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Constraining metasomatism in the oceanic lithosphere

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Serpentinization is the most prominent fluid-mediated alteration process in the oceanic lithosphere, but the physical and chemical conditions of this process are difficult to constrain. It is crucial to establish a framework of mineralogical markers that constrain (a) whether the reaction proceeded without substantial addition of elements from the fluid (isochemical), (b) the reaction is isovolumetric generating no internal stresses and (c) if the overall system was closed with respect to certain elements. We have examined ophiolitic metaperidotites from Norway, combining microtextural and microchemical observations to gain further insight into the complex fluid-mediated phase transformations occurring during the alteration of the oceanic lithosphere. Serpentinization can be isovolumetric, resulting in pseudomorphic mineral replacement reactions (e.g. Viti et al., 2005), or produce an observable volume increase (e.g. Shervais et al., 2005). In the case of olivine, the ideal reaction is commonly written as forsteritic olivine reacting to lizardite and brucite, i.e. $2\ Mg_2SiO_4 + 3\ H_2O \rightarrow Mg_3[Si_2O_5](OH)_4 + Mg(OH)_2$, implying a total volume increase of approximately 20%. However, if Mg was lost from the system, the reaction can also be written as $2\ Mg_2SiO_4 + 2\ H^+ + H_2O \rightarrow Mg_3[Si_2O_5](OH)_4 + Mg^{2+}$. This suggests that the solid volume is preserved and no internal stresses are generated. Therefore, the presence of brucite could be used to constrain volumetric changes during serpentinization. However, the small size and sparse distribution of brucite makes it difficult to find in serpentinized metaperidotites. Here we show that micro-Raman spectroscopy is a reliable tool to identify even nanometer-sized brucite in serpentine. In addition, we also used the electron backscatter diffraction (EBSD) technique to identify volume increase illustrated by the progressive change of olivine orientation at the tip of a crack induced by serpentinization. Furthermore, it is important to constrain the degree of system openness and the transport of elements through the fluid phase. Observations from fractures in metapyroxenite layers from the Røragen-Feragen ultramafic complex provide closer insight into the late stage alteration of the oceanic lithosphere. Detailed electron microscopy reveals that these fractures are filled with polyhedral serpentine, indicating late stage open system conditions (Andreani et al., 2007). However, microtextures and reactive transport modeling suggest that Ca from clinopyroxene dissolution in the metapyroxenite layers was instantaneously precipitated as andradite within the fracture, without major Ca transport. Hence, although the overall system can be regarded as open for water, Ca exhibits closed system behavior on the decimeter scale within the metapyroxenite layers. Our observations show that mineralogical and microtextural markers, such as characteristic phases, their spatial relationship and stress generation associated with replacement, provide an insight into the metasomatic conditions of oceanic lithosphere alteration.

References:

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