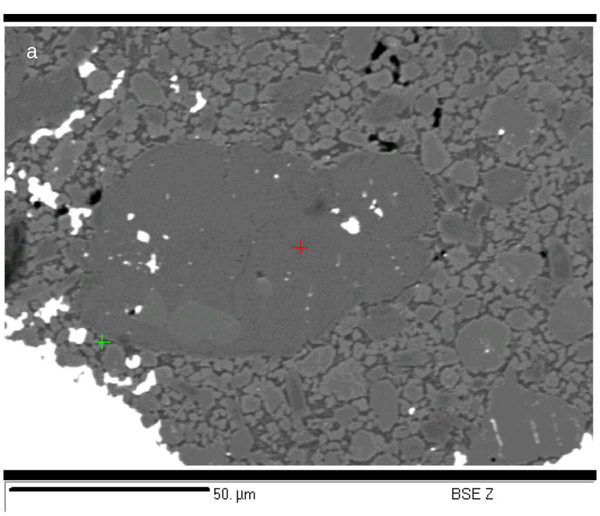
COOLING RATE DETERMINATION FOR H CHONDRITE IMPACT MELT BRECCIA LAP 02240. Leah C. Cheek[1] and David A. Kring[2], [1]Dept. of Geology, The College of William and Mary, Williamsburg, VA 23187 (lcchee@wm.edu). [2]Lunar and Planetary Institute, Houston, TX 77058.

Introduction: Impact melts generated in cratering events on asteroids can provide important information regarding the collisional evolution of the solar system. In particular, the size and timing of events and the structural integrity of parent bodies can be better understood by studying the ages and cooling histories of this important class of meteorites. The purpose of this investigation is to estimate the cooling rate of H impact melt breccia LaPaz (LAP) 02240 in order to provide context for interpretation of its thermal history.

Petrography: LAP 02240 is an H chondrite impact melt that is petrographically similar to the L5 chondrite Cat Mountain [1] and the H6 chondrite Orvinio [2]. The section (141 mm^2) studied in this investigation is predominately melt, with a small amount (9 mm^2 and 15 mm^2) of clastic material along each of two edges. Ar-Ar dating indicates that the melt fraction was generated ~3900 Ma [3] and, therefore, may be linked to a cataclysmic bombardment that affected the inner solar system [4, 5]

Impact Melt. A point count (1720 points) indicates the melt is 86% silicate material and 14% metal and sulfide phases, which is typical of H chondrites and implies the impact did not cause any fractionation of metal from silicate material. The silicate portion is dominated (80%) by fine-grained (<40 µm) olivine and pyroxene (Fa_{17}, Fs_{15}). Larger (40 to 590 µm) olivine and pyroxene xenoliths and xenocrysts comprise the remaining 20% of the silicate phases (Fa_{18}, Fs_{16}) (Fig 1a).



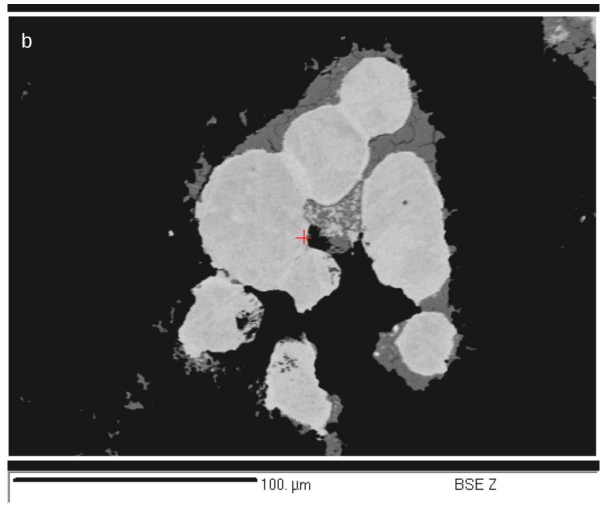


Fig. 1. BSE images of the melt. (a) Matrix of olivine and pyroxene. Many grains show brighter rims, but their narrow widths prevented reliable compositional analyses. Interstitial material was not analyzed due to the small grain size. (b) Metal/sulfide assemblage in the melt matrix. Brightness and contrast have been adjusted so that the silicate material is undersaturated and appears black.

Metal is dominated by relatively low Ni compositions (5.8-14.5 wt% Ni) and typically occurs as rounded orbs surrounded by troilite. These assemblages occur in isolation and as complex aggregates containing multiple metallic orbs (Fig. 1b). Individual orbs range up to 115 µm, but small (<10 µm) particles also occur in the troilite around orbs. The largest metal/sulfide aggregates range up to 570 µm. The metal and sulfide phases show a bimodal size distribution, with the majority of particles having diameters ≤ 1 µm or between 59 and 151 µm (Fig. 2).

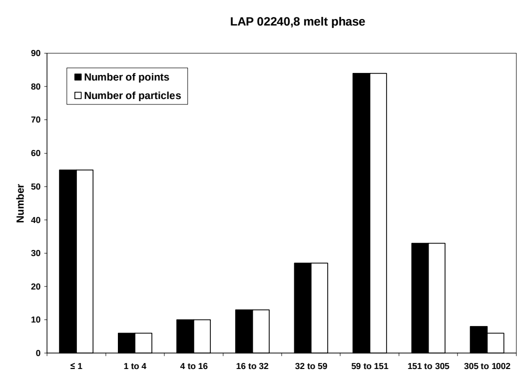


Fig. 2. Point count analyses of melt phase metal and sulfide.

Automated linescans across metal orbs show an increase in Ni content toward the rims (up to 14.5 wt%) (Fig. 3). The metal also contains up to 1.9 wt% P, indicating a P-saturated alloy system [7].

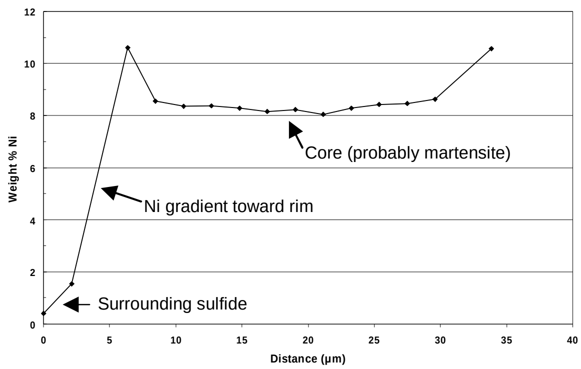


Fig. 3. Typical Ni profile across a metal grain. The Ni content of the core is relatively homogenous, but is enriched near the grain margin which is surrounded by troilite.

Estimated Cooling Rates: The melt portion of LAP 02240 records evidence of two cooling episodes. The first (stage 1) corresponds to the brief period during which the superheated melt thermally equilibrated with relatively cool clast material. In chondritic impact melts, this stage occurs at ~1400 to 950 °C [8] and can be quantified based on metallographic textures. The second (stage 2) represents the rate at which the subsolidus breccia slowly conducted and/or radiated heat to its surroundings on the asteroid parent body. This rate can be estimated by comparison of Ni gradients with other slowly-cooled chondritic meteorites.

Stage 1 rapid cooling. The cooling rate during thermal equilibration affects the nucleation and growth of metal. Thus, individual cell widths and the spacings of adjacent metallic cells were measured following the method of Blau and Goldstein [8] and Scott [9]. The average cell spacing in 12 metal assemblages ranges from 30 to 45 µm, indicating cooling rates of 9 to 27 °C/s. The average cell width in 18 metal assemblages ranges from 20 to 50 µm, reflecting cooling at 6 to 84 °C/s. These rates are comparable to those for the meteorites Dimmitt (H4), Pulsora (H3-7), Tell (H6), Tysnes Island (H3-6), and Weston (H3-6) [9].

Stage 2 slow cooling. Ni gradients in metal indicate fractionation during solidification of the impact-melted metal-sulfide liquids. These gradients confirm that the liquids were not quenched (thus preserving homogenous compositions), but were cooled slowly enough for fractionation to occur.

The survival of the gradients also indicates that subsequent cooling was sufficiently fast that they were not erased. Since longer cooling times or slower cooling rates would be expected to level out the Ni profiles, steeper gradients should be consistent with faster cooling rates. This has been demonstrated experimentally [10], and therefore rim gradients may be used as a semi-quantitative estimate of cooling rate.

The Ni profiles for both Ramsdorf (L6) and Orvinio (H6) are similar to those for LAP 02240. Smith and Goldstein [10] estimated the cooling rate for Ramsdorf as 100°C/day (10^{-3} °C/s) based on structural similarities with experimentally heat-treated samples (heated to 1250°C, cooled at 100°C/day) and semi-quantitative cooling rate criteria. For Ramsdorf, these criteria include high Ni content in troilite (0.11 wt%) and steep rim gradients (from 8 to 20 wt%), which both indicate relatively fast cooling. Orvinio also shows relatively high rim gradients (from 1 to 8 wt%), but its Ni content in troilite is slightly lower than for Ramsdorf (0.08 wt%). The cooling rate for Orvinio was therefore inferred to be 100°C to 15°C/day (~10^{-3} to 10^{-4} °C/s). In our sample, rim gradients (from 2 to 6 wt%) are similar to those in Orvinio, suggesting a cooling rate of ~10^{-3} to 10^{-4} °C/s for LAP 02240.

If cooling was sufficiently slow, secondary kamacite grows along an orb's margin. This was observed in the reheated L chondrites Cat Mountain, Wickenburg, Farmington, Lubbock, and Arapaho, and for the H chondrite Rose City. Based on the width of the rims, these chondrites have reported cooling rates of 10^{-7} to 10^{-10} °C/s [1, 9]. LAP 02240 lacks detectable bands of secondary kamacite (< 1 µm wide), suggesting cooling rates faster than 10^{-7} to 10^{-10} °C/s. This is consistent with the rate of 10^{-3} to 10^{-4} °C/s suggested by comparison with Orvinio. Such a rapid cooling rate implies a relatively shallow burial depth (<10m) in the melt breccia lens, crater walls, or ejected material.

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