CHONDRITES, S ASTEROIDS, AND "SPACE WEATHERING": THUMPING NOISES FROM THE COFFIN? F.P. Fanale and B.E. Clark, Planetary Geosciences, University of Hawaii at Manoa, Honolulu, HI 96822

Introduction: Most of the spectral characteristics of ordinary chondrites and S-asteroids in the visible and infrared can be reduced to three numerical values. These values represent the depth of the absorption band resulting from octahedrally coordinated Fe^{2+}, the reflectance at 0.56 microns and the slope of the continuum (as measured according to convention). This is illustrated in **Figure 1**. By plotting these three characteristics, it is possible to immediately compare the spectral characteristics of large numbers of ordinary chondrites and S-asteroids [1]. Commonality of spectral characteristics between these populations can thus be evaluated on the basis of overlap in position on three two-coordinate systems: albedo vs. band depth, band depth vs slope, and slope vs. albedo. In order to establish identity, members of the two populations must overlap on all three of these independent parameter spaces. In this coordinate system, spectra of 23 ordinary chondrites (representing all metamorphic grades), and 39 S-asteroids were compared [1]. It was found that there was no overlap between the two populations in terms of the slope vs. band depth parameters, nor were most chondrites identical to the S-asteroids with respect to the other criteria.

However, the controversial question remains: Where are the parent bodies of the chondrites? Perhaps an even more critical question is: Where are our samples of the S-asteroids? Considering the geography of the asteroid belt and the theory that early solar-system electromagnetic induction heating differentiated protoasteroids in the inner portion of the main belt [2,3,4], it was suggested [1] that although S-asteroids and ordinary chondrites have very similar mineralogy, the S-asteroids are mixtures of metallic nickel iron and silicates which resulted from magmatism induced by electromagnetic heating whereas chondrites were only slightly metamorphosed nebular condensates. In this scenario chondrites would have been derived from a population of bodies with thermal lag times so short that they were not subjected to melting during the phase of the electromagnetic induction heating event but only to various degrees of pervasive metemorphism. Furthermore, these objects would then have been too small to be observed and systematically included in the library of asteroidal spectra. It was also suggested in [1] that the parametric distribution of S-asteroid spectra could be reproduced by mixing various proportions of Ni-Fe meteorite and achondritic materials. This has also been demonstrated in the laboratory [5,6].

In any case, it was the conclusion of [1] that ordinary chondrite meteorites possess spectral parameters which make them differ too strongly from S-type asteroids to be genetically related. It was also shown that even severe "space weathering" alteration in the form of melting, recrystallization and comminution could not change their spectral parameters enough to result in overlap with the S-type asteroids.

New Developments: Recently, Pieters et al. [7], have argued that maturation of long exposed surface material on the moon is not due to agglutinate formation but is instead due to another process which operates primarily on the finest grain size fraction. They suggested that this process (which we shall refer to as "process X") may also significantly affect asteroidal spectra [7]. Several physically reasonable suggestions have been proposed with respect to the identity of "process X". These include vacuum reduction of Fe^{2+} [8] and reduction of Fe^{2+} by solar wind hydrogen [9]. Because of the vast differences between lunar and asteroidal regolith meteorites, little progress can be made by simplyfying the issue to the question of whether or not "space weathering" actually occurs. Instead, three questions need to be answered: 1.) Does major alteration of spectra occur on exposed lunar material by a process othar than agglutinate formation? 2.) Does the process operate on asteroids to the extent of explaining such minor spectral heterogeneities as have been attributed to Gaspra? and 3.) Does it operate on asteroids sufficiently effectively to alter the spectra of exposed ordinary chondrite material until the spectra resemble those of S-asteroids? Pieters et al. have presented a strong case that the first question will eventually be answered in the positive. In regards to the second question, the heterogeneities on Gaspra are barely demonstrable and it is unlikely that their causes will be identified. We will, however, discuss evidence relative to the third question.

Discussion: *Evidence suggesting spectral alteration of exposed asteroidal material:* To assess the relevance of "process X" to the chondrite-S-asteroid controversy we have plotted the spectral characteristics of mature and immature lunar basalts on the coordinate system referred to above [10]. On the same plots we show the positions of average S-asteroid and ordinary chondrite spectra. The spectral trends required to transform chondrite spectra into S-asteroid spectra parallel those exhibited by maturing lunar samples on all these plots. It should be borne in mind however that very diverse processes can produce similar spectral alteration. For example,

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simultaneous shallowing of absorption bands, continuum slope increase and lowering of the albedo can be accomplished by melting and recrystallization [11] or by addition of NiFe [5].

Arguments against major alteration of asteroidal spectra by "space weathering": 1.) The exposure age of the optical surface on the asteroids must be exceedingly short. Unlike the moon, the gravitational field of most S-asteroids is so low that almost all of the "ejecta" from impacts is, in fact, ejected from the object. In addition, any impact producing a crater >1 km on an object like Gaspra will remix many tens of meters of regolith on a global basis and much smaller impacts can cause global downslope movement [12]. Thus, unlike the case of the moon, any space weathering of the optical surface must occur on a geologically instantaneous basis in order to show up spectrally. 2.) On the asteroid 4 Vesta, the exposure of the optical surface must be much longer than on most asteroids. Yet there is no evidence of such maturation in its spectrum (see **Figure 1**). The possibility that the silicate mineralogy on Vesta may be somewhat different than that of chondrites is utterly irrelevant. The deep Fe^{2+} absorption band in Vesta's reflectance spectrum testifies to the fact that there is abundant Fe^{2+} exposed which has not been reduced significantly by either vacuum melting reduction nor by solar wind related effects. Further, the possibility of renewal of Vesta's surface by endogenic or exogenic processes such as basalt flows or the birth of "baby Vestas" is utterly irrelevant as well. In order to be relevent, such processes must have occurred on a shorter time scale than the lifetime of the optical surface of S-asteroids, which seems highly improbable.

Conclusions: Despite these arguments, much remains to be done before the identity or the non-identity of ordinary chondrites and S-asteroids can be established with certainty:

1.) First, semantic difficulties should hereafter be avoided. The question of effectiveness of space weathering must be resolved at least in terms of the three questions listed earlier. Further, it must be recognized that even if S-asteroids do not supply ordinary chondrites they still were almost certainly derived from them by various extensions of the processes which produced the various degrees of metamorphism of chondrites.

2.) The lifetime of the optical surface on small bodies must be modelled on a quantitative basis. While this may not be possible, at least quantitative limits could be derived theoretically.

3.) The precise physical cause of the spectral alteration of mature lunar soils needs to be established.

4.) The possibility that the lifetime of the optical surfaces on small bodies may be exceedingly short suggests that it may even be possible to duplicate the total H+ dose in the laboratory. The usual heating problems associated with high beam strengths may be of little concern in this case.

References: [1] Fanale et al. *JGR preprint*, 1992, [2] Sonett et al. 1971, [3] Herbert and Sonett, *Icarus, 40*, 1979, [4] Bell et al *In Asteroids II*, 1989, [5] Hiroi and Takeda, *Proc. NIPR Symp. Antarct. Meteorites, 4*, 1991, [6] Takeda et al, 199?, [7] Pieters et al. *Bull. Amer. Astron. Soc., 24*, 1992, [8] Wells and Hapke, *Science, 195*, 1977, [9] Pillinger et al. *Proc. Lunar Sci. Conf. 5th*, 1974, [10] McKay et al. *Lunar Sourcebook*, 285-256, 1991 [11] Clark et al. *Icarus, 97*, 1992, [12] Nolan et al. *Bull. Amer. Astron. Soc., 24*, 1992.

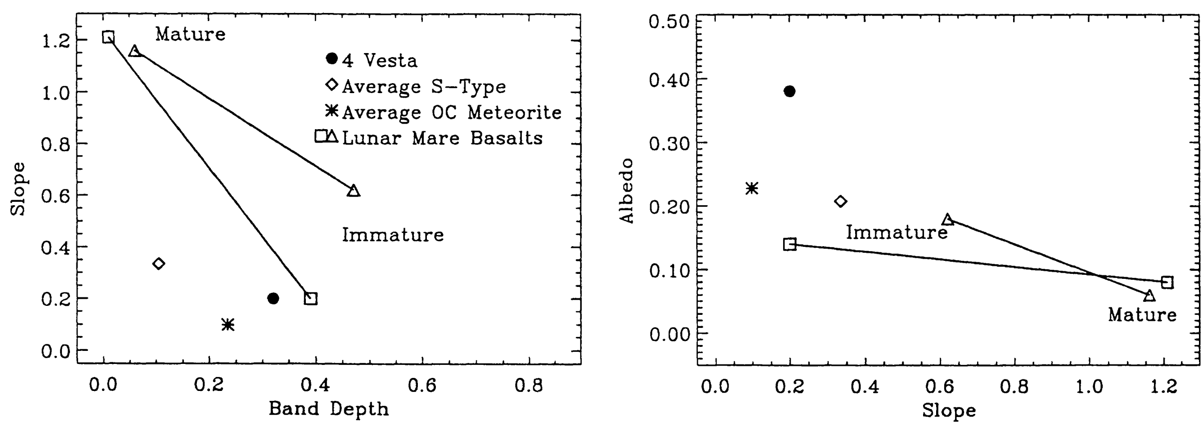

Figure 1 A and B These plots show the three parameters of continuum slope, reflectance at 0.56 microns (albedo) and band depth at 0.95 - 1.0 microns. The spectral trends for lunar mare basalts as they go from "immature" to "mature" are indicated. Note that the trends which would be required of OC meteorites to mature towards S-Type asteroids parallel those seen for the mare basalts. Note also that 4 Vesta appears to be spectrally immature.