Mineralogical Analysis of Asteroids 2521 Heidi, 2875 Lagerkvist, and 5134 Ebilson.
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Introduction: Ordinary chondrites are the most abundant of meteorite falls comprising approximately 80% of the falls; approximately 38% of these are L-chondrites which implies a preferential sampling of L-chondrite parent bodies [1,2]. Antarctic meteorite finds confirm that the abundance has persisted for the past million years [3]. Ordinary chondrites are subdivided, decreasing in metal content, into the H, L, and LL chondrites, reflecting the redox conditions at formation. Due to the high percentages of ordinary chondrites among falls, identifying probable parent sources for these meteorites has long been a priority [4]. Identifying probable parent bodies for meteorites is important in the understanding of gradients in temperature, redox, and composition in the early solar system [4]. Until sample return missions are undertaken to determine unambiguous parent bodies, probable parent bodies (or sources) of the L chondrites are identified via VNIR spectroscopy. Possible parent bodies either have the same composition or are preferentially located near a resonance for delivery to near Earth space; a probable parent body has both characteristics [4].

Fossil L-chondrites have been identified in Swedish Ordovician limestone quarries and also in Ordovician sediments in China and other locations [5-7]. Oxygen isotopes from chromite grains in fossil meteorites match those in the recent falls [5-7]. Most L chondrites have experienced extensive shock and ^{40}Ar-^{39}Ar isochrons from current and Ordovician L-chondrites indicate a short interval from the family forming breakup event to Earth impact [5-8]. These findings point to an influx of L-chondrites above the normal rate occurred during the Ordovician period and places an age limit on the catastrophic event which formed the asteroid family which may be the source of these meteorites [5-8]. Dynamical families have been investigated and the Gefion family has been selected due to its proximity to a fast acting mean motion resonance, its age as determined by numerical models, and the dominant taxonomy of family members [9, 10]. Ordinary chondrites fall in the S(IV) subtype of the S taxonomic class [11]. The Gefion family, with the majority of its members of S type (of the members with available taxonomy), is a good source of candidates in the search for the probable parent source of the L chondrites.

The systematic study of the composition of the Gefion family members has yielded 14 asteroids, 11 of which have good quality reflectance spectra for analysis. To date, the Gefion dynamical family exhibits varied assemblages with no dominant mineralogy; only one unambiguous L chondrite source has been identified [14]. Initial analysis of Gefion family asteroids is inconsistent with the hypothesis that this family is the source of the L chondrites. 2521 Heidi, 2875 Lagerkvist, and 5134 Ebilson have a taxonomic class of S, and SMASS phase II visible spectra from 0.44 to 0.93 microns for an increase in wavelength coverage. 2521 Heidi and 2875 Lagerkvist are part of the core membership of the Gefion dynamical family, while 5134 Ebilson is in the background population of asteroids close to the 5:2 resonance.

Reflectance spectra for this ongoing project are obtained from the upgraded SpeX instrument at the NASA IRTF 3 meter telescope on Mauna Kea [15]. Spectra are taken in the low resolution or asteroid mode, in two channels, A and B, and are stored as Flexible Image Transport System (FITS) files. Flats and arcs (from the argon lamp) are also obtained. 2521 Heidi was observed on September 4th 2014; 2875 Lagerkvist and 5134 Ebilson were both observed on March 1, 2015. Both observation nights included extinction stars and solar analogs.

Spextools is used for the initial data reduction in which the background sky, read noise, and dark current are removed, and the wavelength calibration established [16, 17]. The reduced extinction star, solar analog, and asteroid spectra are converted to a format that SpecPR can read. In SpecPR, the standard star spectra are individually checked for sub pixel shifts due to instrument flexure, the shifts are saved and the best spectra are averaged to create a starpack [5]. Each asteroid spectrum is divided by the starpack in which shifts from sub-pixel variation are also done and rated, with the best used in the final average spectrum. A similar process is done for the solar analog. The final asteroid spectrum is then divided by the solar analog spectrum for a solar corrected asteroid spectrum for analysis.

The continuum of the asteroid spectrum is removed for a given set of intervals (one for each band) and band areas/centers are obtained [5, 11]. Band centers are obtained from the best polynomial fit for each band, saved, and band centers recorded. This is repeated for several sets of channels which cover the band intervals.

The multiple determined band areas and centers provide the errors and the average for the band area ratio (BAR), band 1 and band 2 (BI, BII). Band parameters for each asteroid are plotted on BAR/BI and BII/BI plots; the position will indicate which S subtype and where it falls on the Ca-pyroxene trend. To be considered for a plausible ordinary chondrite assemblage, an asteroid's band parameters must place in both the ordinary chondrite fields of the BII/BI plot and the S(IV) region of the BAR/BI plot. Temperature corrections for ordinary chondrites are then applied to those asteroids which are considered plausible ordinary chondrites. The band parameters are variables in the Gaffey et al (2002) equations which provide Fs and Wo percentages and also test whether the mineralogy matches a range of permissible values for H, L, or LL-chondrites. The Dunn et al. (2010) equations are also used if the asteroid is a plausible ordinary chondrite. Data reduction and analysis is currently in progress for 2521 Heidi, 2875 Lagerkvist, and 5134 Ebilson. Band parameters obtained from prior observations of 2521 Heidi place in the S(V) region of the BAR/BI plot and this object is not a plausible ordinary chondrite but instead is indicative of a partially differentiated assemblage.

References: [1] Wasson, J. T., (1974). *Meteorites*. Springer-Verlag, New York. [2] Burbine, T. H., (2001) In (Bottke et al. Eds.) *Asteroids III*. University of Arizona Press, Tucson, 653-667. [3] Harvey, R., (2003) *Chem. Erde*, *63*, 93-147. [4] Gaffey, M. J., (2011) In *XV Special Courses at the National Observatory of Rio de Janeiro*. AIP Conf. Proc. 1386, 129-169. [5] Heck, P. R. et al., (2008) *MAPS*, *43*, 517-528. [6] Heck, P. R. (2010) *GCA*, 74, 497-509. [7] Schmitz, B. et al (2003) *Science*, *300*, 961-964. [8] Korochantseva, E. V. et al (2007) *MAPS*, *42*, 113-130. [9] Bottke, D. et al (2009) *LPS XXXX*, Abstract # 1445. [10] Nesvorny, D et al (2009) *Icarus*, *200*, 698-701. [11] Gaffey, M. J. et al (1993) *Icarus*, *106*, 573-602. [12] Blagen, J.R. (2012) *Testing the Gefion Family as a possible Parent Body for the L-chondrite Meteorites*. MS Thesis, University of North Dakota. [13] Gaffey, M. J. et al (2002) In (Bottke, W. F. et al eds.) *Asteroids III*. University of Arizona Press, 183-204. [14] Roberts, R. V. and M. J. Gaffey (2014) *LPS XXXXV*, Abstract # 1263. [15] Rayner, J. T. et al., (2003) *PASP*, *115*, 362-382. [16] Cushing, M., C., et al. (2004) *PASP*, *116*, 362-376. [17] Vacca, W. D., et al. (2003) *PASP*, *115*, 389-409.

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