**GEOLOGIC STUDIES OF VOLCANIC CONSTRUCTS IN EASTERN MARE FRIGORIS.**

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**Introduction:** A number of interesting geologic features can be seen in the easternmost portion of Mare Frigoris. The features include cryptomaria, light plains deposits, dark mare units, crater rays, volcanic constructs, and a variety of tectonic structures [1, 2]. The region of interest is centered at the easternmost edge of Mare Frigoris at 53º.2 N, 39º.4 W. We have used a variety of spacecraft imagery and remote sensing data to investigate the morphology, composition, and origin of geologic units in the eastern Frigoris region. Particular emphasis was placed on the volcanic constructs and the surrounding dark unit.

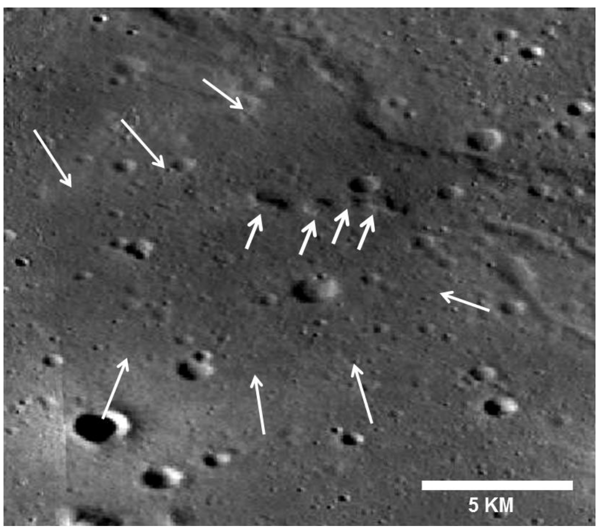


**Figure 1**. Volcanic constructs (short arrows) and surrounding dark unit (long arrows) located in eastern Mare Frigoris. North is up.

**Data and Methods:** LROC WAC and NAC images were utilized in this investigation [3]. The high resolution (0.5 m/pixel) provided by the NAC images was critical for the study of the smallest volcanic features. Regional topographic data were provided by the LROC GLD100 [4]. A high resolution (7m) DTM was produced [5] using NAC images M110327305 L/R and M110330877 L/R. The U.S.G.S. Astrogeology Program published on CD-ROM a Clementine five-color UV-VIS digital image model (DIM) for the Moon [e.g., 6]. This DIM was used to produce an image cube centered on the study area.

This calibrated image cube served as the basis for the production of a number of other data products, including optical maturity (OMAT) images and FeO and $TiO_2$ maps [7, 8]. Five-point spectra were extracted from the calibrated and registered Clementine UV-VIS image cube.

**Results and Discussion:** Volcanic constructs originally mapped as domes by Lucchitta [1] are visible in the center of the eastern Frigoris region (Figure 1). These constructs exhibit low albedo values in both Clementine 750 nm and LROC high-sun imagery. Low albedo values are also exhibited by a dark plains deposit surrounding the constructs.

*Composition.* The volcanic constructs average 13 wt. % FeO which falls within the 12 – 14 wt. % FeO range of the surrounding dark plains deposit. Fresh mare material in eastern Mare Frigoris exhibit FeO values of 13.7 wt. %. $TiO_2$ values for the volcanic constructs and the dark plains average just over 2 wt. %. Values for eastern Mare Frigoris are lower at 0.6 wt. %. which is in the VLT range. Geochemical values for the volcanic constructs and the surrounding dark plains are essentially identical.

Clementine spectra extracted for fresh areas on the volcanic constructs indicate that the areas for which the spectra were obtained have mafic assemblages dominated by high-Ca pyroxenes. The spectra confirm a mare basalt composition. These spectra are very similar to those collected for fresh craters in Mare Frigoris. In summary, the volcanic constructs are composed of basaltic material of the same composition as the mare basalts in the surrounding dark plains deposit.

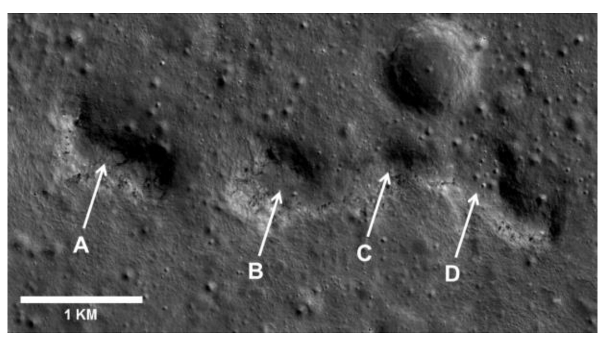


**Figure 2**. Volcanic constructs A, B, C, and D. NAC image M1098579418L. North is up.

*Morphology.* The four volcanic constructs, lettered A through D in figure 2, are oriented linearly in a roughly east-west direction spanning 5 km from end to end. They are irregularly shaped and tend to be elongated in the east-west direction. Each construct is about a kilometer wide as measured in the north-south direction (A: 0.8 km, B: 1.0 km, C: 0.7 km, D: 1.2 km). The volcanic constructs average about 70 m in height above the surrounding plains (A: 84 m, B: 66 m, C: 73 m, D: 67 m). Construct slopes are steeper than typical mare domes [9] which suggest an alternative origin (Figure 3). A has the steepest average slopes at ~13º, and D the least at 11º. Each construct has material surrounding the base which has a gentle slope of ~5 º, which is probably material eroded off of the steeper parts of the feature. Although, four volcanic constructs are described, the morphology is slightly more complicated. Construct A is separate from the others, but constructs B, C, and D are joined by a low ridge, which is 25-35 m below the top of the constructs. The summit of each feature is smooth and block free, with occasional small impact craters. The steep sides of the constructs have scattered clusters of light and dark boulders. The largest boulders span multiple pixels (meter-scale) and grade to smaller sizes below the resolution of the camera. The area under the volcanic constructs is slightly elevated (~50 m) above the surrounding terrain to the west and south. This raised area may be related to a nearby lobate scarp.

Lunar features that have a volcanic origin will often have a vent or summit crater associated with the feature [10, 11]. We investigated the region but were unable to locate any likely vents or summit pits. Although these constructs were mapped as small domes by Lucchitta [1], the features do not seem to fall into any of the dome classes defined by Head & Gifford [9].

The dark plains surrounding the volcanic constructs measures 13 by 15 km. Lucchitta describes this type unit (CEd) as having very low albedo and a smooth velvetlike surface [1]. The low albedo plains transition gradually to a higher albedo to the east and west, is bordered to the south by the ejecta blanket of a 1.8 km fresh crater, and terminates at the edge of the lobate scarp to the north. The geochemical composition of the plains is the same as the constructs, as mentioned above. Other regional features include a 2 km hummock 19 km to the northwest, and a 1.6 km hummock 23 km to the southwest. These hummocks, which are outside of the dark plains, are morphologically different from the subject volcanic constructs. The FeO values for these hummocks, <6 wt. % for the NW hummock and <8 wt. % for the SW hummock, are much lower than the volcanic constructs, thus they are more likely to be just eroded highlands material which are not volcanic. Because of the morphologic and compositional differences these hummocks are not related to the the volcanic constructs shown in figures 1 - 3.

*Tectonic Landforms.* An extensive network of mare wrinkle ridges exists throughout eastern Mare Frigoris. A portion of this mare ridge network occurs northwest of the volcanic constructs. This northwest extension terminates near the mare-highland boundary at the western end of a lobate scarp that occurs north and northeast of the volcanic constructs. Similar wrinkle ridge-lobate scarp transitions have been described by Watters and co-workers [12, 13, 14]. Two small graben can be seen (left side of figure 1) to the east of the volcanic constructs.

**Conclusion:** The consistent dome dimensions, heights, and slopes suggest a common origin for all of the volcanic constructs. In total, the morphologic and compositional data suggest that the volcanic constructs may be low, steep-sided cones of spatter as has been postulated at other locations [15]. The spatter built up on a fissure during the eruptions that emplaced the surrounding dark mare unit.

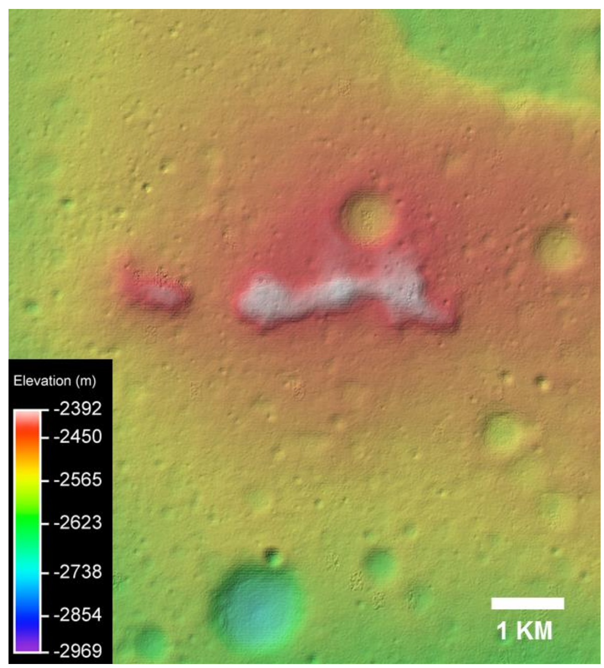


**Figure 3.** Digital Terrain Model of volcanic constructs [5].

**References:** [1] Lucchitta B. (1972) U.S.G.S. Map I-725. [2] Lucchitta B. (1978) U.S.G.S. Map I-1062. [3] Robinson, M. *et al.* (2010) *Space Sci. Rev.*, *150*, 81. [4] Scholten F. *et al.* (2012) *JGR*, *117*, 12 pp. [5] Mattson, S. *et al.*, (2012) *LPSC XLIII*, #2630. [6] Eliason E. *et al.* (1999) *LPSC XXX*, #1933. [7] Lucey P. *et al.* (2000) *JGR*, *105* (E8), 20,297. [8] Lucey P. *et al.* (2000) *JGR*, *105* (E8), 20,377. [9] Head & Gifford, 1980, *Moon and Planets*, *22*, 235. [10] Gustafson, O. *et al.* (2012) *JGR*, *117*, E00H25. [11] Hawke, B. R. *et al.* (2013) *LPSC XLIV*, #1883. [12] Watters T. R. *et al.* (2010), *Science 329*, 936-940. [13] Williams, N. R. *et al.*, (2012) *LPSC XLIII*, #2708. [14] Williams, N. R. *et al.*, (2013) *LPSC XLIV*, #2949. [15] Coombs *et al.* (1988) *PLPSC 18th*, pp 339 – 353.