APOLLO 17: NEW INSIGHTS FROM THE SYNTHESIS AND INTEGRATION OF FIELD NOTES, PHOTO-DOCUMENTATION, AND ANALYTICAL DATA. Harrison H. Schmitt[1], University of Wisconsin, P.O. Box 90730, Albuquerque NM 87199, hhschmitt@earthlink.net

Introduction: A number of new insights into the geology of the valley of Taurus-Littrow and surrounding regions of the Moon have resulted from recent synthesis and integration of transmitted field notes, field recollections, and photo-documentation with over forty years of data from sample analysis and geophysical measurements.

Magma Ocean and Mg-Suite Magma Timing: A test of the duration of magma ocean crystallization comes from the Rb-Sr isochron ages for the primary crystallization of Apollo 17 Mg-suite samples that originated from magmas produced by the partial melting of magma ocean cumulates. The best preserved Apollo 17 Mg-suite samples and their Rb-Sr and Nd-Sm crystallization ages are as follows:

- Troctolite 76535: 4.51±0.07 Ga
- Dunite 72415: 4.45±0.1Ga
- Norite 78236: 4.38±0.02 Ga and 4.43±0.05 Ga

The indicated crystallization age for the oldest of these samples, the troctolite 76535, lies only ~50-120 million years younger than the age of the Solar System of 4.567 billion years [1]. Within that 50-120 million years the following events needed to occur:

- Development of the lunar magma ocean.
- Fractional crystallization of the magma ocean.
- Impact formation of a thick, insulating mega-regolith on the crust.
- Movement of Mg-suite magmas into the lower crust and their fractional crystallization.

Just with respect to troctolite 77535, these events require that fractional crystallization of the magma ocean be essentially complete in significantly less than 120 million years. If one takes into account the ±70 million-year error in the age of 76535, then crystallization may have had less than 50 million years to be completed.

Absolute Ages of Four-Eight Large Basins [2]: Large boulders at the base of the 1600 to 2100m high massif walls of the valley provided many samples of impact breccias. Cluster analysis of 65 radiometric dates by many workers on these samples permit dating of four of the large basin-forming impact events on the Moon and probable dating of four additional such events:

- Imbrium – 3.86-3.87 Ga
- Crisium (?) – 3.91 Ga
- Serenitatis – 3.97 Ga
- Nectaris (?) – 3.99-4.00 Ga
- Fecunditatis (?) – 4.02 Ga
- Tranquillitatis – 4.08 Ga
- South Pole-Aitken (?) – 4.19 Ga
- Procellarum – 4.33 Ga

The South Massif of Taurus-Littrow lies near the basin rims of both Serenitatis and Tranquillitatis. A synthesis of $^{40-39}$Ar ages of impact melt-breccia matrixes from South Massif boulders at Station 2 suggest an age of ~4.08 Ga for the Tranquillitatis event and of ~3.98 Ga for Serenitatis. A large boulder at Station 6, that rolled from a location about 400m above the base of the 1600m high North Massif, includes vesicular, light green-gray impact melt-breccias that have intruded earlier-formed dark blue-gray melt-breccias. The matrixes of both these melt-breccias have a cooling age of ~3.97 Ga, supporting that age for Serenitatis.

A Station 7 dark blue-gray melt-breccia from a boulder that rolled from a location ~500m vertically above the source of the Station 6 boulder and ~700m below the crest also has a matrix with a ~3.98 Ga age. The matrix of vesicular, light green-gray melt-breccia in contact with this blue-gray melt-breccia, however, has an age of ~3.86 Ga. This latter age may date the initial melt-breccia ejected from the Imbrium basin, the edge of which is ~770km northwest. If so, it would indicate ~700m of Imbrium ejecta exists on the North Massif at this location, about 1350km from the center of Imbrium.

Mg-Suite Pluton Ejected from Imbrium [3]: The remarkably detailed photographs returned by the LROC stimulated a new look at the Sculptured Hills. It became clear that the "sculpture" of the Sculptured Hills, an area approximately 10km by 15km, consists of linear swales that comprise roughly orthogonal, northwest-southeast and northeast-southwest physiographic trends. LROC image detail further suggests that one of these trends might outline breaks along layers of differing composition. As there does not appear to be any significant younger basin ejecta covering these structures, the rocks underlying the surface of the Sculptured Hills probably consist of ejecta from Imbrium, the nearest large, post-Serenitatis basin.

The M^3 sensor data [4], with a resolution of about 100m, show that the Sculptured Hills and a few other nearby elevated features have distinct variations in the distribution of plagioclase, orthopyroxene, clinopyroxene and olivine, corresponding, in part, to areas bounded by the orthogonal physiographic trends. These distributions may define portions of an ejected pluton composed largely of anorthositic rocks but with significant masses of noritic anorthosite, gabbroic norite, norite, dunite and a distinct, but unknown rock type. Norite 78238 probably relates to a portion of a large layered igneous intrusive, ejected from the lower crust by the Imbrium impact and ballistically transported as a fractured but largely intact single unit to Taurus-Littrow.

Cooling and Differentiation History of Mare Basalts: The rake sample at Station 1 (71500) provided 38 fragments of titanium-rich basalt, 26 of which have been mineralogically and chemically analyzed [5]. With the assumption that the rake sample fragments represent samples of a single titanium-rich basalt lava (s.g. ~3.1) at various stages of cooling, comparisons of TiO_2/Al_2O_3 and TiO_2/CaO ratios with olivine content in the fragments (figures 1 and 2) would indicate that olivine was first to crystallize, but at ~0.5% olivine was followed by Ca-plagioclase and then by ilmenite. Flotation of Ca-plagioclase (s.g. 2.8) nearly doubled the TiO_2/Al_2O_3 and TiO_2/CaO ratios. The TiO_2/Al_2O_3 and TiO_2/CaO ratios of 71501, the regolith developed on the sampled flow, are consistent with plagioclase enrichment of the top of the flow. At ~6% olivine, however, removal of ilmenite (s.g. ~4.8) by sinking appears to have lowered these ratios by about 50%.

The $TiO_2/MgO+FeO$ ratios in fragments with low olivine content also increased at this early stage of melt crystallization. This suggests that olivine (s.g. 3.6) began to leave the melt by sinking.

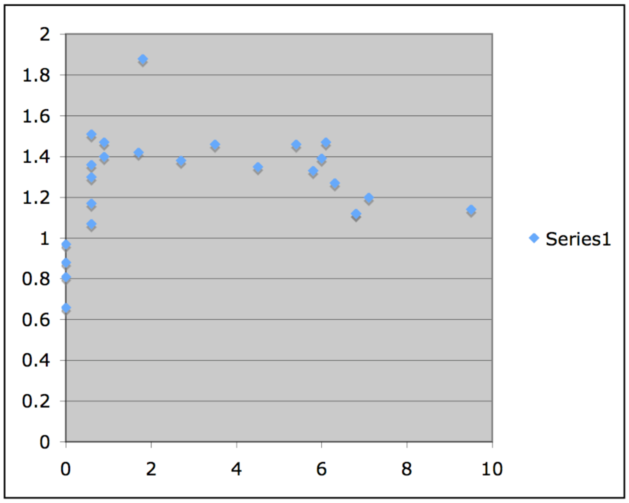

Figure 1. TiO2/Al2O3 (Y-axis) versus Olivine Content (X-axis)

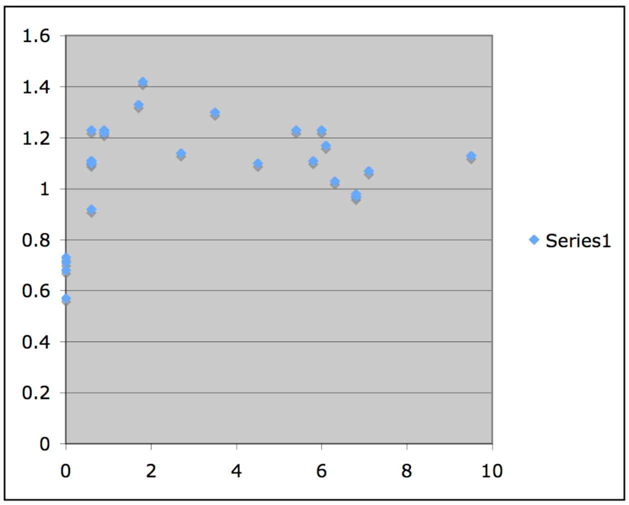

Figure 2. TiO2/CaO (Y-axis) vs. Olivine Content (X-axis)

Nature and Geology of Pyroclastic Deposits [6]: Field observations at Shorty Crater, type location of orange and black pyroclastic ash (74220, 74002), combined with post-mission examination and analysis of samples and a 70cm drive tube core, show that orange and black ash layers form a small isoclinal fold, enclosed by light-gray regolith (74040, 74060). This light-gray regolith derives from the impact pulverization of a post-pyroclastic lava flow that covered and protected the ashes from being mixed with other regolith for about 3.5 billion years. The ash layers are underlain, in sequence, by Type C basalt regolith, Type C basalt (74255, 74275), Type A basalt regolith, and Type A basalt (74235, 74245). The light mantle avalanche deposit overlies the light-gray, basaltic regolith above the ash layers.

Source of Light-Gray Regolith above Orange Pyroclastic Ash: Preliminary micro-probe analyses [7] of residual glass in partially devitrified beads of black pyroclastic ash indicate a compositional trend toward that of the light-gray regolith that overlies the orange and black ash layers at Shorty Crater. This strongly suggests that the light-gray regolith is derived from a flow originating from the devolatilized and partially differentiated magma source that previously produced the orange and black ash.

Confirmation of Regolith Avalanche Off South Massif: Pre-mission photographs of the valley of Taurus-Littrow suggested that the plume-like light mantle unit, extending as much as 5km from the steep north slope of the 2100m high South Massif, might have been the result of an fluidized avalanche of regolith. Solar wind volatiles, primarily hydrogen, released by the initial agitation in the moving avalanche, provided the most likely source of fluidizing gases. Combined field and remotely sensed evidence supports of this hypothesis

Documentation of Variable Micro-Meteor Flux: The well documented, 3.5 billion year old light-gray, basaltic regolith (77240, 77260) exposed at Shorty Crater as a unit stratigraphically overlying the orange ash, has exceptionally low maturity (8% agglutinates and Is/FeO = 5) but an unusually high amount of "ropy" glass (14-18%). (Ropy glass normally constitutes less than one percent of new Taurus-Littrow regolith. It forms within fresh impact craters as a result of macro-meteor impacts, but the current flux of micro-meteors disaggregates such glass within a million years or less.) A significant micro-meteor flux cannot have existed during the formation of this ancient regolith or it would have a higher maturity index and little or no ropy glass. Micro-meteor fluxes thus appear to vary over geologic time, presumably in response to significant impact events in the Asteroid Belt.

Ilmenite Influence on Is/FeO Indexes of Regolith Maturity: Synthesis of Is/FeO maturity indexes for Apollo 17 regolith samples in the valley of Taurus-Littrow on the Moon indicate that high levels of ilmenite in the samples significantly reduces the level of this indicator of space exposure. Surface samples of ilmenite-poor, silicate-rich regolith have about 80-90% higher maturity indexes than surface samples of ilmenite-rich, basaltic regolith of comparable exposure. For comparison of the history of various regolith exposures to the space environment, Taurus-Littrow's light mantle avalanche deposit, the youngest large area stratigraphic unit, provides a specific time horizon. For at least the last ~110 million years, the currently estimated age of the light mantle avalanche, most near surface (upper 1-5cm) areas of regolith in the valley have had approximately the same exposure to micro-meteors. High apparent maturity (Is/FeO >80), however, exists only on three types of regolith surfaces: (1) the North Massif apron (e.g., 77431), (2) the light mantle avalanche deposit (e.g., 72161), and (3) low ilmenite basalt (e.g., 72150). Only intermediate to low maturity (Is/FeO <60) has developed in surface regolith overlying high titanium basalt (e.g., 70181).

References: [1] Amelin, et al, (2004), *Geochim. Cosmochim. Acta, 68*, A759. [2] Schmitt, H. H, (2013) Abst. *GSA*, 2-1. [3] Schmitt. H. H., and Robinson, M. (2010) Abst. *GSA*. [4] Courtesy of Noah E. Petro, GFSC. [5] See Meyer, C. (2008) http://curator.jsc.nasa.gov/lunar/lsc/index.cfm. [6] Schmitt, H. H. (2013) Abst. *GSA*, 2-1. [7] Courtesy of B. Jolliff, WU. [8] Saal, A. E., et al, *Nature, 454*, 192. [9] Schmitt, H.H. (2003), in H. Mark, ed., *Encycl.Space and Space Tech., Wiley,* Chapter 1. [10] Courtesy of J. Plescia, APL.