**A METHOD FOR FINDING THE MASS OF A MILLIGRAM-SIZED ROCK SAMPLE WITHOUT USING A SCALE, WITH POSSIBLE SPACECRAFT APPLICATIONS.** A. M. Fennema[1], R. Bode[1], and T. D. Swindle[1] [1]Lunar and Planetary Laboratory, University of Arizona Tucson AZ 85721-0063 USA. First author's e-mail address:audrie@lpl.arizona.edu.

**Introduction:** Mass is a fundamental observable in many scientific investigations. Measuring mass, one of the simplest tasks on Earth, can be very challenging when done remotely on the surface of another planet. The difficulties of sending a delicate scale onboard a spacecraft are great. An instrument is currently being developed that would perform dating on geological units, in situ, on the surface of Mars, using dating techniques routinely used on Earth. One requirement for this instrument is that the mass of a milligram-sized crushed rock sample must be measured. An alternative method for determining the mass has been developed. If the volume of a sample can be measured and the density estimated, the mass can then be calculated. We discuss here this alternative method along with the results of tests on several samples.

**Background:** The AGE (Argon Geochronology Experiment) [1] instrument is currently being developed to perform potassium-argon (K-Ar) and cosmic-ray exposure (CRE) dating, in situ, on the surface of Mars. Both of these dating techniques require the measurement of the elemental abundances of major and minor elements and the abundance and isotopes composition of noble gases. Elemental abundances are measured using Laser-Induced Breakdown Spectroscopy (LIBS) [2]. Noble gas measurements are made using a miniature Quadrupole Mass Spectrometry Array (QMSA) [3]. Gasses are released from the sample using a radiative furnace with a target temperature of 1500°C. LIBS measures relative abundances, therefore, the mass of the sample is required to convert to absolute abundances. To achieve the desired uncertainties in the dating, the uncertainty in the mass needs to be less than 10%. Since it is impractical to send a scale aboard a spacecraft, an alternative method for determining the mass of a sample had to be developed. This was our motivation.

**Samples:** In this study we began by experimenting with basalts and an ordinary chondrite meteorite. The basalt samples, Columbia River Basalt (CRB) and National Basalt Standard 233 (NBS) are certified NIST rock powder standards. The elemental abundances were provided by NIST. In the spacecraft version, the LIBS measurements would be used.

The meteorite, Bjurböle, is an L4 ordinary chondrite. It was pulverized in the lab, metallic phases removed using a hand magnet and the elemental abundances were assumed to be that of a typical L4 chondrite.

In an effort to investigate the limits of this new method we also chose five samples collected from the San Carlos volcanic field whose melting temperatures were believed to be near or above our furnace target temperature. These samples are mafic and ultramafic xenoliths collected in the field. Their minerology is dominated by varying amounts of olivine, ortho- and clinopyroxene, and spinel. The San Carlos samples were pulverized in the lab and elemental analysis was conducted by the XRF lab at Franklin & Marshall College.

**Method:** A sample of approximately 3 to 7 milligrams of crushed rock was loaded into a .063 inch diameter platinum crucible. The loaded crucible, in an alumina sample holder, was placed in a furnace preheated to approximately 1500°C at 1 atmosphere for several minutes. When it had cooled, the height of the sample in the crucible was measured using a Linear Variable Differential Transformer (LVDT). Using this measured height and the known dimensions of the crucible the volume was calculated. The density of each sample was estimated from the bulk composition using MELTS [4,5], a software application routinely used by igneous petrologists. An uncalibrated mass was calculated for each sample by multiplying the density of the sample type by the calculated volume. However, because of meniscus effects, the single LVDT measurement is not necessarily an accurate measure of the total volume of the melted sample.

After the samples were processed, a calibration curve for each different type of sample was constructed. The ratio of each uncalibrated mass to its respective known mass was plotted as a function of volume. Each uncalibrated mass was subsequently multiplied by the appropriate calibration factor to obtain a calibrated mass.

**Results:**

*CRB and NBS.* At our target temperature, CRB and NBS melted easily and cooled to a homogeneous glass with a very smooth semi-circular meniscus on the surface. For CRB calibrated masses were within 7% (1 sigma) of actual masses and for NBS calibrated masses were within 8% of actual masses.

*Bjurböle.* The sample melted well but did not become completely glassy. It had a relatively smooth

semi-circular meniscus with some small-scale roughness on the surface. Calibrated masses were within 7% of actual masses.

*San Carlos.* Two of the five San Carlos samples had insufficient melting to reliably calculate a volume. There was no meniscus, individual grains could still be seen and the sample had pulled away from the sides of the crucible making it impossible to accurately calculate the volume.

The three remaining San Carlos samples melted somewhat, although not to a glass. The samples had mostly smooth meniscuses on the surface allowing a relatively accurate measurement to be taken for the volume calculation. Calibrated masses for these three samples, PM 2-33, PM 2-47, and PM 2-50C were within 8, 8, and 6% of actual masses respectively.

**Future Work:** Our tests were at 1 atmosphere, so a next logical step would be to do the heating in vacuo, as we plan to do on the spacecraft. Also, we did not test whether the reduced gravity of Mars might lead to a different surface shape. We began to investigate the effects of grain size. Although the effects of grain size on the mass measurement were inconclusive, pulverizing the sample into smaller grains appears to aid the melting. There could be further investigation into this effect.

**Conclusion:** As shown in Table 1, our experimental investigation has demonstrated that if melting is achieved, this alternative method can be used to approximate the mass of 3-7 milligram crushed rock samples to within the targeted 10%. Even if the sample is not completely molten, if only a few small grains remain, the method will still work, as in the case of our Bjurböle samples and the three San Carlos samples that worked.

A single calibration curve was also tried that included all successful sample types. This calibration curve is shown in Figure 1. The results for CRB, NBS and Bjurböle were unchanged. The 1 sigma uncertainties for the San Carlos samples were slightly greater, but still within the targeted 10%.

Some calibration is required, and on a spacecraft, it would not be feasible to melt enough samples to determine a reliable calibration. However, knowing the composition of the melt, it should be possible to determine the calibration with samples of the same composition on Earth. Ideally we would have a single calibration curve applicable to all compositions. The original mineralogy should not be an issue, as long as the sample is molten.

On the other hand, this technique will not work on samples consisting of high-temperature minerals that fail to melt, such as forsteritic olivine. It should be possible to determine when such a pathological sample has been encountered, either from the composition of the sample, or, if available, from imaging of the heated sample container.

**References:**

[1] Swindle T. D. et al. (2005) *LPS XXXIV,* Abstract #1488. [2] Knight A. K. et al. (2000) *Appl. Spectrosc., 54, 331-340.* [3] Orient O. J. et al. (1997) *Rev. Sci. Instrum.,* 68, 1393-1396. [4] Ghiorso M. S. and Sack R. O. (1995) *Mineralogy and Petrology,* 119, 197-212. [5] Asimow P. D. and Ghiorso M. S. (1998) *American Mineralogist,* 83, 1127-1113.

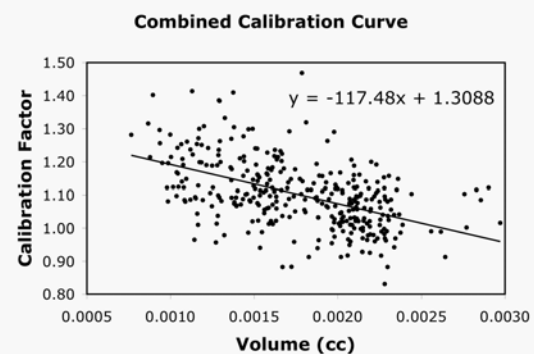| *Sample Type* | *Number of Samples* | *Individual Calibration 1 sigma* | *Combined Calibration 1 sigma* |
|---|---|---|---|
| CRB | 52 | 7% | 7% |
| NBS 233 | 72 | 8% | 8% |
| Bjurböle | 54 | 7% | 7% |
| PM 2-33 | 42 | 8% | 9% |
| PM 2-47 | 65 | 8% | 8% |
| PM 2-50C | 48 | 6% | 7% |

Table 1. Summary of Results



Figure 1. The combined calibration curve was constructed with data from all successful sample types, a total of more than 300 experiments.