Small volcanoes in Vastitas Borealis, Mars: A morphological and spatial analysis. J.R. Conlon[1] and T.K.P Gregg[2], University at Buffalo, 126 Cooke Hall, Buffalo, NY 14260 (jrconlon@buffalo.edu), [2] University at Buffalo, 126 Cooke Hall, Buffalo, NY 14260 (tgregg@buffalo.edu).

Introduction: Vastitas Borealis (VB) is the low-lying region of Mars located above 60°N and extends to the northern polar ice cap [1]. The VB plains are dominated by volcanic material, probably basaltic lava flows, with an uneven cover of aeolian deposits and impact craters [2, 3]. Due to its proximity to the northern polar ice cap, ice-rich deposits are also present, as confirmed by the *Phoenix* lander [4]. Small (2-25 km basal diameter), probably monogenetic, volcanoes are scattered throughout VB, although their precise relationship with the plains material remains unknown [5].

Previous research has established that the morphologies of the VB volcanoes are consistent with those of terrestrial monogenetic volcanoes [6]. The volcanoes were also determined to be geologically young: roughly 1 to 20 million years old [6].

Some of the previously identified volcanoes in VB have similar morphologies to terrestrial Icelandic tuyas, which formed under ice [5]. This implies that the extent of the northern polar ice cap was once greater than it is today. Other volcanoes in VB have morphologies similar to terrestrial shield volcanoes and scoria cones, the latter of which requires more volatiles to form their steep sides than the former [5]. This indicates greater magma-water interaction occurring either at the surface or in the subsurface. “Water” in this abstract refers to liquid and solid (ice) phases. These interactions play an important role in the search for past life on Mars, as well as in the evolution of Mars’s climate.

Small (<1 km tall and 2-25 km basal diameter) monogenetic volcanoes in VB have not yet all been identified and mapped and there has been no comprehensive study on their spatial distribution or morphological distribution [5]. The most extensive study to date examined only 108 volcanoes in VB and did not search the entire region due to a lack of high-resolution (~6m/pixel) visible imagery; therefore, it is likely that unidentified volcanoes remain [5, 7]. Because the distribution of these volcanoes has not been fully determined as yet, the extent of the magma-water interactions that occurred in VB is unknown.

We propose that there is an extensive volcanic field in VB that may contain hundreds of monogenetic volcanoes, and that these volcanoes show evidence of lava- or magma-water interactions. This research is significant because it aids in furthering the astrobiology goals of both NASA and MEPAG, as well as MEPAG’s climate change goals [8, 9].

Methods: To identify and map the small volcanoes in VB, quantitative criteria (Table 1) initially developed by Green and others [10] is being used in a crowdsourced mapping effort performed by volunteers. Each volunteer has a portion of the region that is their own to work on while we act as oversight. The open-source GIS software QGIS is used for preliminary

Table 1. Table showing the characteristics necessary to be considered a volcanic feature instead of an impact crater (modified from [10]).

Strong Evidence (4 pts)	Good Evidence (3 pts)	Weak Evidence (1 pt)
Lobate margins containing darker, rougher material	Summit craters do not fall on depth-diameter distribution for impact craters	Lack of continuous ejecta ring
Asymmetrical summit crater	Presence of pit craters on flanks	Presence of summit depression
Meter-scale sinuous troughs running radial to feature on flanks	Summit crater offset from center of feature	Bright deposits on flanks
Nested summit crater	Meter-scale sinuous troughs running roughly radial to feature within one radius from flanks	Circularity difference between summit crater and feature base
	Flank slope does not steepen to greater than angle of repose	circular shape in the MOLA data
		smooth symmetrical hill with a flat top

identification of the volcanoes based on topographic data from the Mars Orbiter Laser Altimeter (MOLA) [11] (Fig. 1). Once possible volcanoes are identified in QGIS, the same features are located using JMARS so that the Thermal Emission Imaging System (THEMIS) [12] and Context Camera (CTX) [13] imagery can be used to further characterize the edifices. THEMIS daytime infrared and CTX imagery can be used to confirm the presence of a summit crater, for example, and determine whether an ejecta blanket is present (which would indicate the feature is an impact crater rather than a volcano). Using both programs and all three datasets, the edifice is given a preliminary score (Table 1). The coordinates, points, and established criteria are reported in a Google Sheets spreadsheet in a Google drive folder that all participants can access. Flank slope and crater depth-diameter ratio analyses are performed after quality control of existing criteria to determine whether they fall under the "volcano" category.

After the volcanoes are positively identified, clustering analyses will be used in ArcMap to determine whether the monogenetic VB volcanoes are clustered. These analyses will be run for both the volcanoes as a whole and after breaking them into distinct morphological groups based on the volcanic productivity index (VPI) [14]. Another analysis that will be performed is a principal component analysis in MATLAB using the edifice height, basal diameter and flank slope. This analysis will reveal spatial patterns in the defining morphological characteristics of the edifices.

Preliminary Results: A principal component analysis was performed in MATLAB using height, diameter, and flank slope data from 108 edifices identified by Fagan and others [5]. The results of the principal component analysis indicate that the predominant distinguishing feature is basal diameter, accounting for 67% of the variance, whereas the flank slope accounted for ~33% of the remaining variance. Mapping the results of the analysis indicates that there is no significant clusters of heights or diameters, but there is a significant spatial relationship for the flank slope. All identified features between 30°W and 60°W have a comparatively low flank slope (<3°), corresponding with shield volcanoes more than scoria cones. The extent of the phenomenon is still being determined but it is possible that this is because this area had less magma-water interactions than other areas of the region.

Future Work: The primary focus is to complete the survey and cluster analyses. Once that is complete, avenues for future research include a comparison of volcanic clusters in VB and terrestrial Large Igneous Provinces (LIP). If the region is a LIP or there are significant clusters that make up a LIP in the region then there are implications for the tectonic setting of the region. Another area of further research is a potential way to distinguish maar craters from impact craters in Vastitas Borealis. The characteristics that help distinguish maar craters from impact craters in VB are not visible in the data that is currently available, so new criteria would need to be developed.

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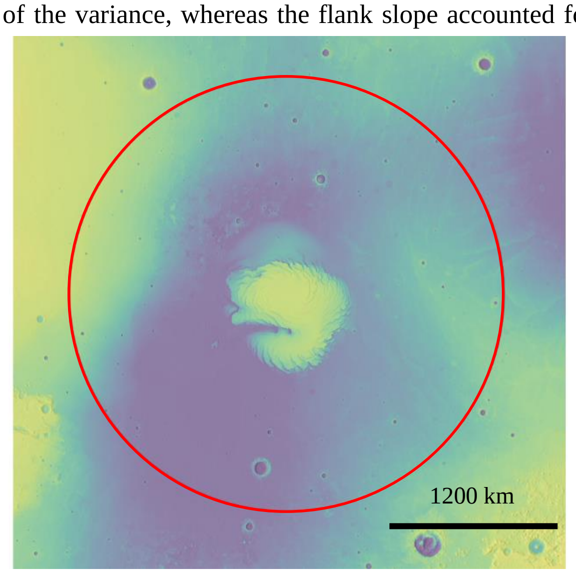

Fig. 1 Polar projection of MOLA data used for crowdsourcing in QGIS (modified from [11]). Greens and yellows represent higher elevation while purple represents lower elevation. The red circle is 60°N and indicates the approximate boundary of VB.