TOMOGRAPHIC LOCATION OF POTENTIAL MELT-BEARING PHENOCRYSTS IN LUNAR GLASS SPHERULES. D. S. Ebel[1,2], R. A. Fogel[1,3], and M. L. Rivers[4]. [1]Dept. of Earth and Planetary Sciences, American Museum of Natural History, Central Park West at 79th St., New York, NY 10024, [2](debel@amnh.org), [3](bobby@amnh.org), [4]Consortium for Advanced Radiation Sources, The University of Chicago (9700 S. Cass Ave., Argonne, IL 60439, rivers@cars.uchicago.edu).

Introduction: In 1971, Apollo 17 astronauts collected a 10 cm soil sample (74220) comprised almost entirely of orange glass spherules. Below this, a double drive-tube core sampled a 68 cm thick horizon comprised of orange glass and black beads (crystallized equivalents of orange glass). Primitive lunar glass spherules (e.g.-A17 orange glasses) are thought to represent ejecta from lunar mare fire fountains [1, 2]. The fire-fountains were apparently driven by a combination of C-O gas exsolution from orange glass melt and the oxidation of graphite [3, 4]. Upon eruption, magmas lost their volatiles (e.g., S, CO, CO_2) to space. Evidence for volatile escape remains as volatile-rich coatings on the exteriors of many spherules [e.g., 5,6]. Moreover, [7] showed that Type I and II Fe-Ni-rich metal particles found within orange glass olivine phenocrysts, or free-floating in the glass itself, are powerful evidence for the volatile driving force for lunar fire fountains.

More direct evidence for the volatile mechanism has yet to be uncovered. Issues remaining include: the exact composition of magmatic volatiles; the hypothesized existence of graphite in the magma; the oxygen fugacity of the magma and of the lunar interior.

In 1996 [8] reported a single ~450 micron, equant olivine phenocryst, containing four glassy melt inclusions (or inclusion cores), the largest ~30micron in size, in a thin section of the 74001/2 drill core. The melt is assumed to sample the parent magma of the lunar basalts at depth, evidenced by the S content of the inclusion (600 ppm) which is 400 ppm greater than that of the orange glass host [8]. Such melts potentially contain a full complement of the volatile components of the parent magma, which can be analyzed by infrared spectroscopy. Although the A17 orange glass magma is thought to derive from ~ 400 km depth [9], the calculations of [7] imply a 4 km depth of graphite oxidation (and melt saturation in C-O volatiles) during ascent.

We have imaged several hundred similar orange glass spherules, from sample 74220,764, using synchrotron x-ray computer-aided microtomography (XR-CMT). Our goals: 1) locate similar phenocrysts containing melt inclusions; 2) analyze phenocrysts to understand the evolution of the magma; 3) analyze melt and fluid inclusions using EPMA and FTIR to obtain direct evidence of magmatic volatiles and pristine bulk compositions.

Technique: Loose spherules were placed in a crease of cellophane paper, and picked up on four 0.2 x 1 x 60 mm plastic strips coated with ambroid, a model airplane glue that dissolves completely in ethyl acetate. Strips were imaged at beamline 13M (GSECARS) of the synchrotron at the Advanced Photon Source (DOE). Density structures (arrays of cubic volume elements, or voxels) at 16-bit density resolution were computed from images collected using 15 KeV x-rays, a Pentamax SL 20x lens (37.5mm tube), for spatial resolution of 1.96 micron/pixel. We then produced stacks of parallel image 'slices', resembling back-scattered electron images in 256 gray scales chosen to enhance contrast (Fig. 1a).

Images contain predictable noise and x-ray shadowing due to a variety of instrumental factors and the Fourier transform reconstruction technique. Circular 'ripples' perpendicular to the z axis probably result from a complex interaction of the ray path with higher energy x-rays passed by the Si[220] monochromator [10]. Surface effects (e.g., along the plastic substrate, Fig. 1a) appear as bright lines at this pixel resolution, due to reflection when incident x-rays are at very small angles to these surfaces. Some internal features of spherules that do not resemble phenocrysts may also be artifacts of the technique.

Results: Visual inspection of tiff format image stacks, and stacks made into mpeg movies, revealed at least one olivine phenocryst in a single spherule. This phenocryst-bearing spherule, and others in segment C of sample OG1, is illustrated in Figs. 1a (close up), and 1b (the entire sample). Tomographic slices in Fig. 1 are perpendicular to the z axis. Note the locations of x and y slices shown in Fig. 2. Raw images show 8-bit renderings of the 16-bit data, in cropped 380x420 pixel frames. Images above have intensities of x-ray attenuation re-scaled to 4000-12000, from -7374 to 23809, with black (air) background made white. The central spherule fragment contains a grain tentatively identified as olivine ~$MgSiO_4$ (spinel also occurs in spherules [8]), that is dark (lower attenuation) relative to brighter, Ca-, Fe-bearing glass. This is the only unambiguous phenocryst found to date. Other spherules contain metal grains, and some features may, in fact, result from dendritic crystal growth in fast-cooling spherules. We also observed clasts which are not spherical, and contain components with high (e.g., metal) and low (e.g., voids) attenuation.

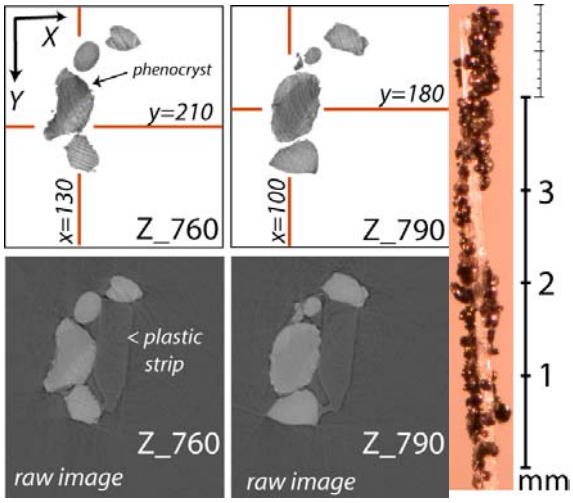

Figure 1 (a) (b)

Discussion: The current work is preliminary in nature and aims to establish proof-of-concept. This initial stage has concentrated on handling these rare spherules non-destructively, and on locating spherules of interest after imaging. Although we did not definitively locate any melt inclusions, the method gives a sense of the abundance of olivine phenocrysts in the aliquot at hand. We have not yet segregated the phenocryst-containing spherule; however, if it did contain melt, we should have been able to see it at 1.96 μm/pixel spatial resolution. We have not yet mounted, cut and imaged sections of spherules. Some of the dendritic and barred textures seen in images of the spherules may be quench textures, and they may allow constraints to be placed on the cooling histories of these spherules.

Other methods of phenocryst identification could be pursued. For example we are exploring use of a binary cut bulk x-ray diffraction method. A tube of spherules passing through an x-ray beam will diffract strongly when phenocrysts occur. Successive halving of the olivine-bearing aliquot can be used to isolate olivine-bearing spherules.

Conclusions: This non-destructive method has promise for identifying important objects that should contain unique clues to the early magmatic history of the Moon. Once phenocrysts with melt inclusions are identified, infrared spectroscopy can reveal the original volatile contents that drove the fire-fountaining of the orange glass parent magmas. This would yield the volatile composition of the ancient orange glass magma.

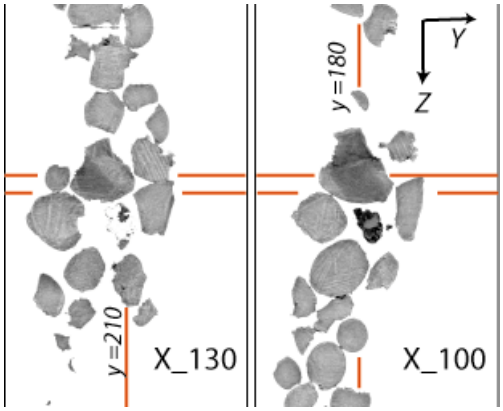

Fig 2a: Tomographic images perpendicular to x axis of segment C of sample OG1. Locations of orthogonal planes shown in Fig. 1 and 2b are shown. Total dimension of z is 250 pixels at 1.96 micron/pixel. Central, phenocryst-bearing spherule is clearly visible in this image, with intensity scaled as in Fig. 1.

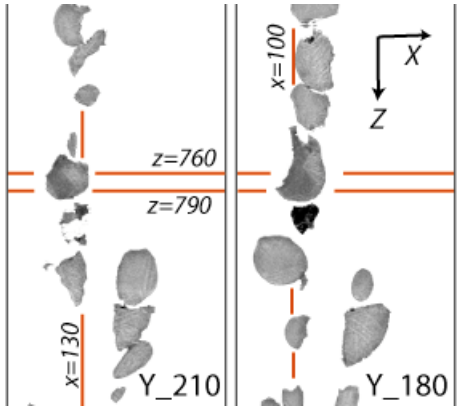

Fig 2b: Tomographic images perpendicular to y axis of segment C of sample OG1. Locations of orthogonal planes shown in Fig. 1 and 2a are shown. Length of z is 250 pixels at 1.96 micron/pixel.

References: [1] Heiken et al. (1974) *GCA* **38**, 1703-1718; [2] Delano (1986) *Proc. LPS* **XVI**, D201-D213;[3] Fogel and Rutherford (1995) *GCA* **59**, 201-215; [4] Sato (1979) *Proc. LPS* **X**, 311-325; [5] Butler and Meyer (1976) *Proc. LPS* **VII**, 1561-1581; [6] McKay (1993) *LPS* **XXIV**, 961-962; [7] Weitz et al. (1997) *GCA* **61**, 2765-2775; [8] Weitz et al. (1999) *MaPS* **34**, 527-540; [9] Green et al. (1975) *Proc. LPS* **VI**, 871-893; [10] http://www-fp.mcs.anl.gov/xray-cmt/rivers/tutorial.html

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