Abundant Late-Stage Andraditic Garnet in Actively Serpentinizing Mantle Rocks in Oman and its Implications for Microbial Habitability

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Abstract

Drilling by the Oman Drilling Project provided a unique opportunity to access partially-serpentinized harzburgite and dunite. These are in contact with alkaline fluids in a subsurface environment that support a microbial ecosystem. In concert with studies of the rock-hosted microbial community, we are characterizing the mineralogy and petrology of the serpentinized mantle rocks that host this ecosystem. Samples of whole-round core were collected and preserved every 10 m from 3 boreholes and split into paired subsamples for microbiology and mineral characterization. Thin sections were analyzed with a petrographic microscope to complete mineral abundance estimations and interpret textural relationships. Raman spectroscopy was conducted on the thin sections to reveal structural/compositional data about mineral phases. Powders were prepared for XRD analysis for quantitative phase identification. The main rock types are altered harzburgite and dunite, and altered veins of gabbro or pyroxenite occur at certain depths. All of the cores have experienced multiple episodes of serpentinization. The observed mineral assemblages include relict olivine, pyroxene and abundant secondary serpentine, brucite, iron sulfide and andradite-grossular garnet. The assemblages are generally expected from partial serpentinization of peridotite, but the widespread distribution of garnet was particularly surprising. Over 50% of the samples contained sufficient garnet to be detected by XRD. Optical and Raman analyses show that garnet occurs in many textural contexts, notably inside mm-scale, late-stage serpentine veins. Andradite garnet in serpentine veins similar to those found here are likely to have formed during serpentinization at temperatures below ~200°C [1,2]. Incorporating Fe3+ into the andradite component could facilitate H2 production, a potent energy source for microbial metabolisms [2]. Its high abundance may provide key insights into H2 production and habitability during late-stage serpentinization of the Oman ophiolite. [1] Ménez et al. (2018) LITHOS DOI: 10.1016/j.lithos.2018.07.022 [2] Plümper et al. (2014) Geochimica et Cosmochimica Acta 141 (454-471).

Abundant late stage andraditic garnet in actively serpentinizing mantle rocks in Oman and its implications for microbial habitability

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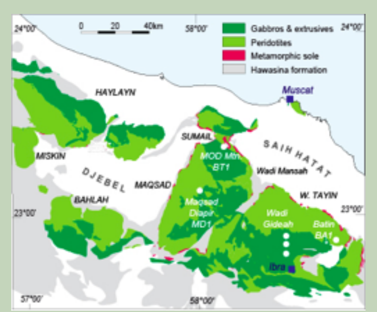
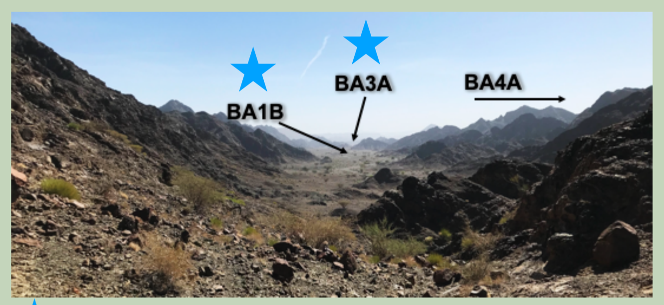
Cores from the active serpentinization site (Oman Drilling Project):

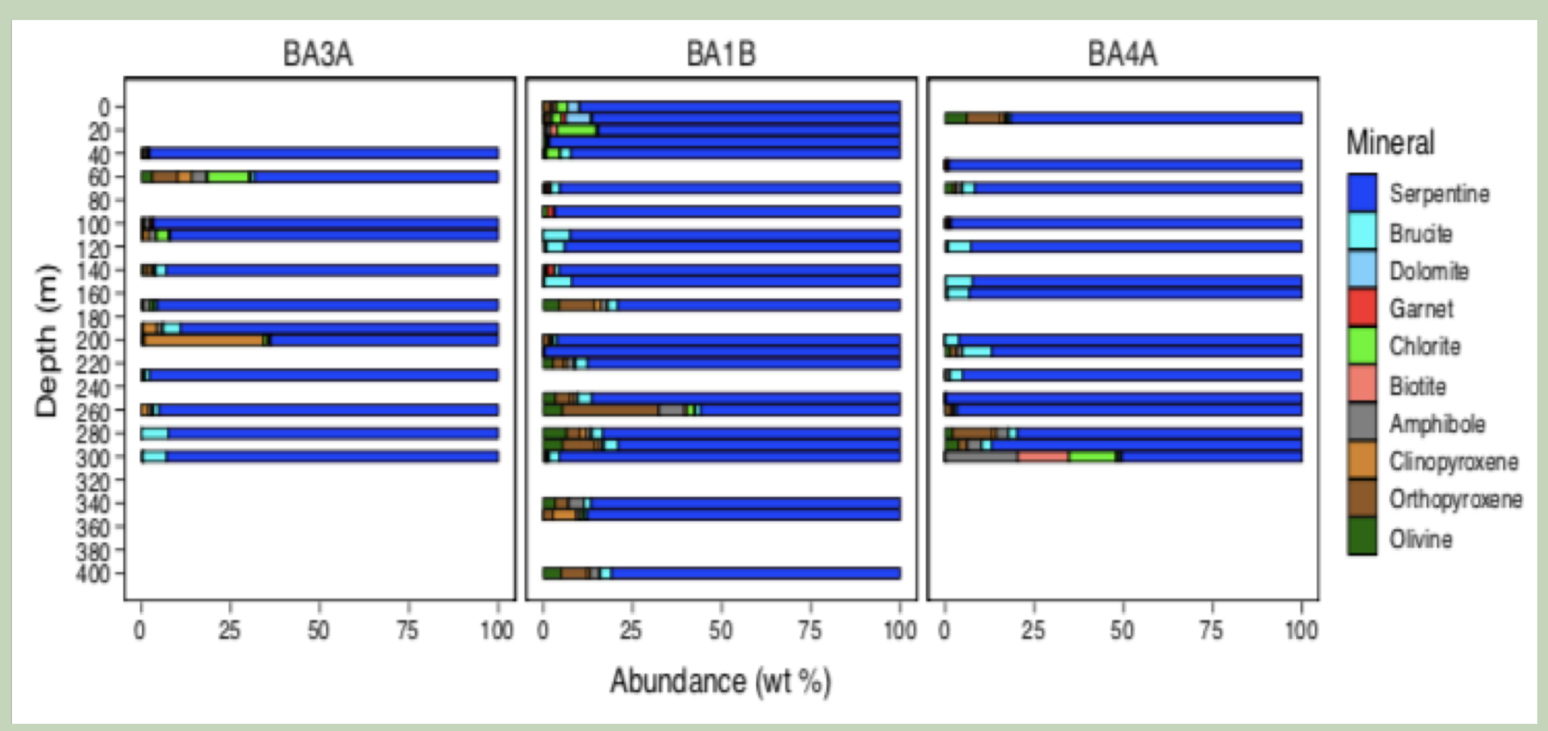
★ : The field sites of the two samples studied in depth for garnet and serpentine chemistry.

Cores from the Samail Ophiolite in Oman were collected for biological and mineralogical analysis.

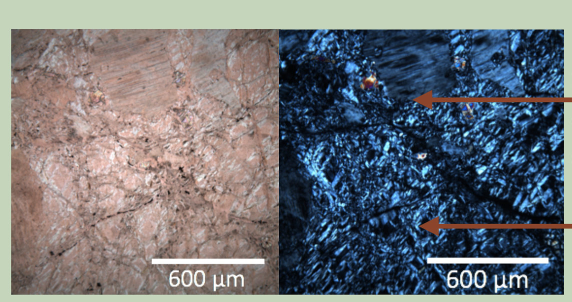
Research Goals:

- To characterize the mineralogy and petrology of the cores to understand the alteration history and **the conditions that may host life**.
- To identify signatures of **late-stage alteration at low temperatures**.

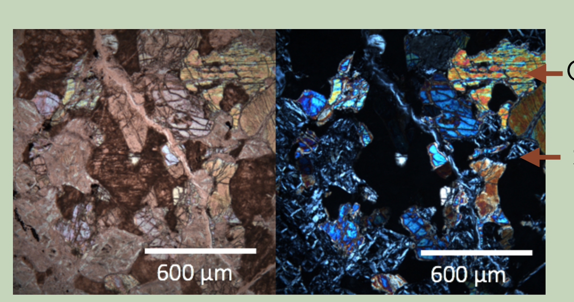
Bulk mineralogy from multiple stages of alteration:



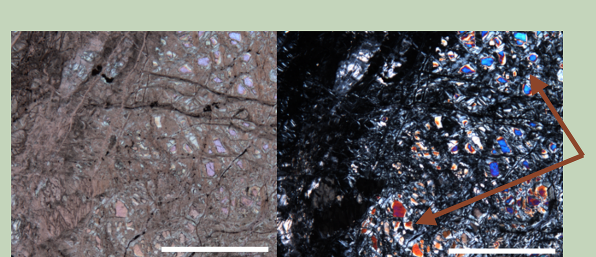
Quantitative XRD bulk mineralogy by borehole depth. [1] Mineralogy ranges greatly in content but is clearly dominated by serpentine with notably abundant brucite.



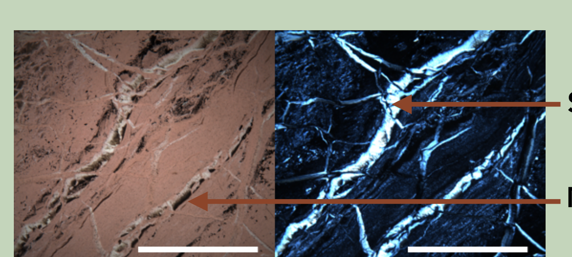
BA1B-300. Serpentine mesh texture.



BA1B-250. Metagabbro.



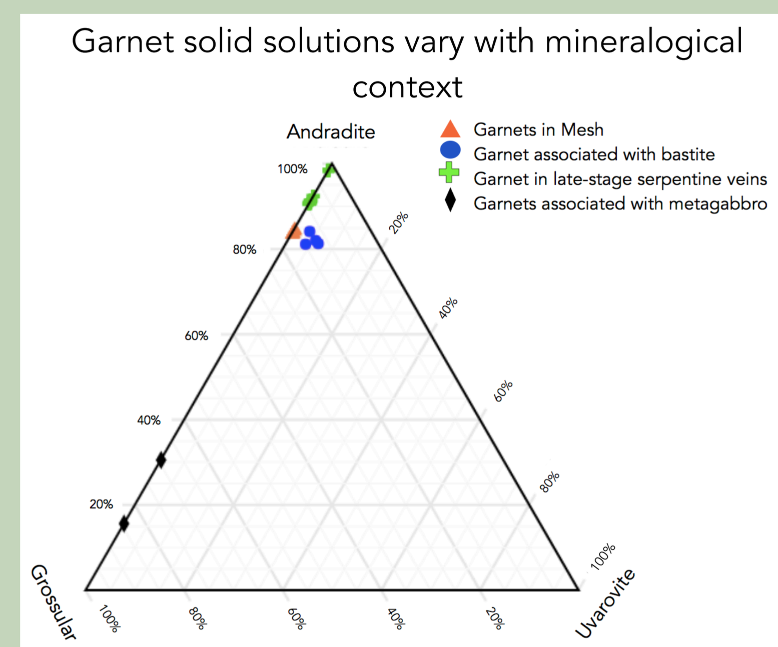
BA1B-400. Relict minerals in mesh cores.



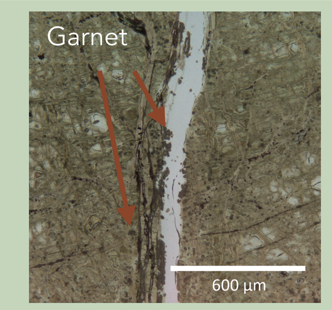
BA1B-300. Large serpentine and magnetite-filled veins.

PPL (left) and XPL (right) photomicrographs. Mineralogy not pictured includes: brucite, iron-sulfides, orthopyroxene, talc, chlorite, garnet, and spinel.

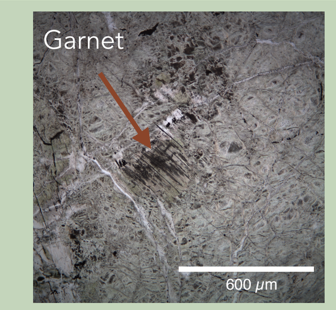
Hydrogarnets occur in several distinct contexts:



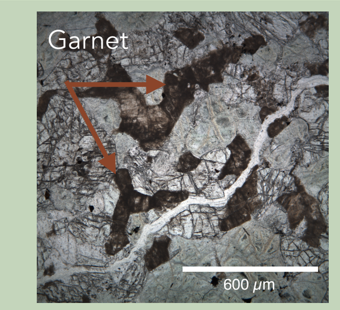
The chemistry of sampled garnets in all mineralogical contexts based on Electron Microprobe analysis data.



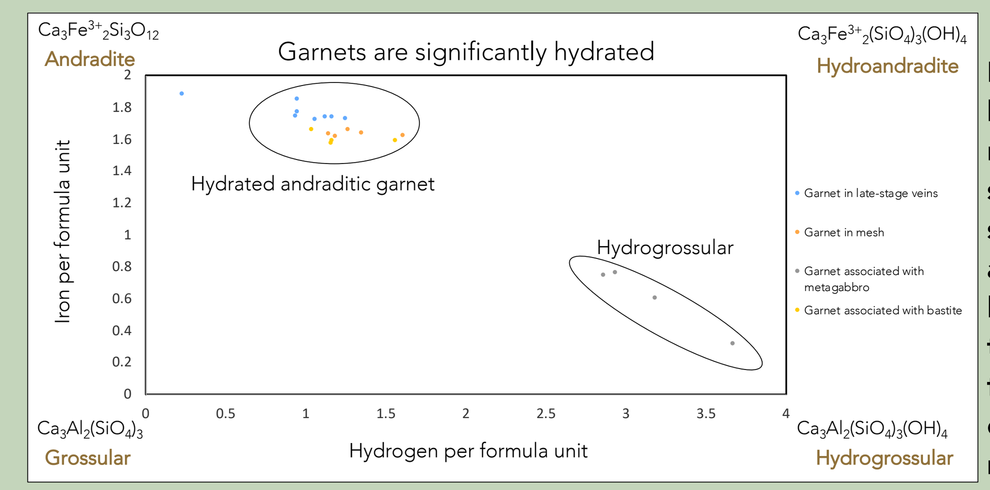
BA1B-140: PPL. Garnet in the mesh and late stage vein.



BA3A-170. PPL. Garnet associated with bastite.



BA1B-250. PPL. Garnet associated with metagabbro.

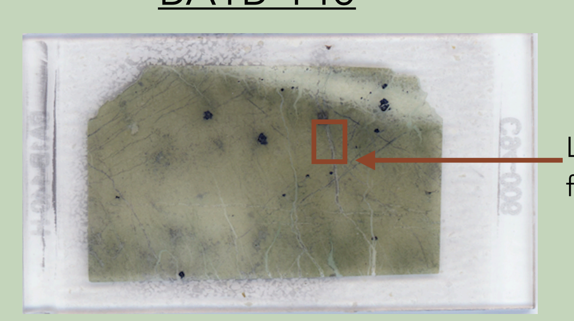


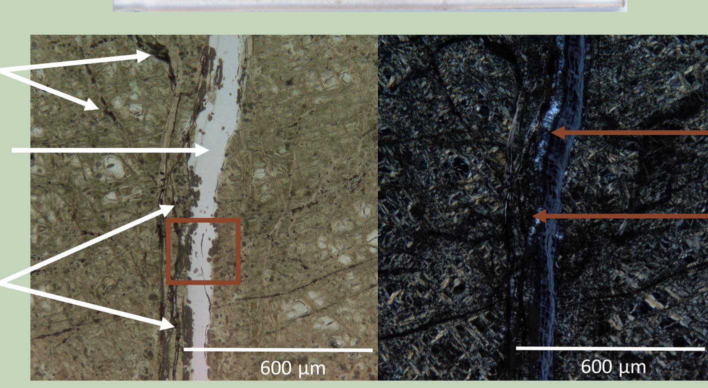
Plotted Electron Microprobe analyses with water content calculated by charge-balance.

Hydrogarnets have been reported in similar serpentine systems associated with lower temperatures of formation and carbonaceous materials. [6]

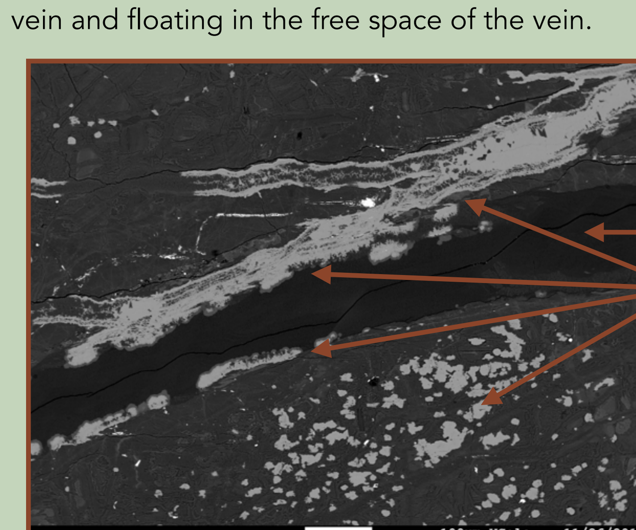
Hydroandradite in serpentine veins was produced during late-stage alteration:

BA1B-140



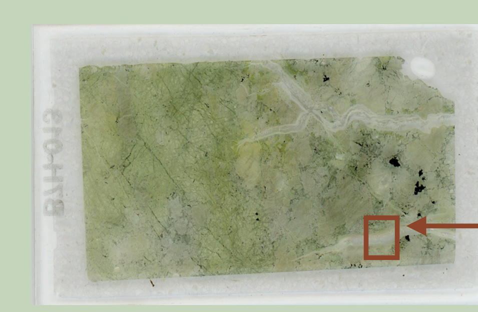


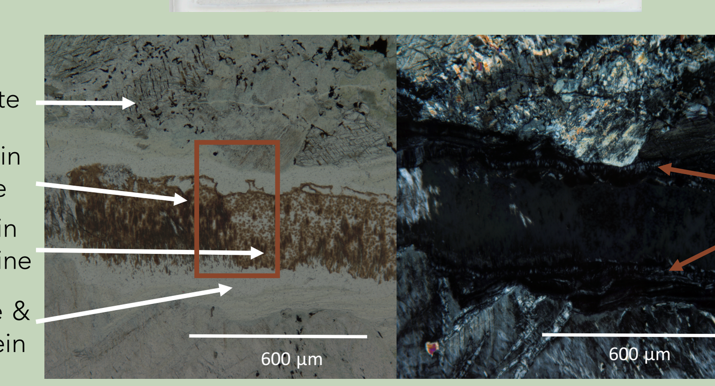
BA1B-140. PPL (left) and XPL (right) images of serpentine-garnet vein. The garnet is found both along the walls of the vein and floating in the free space of the vein.



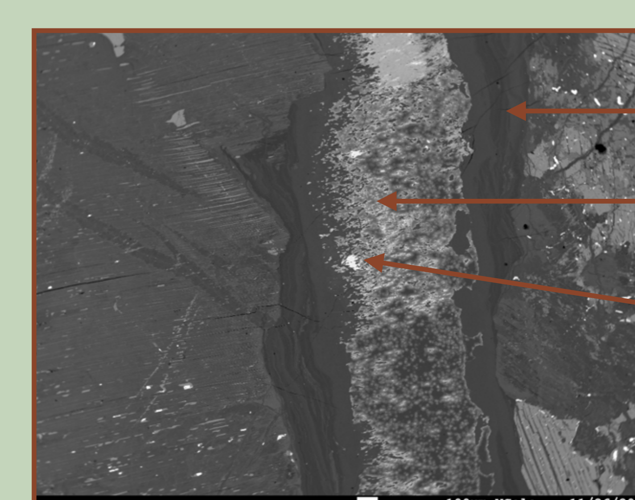
BA1B-140. Backscatter electron image from EPMA.

BA3A-60



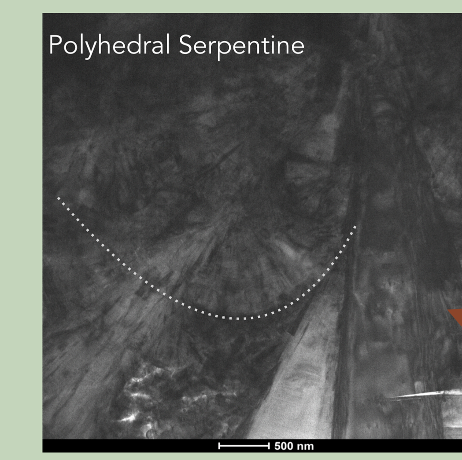


BA3A-60. PPL (left) and XPL (right) images of the serpentine/ xonolite-garnet vein. The garnet is found as both granules and as an amorphous solid.



BA3A-60. Backscatter electron image from EPMA.

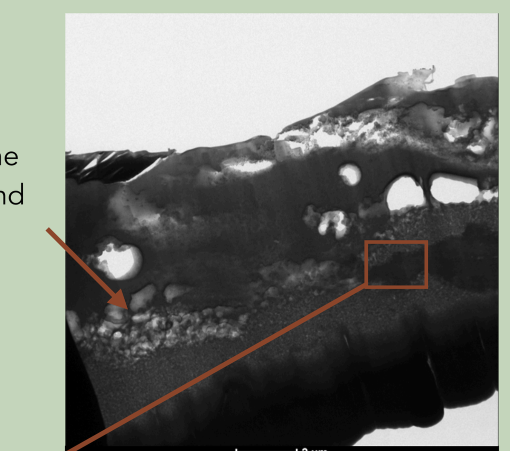
Polyhedral serpentine in contact with hydroandradite suggests a low-temperature of formation:



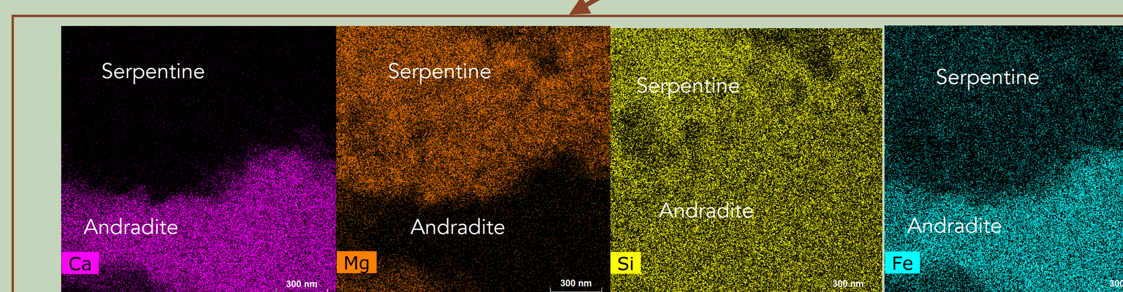
BA1B-140. TEM image polyhedral serpentine.

Onion morphology indicates late stage nucleation of a super-saturated fluid at low-temperature (below 200°C). [2]

Fine textured serpentine (possibly polyhedral) and garnet intermixed. [3]



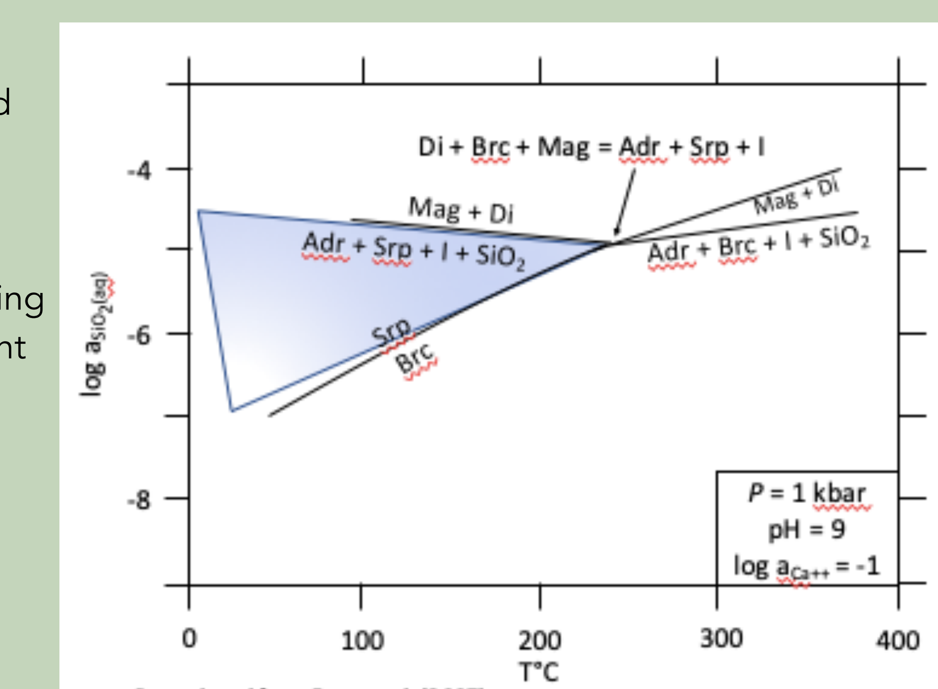
BA3A-60. Brightfield TEM image. Polyhedral serpentine is in contact with garnet and pores.



BA3A-60. On a micron scale garnet is coeval with polyhedral serpentine. Element map from STEM.

Key results and implications:

- Hydrogarnets are abundant and occur in a variety of settings.
- Hydroandradite occurs in late-stage serpentine veins suggesting they formed in a relatively recent stage of alteration.
- Polyhedral serpentine occurs in contact with late-stage hydroandradite.



Andradite-serpentine equilibrium without magnetite and diopside only occurs below ~230 °C (the field shown by the blue triangle). [5]

1. **High water content and association with polyhedral serpentine indicates that hydroandradite precipitated at low temperatures.**
2. **Hydroandradite is an important reservoir of Fe^{3+}. The incorporation of Fe^{3+} into andradite could significantly affect low-temperature hydrogen production and biological activity.**
3. **Late stage veins may contain organic carbon. Carbonaceous materials have been reported in association with hydroandradite-polyhedral serpentine assemblages [4], and should be sought in these cores.**

References: [1] Eberl, DD (2003) *USGS* DOI:10.3133/ofr200378 [2] Andreani et al. (2008) *European Journal of Mineralogy* DOI: 10.1127/0935-1221/2008/0020-1801 [3] Ménez et al.(2018) *LITHOS* DOI: 10.1016/j.lithos.2018.07.022 [4] Ménez et al. (2012) *Nature Geoscience* DOI: 10.1038/ngeo1359 [5] Frost and Beard (2007) *Journal of Petrology* DOI: 10.1093/petrology/egm021 [6] Ménez et al. (2018) *Nature Communications* DOI: 10.1038/s41467-018-07385-6

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