Does elliptical biface morphology differ as a function of raw material color?

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*Archaeologists regularly assume that the physical properties of lithic raw materials are a determining factor in the morphology of stone tools; although, some have argued that this assumption warrants regular testing. Raw material nodule size and mechanical flaking properties are routinely advanced to account for morphological differences that occur between sites and assemblages. The quantitative analysis of raw material color provides a means of assessing morphological similarities and differences associated with color. To evaluate elliptical biface morphology as a function of raw material color, each elliptical biface from 41AN13 was first assigned to a raw material color group, then analyzed using the tools of geometric morphometrics. Results demonstrate that elliptical bifaces differ significantly in shape, but not size, by raw material color group. This finding supports the interpretation that extralocal producers—and local Caddo users/knappers—conditioned elliptical biface shape not based upon nodule size or mechanical flaking properties, but on the basis of raw material color.*

*Keywords: American Southeast; Caddo; lithics; computational archaeology; archaeoinformatics; museum studies; digital humanities; non-Western art history*

Macroscopic color has long been the key determining attribute used in the qualitative assignment of lithic raw materials in the American Southeast (Ford 1951; Ford et al. 1955; Ford and Webb 1956). Color is also useful in characterizing heat treatment (Fields and Gadus 2012; Gadus et al. 2006; Hall 1994; Quigg et al. 2014), and in making probable determinations in debitage analyses that link specific tools and/or flake scars with specific flakes (Weber 2016). However, the assignment of raw material color has, to this point, been a highly subjective enterprise that is not linked, at least not directly, to specific raw materials or raw material sources.

Generations of archaeologists have used the Munsell color system (Munsell 1915) as a means of making descriptive and/or qualitative color comparisons. David Frankel (1994) developed a systematic means of identifying trends in Red Polished wares from the Early and Middle Cypriot Bronze Age that brought value to discussions of cultural transmission and ceramic production. Qualitative comparisons of Munsell color spaces have proven utility in discriminating diagnostic ceramic traits in the American Southwest (Beck et al. 2016), which were expanded to include the CIE Lab color space (McGrath et al. 2017). A quantitative approach to analyzing the Munsell color space was advanced by D'Andrade and Romney (2003), and later expanded by Ruck and Brown (2015) in their analysis of ceramic slip color.

*Raw material nodule size and mechanical flaking properties*

Raw material nodule size is often included in arguments suggestive of differences in morphology (Ashton and McNabb 1994; Bradbury and Franklin 2016; Eren et al. 2014; Hurst et al. 2014; Shott and Sillitoe 2004), as the size of the original nodule dictates the maximum potential size of the final object, and can provide evidence for lithic transportation (Ditchfield 2016; Ditchfield and Reynen 2022; Finkel and Gopher 2018). Nodule size is considered an *external property* “of the initial nodule, block, or blank from which flakes are struck” (Eren et al. 2014:473). Recent efforts to estimate nodule size for cortical cobles and pebbles require as few as 100 cortical fragments, where Douglass et al. (2021:9) argue that “nodule size is a major determinant of assemblage variability and can affect the performance of different lithic indices.” The nodule size estimation advanced by Douglass et al. (2021) was subsequently used to calculate the cortex ratio, a metric that can provide inference to differential mobility and land use (Davies et al. 2022).

Mechanical flaking properties, or the *internal properties* of lithic raw material (Eren et al. 2014:473), have been advanced by some as drivers of lithic morphology as well as function (Goodman 1944; Jones 1979, 1981). More generally, mechanical flaking properties have been advanced as exhibiting differences in overall quality (Whittaker 1994), thought to impact the resulting morphology of the final product (for a more thorough review, see Eren et al. 2011; Eren et al. 2014).

*Elliptical bifaces*

Elliptical bifaces comprise an understudied category of Caddo material culture. The elliptical bifaces from 41AN13 (Jowell Farm) were purchased by the Texas Archeological Research Laboratory (TARL) at The University of Texas at Austin on April 13, 1933, and the site is located near Kickapoo Springs Village, south of Frankston, Texas in Anderson County (Figure 1). The bifaces were excavated from a Caddo burial by a local farmer (George H. Adams), and of the 35 bifaces reportedly acquired by TARL when the collection was purchased, 18 could be located, and 13 of those are complete. Due to the absence of evidence for local production and the dearth of locally-available raw materials of suitable size and quality needed to produce the elliptical bifaces (see Selden Jr et al. 2021:Figure 2), an assumption also made for Gahagan bifaces from the ancestral Caddo region (Selden Jr. et al. 2020; Selden et al. 2018), the elliptical bifaces are thought to have been imported through trade and/or exchange. This study asks whether raw material color may have been a determining factor impacting elliptical biface morphology.

**Figure 1. Location of Jowell Farm and other Caddo sites where elliptical bifaces have been found, which includes all but one major drainage basin in the ancestral Caddo area (dashed/white) (top) and seriation of Allen Phase burial contexts derived from Kleinschmidt (1982) (bottom).**

Temporally, 41AN13 is among the five sites—others include 41AN21, 41AN26, 41CE6, and 41CE12—that Kleinschmidt (1982:213-220) analyzed when he built upon the work of Cole (1975) to propose the Allen Phase in northeast Texas. Pulling directly from Kleinschmidt’s (1982:220) *Cemetery Data and Tentative Chronology* table, a new seriation was assembled for the five Allen Phase sites listed in that table. For the purpose of the seriation, the Poynor Engraved and Patton Engraved types were each collapsed into a single column, and any row or column included in the Allen Phase section of Kleinschmidt’s (1982) table with a sum of zero was omitted (see Figure 1).

METHODS AND RESULTS

The 13 complete elliptical bifaces were scanned at 1200 dpi using an HP ScanJet G4050. Images were subsequently transferred to a transparent background in Photoshop in preparation for analysis using the *colordistance* package in R (R Core Development Team 2023; Weller and Westneat 2019). All images were converted from RGB to CIE Lab color space using the D65 (indirect sunlight) reference white as the default for color conversion, and the upper and lower limits of the color range were determined based on colors present in the sample. A histogram binning method was used to group similar colors, and pairwise distances between histograms were computed using earth mover’s distance, yielding three distinct raw material color groups (Figure 2) (Rubner and Tomasi 2001). Since one cluster included only a single biface (81), it was dropped from the analysis. The remaining bifaces were coded as ColorGroup A and ColorGroup B for the analysis of elliptical biface morphology. Images of the bifaces are not included here due to the fact that they originated from Caddo burial contexts.

**Figure 2. Elliptical bifaces from 41AN13 were used to identify raw material color groups. In this graph, dark pink corresponds to bifaces that express the greatest differences in color, while those in dark blue correspond to bifaces with the greatest similarities. By not splitting the clusters further than two groups, raw material color group assignments allow for shifts in raw material tint that articulate with patination (top) and PCA summarizing shape variation in elliptical bifaces, where ColorGroup A is depicted by gray circles and ColorGroup B by orange plus signs (bottom).**

*Geometric morphometrics*

Prior to landmarking, elliptical bifaces were oriented with the most heavily retouched edge at top right. The landmarking protocol uses three landmarks; two horizontal tangents (top/bottom), and the third placed at the furthest extent of the edge bearing the heaviest amount of retouch. Landmarks and semilandmarks were applied in R using the *StereoMorph* package (Olsen and Westneat 2015; R Core Development Team 2023). Some bifaces include multiple areas of heavy retouch at the top and bottom of the same lateral edge, while others include one retouched edge at top right and another at bottom left, similar to alternately beveled bifaces.

To identify which edge was most heavily retouched, the study used a modified approach to the flaking index initially developed by Miller (2007). The modified approach employs counts of flake scars from each side of the edge in the two most heavily worked areas, paired with a measure of edge length that was collected using the DStretch plugin for ImageJ (inclusive of curvature - this is not a linear metric). The number of flake scars was subsequently divided by the length of the worked edge, with the heaviest worked edge identified by the greater value.

Landmark data were aligned to a global coordinate system (Bookstein et al. 1999; Gunz et al. 2005; Kendall 1981, 1984), achieved through generalized Procrustes superimposition (Bookstein 1986; Rohlf 1999; Rohlf and Slice 1990) in R using the *geomorph* and *RRPP* packages (Adams and Collyer 2015; Adams and Otárola-Castillo 2013; Baken et al. 2021; Collyer and Adams 2018). Procrustes superimposition translates and rotates the coordinate data to allow for comparisons among objects, while also scaling each biface using unit-centroid size—the square root of the sum of squared distances from each landmark to the specimen’s centroid (Chapman 1990; Dryden and Mardia 1998; Gower 1975; Rohlf and Slice 1990). The *geomorph* package uses a partial Procrustes superimposition that projects the aligned specimens into tangent space subsequent to alignment in preparation for the use of multivariate methods that assume linear space (Dryden and Mardia 1993; Kent and Mardia 2001; Rohlf 1999; Slice 2001).

Principal components analysis (Jolliffe 2002) was used to visualize shape variation among the elliptical bifaces, and the scatterplot represents the dispersion of shapes in tangent space (see Figure 2) (Adams et al. 2013; Bookstein 1991; O'Higgins and Jones 1998; Rohlf and Marcus 1993). To assess whether elliptical biface shape and size differed by raw material color group, Procrustes ANOVAs (Goodall 1991) were run that enlist effect-sizes (zscores) computed as standard deviates of the generated sampling distributions (Collyer et al. 2015). A residual randomization permutation procedure (RRPP; n = 10,000 permutations) was used for all Procrustes ANOVAs (Adams and Collyer 2015; Collyer and Adams 2018). Results demonstrate a significant difference in elliptical biface shape (RRPP = 10,000; Rsq = 0.31811; Pr(>F) = 0.0473), but not size (RRPP = 10,000; Rsq = 0.00831; Pr(>F) = 0.7793), by raw material color group.

DISCUSSION AND CONCLUSION

Even if raw material color groups are not found to differ in terms of geochemistry, results clearly demonstrate that two discrete elliptical biface shapes articulate with two distinct raw material color groups, indicating a previously unreported Caddo preference related to local lithic technology. With regard to function, elliptical bifaces may have occupied a ceremonial role in the Serpent/Snake Dance (Howard 1955), in which symbolic implements were heralded to convey elements of the lower world (Gadus 2013). Similar bifaces are depicted in a shell cup recovered from the Craig Mound at Spiro (Phillips and Brown 1978-1984), where both Hero Twins can be seen grasping an elliptical biface (Figure 3). Given the extant differences that occur in elliptical biface shape and color, these implements may have been meant to depict one or more specific species. The amount of retouch along the edges suggests that the bifaces experienced regular use, raising the question of whether the associated colors and shapes may have articulated with specific tools employed to dispatch or prepare offerings for a particular species or group of snakes. Experimental use-wear studies may aid in clarifying whether or not elliptical bifaces were employed for such tasks.

**Figure 3. Depiction of the Hero Twins engaged in the Serpent Dance, with each grasping an elliptical biface (in red). Adapted from Phillips and Brown (1978-1984:Plate192).**

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DATA MANAGEMENT

Reproducibility—the ability to recompute results—and replicability—the chances other experimenters will achieve a consistent result—are two foundational characteristics of successful scientific research (Leek and Peng 2015). The analysis code associated with this project can be accessed through the supplementary materials (<https://seldenlab.github.io/elliptical.bifaces.1>) or the GitHub repository (<https://github.com/seldenlab/elliptical.bifaces.1>), which is digitally curated on the Open Science Framework ([DOI: 10.17605/OSF.IO/2CHFE](https://osf.io/2chfe/)). The reproducible nature of this enterprise provides a means for others to critically assess and evaluate the various analytical components (Gandrud 2014; Gray and Marwick 2019; Peng 2011), which is a necessary requirement for the production of reliable knowledge.

Reproducibility projects in psychology and cancer biology are impacting current research practices across all domains. Examples of reproducible research are becoming more abundant in archaeology (Ivanovaitė et al. 2019; Marwick 2016; Selden Jr et al. 2021; Selden Jr. et al. 2020; Selden Jr. et al. 2018; Selden 2022), and the next generation of archaeologists are learning those tools and methods needed to reproduce and/or replicate research results (Marwick et al. 2019). Reproducible and replicable research work flows are often employed at the highest levels of humanities-based inquiries to mitigate concern or doubt regarding proper execution, and is of particular import should the results have—explicitly or implicitly—a major impact on scientific progress (Peels and Bouter 2018).

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