Laihunite, goethite, jarosite, and other phases in R chondrites NWA 6491 and NWA 6492.

Portland State University

Cascadia Meteorite Laboratory

Niina Jamsja[1], Alex Ruzicka. Cascadia Meteorite Lab, Department of Geology. Portland State University. [1] niinaj@pdx.edu

1. Background

R chondrites are among the most oxidized chondrites. They are essentially free of metal, are usually brecciated, and contain highly ferrous olivine (commonly ~Fa_{38}). Evidence of oxidation in R chondrites is shown by the presence of magnetite, Fe^{3+} bearing spinels, and Ni-rich sulfides [1-4]. Two hydrous phases, amphibole and biotite, were recently found in R chondrite LAP 04840 [5-7]. In this work we describe the presence of two other hydrous phases, goethite-hematire and laihunite-olivine intermixtures, which were found in the NWA 6491 and 6492 R chondrites. These phases likely formed by pre-terrestrial hydrous alteration in the R chondrite parent body.

2. Meteorites

NWA 6491 and 6492 are classified as R3-5 S2-4 and R3-6 S2-4, respectively, and both have a low weathering grade. They are genomict breccias that contain lithic clasts of different petrologic types that range in size from 800 µm to over 13 mm in diameter (Fig. 1). The host portions of both meteorites consist of mineral and lithic fragments of assorted sizes and petrologic types.

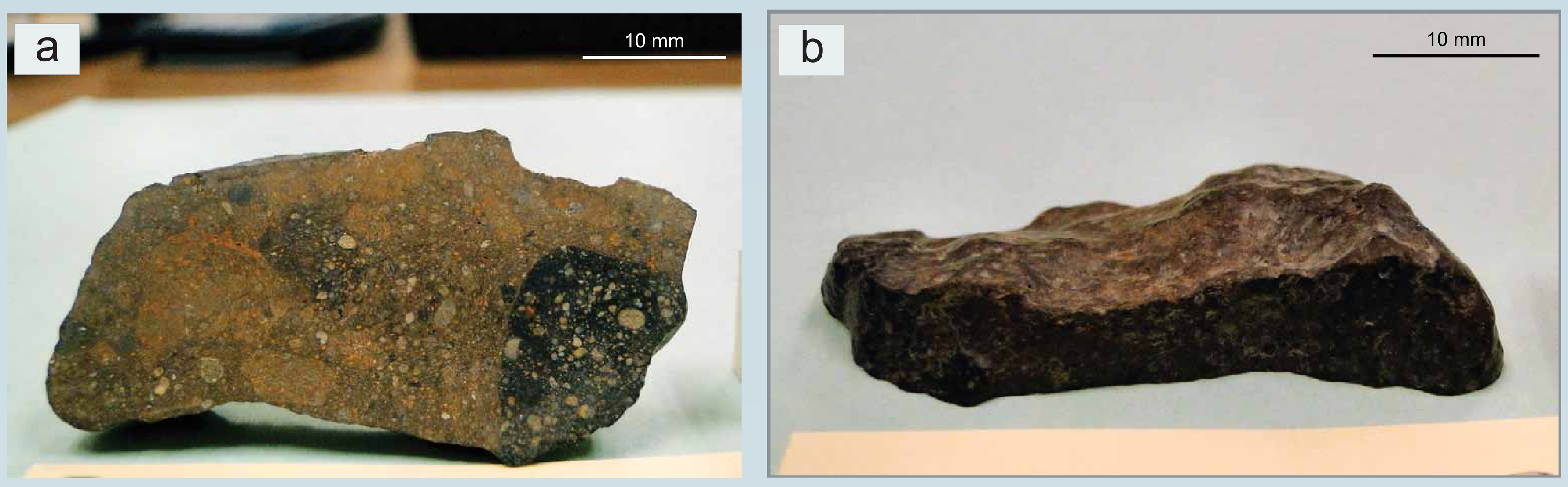

Figure 1. Hand specimens of NWA 6492 show a) dark and light lithic clasts and b) fresh fusion crust.

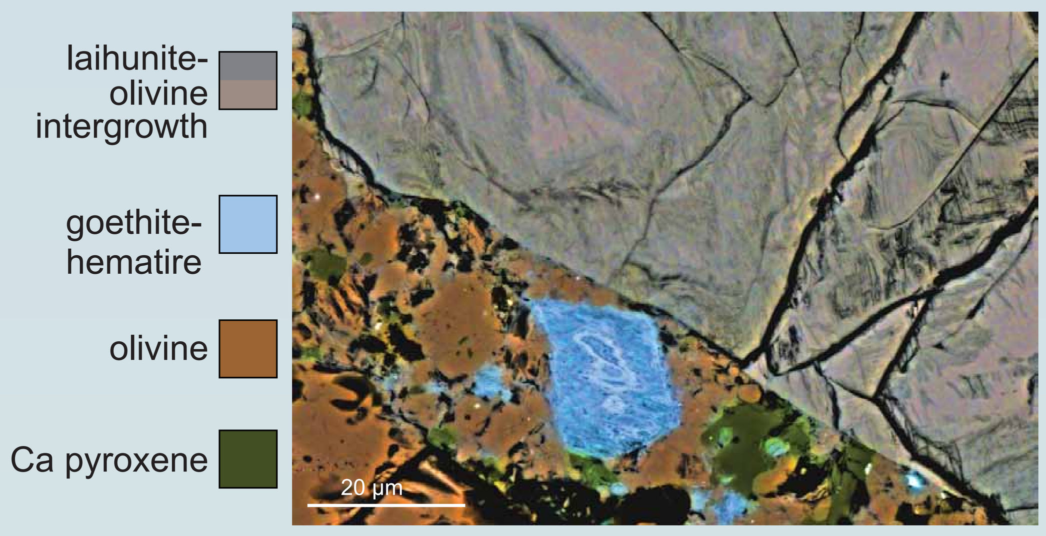

Figure 2. False-colored x-ray map shows a sharp boundary of the laihunite grain. Goethite appears in the vicinity.

3. Laihunite-olivine intermixture

Fourteen grains of laihunite-like phase were identified in both meteorites. This phase occurs strictly in the host (i.e. is not present in any of the chondritic clasts) and has grain diameters from 20 to 200 µm. Chemical analyses (SEM and EMPA) along with Raman spectroscopy data indicate that laihunite-like phase is an intermixture of laihunite and ferrous olivine (Fig. 2). Exact Fa content of olivine is not yet constrained. According to Raman data Fa content is 88, but SEM data indicates that olivine composition is Fa_{60-70}. Deficit in total wt% of the EMPA analyses (90.0% ± 1.4%) suggest that laihunite-olivine intermixture may contain hydrous component such as OH^- or water.

4. Hydrous phases

Common hydrous phases found in NWA 6491 and 6492 include an intermixture of goethite and hematite. This intermixture appears in all parts of both meteorites with no preference in location and forms interstitial to more compact masses (Fig. 3). Other hydrous assemblages have been found. With use of Raman spectroscopy we identified one atypically complex assemblage consisting of jarosite and anhydrite in the core, and goethite and hematite in a rim and in veins that cross-cut the core (Fig. 4). This suggests a complex alteration history, with Ca-sulfate minerals forming before Fe-oxide and Fe-hydroxide.

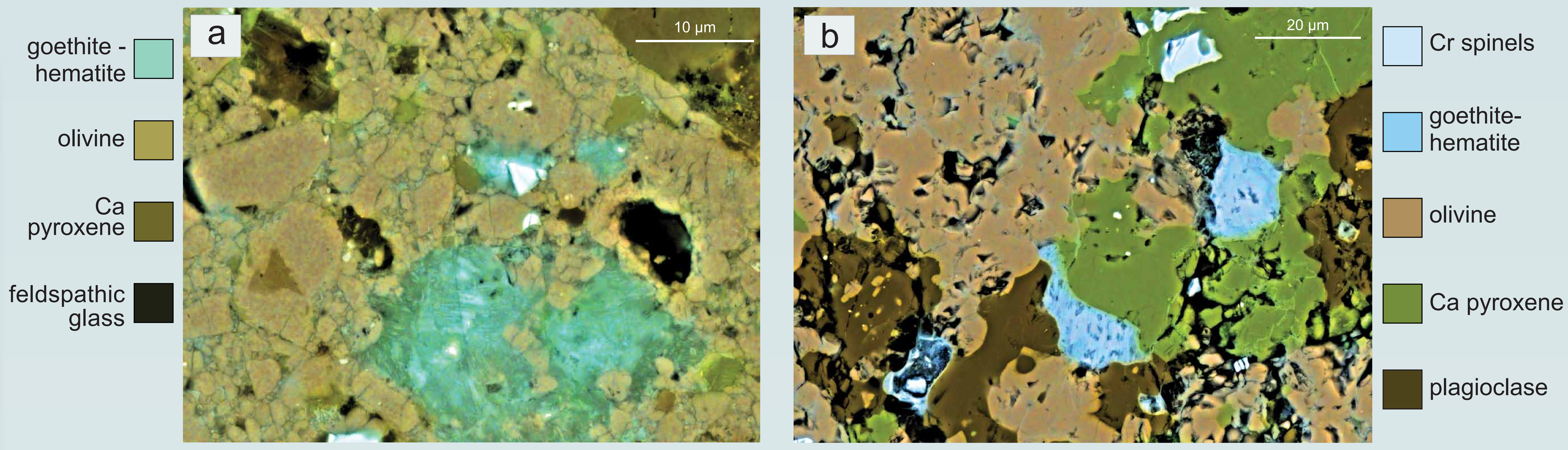

Figure 3. False-colored x-ray maps of goethite and hematite assemblages a) in type 3 clasts is interstitial to silicates, b) in type 6 clasts forming more compact masses.

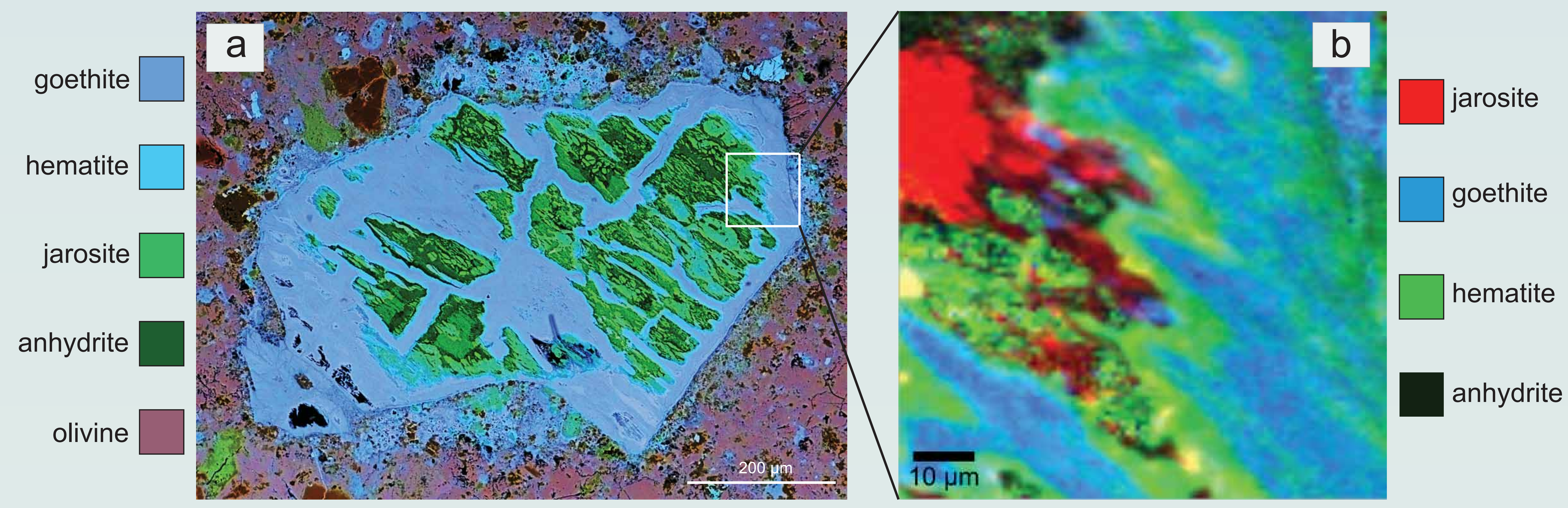

Figure 4. Complex goethite-hematite assemblage is shown a) in false-colored x-ray map, b) part of the jarosite- and anhydrite-rich core is shown in false-colored Raman phase map.

5. Conclusion

The laihunite-like phase probably formed by oxidation of ferrous olivine [8]. Intergrowth of laihunite with olivine indicates incomplete oxidation of the latter.

The goethite-hematite phase is believed to be the oxidation product of Fe-bearing minerals [9], although it is not clear which phase or phases were oxidized. Unlike the laihunite-like phase, the textures of goethite are consistent with *in situ* formation within the chondritic clasts. If clasts of different petrologic types are cogenetic, then goethite formed as an interstitial phase in weakly metamorphosed areas and was modified by thermal metamorphism in more strongly heated areas.

The presence of an atypical assemblage such as the one that contains jarosite, anhydrite, goethite, and hematite suggests a complex hydrothermal history involving an evolutionary process.

The presence of water indicates that hydrous alteration affected both NWA 6491 and 6492. Hydrous alteration was most likely pre-terrestrial as evidenced by:

- the fresh appearance of the fusion crust (Fig. 1b)
- the absence of obvious weathering veins cross-cutting the meteorite interior,
- the presence of well-defined grain edges of the laihunite-like phase (Fig. 2), and
- the textural variation of the goethite-hematite phase by petrologic type.

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