GEOLOGY AND STRATIGRAPHY OF SHORTY CRATER PYROCLASTIC ASH DEPOSITS.

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Introduction A lens-shaped deposit of orange and black “soils” at Shorty Crater (Station 4) was investigated and sampled during Apollo 17 exploration of the valley of Taurus-Littrow in December 1972 [1]. Post-mission examination and analysis of samples 74220 and 74001/2 disclosed that these “soils” consist of very small beads (25-40 μm) and shards of orange glass and black, partially crystallized colorless glass [2]. The apparent black color results from dark microscopic crystallites of olivine, pyroxene and ilmenite [2]. The spherical shapes, very small size, and associated surface volatiles of both orange and black beads are those expected of volcanic ash produced by a volatile-driven eruption of basaltic magma in extreme vacuum [3].

The detailed structure of the ash deposit is likely that of an isoclinal anticline [4] with its axial plane partially overturned and sub-parallel to the rim of Shorty Crater. This structure is consistent with the radial direction of impact forces that created Shorty Crater. The exposed crest of the fold has been planed off through the top orange ash layer. A trench dug through this layer and the fold’s crest exposed light-gray regolith, statigraphically overlying the orange ash unit.

Stratigrapy of Pre-Shorty Impact units. The impact that produced Shorty Crater penetrated about 14 m [5] of roughly layered units of light mantle, ash, and various regolith-like materials as well as the upper portions of underlying basalt. The explosive forces of the impact both ejected and laterally compressed these layers away from the point of impact, creating the floor, walls, rim and surrounding ejecta blanket. Samples obtained provide information on all these local layered units with the exception of the light mantle avalanche deposit and the regolith units developed on the underlying basalt flows. Based on the track exposure age of orange ash sample 74220 [6] and the cosmogenic Kr exposure age of rim basalt 74255 [7], this impact occurred 10-19 million years ago.

Figure 1 summarizes the inferred pre-impact stratigraphy at Shorty Crater. The Type A, subfloor basalt flow at the site, possibly represented by sample 74235, has not been dated. The average of 36 dates between 3.80 and 3.54 Ga for Taurus-Littrow subfloor basalt samples is 3.74 Ga [8]; however, it is likely that this late flow would be the product of one of the youngest Type A basalt eruptions in the valley.

Two Shorty rim samples of Type C basalt, 74275 and 74255, probably represent flows younger that the youngest Type A basalt. The lower Ba/Rb ratios of Type C basalts apparently required a period of fractional crystallization and separation of plagioclase in the subfloor basalt magma chamber. The presence of clinopyroxene phenocrysts with olivine cores in 74255 [9] vs. olivine interpreted as zenocrysts in 74275 [10] suggests that the latter is a sample of the older of these two flows.

Particle size grading from coarse to fine with depth [11] in the deepest definable unit in the double drive tube core suggests that the core penetrated a tilted axial plane of the isoclinal fold and that this unit of the ash (#4) is overturned relative to other units. The interpretation shown in Fig. 1 assumes that unit #4 is the unit exposed in the bottom of the core, i.e., it is stratigraphically above unit #5. Textures in the core and reported ^{81}Kr exposure ages for the locations in the core [12] indicate that several ash eruptions may

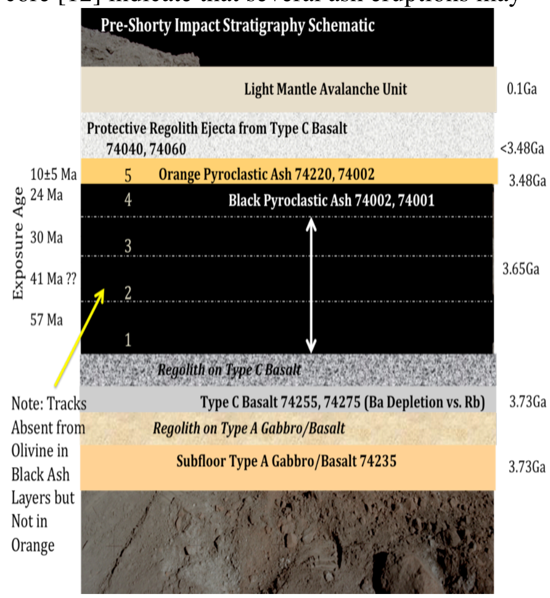

Figure 1. Schematic pre-Shorty impact stratigraphy. Thicknesses not to scale.

have spanned at least 150 Myr. This 150 million year or longer eruption period may explain the difference (on the order of 170 Myr) between the 3.48±03 Ga [13] absolute age determined for the last eruption (orange ash unit #5), and the older, 3.654±0.020 Ga age [14] of black ash unit #1 sampled by the drive tube core.

The thicknesses of five probable ash units in the 74001/2 drive tube core, currently 7-20 cm each, result from combining the exposure age determinations at different depths [15] with reported textural features in the core [11] [16]. Mean grain-size and sorting analyses are roughly consistent with each other and with visual mapping of the core features. Exposure ages also suggest at least five ash eruptions were sampled in this core, consistent with the particle analyses. Depth-correlated changes in the physical properties of the deposited ash might reflect differences in magma viscosity, volatile content, transient atmosphere density, channel size, and/or eruptive dynamics.

Exposure of younger units to cosmic rays could increase the apparent exposure ages of the underlying, older units. It has been estimated that about 25 cm (80 g/cm2) of shielding would be required to prevent this from occurring. [17] 25 cm or more of shielding above each dated sample is not currently present in the drive tube core, although some thinning may have occurred during impact induced folding. Thus, the exposure age of unit #1 may have been increased during the now 7 cm thick unit #2 exposure. Similarly, the exposure age of unit #4 may have been increased during the now 12 cm thick unit #5's exposure; however, an unknown amount of unit #5 has been planed off during crater formation. These possible additional exposure age components, however, do not negate the fact that there were several separate ash eruptions with tens of million years between each.

Nothing in the analyses of the drive tube core provides evidence of regolith development on ash units #1-4. Extremely low Is/FeO maturity indexes for the entire extent of these four units are constant at 0.1 [18] and indicate that micro-meteor flux during at least the period of ash eruptions was very low for possibly 150 million years or longer. The maturity indexes, although remaining very low, increase from 0.1 to 3.6 from 5 cm depth to the top of the drive tube core in ash unit #5 (orange). That interval also has evidence of macro-meteorite gardening in the presence of 1.6% basalt fragments and 1.3% agglutinates. [19] These facts indicate conditions permitted the development of at least 5 cm of apparent regolith at the surface of unit 5, the last ash to be deposited. >5 cm of regolith, however, is likely, given the apparent 24 Myr exposure of unit #5 and the loss of an unknown amount by planing.

A number of issues in the ash stratigraphy remain to be explained. (1) The lack of obvious regolith zones between any tentatively defined ash units as well as the extremely low maturity indexes throughout the core require explanation. Extremely low micro- and macro-meteor fluxes might partially explain this fact. (2) Galactic cosmic ray induced nuclear particle tracks in olivine [6] have not been observed in any ash units below the upper portions of the youngest ash unit (#5). One explanation for the absence of particle tracks may be that each unit was hot enough after deposition to anneal the tracks in the underlying unit. This would require temperatures in the annealed unit to reach a few hundred degrees C for several days. (All tracks disappeared in lunar olivine annealed at 430°C for 32 hours. [20]

Light-gray Regolith: The orange and black ash units at Shorty have not been incorporated into the Taurus-Littrow valley's dark mantle regolith, as has occurred elsewhere. Other than being structurally disturbed by the Shorty impact, these units have remained in nearly pristine form since ~3.5 Ga. For this to be so, a younger deposit must have covered the units soon after the last eruption, specifically, after about 5-10 Myr. (The accumulated 24 Myr exposure age of the orange ash unit #5 minus the apparent age of the Shorty impact.) As noted above and consistent with this hypothesis, it has been estimated that more than 25 cm (80 g/cm^2) of shielding needed to exist above the ash units to maintain this relatively low exposure age.

Stratigraphically, the light-gray, basaltic regolith material, samples 74240 and 74260, that now resides on either side of the orange ash unit must have been the protective deposit. Regolith ejected from some distance away conforms to the characteristics of the samples and with the unit's sharp contact with orange ash. The samples of light-gray material have the chemical characteristics of Type C basaltic regolith [21]. The 90-150μm fraction of 74240 and 74260 [19] consist of, respectively, ~68% and ~63% basaltic fragments, minerals, agglutinate and ropy glass. The low percentage of agglutinate (8 and 7.7%, respectively) and I_s/FeO values of about 5 [18] indicate very low maturity, that is, only limited exposure to micro-meteor impact. On the other hand, exposure age determinations on the order of 200 Myr [22] indicate extended residence at the lunar surface.

The rim of a highly degraded, ~350 m diameter impact crater, named here as "Fitzgibbon," lies about 1000 m north northeast of Shorty Crater. It is a stretch, but still plausible, to have ejecta 25 cm or more thick extend nearly three crater diameters from its impact source. Fitzgibbon Crater also lies on a line between Shorty and the south end of a pyroclastic fissure identified to exist on the flank of the North Massiff, [8] about 2 km away. The flow on which the light-gray regolith originally developed may be a late eruption from this fissure.

The hypothesis that the light-gray regolith on either side of the orange ash originally developed on a nearby flow younger than the ash deposits finds support in the presence of about 8% and 12% ash (orange, black and colorless), respectively, in 74240 and 74260. [19] Both samples have sodium, fluorine, chlorine, bromine, and sulfur concentrations as high to twice as high as the enrichment of these elements found in the adjacent orange ash, indicating a close spatial or genetic correlation. [23]

Conclusions: At least five distinct orange and black pyroclastic ash units in the rim of Shorty Crater make up a partially overturned, isoclinal fold. Eruptions of ash occurred periodically over possibly as much as 150 Myr at about 3.5 Ga. A layer of basaltic regolith ejecta protected the ash units from incorporation in the dark mantle regolith for about 3.5 billion years.

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