COMPOSITIONAL INVESTIGATION OF NEAR-EARTH ASTEROIDS 6456 Golombek, (5660) 1974 MA, (13553) 1992 JE. V. Reddy[1,3], M. J. Gaffey[1,3], P. A. Abell[2,3] and P. S. Hardersen[1,3], [1]Department of Space Studies, Box 9008, University of North Dakota, Grand Forks, North Dakota 58202, vishnu.kanupuru@und.nodak.edu; [2]NASA Johnson Space Center, Astromaterials and Exploration Science, Mail Code KR, Houston, Texas 77058; [3]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, Hawai'i 96720.

Introduction: Near-Earth Asteroids (NEAs) are the most important, yet one of the least understood class objects in the solar system. Of the ~3600 NEAs [1] discovered so far, only a handful have detailed mineralogic and compositional information. While attempts [2,3,4,5] have been made to taxonomically classify a subset of this population, many questions regarding their specific origin, geologic history and meteorite affinities remain unanswered. The work presented here adds to the expanding effort to characterize and understand these objects.

Observations and data reduction: Due to their orbital geometry, NEAs are observable only for very short intervals. An observing campaign was launched in July-August 2005 to obtain near-IR spectroscopic observations of NEAs. A total of seven NEAs were observed during the course of three nights (July 30, 31 & Aug. 1 UT) using the SpeX near-infrared spectrograph [6] at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawai'i. All SpeX data were subsequently reduced using IRAF and the PC-based SpecPR spectral processing program [8]. Isolation of the Band I and II absorption features, and calculation of band area ratios (BARs) [9] were accomplished using SpecPR. All spectral parameters (band centers) have been corrected for temperature-induced spectral effects based on the works by [10,11,12].

Analysis and Results: *6456 Golombek.* The object was discovered from Palomar in 1992 and classified as a member of the Amor class of NEAs. Near simultaneous lightcurve observations for 6456 Golombek were carried out by various groups during the run [7]. Based on CCD photometry, the rotation period was estimated to be 2.50 hours with an amplitude of 0.13 [7]. Sixty spectra covering a full rotation period were obtained on Aug. 1 UT when the asteroid's apparent visual magnitude was 15.2. No spectral variations (band centers and BARs) were observed on opposite rotational phases of the object. The average spectrum of Golombek shown in Fig. 1 exhibits a broad, asymmetric ~1 micron feature and a shallow weaker one at ~2 micron feature. The calculated band centers are 1.0- and 1.95-microns respectively with a lower limit BAR of ~0.31. It is important to note that there is an uncertainty associated with the BAR due to scatter beyond 2.40 microns. Golombek plots above the pyroxene trend line on the band-band plot [13,14] initially indicating the presence of olivine along with pyroxene. Upon applying the band I displacement correction for olivine (~0.1) [15] Golombek drops just below the pyroxene trend line but towards the orthopyroxene side. This would indicate the presence of a Type A clinopyroxene phase along with olivine and orthopyroxene in the assemblage. The inflection at ~1.30-microns could be due to olivine, plagioclase feldspar or high-Fe orthopyroxene [16,17].

It is possible to calculate the mean pyroxene chemistry (orthopyroxene + Type B clinopyroxene) by dropping the olivine uncorrected Band I center on the trend line of the band-band plot. Using calibration work described in [15] we estimate the chemistry of orthopyroxene to be $Wo_{8\pm4}$ $Fs_{40\pm5}$. This chemistry plots in the low-Ca orthopyroxene region on the pyroxene quadrilateral away from chondritic pyroxenes which have much lower Fe and Ca contents. If one takes into account the BAR uncertainties and subsequent olivine corrected band I position, the chemistry changes only in terms of calcium and would move it up and further away from the chondrites on the quadrilateral. We do not believe that space weathering has any significant effect on the derived composition as it does not affect spectral parameters like band centers and BAR [18].

(5660) 1974 MA. This Apollo class NEA was discovered from Palomar in 1974. The rotation period is 17.5 hours with amplitude of ~0.3 magnitude [7]. Seventy spectra, spread over two nights (July 30-31) were obtained when the asteroid's apparent visual magnitude was 14.7. [19] have classified it as taxonomically as a Q-type object. An average spectrum for one night (30 sepctra) of 1974 MA is shown in Fig. 2. Like Golombek, the asteroid shows a broad band I feature at 1.02-microns, a better defied band II feature at 2.0-microns and an inflection at 1.3-microns with a BAR of ~0.06.

Based on band I & II centers 1974 MA plots higher than Golombek on the band-band plot [13,14]. We suggest the presence of sub-equal phases of olivine, ortho and clinopyroxene in the surface assemblage. Applying band I correction for olivine drops the object much lower than Golombek below the pyroxene trend indicating the presence of a clinopyroxene component. As described above, one can calculate the average phase chemistry of the pyroxenes based on the corre-

sponding Band I center at the intersection point between the olivine uncorrected and corrected Band I centers on the trend line. The estimated chemistry of the pyroxenes is $Wo_{12\pm4}$ $Fs_{42\pm5}$ which plots in the pigeonite area of the pyroxene quadrilateral suggesting a possible eucrite-like composition for the pyroxene which would indicate a chondritic partial melt [20].

(13553) 1992 JE. The object was discovered from Geisei, Japan, in 1992 and is classified as a member of the Amor class of NEAs. 1992 JE is a slow tumbling non-principle axis rotator with a rotation period of ~38 hours and an amplitude of 1.1 [7]. Sixty spectra were obtained in total on two nights covering a rotation phase from 0º to 80º. The apparent visual magnitude of the object was 15.0. Fig. 3 shows the average of 20 spectra of 1992 JE from July 30, 2005. A weak band I feature at 0.99-microns with a weaker inflection at ~1.30-microns is seen. The constant reflectance between ~1.6-~2.1-microns rules out a 2-micron pyroxene feature. The sharp rise beyond ~2.1-microns appears to be thermal emission.

Based on its heliocentric distance of 1.180 AU at the time of observation, it is likely that this deviation is due to thermal emission by the asteroid as it is warmed by solar radiation. The observed position of band I (0.99-microns) is too short for a single mineral assemblage like olivine [16]. Using band I position and calibration for olivine/orthopyroxene mixtures by [9] the estimated upper limit for pyroxene in a pyroxene-olivine mixture is 20%. Using methods developed by [21] one can independently estimate the albedo of the object given the excess thermal emission, the phase angle and heliocentric distance at the time of observation. We estimate the albedo of 1992 JE as 3±1% with a thermal excess of 12.5±2.5% at 2.4-microns. Based on the presence of an olivine-pyroxene mixture along with low albedo, possible meteorite analogs for this asteroid would include black or CV3 chondrites [22]. Using the estimated albedo we calculate the diameter of the asteroid to be 5±1 km based on methods by [23].

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References: [1] JPL NEO website, http://neo.jpl.nasa.gov/ (Nov. 2005). [2] Binzel R.P. et al. (2001) *Icarus,* 151, 139-149. [3] Binzel R.P. et al. (2004) *Planet. & Sp. Sci.,* 52, 291-296. [4] Binzel R.P. et al. (2004) *MAPS.,* 39, 351-366. [5] Binzel R.P. et al. (2004) *Icarus,* 172, 408-414. [6] Rayner J.T. et al. (2003) *Publ. ASP,* 115 (805), 362-382. [7] Pravec P. (Pers. Comm.) Aug., 2005. [8] Clark R.N. (1980) *Publ. ASP,* 92, 221-224. [9] Cloutis et al. (1986) *JGR.* 91(B11), 11641-11653. [10] Roush T.L. (1984) Master's thesis, Univ. of Hawaii. [11] Singer R.B. & Roush T.L. (1985) *JGR.* 90, 12,434-12,444. [12] Roush T.L. & Singer R.B. (1986) *JGR.* 91, 10,301-10,308. [13] Adams, J.B. (1974) *JGR.* 79, 4829-4836. [14] Cloutis E.A. & Gaffey M.J., (1991) *JGR.* 96(E5), pp. 22809–22826. [15] Gaffey, M.J. et al. (2002) In *Asteroids III,* 183-204. [16] Burns, R.G. (1993) In *Min. App.of CFT,* pp 551. [17] Adams, J.B. & Goullaud, L.H. (1978) LPSC IX, #1A. [18] Gaffey, M.J. (1991) LPSC XXXII, #1587G. [19] Bus, S.J. & Binzel, R.P. (2002) *Icarus* 158, 146-177. [20] Stolper, E. (1977) *GCA,* 41, 587-611. [21] Abell, P.A. (2003) Ph.D. thesis, Rensselaer Poly. [22] Gaffey, M.J. (1976) *JGR.* 81, #5 905-920. [23] Flower, J.W. & Chillemi J.R. (1992) Tech. Report PL-TR-92-2049, 17-43.

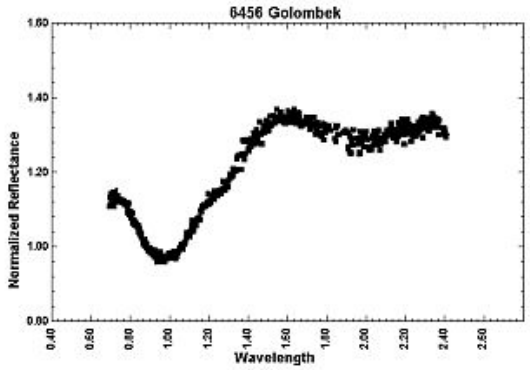

Fig. 1: Average spectrum of Amor 6456 Golombek.

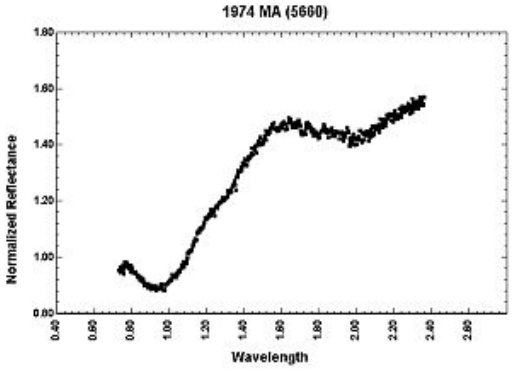

Fig. 2: Average spectrum of Apollo (5660) 1974 MA.

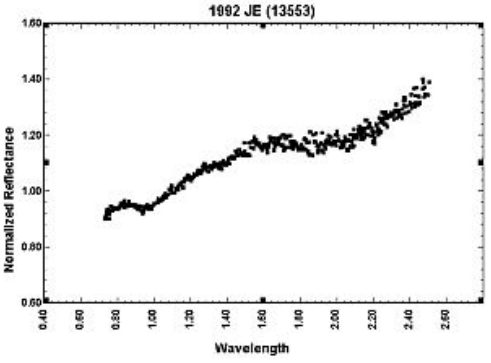

Fig. 3: Average spectrum of Amor (13553) 1992 JE.