HIGHLY POROUS AND COMPOSITIONALLY INTERMEDIATE ORDINARY CHONDRITE LAP 031047.

A. Wittmann[1], D. A. Kring[1], J. M. Friedrich[2,3], J. Troiano[2], R. J. Macke[4], D. T. Britt[4], T. D. Swindle[5], J. R. Weirich[5], D. Rumble III[6]. [1]Lunar & Planetary Institute, Houston, TX. 77058, wittmann@lpi.usra.edu, kring@lpi.usra.edu; [2]Department of Chemistry, Fordham University, Bronx, NY 10458, friedrich@fordham.edu; [3]Department of Earth & Planetary Sciences, American Museum of Natural History, New York, NY 10024; [4]University of Central Florida, Orlando FL 32816, britt@physics.ucf.edu; [5]Lunar & Planetary Laboratory, University of Arizona, Tucson AZ 85721, tswindle@U.Arizona.edu, jweirich@lpl.arizona.edu; [6]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, drumble@ciw.edu.

Introduction: Antarctic meteorite LaPaz Icefield (LAP) 031047 was classified as a partly to completely impact-melted L-chondrite with a fine-grained, uniform texture that includes numerous voids and rounded metal-sulfide particles [1]. Its apparent age of 50 to 100 Ma was determined by Ar-Ar radioisotopic dating, and interpreted as partial resetting due to a late impact event [2]. The high porosity and intermediate chemical character between L- and H-chondrites calls for the exploration of LAP 031047's origin.

Methods and Results: *General petrography:* The sample specimen is dark grey in color, very friable and porous but does not appear to be strongly weathered. Thin section LAP 031047,4 captures an area of ~ 1.5 cm^2 from the original mass of 16.47 g [1]. The rock is shock blackened with abundant inclusions of sub-µm troilite and metal in the silicate minerals. It is mostly composed of crushed chondrules, single mineral fragments, a low amount of fine-grained matrix and contains many voids. Point counting yields a porosity of 26.7 vol.%. Thirteen well-recognizable chondrule fragments (RP, PP, GO, POP, PO, BO) are on average 0.86 mm in size (0.4-1.48 mm), which agrees best with average sizes of chondrules reported for L- and LL-chondrites [3]. The abundance of metal and troilite in the meteorite is similar to that in H-chondrites [4]. Metal-troilite particles approach a bimodal size-distribution with maxima for particle numbers in the ranges < 1µm and 59-151 µm.

Oxygen isotope data: Two sample splits of LAP 031047 yield $\Delta^{17}O$ of 1.21 ± 0.21**,** $\delta^{17}O$ of 3.36 ± 0.23, and $\delta^{18}O$ of 4.07 ± 0.04. According to [5], these $\Delta^{17}O$ values span the full range of what is typical for L and LL-chondrites. The $\delta^{17}O$ values are slightly lower than the mean value of 3.52 ± 0.14 for L-chondrites. However, the $\delta^{18}O$ values match those of H-chondrites [5].

Physical properties: A bulk density of 2.69 ± 0.06 g/cm^3 was measured on a 993 mg chip of LAP 031047, which is much lower than typical ordinary chondrite values of 3.22-3.42 g/cm^3 [6]. Helium pycnometry of the same sample of LAP 031047 using the methods in [7] yielded a grain density of 3.67 ± 0.23 g/cm^3 and, consequently, a porosity of 27.1 ± 5.1%. The grain density falls within the normal range for L-chondrites [6], though the porosity is much higher – and the correlated bulk density much lower – than is typical for meteorites of this type [6]. Synchrotron x-ray microtomography (µCT) data collected at a resolution of 15.9 µm/voxel yielded an observable coarse porosity of 11.6%, which is 43% of the He pycnometry porosity.

Shock petrography: Recognizable shock features are limited to brittle deformation and shock blackening [1]. Undulous extinction occurs in olivine along with planar fracturing. No shock melt, high pressure polymorphs, diaplectic glass, solid state recrystallization or mosaicism were identified. Frequently, radial fractures occur in olivine clasts, which appear to originate from point sources on the rims of mineral clasts. Such features were described by [8] from shocked sandstone of Meteor Crater and termed "concussion fractures". Kieffer interpreted concussion fractures as results from the impact of neighboring grains during pore crushing from the passage of the shock wave. Since pore spaces are retained in LAP 031047 along with concussion fractures, a low-pressure regime (equivalent to ~ 4.5 GPa in porous quartz-sandstone) is indicated [8]. Shock petrographic classification according to the method of [9] suggests weak shock metamorphic overprints of stage S2-3; 45 % of the olivine grains analyzed appear unshocked. Therefore, average shock pressures were below ~10 GPa but a shock metamorphic overprint of up to 20 GPa occurs locally. This is in agreement with the high porosity and the possibility that this rock is composed of variably deformed debris.

Microprobe data: Olivine (Fa_{20-23}, n=123) occasionally exhibits subtle chemical zonations within larger grains that have FeO-enriched rims and more MgO rich cores. Occasionally, Ol is intergrown with minute chromite, sulfide and Fe-Ni metal grains; FeO concentrations between 17.7-20.8 wt.% fall in-between the typical ranges of H and L-chondrites [3]. Compositions of Low-Ca pyroxene (En_{76-84}, Fs_{15-19}, Wo_{1-5}, n=79) are within the typical range of H-chondrites ($Fs_{14.5-20}$). Low-Ca pyroxene is richer in CaO than typical for Low-Ca pyroxene of type 4-6 ordinary chondrites [3], but similar to that in L-chondrite impact melt MIL 05029 [10]. Occasionally, low-Ca pyroxenes are compositionally zoned with respect to MgO and FeO. Most low-Ca pyroxenes are orthorhombic, consistent with higher, type 5 to 6, petrologic type [11]. Pigeonite (En_{75-77}, Fs_{17-20}, Wo_{5-8}, n=12) is a minor phase and High-Ca pyroxene (En54 and 59, Fs14 and 15, Wo27 and 31, 2 augites) occurs as exsolutions in low-Ca pyroxene. Compared to average compositions of H4-6 or L4-6 chondrites [3], LAP 031047 Feldspar (Ab_{42-64}, An_{33-57}, $Or_{0.4-2.8}$; n=28) shows distinct compositions similar to H4 chondrite Yamato 74155 [12]. Relic feldspathic mesostasis associated with chondrules is occasionally present. Troilite exhibits Ni concentrations of ~ 0.1 wt.%. Fe-Ni metal is P-saturated and metal aggregates larger than ~100 µm display textures of isolated ~10 x 4 µm domains of taenite (up to 26.98 wt.% Ni) in a kamacite matrix (~6.5 wt.% Ni). These textures are similar to the "coarse-grained zoneless plessite" particles of [13]. Average Co concentrations of 0.33 wt.% in kamacite (n=128) are slightly lower than what is typical for equilibrated H-chondrites [14]. An affinity with H-chondrites is confirmed by average Co concentrations of 0.18 wt.% (n=15) in taenite domains [15].

Petrologic type: Microcrystalline feldspar, rare relic mesostasis in chondrule fragments and dominant orthorhombic low-Ca pyroxene is indicative of a higher petrologic type 5 [11]. However, olivine and pyroxene compositions are distinctly non-uniform, indicating the possibility that less equilibrated components are part of the assemblage.

Whole rock chemical composition: Using methods of [16], 45 trace elements were analyzed by ICP-MS on three 120 mg sample splits. Lithophile abundances within ordinary chondrites are known to be similar across all the ordinary chondrite groups [17] and LAP 031047 possesses lithophile abundances akin to other ordinary chondrites. CI normalized mean siderophile (Rh, Ir, Mo, Pt, Co, Pd; n=6) abundances of LAP 031047 give an average of 1.73 ± 0.44, which falls between those of the H chondrites (n=2, 1.94 ± 0.33) and L chondrites (n=19; 1.35 ± 0.10). Moderately volatile elements (Sb, Sn, Rb, Cs, Se, Ag, Te, Zn) are severely depleted (≤ 0.12 × CI) in LAP 031047 compared to typical abundances (~0.4 × CI) in ordinary chondrites. As for the cause, a removal of Fe-FeS eutectic can be ruled out because given mass balance considerations, refractory lithophiles in LAP 031047 do not seem enriched enough for significant siderophile loss to have occurred.

Discussion: LAP 031047 is an unusual ordinary chondrite meteorite. It exhibits an oxygen-isotopic composition and petrologic characteristics between those of H- and L-chondrites, is shock-blackened and depleted in fine matrix material. The high porosity of ~25 vol.% requires mild shock-induced lithification without compaction, which is in agreement with the generally low degree of shock metamorphic overprint (<10 GPa) that was shown to be sufficient for grain-boundary melting [18].

The unusual composition of LAP 031047 may indicate that it never accreted a similar abundance of volatiles as the H chondrites, possibly because it accreted at a higher temperature. Otherwise, volatiles may have been lost during an impact scenario that stripped it of fine matrix components and caused the young degassing age [2]. However, the maximum temperature increase of ~50 °C that results from shock pressures of 5-10 GPa is unlikely to cause significant degassing of a consolidated chondrite [9].

The seemingly contradictory composition and petrography of LAP 031047 may be due to repeated impact processing. This could have included deposition as size sorted debris in hot ejecta 50-100 Ma ago, possibly in close proximity to a superheated impact melt pod. Degassing, isotopic resetting and possibly thermal annealing of pre-existing shock features [19] would have resulted. Metallographic textures constrain annealing temperatures to <950 °C because troilite was not melted [20]. The diagnosed shock metamorphic overprint could have then been caused by a younger impact, which sent LAP 031047 into an Earth-crossing orbit.

Most intriguingly, LAP 031047 may stem from an as of yet unrecognized ordinary chondrite-like asteroid.

References: [1] Connolly et al. (2007) *MAPS 42*, 1647-1694. [2] Weirich et al. (2008) *LPSC XXXIX*, Abstract # 1665. [3] Brearley & Jones (1998) *Rev. Min. 36*, 398 p. [4] McSween et al. (1991) *Icarus 90*, 107-116. [5] Franchi (2009) *Rev. Min. Geochem.* 68, 345-397. [6] Consolmagno et al. (2008) *Chemie der Erde 68*, 1-29. [7] Sasso et al. (in press) *MAPS*. [8] Kieffer (1971) *JGR 76*, 5449-5473. [9] Stöffler et al. (1991) *GCA 55*, 3845-3867. [10] Weirich et al. (in prep.) MAPS. [11] Van Schmus & Wood (1967) *GCA 31*, 747-765. [12] Nagahara (1980) *Mem. NIPR Spec. Iss. 17*, 32-49. [13] Reisener and Goldstein (2003) *MAPS 38*, 1679-1696. [14] Rubin (1990) *GCA 54*, 1217-1232. [15] Afiattalab & Wasson (1980) *GCA 44*, 431-446. [16] Friedrich et al. (2003) *GCA 67*, 2467-2479. [17] Kallemeyn et al. (1989) *GCA 53*, 2747-2767. [18] Bischoff et al. (1983) *EPSL 66*, 1-10. [19] Rubin (2004) *GCA 68*, 673-689. [20] Scott (1982) *GCA 46*, 813-823.