WHAT PROCESSES HAVE SHAPED BASALT BOULDERS ON EARTH AND MARS? STUDIES OF FEATURE PERSISTENCE USING FACET MAPPING AND FRACTAL ANALYSIS H.A.Viles[1], J.A.Brearley[1] and M.C.Bourke[1,2], J. Holmlumd[3] [1]School of Geography and the Environment, University of Oxford, Oxford, UK (Mansfield Road, Oxford, OX1 3TB; heather.viles@geog.ox.ac.uk, james.brearley@chch.ox.ac.uk), [2]Planetary Science Institute, # 106, 1700 E Ft. Lowell, Tucson, Arizona 85719 mbourke@psi.edu. [3]Western Mapping, 3323 N. Campbell Ave., #1, Tucson, Arizon, 85719.

Introduction: Basalt boulders on both Earth and Mars are shaped by a range of forces. Structural and lithological characteristics are acted upon by aeolian, fluvial and other process regimes to produce a palimpsest of features. In order to be able to diagnose process histories from features observed on boulders it is important to know which features (or groups of features) are diagnostic of individual process regimes and how persistent such features are under subsequent process regimes. A first step, as reported in a companion paper [1], is to produce atlases of features produced by different process regimes. Following this, techniques such as facet mapping [2] can be used to quantify the presence of various features, either using field survey or imaging. Alternatively, where digital imagery is available, methods such as fractal analysis [3] can be used to quantify surface roughness to see whether fundamental differences in surface topography can be associated with different process regimes. In this paper we present an application of facet mapping and fractal analysis techniques to 1) basalt boulders studied in the field at Ephrata Fan, Washington State, U.S.A. and 2) recorded via imaging by the Spirit Rover at Gusev Crater. At Ephrata Fan, a classic Mars-analog site, we aimed to determine how intensively structurally-controlled and fluvially-created features had been affected by subsequent breakdown processes. At Gusev Crater we aimed to find whether there was any evidence of fluvially-created features remaining on boulders at a site where fluvial processes have been hypothesized as occurring in the past.

Methodology: Facet mapping is a simple technique, originally designed for field recording, which allows quantification of the morphology of boulders at a range of scales (mm to m). The technique is hierarchical, providing information on overall boulder size and shape, on morphology in terms of the number and nature of recognizable facets, and finally on the presence of individual breakdown features within facets. The technique is explained in more detail in [2]. Fractal analysis is a powerful tool for investigating scale differences in topography. Profile data are analyzed using different step lengths to produce variograms, from which Hurst exponents and break points can be identified. Unfortunately, variograms can be highly influenced by the length of the profiles analyzed, with short profiles over rough surfaces producing unrepresentative results.

Ephrata Fan studies: The Channelled Scablands was carved by multiple catastrophic releases of water from late-glacial lake Missoula. The last major flood episode occurred between 17 and 12 ka BP [4]. Facet mapping studies of the number and type of breakdown features present on boulders both on the fan surface and exhumed from the body of the fan have been carried out. Observations were made both in the field using the methodology described in [2] and from images collected in the field to mimic that obtained by Pancam cameras on the Mars Rovers. Schmidt hammer data on rock hardness were also collected. Selected boulders were scanned using 3D laser scanning and transects extracted for fractal analysis. (Fig.1)

The facet mapping exercise illustrated clearly that the boulders on Ephrata Fan surfaces had undergone only minor weathering and aeolian polishing since fluvial transport and deposition, with breakdown focused on areas already weakened by fluvial processes. The imprint of lithology was also clear, with basalt entablature boulders being generally of greater size and complexity, and they had a higher numbers of fractures in comparison with basalt colonnade boulders. Boulders exhumed from the fan material by quarrying had significantly fewer post-fluvial breakdown features than those from the fan surface, and had higher Schmidt Hammer ‘r’ values (implying harder surfaces). Fractal analysis of a series of profiles from Ephrata boulders showed similar Hurst exponents, despite their different overall visual appearances. As an example, the transect in figure 1 on a rounded, highly vesicular surface showed a Hurst exponent of 0.81, a breakpoint in the variogram at 0.56 cm, with the finest step size resolution attainable of 0.00613 cm. The breakpoint probably reflects the characteristic size of vesicles in this sample. Other samples analyzed, however, indicated similar breakpoints in the absence of vesicles, as a result of similar sized percussion marks.

At Ephrata Fan facet mapping has illustrated the persistence over several thousands of years of fluvial-transport derived features. Fractal analysis has indicated the difficulty of using roughness scaling characteristics as diagnostic of different process regimes with differing degrees of structural control.

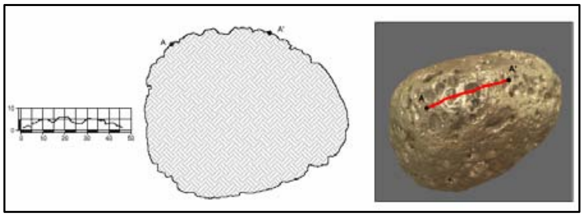

Figure 1: 3D laser scanned model of boulder from Ephrata Fan, with red line showing location of transect for fractal analysis

Gusev Crater studies: Gusev Crater is a flat-floored crater of Noachian age, 160 km in diameter. Its southern rim is breached by Ma'adim Valles, one of the largest branching valley networks on Mars [5]. Dark, fine-grained, often vesicular basalt boulders are found in profusion around the Spirit landing site. It has been hypothesized that Gusev once contained a lake, and that boulders there may have been fluvially transported, and affected by impact and aeolian processes more recently [5]. We have applied both facet mapping and fractal analysis techniques to a sample of 60 boulders from Spirit imagery of the Bonneville crater ejecta and the inter-crater plains.

Facet mapping found only a small number of breakdown features to be present on boulders both on inter-crater plains and Bonneville crater ejecta, with six types (smoothing, pitting, fissuring, undercutting, curvilinear facets and straight razor sharp facet edges) making up 81% of all the breakdown features observed. Smoothing and pitting were the most common features observed. In genetic terms, aeolian features were by far the most common, accounting for ~ 65% of the features on the inter-crater plains and around half those on the crater ejecta. Distinctive fluvial features were absent in both environments. Importantly, the facet mapping exercise confirmed that multiple processes and controls appear to have shaped the boulder surfaces. Clear evidence has been found, for example, of structural control on subsequent aeolian feature development. A hierarchy of feature persistence can be recognized from the facet mapping observations, with structural features being the most persistent, followed by aeolian and finally ejecta features. Such a hierarchy reflects the length and intensity of the process regimes that produced each type of feature.

Fractal analysis on Gusev Crater boulder profiles proved difficult. Firstly, the minimum step size resolution for boulders in Gusev Crater was at least an order of magnitude lower than those from Ephrata Fan, because of the different data sources. Secondly, it was difficult to obtain long enough profiles to allow Hurst exponents and break points in the roughness characteristics to be identified. The fractal analysis found roughness behavior to be far more variable on the Gusev Crater boulders than on those from Ephrata Fan, with different profiles often exhibiting totally different scaling behavior. Two profiles from the boulder named 'Sushi' on facets with elongated pits showed relatively consistent trends. They had Hurst exponents of 0.56 and 0.52 respectively, and break points at 1.3 and 1.9 cm (see figure 2 for example). These break points probably reflect the characteristic size of the asymmetrical pits observed on the surface.

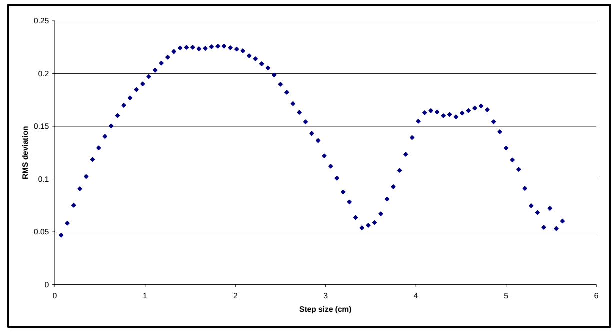

Figure 2: Detrended variogram from Sushi. Vertical axis = RMS deviation, horizontal axis = step size in cm.

Discussion and conclusions: Facet mapping observations at Ephrata Fan bear witness to the potentially high persistence of fluvially-created features on basalt boulders on Earth. The absence of any such features at Gusev Crater may imply that fluvial processes have not affected the boulders there, although the vast timespans under different subsequent process regimes under Martian conditions may have erased them. Facet mapping provides a simple method of collecting structured, quantitative data which can be adapted relatively easily from a field technique to one based on imaging. Thus, it is a powerful technique for collecting data from Mars images. Fractal analysis has the potential to provide novel insights into rock breakdown by quantifying surface roughness at different scales, but there remain problems in collecting suitable profiles for analysis and in relating the results to breakdown regimes. Further research is in progress to refine techniques and improve our understanding of what boulder morphology on Mars tells us about past process regimes.

References: [1] Bourke, M.C. et al., LPSC XXXVI, 2005 [2] Heslop, E.E.M., et al., LPSC XXXV abst. 1445, 2004, [3] Shepard, M.K. et al., *J. Geophysical Res.*, vol. 106, E12, pp. 32,777-32,795, 2001, [4] Baker, V.R., *Geological Society of America Special Paper* no. 144, 79 pp., [5] Squyres, S.W. et al., *Science* vol. 305, 794-799, 2004.