PETROGRAPHY OF MIL05029, THE FIRST ACCRETIONAL IMPACT MELT FROM THE L-CHONDRITE PARENT BODY. A. Wittmann[1], J. R. Weirich, T. D. Swindle[2], D. Rumble III[3], and D. A. Kring[1] [1]Lunar & Planetary Institute, Houston, TX. 77058, wittmann@lpi.usra.edu, kring@lpi.usra.edu, [2]Lunar & Planetary Laboratory, University of Arizona, Tucson, AZ 85721, tswindle@U.Arizona.edu, jweirich@lpl.arizona.edu. [3]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, drumble@ciw.edu.

Introduction: The original description of MIL05029 suggests an impact melt breccia of L-chondrite affinity [1]. Most recently, an Ar-Ar age of 4.53 +/-0.02 Ga was determined for this rock, which makes it the oldest known melt rock from the L-chondrite parent body [2]. This report explores the petrography, chemistry, and cooling rates of MIL05029 to provide new insights into the early evolution of the L-chondrite parent body.

Methods: The modal composition of thin section MIL05029,4 was determined by point counting under reflected light and with BSE images. These results were verified with X-ray compositional maps. Compositions of rock components were determined by EMP, and oxygen isotopes were analyzed in two aliquots of a whole rock sample. Special efforts were made to measure metallographic diffusion profiles across troilite-Fe,Ni metal aggregates to determine cooling rates. A peak equilibration temperature is derived from pyroxene thermometry using the methods of [3].

Results: *Petrography of oxides:* Mineral phases in thin section MIL05029,4 do not exhibit a distinct shape-preferred orientation or alignment. Brecciation or evidence for shock metamorphism is not apparent; no clasts were detected; and no compositional zonation is optically visible in the major constituents. A network of cracks overprints the rock's fabric.

MIL05029,4 has a medium-grained, fairly well-equilibrated igneous texture (Fig. 1). Subhedral to anhedral, 3-5 mm size low-Ca pyroxene ($En_{73.1-77.1}$, $Fs_{20.3-23.1}$, $Wo_{1.9-6.6}$) and up to 2.5 mm-size high-Ca pyroxene (augites, $En_{46.9-52.3}$, $Fs_{8.9-12.1}$, $Wo_{35.8-44.2}$) poikilitically enclose small, 50-100 µm-size, euhedral olivines ($Fo_{74.3-78.4}$, $Fa_{21.6-25.7}$). Interstitial spaces are filled with up to 0.8 mm size plagioclase (high-albite to oligoclase, $Ab_{90.2-78.2}An_{19.7-4.6}Or_{5.7-1.7}$), up to 0.5 mm size chromian spinel ($Fe^{2+}_{0.75-0.83}Mg_{0.15-0.24}Mn_{0.01-0.02}Cr_{1.57-1.64}Al_{0.16-0.26}Ti_{0.06-0.10}$ $Fe^{3+}_{0.07-0.11}V_{0.01-0.02}O_{32}$), and Ni,Fe-metal and troilite that are poikilitically intergrown with small, euhedral olivines. Minor chlorapatite occurs as anhedral, mm-size grains. Olivine, pyroxene, and plagioclase contain melt inclusions that are round to angular in shape with typical sizes ~10 µm. They have variably feldspathic (Na_{46-79}, K_{1-53}, $Ca_{0.3-26}$), but non-stoichiometric, compositions.

Two-pyroxene thermometry: The two-pyroxene thermometer of [3] yields an equilibration temperature of ~1050-1100 °C for the compositions of the low- and high-Ca pyroxene pairs.

Modal composition: Compared to the average normative composition of L-chondrites, MIL05029,4 appears strongly depleted in metal and troilite and strongly enriched in plagioclase (Table 1).

TABLE 1. *Modal composition of MIL05029,4 and the normative mineralogy of L-chondrites.*

	MIL05029,4 vol.%*	[4] rel.%	[5] rel.%
plagioclase	20.5	10.1	9.7
olivine	49.6	47	44.8
low-Ca pyroxene	23	22.7	24.2
high-Ca pyroxene	3.5	4.6	5
chromite	0.4	0.6	0.8
troilite	0.9	6.1	5.8
Ni,Fe-metal	1	7.5	8.4
apatite	0.5	0.6	0.5
melt-inclusions	0.7	0.6	0.6
total	100	99.8†	99.8†

*normalized to 100 vol.%, excluding 2.7 vol.% cracks and voids; †contains 0.2 rel.% ilmenite.

Oxygen isotopes: Because of the unusual modal composition, oxygen isotopic signatures were analyzed to confirm L-chondrite affinities. The oxygen isotopic signatures of MIL05029 are 1.139 and 1.094 $\Delta^{17}O$, 3.37 and 3.49 $\delta^{17}O$, and 4.25 and 4.55 $\delta^{18}O$, consistent with those of L-chondrites [6].

Petrography of troilite and metal assemblages: These phases occur in different size grains and/or assemblages. The largest is a ~1.1 mm intergrowth of lamellar taenite, martensite, and kamacite that form a Widmannstätten pattern, implying a slow cooling rate. Another large grain is composed mostly of fragmented metal and a small amount of sulfide. Smaller opaque grains of sizes <0.5 mm are anhedral, of interstitial types with inclusions, while larger grains tend to be subrounded. Troilite contains very low amounts of Ni (0.01-0.05 wt.%), suggesting slow cooling [7]. Nickel-phosphides have not been found in the troilite-Fe,Ni metal assemblages and P concentrations in metal range from <0.01 to 0.03 wt.%, indicating P-undersaturation. Metal and troilite occur both as separate grains and paired assemblages. This type of texture is similar to that in higher petrologic type (~6) ordinary chondrites [8]. No inclusions of spinel, silica, or phosphate were recognized in the metal and Si and

Ca were typically below detection (<0.01 wt%), which suggests redistribution of these components, also typical for higher petrologic types of ordinary chondrites [9]. Kamacite (Ni 6.7-7.2 wt.%) and taenite (Ni up to 32.4 wt.%) / martensite domains (Ni average concentrations of 20.15 and 15.6 wt.%) exhibit typical concentration profiles of "zoned taenite and kamacite particles" [10]. Smaller grains exhibit well developed taenite-martensite profiles, larger grains display several taenite shoulders, interdispersed martensite and few kamacite domains in profiles, likely due to the formation of polycrystalline tetrataenite [10]. Concentrations of 0.7 - 0.96 wt.% Co in kamacite are characteristic of type 4-6 L-chondrites [11] and Co-contents of taenite and martensite (Ni-contents of 11-32 wt.%) fall clearly into the typical range for L-chondrites [11].

Metallographic cooling rates: Following the method of [7] and using the recent P-free Ni-Fe phase diagram of [12], cooling rates were calculated from two traverses through metal particles. They yield cooling rates of 12 and 7 °C / Ma.

Origin of melt: The medium-grained poikilitic texture of MIL05029 (Fig. 1) implies crystallization of a melt in a relatively stable environment, similar to that in plutonic magmas or impact melt sheet settings. Adjacent pyroxene crystals also have 120° junctions, further evidence of a stable and fairly equilibrated texture. Metallographic cooling rates are in the typical range reported for L6-chondrites [13] and the occurrence of Widmannstätten patterns further support very slow cooling rates on the order of 10 °C/Ma [14]. Based on Ar-Ar systematics, the meteorite reached a closure temperature within ~30-40 Ma of solar system formation [2], implying an origin that is indistinguishable from the planetesimal accretion. Other meteorites with L-chondrite affinities are limited to primitive (type 3) and thermal metamorphic states (types 4-6), which suggests the planetesimal was never sufficiently heated to differentiate and produce internal magmatic conditions. Thus, if MIL05029 comes from the same L-chondrite planetesimal, it was likely produced in an impact melting event during the accretion of the L-chondrite planetesimal. The impact event either stripped metal and sulfide from the shock-metamorphosed target rocks or created a melt volume that was sufficiently large and remained sufficiently hot long enough to allow for density-driven segregation of metal-sulfide from silicate melt. In a relatively low-gravity environment like that on an asteroid, this is a slower process than on Earth, but not an inconceivable one [15]. Because cooling rates are similar to those of L6 chondrites [13], MIL05029 could have cooled at the bottom of a simple crater that excavated to depths of the L6 thermal regime. Modeling by [16] suggest minimum depths of 5-12 km for these conditions on the L-chondrite parent body. Using scaling relationships [14], the minimum crater diameter can then be approximated to 15-60 km.

Implications: MIL05029 appears to be the first accretional impact melt associated with the L-chondrite parent body. Collisional velocities were sufficiently high to produce impact melting and some of that melt was buried several km below the surface in craters with diameters ~10-30% that of the parent body. Thus, the gardening process that disrupted the simple onion-shell thermal structure apparently began before the interior had even had time to fully cool, as previously inferred by [13].

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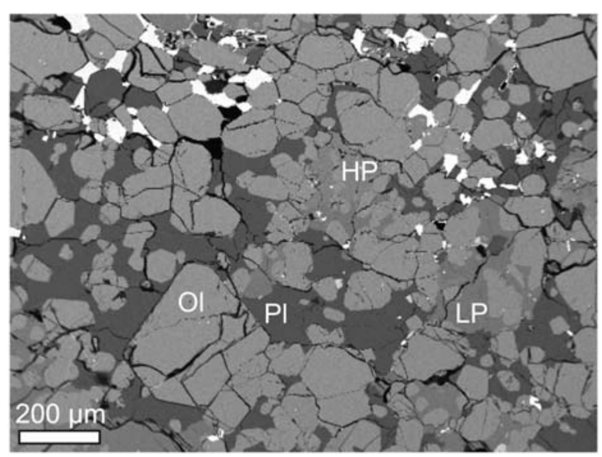

Fig. 1 *SEM-BSE image of MIL05029,4. Ol-olivine, HP-high-Ca pyroxene, LP–low-Ca pyroxene, Pl-plagioclase, bright phases are Fe, Ni metal-troilite or chromian spinel.*