DISCOVERING SPECTRAL AND MINERALOGICAL DIVERSITY AMONG THE M-ASTEROID POPULATION.

P. S. Hardersen[1], M. J. Gaffey,[1] E. A. Cloutis[2], P. A. Abell[3], and V. Reddy[1]. [1]Department of Space Studies, Box 9008, University of North Dakota, Grand Forks, North Dakota 58202. Hardersen@space.edu, gaffey@space.edu, vishnu.kanupuru@und.nodak.edu. [2]Department of Geography, Room 5L13, University of Winnipeg, Manitoba, Canada. e.cloutis@uwinnipeg.ca [3]Planetary Astronomy Group, Astromaterials Research and Exploration Science, NASA Johnson Space Center, Mail Code SR, Houston, Texas 77058. paul.a.abell1@jsc.nasa.gov.

Introduction: Spectral and mineralogical diversity within different asteroid taxonomic classes has been suggested since at least the 1990s [1,2]. This diversity has been most clearly demonstrated for the S-asteroid population [2] due to these asteroids' prominent spectral absorption features in the near-infrared (NIR) (~0.7 to 2.5 microns) spectral region. However, the diversity suggestion has been more difficult to prove for the "featureless" taxonomic classes as the lack of spectral absorption features does not allow rigorous constraints to be placed on an asteroid's mineralogy, composition, or formation conditions.

Recent work on the M-asteroid population [3,4,5,6,7] has begun to show spectral and, consequently, mineralogical diversity among this taxonomic class of ~40 asteroids. [6] has found 16 X-type asteroids, 8 E-types, 4 M-types, and 1 P-type asteroid with weak ~0.9-micron features. [7] reported that 6 M-type asteroids had a weak ~0.9-micron feature that is strongly suggestive of low-Fe pyroxenes on these asteroids' surfaces. Both [6] and [7] have reported similar features for the M-asteroids 16 Psyche, 110 Lydia, and 216 Kleopatra.

[3,4,5] have observed M-asteroids in the 3-micron region and attempt to identify asteroids with 3-micron absorption features that are presumably indicative of phyllosilicate minerals. However, debate continues over the cause of these putative 3-micron features [8,9]. Observations in the NIR and 3-micron region have already led to significantly divergent interpretations for 110 Lydia and 201 Penelope [4,7]. These differences are still unresolved.

Observations and data reduction: This work is the continuation of a detailed spectral survey of the M-asteroid population. Of the 44 M-asteroids listed in [7], 28 of these asteroids have been observed using the SpeX near-infrared spectrograph [10] at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawai'i. Reduction and analysis procedures are applied uniformly for all asteroids and are fully described in [7].

Results: We report results here for 8 additional M-asteroids. The various observing runs occurred in October 2001, January 2004, and May 2004. In contrast to the initial verification of the presence of weak ~0.9-micron absorption features in the spectra of some M-asteroids in [6] and [7], we are now finding greater spectral variations among the M-population. The asteroids reported here have spectra that show indications of olivine-, pyroxene-, and phyllosilicate-bearing surfaces along with other asteroids that are spectrally featureless.

Olivine-bearing M-asteroids. 766 Moguntia and 1210 Morosovia both display NIR spectra with well-defined absorption features in the 1-micron region. Interestingly, [11] classifies both asteroids as anomalous M-types. 766 Moguntia displays a continuum-removed feature with a band center of ~1.07-1.08 microns. This feature has a band depth of ~5%. Moguntia was observed through more than one full rotation.

1210 Morosovia has a similar absorption feature with a continuum-removed band center of ~1.07-1.08 microns and a band depth of ~7%. Morosovia was observed only through a small portion of a full rotation.

The absorption features observed in both asteroids strongly suggests the presence of olivine on the surfaces of these asteroids. Coupled with their moderate IRAS albedos (766: 0.1572; 1210: 0.1695), relatively small IRAS diameters (766: 31.28 km; 1210: 33.65 km) [12], and the shallowness of the features (potentially suppressed by the presence of metal), the pallasites are plausible meteorite analogs for these asteroids. Other interesting notes are that both asteroids are members of the Eos family and have semimajor axes just beyond 3 AU.

Pyroxene-bearing M-asteroids. 22 Kalliope, 347 Pariana, and 558 Carmen all display weak ~0.9-micron absorption features in their NIR spectra.

22 Kalliope is a binary asteroid system with a primary IRAS diameter of 181 km, an IRAS albedo of 0.1419, and a derived global density of 2.37 ± 0.4 g/cm^3 [13]. [13] suggests Kalliope is composed of chondritic material with a porosity of ~30%. NIR spectra of Kalliope reveal a continuum-removed band center at 0.91-microns with a band depth of ~3%. The band depth and position of this feature, along with Kalliope's IRAS albedo of 0.1751, is consistent with the presence of low-Fe pyroxenes as discussed in [7].

347 Pariana also exhibits a similar ~0.9-micron feature. Observations were conducted through more than one full rotation of the asteroid (>4.0529 h). Con-

tinuum-removed band centers range from 0.88- to 0.93-microns with band depths of ~3%. The band center variations are equivocal as imperfectly-removed telluric water vapor features introduced variable noise into various spectra.

These absorption features, along with an IRAS albedo of 0.1751 for Pariana, suggest the presence of low-Fe pyroxenes on this asteroid's surface.

558 Carmen is the third M-asteroid in this group to exhibit a weak ~0.9-micron absorption feature. Observed through about $1/3^{rd}$ of a full rotation, Carmen exhibits continuum-removed band centers ranging from ~0.91- to 0.94-microns. Band depths average ~2%.

Interpretations for these low-Fe pyroxenes are described more fully in [7], but include 1) remnant mantle material surrounding a metallic core of a relatively chemically reduced, differentiated, and disrupted asteroid parent body, 2) pyroxenes resulting from a smelting process occurring on strongly heated parent bodies, 3) as consistent with the mineralogy and expected spectra of the Bencubbinite meteorites, and 4) as collisional debris. The authors in [7] generally prefer the first interpretation as the most probable.

[13] suggests a chondritic (presumably ordinary chondritic) interpretation for 22 Kalliope. However, our NIR spectra are inconsistent with that suggestion. Ordinary chondrites (OC) are mixtures of olivine, pyroxene, metal, and other minor mineral phases [14]. The observed absorption feature is too narrow and positioned at a sufficiently short wavelength region to preclude the necessary olivine abundances for an OC interpretation.

Phyllosilicate-bearing M-asteroids. 129 Antigone has clearly produced the most interesting spectrum from this group of asteroids. NIR spectra of Antigone show multiple sharp, relatively weak absorption features at 0.76-, 0.90-, 1.07-, and 1.39-microns. The overall spectral slope is concave and shows what may be a weak absorption feature in the ~2.2-micron region.

Our spectrum is consistent with the 24-color survey spectrum of Antigone in the ~0.7- to ~1.1-micron wavelength region [15]. The 24-color spectrum displays two weak features at ~0.76- and ~0.93-microns, which is very similar to the band minima in our spectrum. In addition, a USGS spectrum of antigorite is mostly consistent with the features found in our Antigone spectra.

Based on these similarities, we tentatively suggest that Antigone has a surface with antigorite. [4] has suggested the presence of phyllosilicate minerals on the surface of Antigone, which is consistent with our suggestion.

Radar work by [17] strongly suggests that portions of Antigone's surface have a significant metal content, which further complicates interpretations of this asteroid's surface composition. However, based on the above information, two potential interpretations result: 1) as an analogue to the CR chondrites, which contain both FeNi metal (~7 vol%) found mostly within chondrules and matrix phyllosilicates [18], and 2) as a collision product between a CI/CM-chondrite-like asteroid and a stripped iron core from a differentiated asteroid.

Additional spectra of 129 Antigone have been obtained in order to verify the presence of the absorption features found in the original spectrum.

Featureless M-asteroids. 97 Klotho exhibits a featureless, relatively flat spectrum across the NIR region. This asteroid has a very long rotation period (35.15 h) and only a small fraction of its surface was observed. Klotho has an IRAS albedo of 0.2285 and an IRAS diameter of 82.83 km.

498 Tokio also exhibits a featureless spectrum across the entire NIR region. However, Tokio displays a unique and significantly blue spectrum, especially at wavelengths shortward of ~1.3-microns. Tokio has a low IRAS albedo for an M-asteroid (0.0679) and an IRAS diameter of 82.75 km.

Based on the lack of absorption features or other diagnostic information, these two asteroids have poorly constrained compositions. 97 Klotho may have enstatite chondritic or metallic composition [19]. 498 Tokio, due to its unique spectral slope and low albedo, has no apparent meteorite affinities.

References: [1] Gaffey M.J. et al. (1993) *Meteoritics* 28, 161-187. [2] Gaffey M.J. et al. (1993) *Icarus* 106, 573-602. [3] Rivkin A. S. et al. (1995) *Icarus* 117, 90-100. [4] Rivkin A. S. et al. (2000) *Icarus* 145, 351-368. [5] Rivkin A. S. et al. (2002) *Asteroids III*, 235-253. [6] Clark B. E. et al. (2004) *AJ* 128, 3070-3081. [7] Hardersen P. S. et al. (2005) *Icarus* 175, 141-158. [8] Gaffey M. J. et al. (2002) *Asteroids III*, 183-204. [9] Starukhina L. (2001) *JGR* 106, 14701-14710. [10] Rayner J.T. et al. (2003) *PASP* 155, 362-382. [11] Tholen, D.J. *Asteroids II*, 1139-1150. [12] Tedesco E. F. et al. (2002) *AJ* 123, 1056-1085. [13] Margot J. L. and Brown M. E. (2003) *Science*, 1939-1942. [14] McSween H. Y. et al. (1991) *Icarus* 90, 107-116. [15] Chapman C. R. and Gaffey M. J. (1979) *Asteroids*, 655-687. [16] Clark R. N. (1993) *USGS Digital Spectral Library*, *OFR 93-592*. [17] Shepard M. K. et al. (2005) *DPS #37*, #07.07. [18] Brearley A. J. and Jones R. H. *Planet. Mat.*, 3-63, 3-230. [19] Gaffey M. J. and McCord T. B. (1979) *Asteroids*, 688-723.