MINERALOGICAL COMPOSITION OF (25143) ITOKAWA 1998 SF_{36} FROM VISIBLE AND NEAR-INFRARED REFLECTANCE SPECTROSCOPY: EVIDENCE FOR PARTIAL MELTING. P. A. Abell[1,4,*], F. Vilas[1,5,†], K. S. Jarvis[1,2], M. J. Gaffey[3,4], and M. S. Kelley[1,4,*,‡], [1]Planetary Astronomy Group, Astromaterials Research and Exploration Science, NASA Johnson Space Center, Mail Code KR, Houston, TX 77058, paul.a.abell1@jsc.nasa.gov. [2]Jacobs Sverdrup, ESC Group, 2224 Bay Area Blvd., Houston, TX 77058. [3]Department of Space Studies, Box 9008, University of North Dakota, Grand Forks, ND 58202. [4]Visiting Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawai'i under contract from the National Aeronautics and Space Administration, Mauna Kea, HI 96720. [5]Visiting Astronomer, McDonald Observatory, University of Texas at Austin, Fort Davis, TX 79734. [*]National Research Council Associate. [†]Present Address: MMT Observatory, P.O. Box 210065, University of Arizona, Tucson, AZ 85721-0065. [‡]Present Address: Department of Geology and Geography, Georgia Southern University, Statesboro, GA 30460.

Introduction: In September 2005, the Japanese spacecraft Hayabusa arrived at the near-Earth asteroid (25143) Itokawa for a planned 3 month encounter. The Hayabusa (MUSES-C) mission was primarily a proof of concept engineering mission, designed to demonstrate many technologies and objectives. In the process, the Hayabusa spacecraft obtained NIR spectra (~0.85 to 2.1 µm) across the surface of much of the asteroid using the NIRS spectrometer, and VNIR images through broadband filters selected to match the Eight-Color Asteroid Survey (ECAS) using the AMICA imager [1].

To support the mission, spectral data was gathered in March 2001 via ground-based telescopes in order to ensure that good constraints of the composition of Itokawa were obtained before the subsequent spacecraft encounter. Detailed rotationally-resolved ground-based observations were collected to address questions about the mineralogy of the asteroid, and to give a context for the spectral data that Hayabusa acquired. By providing a data set of wider wavelength coverage and higher resolution, the ground-based data could also be used to help calibrate data obtained from the spacecraft sensors.

Observations: Spectral reflectance observations of asteroid (25143) Itokawa were obtained at two separate telescopes with instrumentation producing overlapping wavelength ranges, in order to maximize coverage in the spectral region where mineralogically-diagnostic features are prominent. VNIR observations were obtained of (25143) Itokawa on the nights of March 24, 26, and 27, 2001 UT using the facility CCD cassegrain spectrograph (ES2) at the 2.1-m Otto Struve telescope, University of Texas McDonald Observatory.

Near-infrared observations of asteroid (25143) Itokawa were obtained using the SpeX instrument on the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawai'i [5]. Asteroid (25143) Itokawa was observed during this apparition over a M_v range of 14.10 to 14.96 and a phase angle range of approximately 24 to 52º. Two hundred and thirty-four 120-second near-infrared spectra were taken of this object between 1.00 and 1.30 airmass on March 10, 11, 12, 23, and 24, 2001 UT.

Data Analysis: Combining the data sets from the two telescopes described above gives the opportunity for a good compositional study of asteroid (25143) Itokawa. However, given that asteroid (25143) Itokawa is an NEO, any visible and near-infrared data should ideally be from observations of the object obtained relatively close in time. This is to minimize potential differences in the spectra due to rapidly changing phase angle effects and sub-Earth observations points. Fortunately, observations were obtained at both McDonald Observatory and the NASA IRTF on March 24, 2001 UT with very little difference in viewing geometry of the asteroid.

The combined visible and near-infrared data show excellent agreement and are well matched in the overlap region from ~0.7 to 0.8 µm (Fig. 1). This suggests that any slight differences in viewing geometry of the asteroid at the time of the observations were minor and had little effect on the spectral response of the data obtained from the two telescopes.

A preliminary analysis of the two absorption features, based on approximate band position and shape, suggests that this is an assemblage containing olivine and pyroxene. Pyroxene has absorption features centred near these regions and the presence of an olivine component would contribute to the asymmetric shape of the absorption feature centred near 1.0 µm as is seen in the Itokawa near-infrared spectra shown in Figure 1 [6]. Taxonomically, (25143) Itokawa would be classified as an S-type asteroid from this type of preliminary analysis [7].

More detailed analyses of the data were conducted by isolating the absorption features and removing a linear continuum from the near-infrared spectra [8]. This technique provides a much better constraint on the actual mineralogy of a particular object rather than relying on the taxonomic classification scheme alone

[9,10]. Detailed analyses of the SpeX data set from March 2001 indicate that the average Band I centre is 0.99 ± 0.005 µm, the average Band II centre is 2.01 ± 0.02 µm, and the average Band Area Ratio (BAR) is 0.56 ± 0.16.

Interpretation: Plotting the Band I position and BAR of this asteroid on a Cloutis diagram places (25143) Itokawa within the S(III) field, which is described as a region where the assemblage is considered to bear a significant calcic pyroxene component [9]. The BAR value can also be used as an approximate measure of the abundance of the spectrally dominant mineral phases located on the surface of (25143) Itokawa. The average BAR value of 0.56 ± 0.16 indicates that the abundance of the olivine and pyroxene phases on the asteroid are roughly 70:30, respectively, based on the BAR calibration developed by Gaffey et al. [10]. The BAR values for the entire data set indicate that there is at least a 10% variation across the asteroid's surface, which suggests that there appears to be some degree of heterogeneity on the surface of this object in terms of the relative abundance of olivine and pyroxene phases.

A band-band plot of the two Band centres reveals that the point for the asteroid lies above the calibration curve for orthopyroxenes and clinopyroxenes shown in Figure 2 [11,12]. The two band centre positions determined from the spectral analysis of asteroid (25143) Itokawa applied to the calibrations found in Gaffey et al. [10] give a pyroxene chemistry of ~$Wo_{16 \pm 5}Fs_{44 \pm 5}$. This chemistry is atypical for an ordinary chondrite S(IV) assemblage. The Band I centre position is consistent with similar values found among the LL-chondrites [13], but the corresponding Band II position is markedly outside the range observed for these meteorites [10,13]. Typical LL-chondrite assemblages have the Band II position located approximately at 1.97 µm with a pyroxene composition containing Fe_{22-25} [14,15] (Fig. 2). The observed Band II position for (25143) Itokawa gives a pyroxene composition of $Fe_{44 \pm 5}$, which is much higher than those observed in LL-chondrites. This suggests that Fe (and most likely Ca), is enriched in some portion of the pyroxene found on the asteroid. Hence the data suggest that two pyroxenes are present: primarily a low-Ca orthopyroxene accompanied by a spectrally significant (~15-20%) Ca-pyroxene phase.

Conclusions: The data presented here suggest that (25143) Itokawa has pyroxene compositions that are indicative of phases crystallized from partial melts. This would indicate that the parent body of (25143) Itokawa reached temperatures sufficient to initiate partial melting (~1050 to 1250º C), but that it did not attain the degree of melting required for significant melt mobilization and efficient segregation of the basaltic melt component from the unmelted residual olivine portion. If the interpretations concerning the high olivine content and the pyroxene chemistry are correct, then (25143) Itokawa's parent body most probably was an olivine-rich L- or LL-ordinary chondrite, which started to produce eutectic melts that did not adequately mobilize. Hence the composition of this asteroid would most likely resemble a primitive achondrite.

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Fig. 1: Ave. spectrum of Itokawa for Mar. 24, 2001 UT

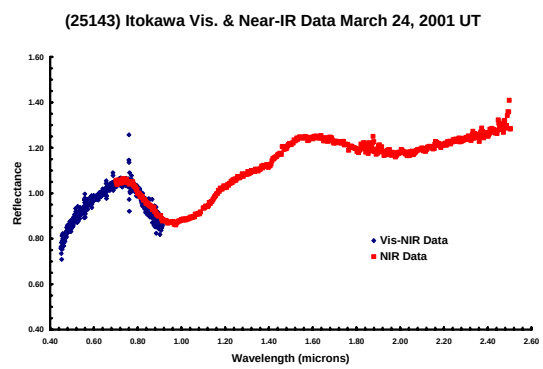

Fig. 2: Pyroxene Band I vs. Band II plot