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Mineralogy of Asteroid 1459 Magnya and implications for its origin

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Abstract

Detailed near-infrared spectral observations of Asteroid 1459 Magnya reveal an asteroid that is primarily composed of pyroxene and plagioclase feldspar, confirming earlier suggestions that Magnya has a basaltic composition. The average Magnya spectrum for March 23, 2002 has a Band I center of 0.926 µm and a Band II center of 1.938 µm. Observations over $4\frac{1}{2}$ hours show little variation in band center positions. The feldspar-to-pyroxene ratio is ~ 0.6 on Magnya's surface. Comparing Magnya with the spectral parameters from 4 Vesta shows discordant pyroxene chemistries; Magnya's pyroxenes contain ~ 10 mol% less Fs than Vesta's pyroxenes. This suggests that Magnya originated from a parent body other than 4 Vesta and that its progenitor formed in a more chemically reduced region of the solar nebula within the asteroid belt.

Keywords: Asteroids, composition; Mineralogy; Spectroscopy; Infrared observations

1. Introduction

Lazzaro et al. (2000) reported discovery observations of 1459 Magnya, an asteroid with a radius of ~ 15 km and a semimajor axis of 3.14 AU. Based on their combined datasets from different observatories, with wavelength coverage from ~ 0.4 to ~ 1.6 µm, and by comparison with meteorite spectra, these authors suggest that Magnya is a basaltic achondrite-like asteroid. Besides 4 Vesta and its associated ejecta population (McCord et al., 1970; Drake, 1979; Feierberg and Drake, 1980; Feierberg et al., 1980; Gaffey, 1983; Binzel and Xu, 1993; Binzel et al., 1997; Gaffey, 1997; Thomas et al., 1997, and Vilas et al., 2000), Magnya is currently the only other asteroid in the main belt that has been identified as having a basaltic surface.

A more in-depth dynamical and taxonomic investigation of the spatial region around Magnya by Michtchenko et al. (2002) addresses many interesting questions that relate to Magnya and the entire asteroid belt. Dynamical analysis shows that Magnya's orbit is stable, but is bounded by several high-order secular resonances (Michtchenko et al., 2002). These resonances seem to be efficient at dispersing disrupted asteroids as Michtchenko et al. (2002) show that the majority of an asteroid parent body ($\sim 70\%$) can be lost in this region in only 500 Myr. Taxonomic investigations of the region surrounding Magnya show that several candidate asteroids exist that may be genetically related to Magnya; Michtchenko et al. (2002) also show that most asteroids in this spatial region (~ 70–80%) lack a taxonomic classification. Hence, the existence of any other members from Magnya's parent body is still an open question.

Other interesting questions arise concerning the discovery of Magnya in a relatively eccentric and inclined ($e \sim 0.238$ and $i \sim 16.95°$) orbit in the outer portion of the asteroid belt. The first, which was addressed in part by Lazzaro et al. (2000), is whether or not Vesta and Magnya are genetically related. A second question concerns the mineralogic and petrologic similarity of Magnya's surface materials to the howardite, eucrite, and diogenite (HED) suite of basaltic achondrites, which are generally presumed to be pieces from Vesta (Mittlefehldt et al., 1998). Another intriguing question concerns the location of Magnya in the asteroid belt and the implication for the heating distribution in the inner Solar System during the formation epoch. Resolution of these issues can begin to provide additional insights into the basic

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nature and properties of the asteroid belt, from developing a more complete inventory of the diverse types of asteroids to constraining the thermal regimes that they experienced.

2. Observations and data reduction

Observations of 1459 Magnya were acquired using the SpeX near-infrared array spectrograph at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii (Rayner et al., 2003). For asteroid observations, SpeX is used in the low-resolution mode, which covers the wavelength range from ∼ 0.7 to ∼ 2.5 µm. Asteroid observations are optimized at low resolution ($R \sim 100$) and with a high signal-to-noise ratio (SNR ∼ 100–200); this combination, along with photometric observing conditions, allows the detection of near-infrared spectral features as weak as ∼ 1%, as recently demonstrated for some M-type asteroids (Hardersen et al., 2002, 2003; Hardersen, 2003). Eighty spectra, distributed among eight individual sets of 10 observations, were obtained on the evening of March 23, 2002 (UT). Weather conditions on the mountain were good and the skies were clear. See Table 1 for a list of the observational parameters for 1459 Magnya.

Asteroid and stellar spectra were extracted using IRAF and subsequently exported into SpecPR for detailed processing (Clark, 1980; Gaffey et al., 2002; Gaffey, 2003). Observations of a standard star, HD 125297, over a wide air mass range allowed modeling of the atmosphere over Mauna Kea. Multiple standard star observations were used to derive the extinction coefficient at each instrumental wavelength. These corrections were then used to adjust the effective standard star flux to the same airmass as the asteroid that is paired with its standard star. This method is used to remove the spectral effects of atmospheric absorption and scattering, especially the strong telluric water vapor features at ∼ 1.4- and ∼ 1.9-µm. This method allows more accurate and objective removal of the water vapor features than other techniques in common use, which often involve only a single observation of a standard star. Extinction coefficients derived from multiple standard star observations helps to reduce the scatter and noise in the asteroid spectra. This is very important in the later analysis efforts to extract spectral parameters (band centers and band areas) that allow the identification and characterization of any detectable minerals present on an asteroid's surface.

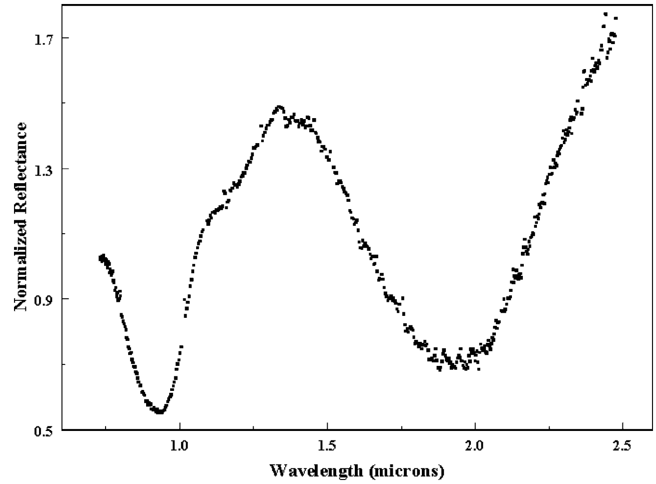

Fig. 1. All-night average spectrum (78 spectra) of 1459 Magnya for the night of March 23, 2002.

The spectra of Magnya are shown in Figs. 1 and 2. Figure 1 shows the all-night average spectrum while Fig. 2 shows the eight individual spectral sets. Only two (in Set #2) of the 80 spectra were discarded before averaging due to unacceptable scatter in the short wavelength regions of those spectra.

Qualitatively, all spectra exhibit deep absorption features in the ∼ 1- and ∼ 2-µm regions. An inflection is also present in the ∼ 1.2-µm region. Straight-line continua were applied across each of the two main absorption features to produce continuum-removed absorptions that were subsequently best-fit to polynomial functions to determine their respective band centers. Band areas of the continuum-removed features were also determined. The ∼ 1.2 µm feature was isolated by ratioing the measured spectrum to a curved continuum. The curvature of this continuum was derived from the limb profile of the pyroxene absorption band across the spectral interval encompassing the feature. The band center and band area for this feature were also determined.

The presence of the ∼ 1.2 µm feature in the spectra of basaltic achondrites is indicative of the presence of sub-

Table 1
Observational parameters for 1459 Magnya

Set #	UT Time	RA	Declination	*V* Mag	Airmass	Solar distance (AU)	Phase angle
1	1023	$14^h11^m16^s$	−6°41′11″	15.74	1.337	3.851	7.78°
2	1103	$14^h11^m15^s$	−6°41′9″	15.74	1.215	3.851	7.77°
3	1138	$14^h11^m14^s$	−6°41′7″	15.74	1.154	3.851	7.76°
4	1219	$14^h11^m13^s$	−6°41′4″	15.74	1.122	3.851	7.76°
5	1253	$14^h11^m12^s$	−6°41′2″	15.74	1.124	3.851	7.75°
6	1331	$14^h11^m11^s$	−6°41′0″	15.74	1.159	3.851	7.75°
7	1418	$14^h11^m10^s$	−6°40′57″	15.74	1.258	3.851	7.74°
8	1456	$14^h11^m09^s$	−6°40′54″	15.73	1.398	3.851	7.73°

Orbital parameters calculated from *Ephem*, Version 1.2, Tholen (1999). Copyright by Celestech. UT time and airmass recorded while observing at IRTF. Epoch: July 6, 1998.

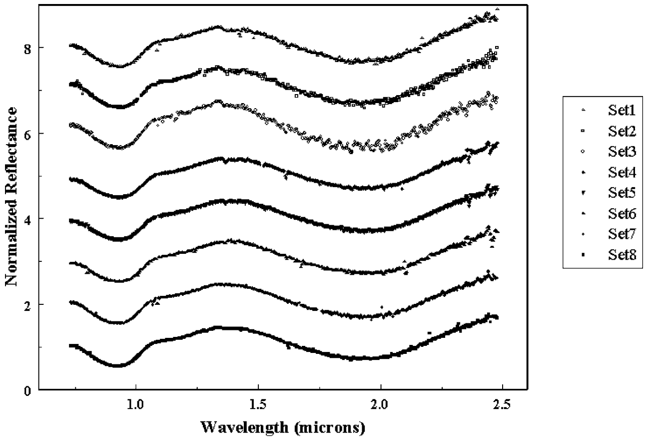

Fig. 2. The eight individual spectral sets of 1459 Magnya, ordered chronologically with Set #1 at the top through Set #8 at the bottom. The first three sets exhibit more point-to-point scatter compared to the latter five sets. Noise variations between the spectral sets are independent of object airmasses and may be due to asymmetries in atmospheric stability, instrumental effects, or due to other causes.

stantial feldspar in the surface materials. This suggests that the spectra are similar to eucrites, which have a feldspar-to-pyroxene ratio of $\sim 1:1$ (Gaffey, 1976). The 1.2 µm feature is much weaker in the spectra of howardites which have a lower feldspar abundance and the feature is absent in the spectra of diogenites which lack feldspar (Gaffey, 1976).

3. Data analysis

3.1. Mineral chemistries and abundances

Band I centers for Magnya range from 0.923- to 0.928-µm; Band II centers vary from 1.922- to 1.943-µm. Band centers were determined by calculating the best-fit polynomial function across each isolated absorption feature. Variations of the spectral parameters over the eight sets are minor. Application of the pyroxene calibrations (Gaffey et al., 2002) show minor variations in the wollastonite (Wo), ferrosilite (Fs) and enstatite (En) abundances in Magnya's pyroxenes. The average pyroxene composition for Magnya is $Wo_{7-9}Fs_{36}En_{55-57}$. (The uncertainties in the absolute compositions of the pyroxenes are ± 5 units for Wo and Fs. The uncertainties in the relative compositions are much smaller.) When plotted on the pyroxene calibration curve of Adams (1974), later modified by Cloutis and Gaffey (1991), the Magnya data cluster together directly on the curve (Fig. 3).

The band area ratios (BAR) of Magnya suggest that orthopyroxene is the dominant or sole mafic mineral present with at most only minor or accessory olivine. BAR values for Magnya range from 3.40 to 4.32, which plot off the right side of Fig. 1E from Gaffey et al. (1993a) that is modified and reproduced here as Fig. 4. Note that Magnya's data plots to the right of the basaltic achondrite region in this figure. Due to the eucrite-like nature of the surface material of Magnya, this result suggests that the basaltic achondrite region

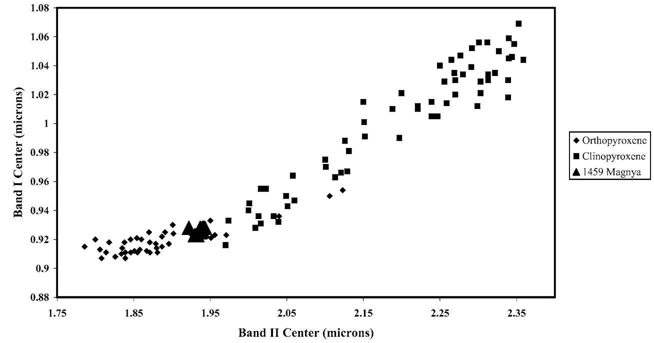

Fig. 3. Spectral parameters for 1459 Magnya plotted on the pyroxene determinative curve from Adams (1974), as modified by Cloutis and Gaffey (1991).

Table 2
1459 Magnya spectral parameters

Observation	Band I (microns)	Band I (adjusted)	Band II (microns)	Band II (adjusted)
All night avg.	0.926	0.929	1.938	1.946
Avg. of 50 spectra	0.925	0.928	1.937	1.945
Set #1	0.928	0.931	1.943	1.951
Set #2	0.928	0.931	1.937	1.945
Set #3	0.928	0.931	1.922	1.930
Set #4	0.928	0.931	1.941	1.949
Set #5	0.928	0.931	1.940	1.948
Set #6	0.927	0.930	1.936	1.944
Set #7	0.923	0.926	1.933	1.941
Set #8	0.923	0.926	1.930	1.938

Adjusted band centers reflect changes caused by asteroid surface temperature differences. Band I centers are temperature corrected from Roush and Singer (1986). Band II centers are temperature corrected from Singer and Roush (1985). Original band centers derived from calibrations in Gaffey et al. (2002).

in Figs. 1E and 1F of Gaffey et al. (1993a) can be extended to the right to encompass BAR values of at least 4.3.

The band center for the putative plagioclase feldspar feature is 1.17 µm. The continuum-removed absorption feature is relatively deep for feldspar ($\sim 10\%$) and suggests a relatively high abundance of this mineral on Magnya's surface. Application of the calibration from McFadden and Gaffey (1978) produce a feldspar-to-pyroxene ratio of ~ 0.6. This corresponds to a surface consisting of $\sim 37\%$ plagioclase feldspar and $\sim 63\%$ orthopyroxene. See Tables 2 and 3 for a summary of the spectral and mineralogical parameters for Magnya.

3.2. Rotational variations

No rotation period has yet been determined for Magnya; however, the eight observational sets span $4\frac{1}{2}$ hours. Assuming that Magnya is not an extremely slow rotator (on the order of > 1 day), at least $\sim 20\%$ of the surface has been surveyed.

To look for rotational spectral variations, each observational set was ratioed to the nightly average spectrum. This produced eight figures that are shown, offset, in Fig. 5. The

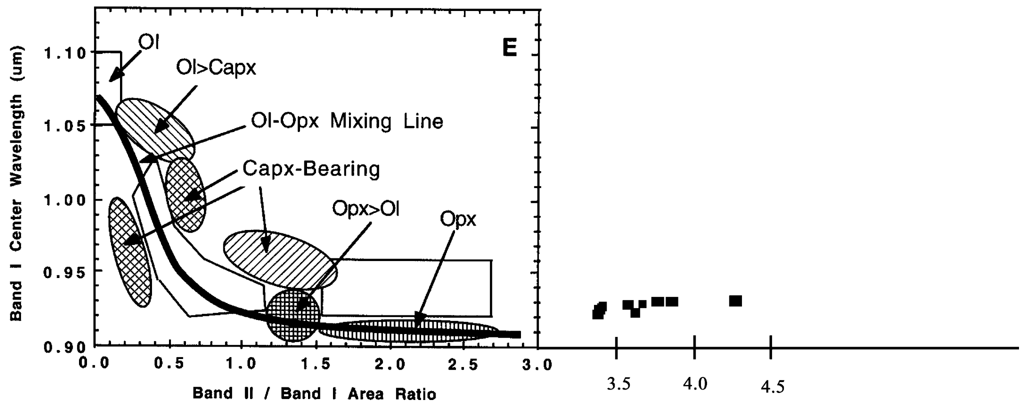

Fig. 4. This is a modified version of Fig. 1E from Gaffey et al. (1993a). The band area ratios for 1459 Magnya have larger values than can be accommodated by the original figure and the x-axis has been subsequently lengthened. This data suggests that the rectangular basaltic achondrite region and the elliptical orthopyroxene region, shown to the left of the Magnya data, can be extended to encompass the Magnya values.

Table 3
1459 Magnya mineralogical parameters

Observation	Wo content (mol%)	Fs content (mol%)	Mineralogy
All night avg.	7–9	36	$Wo_{7–9}Fs_{36}En_{55–57}$
Avg. of 50 spectra	7–8	35	$Wo_{7–8}Fs_{35}En_{57–58}$
Set #1	8–9	37	$Wo_{8–9}Fs_{37}En_{54–55}$
Set #2	8–9	36	$Wo_{8–9}Fs_{36}En_{55–56}$
Set #3	8–9	32	$Wo_{8–9}Fs_{32}En_{59–60}$
Set #4	8–9	37	$Wo_{8–9}Fs_{37}En_{54–55}$
Set #5	8–9	37	$Wo_{8–9}Fs_{37}En_{54–55}$
Set #6	7–9	36	$Wo_{7–9}Fs_{36}En_{55–57}$
Set #7	6–8	36	$Wo_{6–8}Fs_{36}En_{56–58}$
Set #8	6–8	34	$Wo_{6–8}Fs_{34}En_{58–60}$

Observation	Feldspar band center (microns)	Feldspar band area	Plagioclase/pyroxene volume %
Avg. of 50 spectra	1.171	0.014684	59

Feldspar calibration from McFadden and Gaffey (1978).

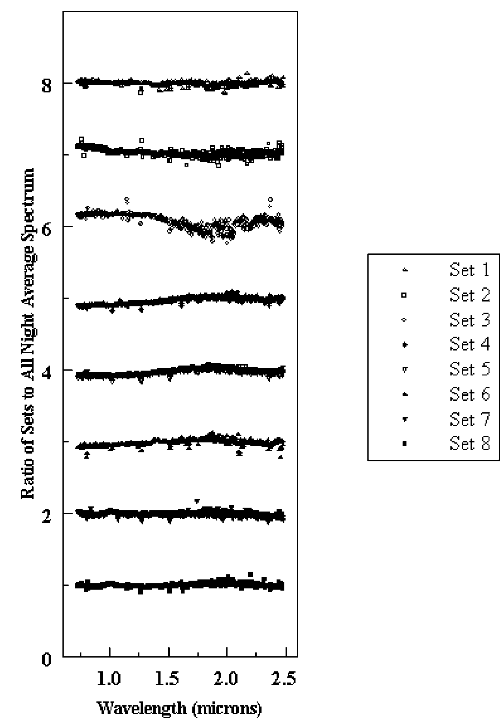

Fig. 5. Ratios of each observational spectral set to the all night average spectrum for 1459 Magnya. Relative variations in the mineral chemistries of the surface pyroxenes with rotation can be seen by comparing the ratios. See text for a detailed discussion. The scatter in each set is correlated with the scatter in the spectra used to perform the ratios. The first three sets show greater noise than the last five sets; Set #3 is the noisiest of the entire night. The noise likely contributes somewhat to the deviations from average for Set #3 in the longer wavelength region. Set #1 is nearly flat across the entire interval and Set #2 displays average values beyond ~ 1.5 μm—an indication that the greater noise in these ratios are not hiding any important variations.

ratios in Fig. 5 are chronologically-ordered from top to bottom and range in time from 1023 to 1456 UT on March 23, 2002. Viewing the sets from top to bottom, several of the ratios exhibit unique features that may be indicative of varying pyroxene chemistries on Magnya's surface.

Mineral abundance variations and changes in particle size on a surface can increase or decrease the intensity of an absorption feature. However, in such situations, the entire absorption feature will be strengthened or weakened, and a normalized ratio of the spectrum to other spectra of the same object will show a positive or negative profile of the feature. However, if there is a change in the relative abundance of mineral species contributing to different wavelength intervals of the feature, the ratio will show a change in one portion of the feature which is not shown in the entire feature. The 1 and 2 μm absorption bands in pyroxenes are each composed of two relatively strong features (e.g., Sunshine et al., 1990). Most relatively low-Ca pyroxenes consist of an exsolved high-Ca pyroxene phase in a nearly Ca-free pyroxene matrix. The shorter wavelength component of the 1 μm feature is produced primarily by the low-Ca phase while the long wavelength component is produced by the higher-Ca phase. The two components of the 2 μm band are produced primarily by the low-Ca (low to high-Fe) and high-Ca (low-Fe) pyroxene components.

For example, Set #2 has a relatively weaker (i.e., ratio > 1.0) short-wavelength wing of the Band I feature relative to the nightly average. This suggests that this portion of Magnya's surface contains a lower abundance of Ca-poor pyroxenes (which would contribute to the short wavelength wing of the feature) relative to Ca-rich pyroxenes than the "average" surface. Set #3 shows a distinct strengthening of the short-wavelength side of the Band II feature, suggesting a higher abundance of the lower-Ca, Fe-rich component of the pyroxenes.

Sets #4, #5, and #6 are very similar and the short-wavelength (i.e., Band I) regions of these spectra suggest a relative increase of the Ca-poor pyroxene component of the surface pyroxenes. Sets #7 and #8 are also similar and relatively flat. The only noticeable feature is a minor peak at $\sim$ 1-μm that might indicate a minor decrease in the Ca-rich pyroxene component. The subtle differences that exist among these sets may indicate the lack of full-rotational coverage. An important future project involves identifying the rotation period for 1459 Magnya.

3.3. Temperature effects

Temperature variations have important secondary effects on near-infrared reflectance spectra and must be taken into consideration (Singer and Roush, 1985; Roush and Singer, 1986; Moroz et al., 2000). In particular, when room temperature laboratory spectra are compared with spectra from Solar System bodies, the temperature difference between the two materials can lead to errors when estimating an object's mineral chemistries (Singer and Roush, 1985). In this paper, temperature effects are potentially important when comparing spectral parameters from 4 Vesta and 1459 Magnya as the Magnya observations were made with the asteroid at an aphelion distance of 3.85 AU. The diameters, albedos and heliocentric distances of these two asteroids are sufficiently disparate that ignoring temperature differences may lead to non-trivial errors. See Table 4 for a comparison of select parameters from 4 Vesta and 1459 Magnya.

To compensate for temperature, we utilized a computer program that calculates the distribution of temperatures across an asteroid surface based on the Standard Thermal Model (STM) (Lebofsky and Spencer, 1989) and assumed values for the various input parameters (albedo, heliocentric distance, phase angle $= 0°$, emissivity $= 1.0$, and beaming factor $= 1.0$). Results were produced for both 4 Vesta and 1459 Magnya. Results calculated a subsolar Vesta surface temperature of $\sim$ 222 K and a subsolar Magnya surface temperature of $\sim$ 195 K—a difference of $\sim$ 28 K.

A temperature increase will cause both pyroxene band centers to migrate to longer wavelengths (Singer and Roush, 1985; Roush and Singer, 1986; Moroz et al., 2000). Using the several calibrations derived from the band positions presented in those papers, Magnya's Band I centers are shifted 0.003 μm (possible range from 0.0004 to 0.003 μm depending upon which calibration was used) and the Band II centers are shifted 0.008 μm (possible range from 0.004 to 0.009 μm)—both toward longer wavelengths to match the higher temperature on Vesta's surface. These band center shifts are incorporated into Magnya's data when making spectral comparisons with Vesta.

Table 4
Comparison of specific parameter for 4 Vesta and 1459 Magnya

Asteroid	Radius (km)	Albedo	Heliocentric distance (AU)	Surface temperature (K)
4 Vesta	289 (max)[1]	0.42[3]	2.36	223
1459 Magnya	15[3]	0.12[3]	3.85[2]	195
1459 Magnya	15[4]	0.22[4]	3.85[2]	189

[1] Thomas et al. (1997).
[2] Magnya heliocentric distance at time of observation on March 23, 2002.
[3] Tedesco et al. (1992).
[4] Tedesco et al. (2002). The revised albedo for 1459 Magnya is 0.22, although it is only based on one sighting. The calculated surface temperature differences cause insubstantial changes in the band center measurements.

4. Comparison with 4 Vesta

A test of a genetic link between 4 Vesta and 1459 Magnya can be made on the basis of mineralogical comparisons of the two asteroids as well as consideration of the dynamical arguments that may support or oppose any linkage. From the standpoint of pyroxene chemistry, 4 Vesta and 1459 Magnya possess distinguishable orthopyroxene chemistries. Magnya's orthopyroxenes have 10 mol% less of the ferrosilite [Fs] component than Vesta's pyroxenes, which have an average composition of $Wo_8Fs_{46}[En_{46}]$ (Gaffey, 1997). Magnya's pyroxene chemistry is $Wo_{7-9}Fs_{36}En_{55-57}$. Figure 6 plots the spectral parameters of both Magnya and Vesta relative to the HED meteorites and is adapted from Fig. 10A in Gaffey (1997).

Figure 6 shows that the Vesta and Magnya pyroxenes plot in discrete and separate regions of the diagram. Although systematic errors may be present due to calibration uncertainties, any errors would shift both the Magnya and Vesta band center data similarly, maintaining their separate identities and lack of overlap. Vesta's pyroxenes plot between the eucrite and diogenite fields, but are closer to the eucrite field. That led Gaffey (1997) to suggest that the surface material of Vesta is composed of basalts of a polymict eucrite or howardite composition. Magnya's pyroxene data plots below and to the left of the Vesta data with some points lying near the diogenite field. This indicates that Magnya represents a eucrite-like assemblage (i.e., pyroxene plus abundant feldspar), based on the overall shape of its reflectance spectrum, with diogenite or diogenite-like orthopyroxenes. This is a combination that has not yet been found among the HEDs in the terrestrial meteorite collections.

Based on oxygen isotopes, Yamaguchi et al. (2002) recently identified a non-HED-related basaltic achondrite (NWA011). Earlier Grossman et al. (1981) had a eucrite-like clast in the polymict eucrite ALHA 76005 whose oxygen isotopes suggested that it derived from a different parent

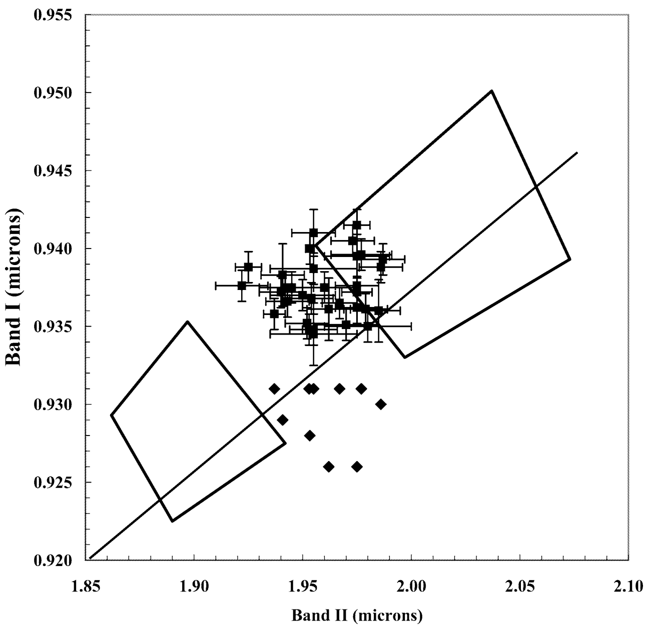

Fig. 6. This is a modified version of Fig. 10A from Gaffey (1997). The data points with error bars represent band center data from 4 Vesta. The data to the lower left of the Vesta region include band center data from 1459 Magnya. The Magnya data are temperature-corrected relative to 4 Vesta. Error bars for Magnya are within the data points and are not plotted. The different locations of the data for Vesta and Magnya suggest differing pyroxene chemistries and origins from different parent bodies.

body than the HED meteorites (or from the NWA011 parent body). These results indicate the existence of at least two basaltic parent bodies in addition to Vesta. Although it is not suggested that Magnya is related to either NWA011 or the ALHA 76005 clast, this discovery lends credence to the idea that there were other basaltic achondrite parent bodies present in the original asteroid belt. Assuming that Magnya formed in the vicinity of its current orbital position, this indicates that Magnya formed in a region of the outer asteroid belt that was more chemically reducing compared to the region from which Vesta formed.

Another consideration is that the HED meteorites are often thought to be actual fragments from the surface of 4 Vesta (Mittlefehldt et al., 1998). Presuming that Magnya is not genetically related to Vesta, it is plausible that Magnya's pyroxenes will be chemically different from the HED or Vesta pyroxenes. Formation in different regions of the solar nebula allows asteroids (and their parent bodies) to exhibit oxidation variations based on the mineral chemistries of the surface materials. This appears to be the case for Magnya and Vesta and bolsters the argument that Magnya is a fragment of a parent body that originally formed in the outer asteroid belt.

Currently, there is no meteorite in the terrestrial collection that matches the spectral characteristics of 1459 Magnya. The less abundant Fs component in Magnya's pyroxenes suggests that this asteroid's parent body formed in a somewhat more chemically reducing environment compared to Vesta. (Although nebular models generally describe an increased oxidation state of solid phases with increasing distance, observations of asteroids indicate that a wide range of oxidation states can occur at any heliocentric distance in the asteroid belt.) We interpret Magnya's surface as being composed of a eucrite-like basaltic assemblage with diogenite-like pyroxenes. The lack of a meteoritic analog in terrestrial collections is consistent with the dynamical arguments suggesting that asteroids beyond 2.8 AU cannot readily provide fragments to Earth and the inner Solar System (Bottke et al., 2000).

Dynamically, Lazzaro et al. (2000) suggest that Magnya and Vesta are not related due to implausibly high ejection velocities that would be necessary to transport the ejecta fragment from 2.36 to 3.14 AU. Another potential mechanism that might work to transport Magnya—if it were a piece of Vesta—is the Yarkovsky effect. However, this mechanism nominally produces asteroid drift in objects with radii < 10 km; peak efficiency of this drift mechanism is for objects with much smaller radii of ~ 10 meters (Bottke et al., 2000). Magnya's radius is estimated to be ~ 15 km (Tedesco et al., 2002).

Only the diurnal Yarkovsky effect can transport asteroid fragments to greater solar distances and this requires prograde rotation (Bottke et al., 2000). Rotation rate and the sense of rotation for Magnya have not yet been reported. Dynamical evidence currently does not support the suggestion that Magnya is a large ejecta fragment from Vesta.

5. Other issues

Michtchenko et al. (2002) raised a variety of important issues about Magnya, its as-yet undiscovered family and the dynamics of the outer asteroid belt beyond 3.0 AU. While their dynamical study raised important insights concerning the presence of many higher-order resonances in the Magnya region, their search for related objects relied only on taxonomy and albedo. Taxonomies, when coupled with albedo information, *can* be *suggestive* of a *general* composition. However, the amount of mineralogic and chemical diversity within the asteroid population simply overwhelms any taxonomy whose goal is to study asteroid compositions (Chapman et al., 1975; Bowel et al., 1978; Tholen, 1984; Barucci et al., 1987; Tedesco et al., 1989; Burbine, 1991; Howell et al., 1994; Bus and Binzel, 2002). Asteroid taxonomies based on observational parameters (rather than mineralogical parameters) are unable to distinguish the many different types of asteroids that exist within a single taxonomic group (Gaffey et al., 1993b).

The question of the existence of any remaining members of the Magnya family will require detailed spectral investigations of asteroids in the region of space bounding Magnya. Michtchenko et al. (2002) list plausible asteroids as potential family members, but their suggestions must be followed with detailed spectral analyses and an investigation of the large number of asteroids in this region that lack even a taxonomic identifier.

6. Conclusion

Mineralogical characterizations strongly suggest that 1459 Magnya is a basaltic fragment from the surface of a differentiated parent body that experienced significant heating, extrusion, potentially full differentiation and later disruption. Furthermore, Magnya's relatively Fs-deficient pyroxenes, relative to Vesta, preclude it from being a fragment from Vesta.

Acknowledgments

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