Jarosite Occurrences in the MIL 03346 Nakhlite: Implications for Water on Mars

J.K. Hong and C.D.K. Herd
Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada
jkhong1@ualberta.ca

Summary

Nakhlites are basaltic martian meteorites that have been shown to contain aqueous alteration products (Treiman 2005). Among the alteration products is the mineral jarosite, which was discovered in the Miller Range (MIL) 03346 nakhlite (Herd 2006). Jarosite formation requires an acidic and oxidizing environment (Papike et al. 2006), and its occurrence in the MIL 03346 nakhlite provides an opportunity to study possible ancient martian environments and related martian near-surface processes in the lab. In this study, we have located multiple occurrences of jarosite using electron microprobe methods (X-ray mapping) in two separate MIL 03346 thin sections. These areas of alteration are on the order of 10's of microns in size and are typically found within the mesostasis and along fractures that run through augite and olivine grains.

Introduction

Aqueous alteration products are observed in a subgroup of basaltic martian meteorites known as the nakhlites. Nakhlites are clinopyroxenites that are composed mainly of cumulate augite. Other mineral phases in MIL 03346 include minor amounts of cumulate and mesostasis olivine, and titanomagnetite. The titanomagnetite occurs as skeletal grains within the glassy mesostasis. The nakhlites were formed on Mars in a relatively shallow igneous intrusion at 1.3 Ga and cooled at varying rates, with MIL 03346 cooling among the fastest (Treiman 2005). An important feature of the nakhlites is the occurrence of pre-terrestrial aqueous alteration minerals, most commonly observed as iddingsite, a mixture of smectite clay, iron oxy-hydroxides, and salt minerals (Treiman 2005). Iddingsite, which is a result of low-temperature aqueous alteration, precipitates along cracks in the cumulate grains, especially olivine, and within the mesostasis.

In 2004, the Mars Exploration Rover *Opportunity* discovered the presence of the mineral jarosite at Meridiani Planum (Klingelhöfer et al. 2004). Jarosite is a potassium-iron hydrous sulfate mineral that forms from acidic, oxidizing water (Papike et al. 2006); therefore, this discovery is strong evidence for surface water on Mars at one time in the past. Evidence for aqueous alteration by crustal waters is supported by the enrichment of deuterium in alteration products in younger martian meteorites, which is due to the preferential loss of hydrogen to space (Greenwood et al. 2007). In 2006, jarosite was discovered in the Miller Range (MIL) 03346 nakhlite (Herd 2006). This find provides a unique opportunity to study jarosite in the lab. The focus of this research is to first identify and systematically characterize the jarosite in the MIL 03346 meteorite and to constrain, as best as possible the conditions under which the mineral formed including, for example, the composition of the altering water, the water/rock ratio, and the pH.

Method

Areas of alteration in the MIL 03346 samples were found using optical microscopy, by locating areas of rust-coloured staining representing aqueous alteration within the thin section. Alteration was most noticeably found within the mesostasis or intercumulus areas, but also occurred in veins cutting through cumulate minerals, which consist of augite and isolated olivine grains.

The areas of alteration were studied in detail using a Cameca SX-100 electron microprobe. Stage scan X-ray mapping of K, S, Fe, Si, and Al was carried out in order to locate jarosite ($KFe_3(OH)_6(SO_4)_2$). Selected areas were mapped using a step size of 1 μm, a dwell time of 15 ms, and a beam source running at 20 kV and 49A.

The resulting X-ray maps were processed using the ImageJ program. To reveal areas of jarosite alteration, image operators in the ImageJ software were used on the elemental maps for K, S, and Fe (K AND S AND Fe). The resulting image isolates areas where K, S, and Fe occur together, i.e. jarosite. The processed images were overlain onto corresponding BSE images to study the setting of the jarosite in relation to the host rock.

Examples

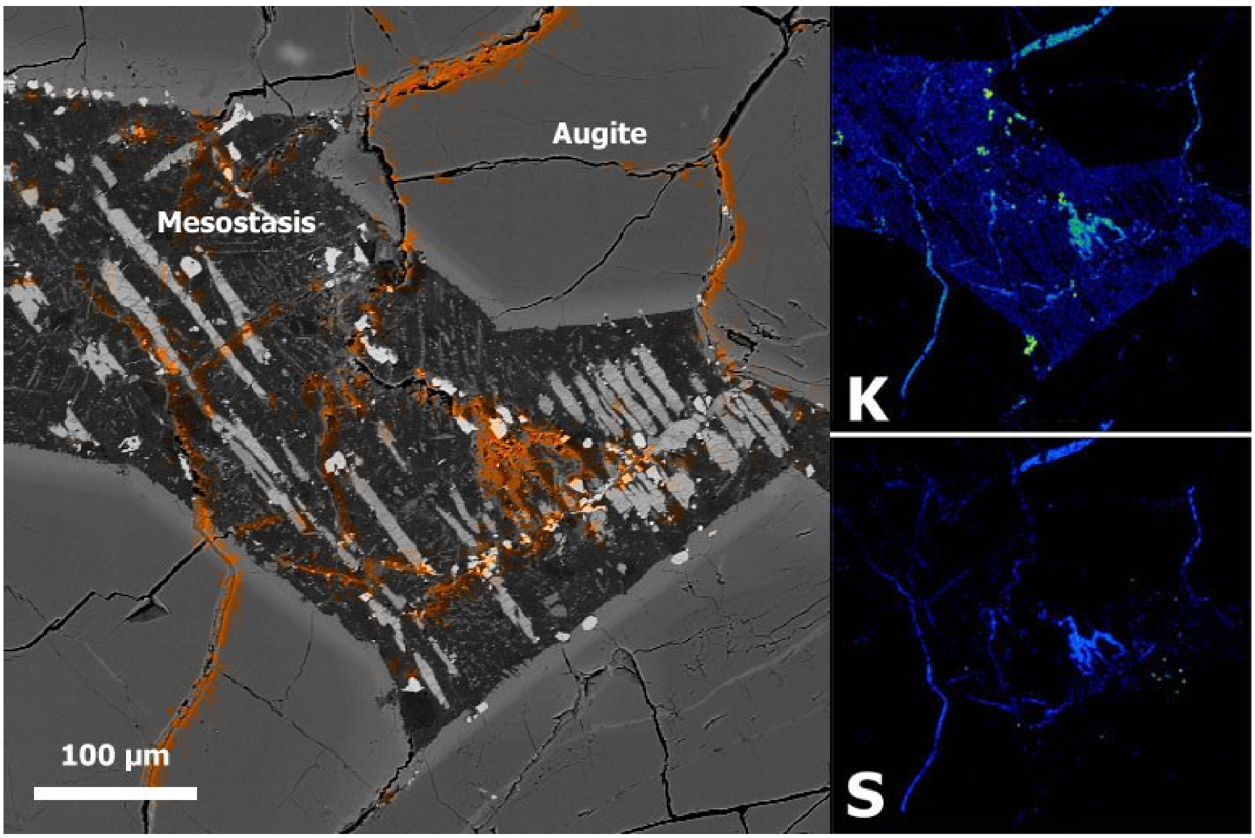

Figure 1. Jarosite (shown in false colour orange) occurs in mesostasis and along cracks in neighboring cumulate augite grains. X-ray maps on the right show abundances of K and S (brighter areas represent higher concentrations).

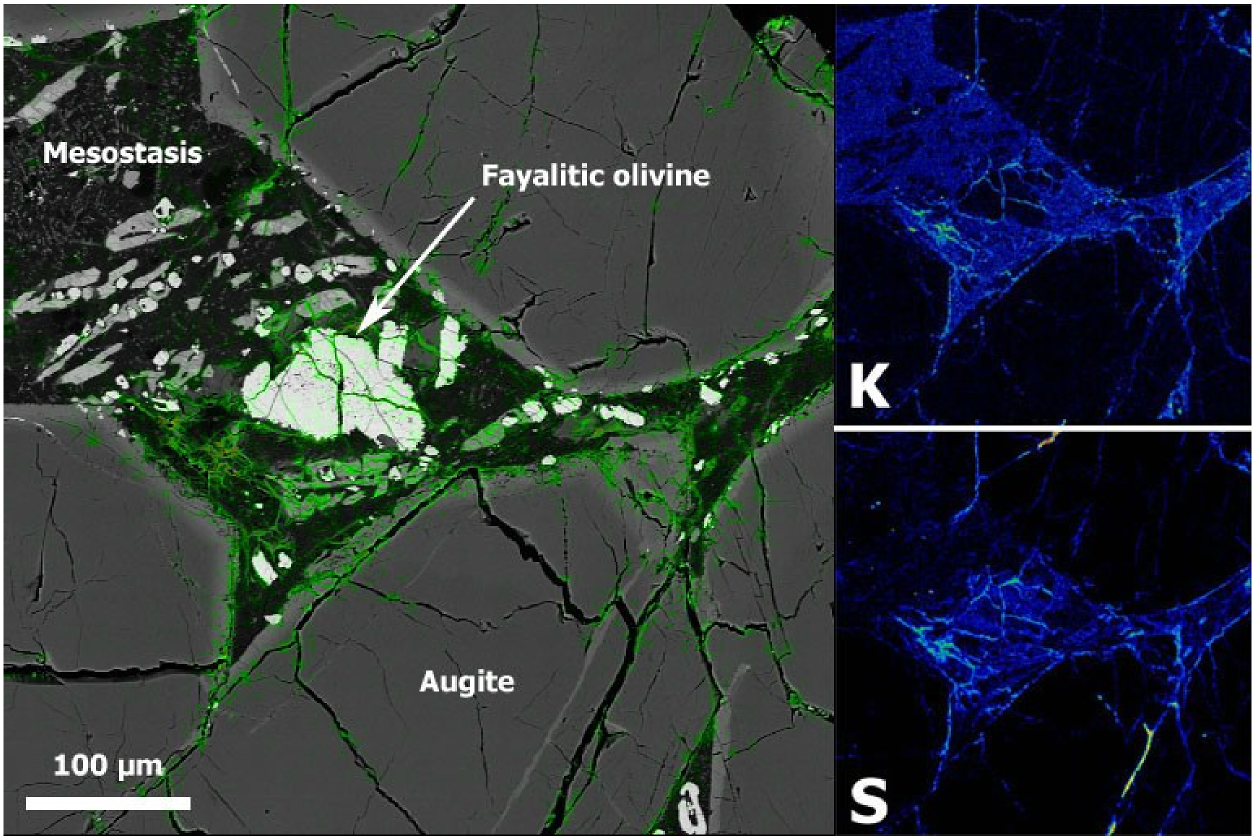

Figure 2. Jarosite (shown in false colour green) occurs in mesostasis and along cracks in an isolated Fe-rich (fayalitic) olivine grain. X-ray maps on the right show abundances of K and S (brighter areas represent higher concentrations).

Figures 1 and 2 show typical occurrences of jarosite in the MIL 03346 samples, based on our results thus far. In Figure 1, the jarosite occurs in veins along cracks in the cumulate augite. A large 50 µm concentration of jarosite is located in the mesostasis. This mesostasis jarosite appears to be connected to a common fracture that continues into the cumulate augite nearby. In Figure 2, the jarosite occurs mainly in the mesostasis and along cracks within an isolated fayalitic olivine grain. This single olivine grain is located within the mesostasis but appears to accommodate the jarosite in a similar manner as the cumulate augite.

Conclusions

Figure 1 shows a setting in which jarosite forms along veins cutting through cumulate grains, continuing into the mesostasis. This observation indicates that the components required to precipitate jarosite were carried by the waters moving through the rock. The low abundances of K and S in the mesostasis and the network of K- and S-rich veins support the idea that these components are being mobilized from outside sources and deposited in the rock.

Figure 2 shows a setting in which the jarosite preferentially forms around mesostasis phases and within an isolated fayalitic olivine. This observation is similar to the occurrence of jarosite found within a fayalitic olivine by Herd (2006). The lack of sulfides or K-rich glass within the mesostasis also supports the idea that the K and S components were brought in from outside sources.

The data and observations thus far show that the aqueous alteration in the MIL 03346 nakhlite is significant. The jarosite tends to form along fractures cutting through cumulate grains and within the mesostasis. Thin deposits of jarosite are found within these fractures while larger pockets occur in the mesostasis. Both the studied areas give evidence that K and S were mobilized by the waters flowing through the host rock during jarosite formation. The area of alteration is also quite significant, covering areas 100's of microns wide, which should allow for more detailed analysis by other microbeam methods.

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