

**COMPOSITIONS OF PARTLY ALTERED OLIVINE AND REPLACEMENT SERPENTINE IN THE CM2 CHONDRITE QUE93005.** M. A. Velbel<sup>1</sup>, E.K. Tonui<sup>2</sup>, and M.E. Zolensky<sup>3</sup>, <sup>1</sup>Department of Geological Sciences, Michigan State University, East Lansing, MI 48824-1115 (velbel@msu.edu), <sup>2</sup>Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, <sup>3</sup>Astromaterials Research & Exploration Science Office, NASA Johnson Space Center, Houston, TX 77058.

**Introduction:** Some phyllosilicates in CM carbonaceous chondrites formed by aqueous alteration of anhydrous precursor phases (e.g., [1-3]). Although broad trends in the compositions of hydrous phyllosilicates are recognized and believed to be related to trends in degree of aqueous alteration [2,4], details of the reactions that formed specific secondary minerals remain obscure.

This paper reports compositional relationships between remnants of partially pseudomorphically (or alteromorphically; terminology of [5]) replaced silicates and their alteration products (serpentine) in the CM2 chondrite QUE93005 and compares it with previously published results for ALH81002 [6]. Reactants and products were characterized by optical petrography, backscattered scanning electron microscopy (BSEM), and electron microprobe. By focusing on serpentine formed from known reactants (olivines), and on only those instances in which some of the reactant silicate remains, direct compositional relationships between reactants and products, and the elemental mobility required by the reactions, can be established.

**Results:** QUE93005 (CM2; [7]) is not discernibly brecciated at thin-section or hand-specimen scales. Chondrules are abundant. Most olivine-bearing objects are subrounded to rounded, and exhibit elliptical to circular cross-sections in thin-section. Most also have fine-grained rims visibly identical to "accretionary" rims noted in carbonaceous chondrites interpreted by some as "primary accretionary rocks" [3]. Olivine compositions ranging from  $Fo_{77}$  to  $Fo_{99}$  were observed partially replaced by serpentine in QUE93005; more fayalitic but unreplaced olivine also occurs. Most fayalitic olivines are replaced pseudomorphically, with replacement beginning along crystal boundaries and progressing inward (Fig. 1; centripetal replacement [5]). Some serpentine replacement of fayalitic olivine forms meshwork serpentine (Fig. 2), initiated along fractures traversing olivine crystals. Some altered forsteritic olivine was partially replaced by meshwork serpentine (Fig. 3). However, many occurrences of serpentine that appeared in BSEM to be meshwork were revealed by optical petrography to be centripetal replacements of multiple different but compositionally identical forsterites. Fayalitic olivine is more extensively replaced than forsteritic olivine. Despite the broad

range of reactant olivine compositions, serpentine meshworks across, and pseudomorphic centripetal partial replacements of, olivine in QUE93005 have a narrow range of  $Fe/(Fe+Mg)$  (molar) ratios, around  $0.28\pm 0.03$ , regardless of the composition of the reactant olivine.

**Discussion:** *Comparison with ALH81002.* ALH81002 has been described as an unbrecciated "primary accretionary rock" [6]. In ALH81002, all silicate-replacement (i.e., chondrule and matrix aggregate) serpentines (including those formed from compositionally diverse olivines, orthopyroxene, clinoenstatite, and augite) are uniformly  $Mg/(Fe+Mg) = \sim 0.50-0.55$  (wt%), regardless of the reactant mineral, but different from serpentine replacing glass  $Mg/(Fe+Mg) = \sim 0.3$  (wt%) [6]. (Glass commonly exhibits alteration to phyllosilicates before other phases in CM chondrites, and phyllosilicates after glass commonly differ compositionally from phyllosilicates after other phases, e.g., [6,8].) ALH81002 replacement serpentines are similar in composition to serpentines in the texturally similar QUE93005 ( $Fe/(Fe+Mg)$  (molar)  $\sim 0.3$ ).

*Elemental mobility during aqueous alteration:* Stoichiometric replacement reactions were written based on the assumption of constant solid volume before and after reaction. Regardless of the composition of the reactant olivine, isovolumetric replacement of olivine by serpentine of the observed composition always requires loss of Mg and Si from the replaced volume. These elements may have been taken up in the products of simultaneous aqueous reactions in surrounding phases. The behavior of Fe was different from that of Mg and Si. Formation of serpentine of the observed uniform alteromorph composition from olivine that is more forsteritic than  $Fo_{83.2}$  required importation of Fe into the replaced volume. Formation of serpentine of the same composition from olivine that is more fayalitic than  $Fo_{83.2}$  released excess Fe, which was either exported or taken up as discrete sulfides.

The observed spatial uniformity in the composition of the replacement serpentine throughout the examined volumes in QUE93005 and ALH81002 indicates that the geochemical environment of serpentine formation was uniform throughout the sampled volume. The environment for replacement-serpentine formation was

chemically homogenous on the scale of the QUE93005 and ALH81002 meteorites themselves (order 2-4 cm).

**Implications:** (1) Importation of Fe is required in some pseudo/alteromorphs in each of the two CM chondrites, and Fe exportation is required in others, suggesting that secondary-mineral composition depended little on elements supplied locally by the reactant mineral and more strongly on external factors such as solution composition.

(2) Intrameteorite homogeneity of replacement serpentine exists in each CM chondrite, regardless of the composition of the reactant olivine. This strongly suggests that the aqueous medium driving the replacement reaction was compositionally uniform on scales much larger than individual olivine crystals or chondrules in each CM meteoroid.

(3) QUE93005 and ALH81002 olivines altered to serpentine in geochemically similar environments.

(4) Replacement serpentine in the brecciated CM2 Nogoya [1,9] has a different composition than the replacement serpentine in QUE93005 and ALH81002. The geochemical environment of olivine alteration in QUE93005 and ALH81002 was different from the alteration environment experienced by Nogoya [9]. It remains to be determined by additional intermeteorite comparisons whether the association of different geochemical environments with different degrees of brecciation is significant or coincidental.

**References:** [1] Bunch T.E. and Chang S. (1980) *GCA*, 44, 1543-1577. [2] Browning L. B. et al. (1996) *GCA*, 60, 2621-2633. [3] Metzler K. et al. (1992) *GCA*, 56, 2873-2897. [4] Zolensky M. E. et al. (1993) *GCA*, 57, 3123-3148. [5] Delvigne J. (1998) *Can. Mineral. Spec. Publ.* 3. [6] Hanowski N.P. and Brearley A.J. (2001) *GCA*, 65, 495-518. [7] Clayton R.N. and Mayeda T.K. (1999) *GCA*, 63, 2089-2104. [8] Fuchs L. H. et al. (1973) *Smithsonian Contrib. Earth Sci.*, 10. [9] Velbel M. A. et al. (2002) *LPSC XXXIII* #1336.

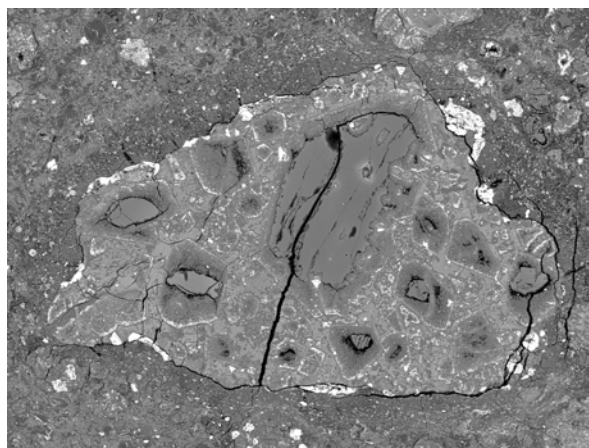


Fig. 1. Porphyritic olivine object. Euhedral fayalitic olivines are partially pseudomorphed by serpentine. BSEM image; field of view is 900 microns across.

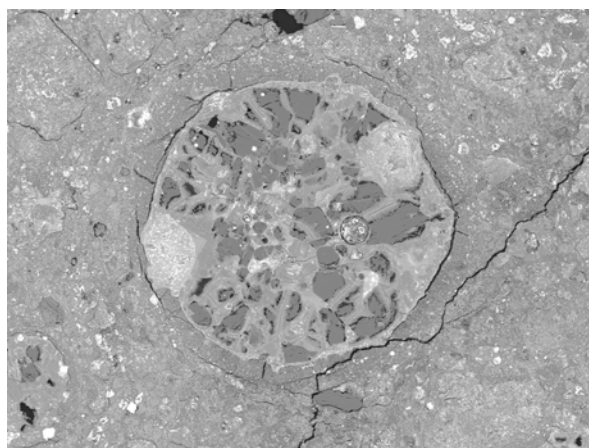


Figure 2. Porphyritic olivine chondrule. Fayalitic olivines are partially pseudomorphed by serpentine. BSEM image; field of view is 1.5 millimeters across.

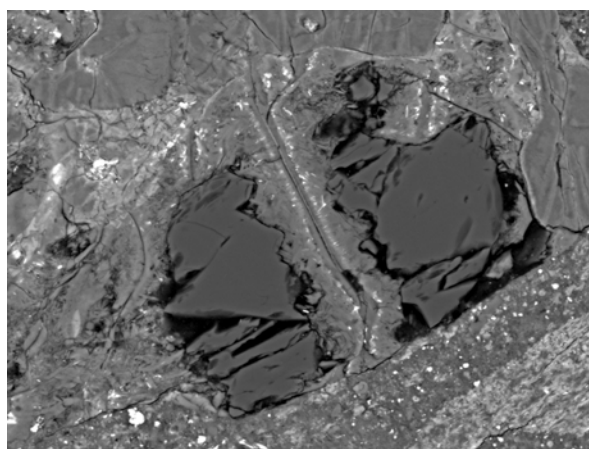


Figure 3. Forsteritic olivine partially replaced by meshwork serpentine. BSEM image; field of view is 170 microns across.