LUNAR IMPACT HISTORY FROM APOLLO 12 GLASS SPHERULES. J. Levine[1], D. B. Karner[1], R. A. Muller[1,2], and P. R. Renne[3,4], [1]Department of Physics, University of California, Berkeley, California 94720, USA (jlevine@socrates.berkeley.edu), [2]Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA, [3]Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, California 94709, USA, [4]Department of Earth and Planetary Science, University of California, Berkeley, California 94720, USA.

Introduction: Glass spherules in lunar soils are formed by meteoroid impacts on the lunar surface, though some are believed to be due to volcanic fire-fountaining events [1]. We recently reported [2] the ages of 155 lunar spherules from Apollo 14 soil sample 14163, determined by the $^{40}Ar/^{39}Ar$ isochron technique. These spherules are all inferred to have been formed in impacts, and, since the sample was from the ejecta blanket of the ~25 Ma Cone Crater impact, the dated spherules constitute a random sampling of the lunar regolith. The distribution of their ages, therefore, represents a measure of the impactor flux in the vicinity of the Earth and Moon throughout the last ~3.8 Ga. The most surprising observation of [2] was the abundance of young spherules; on this basis, an increase in the lunar cratering rate by a factor of 3.7±1.2 in the last 400 Myr was inferred. This conclusion was challenged by [3], who suggested instead that a bedrock-exposing event 400 Ma could have led to an increase in spherule production without requiring an increase in the impactor flux. Though continuous ~1 Ga rays of Copernicus ejecta across the Apollo 14 landing site indicate that the regolith was not locally removed 400 Ma, it is nevertheless possible that the increase in production of <400 Ma spherules was the result of a phenomenon local to the Apollo 14 landing site and not, as we suggested in [2], the result of increased impacts on the Moon. As we noted in [4], measuring spherule ages at another location on the Moon could test whether the Apollo 14 spherule production record reflects a local event or the history of the entire Moon. We have begun this experiment using a regolith sample collected during the Apollo 12 mission to the Procellarum Basin.

We are extracting spherules from 5 g of soil from sample 12023,151. We will measure the ages of approximately 150 spherules from this sample to determine the cratering history and assess whether there is evidence of the 400 Ma increase in spherule production.

Sample Selection: Soil 12023 is a trench sample entirely from within the rim-crest deposit of Sharp Crater, a very young bedrock-penetrating crater [5]. We chose ejecta from a recent crater, as in [2], to obtain a well-mixed sample of all depths of the regolith. The Apollo 12 landing site was chosen for this experiment because most spherules are inferred to be chemically similar to locally exposed rocks [6, 2], and because the Apollo 12 landing site is, after the already-studied Apollo 14 site, the richest in potassium [7]. With the Moon severely depleted in K relative to Earth, and given the small size of the glass spherules, K content places the strongest limit on the precision of dates we expect to achieve. For the Apollo 14 spherules in [2], the median uncertainty in the age was 150 Myr. We anticipate reaching comparable precision because the Apollo 12 spherules we have extracted are larger than those studied in [2], which should compensate for the lower K content at this site.

Analysis: Our observations of the spherules are in a preliminary stage and are ongoing. An update of our progress will be presented at the conference.

Visual observations. The spherules were extracted from the lunar soil under the binocular microscope. The surfaces of most spherules are smooth and reflective. The majority of spherules have small amounts of foreign material adhered to the surface, and probably have inclusions as well. Four spherules were shattered during handling, revealing highly vesicular interiors. In addition, other spherules have apparent holes on the surface leading to cavities in the interior. These observations are consistent with the spherules' having formed in impact ejecta plumes as melt droplets in close association with unmelted material and vapor. Many of the spherules appear to be deep red or yellow-brown in color.

Other spherules have dull, gray, crusty surfaces, and still others have patches both of smooth, reflective surface and of dull, crusty surface. Investigations into the nature of the two surface types are ongoing, and, in particular, we are alert to the possibility that spherules with a lot of the crusty material may be systematically older than the smooth-surfaced spherules. We are taking steps to avoid biasing the spherule age distribution that we measure.

Scanning electron microscopy. We have begun to make observations of the spherules using a field-emission scanning electron microscope (FESEM) at the National Center for Electron Microscopy. The FESEM observations serve two purposes. First, the very high magnification attainable with the electron microscope aids in the observation of surface textures and features, including the crusty material. Second, using a mounted energy dispersive spectrometer, elemental analyses are determined from the x-rays emitted when electrons in the microscope beam interact with atoms in the spherules. Both surface textures and chemical composition (particularly the Al/Mg ratio) may be used as indicators of spherule genesis, whether by impact or by fire-fountaining [8].

The FESEM image and x-ray spectrum of a typical spherule are shown in Figures 1 and 2.

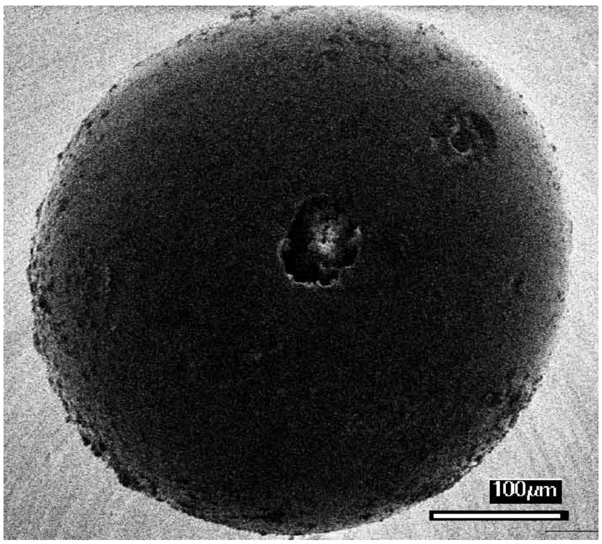

Figure 1: This spherule has a bubble that has ruptured the surface at the center of the figure, and a zap pit from a micro-impact near the top right. Scale bar is 100 μm.

^{40}Ar/^{39}Ar geochronology. The ultimate aim of this experiment is the determination of the ages of many impacts on the Moon's surface by measuring the formation ages of many glass impact spherules. After determining the origin of each collected spherule using the FESEM, we will measure its formation age using step-wise laser heating and the ^{40}Ar/^{39}Ar isochron technique. This work will be performed at the Berkeley Geochronology Center.

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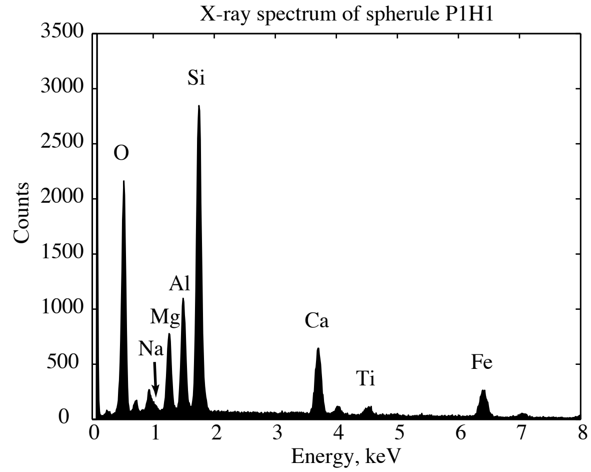

Figure 2: An x-ray spectrum of the spherule in Figure 1, with prominent K transition lines labeled. These peaks correspond to a composition (in atomic weight percent) of O 36%, Na 1.3%, Mg 5.7%, Al 9.4%, Si 24%, Ca 8.8%, Ti 1.6%, and Fe 13.2%, neglecting trace elements.

References: [1] Chao E. C. T. et al. (1970) *JGR*, *75*, 7445-7479. [2] Culler T. S. et al. (2000) *Science*, *287*, 1785-1789. [3] Hörz F. (2000) *Science*, *288*, 2095a. [4] Muller R. A. et al. (2000) *Science*, *288*, 2095a. [5] Shoemaker E. M. et al (1970) *Apollo 12 Prelim. Sci. Report* (NASA pub. SR-235) 113-156. [6] Reid A. M. et al. (1972) *Proc. Lunar Sci. Conf. 3*, 363-378. [7] Lawrence D. J. et al. (1988) *Science*, *281*, 1484-1489. [8] Delano J. W. and Livi K. (1981) *Geochim. Cosmochim. Acta*, *45*, 2137-2149.