Mineralogy and Sulfur X-Ray Absorption Near Edge Structure (S-XANES) Analysis of Bockfjord Volcanic Complex Carbonates, a Potential Martian Analog

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The surface of Mars was possibly more habitable during the Noachian period [1], and Martian carbonates from the period are important records of the condition of aqueous environments, but no sample other than the unique meteorite Allan Hills (ALH) 84001 is available for study [2]. Carbonate-bearing igneous rocks from the Bockfjord Volcanic Complex (BVC) on the Spitsbergen Island, Svalbard, Norway, are a potential terrestrial analog for Martian carbonates due to their globular carbonate deposits similar in appearance to those in ALH 84001 [3]. However, few studies have been conducted on the BVC carbonates, and their formation process and environment have remained poorly constrained. In this study, we analyzed the mineralogy and sulfur speciation (as a redox proxy) of a carbonate-bearing basaltic breccia sample from the Sverrefjell Volcano in the BVC in order to constrain the formation process and fluid environment.

Mineralogical analysis using scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS) identified three different types of carbonate globules with different Fe contents, all having Fe-rich outermost layers. Silicate alteration products, including a silica phase, zeolite, and talc, were found between the host rock and carbonate globules. Together, these observations suggest that alteration products were deposited in the following sequence: silicates → carbonates → Fe-rich phase.

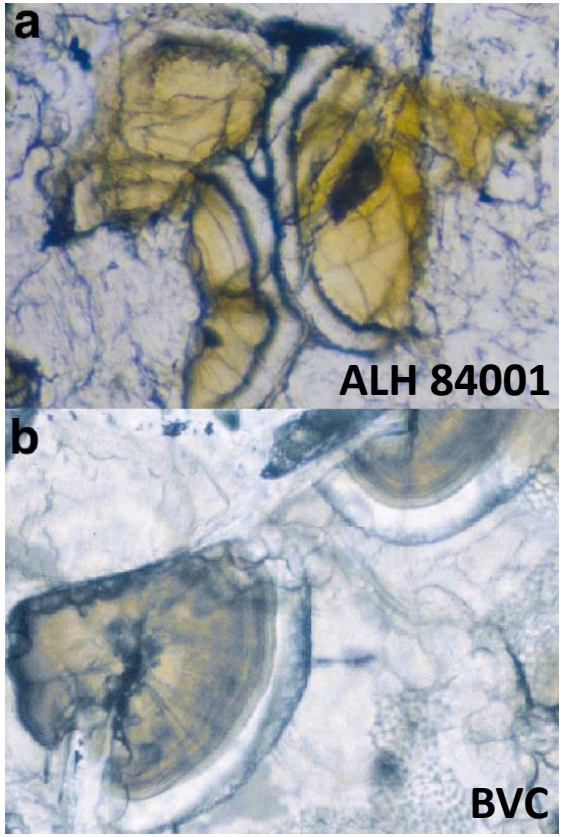
The speciation of S was measured using X-ray absorption near-edge structure (XANES). The X-ray absorption peak energies indicate that the dominant S species in the carbonates is carbonate-associated sulfate, a result consistent with that from a previous study on ALH 84001 carbonates and suggests potentially similar formation fluid acidity and redox potential [4]. Inorganic, reduced S was found in the interior of the globules and is attributed to Fe sulfide crystals mixed in the carbonates. Organic sulfide was found concentrated in the rims of the carbonate globules, in association with the Fe-rich phase identified by SEM-EDS. Determination of the Fe-rich phase was not possible with SEM-EDS and S-XANES, but magnetite is a possible candidate since it was previously reported in both ALH 84001 carbonates and another xenolith BVC carbonate sample as a part of magnetite-macromolecular carbon assemblages [5].

References

[1]] Ehlmann B. L. et al. (2016) J. Geophys. Res. Planets, 121, 1927–1961. [2] Bridges J. C. et al. (2018) Volatiles in the Martian Crust, 89–118. [3] Treiman A. H. et al. (2002). EPSL, 204, 323–332. [4] Kajitani I. et al. (2020) LPSC LI, Abstract #1703. [5] Steele A. et al. (2007) Meteorit Planet Sci, 42, 1549–1566.

Introduction

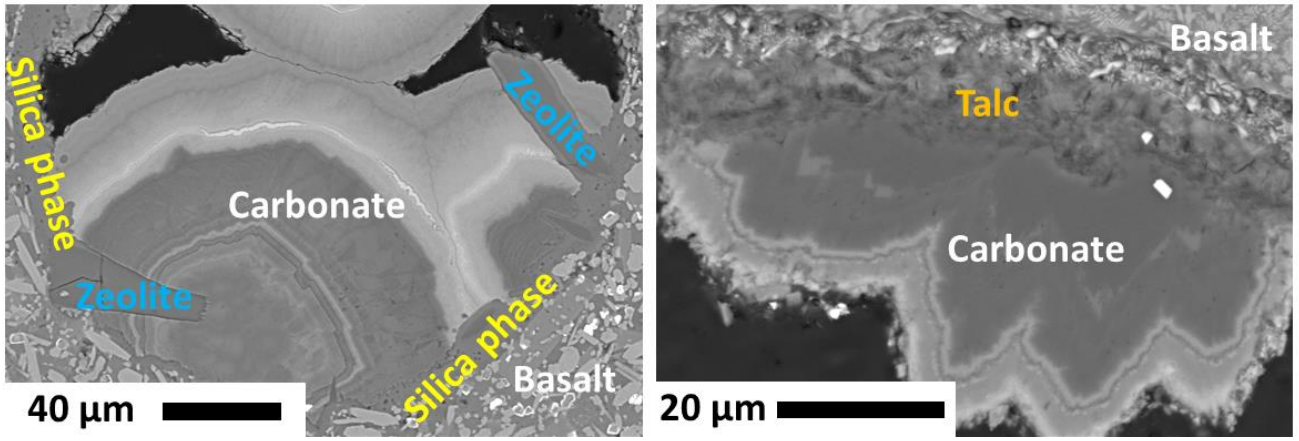
- Mars was possibly more habitable in the Noachian Period (~4 Ga) (Ehlmann et al., 2016)
- Carbonates are the key to understanding the environment of Noachian Mars, but only a single sample is available (ALH 84001) (Bridges et al., 2018)
- Bockfjord Volcanic Complex (BVC) carbonates are a potential terrestrial analog (Treiman et al., 2002)
- Objective: characterize the mineralogy and formation fluid condition of BVC carbonates
- Methods
  - SEM/EDS: Mineralogy
  - S-XANES: Oxidation state of S -> fluid redox condition



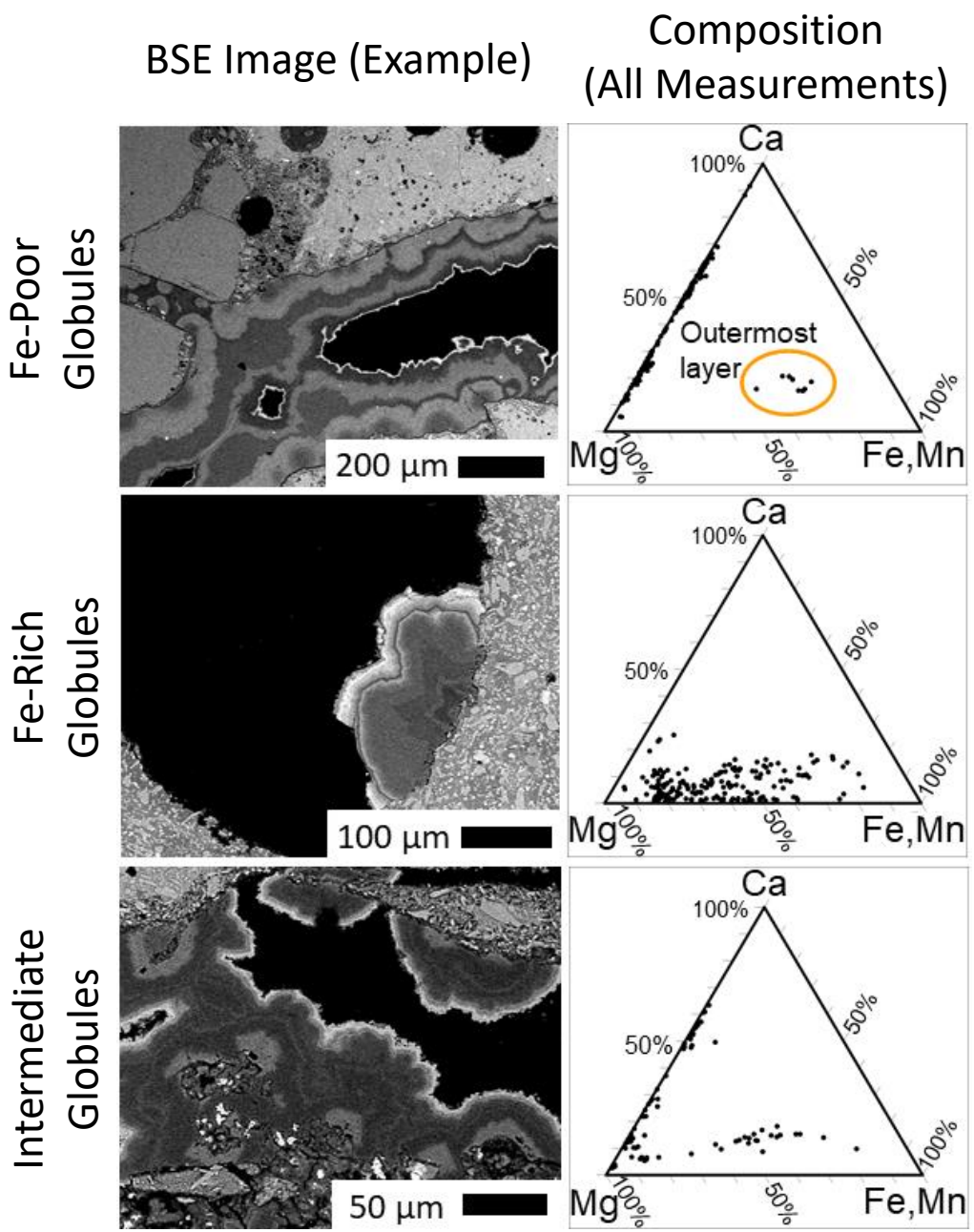
Similar carbonate globules in ALH 84001 and BVC carbonates (Treiman et al., 2002)

Mineralogy

- Complete mineral assemblage of carbonate formation process
- Three types of carbonate globules
- Silicate alteration products
  - Deposited before carbonates

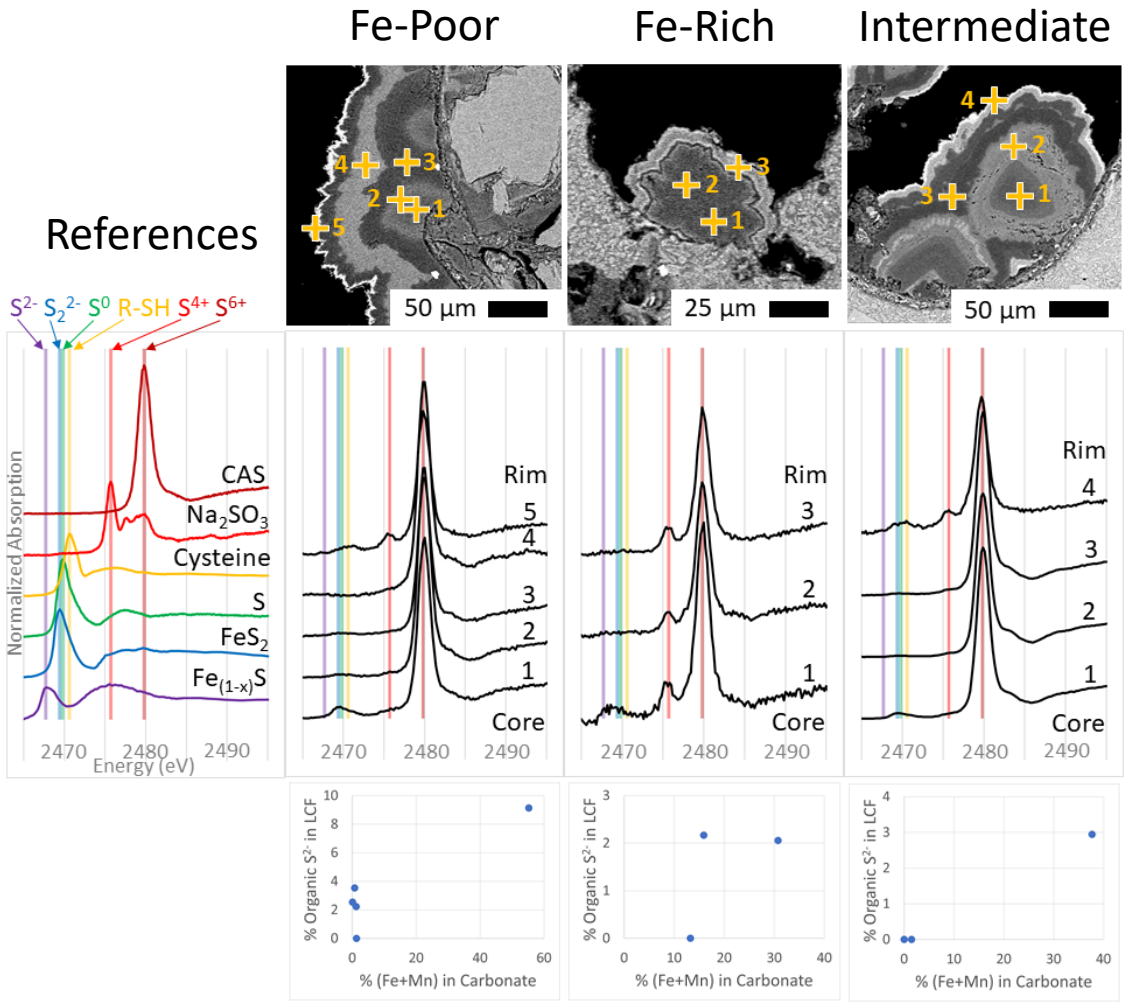


Silicate alteration products associated with carbonates



Sulfur Speciation

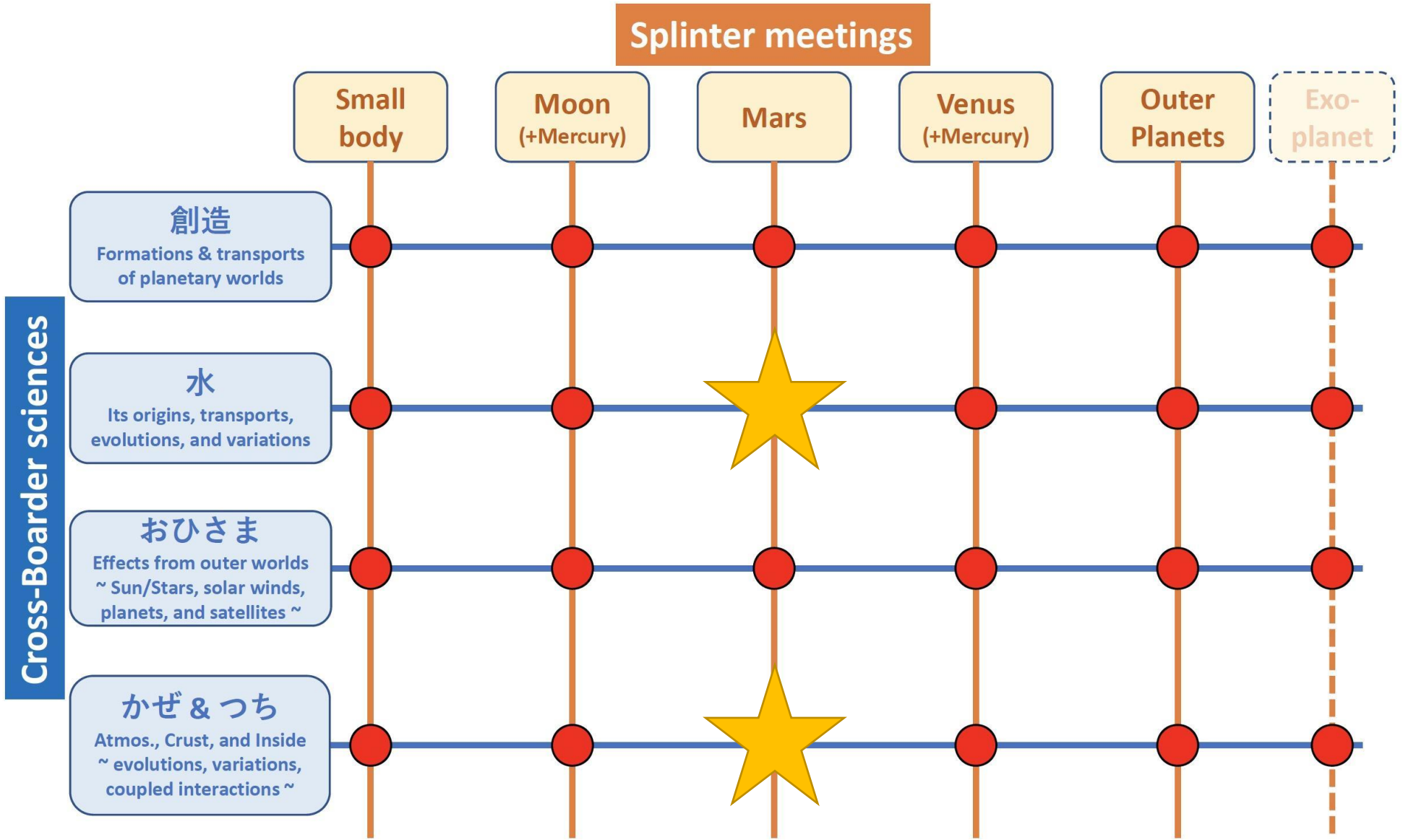
- Sulfate is the dominant S species
  - Mostly carbonate-associated sulfate
  - Similar formation fluid condition as ALH 84001 carbonates (Kajitani et al., 2020)
- Reduced S
  - Inorganic (i.e., pyrite or pyrrhotite) in the interior
  - Organic sulfide in the rim
    - Possibly associated with magnetite
    - Magnetite-macromolecular carbon assemblages were previously found in both ALH 84001 and xenolith BVC carbonates (Steele et al., 2007)



Example S-XANES Spectra

Focus of the Symposium 2022

Multiple Column x Low approach for Science requirement & Mission strategy



Making borderless teams and finding/investigating seeds for future explorations!