**SUPPLEMENTAL MATERIAL**

The discovery of 14 WST projectile points placed together in PFP1 provides a unique opportunity to examine aspects of WST technology, particularly if the artifacts were made during a brief interval of time by a knapper or knappers who employed a specific set of design rules. Most often, WST projectile points are found in temporally ambiguous contexts, such as on the surface of the modern landscape or within a stratigraphic unit that formed over hundreds to thousands of years, making their relative ages unknowable or uncertain. In contrast, we take the fact that these projectile points were found in a pit feature with a single internal chamber as evidence that they represent a contemporaneous set of artifacts. As such, they represent a “snapshot” in time and as a group provide technological and morphometric benchmarks to which other stemmed projectile points can be compared.

The discovery of PFP1 and its archaeological contents is notable, and more so considering that it is the second such cache of artifacts found at the Cooper’s Ferry site. Excavations led by Davis in 1997 discovered a pit feature (designated Pit Feature A2 (PFA2)) bearing 13 stone tools, including a large uniface, three blades, two cores, two modified flakes, a hammerstone, and four stemmed projectile points (Davis and Sisson 1998; Davis and Schweger 2004; Davis et al. 2014). Davis et al. (2015) employed the GLiMR method and a 2D Generalized Procrustes Analysis to make a preliminary comparison of the WST projectile points from the PFA2 cache found in 1997 and the recently discovered PFP1 stemmed projectile points and demonstrated that the two groups of projectile points cluster together on the basis of their 3D GM form and are therefore probably of a similar age. Stratigraphically, PFA2 was seen to originate from a deeply buried loessal deposit bearing the Rock Creek paleosol (Davis and Schweger 2004: Figure 5; Davis et al. 2014: Figure 2) and is associated with wood charcoal samples radiocarbon dated to 11,370 ± 40 B.P. and 11,410 ± 130 B.P. (see discussion in Davis et al. 2014 for details about these ages). Davis et al. (2015) employed the GLiMR method and a 2D Generalized Procrustes Analysis to make a preliminary comparison of the WST projectile points from the PFA2 cache found in 1997 and the recently discovered PFP1 stemmed projectile points and demonstrated that the two groups of projectile points cluster together on the basis of their 3D GM form and are therefore probably of a similar age.

The benefits of employing 3D scanning are many and include: greater accuracy in the measurement of artifact surface variation (e.g., 0.01 mm spacing between individual XYZ data points is easily achievable with systems that cost less than $5,000); increased accessibility of the 3D scan file amongst archaeologists via internet file transfers from online archives; significant reduction of inter-observer error and high degree of replication of measures (cf. Beck and Jones 1989); the study of digital 3D scan files bears no risk of damaging or otherwise compromising the original object; scan files can be used to create physical replicas of the original artifact via 3D printing and machining technologies.

**David SLS-2 3D Scanning Procedure**

We used a David SLS-2 structured light scanner to obtain high-resolution surficial meshes of projectile points. Scanner was calibrated using manufacturer’s recommendations using the 60mm calibration scale. Projectile points were suspended in vertical orientation in a medium density, closed cell polyethylene foam with approximately 75% of the projectile point visible and then coated with a thin dusting of a commercially available fungicide powder[[1]](#footnote-1). The spray is fast drying, matte, and opaque in surficial characteristics, which allows for high quality images to be obtained on reflective and translucent artifacts. Furthermore, particles in the spray are small enough that the topography of the artifact specimen is not altered (at least to the scale of the David SLS-2 scan resolution), and the spray is easily removed with a light dry brushing.

After a projectile point was sprayed, the foam block and projectile point was placed on a rotating stage and a series of ten to twelve scans were performed at the software’s “high quality” mode at roughly a 45° angle relative to the projectile point. After each scan any background noise was trimmed from the scan and an alignment to the previous scan was performed. Particular care was given to the bifacial margins of the projectile points in order to capture maximum surficial detail. In some cases, background was left in to aid in alignment of separate faces and then removed once a good alignment had been obtained.

Once a complete revolution had been scanned and aligned, the projectile point was removed from the foam, cleaned using a dry brush, and then reinserted into the foam block in a reversed orientation. The above procedure was then repeated, with each scan being aligned and cleaned as it was obtained. The overlapping 25% from the first set of scans to the second allowed for alignment of the two sets of scans and a complete point to be constructed. Following scanning and removal of any background noise, a fine alignment was performed, and then a fused model was created with vertex spacing between 0.08 mm to 0.12 mm. Closed 3D models were then exported as a Wavefront OBJ files.

**GLiMR Procedure and Measures**

The GLiMR software is written in Python 2.7 and uses ArcGIS 10.3 procedures to extract geometric morphometric data from 3D scan files. GLiMR builds 3D topographic surfaces of both faces, extracts the 3D trace of the bifacial edge, and computes volumes and cross-sections. It further analyzes surface and thickness properties (topography, slope, aspect, and curvature), generates profile traces (cross-section or outline), and quantifies areas of material removal (reentrants). Cross-sectional areas, whole or partial volumes, and curve fits are also computed. The results may be viewed visually in ArcGIS and numerically in Microsoft Access or exported as comma separated value files. The resulting detailed geometry and attributes are organized as geodatabases containing ArcGIS point, line, and polygon feature classes, associated attribute tables, grids, and summary databases.

A series of measures were collected from the 3D scan of each stemmed point that describes a set of geometric morphometric attributes, including: length, width, and thickness; convex hull[[2]](#footnote-2) and reentrants; 3D landmarks and semi-landmarks; cross section areas; and many angles between features. Statistical analyses of the GLiMR data are directed to answer questions about the range of morphometric variation, the average morphometric shape of the artifacts, and the degree of morphometric similarity shared among the 14 PFP1 projectile points. Numerical mean, standard deviation, and coefficient of variation (CV) were calculated. Here, we present a more sophisticated analysis of 3D landmarks data generated by GLiMR[[3]](#footnote-3) through Generalized Procrustes Analysis (GPA) using Geomorph, an R package for the collection and analysis of GM shape data (Adams and Otárola-Castillo 2013). The primary 3D digital scan point cloud files for each of the 14 WST projectile points described in this paper are available for download from Oregon State University’s ScholarsArchive (https://ir.library.oregonstate.edu/xmlui/).

Two and three-dimensional metrics calculated by GLiMR from 3D scans fall into two groups: absolute dimensional data (coordinates, distances, areas, volumes, and angles) and dimensionless data (ratios and curve coefficients). For a specific projectile point, absolute dimensions quantify the size; however, various dimensionless ratios, together with key angles, are better for comparison among of a set of artifacts. Full definitions for each of the GLiMR metrics are provided in the supplemental materials, but many dimensionless values will be discussed below. Tables 2 and 3 show selected metrics reported by GLiMR grouped into dimensional and dimensionless subsets. Dimensional data can be grouped by Euclidian measures such as length, width, thickness, area, and volume. Dimensions may be measured on the entire projectile point or of a sub-domain such as blade or haft elements. These are typically expressed relating a part to the whole as a percentage. For example, if separate blade and haft elements are defined, then blade and haft sub-volumes may be computed separately and will sum to the volume of the complete projectile point. Similarly other dimensionless parameters based on distance, area, and volume metrics can be computed comparing the sub-domain (part) to the same metric for the entire projectile point.

Measuring angles (i.e., edge, blade) on a projectile point is problematic because most of the surfaces and margins are curved and therefore cannot be characterized by a single observation (such as that provided by a goniometer) and are often prone to low reproducibility. Profiles, such as from an outline blade edge or a cross-sectional slice, yield 2D curves that can be characterized mathematically by fitting linear and quadratic curves to specific profile segments and capturing their coefficients for comparison.

Reentrants are a set of polygons that define the areas that lie outside of a projectile point’s outline yet inside of the convex hull encompassing the projectile point (Figure 5) and represent areas where material has been removed during manufacture. On notched projectile points, reentrants represent the more narrow negative spaces associated with hafting notch elements, but on stemmed projectile points they represent the area where material is removed to create the constricted margins of the haft element. The position, elongation, and angular orientation of these particular reentrants can be very diagnostic and useful for comparing different kinds of projectile point forms. To do this, we compute the mean GM values of the left and right reentrants. For parameters such as bearings or X-coordinates where left and right values cannot be directly combined for an arithmetic mean, they are appropriately mirrored and their mean values are presented as if they were for a right reentrant. To bring these measures into a clearer context, Figure 6 shows the application of reentrant measurements to a range of different projectile point forms.

Questions about how similar the 2D and 3D shapes of objects are to one another are fundamental to archaeology and comparisons of projectile point form to an ideal shape are the basis for making identifications of typological objects. Indeed, the comparison of geometric form among early projectile points has been used to infer the degree to which cultural knowledge about stone tool technology is shared over time and space (e.g., Bettinger and Eerkens 1999; Buchannan and Collard 2007; Davis et al. 2012; Sholts et al. 2012). Traditional approaches to the study of projectile point shapes often employ simple bounding box measures or more complex measurements that subdivide elements of a projectile point into different morphometric domains, including blade, haft, tangs, and notches. Once 3D data are available, Generalized Procrustes Analysis (GPA) is an attractive approach for morphometric analyses as it translates, rotates, and scales objects to get the closest possible match between specimens, then creates a mean shape based on landmark data (Bookstein 1991). 3D GPA landmark points (XYZ) are determined at similar locations on the 3D surface of each object (see the supplementary material section for details on GPA methodology). For each individual object, specific landmarks are then compared to their corresponding landmark on the mean shape of all objects. The numerical offset (in XYZ space) from the mean shape landmark to the individual object's corresponding landmark is termed the Procrustes Distance, which is a vector whose orientation and length show the amount of change in position of a landmark. The mean Procrustes Distance of all landmarks for each object may be used to quantify shape comparisons and can be mapped onto the surface of the mean shape of the PFP1 projectile points to illustrate the differing amounts of shape variation in different parts of the surface. Instructions for viewing and downloading this landmark dataset are presented in the OSU ScholarsArchive sharepoint.

**Additional Thoughts on the Function of the Haft Saddle**

The 3D form of the haft saddle may have been designed to enhance the strength of the intersection between the lithic and a wood/antler/bone/ivory haft element in a similar way that traditional woodworking splice joints create secure intersections between two pieces of wood (e.g., hooked scarf joint, stepped gooseneck splice). Soaking or boiling an antler or bone foreshaft element in water, wood ash and water, or urine would soften the organic haft element and give it a plasticity that would harden into a formed shape once dried (Jochelson 1908; Burch 2006:199). We hypothesize that the PFP1 stemmed points may have been mounted into a softened organic foreshaft with some kind of natural glue (e.g., tree pitch mixed with powdered charcoal) that was bound tightly with sinew. As the glue, sinew, and foreshaft material dried, the sinew would constrict the haft element and mold the softened organic surfaces of the foreshaft into the negative impressions of the haft saddle, where they would dry and conform to the shape of the haft saddle, creating a strong union between projectile point and projectile foreshaft.

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1. Tinactin (Tolnaftate 1% Antifugal) Powder Spray. [↑](#footnote-ref-1)
2. A convex hull is the smallest convex polygon that contains all of the spatial points (here, in XY), like a digital “shrink-wrap” that encompasses the artifact’s extremities. The areas between the convex hull and the artifact’s outline are termed reentrants (Clopton 2004; Polly et al. 2011) and, in the case of flaked stone tools, commonly represent areas of material removal along margins (e.g., serrations, denticulations, notches). [↑](#footnote-ref-2)
3. The Davis et al. (2015) paper on GLiMR provides a less sophisticated 2D approach to Generalized Procrustes Analysis (focusing on landmarks distributed around projectile point outline shapes), does not explore the GM significance of reentrants on stemmed projectile points, and lacks an inquiry of cross sectional and thickness data, as presented in this study. Readers are encouraged to consult the Davis (2015) paper for a deeper understanding of the conceptual and methodological basis that underlie the GLiMR approach. [↑](#footnote-ref-3)