THE PETROLOGY OF FINE-GRAINED MICROMETEORITES: EVIDENCE FOR THE DIVERSITY OF PRIMITIVE ASTEROIDS. M. J. Genge[1], J. Bradley[2], C. Engrand[3], M. Gounelle[1], R. P. Harvey[4] and M. M. Grady[1], [1]Department of Mineralogy, The Natural History Museum, London SW7 5BD, [2] MVA Inc, Atlanta, USA, [3]C. S. N. S. M., Orsay, France, [4]Case Western Reserve Univ., Ohio, USA.

Introduction: Micrometeorites (MMs) are the fraction of the Earth's cosmic dust flux to survive atmospheric entry and to be recovered from the surface. MMs recovered by melting of Antarctic ice are generally >50 μm in diameter and thus experience greater heating during passage through the atmosphere than the smaller interplanetary dust particles (IDPs) collected in the stratosphere [1]. Previous studies of MMs indicate that despite heating many particles retain enough of their original mineralogy to provide information on the nature of their parent bodies [2, 3, 4].

Because of their small sizes, different MM types may be derived from the same parent body, since they probably sample individual components of asteroidal materials. Fine-grained MMs (fgMMs) are an abundant and important group of particles since they have affinities to the fine-grained matrices of carbonaceous chondrites and thus sample primitive asteroidal components. Previous studies of the compositions of MMs suggest that most have affinities to CM2 chondrite matrix, however, CI1- and CR2-like fgMMs are also common [2, 3, 4]. The presence of phases such as framboidal and platelet magnetite and tochilinite are also consistent with these meteorite groups and suggest the parent bodies of these MMs have been affected by aqueous alteration. The matrices of the least heated fgMMs are dominated by sub-micron acicular to sheet-like phases that have been likened to phyllosilicates and/or their dehydration products the dehydroxylates. Electron microprobe analyses of matrices has been used to suggest that matrices are composed mainly of serpentine [2, 3].

Contrary to expectation, smectite is the only phyllosilicate to have been positively identified by transmission electron microscopy (TEM) in fgMMs and only within two particles [5, 6] This clay mineral is found in low abundances in CV3 chondrite matrices [7] and with serpentine in CI1 chondrite matrix [8], however, only in aqueously altered ordinary chondrites [9] and hydrous IDPs [5] has it been found in abundance without serpentine. On the basis of this evidence fgMMs have been suggested to be a new and distinct form of primitive asteroidal materials [6].

We report TEM observations of phases which may be dehydroxylates after serpentine in several CI1- and CM2-like fgMMs and the identification of serpentine in one CI1-like fgMM. These results suggest that MMs sample a diverse population of primitive asteroidal materials.

Samples and techniques: Micrometeorites for this study were collected by melting of Antarctic ice in Cap Prudhomme [10] and the South Pole Water Well [11]. Fine-grained particles with matrices containing sub-micron acicular to sheet-like phases were selected since these were considered to be the least heated and the most likely to retain phyllosilicates. Ultramicrotomed sections were mounted on a carbon-film coated grids for high magnification bright field imaging, energy dispersive spectroscopic (EDS) analysis and selected area electron diffraction (SAED) using a TEM (JEOL 2010, Hitachi 7100 and a Phillips CM12).

Thermally altered fgMMs: All but one of the seven MMs studied by TEM have textures and mineralogies suggesting thermal alteration of their mineral phases. Three distinct types of component matrix are recognised on the basis of texture and mineralogy: (1) aggregates of Fe-bearing olivine and pyroxene with grain sizes of 10-150 nm with amorphous silicate, (2) acicular to sheet-like amorphous Mg-silicate phases <100-800 nm in length and (3) clusters of fine-grained (<50 nm) aggregates of Fe-rich, C, S, and Si-bearing sheet-like phases. Other phases, including a variety of Fe-oxides and coarser grained olivines and pyroxenes, were also identified and are thought to have survived atmospheric entry unchanged.

Aggregates of small (~100 nm) olivines and pyroxenes with glass are thought to represent the thermal decomposition products of phyllosilicates. This matrix was observed only in the three fgMMs that also have thermally altered rims and thus were expected to be moderately heated with some areas reaching temperatures >700°C [12].

Matrix consisting of clusters of acicular to sheet-like Mg-silicate phases are present in all the studied fgMMs. Qualitative EDS indicate these Mg-silicates lack appreciable Al and Ca, and contain little Fe, and SAED suggest they are largely amorphous. The origin of these phases is problematic, however, studies of the dehydration of serpentine suggest that loss of water causes structural deformation and the loss of long range order [13]. Considering the composition, amorphous nature, shape and distribution of these grains it seems likely that they are dehydroxylates after serpentine group minerals.

Iron-rich areas consisting of aggregates of tiny acicular to sheet-like phases are identified as regions of ferrihydrite by reference to previous studies of fgMMs [4]. These ferrihydrite patches are often found filling pore spaces and are present in all fgMMs studied. Even though ferrihydrite in MMs has high D/H ratios [4], its presence within moderately heated fgMMs together with its low decomposition temperatures indicates an origin due to terrestrial weathering.

Phyllosilicate-bearing fgMM: Particle SP96-007 is a compact CI-like particle containing framboidal magnetite and has a two component matrix consisting of fine-grained and coarse-grained sheet-like phases.

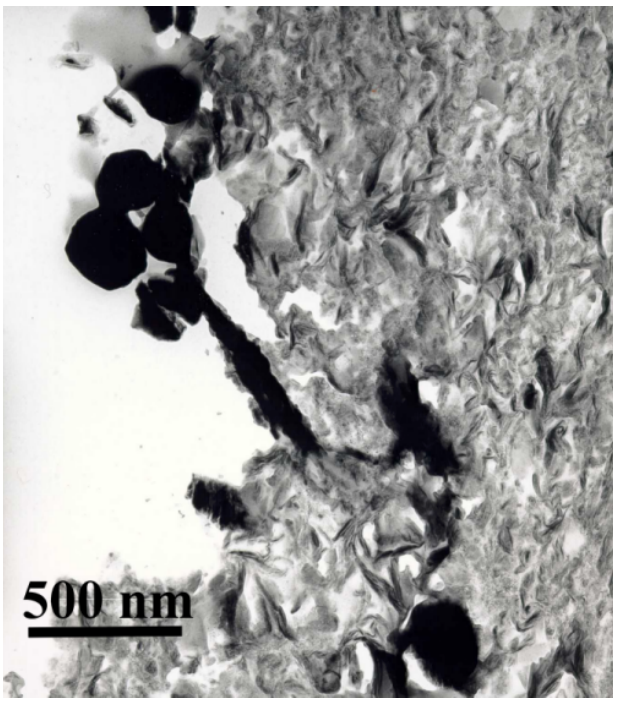

Figure 1 Bright field image of an ultramicrotomed section of particle SP96-007.

At high magnification under the TEM the fine-grained matrix consists primarily of short, curved sheet-like phases <200 nm in length. The EDS spectra of these phases indicate they are Mg-silicates containing minor Ca and Al. Isolated larger sheet-like Mg-silicate phases are observed in places and SAED reveal a 0.73 nm basal spacing consistent with the Mg-rich serpentine end-member crysotile. The smaller curved phases are are mostly amorphous or poorly crystalline and visibly decompose under the electron beam. Considering their compositions these phases may be smectite, however, no lattice fringes could be detected. The overall texture of the phyllosilicates in particle SP96-007 is remarkably similar to that of the Tagish Lake meteorite including the reported preferred orientation [14].

Framboids of magnetite are resolved in ultramicrotomed sections and are spatially associated with 'darker' veins that cut the sections. The veins can be followed from section to section and thus do not appear to be an artifact of ultratoming. Qualitative EDS suggest the veins consist of more Fe-rich sheet-like phases than the surrounding materials and may therefore be genetically related to the clusters of framboidal magnetite.

A number of grains of iron sulphide containing detectable Ni also occur within the matrix of this particle and imply that peak temperatures less than ~375°C were reached during entry heating. Considering particle SP96-007 is 400 μm in diameter it must have entered the atmosphere at a very favourable angle and velocity to have escaped significant heating.

Conclusions: Observations in the present study of: (1) serpentine group minerals in particle SP96-007 and (2) of clusters of amorphous Mg-silicates with acicular to sheet-like shapes interpreted as dehydroxylates after serpentine, suggest that many fgMMs contained serpentine prior to atmospheric entry. This is consistent with previous observations of serpentine in CI1-like IDPs [15]. Following previous reports that two fgMMs contained smectite as the only phyllosilicate this indicates that fgMMs sample a diverse population of primitive parent asteroids that can only be described by the detailed study of large numbers of particles.

The association of framboidal magnetites with veins of Fe-rich sheet-like minerals within particle SP96-007 implies that magnetite formation may have occurred at a relatively late stage in the aqueous alteration process on the parent body. Concentration of framboids close to veins may suggest that these represent fluid flow pathways along which solutions percolated altering the previously formed matrix. Similar Fe-rich veins have, however, not be described in the matrices of CI1 chondrites.

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