proportions, suggesting the presence of a Na(Al<sub>0.5</sub>Cr<sub>0.5</sub>)SiO<sub>4</sub> component in olivine. In *spinel-facies* olivine a large excess of Al is present, which may be explained by uptake of Al via Tschermak-style substitution.

The temperature dependence of Group II elements can be used to express simple geothermometers solely based on the concentrations of these elements in olivine. The most promising of these is Al-in-olivine for garnet peridotites:

$$T_{\text{Al-in-ol}} (K) = [12184 + 48.9P (kb)] / [14.61 - \ln Al_{\text{ol}} (ppm)]$$

which predicts *T* within 20°C, is applicable to cpx-free harzburgites, and might, for example, be used to determine formation conditions of olivine inclusions and their host diamonds.