LL-CHONDRITE DOMINION RANGE 10092: A SHOCK-METAMORPHOSED SAMPLE FROM AN IMPACT-MODIFIED ASTEROID. Patrick R. Phelps[1], Martin Schmieder[2,3] and David A. Kring[2,3], [1]Depts. of Geosciences and Physics, University of Tulsa, 800 S. Tucker Dr., Tulsa, OK 74104, patrick-phelps@utulsa.edu. [2]Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston, TX 77058. [3]Solar System Exploration Research Virtual Institute.

Introduction: The purpose of this study is to analyze the petrological and chemical properties of the meteorite Dominion Range (DOM) 10092, which was classified as an LL impact melt breccia [1]. The classification was done using DOM 10092,2. We found that our split (DOM 10092,7) of the sample did not contain any impact melt, but is instead cross-cut with much lower temperature cataclastic zones. Either melt is heterogeneously distributed in the sample or the sample should be reclassified as an LL chondrite with a type 4 thermal metamorphic overprint and a subsequent stage 3 shock metamorphic overprint.

Analytical Methods: Optical microscopy was used to evaluate the lithologies and minerals within the meteorite. Chemical compositions of minerals were measured with a JEOL 8530F electron microprobe at the Johnson Space Center. Silicate, oxide, and metal phases were analyzed with an accelerating voltage of 15 kV, a beam current of 20 nA, and a beam diameter of ~1 µm. Sulfides were analyzed with a beam diameter of ~3 µm. Some analyses were conducted as line-scans with an analytical spacing of 2 µm.

Petrography: DOM 10092,7 has two textural domains: (i) a chondrule-bearing domain that largely preserves the original chondritic texture of the accreted asteroid and (ii) a fragmental domain that is optically dark. A point count (2,676 points) indicates the thin-section (81.1 mm^2) is 60.4% domain (i) and 39.6% domain (ii). Fusion crust is also apparent along one edge of the thin-section with most of the sample near it covered with a small amount of hematite. Some of the metal/sulfide shock veins that cross-cut the sample have also been altered to hematite. Large metal and sulfide particles are more abundant in the fragmental domain than in the chondrule-bearing domain (twice as many with sizes greater than 200 µm). However, particles smaller than 80 µm are more abundant in the chondrule-bearing domain (almost 3x as many). Feldspathic minerals are very rare in this sample, mainly residing in chondrule mesostasis as microcrystalline aggregates. Most of the feldspathic grains are too small to analyze. Rare chromite was observed.

Chondrule-bearing domain. Chondrules dominate (80.5%) this domain. Intervening areas are affected by hematite alteration, making identification of matrix phases difficult. The chondrules are sharply defined to readily delineated. The average chondrule diameter is ~580 µm, which corresponds to the dimensions seen in other LL chondrites [2]. Olivine and pyroxene within the chondrules tend to be fairly large (on average ~200 µm) and have euhedral to subhedral morphologies. The pyroxene crystals have both structural states: orthorhombic and monoclinic. However, >80% are orthorhombic.

Olivine compositions range between Fo_{70} and Fo_{75}, with the majority having a composition of Fo_{72} or Fo_{73}. Pyroxene compositions cover a much wider range. Of the grains analyzed, only a few can be considered high-Ca pyroxenes (greater than 5% Wo content), ranging over $Wo_{6\text{-}31}En_{53\text{-}78}Fs_{14\text{-}20}$. Low-Ca pyroxene compositions range over $Wo_{0\text{-}4}En_{49\text{-}96}Fs_{3\text{-}48}$. Larger (>15 µm) crystals of pyroxene are zoned. The widest zoning range within one grain had a core of $Wo_0En_{92}Fs_7$ and a rim of $Wo_0En_{77}Fs_{22}$. For a complete distribution of both sets of data, see Figure 1. The sulfide is troilite, having a nearly 1:1 ratio of atomic Fe to S. The Ni content is always less than 1 mol%. Large particles of metal suitable for microprobe analyses are rare. Therefore, no analyses were done on metals within this domain. Chondrule mesostases either quenched to a microcrystalline assemblage or once-glassy mesostases are devitrifying.

Fragmental domain. Olivine and pyroxene compositions are similar to those in the chondrule-bearing domain. Little of the pyroxene is zoned, which may be due to fragmentation of zoned grains and/or diffusional equilibration of the smaller (<15 µm) crystal fragments. Only rare fragments >15 µm show zoning. Troilite and metal are both present. The metallic minerals are taenite and kamacite. Taenite compositions range from 37-54 wt% Ni, with the rest of the mineral being made up of mostly Fe and small amounts of Co and Cu (~0.2 wt% and ~0.3 wt%, respectively). The majority of compositions fall between 48-54 wt% Ni, which is high for taenite found in most LL chondrites [4, 5]. The kamacite has an Fe content of 94-97 wt%, a Ni content of 2-5 wt%, and an average Co content of 1.6 wt%. The Co composition in the kamacite along with the mol% Fo in olivine is indicative of an LL chondrite [5]. There is <0.01 wt% P within the metals, which indicates P undersaturation.

This optically-dark domain is made up of a fine-grained matrix of sorts that surrounds many relic clasts of olivine and pyroxene (over 30%). At first glance, it appears to be a melt matrix that has begun to crystallize. However, at higher magnification, especially in backscattered electron (BSE) images, one can see that the individual grains are anhedral and seem to be fragmented (Figure 2). They do not have a characteristic igneous texture of grains that have crystallized out

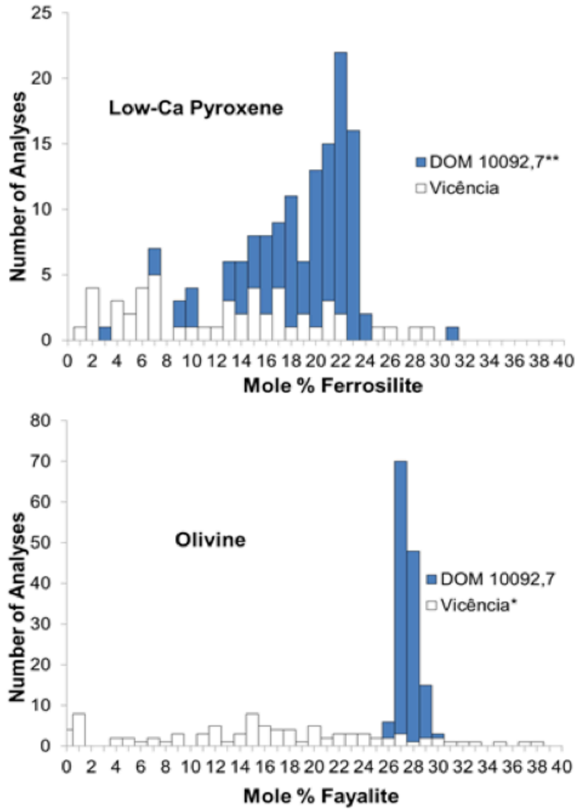

***Figure 1:** Compositional histograms of low-Ca pyroxene and olivine of DOM10092,7 compared to Vicência [3], a lightly shocked, LL3.2 ordinary chondrite. This shows the typical spread of a thermally unmetamorphosed LL chondrite compared to the data collected on this sample. **Data points above 40% Fs are excluded. *Matrix olivine data, which occurs above 40% Fs, is excluded.*

of a melt. Also, there does not appear to be any glass or melt in between the grains (e.g., as in [5]), only empty space. Among the relics, there are 4 fragments of barred olivine chondrules and 2 of radial pyroxene chondrules. They range in size from 10 µm to over 1 mm. The matrix-like grains are typically <10 µm. The metal, where present, adjoins the sulfide edge and has a lithic or ingrown texture. It does not have a spherical morphology indicative of immiscibility in an impact melt. Also, the metal does not have the zoned Ni abundances typical of metal entrained in impact melt. The kamacite is randomly distributed and somewhat intergrown with taenite.

Metamorphic Conditions: *Thermal metamorphism*. We used the metamorphic classification scheme of Van Schmus & Wood [8] to evaluate the meteorite. The meteorite has a narrow range of olivine compositions (type 4) compared to a broad distribution of pyroxene compositions (type 3). The structural state of the pyroxene indicates a higher metamorphic state (type 5). The properties of the chondrule glass and the

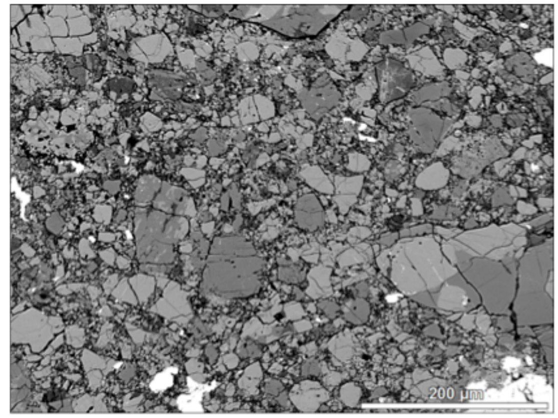

***Figure 2:** Backscattered electron image of the optically-dark cataclastic zone in DOM 10092,7.*

chondrule matrix glass indicate a type 3 or 4. This is not very reliable, since the glass is difficult to locate and much weathering has occurred. The overall chondrule sharpness indicates a type 4. Lastly, secondary feldspars being mainly microcrystalline aggregates seen with BSE images indicate a type 4 or 5. The source of the discrepancy among thermal metamorphic indicators is unclear.

Shock characteristics. Although the meteorite was originally classified as an impact melt breccia (using DOM 10092,2), it is clear that the shock state needs to be revisited. Using the criteria of Stöffler et al. [7], 20 olivine grains were analyzed for undulatory extinction (present), parallel planar fractures (present), mosaicism (not present). Nor did we observe any bulk melt in our thin-section. These observations indicate our split has a shock state of S3 (weakly shocked), reflective of 15-20 GPa shock pressures and a post-shock temperature increase of only 100-150 ºC [7], which contrasts sharply with the impact melt nature of the classified sample.

Conclusions: While we requested this sample to determine the cooling rate of an LL-chondrite impact melt and possibly determine the dimensions of the crater that produced it, our split does not have any impact melt, indicating impact melt is heterogeneously distributed between different areas of the meteorite or, possibly, that zones of fine-grained cataclasis was misidentified as impact melt in the type thin-section.

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