

**FATE AND TRANSPORT OF SOLUTES IN MICROPOROUS CHONDRITIC ASTEROIDAL AQUIFERS - AND CORES OF OCEAN-WORLDS?** M. A. Velbel<sup>1,2</sup>. <sup>1</sup>Michigan State University, Department of Earth and Environmental Sciences, East Lansing, MI, USA 48824-1115 ([velbel@msu.edu](mailto:velbel@msu.edu)), <sup>2</sup>National Museum of Natural History, Department of Mineral Sciences, Division of Meteorites, MRC 119, Smithsonian Institution, 10<sup>th</sup> St. and Constitution Ave. NW, Washington, DC USA ([VelbelM@si.edu](mailto:VelbelM@si.edu)).

**Introduction:** Several groups of carbonaceous chondrites (C-chondrites) show long-recognized evidence of mineral reactions with no-longer-present water. The degree of aqueous alteration of CM and CI chondrites is widely understood to be measurable in the abundances and Mg/Fe systematics of their volumetrically abundant phyllosilicates [1-5]. CM chondrites are sufficiently abundant that available samples encompass a well-studied range of compositional variations among aqueous alteration products including phyllosilicates, amorphous silicates, carbonates, and sulfates, and corresponding degrees / extents of aqueous alteration.

**Observations from mineral compositions, assemblages, and textures in CM chondrites:** A common view of compositional relations between CM reactant and product silicates is that those secondary phyllosilicate minerals that formed as pseudomorphic alteration products of anhydrous primary Mg-Fe silicate minerals preserve the Mg-Fe ratios of the primary minerals they replace. However, the composition of serpentine (srp) replacing chondrule-hosted and isolated olivine (ol) and pyroxene (px) during advanced alteration is much more uniform in any given CM2 chondrite than the wide range of olivines replaced [6-8]. Also, means and ranges of serpentine compositions differ between CMs [7,8]. Finally, only some CMs show coarse sulfides decorating pseudomorph margins [8].

**Implications for duration of serpentinization reactions:** Persistence of primary-silicate remnants within partially pseudomorphic and meshwork serpentine indicates that replacement of coarse (chondrule-hosted and isolated) primary anhydrous silicate minerals (olivine and pyroxene) by serpentine ceased before their complete consumption. Either the aqueous alteration episodes in the parent-body volumes represented by individual meteorites were too short (ephemeral, transient) to allow complete replacement of primary silicates by serpentine, or one or more reactants (most likely water) were completely consumed before the coarse primary silicate was completely replaced [7,8].

**Inferring solute attributes and stoichiometric mass-action expressions:** Comparison of several previously published stoichiometric mass-action expressions for the serpentinization of olivine [9] reveals that a reaction describing isovolumetric replacement of coarse chondrule-hosted and isolated olivine by serpentine ( $5\text{ol} \rightarrow 2\text{srp}$  - serpentine pseudomorphic after olivine) conforms to textural observations, quantitative modal-abundance data, and constraints from geochemical kinetics better than other common reactions [8,9].

**Implications for elemental mobility as solutes:** The  $5\text{ol} \rightarrow 2\text{srp}$  (isovolumetric) reaction requires that (in addition to water) some dissolved (solute) species must have been added to or removed from the volume within which pseudomorphic / alteromorphic replacement of olivine by serpentine occurred [9]. Solute redistribution between primary and secondary minerals resulted in control of secondary mineral compositions by the interplay between primary-mineral reaction rates and depletion, and the associated evolving solute compositions of the aqueous medium [8]. Solvent and solute species diffused through the serpentine between the olivine-serpentine interface and the aqueous solution outside the pseudomorphs [8]. Regardless of the olivine's composition, isovolumetric replacement of coarse olivine by serpentine of the observed composition always released more Mg and Si from the replaced volume than was required to form serpentine of the observed composition, and the excess Mg and Si were exported from the replaced volume and available to be incorporated into the last neoformed Mg-rich serpentine in surrounding, rim, matrix, and more distant pseudomorphs after other olivine crystals or grains [8].

Redox-sensitive elements had more complex import-export behaviors during serpentinization. To form serpentines of the observed compositions, Fe had to be exported from pseudomorphs after ferroan olivine but imported into pseudomorphs and meshwork after forsteritic olivine; thus, Fe must have been a mobile solute in these aqueous solutions [8]. Occurrences of sulfides within pseudomorphs in only some CMs require (1) a soluble form of S in the aqueous solution and (2) that the abundance and/or mobility of S differed among the alteration environments of different CMs [8].

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