THE Mg-SUITE ROCKS FROM THE TAURUS-LITTROW VALLEY: A LINCHPIN OF LUNAR SCIENCE. S. M. Elardo[1,2] and C. K. Shearer[3] [1]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA. [2]Department of Physics, Astronomy, and Geoscience, Towson University, Towson, MD 21252, USA. [3]Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA. selardo@carnegiescience.edu. **Invited Abstract – Special Session on the Taurus-Littrow Valley 45 Years After Apollo 17**

Introduction: Samples of the lunar magnesian suite, or Mg-suite were found at every Apollo landing site except the Apollo 11 site. None, however, have been more influential on lunar science than those collected in the Taurus-Littrow valley during the Apollo 17 mission (A17). The A17 Mg-suite samples are more numerous, larger in mass, and more texturally and geochemically pristine than their counterparts from other landing sites. As such, they underpin much of what is known about the early, post-magma ocean phase of lunar evolution.

From studies of Mg-suite samples, primarily those from A17, lunar scientists have made numerous insights about the physical state of and geologic processes occurring on the Moon during the time immediately following the lunar magma ocean (LMO). The Mg-suite appears to be the product of intrusive magmatism in the primary anorthosite crust based on the cumulate nature of the rocks themselves [1]. The A17 samples in particular record a magmatic fractionation sequence from primitive cumulates (i.e., dunites and troctolites) to more evolved cumulates (i.e., norites, gabbronorites, and possibly the alkali suite). The most primitive members have Mg#s of ~90 and the characteristic incompatible trace element compositions of the KREEP reservoir [2-4]. These characteristics separate the Mg-suite from the cumulate ferroan anorthosites (FANs) and require the mixing of a very geochemically primitive component with KREEP. One of, if not the only possible reservoirs for such a primitive component is the Mg-rich cumulates that formed early in LMO crystallization [4, 5]. This requires mantle overturn to transport and emplace these hot, deep mantle cumulates to the base of the crust [6]. The KREEP component in the Mg-suite formed contemporaneously and was available to incorporate into Mg-suite parental magmas. This "geochemical chronology" supports inferences from isochron ages of Mg-suite samples indicating an ancient, post-LMO formation period [7, 8].

The pristine nature of many of the A17 Mg-suite samples has enabled a wide range of science. A number of studies have shown that these rocks record an extended period of subsolidus reequilibration, secondary alteration, metasomatism, and excavation [e.g., 9]. They also record the Moon's remnant magnetic field, allowing for the construction of geophysical and geochemical models of the lunar core [10]. The mineralogy and textures of the A17 Mg-suite rocks have allowed for the construction of models of the physical structure and stratigraphy of the nearside crust that can be compared with remote observations [e.g., 11]. In this abstract, we summarize a few of the many intriguing observations and models that have come from the study of the Mg-suite rocks from A17 and a few of the outstanding issues that remain unanswered.

Mg-Suite Ages and the Early Moon: The ages of ancient lunar crustal rocks, specifically the FANs and the Mg-suite, provide important constraints on planet-scale processes occurring on and within the early Moon. Currently, 80% of reliable Mg-suite ages come from Taurus-Littrow samples, owing to their large size and relative pristinity [7]. The widespread apparent overlap in ages between FANs and the Mg-suite was first noted in the 1970's. However, it has become more problematic for petrogenetic models as the precision on isochron age determinations has increased recently, down to the million year-level, without resolving an age difference between the two groups [7, 8]. Reliable FAN and Mg-suite isochron ages now tightly cluster around 4.37 Ga [7] and are also nearly identical to model ages for the formation of both KREEP and mare basalt source regions [12].

The tight clustering of ages of crustal rocks and mantle reservoirs has been difficult to reconcile with lunar petrogenetic models and other datasets. Borg et al. [13] suggested that the ~4.37 Ga age may represent the age of the Moon, which would be younger than most previous estimates. Although this is perhaps the most straight forward interpretation of the age data, it is not without issues. If 4.37 Ga represents the age of the Moon, it would imply very rapid solidification of the LMO followed by rapid overturn of the mantle cumulate pile and onset of Mg-suite magmatism in order to explain identical FAN/Mg-suite crustal ages and model ages for KREEP and the mare sources. This is inconsistent with thermal models of LMO crystallization, which suggest crystallization would have slowed considerably with the formation of a coherent anorthosite crust [14]. Such a young age for the Moon is also very difficult to reconcile with the terrestrial record from Jack Hills zircons. The oldest ages for Jack Hills zircons are also ~4.37 Ga [e.g., 15] and the zircons have trace element compositions and inclusion assemblages consistent with evolved, wet magma compositions that seem at odds with hot the Earth surface conditions expected immediately after a giant planetary impact. An alternative explanation is that the prominent ~4.37 Ga age represents a widespread thermal event that reset reservoir and sample ages. Such an explanation is attractive because it would allow for an older lunar age more in line with constraints from the Jack Hills zircons and ease the constraint that the FANs, mare sources, KREEP, and Mg-suite must all form within the resolution of isochron measurements. However, the nature of such an event, and whether one could conceivably reset the radiometric clocks of essentially the entire crust and mantle, is unknown. In addition, this model may not be consistent with measured isotopic ratios. This thermal event may represent LMO cumulate overturn in the mantle or a large impact event such as South Pole-Aitken basin [e.g., 1], but this issue remains unresolved.

Structure of the Crust and Sample Provenance: The number, diversity, and pristinity of the Mg-suite samples from Taurus-Littrow have allowed some workers to make inferences regarding the emplacement conditions of Mg-suite plutons and consequently the structure of the mid to lower crust. The most pristine Mg-suite samples have coarse grained cumulate textures indicative of very slow cooling, likely in a layered intrusion setting [e.g., 16]. Estimates of crystallization depths for troctolite 76535 based on thermobarometry using mineral assemblages are 40-50 km [17]. Earlier quantitative estimates for formation depths of other Mg-suite samples such as the dunite 72415 range from a mantle origin to the very shallow crust [e.g. 18]. However, geochemical and mineralogical observations show that 72415 is very likely not a mantle sample [e.g., 19] and the shallow depth estimates are likely underestimates owing to the difficulty in estimating formation depths in the low lunar pressure gradient where pressure-sensitive phase transitions are lacking. Overall, textural and mineralogical constraints support an intrusive and/or under-plating relationship of Mg-suite magmas to the anorthosite crust. This is consistent with remote observations of that suggest the lunar crust, at least in certain regions, becomes more mafic with depth.

The A17 Mg-suite samples were recovered from numerous locations in the Taurus-Littrow valley from different settings (i.e., soils, boulders, breccias), so determining their original provenance is difficult. Nevertheless, progress has been made in this area. Using Lunar Reconnaissance Orbiter images and sample constraints, many of the Mg-suite sample host rocks and boulders have been traced to the Sculptured Hills formation in the Taurus-Littrow valley [20, 21]. It is thought that the Sculptured Hills formation may have been ballistically emplaced at the Taurus-Littrow valley by the Imbrium basin-forming impact. If this is the case, then the A17 Mg-suite samples would not be "native" to the area surrounding the Taurus-Littrow valley, and therefore may represent a layered mafic intrusion that was excavated from the lower crust by the Imbrium event. Gravity data from the GRAIL mission has been interpreted as indicating many large basin forming events may have excavated the deep crust or even the mantle.

Crustal Alteration Processes: Although as a whole, the A17 Mg-suite samples are the most pristine samples of the suite, impact modification is still prevent and often obscures primary textures. A few samples, however, retain their primary cumulus or post-cumulus textures despite ~4.3 billion years in and on the battered lunar crust. These samples, in some cases, also record secondary alteration processes. Troctolite 76535 and dunite 72415 contains symplectite assemblages consisting of chromite and two pyroxenes that may be the result of metasomatism by a basaltic melt [8]. Additionally, 72415 contains apatite veining with textures suggestive of a secondary origin [1], possibly by a fluid, which has been suggested for granulite 79215 [22]. Additionally, troctolite 76535 contains sulfide-rich veining [9] that may indicate S-rich fluids/vapors in the crust similar to those observed in some Apollo 16 breccias [23].

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