THE MARE BASALTS OF EASTERN FRIGORIS. Georgiana Y. Kramer[1†], Bernard R. Hawke[2], Thomas A. Giguere[3], Garrett Heitman[1], and Thomas B. McCord[1,2], [1]Bear Fight Center, Winthrop, WA, 98862, [2]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, [3]Intergraph Corporation, P.O. Box 75330, Kapolei, HI 96707, [†]gkramer@bearfightcenter.com

Introduction Mare Frigoris is an intriguing region for a number of reasons, not least of which is its elongated shape, an atypical feature among its circular shaped brethren. Orbital photographs and other remote sensing data reveal diverse geology including light plains deposits, stress fractures, volcanic vents, rilles, pyroclastic deposits, cryptomare, and diverse mare basalt compositions [1, 2, 3]. Our attention was drawn to the eastern portion of Mare Frigoris because, relative to other mare basalts, the surface composition is low-Fe, very low-Ti, and high-Mg [4, 5, 6]. These characteristics suggest a singular, possibly unsampled, mare basalt type, and deserves further investigation.

Methodology Detailed analysis of Eastern Mare Frigoris utilized 100 m/pixel resolution, 5-band Clementine UV-VIS data and 500 m/pixel resolution, 6-band NIR data. To improve analytical efficiency, the NIR data was resampled to the UV-VIS resolution and the two datasets combined to make one seamless 11-band image cube. Processing and calibration used Integrated Software for Imaging Spectrometers (ISIS) [7] and Clementine orbital data available through Planetary Data Systems (PDS) [8]. FeO and optical maturity image data were produced using the methods of [9]. TiO_2 image data were produced using the methods of [10].

We intend to characterize the *pristine* mare basalt unit(s) in Eastern Frigoris. To achieve this we extract compositional information from pixels that depict the rims and proximal ejecta of small, immature craters (0.5-5 km in diameter) that impacted into the region of interest (ROI). These small craters act as windows through the ubiquitous, obscuring regolith, exposing the underlying, uncontaminated mare basalt [11, 12, 13, 14]. Impact cratering studies and analysis of impact ejecta mechanics demonstrate that near the crater rim the original stratigraphy of the impact target is inverted [e.g., 15]. Therefore collecting data from this region provides the best approach to deriving the composition of the underlying basaltic unit [13].

Results The compositions of the 340 analyzed impact craters in this ROI range from 8-14 wt% FeO and 0.5-1.5 wt% TiO_2. Mapping Eastern Mare Frigoris as one basalt unit (white boundary line in Fig. 1) would mean its FeO abundance is represented by impacts with the highest FeO concentration in their ejecta: 13.5-14.5 wt% (the highest FeO recorded is 14.1 wt%). The narrow range in TiO_2 exhibited in the impacts make it a poor parameter for distinguishing more than one mare basalt unit. The range does, however, provide strong evidence that at least some of the basalt flows in Eastern Frigoris have a TiO_2 abundance of 1.5 wt%.

Craters with FeO abundances between 8-11 wt% (represented as red and yellow dots in Fig. 1), are too low to represent exposures of pure mare basalts. Most of these impacts are located near a mare-highand contact or lie on a thick ejecta deposit from a large crater, thus the composition of their ejecta likely reflects contamination from nearby highlands material. Small impact compositions more representative of the mare basalt unit are apparent from their broader distribution over the mare surface and relatively low optical maturity parameters. Blue dots, indicating FeO abundances between 12-13 wt% are more or less randomly distributed across the ROI. FeO abundances in the 11-12 wt% range (represented as green dots) also span the ROI, although craters with these values form a denser cluster in the NW half of the mare. Purple dots (13-14 wt% FeO) do not have the broad distribution like the green and blue population. This range, representing the highest FeO concentrations in the ROI, appear to terminate SE of a possible boundary (marked by the arrows in Fig. 1) that divides Eastern Mare Frigoris into NW and SE halves.

As the only quantifiable piece of evidence, a difference of 2 wt% FeO is insufficient to conclude that the grouping of exposed FeO abundances of 11-12 wt% and 13-14 wt% represent two different mare basalt units. Supporting evidence, such as a sharp change in albedo, color distinctions (as would be apparent in a color composite image such as Fig. 2), observable basalt flow fronts, or distinct spectral features that correlate with location is lacking. The distribution of crater ejecta compositions could also be interpreted as describing a very gradual decrease in FeO abundance traversing the mare in a NW direction. Despite the analytical focus on the rim and proximal ejecta of immature impacts, the ejecta rays from large craters, particularly Aristoteles, could be overwhelming the mare composition.

Discussion Eastern Mare Frigoris got our attention because of its atypical surface composition. The region is even more intriguing because our analysis showed that the regolith composition is not the result of highlands contamination of a thin, old, typical mare basalt unit; we demonstrated that the underlying basalt *is* an atypical mare basalt. The low-Fe abundance of the ROI suggests it may be a HA basalt.

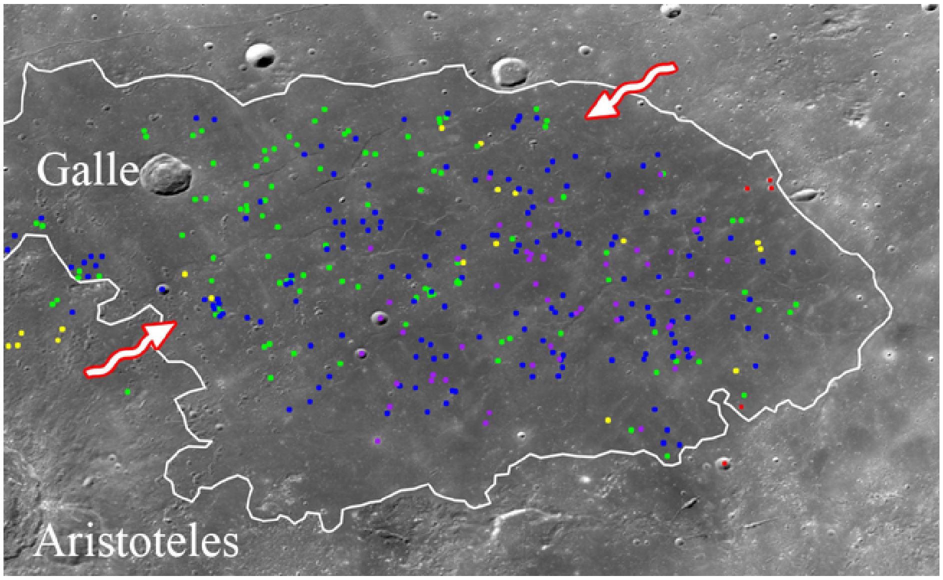

Figure 1: Eastern Mare Frigoris. Colored dots indicate distribution and correspond to FeO abundance of underlying mare basalt exposed in the rim and proximal ejecta of small impact craters analyzed as part of this study: red = 8-10 wt%, yellow = 10-11 wt%, green = 11-12 wt%, blue = 12-13 wt%, purple = 13-14 wt% FeO. Arrows approximate the location of a boundary line between two possible (unlikely) mare basalt units.

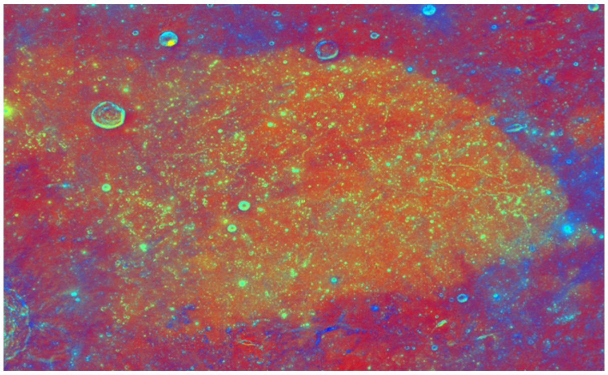

Figure 2: Color composite image of Eastern Mare Frigoris, which demonstrates well the delineation of the mare. Ejecta rays from Eudoxus crater (not pictured) [cf. 1] cross the mare at a location coincident with an apparent boundary between two crater populations of slightly differing FeO abundance (see Fig. 1).

High-alumina (HA) mare basalts are a unique group of the lunar sample collection. Basalt sample geochemistry demonstrates an inverse correlation between Al_2O_3 and FeO, which, compared to other mare basalts, indicates higher modal proportions of plagioclase and lower proportions of pyroxene and olivine [cf. 16]. Their aluminous nature suggests their sources contained significant plagioclase, which has implications regarding the efficiency of plagioclase separation in the crystallizing Lunar Magma Ocean (LMO) and hence the heterogeneity of the lunar mantle [17, 18]. Some of the Apollo 14 HA basalts were radiometrically dated at 4.25 Ga [19] making them among the oldest sampled mare basalts. Ages of HA basalts sampled by Luna 16 demonstrates aluminous basaltic volcanism spanned over 1 billion years. Identifying high-Al basalt exposures is necessary for locating potential future sample return sites as they may represent outcrops of pre-4 Ga volcanism and be a window to early processes within and compositions of the lunar mantle.

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