

**THE SURFACE FEATURES OF 'PRISTINE' FLOOD-TRANSPORTED BOULDERS.** M.C. Bourke<sup>1,2</sup>, J. A. Brearley<sup>2</sup>, R. Haas<sup>3</sup> and H. A. Viles<sup>2</sup> <sup>1</sup>Planetary Science Institute, 1700 E. Ft. Lowell, Tucson, Arizona 85719, [mbourke@psi.edu](mailto:mbourke@psi.edu) <sup>2</sup>School of Geography, University of Oxford, Oxford, OX1 3TB, UK, <sup>3</sup>Western Mapping, Tucson, AZ

**Introduction:** Specific processes on Earth can be shown to produce a particular size and shape of morphological response on rocks. For example, rocks subject to fluvial transport tend to be well rounded [1], whilst those freshly collapsed from bedrock walls are angular. Of importance to planetary studies is an assessment of the extent to which rock breakdown (e.g. aeolian abrasion or salt weathering) masks signatures of geomorphic transport processes (e.g. fluvial transport or crater ejecta). Equally important is the extent to which geomorphic processes mask past weathering. This has not been determined for rock surfaces on Earth or for other planets. The situation is complicated by the lithological imprint; some rocks respond more rapidly and in different styles to breakdown processes. Over time, the inheritance of both initial lithology and past processes may also complicate the relationship between current process and morphological response.

Four of the five successful Landers and Rovers on Mars are situated on hypothesised flood deposits. Studies of rock morphology, placement and form have suggested that the sediments are indeed the typical deposits of catastrophic floods [e.g. at Pathfinder site, 2]. However, the rocks are likely to have been significantly modified by breakdown processes and the identification of definitive fluvial signatures on the rock surface has been difficult.

Therefore there is a need to establish feature persistence, i.e., the exact nature and strength of the different morphological signatures on different rock types and how they combine with one another. A first step towards constraining the links between process, inheritance, and morphology is to identify *pristine* features produced by different process regimes. These studies should be conducted on Mars analogue rocks (such as basalt and andesite). To this end we are compiling a series of feature atlases. These will detail the features typical of fluvial, ejecta, micro-impact and aeolian abrasion processes. In this paper we focus on the features typical of fluvial transport preserved on basalt boulders.

**An Atlas of flood transported boulders:** A review of the literature indicates that features such as breakage and rounding are frequently observed following flood transport. These simple observations mask a detailed surface texture that has the potential to be preserved over several millenia. Archaeologists have been analyzing percussion marks since the turn of the century and while the systematic reduction of stone into stone tools by humans is a different agent of dete-

rioration, the fundamental principals of rock percussion are the same (Fig. 1). We have utilized both the archaeological literature and geomorphic field observations to construct a classification of the surface texture of flood transported boulders. We collected data from two environments: the sub-aqueous fan deposited by the catastrophic Missoula Flood at Moses Lake, Washington and basalt boulders in Oak Creek Canyon, Arizona. Table 1 summarises the typical shape and surface morphology attributes of fluvial and flood-transported boulders. Below we detail some of the less well known signatures.

*Percussion features* occur on conchoidal fracture faces and are signatures of percussion events. Such features include compression rings, bulbs of percussion, fracture initiation points, platform surfaces, radial fissures, and terminations (fig.1). The presence and morphometry of these attributes are influenced by mineralogy, collision geometry, and force. These features, which vary in size from a few up to tens of centimetres scale, occur due to a high magnitude ballistic impact between two clasts. They occur most commonly where the impact has taken place on the edge of a clast, though face percussion marks can be observed if the impact force is especially high [3, 4]. The edges of the mark can be straight, curved or irregular depending upon the angle of impact and the structure of the rock. They can have step, hinge, feather, outcrop or multiple terminations depending on the size of angle of the impact (Fig.3).

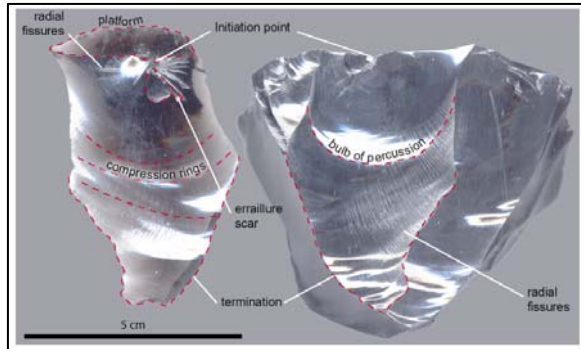
*Incipient cones:* These centimetre-scale crescent-shaped depressions found on the faces of some of the boulders are the result of clast collisions in the flood flow that had insufficient energy to produce full percussion marks (Fig. 2).

*Ripple marks:* These are parallel centimetre scale crescent-shaped undulations, which originate from the bulb of percussion of an impact event, and are the morphological expression of the radiating shockwave that originates from the impact. They decline in magnitude and frequency from the point of impact.

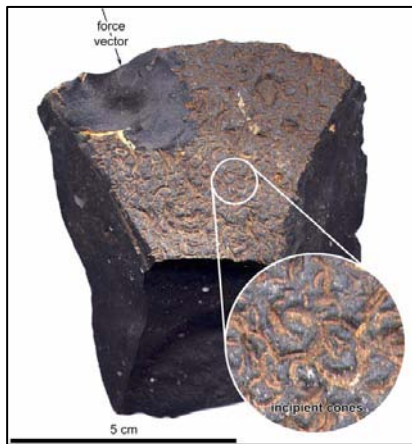
*Radial fissures:* These are an alternative morphological expression of a shockwave, in which the fissures originate at the point of impact in a radiating pattern.

**Conclusion:** Unique surface texture signatures of flood-transported boulders do exist and have been identified on rocks transported in the Late Pleistocene [5]. Following on from the work presented here, and

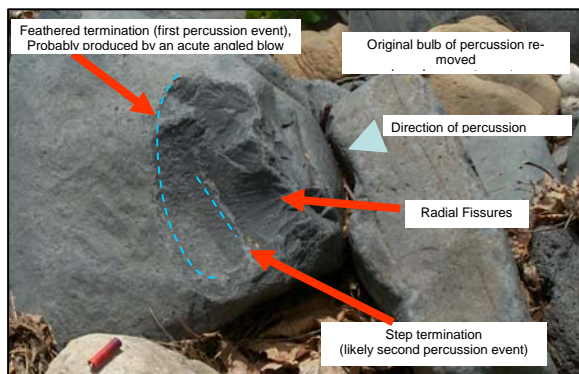
as reported in a companion paper [5], techniques such as the facet mapping [6] can be used to quantify the presence of various features and methods such as fractal analysis [7] can be used to quantify surface roughness. This will establish if fundamental differences in surface topography can be associated with different process regimes.



**Figure 1.** Diagnostic fracture features on volcanic glass from Glass Buttes, Oregon. The flake on the left was detached from the cobble on the right.



**Figure 2.** Percussion-flake scars and incipient cones on rhyolite from Partridge Creek, Arizona. The crescentic depressions (incipient cones) on the cortical surface are the result of rock-to-rock collisions during flood events.



**Figure 3.** Flood transported basalt boulder from Oak Creek Canyon, Arizona. A clear feather termination can be seen, indicating that the percussor hit with an acute striking angle. The step termination, found within the percussion mark, is most likely a later percussion event which hit with greater force and/or at an obtuse striking angle. The radial fissures associated with the impact event that produced the step termination.

**Table 1.** Surface characteristics of flood-transported clasts

Feature	Process	Ref.
<b>Fluvial boulder</b>		
Polished (on up-stream side)	Abrasion by suspended load	[8]
Flutes	Abrasion by suspended load	[8, 1]
Potholes (on downstream side)	Abrasion by suspended load	[8]
Strongly rounded	Fluvial abrasion	[1]
Angular, sub angular	-block quarrying from in-channel bedrock exposures, -local input from canyon walls	[9, 1]
<b>Flood-transported boulder</b>		
Basal striations	Hydraulic dragging of boulder along gravel base	[10]
Chink-faceted pebbles, Angular facets	Ballistic impact, Result of break-age during transport, local source	[11, 9, 1]
Percussion marks	Ballistic impact by other entrained clasts	
Radial fissures	Shock wave manifestations (percussion)	
Ripple Marks	Shock wave manifestations (percussion)	
Fracture plains, fissuring & splitting	Collision, can also be due to micro-meteorite impact, ejecta, structural.	
Chipping	Ballistic impact from other entrained clasts	
Incipient Cones	Low velocity collisions	

**Reference**

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