THE ROLE OF PRE-EXISTING TOPOGRAPHY IN MODULATING LUNAR LAVA FLOW WIDTHS, DEPTHS AND CHANNEL STRUCTURE: AN EXAMPLE OF AN ERATOSTHENIAN LAVA FLOW IN MARE IMBRIUM (PART 1-OBSERVATIONS). Y. Chen[1, 2, 3], J. W. Head[3], C. L. Li[1], M. Kreslavsky[4], L. Wilson[5], J. J. Liu[1], X. Ren[1] [1]Key Laboratory of Lunar and Deep Space Exploration, National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China, [2]University of Chinese Academy of Sciences, Beijing, China, [3]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA, [4] Earth and Planetary Sciences, UCSC, Santa Cruz, CA 95064 USA, [5]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ UK. Contact: cheny@nao.cas.cn.

Introduction: Volcanism is the most important endogenic process on the Moon. Recent advances in the analyses of the generation, ascent, intrusion, and eruption of basaltic magma on the Moon [1-3] have related thermal evolution and emplacement models to observed volcanic features and provided new insights into the nature of volcanic eruptive mechanisms. Several studies [eg. 4,5] have discovered distinctive volcanic features and explored new modes of their origin, further illustrating the diversity and complexity of magma generation and emplacement processes. Most models of lava flow emplacement adopt the simplifying assumption of eruption onto a flat surface or a specific slope, assuming that this slope persists throughout the emplacement and cooling of the flow. It is well known, however, that a variety of processes (impact, tectonic and volcanic) can produce emplacement substrate topographic variations in space (for a single flow) and time (for successive flows). In this two-fold study, we are (Part 1) documenting the nature of the effects of topography on a well-preserved Eratosthenian-aged lava flow in Mare Imbrium, and (Part 2) assessing how the observed effects can improve our understanding of our models of topography formation and lava flow emplacement and cooling behavior [2].

Background: Long, lobate, high-Ti Eratosthenian-aged (3.2–1.2 Ga) lava flows have been documented in Mare Imbrium [6-11]. Recent modeling studies [1-3] propose that the extremely long lava flows were produced during high effusion rate eruptions. During successive stages of an eruption, changes in magma overpressure, magma rise rate and gas production combine with the cooling behavior of the extruded lava flow to produce characteristic flow textures and morphologies [12]. As yet unaccounted for in these models is the influence of pre-existing topography on lava flow emplacement [7]. Here we combine high resolution images, altimetry and detrended topography data [13] to document the role of topography in modifying lava flow morphology and morphometry. We specifically document the interaction of a lava flow with topography (generally orthogonal to lava flow direction) related to the presence of mare ridges and arches [7] formed from loading, flexure and deformation due to earlier-emplaced flows [15].

Topographic and morphologic features along a single lava flow: We choose an individual lava flow, about 250 km in length and ~10–25 m in thickness, that crosses a series of wrinkle ridges and we document the topography/morphology in both along-flow and across-flow directions (Fig. 1a). Flow boundaries (Fig. 1b) are defined using detrended altimetry data which removes regional slope and reveals local relief [13]. As seen in the topographic profile (TP) of the midline of the lava flow (Fig. 2), the along-flow relief shows a staircase pattern defined by five ridges (R) with heights of ~50–200 m, trending across the lava flow and the lava ponds (LP).

According to the across-strike profiles (Fig. 3), lava flow widths from TP1 to TP6 are generally stable (~10 km). A channel is observed along the central part of the flow and its width varies from ~2.5–5 km. TP6 exhibits the largest elevation variation as it is located in ridge 1 (R1). In TP7 and TP8, the flow narrows sharply by ~1/4–1/3. At the same time, the lava channel widens and deepens significantly, suggesting variations in flow velocity due to geometry. Ponded lavas (TP9–TP17) occur both before and after R2 (TP13) (Figs. 1,2). The fact that R2 influenced the superposed lava flow means that R2 predated the flow. However, we interpret the ridge to have been at an early stage of development, as the height of lava in the LP1 (TP11 & TP12) is ~15–20 m, while the present height of R2 is up to ~200 m. The morphology of LP2 resembles a flood fan (Fig. 1), except that it displays depressions in the interior region as is indicated by the cross-strike profiles. Bowl-shaped TP16 and flat-bottomed TP17 clearly display the baseline geometry of lava pond LP2 (after R2), reflecting the preexisting topography.

The >20 m deep channels at TP18–TP20 again reflect the distinct changes in channel and flow characteristics related to topographic barriers and constrictions. The lava flow was once again blocked by the R3 ridge (TP22), and a portion of the flow experienced almost the same process as seen surrounding R2. The other part of the lava flow spread westward and filled the lowland in front of R3, as seen in the detrended image (Fig. 1b). The western section of R3 may not have existed at the time of emplacement of this flow, as the lava seems to have flowed directly to the north without deviation. From TP23 to TP28, the lava channel gradually disappears, perhaps due to a decrease in velocity and ponding. Two additional ridges (R4 & R5) existed between TP29 and TP38, as the lava width continues to change, but no traces of channels can be observed along the remaining part of the lava flow. A possible lava pond (LP4) is suggested just before R5 on the basis of flow widening and narrowing. On the basis of the length, width and thickness, the total volume of this individual lava flow is estimated to be ~50–125 km^3.

Summary of flow behavior: 1. A narrow lava flow extended downslope in an area currently characterized by five across-strike topographic ridges of various heights. 2. The lack of modification of the flow characteristics at R1 suggests that the ridge postdates the flow. 3. The flow continued until it was blocked by mare ridge R2, more subdued in its topography than at present (~20 m height, versus ~200 m today). Lava then ponded locally behind the ridge until its height exceeded that of a gap along the ridge. 4. The gap provided a pathway for the lava rising behind the obstruction to flow through the low in R2 and produce a fan-shaped lava pond (LP2) on the other side of the ridge (Fig. 4). 5. This lava pond (LP1) continued in accumulating until a large volume of lava broke through this gap, flowed along the downslope surface of R2, spread out in the low between R2 and R3, and formed deep channels in the left side of the LP2. Channel width and depth varied with topographic slope with deeper channels on steeper slopes. 6. Some of the lava was ponded on the east side before R3, while some headed northward on the west side as no terrain obstacles appear to have existed at that time. 7. After R3, images and profiles show that lava channels gradually disappeared. 8. The lava flow width appears to have been unmodified by the presence of R4 (suggesting it did not exist at the time) and the blunt shape of the flow termination at R5 suggests that R5 served as a final barrier as the flow stopped advancing.

Implications for formational processes and regional tectonism: On the basis of these observations, we consider the following points that will be important in the further understanding of lava flow emplacement and the evolution of topography in lunar basins (Part 2): 1. How does the emplacement behavior of this lava flow compare with the theoretical predictions of flow velocity and cooling behavior [1-3]? 2. What insights about the relationships among flow width, levee formation and heat loss at the lava margins can be derived from lava flow blockage and spreading behavior? 3. What insights into lava flow velocity and potential thermal erosion can be obtained from the behavior of the lava channels at, and between topographic barriers. 4. What is the relationship between lava flow width/channel width, and flow velocity, turbulent and laminar flow and the possibility of thermal erosion? 5. What implications do these results have for the general emplacement of lunar mare basalt lava flows? 6. What is the history of topography and the formation of wrinkle ridges and arches in the SW Imbrium basin?

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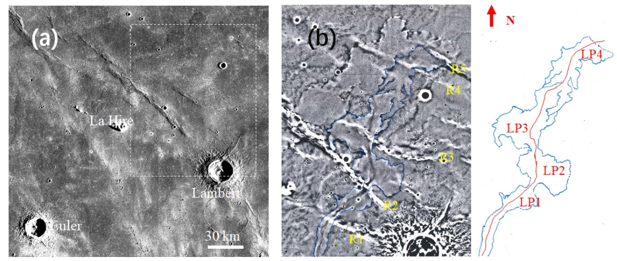

Fig.1 a) The location of individual lava flow in Mare Imbrium. b) The detrended data and outline of the individual lava flow.

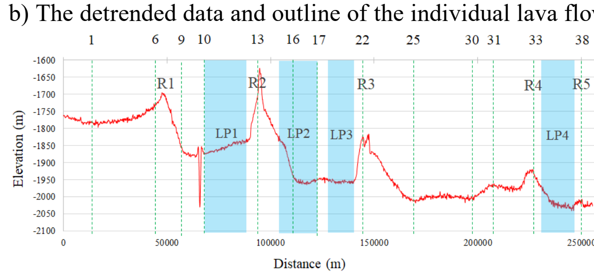

Fig.2 Longitudinal curve of the target lava flow. Blue areas are ponding lavas. Green dotted lines and numbers indicate the locations of lateral elevation curves.

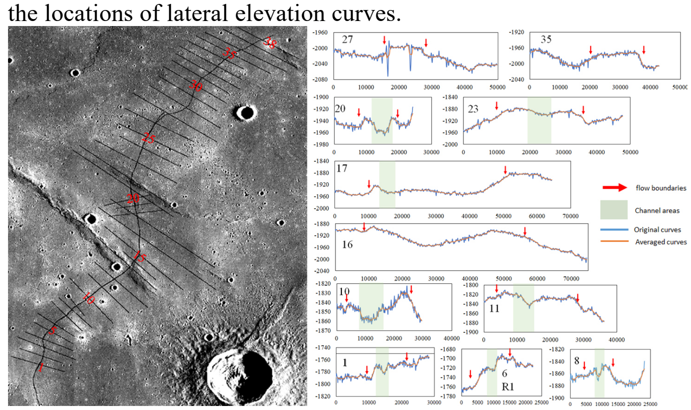

Fig.3 Lateral curves (portion) across the lava flow.

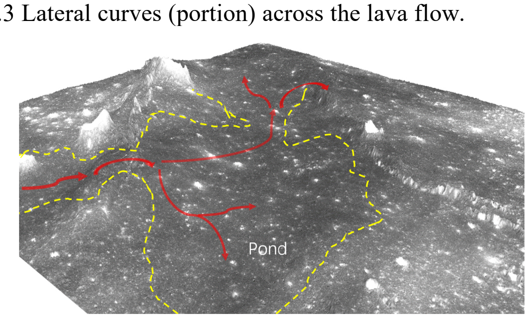

Fig.4 Three-D simulation of lava flowing pathways (vertical elevations exaggerated by 15 times).