Aqueous alteration in the nakhlites Y 000802

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Mars rover Curiosity found manganese (Mn) concentrated in the sediments of the Gale crater. Mn can have six kinds of valence: +2 ~ +7. The valence of Mn depends on the pH-Eh conditions of the fluid that precipitated Mn-oxides and -hydroxides. Hence, Mn can become an important clue for clarifying ancient Martian surface conditions. However, few previous works have worked on Mn-oxides and -hydroxides in a Martian meteorite. The Yamato (Y) 000593, 749, and 802 are the members of nakhlites. Previous works reported that many kinds of alteration minerals occur in Y 000593 and 749 (e.g. [1]). In contrast, the alteration minerals in Y 000802 were not investigated so far. Accordingly, we described the alteration minerals in Y 000802, especially focused on the Mn concentrated to clarify the alteration process and condition.

Y 000802 consisted of olivine, clinopyroxene, and mesostasis. The mesostasis consisted of plagioclase, K-feldspar, tridymite, pyrrhotite, phosphate mineral, and titanomagnetite. The alteration texture named iddingsite was distinctive along with the fractures and grain-boundaries of the olivine grains. Laihunite, magnetite, opal, and jarosite occurred in the iddingsite. We found alteration minerals and Mn-concentrated portions in the mesostasis. The alteration occurred in veinlets crossing the mesostasis. Ferroan saponite (+ opal) replaced the plagioclase and K-feldspar grains with maintaining their original crystal habits. Pyrrhotite and phosphate mineral grains showed a dissolution texture. Jarosite, iron oxides, and iron hydroxides also occurred in the veinlets.

There are two different types of Mn-concentrated portions between the feldspar grains replaced with ferroan saponite (+ opal). One of them is an ultra-high-Mn-concentrated portion and the other is a high-Mn-concentrated portion. Mn-concentrated portions accompanied iron. The Mn/Fe atomic ratios of the ultra-high-Mn- and high-Mn-concentration portions are ~3 and ~1, respectively. Mn L-edge XANES spectra showed the existence of Mn^{2+}, Mn^{3+}, and Mn^{4+} in the Mn-concentrated portions. Mn^{3+} along with Mn^{2+} is dominant in the ultra-high-Mn-concentrated portions, whereas Mn^{2+} (and trace Mn^{4+}) is dominant in the high-Mn concentrated portions. The weak peak of O K-edge XANES at 534 eV and C K-edge XANES at 290 eV also appeared in the Mn-concentrated portions, implying the existence of CO_3^{2-}. Based on TEM and STXM analysis, the Mn-concentrated portions consisted of hausmannite ($Mn^{2+}Mn^{3+}{}_2O_4$), and trace amounts of manganite (γ-MnOOH), rhodochrosite ($MnCO_3$), and pyrolusite (MnO_2). The Mn-concentrated portions included trace amounts of sulfur.

We expect that high-temperature fluid (400–700 ˚C) ascending in the nakhlite body induced the alteration from olivine to laihunite (+ opal and iron oxides/hydroxides). Mn ion dissolved from olivine (and probably pyroxene) through the formation of laihunite and precipitated as hausmannite + rhodochrosite assemblage in the mesostasis. Considering the pH-Eh diagram in the C-S-O-H system, the Eh and pH of the fluid that precipitated the assemblage are ~0 and 9.5–11.5, respectively. Simultaneously, plagioclase was replaced with ferroan saponite by the fluid.

Subsequently, an acidic fluid, which is due to the dissolution of pyrrhotite, induced the alteration of the hausmannite + rhodochrosite assemblage, thus leading to form manganite and pyrolusite. SO_4^{2-} and Fe^{2+} released by the dissolution of pyrrhotite and K released from K-feldspar by the acidic fluid precipitated as jarosite. We expect that these alterations occurred mainly on Earth as a terrestrial contaminant because pyrrhotite can dissolve easily.

Reference [1] Shiraishi et al. (2018) Aqueous alteration of Yamato 000749 based on multi-probe microscopic observation. The Ninth Symposium on Polar Science, abstract.

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