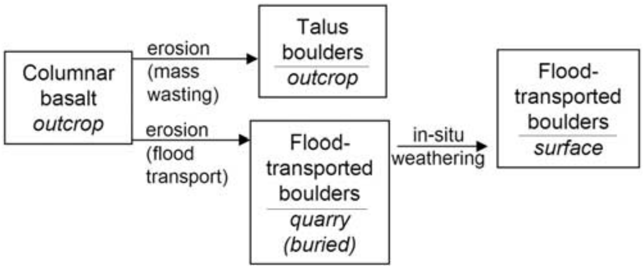

Figure 2. Rock breakdown sequence at the Ephrata Fan. Boulders at the base of the outcrop are $\sim 10^1-10^2$ year old talus. Quarry and surface boulders underwent flood transport and were, respectively, buried and removed from the surface environment or exposed to the surface weathering environment for $\sim 10^4$ years.

1978; *Clague et al.*, 2003]. Preexisting soils and glacial debris were removed creating the Channeled Scabland morphology of kilometer scale scoured channel systems, megaripples, and large boulder bars [*Baker*, 1978a]. The Ephrata Fan, our study site, is at the distal end of Grand Coulee where during the most recent episode of flooding, waters exiting the coulee decelerated, depositing their sediment load in a subaqueous fan extending approximately 800 km^2 (Figure 1a) [*Bretz*, 1923]. Boulder-sized objects near the mouth of the coulee fine southward, away from the mouth, to sand-sized sediments which have been reworked into the Moses Lake dune field [*Rice and Edgett*, 1997]. The 10 km of the Ephrata Fan closest to Soap Lake has a notable concentration of boulders due to erosion of fines during late stage drainage of the basin [*Golombek and Rapp*, 1997]. Approximately 90% of the boulders are basalt, derived from the Columbia River flood basalts [*Rice and Edgett*, 1997; our field observations]. In some places boulders are overlain by flood transported sediments [*Swanson and Wright*, 1978].

[12] From $\sim$10 ka BP, grasslands have dominated eastern Washington, and all data suggest a continuously cool and dry climate since the Lake Missoula floods [*Mehringer*, 1985]. Human agriculture and aeolian reworking of flood sediments and glacial loess have been the most active geomorphic processes since the last Scabland flood [*Rice and Edgett*, 1997]. Present-day average precipitation is less than 20 cm. Average daily temperature range in the summer is 15 to 30°C and during the winter is −5.5 to 1°C (National Weather Service, Observed data for Ephrata, 1950–2005, Cooperative Observer Data, National Weather Service Forecast Office, Spokane, Washington, accessed 2 August 2006, available at http://www.wrh.noaa. gov/otx/climate/coop/coop.php).

2.3. Field Locations for Boulder Sampling

[13] Three boulder sampling sites were identified: surface, quarry, and outcrop (Figures 1b–1d). The surface site is a field of exposed boulders on the Ephrata fan surface. The quarry site is a large open pit dug into the Scabland flood-transported sediments on the southern end of the Ephrata Fan. These are being mined for concrete production. The outcrop site is located in the basalt cliffs along the eastern shore of Soap Lake. Care was taken to select an outcrop where the colonnade structure was readily apparent.

[14] We hypothesize that each of these sampling sites represents a different path taken in the rock breakdown process (Figure 2). This allows certain assumptions to be made regarding the types and timescales of processes which have acted on the boulders at each of the sites and which can be related to their morphology. Quarry boulders were transported in the Lake Missoula flood events (between 12,000 and 17,000 years ago) and were buried immediately by finer debris as floodwaters receded. Thus protected from the subaerial weathering environment, they should represent boulders with a clear flood transport imprint and little subsequent alteration. This assumes burial in alluvium does not enhance weathering, an appropriate assumption given that soils of semiarid Eastern Washington form well above the water table and do not have well-defined horizons. *Birkeland* [1999, p. 172] noted a similar lack of weathering of buried granite boulders in <20,000 year old tills in California. Boulders from the Ephrata fan surface have experienced flood transport followed by exposure to the Ephrata surface weathering environment for up to 12,000 years. From the climate of the area, we hypothesize rock breakdown to be dominated by freeze-thaw and/or thermal cycling, chemical oxidation of iron bearing minerals, and lichen-induced biological weathering. We assume both quarry and surface boulders are unlikely to have inherited preflood transport weathering features since the high energy transport would have erased any surface signatures. Boulders from the outcrop represent a different breakdown path whose time of exposure is not as well constrained but is probably no more than $\sim 10^2$ years (as boulders). This corresponds to the approximate time of construction of Soap Lake Road (Route 17) when boulders were likely cleared from the base of the outcrop (Figure 1). Boulders at the outcrop site have not experienced transport but have simply detached from the outcrop and remained at its base. In addition to lack of fluvial transport, the method of detachment also may differ from flood transported boulders, e.g., mass wasting following weakening by freeze-thaw or chemical weathering as opposed to cavitation and plucking and abrasion. Outcrop boulders will also have experienced in situ weathering, like the fan surface boulders; however, the time span available for such weathering is likely at least an order of magnitude less than for the fan surface boulders. Furthermore, unlike the quarry and fan surface boulders the outcrop boulders may have inherited features from in situ alteration, such as caused by percolating reactive fluids within joint systems.

3. Methods

[15] For each of the three boulder sites, measurements were made to characterize the extent and characteristics of rock breakdown experienced by boulders, boulder morphology, and boulder surface texture. Specific quantitative parameters measured are listed in Table 1. At each sampling site, 10–50 boulders were selected for measurement and 10 samples were chosen for casting so that detailed laser scanning could be undertaken in the laboratory. Boulders were chosen by laying a transect and, at intervals, selecting the nearest boulder. Quantitative parameters were compared