Geochemistry of Mineral-Water Interactions in Basaltic Lava Caves as Earth Analogs

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Basaltic lava caves are important Earth analogs in our search for life on Mars and other planets. Geochemical investigation of secondary mineral deposits (speleothems) and associated water in terrestrial caves may help identify potential biotic or abiotic pathways for the formation of these mineral biomarkers, which could persist over geologic time. We collected water and speleothem samples from seven caves at Lava Beds National Monument (CA, USA) that varied in age, temperature, moisture content, light intensity, and frequency of visitation. Hydrochemical characterization of cave water was done by measuring dissolved inorganic and organic constituents. Mineralogical and chemical characterization of speleothems were determined via x-ray diffraction and fluorescence analyses and petrographic examination of corresponding thin sections. Results revealed that the cave waters contained elevated dissolved organic carbon (9-21 mg/L), total dissolved nitrogen (1-4 mg/L), as well as nitrate (3-21 mg/L). High DOC and TDN in basaltic cave waters are unusual and suggest influx of C and N that support microbial growth. Elevated nitrate in such waters may indicate an agriculturally influenced regional surface water source or in situ oxidation of ammonia or organic N within the caves by nitrifying bacteria. Moreover, the dissolved organic matter in cave waters was found to have macromolecular structure, being plant-derived, highly humified, and microbially processed. Major elements in cave waters include Si, Na, K, Ca, and Mg and represent basaltic host rock chemistry. Speleothems contained 29-79 wt% of crystalline, cryptocrystalline, or amorphous SiO_2, and secondary minerals such as calcite, iron-hydroxide, magnetite, hematite, vaughanite, apatite, and vanadium oxide. These findings complement an ongoing work of the NASA BRAILLE (Biologic and Resource Analog Investigations in Low Light Environments) project to study basaltic lava caves as Earth analogs and ultimately provide insights for planning future missions to search for biosignatures on Mars and other planetary bodies.

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