IMPROVING SOLAR SYSTEM CHRONOLOGY WITH LUNAR IN-SITU DATING: THE *MARE* DISCOVERY MISSION F. S. Anderson[1], D. Draper[2], P. Christensen[3], J. Olansen[2], J. Devolites[2], W. Harris[2], T. J. Whitaker[1], J. Levine[4], and the entire MARE science and engineering team, [1]Southwest Research Institute, 1050 Walnut St, Boulder CO; anderson@boulder.swri.edu, [2]Johnson Space Center, Houston TX 77058, [3]Arizona State University, Tempe, AZ, 85281, [4]Colgate University, Hamilton, NY 13346.

Introduction: Current models of inner solar system chronology have billion year uncertainties during the period from one to three billion years ago, due to a lack of lunar samples with well understood provenance. These problems fundamentally affect our understanding of events in solar system history, such as the duration of the era of water and volcanism for Mars and the Moon, and the bombardment environment under which life evolved. We have proposed a new Discovery-class mission called *MARE* to close this critical gap in understanding of solar system history. Only by returning to the Moon to fill these sampling gaps can the cratering models be corrected, delivering results of far-reaching import that span multiple planetary bodies. The *MARE* mission directly addresses the high priority Decadal Survey goals for new lunar age determinations: “Priority mission goals include... the reconstruction of the impact history of the inner solar system through the exploration of better characterized and newly revealed lunar terrains” [1].

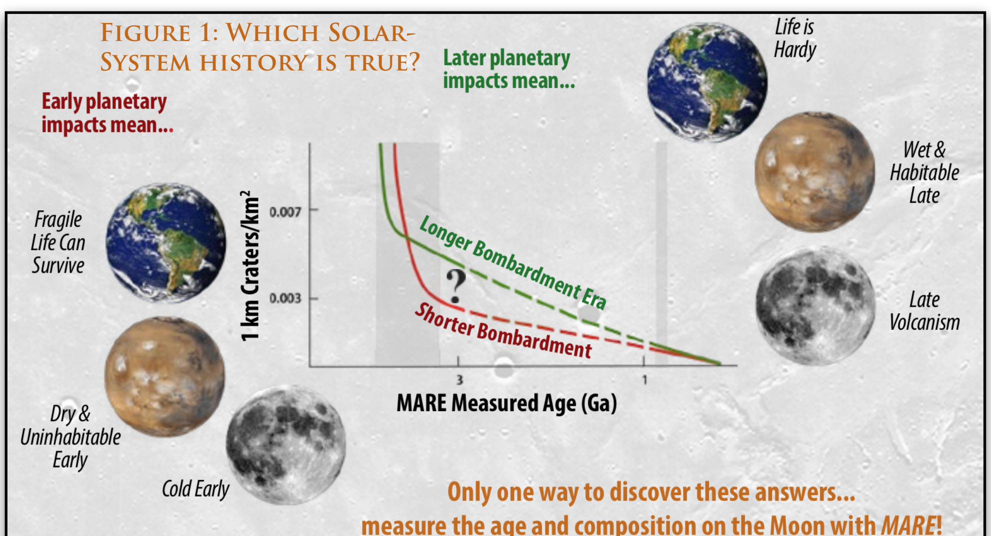
Background: Understanding the relative timing of geologic events using crater counting is of fundamental importance to unraveling the history recorded on the surfaces of rocky bodies. Crater counts, in conjunction with radiometrically-dated Apollo and Luna samples, have been used to estimate the absolute ages of events on the Moon [2], and extrapolated to Mars [3], Mercury [4, 5], Venus [6], Vesta [7-9], and used in models of early solar system dynamics [10].

However, recent analysis [11] indicates three major complications to the crater chronology picture: a) crater counted terrains may not be the sources of dated samples, b) the need to extrapolation/assume crater count relationships to very young and old terrains, and c) there is a two-three billion year gap of samples with well-known provenance suitable for crater counting.

These problems result in billion-year uncertainties for the history of the Moon and solar system. For example, the era of bombardment of the inner solar system, as recorded by lunar impacts, may have effectively ended ~3.7 Ga ago, or at some younger time. Because life on Earth is thought to have arisen between ~3.7 and ~3.0 Ga ago, the model improvement could reveal new insights about the habitability of the early Earth. Similarly, the era of liquid water on the Martian surface, intimately related to possible life on Mars, as well as the eras of voluminous volcanism on the Moon and Mars, might have ended ~3 Ga ago, or extended to as recently as ~1.7 Ga ago.

The key to addressing these issues [11] is dating additional samples with well understood provenance, from terrain with undisputed crater counts, and associated with terrains of age 1-3 Ga. The young lava flows south-west of Aristarchus are ideally suited for this purpose.

The *MARE* Discovery Mission: After landing at a site southwest of the Aristarchus plateau, samples within reach of the lander’s arm will be assessed using onboard imaging and NIR/TIR mineralogy instruments, and then ranked and prioritized for analysis. The analysis process consists of retrieving a sample with the arm, preparing the sample surface with a grinder, presenting it to the Chemistry and Dating Ex-



periment (CDEX) instrument, and analyzing that surface for chronologic and compositional data. Throughout the first lunar day, context measurements of the landing site will be acquired at infrared wavelengths and downlinked to Earth. A second full lunar day of science measurements is planned as operational margin to ensure mission success.

MARE will provide age measurements that are more than twice as precise as the in-situ dates for Mars made by the Mars Science Laboratory (MSL). *MARE* microscopic geochemistry, mineralogy, and imaging will allow us to determine the petrology, and hence the thermal and magmatic history of the young mare flows, as well as placing them in local, regional, and orbital context. These *MARE* measurements will provide the first ground-truth for correlation with lunar orbital data, including directly comparable thermophysical and mineralogical measurements. Only *MARE* can perform this combination of measurements on the Moon, supplying the science required to write fundamentally new chapters of inner solar system history.

In-Situ Dating: The CDEX instrument operates in two modes. High-precision Rb and Sr isotopic measurements for age-dating are acquired in Laser-Ablation Resonance Ionization Mass Spectrometry (LARIMS) mode, and contents of major, minor, and trace elements are acquired in Laser-Ablation Mass Spectrometry (LAMS) mode. Using CDEX-LARIMS, the baseline mission will determine the ages of a minimum of 10 rocks (1 to 2.5 cm in longest dimension) from the landing site. CDEX prototype instruments have obtained accurate ages for a lunar basaltic analogue, the Duluth gabbro (**Fig. 2**). The Duluth gabbro has a slightly lower concentration of Rb than do Apollo 15 KREEP basalts [12-14], but is similar to that expected at our candidate landing site. We obtained an ^{87}Rb-^{87}Sr isochron age of 990 ± 180 Ma (1σ uncertainty), compared with the age of 1096 ± 14 Ma determined by [12] (after recalibration to the modern value of the ^{87}Rb decay constant [15]). Our age determination came from hundreds of spot analyses on a single ~1 cm rock chip, similar to the samples we will obtain from our landing site on the Moon. **Fig. 2** shows all the spot analyses on the lunar analogue in which Rb and Sr were detected; each analysis is represented by a small dot and its 1σ uncertainty ellipse. The isochron age is found from the slope of the best-fit line (shown with its 1σ uncertainty envelope) through all the data, and the quantity MSWD represents the goodness of the linear fit to all of the spot analyses. The 180 Ma precision we achieved meets the benchmark requirement of the NASA Technology Roadmap [16].

Summary: The *MARE* mission will revolutionize our understanding of the impact history of the inner solar system, by collecting samples from a young, nearside lunar lava flow to measure their radiometric ages, geochemistry, and mineralogy. These measured ages, when related to the number of craters at the site, will redefine the crater-based chronology models on which much of our understanding of the history the inner solar system depends.

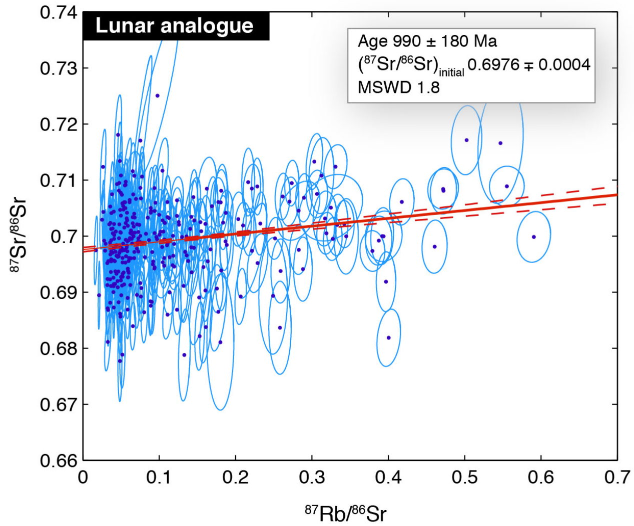


Figure 2: MARE's CDEX instrument reproduces ^{87}Rb-^{87}Sr age of Duluth gabbro [17], an analogue for Apollo 15 KREEP basalt.

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