VESICULATION IN ORDINARY CHONDRITES DUE TO IMPACT MELTING: THE "PAT" 91501 ANSWERS.

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Introduction: Vesicular meteorites are rare among the world's collections. Of the few that exist, most are basaltic in composition. In these basaltic meteorites the presence and distribution of vesicles is used to unravel differentiation processes on their parent bodies [1]. The question has been raised whether impact processes can form vesicular basalts on differentiated asteroids. We undertook this study to determine if vesicular impact melts resemble vesicular basaltic meteorites.

Vesicles have been reported in three ordinary chondrite impact melts: Shaw[2], Cat Mountain[3], and PAT 91501[4]. These studies focused on bulk chemistry and textural features of these meteorites, but did not delve into the formation of the vesicles. Understanding the formation mechanism of vesicles in these meteorites is important. What is the volatile species that could form the bubbles? Why do the bubbles stay in these particular impact melts? This abstract is a preliminary report of an effort to try to answer these questions.

Samples and Analytical Methods: We focused on PAT 91501 because it contains vesicles; there is abundant material (more than 8 kg of material were returned); and it is thought to be a total impact melt [6]. Visual inspection of PAT 91501,50 and ,78 show clastless, light colored surfaces with large (cm-sized) vesicles and metal/troilite blobs. Studies of thin sections [5,6] indicate a medium- to coarse-grained, igneous-textured rock with L chondrite bulk chemistry.

We scanned the samples PAT 91501,50 (2814.3 g) and PAT 91501,78 (127.6 g) using the high-resolution x-ray computed tomography (CT) facility at the University of Texas at Austin. CT creates images of "slices" through an object in which gray values correspond to x-ray attenuation, which is a strong function of density. A series of contiguous slices can be used to fully describe a volume, and the resulting data are amenable to visualization and extraction of quantitative information, such as sizes, shapes, and contact relationships among vesicles and metal/sulfide assemblages.

Results: CT scans offer a unique view of the context of a whole meteorite. In the case of PAT 91501, a new perspective on the metal/sulfide and vesicle distribution is available. Sample 91501,50 was scanned at roughly 0.5 mm resolution owing to its size, while the smaller sample ,78 was scanned at ~70 µm resolution, allowing measurement of many more small vesicles. In sample ,50 over 5000 vesicles were measured, roughly 2% of the sample, while in sample ,78 has more than 36,000 vesicles comprising ~4% of the total rock. Vesicle volumes range from $0.11 mm^3$ to $1450 mm^3$ in PAT 91501,50 and from $<0.001 mm^3$ to $72 mm^3$ in ,78. This can be seen in the range in vesicle sizes shown in Figure 1, which is an image from the 3D reconstruction of PAT 91501,50. Metal and sulfide are estimated to make up less than ~1% of each sample, with sulfide having a slightly higher abundance overall. The modal abundance of sulfide and metal for a given metal/sulfide assemblage will be determined prior to the meeting.

One of the most striking results of the CT scan work is the marked association of larger vesicles with large metal/sulfide melt assemblages. This association is also true for the smaller piece, PAT 91501,78. Furthermore, the metal-sulfide contacts all have the same orientation. The large vesicles are associated with the metal-sulfide interface. Visual inspection of slices of Shaw (USNM #3440) and Cat Mountain (USNM #6848) show this association as well, although vesicle sizes are much smaller.

Discussion: Using information obtained from the CT scans and doing some preliminary calculations, we can determine several features of the physical conditions under which the vesicles formed.

What is the volatile? While there is some small amount of H_2O in bulk L chondrite [7], the association of the metal/sulfide assemblages with large vesicles is intriguing and leads us to the hypothesis that the gas that formed the vesicles is SO_2 formed by vaporization of the FeS during melting of Fe,Ni metal and sulfide. Vaporization of sulfide due to impact has been suggested for the H chondrite, Smyer[8]. In that case, it was hypothesized that sulfide evaporated when the shock pressure from the impact was released. The S_2 vapor that was formed pervaded cracks surrounding both melted and unmelted silicate and scavenged Fe to recondense as FeS. Vesicles have not been reported in Smyer.

How much volatile is there? We can determine how much SO_2 would be formed by vaporizing the FeS in an L chondrite because we know the starting and ending abundances of troilite. Using data from

[7,9], the starting abundance of troilite in L-chondrites is ~4vol%. The amount of troilite in PAT 91501 estimated from the CT scans is <1vol%. It is likely that not all of the troilite that is lost has been vaporized, but we can use the difference to determine an upper limit on the amount of SO_2 that would be available to form the vesicles. If we consider a cubic meter of meteorite, using the above volume % numbers and the various masses of FeS and SO_2, we find the density of SO_2 is ~ 3200 kg/m^3.

The pressure at which this density is stable can be determined from the gas law. If we use the liquidus temperature of an L-chondrite melt (1500K) we find the pressure is 620 MPa. This implies an impact speed of <1km/s. Since the pressure required to melt rocks is closer in the range of 40 to 50 GPa, and thus requires impact speeds of at least 5km/s we infer that our calculated pressure represents the equilibrium pressure. The bubbles themselves would have formed at a higher pressure and then expanded to reach equilibrium. We can estimate how much the bubbles grew from a ratio of the initial impact pressure to the final equilibrium pressure. We get a ratio of 64, which leads to a diameter increase of 4. This implies that the bubbles in the meteorite now are 4 times their original size.

Why are the vesicles there? It seems clear from the bulk chemistry and textural features that this rock is an L-chondrite impact melt. Why doesn't it look like other impact melt rocks (i.e. Cat Mountain and Shaw)? Those meteorites have unmelted clasts that are surrounded by impact melt veins and vesicles are generally associated with the melt veins not pervasive throughout the entire meteorite. The major difference between PAT 91501 and these other impact melt breccias is that PAT is a total impact melt. Therefore the amount of volatiles released is greater. The fact that there are so many vesicles and that they grow to such a large size indicates the melt must have been buried at some depth after formation, but before solidification. [6] suggested that PAT 91501 was formed as either as an impact melt vein that was injected in the crater floor during impact or as a melt layer in the melt sheet that collected on the crater floor. That vesicles are seen and are as big as they are, implies the melt sheet in the crater that was either thick enough to allow bubble formation or that the impact melt was buried relatively quickly in order to seal in the vesicles as well as the Fe,Ni-FeS melt assemblages. Since Shaw and Cat Mountain also contain vesicles, they must have been under some confining pressure as well. This means that impact melt rocks containing vesicles are buried after formation. Further refinement of these preliminary calculations is planned to try to establish the burial depth.

An important result of this study is that vesicular basalts are not formed by impact. Vesicular basaltic meteorites offer information about the igneous processes that occur on asteroids.

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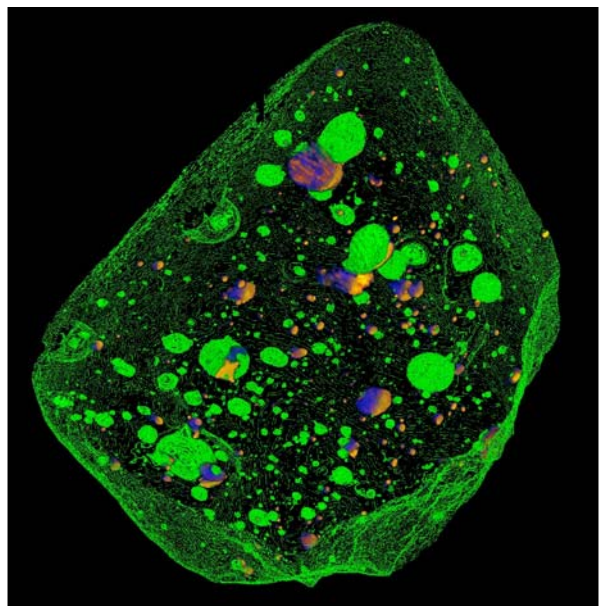

Figure 1. 3-dimensional image of PAT 91501,50 from CT scans showing the distribution of vesicles (green) and metal (purple)/sulfide(orange) blebs. The long dimension is approximately 15cm. Some of the larger vesicles are greater than 1 cm in diameter.