**DETAILED MINERALOGICAL CHARACTERIZATIONS OF FOUR S-ASTEROIDS: 138 TOLOSA, 306 UNITAS, 346 HERMENTARIA, AND 480 HANSA.**

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**Introduction:** The S-asteroid taxonomic class is the second largest grouping of main-belt asteroids that are primarily located in the inner main belt (*a* < 3.0 AU) [1]. These asteroids have historically been the subject of interest within the asteroid community for several reasons. Continuing discussions about the nature of the S-asteroids (ordinary chondrite-like or thermally-evolved) and the putative space weathering effect on S-asteroids serve as examples of issues currently unresolved within the community [2,3].

Despite this general interest, detailed mineralogical investigations of individual S-asteroids has been relatively rare. A few workers have studied individual, or small groups of, S-asteroids [4,5,6,7]. Gaffey et al. [2] published their S-asteroid survey in 1993 that characterized 39 of the 144 then-classified S-asteroids. Despite the work already accomplished, the need exists to rigorously characterize the remaining S-asteroid population to gain a better understanding of these asteroids' origin, nature, and physical characteristics.

**Observations:** Four S-asteroids, 138 Tolosa, 306 Unitas, 346 Hermentaria, and 480 Hansa were observed with the SpeX near-infrared spectrograph at the NASA Infrared Telescope Facility (IRTF), Mauna Kea, Hawaii, in October 2001, March 2002, and/or October 2004 [8]. 306 Unitas was observed for six nights: three nights in October 2001 (26 spectra) and three nights in October 2004 (85 spectra). 138 Tolosa (6 spectra, 10/01), 346 Hermentaria (10 spectra, 3/02), and 480 Hansa (6 spectra, 10/01) were observed on single nights.

**Data reduction:** Asteroid, standard star, and solar analog star data were extracted into one-dimensional arrays of flux values using IRAF that were then processed into fully-reduced spectra with SpecPR [9]. The general data reduction process leading to an average, normalized asteroid spectrum can be summarized by the following equation: Asteroid/Sun = (Asteroid/SS) * (SS/SA), where SS = standard, or extinction, star observations and SA = solar analog star observations. Standard stars are of spectral type (or near) G2V and the solar analog stars are calibrated standards.

During processing of 306 Unitas data, we discovered a spectral artifact that caused the average Unitas spectrum for different nights to exhibit variable overall spectral slopes. This effect was traced to the SA/SS ratios, which exhibited variable, non-horizontal spectral slopes on different nights, despite both stars usually being spectral type G2V. When taking the ratio of two stars of equivalent spectral type, the expectation is that this ratio will produce a horizontal or near-horizontal line. This is not what is observed.

Upon review of solar analog star data from several previous observing runs, it was found that this anomalous behavior is consistently present and apparently random in behavior. Based on communications with John Rayner at the IRTF and a review of SpeX operational characteristics [8,10], the anomalous spectral behavior is tentatively attributed to SpeX. The combination of decreasing short-wavelength instrumental throughput and several wavelength- and time-dependent effects may be causing this spectral variability [8,10].

**Data analysis and interpretations:** Band centers, depths, and areas were extracted from each asteroid's nightly average spectrum to allow mineralogical characterization of each asteroid's surface. Note that the identified spectral artifact does not significantly affect band center values, but can potentially alter overall spectral slopes, band shapes, and band areas if the SA/SS ratio is significantly non-horizontal. For this analysis, solar analog stars were not used to derive the final average spectra for 306 Unitas and 480 Hansa.

*138 Tolosa.* This asteroid exhibits a broad 1 μm feature with a double minimum at ~0.93- and ~1.03-μm. The derived Band I center is at 1.04 μm. The Band II center is at 1.96 μm and is relatively weak with a band depth of only ~3%. The calculated pyroxene chemistry from [11] is ~$Wo_{48}Fs_{46}En_6$, which is a Ca- and Fe-rich calcic clinopyroxene (hedenbergite). Tolosa's average spectrum is shown in Fig. 1.

The meteorite type with the greatest modal abundance of calcium clinopyroxene is the nakhlites [12]. Pure hedenbergite spectra display a 1 μm feature while lacking any 2 μm absorptions [13]. This suggests that Tolosa's surface is dominated by a hedenbergite component and a lower Ca-pyroxene component. The low-Ca pyroxene is suggested due to the relatively short wavelength position of the Band II feature. Hedenbergite is a common terrestrial igneous crystallization product, which suggests that this is a thermally-evolved asteroid that has experienced at least partial melting temperatures.

*306 Unitas.* The average Band I center is ~0.92 µm; the average Band II center is ~1.92 µm. The averge spectrum from 10/10/01 is shown in Fig. 2. From [11], this results in a pyroxene chemistry of ~$Wo_8Fs_{32}En_{60}$. The opx/(olivine + opx) abundance ranges from ~40-60% based on variations in band area ratio values. From Fig. 1F in [2], Unitas plots below the S-IV region and into the S-VI region and is classified as an S-VI. Potential meteorite analogs include the siderophyre meteorites, lodranites, and winonaites/IAB irons [2].

The above information indicates that Unitas' pyroxene chemistry and orthopyroxene/olivine abundance ratios are inconsistent with those of ordinary chondrites (OC). Type 4-6 ordinary chondrite low-Ca pyroxene chemistry ranges from ~$Fs_{14-26}$ [14] while the normative OC opx/ol ratio ranges from ~29-43% [15]. It seems likely that Unitas is a thermally-evolved asteroid that has experienced temperatures allowing at least partial melting.

*346 Hermentaria.* The Band I center is 0.95 µm and the Band II center is 1.92 µm, resulting in a pyroxene chemistry of ~$Wo_{17}Fs_{38}En_{45}$. This chemistry characterizes these pyroxenes as pigeonites or perhaps as relatively low-Ca augites. The BAR value = 0.428. The average spectrum for 3/22/02 is shown in Fig. 3.

Hermentaria's band parameters plot above the opx/cpx trend in the pyroxene band-band plot [11], which indicates the presence of either an olivine or Ca-pyroxene component. The asteroid's spectrum shows a broad Band I feature with a relatively weak Band II feature. Applying the methods in [11] and based on the pyroxene chemistry above, Hermentaria's surface likely consists of a mixture of pigeonite and perhaps a higher-Ca clinopyroxene, with the possibility of relatively minor olivine. Based on this information, Hermentaria has a surface mineralogy that is inconsistent with that of ordinary chondrites (despite being classified as an S-IV), which also suggests that this is a thermally-evolved asteroid that has experienced at least partial melting temperatures.

*480 Hansa.* This asteroid has a Band I center at ~0.92 µm and a Band II center at ~1.87 µm. This results in a pyroxene chemistry of ~$Wo_5Fs_{19}En_{76}$. The BAR value is 1.25. The opx/(olivine + opx) abundance is ~57%. From [2], Hansa is classified as an S-VI asteroid. Potential meteorite analogs include the siderophyre meteorites, lodranites, and the winonaites/IAB irons [2].

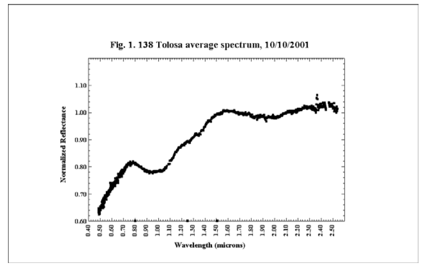

Fig. 1. 138 Tolosa average spectrum, 10/10/2001

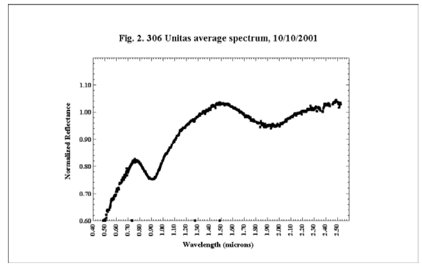

Fig. 2. 306 Unitas average spectrum, 10/10/2001

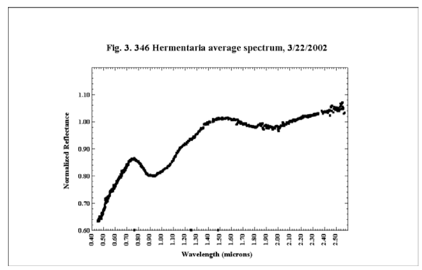

Fig. 3. 346 Hermentaria average spectrum, 3/22/2002

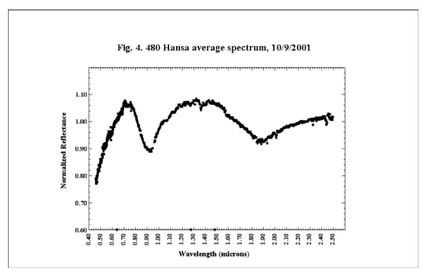

Fig. 4. 480 Hansa average spectrum, 10/9/2001

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