Magnetite-free, yellow lizardite serpentinization of olivine websterite, Canyon Mountain complex, N.E. Oregon

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ABSTRACT

We document an example of serpentinization of olivine and orthopyroxene that produced virtually no magnetite, but instead relatively Fe-rich yellow-colored lizardite (XFe = 0.08 to 0.17), and the native Fe-Ni-Co metals, awaruite and wairauite. Lizardite’s identity was confirmed by micro-Raman spectroscopy, although peaks are broad. Electron microprobe analyses of the lizardite yield a continuous compositional trend of formula contents suggestive of the progressive uptake of Fe3+ exclusively on M sites, where it is charge balanced by vacancies. Although these observations are unusual, this secondary mineral assemblage can be explained in terms of the likely intensive variables $T$, $f_{O_2}$, $f_{H_2}$, and $a_{SiO_2}$ attending the alteration. The absence of magnetite in serpentinization does not signify a lack of oxidation. By forming the hydrated phase-component ferri-lizardite instead of magnetite from the fayalite and ferrosilite components, the yield of hydrogen is reduced by two-thirds. The usual inverse correlation of rock density with magnetic susceptibility is unlikely to be the case in this kind of serpentinization.

Keywords: Serpentinite, ferrian lizardite, olivine-websterite, micro-Raman, hydrogen, magnetic susceptibility

INTRODUCTION

The serpentinization of olivine and orthopyroxene by low-temperature aqueous fluids normally produces serpentine that is noticeably richer in Mg (higher Mg/Fe ratio) than the primary silicates. Aside from the addition and release of volatiles and trace elements, serpentinization has been shown in most cases to be broadly isochemical (O’Hanley 1996). Consistent with the MFSHO phase diagram, mass balance then results in the precipitation of a small modal percentage of magnetite, typically as a dusting at the margins of serpentine mesh pseudomorphs after olivine.

Following up a suggestion made in Evans (2004), it was later argued (Evans 2008) that the Mg-rich nature of serpentine reflects the ambient chemical potentials of Fe and Mg components in the grain-boundary regions of a peridotite undergoing serpentinization, with the understanding that this control will weaken as the modal amounts of primary olivine and orthopyroxene decline, or when the system is infiltrated by large amounts of aqueous fluid. This is the same internal thermodynamic control that establishes the low oxygen and silica activities that the mineralogy of typical serpentinites reflects (Frost 1985; Frost and Beard 2007).

Frost and Beard (2007) pointed out instances when the product serpentine is more iron rich, in some cases with an Mg/Fe ratio comparable to that of the primary silicates. They proposed the presence of higher silica activities than elsewhere, such as might be the case in the vicinity of orthopyroxene grains, as an explanation for the higher Fe content of the serpentine.

Unlike chrysotile, whose iron content expressed as $X_{Fe}$ [=Fe/(Fe+Mg)] shows a sharp frequency maximum at 0.03 in a histogram of analyzed samples from the literature, the $X_{Fe}$ of lizardite in serpentinized mantle peridotite has a broad maximum, ranging in $X_{Fe}$ values from 0.02 to 0.08 (Fig. 1). Primary olivine and orthopyroxene in such rocks have $X_{Fe}$ ratios mostly in the range 0.08 to 0.12. In the vast majority of examples of lizardite in both mesh and bastite pseudomorphs, microanalyses (Evans 2008, Figs. 3 and 6) show that increasing total Fe apfu in the lizardite is accompanied by decreasing Si apfu (or Si+Al/2, or Si+Al/2+Cr/2). This correlation indicates that low levels of Fe2+ become augmented by increasing amounts of Fe3+ that are taken up in a ferri-Tschermaks substitution involving a cronstedtite component: (Fe3+Fe2+)(Fe5+Si)O3(OH)2. This conclusion is consistent with the Fe3+/total-Fe ratios of highly and fully serpentinized peridotites (Thayer 1966; Evans 2008, Fig. 1), most of which are in the range 0.5 to 0.95, with an average close to that of ideal magnetite (0.67), and with Mössbauer spectroscopy studies (O’Hanley and Dyar 1993; Votyakov et al. 1993). Thus, the shape of the lizardite histogram reflects the presence of both ferrous and ferric iron, and we infer that the higher $X_{Fe}$ values correspond to larger Fe3+ contents.

Whereas the cronstedtite substitution accounts for ferric iron in most high-Fe lizardites, there are also examples where the uptake of iron is accompanied by what appears to be an increase in Si apfu (or Si+Al/2). In these cases, the ratio of total T to total T+M cations rises to values well above the ideal stoichiometric