[3] Rock masses are transformed into soil and sedimentary debris by the combined effects of weathering and erosion. These processes may be collectively referred to as rock breakdown. Boulder morphology is controlled by the interaction between lithology and the particular rock breakdown processes at work, which are largely dictated by climate and tectonic setting. Past environments should thus be recorded by the morphology of boulders. Previous studies have identified specific features as produced by individual breakdown processes, e.g., ventifacts from aeolian abrasion [e.g., *Greeley et al.*, 2002], percussion marks, potholes, incipient cones, and chink facets from fluvial transport [e.g., *Tinkler and Wohl*, 1998; *Bourke and Viles*, 2007]. However, techniques for geomorphological analysis have been mostly qualitative at these centimeter and meter scales, making comparison of boulder shape and texture across locations and between studies difficult at present.

[4] Understanding the uniqueness and persistence of boulder morphological features are two key challenges for improving the utility of boulders as a source of paleoenvironmental information. For example, spheroidal boulders are found in systems with high energy fluvial transport [*Williams*, 1983] but also as corestones in chemically weathered sedimentary strata [*Ryan et al.*, 2005]. Additionally, as the timescales under consideration increase, multiple processes interact, making interpretation of process signatures increasingly difficult. Boulders represent a palimpsest, with signatures of later processes overprinting or destroying earlier morphological imprints. In order to address these challenges replicable methods of describing boulder morphology need to be developed.

[5] Physical parameters for rock breakdown extent are already readily and routinely quantified, e.g., Schmidt hammer rebound values as a proxy for hardness, porosity as a volumetric ratio, rind depth in millimeters. No standardized set of quantitative metrics as yet exists to describe morphology, however. Reporting boulder surface forms still relies largely on qualitative description of surfaces as "pitted," "abraded," and "fractured" without conventions for describing scale, extent, and form. A feature atlas including images, descriptions of morphology, and formation processes has been completed for fluvial, aeolian, and weathering rock breakdown morphologies at the boulder scale [*Bourke and Viles*, 2007]. This allows assessment of the frequency of these features (e.g., by facet mapping [*Heslop et al.*, 2004]), but does not standardize reporting variation in their form or the boulder's general shape. Other studies focus on particular weathering features and their reporting, e.g., cracks [*McFadden et al.*, 2005], tafoni [*Turkington and Phillips*, 2004], or fluvial sculpted forms [*Richardson and Carling*, 2005]. In terms of the general morphology, boulder studies often borrow the semiquantitative, categorical metrics of sphericity and rounding (e.g., those of *Sneed and Folk* [1958], see *Barrett* [1980] for a review) used in sedimentological grain analysis and are usually based on comparison to visual charts. A few researchers move beyond categorical to quantitative indices. *Yingst et al.* [2007] quantify elongation, sphericity and curvature of boulders at the Mars Pathfinder landing site using boulder axis measurements and inscription of circles to boulder perimeters and edges. *Rouai and Dekayir* [2001] and *Yang and Wu* [2006] employ the fractal box-counting method on the perimeter of a 2 d projection of the boulder. *Durian et al.* [2006] image clasts and trace their outlines and find that boulders from different environments have varying statistical distribution of curvatures.

[6] While these measures of size, specific morphology, and shape outline may be sufficient to capture the diversity of sand and gravel-sized particles (<6.4 cm), additional information on rock breakdown processes at the boulder scale can be obtained by more fully examining three dimensional information, including morphologic parameters such as surface texture and the angle of intersection of facets of a boulder. In particular, to parameterize boulder surface texture, the potential exists to borrow and apply tools from other disciplines. Herein, we utilize two techniques from landscape analysis: fractal analysis of surface roughness [*Shepard et al.*, 2001] and morphometric classification of surface forms at multiple scales [*Wood*, 1996] (see section 3).

[7] In the following sections we first develop a quantitative parameter set for reporting boulder size, shape and texture. We then test the ability of this parameter set alongside standard methods to distinguish three boulder populations in the Channeled Scabland which have well-constrained and different environmental histories. The degree to which boulder morphology is diagnostic of rock breakdown process and extent is considered.

## 2. Study Site

[8] To study the effects of distinct breakdown processes in shaping boulder morphology, we required a site for which we had (1) extensive a priori knowledge of its geology and geomorphic history; (2) distinct groups of boulders with well-constrained but divergent rock breakdown histories; and (3) boulders of similar lithology in order to control its effects on boulder form and thereby isolate the effects of geomorphic processes. The Ephrata Fan in the Channeled Scabland of eastern Washington (47°20′N, 119°30′W, Figure 1) is particularly well suited to fulfilling these criteria. Additionally, the Channeled Scabland megaflood site has planetary science relevance: it has long been recognized as an analog for large outflow channels on Mars similar to Ares Vallis and the Mars Pathfinder landing site [e.g., *Golombek and Rapp*, 1997] and Columbia River basalt is geochemically similar to some basalt on Mars [*Wyatt and McSween*, 2002].

### 2.1. Geology and Boulder Lithology

[9] The Ephrata Fan is dominated by boulders of the Columbia River Basalts (CRB), a 20,000 $km^2$ layered continental flood basalt sequence up to 1 km thick, 98% of which was deposited in a series of eruptions between 16.5 and 14.5 Ma BP [*Swanson and Wright*, 1978]. CRB flows are rich in labradorite, plagioclase, augite, pigeonite, and occasionally Fe-rich olivine [*Hooper et al.*, 2007]. Outcrops near our site at the southern end of Grand Coulee contain the Lookingglass and Frenchman Springs members of the Wanapum formation which are undifferentiated fine grained to aphanitic flow units with hackly columnar jointing (Figure 1b) [*Grolier and Bingham*, 1971; *Swanson et al.*, 1979; *Hooper et al.*, 2007].