MINERALOGICAL VARIATIONS WITHIN THE S-ASTEROID POPULATION. M.J. Gaffey, Rensselaer Polytechnic Institute; J.F. Bell, U. Hawaii; R.H. Brown, JPL; and T. Burbine, U. Pittsburgh.

It has been known for some time that there are systematic trends in the spatial distribution of asteroidal taxonomic types [1]. It is probable that these trends represent variations in the primordial compositions and/or thermal histories of the asteroids. A number of attempts have been made to use the distribution of asteroid types to constrain the nature and processes of the late solar nebula and early solar system [2,3]. The distribution has been interpreted as the signature of both a nebular compositional gradient and of early post-accretionary heating events.

By most criteria, the S-asteroids are the most heterogeneous group of asteroids and their compositions and thermal histories are the most strongly debated [4,5]. In particular, the igneous interpretation of the S-asteroids has generated significant controversy. Of all the asteroid types inferred to have igneous affinities, the S-asteroids are the most common, dominating the inner belt population, and will have the greatest impact on nebular models. The variety of S-asteroid surface assemblages should provide an important insight into the nature of this class of objects, into the processes which produced them, and into the existence of discrete sub-populations. Previous work has shown systematic variations in S-asteroid colors with semimajor axis [6] and have identified an important subclass (class K) of C3-type assemblages within the S-type [7,8].

The determination of asteroid surface mineralogy (mineral species, mineral composition) and petrology is currently the sole means of directly investigating the thermal and chemical evolution of specific minor planets. The surface composition can be constrained by various methods, but visible and near-infrared (VNIR) reflectance spectroscopy is the most sensitive technique presently employed [5]. An extensive set of 52-color S-asteroid data is available for the spectral interval from 0.3 to 2.5um [9]. We have extracted diagnostic spectral parameters from these data to investigate the mineralogical variety present within in this population.

We have utilized the principal component (PC) analysis [10] of the 8-color asteroid survey (ECAS) data [11] to provide a preliminary estimation of relative compositional variation within the S-asteroid population. In the PC analysis, the S-field lies along an apparent mixing line between the metal-rich M-types and the olivine-dominated A-types. In general, position along the M-S-A trend is proportional to relative olivine abundance, as shown by the increase in the strength of the 1um olivine absorption feature in spectra of S-objects lying along this trend (Figure 1). The four S-asteroids are plotted according to relative location along the M-A line.

Figure 2 shows relative olivine abundance for individual S-objects derived from the principal component position along the M-S-A trend line plotted with respect to heliocentric distance. Even with the scatter in the data, there is a clear general decrease in olivine abundance with heliocentric distance. A linear least squares fit (solid line) emphasizes this decrease. There is certainly NOT an increase, which would be expected for a suite of primarily undifferentiated assemblages (i.e. nebular temperature should decrease and oxidation state increase with increasing distance from the center of the solar nebula, conditions which should increase olivine abundance in anhydrous assemblages). The observed pattern probably requires either an S-population dominated by igneously differentiated assemblages, or a revision of nebular models to permit significant temperature/redox reversals.

Figure 3 shows the 1um band centers plotted relative to the ratio of the 2um and 1um absorption band areas for 23 S-asteroids plus Vesta compared to those for the chondritic and achondritic meteorites. Band centers and band areas were determined below a linear continuum tangent to the maxima in the merged ECAS and 52-color data sets. The relatively good precision of these determinations is indicated by the close agreement for different 52-color observations of the same object (the circled pairs of points). The 1um band position is a function of the abundance and composition of the olivine and pyroxene phases. The 2um/1um (BII/BI) band area ratio is primarily a function of the relative abundance of the olivine and pyroxene phases [12]. The chondrites have relative low BII/BI ratios and BI positions because of their relatively low opx abundance and Fa/Fs contents. The basaltic achondrites have high BII/BI ratios (no olivine) and moderate Fs contents. Chassigny is nearly pure olivine, while Nakhla is an olivine-clinopyroxene(diopside) mixture.

The S-asteroids generally lie above the ol-opx line especially in the chondritic zone (BII/BI $\leq$ 1.2). A similar shift has been seen in prior S-asteroid studies [4]. The displacement of BI position relative to the ol-opx trend line could be produced by a combination of several effects including: (a) more iron-rich olivine, (b) more calcium or iron-rich opx, (c) increased cpx abundance, and (d) a systematic wavelength shift between the observational and laboratory data set. The first two cases can shift the band center toward longer wavelength by up to 0.04um [12,13], the third case toward longer wavelengths by up to 0.15um [13], while the fourth case would have no preferential direction or magnitude of shift. The magnitude of the fourth option is small ($\leq$0.015um) based upon the close agreement of the Vesta point with the basaltic achondrites. The effect of shock blackening on this set of spectral parameters appears to be minimal.

The offsets of the S-asteroid relative to the ol-opx (chondritic) trend ranges from 0.00 to +0.15um. Displacements greater than +0.05um are common. There appears to be a significant subsets of cpx-bearing S-asteroids (ureilite silicates?), ol-dominated S-asteroids (pallasites?), ol-opx-bearing S-asteroids (primitive achondrites?, ordinary chondrites?) and basalt-bearing S-asteroids (mesosiderites?). With the possible exception of the latter case, the S-population appears to be a continuum. The correlations with spectral slope, absolute absorbance, other mineralogic parameters, albedo, body size, and heliocentric distance are being investigated.

S-ASTEROID MINERALOGICAL VARIATIONS: Gaffey M.J. et al.

Various portions of this research were supported by NASA (Planetary Geology and Geophysics) grant NAGW-642 and by NSF (Solar System Astronomy) grant AST-8616634.

REFERENCES: [1] Chapman, C.R. et al. (1975). Icarus 25, 104-130. [2] Gradie, J. and Tedesco, E. (1982). Science 216, 1405-1407. [3] Bell, J.F. et al. (1989). In Asteroids II (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), Univ. Arizona Press, Tucson, pp. 921-945. [4] Feierberg, M.A. et al. (1982) Astrophys. J. 257, 361-372. [5] Gaffey, M.J. et al. (1989). In Asteroids II (R.P. Binzel, T. Gehrels, and M.S. Matthews, eds.), Univ. Arizona Press, Tucson, pp. 98-127. [6] Dermott, S.F. et al. (1985) Icarus 62, 289-297. [7] Bell, J.F. et al. (1987). Bull. A.A.S. 19, 841. [8] Tedesco, E.F. et al. (1989). Astron. J. 97, 580-606. [9] Bell, J.F. et al. (1988) Lunar Planet. Sci. XIX, pp. 57-58. [10] Tholen, D.J. (1984). Asteroid Taxonomy from Cluster Analysis of Photometry. PhD Dissertation, Univ. of Arizona, Tucson, 150pp. [11] Zellner, B. et al. (1985) Icarus 61, 355-416. [12] Cloutis et al. (1986) J.G.R. 91, 11641-11653. [13] Adams, J.B. (1974) J.G.R. 79, 4829-4836.

Figure 1: 52-color spectra of asteroids lying along the M-S-A trend. The four S-asteroids are plotted in order of relative relative distance from either end-member. Note the increase in the strength of the 1um olivine absorption feature among the S-asteroids from top (6) to bottom (113).
Figure 2: Location of individual S-asteroids along the MSA-line versus semimajor axis. Relative olivine abundance increases upward.
Figure 3: The 1um absorption band position versus 2um/1um absorption band area ratio for 23 S-asteroids (#3,6,7,9,11,15,18,20,26,39,40,42,43,63,67,68,80,89,115,349,354,584,1036) plus Vesta (large solid triangles; V=Vesta) compared to those for the chondritic ("X" symbols) and achondritic meteorites ("+" symbols; C=Chassigny; N=Nakhla). Duplicate determinations for asteroids 15, 43 and 349 from independent 52-color observations are circled. The solid line is the approximate trend of olivine-orthopyroxene mixtures [12].