Table 4. Summary Statistics for Surface Roughness as a Function of Scale for Boulder Molds[a]

	RMS Height, mm		RMS Slope, °	
	1 mm	1 cm	1 mm	1 cm
Quarry	0.53 ± 0.27	2.58 ± 1.43	12.9 ± 5.7	7.9 ± 4.9
Outcrop	0.76 ± 0.33	3.62 ± 1.26	19.8 ± 11.9	9.9 ± 4.6
Surface	0.86 ± 0.26	4.52 ± 1.71	19.8 ± 9.6	11.3 ± 3.6

[a]Number of samples to compute statistics is listed in Table 5.

Lichens concentrate in depressions on the boulder surface, probably because of the increased moisture trapping potential of topographic lows. These depressions are typically percussion fracture facets from flood transport, suggesting lichen weathering preferentially obscures and degrades these diagnostic morphological features.

[49] Outcrop boulders are intermediate in breakdown extent compared to the quarry and surface boulders in hardness and degree of fracturing. Detached and protruding grains seen in thin section may indicate loss of material through granular disintegration. Hand samples show reddish oxidation from the surface to 1 cm toward the interior on some samples. Others display a banded oxidation zone: a ~1 mm thick band of intense iron staining about 3 mm beneath the rock surface. It is not entirely clear whether this near surface weathering of outcrop boulders occurred before or after detachment from the outcrop.

[50] The boulders' different breakdown paths are recorded by statistically significant morphological differences. Similarity between sites in the macroscopic shape of the boulders indicates that the initial fracture pattern of the parent rock probably controls their moderately "compact" appearance. Parameters for size, edge angle, and radius of curvature were more helpful than *Sneed and Folk*'s [1958] maximum projection sphericity, deviation from compactness, and form factors in providing information which enabled boulders of the three sites to be distinguished. Of all morphological measurements considered, rounding as measured from radius of curvature is the clearest morphological indicator of flood transport with nearly an order of magnitude more rounding in quarry and surface samples as compared to outcrop talus (Table 3, Figure 9b). The existence of some facets with poorly rounded edges among the surface boulders (Figure 9a) is consistent with ongoing breakdown producing fresh, unrounded fractures, like those in outcrop talus.

[51] Roughly equivalent sizes for the outcrop columns and the quarry and surface boulders may reflect boulder formation by plucking of floodwaters exploiting preexisting columnar fractures in the basalt outcrop colonnade [*Baker*, 1978b]. Size sorting during fluvial transport did not significantly influence size over the 6 km separating the quarry and surface site.

[52] Average boulder edge angles for the quarry boulders (Table 3) compare remarkably well to the 120° theoretical mean angle for fracturing during production of hexagonal basalt columns during lava flow cooling [*Lyle*, 2000]. Average values <120° are consistent with measured angles reflecting a combination of preexisting fractures (such as those in hexagonal columnar basalt) and horizontal fractures in the outcrop, perhaps related to unloading (Figure 6c). During initial plucking of boulders from the outcrop, breaks would be primarily along hexagonal columnar joints where cavitation could dislodge fragments. Subsequent posttransport fracturing of flood-transported boulders under the current weathering regime on the fan surface seems to instead release boulder fragments along perpendicular fracture angles. This is reflected in the "tail" of low values in the frequency distribution of edge angle values (Figure 9a).

[53] Outcrop talus boulder shape parameter values are significantly different from those of flood-transported boulders in all aspects. Talus boulders are significantly smaller in comparison to both other boulders and hexagonal column width. Further, talus boulder edges meet at angles far smaller than 120°. Both of these facts are consistent with a different formation mechanism than plucking by floodwaters along columnar fractures. Instead, fractures at a smaller scale are created or preexisting features are propagated until the blocks are released. This was not an expected result but is revealed by examination of the quantitative morphologic parameters. We speculate that a single surface weathering process, recently or presently active, is responsible for detachments which both create the outcrop boulders and cause the surface boulders to fracture in situ. This process creates characteristic 90° angles for fragments typically a few tens of centimeters in size. The present regional climate suggests freeze-thaw cycling as one possible mechanism. Ice segregation could lead to fracture along preexisting joints of rock weakness [*Hallet et al.*, 1991]. Alternatively, moisture percolating along jointing planes might have assisted chemical weathering, weakening the basalt by altering minerals to clays, forming zones of alteration particularly susceptible to failure [*McGreevy*, 1982]. Insolation weathering also can fracture boulders. Cracks formed from these have a specific orientation related to incident solar insolation [*McFadden et al.*, 2005]. To test whether one of these processes is responsible for the most recent morphological imprint from weathering on both surface and outcrop boulders, further variables must be assessed in field study at the Ephrata Fan in relation to the parameters. These include rock temperature variation

Figure 10. (a) Photograph of the control boulder (right) taken postmolding and next to its plaster mold (left). Note photograph was taken angled from normal viewing. Gridlines in the upper left of the photo have centimeter spacing. The transect is labeled. (b) Digital elevation model at 0.5 mm spacing of the control mold. DEM values have been inverted so features match the orientation of the original surface. The x in the DEM center was an indentation left by a marker pen. (c) Profile taken from digital elevation models of the original rock surface, the plaster mold, and the rock surface postmolding. The zone where lichen interfere with accurate recording of elevations is indicated. (d) RMS deviation as a function of scale for the surface of the control rock, the rock surface after casting with plaster, and the mold. H values are the same for the original rock and the mold; breakpoint location may differ ~1 mm or less.