LATE STAGE LUNAR LAVA FLOWS AND CINDER CONES.

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Introduction: The lunar mare are characterized by massive low-viscosity, high-eruption-rate lava flows with subtle topography, filling the low topography of pre-existing impact basins [1]. While such flows constitute the bulk of extruded volcanics, scattered across the mare are many constructional edifices, typically referred to as "lunar domes", localized lava flows, cinder cones and broad pyroclastic deposits.

The term "lunar dome" is a misnomer as these features do not resemble terrestrial volcanic domes and typically exhibit low slopes (2-5°) are more accurately termed "low shields" [2]; a few (e.g., Compton-Belkovich, Gruithuisen) could reasonably be termed "domes" having steeper slopes (~20-25°) and a silicic composition [3-6].

Several compilations have been produced and more than 1000 features have been identified [7-8]; it should be noted that while in many cases an often subtle topographic feature is present at the coordinates, the origin of the feature is undefined. Studies of individual groups of low shields have been conducted and they are characterized as having shallow slopes (<5°) and a summit crater, and presumably the result of low-volume, low-effusion rate eruptions [9-11]. Lava flows are not typically observed. In some locations, a strong structural control is evident by an alignment of edifices and elongate topography and summit crater shape [12]. Low shields often have radar, spectral or chemical anomalies with respect to the surrounding areas [13-15].

Young Flows and Cones: A number of lava flows and features characterized as pyroclastic constructs (i.e., cinder cones) are scattered across the lunar surface. Using recent spacecraft data, the morphology, morphometry and composition can be examined. These features are stratigraphically young as they are clearly superposed on the surrounding terrain. Their absolute age is difficult, if not impossible, to define via crater counting as the surface areas are often very small.

Eastern Crisium. Two cinder cones and several flows are observed in the eastern mare (Figure 1). The unnamed cinder cone is 3 km diameter, 50-80 m high, and the floor lies 50 m below the surrounding terrain. Mons Latrelle is 6 km diameter, 100-180 m high, with a breached south side. Sourced at a flat topped vent 3.7 km wide; the north flow is leveed with several breakouts, 32 km long, 5-13 km wide and 30 m thick. The central flow field consists of four flows and two cinder cones. Flows are 10-20 km long, the largest is leveed with numerous breakouts.

The unnamed cinder cone and Mons Latrelle exhibit Clementine color ratio anomalies, high FeO, low clinopyroxene, but high olivine and slightly high orthopyroxene and have low maturity. The North flow has slightly enhanced clinopyroxene, the central and southern flows do not exhibit spectral anomalies.

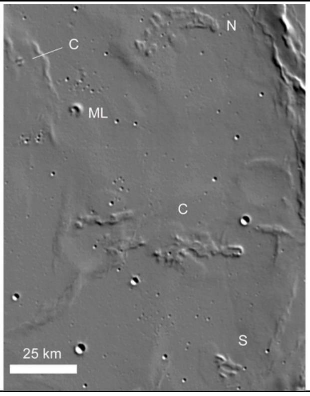

Figure 1. Eastern Crisium (17.53°N, 63.50°E). N: North flow, C: Central flow field, S: Southern flow, C: Unnamed cinder cone, ML: Mons Latrelle. Shaded topography.

Tobias Mayer. South of the crater Tobias Mayer is a well-defined lava flow erupted from a cone ~3 km diameter (Figure 2) extending 11 km to the northwest where it is dammed against a massif, covering an area of 64 km^2. The flow consists of at least two phases. Near the cone, the flow is wide (up to 7 km) and 40-50 m thick. A second flow appears to be superposed and is 100-150 m thick. Crater frequencies on the flow are higher than on the adjacent mare surface. The flow has a higher FeO content than the immediately adjacent mare, but similar to that to the northwest.

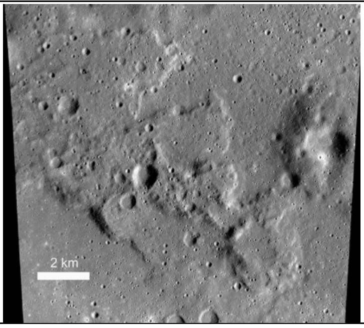

Figure 2. Tobias Mayer flow 13.92°N, 330.37°E.

Hortensius. Among the numerous low shields of the Hortensius region, is a northeast-trending 9 km ridge, 0.1 to 2 km wide (Figure 3). The ridge is some 50-60 m high and characterized by locally coalesced elongate depressions. The floors of the depressions typically lie above the surrounding terrain. Locally, the ridge displays high clinopyroxene. To the northeast, a cinder cone and low shield straddle a northeast-trending rille.

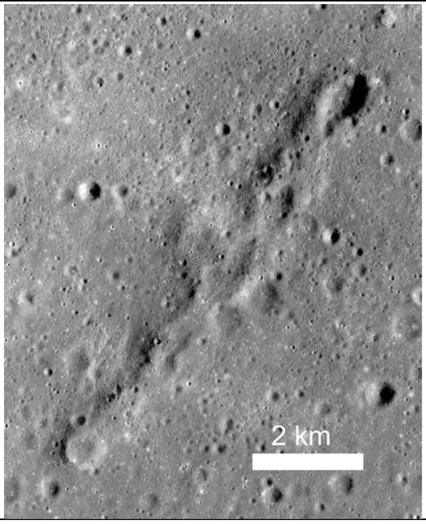

Figure 3. Hortensius spatter cone ridge 7.28°N, 332.87°E.

Discussion: The characteristics of these types of effusive volcanics allow insight into a various aspects of late-stage lunar volcanism.

While model-dependent absolute ages are typically lacking, the stratigraphic context indicates that these features are late stage. In the cases of some of the low shields, in areas like Mare Tranquillitatis, the relative ages of the shield and surrounding mare lavas are equivocal. Lava flows cannot be traced from the edifice onto the surrounding plains, which would demonstrate the edifice is younger. However, it is clear that magma source areas were maintained allowing eruptions late in lunar volcanic history, either from isolated shallow sources or a connection to a deeper source.

Morphologic and morphometric aspects of the lava flows indicate that the eruption conditions and/or lava composition is distinctly different from that forming low shields and the mare flows. Differences in mineralogy and chemistry (e.g., FeO) between and among the flows and cones and surrounding mare and other low shield edifices are observed. Such differences are consistent with an evolved / fractionated magma source or one distinctly different from that which supplied the low shields and the mare flows.

Small flow and cone volumes indicate either limited source regions that were rapidly depleted, or low pressures such that it was more conducive to exploit a different path to reach the surface and form a new vent than to continue to build a given edifice higher.

The close proximity of independent vents suggest that multiple pathways from the source(s) to surface were possible, rather than a single primary pathway. While the linear orientation of constructs such as in Hortensius and features in Mare Tranquillitatis [16] are consistent with at least a short dike feeding the eruption, the random scattering of vents over areas of 50-100 km or more would not seem consistent with control by an extensive deep seated dike. Additionally, localization of the vents in eastern Crisium with wrinkle ridges suggests that at least at shallow depths, magma can utilize pre-existing compressional fractures to reach the surface.

Conclusions: While the total volume of these flows and pyroclastic deposits (as well as the low shields) is small, their widespread distribution indicates that numerous (albeit small volume) magma sources survived across the Moon for a period of time beyond that of typical mare volcanism. Such small volume localized effusions would not seem to be consistent with suggestions by [9-11] that late-stage eruptions would be characterized by high-volume and high-effusion rates.

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