Layer lattice silicates in CM carbonaceous chondrites are commonly referred to as phyllosilicates and have been identified as chamosite in Murchison (1), cronstedtite in Cochabamba (2,3), ferric chamosite or cronstedtite in Jodzie CM inclusions (4), and cronstedtite to ferric cronstedtite in Murchison and Murray; in addition to others tentatively identified as montmorillonite group minerals. Arguments for the origin of phyllosilicates in the past range between alteration products in C1 meteorites (5,6) to direct condensation from the solar nebula (7,8).

Petrographic observations of Jodzie, Murchison, and Murray together with X-ray diffraction, electron microprobe, TEM and SEM investigations indicate that these meteorites are regolith breccias composed of partly to completely altered chondrules, aggregates, rock and mineral clasts with matrices of phyllosilicates, partially altered sulfides and metal, calcite, magnetite, carbonaceous matter, and two "poorly characterized phases" (PCP). The overall textural impression is one of terrestrial hydrothermally altered tuffs and mafic rocks.

Phyllosilicates were separated from the matrix of Murchison by a freeze-thaw sonication-density settling technique which provided a sample of at least 98% purity; phase evaluation was made by SEM energy dispersive analysis (SEM-EDA), TEM electron diffraction, and X-ray powder diffraction. The heaviest, most abundant phyllosilicate is cronstedtite-ferric cronstedtite. Electron microprobe analyses of a pressed bulk sample gave high precision analyses of SiO$_2$, Al$_2$O$_3$, Cr$_2$O$_3$, Fe$_3$O$_4$ (calc.) MgO, Mn$_2$O$_3$, CaO, MgO, FeO, NiO, Na$_2$O, K$_2$O, S, $\sum_{\text{water}} = 99.19$ wt% (by weight diff.), $\sum_{\text{water}} = 99.19$ wt%. Carbonaceous material is also associated with the phyllosilicates, therefore, C was excluded from the analyses. Element ratios relative to Si were confirmed on single grains by SEM-EDA. This composition is similar to broad beam analyses of Jodzie (4), Murchison (1), Cochabamba (2) and Orgueil (9) matrices, although S and Ni contents in the matrix analyses (when analyzed) are higher by a factor of 2-3. This discrepancy is attributed to the existence of very fine-grained Ni-bearing sulfides or PCP intimately mixed with phyllosilicates.

Two "poorly characterized phases" (PCP) are present in all CM's studied and correspond generally to Fe-S-O in Murchison (1), Fe-C-S in Mighei (10), and Fe-Ni-S-O phases observed in many CM's (8). One PCP is dull tan in reflected light, shows variable anisotropy and reflectivity, and occurs as large clasts ($\geq 1$ mm), fibrous clusters, as thin foliated bands, and as encrustations on or as projections into calcite grains. Composition is variable and similar to PCP in Murchison (1) with the exception of higher carbon (1-3.1 wt%). The other PCP phase is dull grey, has much lower anisotropy, and occurs as small patches and as clusters of needle-like projections into calcite (some calcite grains are associated with both phases).

Many matrix pyrrhotite and pentlandite grains show various stages of alteration and oxidation; several outer margins contain up to 14 wt % oxygen (microprobe analyses). An unusual primary sulfide mineral was found in all CM samples that is similar to the predicted "Q" phase composition in noble gas-rich meteorites (11). Microprobe analyses of 11 small grains (<10 $\mu$m) within
the matrix and 4 in forsteritic aggregates show variable composition among the samples: Fe, 22-31; Ni, 23-30; Cr, 8-12; P, 3-6; K, 0.4-1.0; and S, 17-26 wt%. This new mineral is not chromiferous pentlandite. Further characterization is in progress.

A strong case can be argued for low temperature (<450°K) aqueous alteration for CM meteorites and for post-accretion alteration origin of CM phyllosilicates and PCP. Matrix textures clearly indicate in situ alteration of pre-existing silicate-sulfide-metal matrix components. Moreover, many smaller olivine and olivine-orthopyroxene aggregates are pseudomorphed by phyllosilicates. Hydrated iron oxides are also present. Larger chondrules and aggregates are not commonly altered, although interstitial glass within chondrules are mostly devitrified to "spinach". The existence of several different intimately mixed phyllosilicates is unlikely to be explained by direct vapor condensation. Furthermore, Na is more depleted from K in phyllosilicates relative to bulk compositions which is accomplished by aqueous ion exchange, a point raised by Kerridge (6) in arguing for an alteration origin of Orqueil phyllosilicates. PCP phases are oxysulfides that originated from aqueous alteration of fine-grained sulfides and metal. The strongest argument is manifested by Nogoya, which is 95% altered. All of the matrix was converted to phyllosilicates (at least 3), PCP, iron oxides and secondary carbonates. Entire chondrules have been replaced by phyllosilicates and carbonates. "Serpentine mesh" textures prevail in partly altered chondrules.

As expected of CM2 meteorites, Nogoya contains organic carbon in the form of amino acids. By comparison with Murray and Murchison, however, Nogoya's amino acid abundance is depleted by a factor of 6 (12). This depletion is likely to be even higher in light of Nogoya's 96 year terrestrial history and the fact that ubiquitous terrestrial contaminants could not be excluded from the analysis. Amino acids are known to be thermally lable in meteorite matrices (13) and their depletion in Nogoya would be consistent with complete alteration of the CM2 matrix to phyllosilicate if this alteration occurred during and/or after amino acid synthesis and required a long duration at temperatures in excess of 350°K. Heating of a sample of Murchison under vacuum at 458°K for one week reduced the abundances of individual amino acids by factors of 2 to 17 (13). We expect that the abundances of thermally lable organic matter in meteorites would correlate inversely with degree of alteration.

Precursory matrix components prior to alteration were likely to have been Fe-rich olivine, high Ni-metal, and Ni-bearing sulfides. This unaltered assemblage is present as dark, fine-grained (<0.1-<2.0μm) "halos" that surround chondrules and aggregates in Allende and occur as relics in CM's. These halos could be the initial growth period of the low temperature condensates (iron-bearing olivines) in contact with earlier formed high temperature phases. SEM observations and EDA show that these halos in Allende consist of an interlocking network of mostly olivine (Fo48-Fo52) with minor amounts of platelet metal and pentlandite with no intergranular material. Olivine surfaces have a micromound texture which is probably vapor deposited carbon. These observations are consistent with earlier findings (14,15) with the exception that our analyses of the olivine indicates a fairly constant presence of CaO.
(\(\approx 0.5\)); \(\text{P}_2\text{O}_5(\approx 0.4)\); \(\text{NiO}(\approx 0.5)\); \(\text{Cr}_2\text{O}_3(\approx 0.3)\); \(\text{Al}_2\text{O}_3(\approx 0.4)\) and \(\text{S}(0.1-0.7)\) wt %. Consistent with the darker appearance of the halo regions is the observation that their carbon content is invariably higher than that measured in the bulk matrix. The above data strongly suggest condensation of Fe-olivine followed by vapor deposition of amorphous carbon. The presence of \(\text{S}, \text{Al}, \text{and P}\) within or on olivine grains may be attributed to adsorption during olivine crystal growth. Even though it is unlikely that these elements could be accommodated into the olivine structure, no mineral inclusions or negative crystals were observed down to a grain size of 500 \(\AA\) with the SEM.

In summary, chemical and textural evidence suggest that phyllosilicates in CM meteorites originated in situ through low temperature aqueous alteration of a precursory phase assemblage analogous to those constituents that form the so-called halos in Allende. The more Mg-rich phyllosilicates probably resulted from alteration of chondrule-aggregate-clast components.

References:

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