AN INVESTIGATION OF PHYLLOSILICATES, C CHONDRITES, AND C ASTEROIDS USING CONTINUUM SLOPES OF NEAR INFRARED SPECTRA.

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Introduction: The complex of C asteroids constitutes about ~25% of the asteroid population [1], however because spectral features are weak or absent, little is known about their detailed mineralogy. Many asteroids contain a feature at 3 µm caused by water absorption [2], and this correlates with a weak 0.7 µm feature thought to be due to Fe^{3+} in phyllosilicates [3]. Similar features are observed in CM chondrites. A feature at 0.9 µm has been used to draw conclusions about the similarity of the C asteroid Mattilde and C chondrites [4]. Like C asteroids, the C chondrites also show relatively featureless spectra, especially when compared with spectra for phyllosilicates (Fig. 1). Many authors presume that the C chondrites are related to the C asteroids and thus that surfaces of C asteroids are composed of Fe-rich phyllosilicates [2-4]. There are two caveats that should be borne in mind. One is that the silicates in C chondrites are highly complex intermixtures of phases, which are in general poorly characterized [5]. In fact, for many years the matrix of some C chondrites was referred to as PCP ("poorly characterized phase") [6]. The second caveat, is that the C chondrites are rare on earth and there are almost certainly major selection effects due to their mechanical weakness which handicaps their delivery to earth and subsequent recorvery [7]. Thus the material reaching Earth is not representative.

A well-known characteristic of asteroid surfaces is that they have been heavily impacted, heated, and mixed in regolith [8]. Such processes have been well-studied using meteorites and lunar samples and the net effect is heating [9]. Thus we have subjected a suite of phyllosilicates of diverse composition and structure to heat treatments and obtained their near-IR spectra [10,11]. We compare the results with data for eleven C asteroids, we have obtained using IRTF [12], and for C chondrites using spectra obtained from the on-line databases. Here we report recent developments in our work.

Experimental: Since the heat treatments weaken and remove absorption features, to produce the relatively flat spectra we see on asteroids, we focus on the slopes of their continua as defined in Fig. 1. We chose the spectral regions 1.0-1.75 and 1.8-2.5 µm because there often seemed to be a discontinuity at ~1.8 µm but within these intervals the spectra are reproducible and well-characterized. A negative slope at long wavelengths reflects a variety of complex water-host interations, while the meaning of a positive slope is unclear. We obtained five phyllosilicates from Ward's Scientific (Table 1). Samples were heated in air and argon at temperatures 100-1100°C in 100°C intervals and the IR spectra obtained.

Table 1. Phyllosilicates used in the present study with relevant data.

Sample, Catalog No., Location **Nominal Composition**	**Structure**
Kaolinite, 46E0995, Edgar, Florida $Al_2Si_2O_5(OH)_4$	1:1
Serpentine, 46E7263, Eden Mills, Vermont $Mg_3Si_2O_5(OH)_4$	1:1
Nontronite, 49E5108 Cheney, Washington $Na_{0.3}Fe^{+3}{}_2Si_3AlO_{10}(OH)_2{\bullet}4(H_2O)$	2:1
Montmorillonite, 46E0438 Panther Creek, Colorado $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2(H_2O)_{10}$	2:1
Chlorite, 46E1923, Madison Co., North Carolina $(Mg,Fe^{+2})_5Al(Si_3Al)O_{10}(OH)_8$	2:1:1

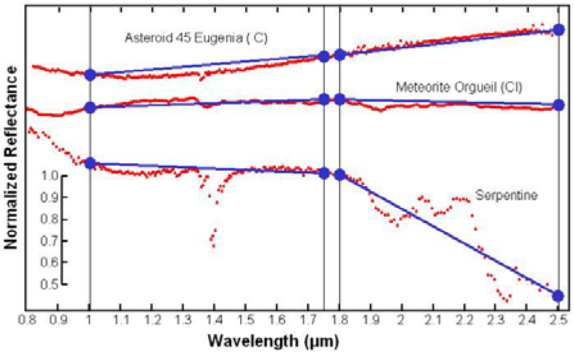

Fig. 1. Representative spectra for an asteroid, a meteorite and a terrestrial phyllosilicate explaining how continua slopes were determined. The spectra are normalized to 0.875 µm and are displaced vertically for clarity. Such slopes seem to be an excellent way to characterize the spectra as discrete features are first weakened and removed.

Results: Figure 2 summarizes the results of our phyllosilicate measurements. The phyllosilicates occupy a large field with negative slopes over the longer wavelength interval with no simple correlation with composition or structure. Upon heating, their data migrate across the phyllosilicate field in reasonable agreement with prior work of Hiroi and coworkers whose heating experiments terminated at 600°C [12, 13]. Above 700°C the data leave the phyllosilicate field and form a number of fairly well-constrained fields with positive long wavelength slopes. It is well know that phyllosilicates lose their chemically bound water when heated to >600°C.

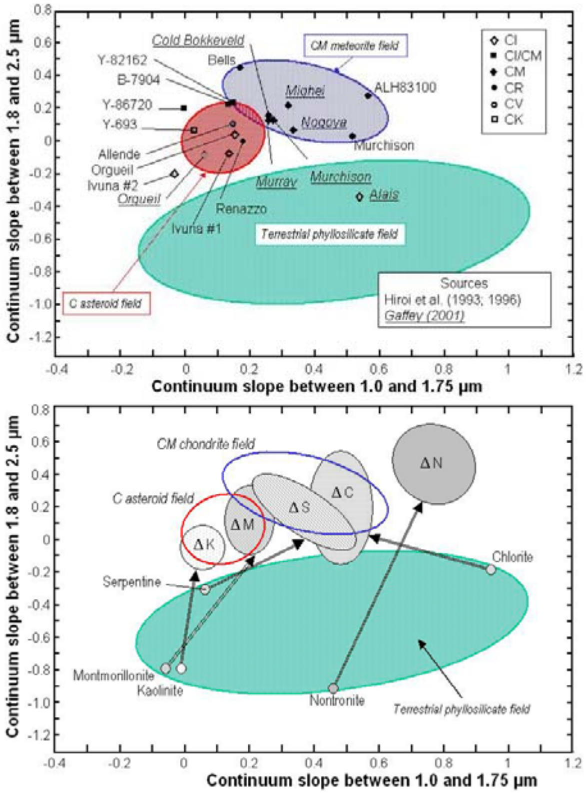

Fig. 2: Continua in the short wavelength interval plotted against against continua in the long wavelength region. (a, above) Phyllosilicates, C asteroids, and CM chondrites plot in the fields indicated. Other classes of C chondrite, plot in the C asteroid field. (b, below) The fields marked ΔK, ΔM, ΔS, ΔC, ΔN, refer to data for samples of kaolinite, montmorillonite, serpentine, chlorite, and nontronite, respectively, heated above 700°C.

Discussion: Taken at face value, our experiments are consistent with the conclusion that C asteroids are mineralogically most similar to kaolinite and montmorillonite that have been heated by impact processes to temperatures in excess of 700°C. This conclusion is broadly consistent with the known mineralogy of many of the C chondrite classes that plot in the C asteroid field. Similarly, our experiments are consistent with the idea that CM chondrites are composed of serpentine and chlorite heated above 700°C, and again this is consistent with the understood mineralogy of the CM class. While a large variety of phyllosilicates have been reported in CM and other C chondrites (see ref 14 for a review), there has been no suggestion that nontronite is present in C asteroids or CM chondrites and this is consistent with the present data.

While we have limited our analysis to the near IR, studies made outside this interval (reviewed in the Introduction above) and which largely related to the presence of water, and phyllosilicates on the C asteroids, are essentially in agreement with our findings. We mention in passing that the heating experiments of Hiroi are consistent with the surfaces of C asteroids being heated equivalents of the CM and CI chondrites [13].

A perplexing issue for C asteroid and C chondrite spectroscopioc studies is why the CM chondrites, which contain up to 20 volume % water, and are supposed to be composed of phyllosilicates, have such featureless spectra (Fig. 1). Half the water in these meteorites is not associated with phyllosilicates, but is trapped in the ionic solids (such $MgSO_4.7H_2O$, epsomite), which are probably evaporites, as water of crystallization [15]. A mixture of phyllosilicates and ionical epsomite would explain the loss of certain spectral features, but not the loss of the negative long wavelength continuum slopes. Either the silicates in C chondrites are "painted" with an opaque (possibly organic) substance, or the minerals are largely amorphous. This would be consistent with the CM chondrites consisting of amorphous impact-dehydrated phyllosilicates to which water had subsequently been added. In this case, the surfaces of asteroids are not phyllosilicates as often stated, but are largely amorphous.

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