DECIPHERING 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. This uncertainty fundamentally affects our understanding of events in solar system history, such as the duration and evolution of volcanism on the Moon, duration of the era of water and volcanism for Mars, and the bombardment environment under which life evolved on Earth (**Fig. 1**). To close this critical gap in lunar chronology, we have proposed a new Discovery-class mission called *MARE: the Moon Age and Regolith Explorer*. 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 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 the keystone 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]. The resulting cratering flux has been 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 extrapolate crater count relationships to very young and old terrains, and c) there is a two-billion year gap of samples with well-known provenance suitable for crater counting from 1 to 3 Ga.

These problems result in billion-year uncertainties for the history of the Moon [11] 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, which is 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 is dating additional samples with well understood provenance, from terrain with undisputed crater counts, and from terrains of age 1-3 Ga. The young lava flows southwest of Aristarchus are ideally suited for this purpose.

The *MARE* Discovery Mission: After landing southwest of the Aristarchus plateau, samples within reach of the lander's arm will be assessed using on-board imaging and near/thermal infrared mineralogy instruments, and then ranked and prioritized for analysis. The analysis process consists of retrieving a sam-

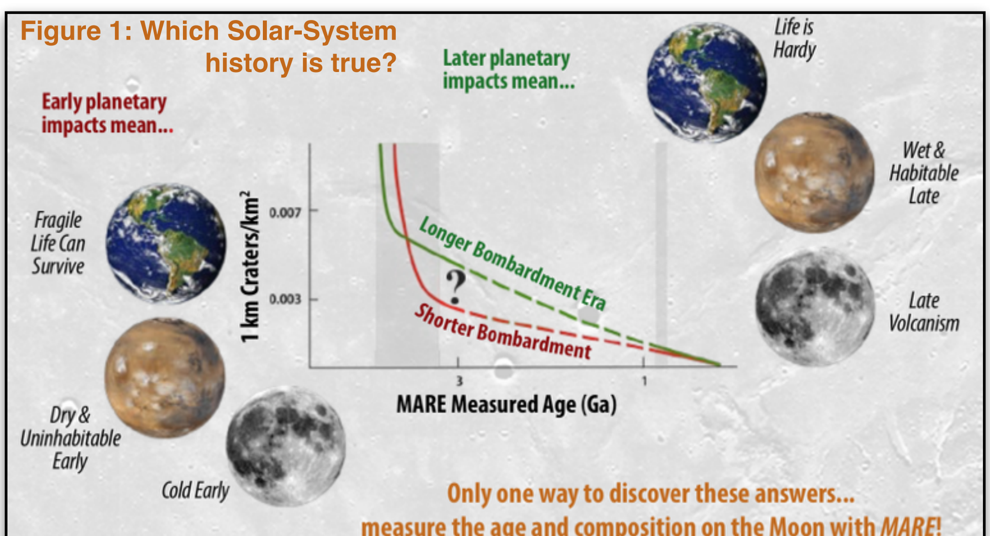

Figure 1: Which Solar-System history is true?

ple with the arm, preparing the sample surface with a grinder, and interrogating that surface for chronologic and compositional information with the Chemistry and Dating EXperiment (CDEX). Visible and infrared landing-site context measurements will be interfingered with geochronology and chemistry analyses throughout the day. A second full lunar day of science measurements is planned as operational margin to ensure mission success.

MARE microscopic geochemistry, mineralogy, and imaging will allow us to determine the petrology, and hence the thermal and magmatic history of young mare flows, as well as placing them in local and regional 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 data 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 the abundance 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 diameter) from the landing site. A CDEX prototype has obtained accurate ages for a lunar basaltic analogue, the Duluth Gabbro (**Fig. 2**) and the Mars meteorite, Zagami [12, 13]. The Duluth gabbro has a slightly lower concentration of Rb than do Apollo 15 KREEP basalts [14-16], similar to that expected at our candidate landing site, and our specimen exhibited a smaller range of Rb/Sr ratios than reported among the phases in KREEP basalt clast 72275,543 [17]. Using a new internal isotope calibration approach that accounts for fractionation between sample and standard, we obtained an improved ^{87}Rb-^{87}Sr isochron age of 1100 ± 200 Ma (1σ), compared with the age of 1096 ± 14 Ma determined by [14] (after recalibration to the modern value of the ^{87}Rb decay constant [18]). Our age determination came from 310 spot analyses on a single ~1 cm rock chip, similar in size and shape to those we will obtain on the Moon. The 200 Ma precision we achieved exceeds that required to reduce the current billion-year uncertainty.

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,

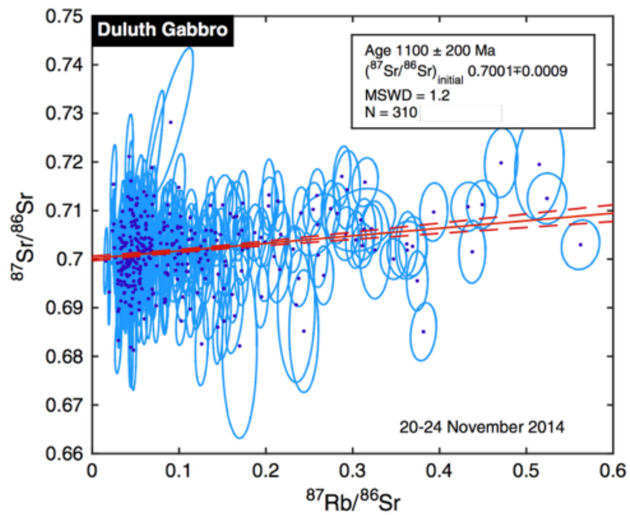

Figure 2: MARE's CDEX instrument reproduces ^{87}Rb-^{87}Sr age of Duluth gabbro [14], an analogue for Apollo 15 KREEP basalt. Points represent each spot measurement with 1σ ellipses; spots with SNR <2 are rejected. The slope of the best fit line is used to determine the age, for which the MSWD indicates an excellent fit.

will redefine the crater-based chronology models on which much of our understanding of the history the inner solar system depends.

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