SHIELD VOLCANO SLOPE DISTRIBUTIONS: AN APPROACH FOR CHARACTERIZING MARTIAN VOLCANIC PROVINCES. J.E. Bleacher, and R. Greeley, Dept. of Geological Sciences, Arizona State University, PO Box 871404, Tempe, AZ 85287-1404. jake13@asu.edu, Greeley@asu.edu

Introduction: Terrain analyses are commonly used to study the geomorphic processes that have modified surfaces [1]. Our approach is based on analysis of slopes, which are the irregular surface expressions of the processes responsible for shaping landscapes [2]. Slope distributions likely represent unique surface forming processes and can be used to characterize entire landscapes at a given scale [3]. Because terrestrial slopes are constantly changing due to the influence of exogenic agents this approach is typically used to examine erosional processes. However, it is reasonable to utilize slope distributions to identify different lava flow emplacement processes and therefore volcanic style, when the overall surface construction rate is higher than the surface modification rate or when the opposing processes are separable upon analysis. The final form of a lava flow is dependent, in part, on the physical properties of the lava and the effusion conditions [4]. Thus the slope distributions displayed by different volcanic terrains should be unique to their emplacement conditions. We present slope distributions for the shield volcanoes on the island of Hawaii as a possible comparative approach to characterize martian volcanic provinces.

Background: The volcanoes of Hawaii satisfy the criteria presented above allowing quantitative characterization of their constructional processes based on slope distributions. The island of Hawaii consists of five Quaternary shield volcanoes at various stages of their eruptive sequence [5]. Kohala and Mauna Kea are thought to be extinct and have undergone some erosion, Hualalai is likely dormant, and both Mauna Loa and Kilauea are active [5]. The general shield morphology of Hawaiian volcanoes evolves from a broad, gently sloping structure composed of long, thin, overlapping tholeiitic basalts, to a steeper structure surrounding the vent when lavas become more silicic [5] and eruption volumes and duration diminish as the volcano becomes inactive [6,7]. With a range of eruptive stages and emplacement conditions present, Hawaii presents an ideal location to test the validity of characterizing terrestrial basaltic shields according to slope distributions. The availability of the MOLA topographic dataset [8] provides the opportunity for comparisons between terrestrial slope distribution trends and trends displayed by martian volcanoes.

Results: The complete Hawaiian USGS 10 m/pixel DEM grid (mosaiced in ArcView GIS 3.2 by ESRI) is used to calculate slopes over each volcano. The study is based on the published USGS geologic boundaries [9]. The slope distributions are presented as histograms of normalized percentages at a given slope so that volcanoes of different sizes can be compared.

All five volcanoes display positively skewed gaussian distributions with unique amplitudes (Fig 1). The slope abundances have higher amplitudes centered at lower slopes for the younger volcanoes with a progression to lower amplitudes centered at higher slopes with increased age. Kohala displays a second, minor, increase in slope frequency at higher slopes centered at 75° (Fig 2). This trend is not present for the four younger volcanoes. Kohala is the oldest of the five Hawaiian volcanoes and the windward coast has undergone significant erosion resulting in deeply incised canyons. The minor gaussian distribution of slopes centered around 75° for Kohala correlates with the erosional canyons. In this case, more analysis is needed to separate the aggradational and degradational processes. Analysis excluding the canyons shows a slope distribution similar to that of the younger, uneroded shields.

The three inactive Hawaiian shields produce a similar slope distribution. Both Kohala and Mauna Kea have a median of 20°. Hualalai has a median of 19° but could undergo late stage explosive eruptions as seen in the rock record for the two older volcanoes. Kilauea has the highest abundance of low slopes. Mauna Loa, an older but still active volcano, displays a larger abundance of higher slopes than Kilauea, which has the lowest median at 8°. Mauna Loa has a median value (16°) and slope distribution closer to those of the inactive volcanoes.

Discussion: Kurita and Higuchi [10] presented preliminary slope distribution assessments for some martian volcanoes. Their results show a positively skewed gaussian distribution centered around 2-3° for Olympus Mons. They conclude, according to the slope distributions, that Olympus, Ascraeus, Arsia, and Pavonis Mons are likely shield volcanoes. Other volcanoes, such as Ceranius Tholus, do not display the same type of gaussian distribution. The results for Hawaiian shield volcanoes can be compared with martian volcanoes to determine if they display similar slope distributions and therefore, could have formed through the result of similar processes.

The inactive volcanoes have similar median values (19-20°) and slope distribution signatures. The difference in median values between the three inactive volcanoes might indicate that Hualalai has not yet completed its eruptive stages. Due to their similarity, the average slope distributions for the three inactive volcanoes likely represents the final morphometry of a Hawaiian shield volcano. The progression of the median values, which range from 8° for the youngest, to 16° for older Mauna Loa, to 19-20° for the inactive volcanoes (Fig 1) could be related to the changing emplacement conditions for Hawaiian volcanoes at different eruptive stages. The results hold true at the 10 m scale, but are likely to be scale-dependent.

Quantitative characterization of terrestrial shield volcanoes allows comparisons with the martian volcanoes. Although we do not propose direct quantitative comparisons at this point (because the different planetary conditions should play a significant role in martian slope development) we can begin to compare general data trends. Kurita and Higuchi [10] suggest that slope distributions for Olympus Mons indicate that it is a shield volcano. Comparisons with Hawaiian shield slope distributions support this. Although Olympus Mons slope distributions are centered at lower values (2-3°), the positively skewed distribution trends are similar to those for the Hawaiian shields. Martian shields would not be expected to evolve toward distributions centered at higher slopes as they are not being pulled away from the magma source due to a lack of plate tectonics. If Hawaiian shield slopes increase due to a decrease in eruptive volume and duration as the volcano moves away from the source [6,7], then martian shields would likely retain a slope distribution similar to young terrestrial shields that have not undergone significant erosion. Martian modification processes and the different scale of analysis should also be further considered when making terrestrial comparisons.

Conclusions: Slope distribution analyses allow a quantitative characterization of Hawaiian shield volcanoes. These distributions demonstrate a progression from young, active shields to older, inactive shields. Comparison with martian volcanoes will allow characterization of martian volcanic processes. Slope distributions for Olympus Mons [10] compare favorably with Hawaiian shield volcanoes, suggesting that it was constructed via similar processes, while some other volcanoes, such as Ceranius Tholus, likely involved other constructional or modification processes.

References: [1] Wilson J.P. and Gallant J.C. (2000) *Terrain Analysis*, John Wiley and Sons Inc., 1-26. [2] Scheidegger A.E. (1970) *Theoretical Geomorphology*, Springer-Verlag, 73-154. [3] Pike R.J. (2000) *Progress in Physical Geography* 23, 1-20. [4] Hulme G. (1974) *Geopys. J. R. Astr. Soc.* 39, 361-383. [5] Peterson D.W., and Moore R.B. (1987) *Volcanism in Hawaii*, 149-190, U.S. Geological Survey Professional Paper 1350. [6] Rowland S.K., and Walker G.P.L. (1990) *Bull. Vol.* 52, 615-628. [7] Peterson D.W. et al. (1994) *Bull. Vol.* 343-360. [8] Smith D.E. et al. (2001) *J. Geophys. Res.*, 106, 23689-23722. [9] Wolfe E.W., and Morris J. (1996) *Geologic map of the island of Hawaii, U.S. Geological Survey Misc. Inv. Map I-2524-A.* [10] Kurita K., and Higuchi S. (2002) EOS Trans. 83 (47) Fall Meet. Suppl., P71B-0464.

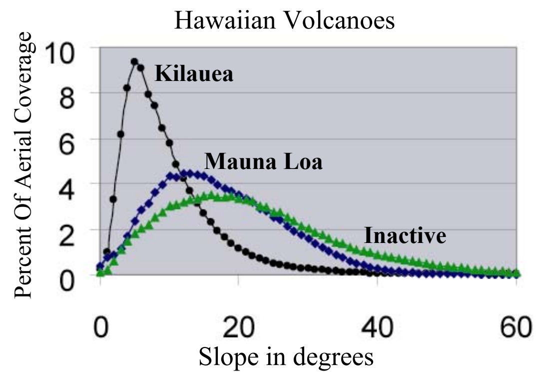

Figure 1. Slope distributions for Kilauea, Mauna Loa and an average of the three inactive volcanoes. A progression can be seen from young to old Hawaiian shields as the distributions become skewed toward higher slopes with age.

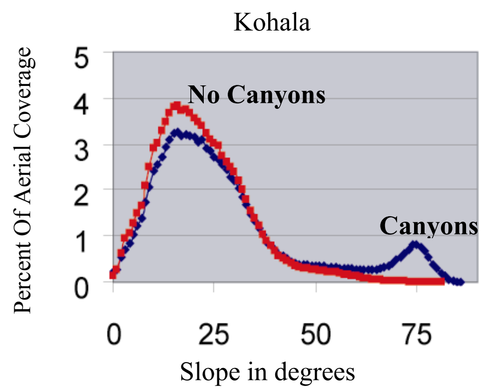

Figure 2. Slope distributions with and without erosional canyons for Kohala. Canyon forming erosion causes a minor increase in slope abundance at 75°.