DISTINGUISHING BETWEEN PRIMARY AND SECONDARY EMPLACEMENT EVENTS OF BLOCKY VOLCANIC DEPOSITS USING ROCK SIZE DISTRIBUTIONS. M. H. Bulmer[1] L. S. Glaze[2], and S. Anderson[3] [1]JCET, University of Maryland, Baltimore County, Baltimore, MD 21250 (mbulmer@jcet.umbc.edu), [2]Proxemy Research Inc. 14300 Gallant Fox Lane, Suite 225, Bowie, MD 20175, [3]Black Hill State University, Spearfish, South-Dakota 57799-9102.

Introduction: A primary key to understanding past history of a volcano, and potentially future behavior, is interpretation of surface deposits. However, interpreting the origin of a blocky geologic surface is difficult, especially in instances where ground observations are not possible or where additional evidence that could provide spatial and temporal context for the deposit is ambiguous. This difficulty is compounded in volcanic terrains where lava flows and rock avalanches can ocur in the same material and locality. Furthermore, post-emplacement processes such as glaciation or fluvial activity may contribute additional complexity to interpreting the origin of a blocky surface.

Although several previous studies have investigated morphologic characteristics of lava flows and rock avalanches [*e.g., 1,2,3*], relatively few have addressed surface rock size distributions. Those that do address geologic rock size are often limited to qualitative discussions of angularity and sorting [e.g. *4*]. Where more quantitative data have been acquired, size information has been reduced to cumulative size-frequency distributions [e.g., *5,6,7*]. However, much of the detail contained in the raw measurement data is lost in this type of analysis.

Field Sites: We investigate blocky surfaces on lava flows, lava domes and a rock avalanche from a collapsed lava dome. The lava flows discussed are composed of dacitic and andesitic lavas that typically erupt as domes and flows with the surfaces dominated by rocks that range from < 5 cm to > 6 m. While blocks are formed at the vent they can be modified during flow by processes such as autobrecciation [*8*]. Blocks can also be added downslope through the exposure of cooled interior lava during compressional ridge formation [*Anderson et al.,* 1998]. For the purposes of discussion, we refer to lava flow and dome emplacement as primary emplacement mechanisms.

A rock avalanche from collapse of a lava dome primarily comprises blocks from the pre-avalanche dome that were broken during mass movement. An avalanche requires no interstitial medium (unlike a debris flow) and can develop by the sudden mobilization of slope forming materials. An avalanche following mechanical collapse of an existing edifice (e.g., lava dome) is referred to here as a secondary emplacement mechanism. The fundamental distinction between primary and secondary processes is that secondary mechanisms can only break existing rocks, whereas primary mechanisms are capable of both creating and degrading rocks.

Detailed measurements used here were collected from the Chaos Jumbles (USA) rock avalanches, a blocky lava flow at Sabancaya Volcano (Peru), and the Inyo domes and Medicine Lake Volcano (USA).

Field Approach: The objective of this field study was to quantitatively characterize the surface block size distributions at each location and to develop a technique that could easily be applied to remote sensing images of blocky planetary flows. Our approach is just one of many choices for estimating the actual distribution of block sizes on the surface. The one dimensional method used here benefits from the fact that it does not require any interpretation in the field and leads to consistent, repeatable measurements. We have recently demonstrated that this approach to estimating block size is effective for addressing the key objectives of this study [9].

Measurements from 13 sites were obtained along each of two transects that ran the length of the most recent Jumbles deposit. At each location, rocks were identified as being part of flow unit I, II or III. At Sabancaya rock size measurements were made at 19 sites along transects that ran both along and across the flow 2a.

Following the rock measurement approach used by [*7*], only the dimension of each rock ≥ 2 cm under two 20 m rope lengths was recorded. There is very little ambiguity in this measurement approach. Simply, every rock lying directly beneath the rope is measured.

Statistical Analysis:

The surface rock size distributions collected at the Jumbles, Sabancaya, Inyo and Medicine Lake Volcano can be used to distinguish between their emplacement regimes (Figure 1). We have used inferential statistical procedures called analysis of variance (or ANOVA in the statistical literature, *e.g.*, *Sheskin*, [1997]) to evaluate the significance of differences between the mean values of more than two samples. For this ANOVA analysis, we combined rock size data for all samples from each deposit resulting in six pooled samples, one each for avalanche deposits I, II and III at the Jumbles, lava Flows 1 and 2a at Sabancaya, and all the silicic

domes and flows at Inyo and Medicine Lake. Figure 1 shows the results of ANOVA comparing the mean rock sizes for deposits from all three sites. Error bars correspond to the 95% Bonferroni intervals.

From Figure 1, Jumbles deposit (I) has the smallest mean rock size, and is distinct from any of the other deposits (i.e., Bonferroni intervals do not overlap with any others). Deposits II and III are indistinguishable from each other (based solely on rock size), but are significantly larger than deposit I and significantly smaller than the rocks found at the Inyo lava domes, Medicine Lake Volcano and at the Sabancaya flow. At Sabancaya, we find that the geometric mean rock sizes on the 1 and 2a flows are indistinguishable from each other, but significantly larger than all other deposits.

Discussion: The main inferences related to the rocky deposit as a whole (Figure 1) is that the size distributions of the surface deposits at the Jumbles, Sabancaya, Inyo and Medicine Lake Volcano are distinct and significantly different. Compositionally, the deposits at all locations are relatively similar. They are all silicic (andesite to dacite) volcanic deposits. They were, however, each emplaced by very different mechanisms. Thus, the distinction between the surfaces we have examined may be used as a remote diagnostic tool to determine their emplacement origin. Additional information on rock size distributions for other deposits emplaced by similar mechanisms as those studied here would be very helpful in quantifying the amount of variability that exists within each category.

The domes and lava flows at Inyo, Medicine Lake, and Sabancaya Volcanoes were all extrusive volcanic events. Thus, new (primary) rocks (e.g., crust) were forming simultaneously as older (cooler) rocks were broken during emplacement. Conversely, the rock avalanches at the Jumbles were emplaced when existing domes with a primary rock population collapsed owing to mechanical failure. There is no evidence that these avalanches were hot (nor molten) when they were emplaced. Thus, there was no mechanism within the avalanche event for creating a primary rock population, only the ability to break up existing rocks forming a secondary rock population. In short, primary processes create the initial rock size populations. Secondary processes mobilize that population and can only modify the primary rock-size distribution.

It is also interesting that the Sabancaya, Inyo and Medicine Lake Volcano data are statistically different from each other. [7] suggest that primary rock size, for lava flows of similar composition, is a function of the rate of extrusion. This argues that the larger rocks at Sabancaya are the result of a relatively slower extrusion rate. However, this is at odds with the distance the flow traveled. Perhaps the best explanation for the long flow, large volume and large rocks is that the flow was hot and produced many new blocks during emplacement because of break-up of the crust.

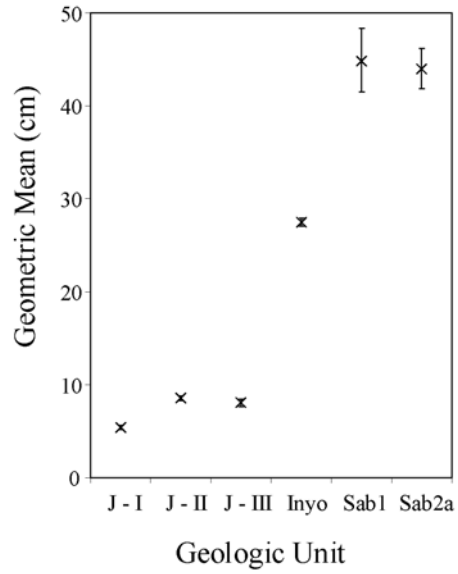

Fig 1. Geometric mean block size and 95% Bonferroni intervals for several volcanic units. Error bars for most points are smaller than the "X" indicating the geometric mean. J-I, J-II, and J-III refer to the three flow units at Chaos Jumbles. Inyo refers to the silicic domes and flows at Inyo and Medicine Lake. Sab1 and Sab2a refer to the 1 and 2a lava flows at Sabancaya.

Conclusion: Here we demonstrate that the individual sampling distributions can be used to distinguish between different emplacement processes that have statistically different rock size populations. This is significant in that conditions such as eruption rate, duration, velocity, and material rheology during emplacement can be assessed for events, such as lava flows and rock avalanches, that were unobserved. It therefore becomes possible, using high-resolution images of rocky surfaces on Earth and on planets such as Venus and Mars, to calculate rock size populations and obtain greater understanding of their emplacement histories.

References: [1] Fink, (1983) Geol. Soc. Am. Bull., 94, 362-380 [2] Eppler et al., (1987) J. Geophys Res., 92:3623-3633 [3] Anderson et al., (1995) J. Volcanol. Geotherm. Res., 69, 105-116, [4] Blair, T.C. and J.G. McPhearson, (1999) J. Sed. Res., 69, 6-19 [5] Malin, (1988) NASA Tech Mem 4041, 502-504 [6] Golombek and Rapp, (1997) J. Geophys. Res., 102, 4,117-4,130 [7] Anderson et al., (1998) Geol. Soc. Am. Bull., 110, 1258-1267 [8] Cas and Wright, (1987) Volcanic successions, Allen & Unwin, London, United Kingdom, 528 pp, [9] Bulmer et al. (2005) JGR – Earth in press.