QUANTIFYING BOULDER SHAPE AND SURFACE TEXTURE: USING MORPHOLOGY TO INFER ENVIRONMENTAL HISTORY AT THE EPHRATA FAN, CHANNELED SCABLANDS, WASHINGTON.

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Introduction: Environmental processes operating on planetary surfaces leave morphological imprints at scales from nm to km [1]. Quantitative geomorphological studies at landscape and sediment scales reveal many process-form linkages [e.g. 2,3]; however, cm- and meter-scale controls on morphology, particularly for boulders, are less well understood. As landed planetary missions most commonly encounter only float rocks [e.g. 4,5], this presents a challenge for deducing site environmental history when few other sources of data exist.

Boulders result from the breakdown of rock masses through the combined effects of erosion, transport, and weathering (Fig. 1). Each leaves characteristic signatures on boulder surfaces and shapes their overall form; hence, boulder morphology reflects both climate and lithology.

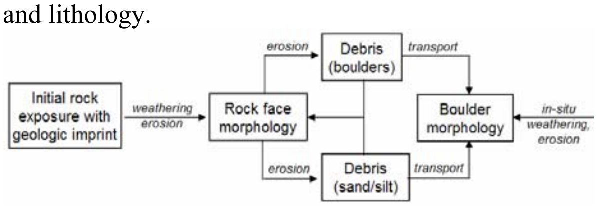

Figure 1. Schematic of the rock breakdown to form boulders.

Interpreting boulder morphology is difficult as persistence, inheritance, uniqueness, and scaling of features are incompletely understood. A key challenge in developing models relating environmental processes and rock properties to boulder forms is lack of standardized parameters for reporting boulder morphology, especially surface texture, and comparing datasets across sites. We developed a comprehensive set of quantitative parameters for studying boulder form and surface texture for use in the field or with stereo models. These were then pilot tested to attempt to distinguish three populations of boulders with different breakdown histories at the Ephrata Fan, a site chosen because of its well-constrained environmental history and its interest as a geomorphic and geochemical Mars analogue [6,7].

Site and sampling: Catastrophic floods in the Columbia River flood basalt province in central Washington carved the Channeled Scablands 17-12 kyr BP. The ~800 km^2 Ephrata Fan was formed during deposition of entrained boulders as floodwaters exiting Grand Coulee slowed [6]. Since then, the climate has been cool and dry with average precipitation <20cm/yr [8]. To control for the effects of lithology only basalt boulders with axes >15 cm were sampled. Ten to fifteen boulders were sampled at 3 sites, each with a distinct environmental history: (1) basalt outcrop talus, north of Ephrata Fan, (2) unweathered, flood transported boulders recently excavated from a quarry in Ephrata Fan, and (3) flood-transported boulders, extensively weathered in-situ on the Ephrata Fan surface.

Quantitative Parameters: Boulder shape was assessed in the field via standard sedimentological size and shape metrics [9] coupled with measurements of radii of curvature and angle of boulder facet edges. Boulder surface texture was assessed using two geomorphometric techniques sometimes employed in landscape analysis: fractal analysis of roughness [10] and morphometric classification (Fig. 2) [11,12]. Since field laser scanning and stereo imaging were unavailable, plaster casts were taken of boulders and laser scanned in the laboratory at 0.2 mm resolution to obtain DEMs of boulder surfaces. The extent of rock breakdown was characterized by Schmidt hammer rebound which is related to the rock compressive strength [13], counting the number of fractures and detached blocks, assessment of percentage lichen cover, and thin section analysis of weathering rinds.

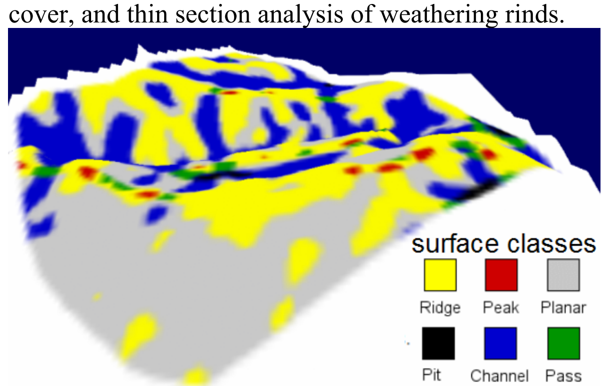

Figure 2. 1cm-scale morphometric classification map draped over a DEM of a quarry boulder cast. The central trough is from a conchoidal fracture. Total relief is 2cm and the cast is 13x15 cm.

Results: Schmidt hammer values show significant differences in the strength of boulders from each site with surface boulders the weakest and quarry boulders the strongest (Table 1), consistent with surface boulders having been subject to 12 kyr of surface weathering while quarry boulders were protected and talus boulders were formed recently. Standard sedimentary shape parameters [9] showed no significant differences between boulders at the three sites. However, using the suite of morphological parameters listed in Table 1 outcrop boulders were found to be significantly different from flood-transported boulders. Surface and quarry boulders were not significantly different from each other in these parameters, nor in size from columnar joints in outcrops which were ~74cm. Fractal measurement of surface roughness showed that, at all scales, surface boulders were roughest and quarry boulders the most smooth. Additionally, there were more breakpoints in the deviogram slope of outcrop and quarry boulders than surface boulders, perhaps indicating the dominance of different processes at different scales acting on these boulder surfaces (Fig. 3). Morphometric classification also showed significant differences among populations with more channel and ridge features on surface boulders and more pits and peaks on outcrop boulders.

Conclusions: The set of quantitative morphologic parameters developed allow populations of boulders to be distinguished based on their breakdown histories. Furthermore, past and present breakdown processes can be inferred. At Ephrata, flood-transported boulders were removed from outcrops by fracturing along pre-existing hexagonal columnar joints in basalt columns, thus creating facet edge angles of ~120° and boulders approximately the same width as the columns. Subsequent transport rounded edge angles. Untransported talus boulders have measurably sharper edges, are smaller in size, and have more angles of ~90°, indicating a different method of removal from the outcrop, perhaps freeze-thaw weathering. Interestingly, surface boulders also have a high number of 90° facet angles, perhaps indicating the same breakdown process. Relative ranking of surface roughness shows that surfaces of intermediate roughness (talus/outcrop) were smoothed during transport but subsequent exposure to the surface weathering environment, including biological weathering by lichen, has caused re-roughening at all scales and changes in surface morphology. Future work includes application of this parameter set to other types of terrestrial environments and to planetary stereo imaging datasets.

References: [1] Viles, H.A. (2001) *Geomorph., 41,* 63-72. [2] Evans, I.S. and McClean, C. (1995) *ZfG Suppl. Bd., 101*, 127-147. [3] Mahaney, W.C. (2002) *Atlas of Sand Grain Surface Textures,* Oxford Univ. Press, 237p. [4] Golombek, M.P. et al (1999) *JGR, 104*, 8523-8553. [5] Tomasko, M.G. et al. (2005) *Nature, 438*, 765-778. [6] Rice, J.W. and Edgett, K.S. (1997) *JGR, 102*, 4185-4200. [7] Wyatt, M. and McSween, H.Y. (2002) *Nature, 417*, 263-266. [8] Mehringer, P.J. (1996) Columbia River Basin Ecosystemes, U.S. Forest Service Ecosystem Project. [9] Sneed, E.D. and Folk, R.L. *1958. J. of Geology, 66,* 114-150. [10] Shepard, M.K. et al. (2001) *JGR, 106*, 32777-32795. [11] Wood, J. (1996) PhD thesis, University of Leicester. [12] Landserf 2.2 software, www.landserf.org. [13] Day, M.J. and Goudie, A.S. (1977) *BGRG Tech. Bulletin, 18,* 19-29.

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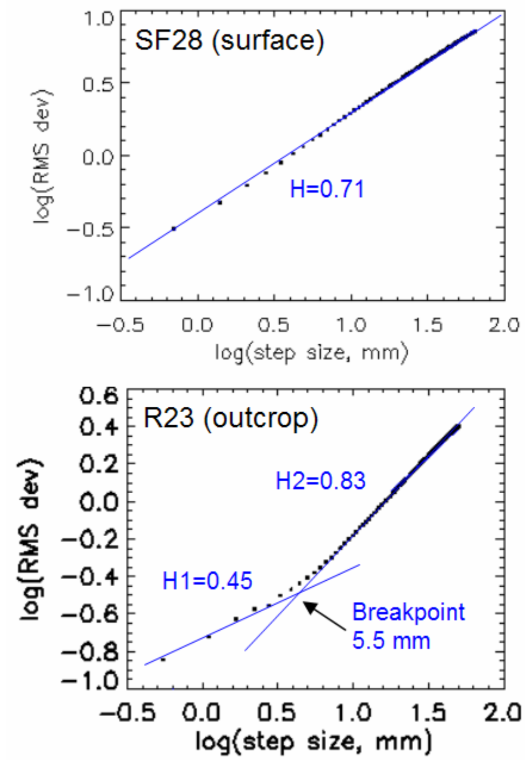

Figure 3. Deviograms from a surface and an outcrop boulder. RMS deviation refers to the average difference in elevation between two points separated by a given step size.

	Size	Shape		Texture		Weathering extent
	Long axis (cm)	Radius of curvature ratio	Facet edge angle (deg)	RMS slope, 1 mm (deg)	RMS slope, 1 cm (deg)	Schmidt hammer rebound
Quarry	78.5 ± 25.6	0.13 ± 0.06	115 ± 12	12.9 ± 5.7	7.9 ± 4.9	65.2 ± 4.6
Surface	80.6 ± 44.4	0.14 ± 0.11	109 ± 15	19.8 ± 9.6	11.3 ± 3.6	55.9 ± 7.1
Outcrop	40.5 ± 10.9	0.02 ± 0.02	102 ± 11	19.8 ± 11.9	9.9 ± 4.6	58.4 ± 7.1

Table 1. Select boulder parameters, the first five are morphological, the last, a measure of weathering extent. Radius of curvature is reported as a ratio between the largest circle that can be inscribed in a curve and the average radius of a boulder.