Near-infrared Spectroscopy of 3:1 Kirkwood Gap Asteroids: A Battalion of Basalts. S. K. Fieber-Beyer[1,2] and M. J. Gaffey[1,2], [1]Dept of Space Studies, Box 9008, Univ. of North Dakota, Grand Forks, ND 58202. [2]Visiting astronomer at the IRTF under contract from the NASA, which is operated by the Univ. of Hawai'i Mauna Kea, HI 96720. sherryfieb@hotmail.com gaffey@space.edu

Introduction: The mineralogy, petrology, isotope chemistry, and cosmic ray exposure history revealed by laboratory study of the meteorites provides detailed insights into the relative and absolute timing of major processes operating and conditions present in the early inner solar system. However, the source regions of the individual meteorite types are poorly constrained because their specific parent bodies and hence their early solar system locations have generally not yet been identified. Mineralogical characterizations of the asteroids provide a "geologic map" of conditions and processes in the early solar system. The chronological studies of the meteorite types provide a "clock" for the relative timing of those events and processes. By identifying the source asteroids of particular meteorite types, the "map" and "clock" can be combined to provide a much more sophisticated understanding of the history and evolution of the early solar system.

The Kirkwood Gaps (KG) are zones in the asteroid belt located at proper motion resonances with Jupiter. The KGs are depleted in asteroids. According to several theoretical models, the bulk of meteoroids and near-Earth objects delivered to the inner solar system originate from the 3:1 and ν_6 resonances [1-4].

The current spectroscopic investigation of the 3:1 KG asteroids assumes each of the targeted asteroids is individually a potential parent body of one of a variety of meteorite types. The original parent bodies of these objects were disrupted so long ago, that any other surviving remnants are lost in the background population. The results of the Fragment Injection Model [1] were used to select asteroid targets predicted to be strong sources of meteoroids in Earth-crossing orbits. In addition, asteroids with i >30° were not selected due to high geocentric velocities.

Probable parent bodies have been identified for four [5-7] of the 135 distinguishable meteorite classes [8]. These three parent bodies: 4 Vesta, 3103 Egar, and 6 Hebe account for ~40% of terrestrial meteorite falls. Therefore ~60% of the meteorite fall flux and ~97% of the meteorite classes still need to be accounted for. Asteroids within the "feeding zone" of the 3:1 KG are good candidates for such parent bodies.

Previous VNIR (~0.3 – 0.95 μm) spectral observations [9-13] of 3:1 KG asteroids do not permit the detailed mineralogical analysis required to rigorously test possible meteorite affinities. Ambiguities introduced by space weathering undermine the validity of any putative asteroid-meteorite links derived from curve matching, requiring the use of interpretive methodologies insensitive to space weathering [14].

Near-infrared spectral data in the 0.8-2.5 μm wavelength range is necessary for detailed characterizations of surface minerals and is not available for most asteroids adjacent to the 3:1 KG. Thus far, the current research project has been successful in linking several asteroids to meteorite types such as the mesosiderites, H & LL chondrites, CCV/CO chondrites, pallasite/olivine bearing, & winonaite meteorites [15-18].

Observations and Data Reduction: NIR spectra of asteroids (660) Crescentia, (797) Montana, (879) Ricarda, (1018) Arnolda, (1064) Aethusa, (1166) Sakuntala, (1391) Carelia, (1501) Baade, (1607) Mavis, (1644) Rafita, (1722) Goffin, (6649) Yokotatakao were obtained June 12 & 13, 2010, June 3 & 4, 2011, and July 19-21, 2011 at the NASA IRTF using the SpeX instrument [19] in the low-res spectrographic mode. Asteroid & standard star observations were interspersed within the same airmass range to allow modeling of atmospheric extinction. Data reduction was done using previously outlined procedures [20,21].

The particular subset of asteroids presented here each have absorption features located near 1- and 2-μm. Figure 1.The band centers and band area ratios (BAR) are diagnostic of abundance and composition of the mafic silicates [e.g.,20-29] and are measured relative to a linear continuum fit tangent to the spectral curve outside the absorption feature [e.g. 24]. To estimate the error, several polynomial fits were used sampling different ranges of points within the Band I & II spectral intervals. The uncertainty was estimated from the difference between the min and max determined values (Table 1).

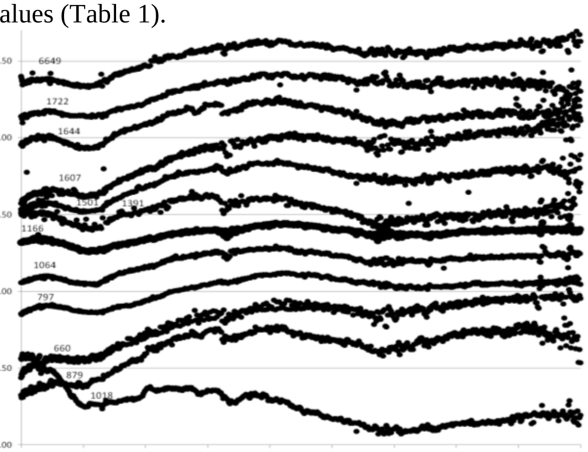

Figure 1

Analysis: After initial measurement of the Band I and Band II centers, the pyroxene chemistry is determined using [20]. If the pyroxene chemistry is consistent with an HED assemblage, the [28] equations are used to verify the pyroxene chemistry and if the pyroxene chemistry is consistent with an ordinary chondrite assemblage the [29] equations are applied as verification of the derived silicate mineralogy. Meteorite affinities are currently under investigation.

Conclusions: Not all igneous activity produces fully differentiated bodies. Once heating has occurred to produce a melt, three possible outcomes are possible: I. Low degree of partial melting and extraction of basaltic melt to surface leaving a residue of olivine with Fe-Ni interior II. Extensive partial melting with extraction of basalt (crust), residue olivine, and NiFe melts (core) III. Complete melting and differentiation with a basaltic crust, cumulate olivine mantle, and NiFe core.

All twelve asteroids presented in this paper exhibit two absorption features located near 1 and 2 µm, with varying spectral redness, which are typical of anhydrous mafic silicate (i.e., olivine and pyroxene-bearing) assemblages. Each are derived from partial melt residues, cumulates, or complete differentiation. The iron/stony-iron meteorite groups indicate a minimum of 70 discrete parent bodies. The crustal and mantle portions of these disrupted bodies are grossly under represented in the terrestrial meteorite collection.

Understanding the compositional and dynamical nature of asteroids is necessary to address: attainment and exploitation of space resources, impact hazards to society, impact mitigation strategies, and biological consequences on Earth due to impact.

References: [1] P. Farinella et al. (1993) *Icarus* 101, 174-187. [2] A. Morbidelli et al. (1995) *Icarus* 114, 33-50. [3] A. Morbidelli et al. (1995) *Icarus* 115,60-65. [4] J.H. Ji et al. (2007) *Chin. J. Astron. Astrophys* **7**, 148-54. [5] T.B. McCord et al. (1970) *Science* 168, 1445-47. [6] M.J. Gaffey et al. (1992) *Icarus* 100, 95-109. [7] M.J. Gaffey et al. (1998) MAPS 33, 1281-95. [8] K. Keil (2000) *Planet. Space Sci.* 48, 887-903. [9] L.A. McFadden et al. (1984) *Icarus* 59, 25-40. [10] L.A. McFadden et al. (1987) *Lunar Planet. Sci. XVIII*, 614-15. [11] L.A. McFadden et al. (1991) *Asteroids, Comets, Meteors* 416-23. [12] F. Vilas et al. (1992) *Icarus* 100, 85-94. [13] C.R. Chapman et al. (1979) Univ. of Arizona Press, Tucson, 655-87. [14] M.J. Gaffey (2010) *Icarus* 209, 564-74. [15] S.K. Fieber-Beyer et al. (2011) *Icarus* 212, 149-57. [16] S.K. Fieber-Beyer et al. (2011) *Icarus* 213, 524-37. [17] S.K. Fieber-Beyer et al. (2011) *Icarus* 214, 645-51. [18] S.K. Fieber-Beyer and M.J. Gaffey (2012) *Icarus* 221, 593-602. [19] J.T. Rayner et al. (2003) *Pubs. of the Astronomical Society of the Pacific* 115, 362-82. [20] M.J. Gaffey et al. (2002), *Asteroids III*, 183-204. [21] P.S. Hardersen et al. (2005) *Icarus* 175, 141-58. [22] J.B. Adams (1974) *JG R*79, 4829-36. [23] J.B. Adams (1975) *In Infrared and Raman Spectroscopy of Lunar and Terrestrial Minerals*, 91-116. [24] E.A. Cloutis et al. (1986) *JGR* 91, 11641-53. [25] M.J. Gaffey et al. (1993) *Icarus* 106, 573-602. [26] H.K. Gastineau-Lyons et al. (2002) *MAPS* 37, 75-89. [27] T.H. Burbine et al. (2003) *Antarct. Meteorite Res.* 16, 185-95. [28] T.H. Burbine et al. (2009) *MAPS.* 44, 1331–41. [29] T.L. Dunn et al. (2010) *Icarus 208, 789–97*.

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Table 1

Asteroid	BI µm	BII µm	BAR	Chemistry*,**,***	Ol ****
660	0.93 ±.01	1.91 ±.03	1.59 ± .11	$Fs_{28.5(\pm5)}Wo_{7.4(\pm4)}$* $Fs_{33.4(\pm3)}Wo_{6.1(\pm1)}$**	28%
797	0.95 ±.02	1.98 ±.02	1.61 ± .10	$Fs_{41.1(\pm5)}Wo_{15.5(\pm4)}$ $Fs_{50.8(\pm3)}Wo_{12.8(\pm1)}$**	27%
879	0.92 ±.01	1.87 ±.03	2.56 ± .30	$Fs_{17.8(\pm5)}Wo_{2.8(\pm3)}$* $Fs_{24.1(\pm3)}Wo_{2.5(\pm1)}$**	0%
1018	0.92 ±.02	1.87 ±.03	1.75 ± .15	$Fs_{17.8(\pm5)}Wo_{1.3(\pm3)}$* $Fs_{24.1(\pm3)}Wo_{2.5(\pm1)}$**	22%
1064	0.93 ±.01	1.91 ±.05	1.07 ± .15	$Fs_{25.4(\pm5)}Wo_{3.8(\pm4)}$* $Fs_{16.9}Fa_{15.1}$***	50%
1166	0.93 ±.01	1.93 ±.03	0.87 ± .03	$Fs_{16.5(\pm5)}Wo_{0(\pm4)}$* $Fs_{16.9}Fa_{15.1}$***	59%
1391	0.93 ±.02	2.00 ±.05	2.31 ± .34	$Fs_{52.7(\pm5)}Wo_{8.7(\pm4)}$* $Fs_{42.6(\pm3)}Wo_{9.7(\pm1)}$**	0%
1501	0.93 ±.01	1.94 ±.02	1.47 ± .30	$Fs_{36.6(\pm5)}Wo_{6.2(\pm4)}$* $Fs_{36.5(\pm3)}Wo_{7.3(\pm1)}$**	33%
1607	0.93 ±.01	1.95 ±.04	1.19 ± .08	$Fs_{22(\pm5)}Wo_{3(\pm3)}$* $Fs_{16.9}Fa_{15.1}$***	45%
1644	0.93 ±.01	1.89 ±.02	1.74 ± .10	$Fs_{23.2(\pm5)}Wo_{5.8(\pm3)}$* $Fs_{31.4(\pm3)}Wo_{5.3(\pm1)}$**	22%
1722	0.94 ±.01	1.95 ±.03	0.56 ± .20	$Fs_{22.6(\pm5)}Wo_{2.8(\pm3)}$* $Fs_{16.9}Fa_{19.5}$***	71%
6649	0.93 ±.01	1.92 ±.04	2.10 ± .13	$Fs_{31.2(\pm5)}Wo_{8.7(\pm4)}$* $Fs_{34.4(\pm3)}Wo_{6.5(\pm1)}$**	7%

*The pyroxene Fs & Wo value were derived using [20].
** The pyroxene Fs & Wo value were derived using [28]
***Fs and Fa value was derived from [29]
****The olivine abundance was calculated using [20]