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

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*Abstract: The physical properties associated with lithic raw materials are regularly assumed to be a determining factor that articulates with stone tool morphology. Among those attributes most frequently advanced to account for differences between sites and assemblages are raw material size and mechanical flaking properties. Quantitative analysis of raw material color can provide a consistent, and replicable, means of assigning bifaces to raw material color groups. To evaluate whether elliptical biface morphology differs as a function of raw material color, each elliptical biface from 41AN13 was 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; ovoid biface; Galt biface; Nikolas knife; Jowell knife; Jowell knives; Jowell biface***

Descriptive and/or qualitative color comparisons have been employed by generations of archaeologists using the Munsell color system ([Munsell 1915](#_ENREF_64)). Discussions of cultural transmission and ceramic production were advanced by [Frankel (1994)](#_ENREF_32), who developed a systematic means of identifying trends in Red Polished wares from the Early and Middle Cypriot Bronze Age. Comparisons of color attributes were used by [Beck et al. (2016)](#_ENREF_7) to identify diagnostic ceramic traits in the American Southwest, which [McGrath, Beck, and Hill (2017)](#_ENREF_62) later expanded to include the CIE Lab color space. [D'Andrade and Romney (2003)](#_ENREF_18) developed a quantitative approach to analyzing the Munsell color space that [Ruck and Brown (2015)](#_ENREF_77) later built upon to analyze ceramic slip color. Through debitage analyses, color has also been used to link specific tools with specific flakes ([Weber 2016](#_ENREF_85)), and color also has utility in characterizing heat treatment/s ([Fields and Gadus 2012](#_ENREF_30); [Quigg et al. 2014](#_ENREF_70); [Gadus, Fields, and Kibler 2006](#_ENREF_35); [Hall 1994](#_ENREF_43)). 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.

*Nodule size and mechanical flaking properties*

Nodule size has been advanced as a source of morphological variation in stone tools ([Ashton and McNabb 1994](#_ENREF_5); [Eren et al. 2014](#_ENREF_29); [Hurst et al. 2014](#_ENREF_48); [Bradbury and Franklin 2016](#_ENREF_11); [Shott and Sillitoe 2004](#_ENREF_83)), providing evidence for lithic transportation ([Finkel and Gopher 2018](#_ENREF_31); [Ditchfield and Reynen 2022](#_ENREF_23); [Ditchfield 2016](#_ENREF_22)), while limiting the maximum size of the implement. [Eren et al. (2014:473)](#_ENREF_29) considered nodule size to be an external property “of the initial nodule, block, or blank from which flakes are struck”. [Douglass et al. (2021:9)](#_ENREF_24) argue that “nodule size is a major determinant of assemblage variability and can affect the performance of different lithic indices,” and developed a method that requires as few as 100 cortical fragments to estimate nodule size for cortical cobbles. That method has been used to calculate the Cortex Ratio ([Dibble et al. 2005](#_ENREF_21)), a metric that can provide inference to patterns of movement and technological behavior ([Lin, McPherron, and Dibble 2015](#_ENREF_59)) used in arguments for differential mobility and land use ([Davies et al. 2022](#_ENREF_19); [Dibble et al. 2012](#_ENREF_20); [Douglass and Holdaway 2011](#_ENREF_25)).

Mechanical flaking properties have been advanced in discussions of raw material quality ([Whittaker 1994](#_ENREF_87)), which is also thought to impact the resulting morphology of the final product (for a more thorough review, see [Eren et al. 2011](#_ENREF_28); [Eren et al. 2014](#_ENREF_29)). Advanced by some as drivers of function as well as lithic morphology ([Jones 1979](#_ENREF_51), [1981](#_ENREF_52); [Goodman 1944](#_ENREF_39)), mechanical flaking properties, or the internal properties of lithic raw material ([Eren et al. 2014:473](#_ENREF_29)), have been thought to hamper lithic design by reducing the predictability and consistency of large flake and flake element removals ([Brantingham et al. 2000](#_ENREF_12)), imposing what others have interpreted as a serious technological challenge to lithic production ([Andrefsky Jr. 1994](#_ENREF_4); [Crabtree 1964](#_ENREF_17); [Kuhn 1995](#_ENREF_57)).

*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), are thought to be synchronous, and no additional provenience information was provided. Of the 35 bifaces reportedly acquired by TARL, 18 could be located, and 13 of those are complete.

**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), and where solid gray lines indicate geographic borders delimiting Arkansas, Louisiana, Oklahoma, and Texas (top); and seriation of Allen Phase burial contexts derived from Kleinschmidt (1982), for which the sequence runs from bottom to top, illustrating 41AN13 as the earliest Allen Phase site and 41AN21 as the latest.**

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](#_ENREF_80)), an assumption also made for Gahagan bifaces from the ancestral Caddo region ([Selden Jr., Dockall, and Dubied 2020](#_ENREF_81); [Selden Jr., Dockall, and Shafer 2018](#_ENREF_82)), the elliptical bifaces are thought to have been imported by the Caddo through trade and/or exchange. Due both to their size and the colors that the elliptical bifaces fluoresce when examined beneath high and low frequency ultraviolet light (orange-amber), all bifaces are thought to have been manufactured using Edwards chert ([Hofman, Todd, and Collins 1991](#_ENREF_46); [Hillsman 1992](#_ENREF_44); [Reitze, Sinkovec, and Huckell 2012](#_ENREF_72); [Hofman 1990](#_ENREF_45); [Gonzalez et al. 2014](#_ENREF_37)). This study asks whether raw material color was a determining factor that impacted elliptical biface morphology.

Temporally, 41AN13 is thought to be the earliest of the five sites—others include 41AN21, 41AN26, 41CE6, and 41CE12—that [Kleinschmidt (1982:213-220)](#_ENREF_56) analyzed when he built upon the work of [Cole (1975)](#_ENREF_14) to propose the Allen Phase in northeast Texas. The single radiocarbon date from 41AN21 was recalibrated, and articulates with the end of this series ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)). Pulling directly from Kleinschmidt’s (1982:220) Cemetery Data and Tentative Chronology table, a new seriation was assembled for the five Allen Phase sites (Figure 1, bottom) ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)). 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) ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)).

METHODS AND RESULTS

The 13 whole/complete elliptical bifaces from 41AN13 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 ([Weller and Westneat 2019](#_ENREF_86); [R Core Development Team 2023](#_ENREF_71)). A histogram binning method was used to group similar colors, and pairwise distances between histograms were computed using earth mover’s distance (Figure 2) ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)), yielding three distinct raw material color groups (Figure 2, bottom) ([Rubner and Tomasi 2001](#_ENREF_76)).

**Figure 2. Color binning process for a single object; adapted from** [Weller and Westneat (2019:Figure 2)](#_ENREF_86)**. In a, image of a Perdiz arrow point with a transparent background; b, 3D scatterplot of 10,000 non-background pixels in RGB color space; c, clusters from the histogram in b displayed in RGB color space; and d, histogram showing the proportion of non-background pixels assigned to each of eight bins. In the matrix at bottom, dark pink corresponds to bifaces that express the greatest differences in color, while those in dark blue correspond to bifaces with the greatest similarities, with ColorGroup A is highlighted in gray, and ColorGroup B in orange.**

Since one cluster included only a single biface (81), it was dropped from the analysis, and the remaining bifaces were coded as ColorGroup A (Figure 2, bottom, gray) and ColorGroup B (Figure 2, bottom, orange) for the analysis of elliptical biface morphology. By not splitting the clusters further, raw material color group assignments allow for shifts in raw material tint that articulate with patination known to occur on Edwards chert ([Frederick et al. 1994](#_ENREF_33)). The distance matrix was subsequently exported for a permutational multivariate analysis of variance in the vegan package to evaluate whether elliptical biface colors differ between the two color groups (permutations = 10,000; Rsq = 0.60308; Pr(>F) = 0.0011) ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)), and non-metric multidimensional scaling (NMDS) was used to illustrate the differences in color space for elliptical bifaces from each raw material color group (Figure 3, top) ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)).

*Geometric morphometrics*

Prior to landmarking (Figure 3, bottom left), 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](#_ENREF_66); [R Core Development Team 2023](#_ENREF_71)). 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)](#_ENREF_63). That approach employs counts of flake scars from both sides 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](#_ENREF_10); [Gunz, Mitteroecker, and Bookstein 2005](#_ENREF_42); [Kendall 1981](#_ENREF_53), [1984](#_ENREF_54)), achieved through generalized Procrustes superimposition ([Bookstein 1986](#_ENREF_8); [Rohlf and Slice 1990](#_ENREF_75); [Rohlf 1999](#_ENREF_73)) in R using the geomorph and RRPP packages ([Adams and Collyer 2015](#_ENREF_1); [Collyer and Adams 2018](#_ENREF_15); [Adams and Otárola-Castillo 2013](#_ENREF_2); [Baken et al. 2021](#_ENREF_6)). 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](#_ENREF_13); [Dryden and Mardia 1998](#_ENREF_27); [Gower 1975](#_ENREF_40); [Rohlf and Slice 1990](#_ENREF_75)). 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](#_ENREF_26); [Kent and Mardia 2001](#_ENREF_55); [Rohlf 1999](#_ENREF_73); [Slice 2001](#_ENREF_84)).

Principal components analysis ([Jolliffe 2002](#_ENREF_50)) was used to visualize shape variation among the elliptical bifaces, and the scatterplot represents the dispersion of shapes in tangent space (Figure 3, bottom) ([Adams, Rohlf, and Slice 2013](#_ENREF_3); [Bookstein 1991](#_ENREF_9); [O'Higgins and Jones 1998](#_ENREF_65); [Rohlf and Marcus 1993](#_ENREF_74)). To assess whether elliptical biface shape and size differed by raw material color group, Procrustes ANOVAs ([Goodall 1991](#_ENREF_38)) were run that enlist effect-sizes (zscores) computed as standard deviates of the generated sampling distributions ([Collyer, Sekora, and Adams 2015](#_ENREF_16)). A residual randomization permutation procedure (RRPP; n = 10,000 permutations) was used for all Procrustes ANOVAs ([Adams and Collyer 2015](#_ENREF_1); [Collyer and Adams 2018](#_ENREF_15)). 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 ([Supplementary Materials](https://seldenlab.github.io/elliptical.bifaces.1/)).

**Figure 3. NMDS summarizing color variation in elliptical bifaces in color space, where ColorGroup A is depicted in gray, and ColorGroup B in orange (top); position of the three landmarks (red) where semilandmark curves were placed between (bottom left), and PCA summarizing shape variation in elliptical bifaces in morphospace, where ColorGroup A is depicted by gray circles and ColorGroup B by orange plus signs (bottom right).**

DISCUSSION AND CONCLUSION

Results clearly demonstrate that two discrete elliptical biface color groups articulate with two distinct shapes, and regardless of whether or not the two groups differ in geochemistry, these findings advance a previously unreported Caddo preference related to raw material color and local lithic technology. The raw material used in the manufacture of elliptical bifaces is thought to be the same (Edwards chert), thus nodule size and mechanical flaking properties are not thought to differ; rather, color is advanced as the driver of elliptical biface shape. Thus, in terms of lithic technological organization, these findings demonstrate that elliptical biface shape was conditioned by raw material color, where one group is comparatively slimmer and browner, while the other is wider and grayer. This study provides evidence for two discrete, contemporary, and sympatric Caddo knapping communities delimited by macroscopic production attributes, and posits differential production-based intention among Caddo knappers.

In terms of function, elliptical bifaces may have occupied a ceremonial role in the Serpent/Snake Dance ([Howard 1955](#_ENREF_47)), in which symbolic implements were heralded to convey elements of the lower world ([Gadus 2013](#_ENREF_34)). Similar bifaces are depicted in a shell cup recovered from the Craig Mound at Spiro ([Phillips and Brown 1978-1984](#_ENREF_69)), where both Hero Twins can be seen grasping an elliptical biface (Figure 4). 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, or groups of snakes. 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 the snakes. Experimental use-wear studies may aid in clarifying whether or not elliptical bifaces were employed for such tasks.

**Figure 4. 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)](#_ENREF_69)**.**

AUTHOR DECLARATIONS

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CONFLICTS OF INTERESTS/COMPETING INTERESTS

The author declares no conflict of interest.

ETHICS APPROVAL/DECLARATIONS

Not applicable.

CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

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](#_ENREF_58)). 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 ([Gray and Marwick 2019](#_ENREF_41); [Peng 2011](#_ENREF_68); [Gandrud 2014](#_ENREF_36)), 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 ([Marwick 2016](#_ENREF_60); Ivanovaitė et al. 2019; [Selden Jr., Dockall, and Shafer 2018](#_ENREF_82); [Selden Jr., Dockall, and Dubied 2020](#_ENREF_81); [Selden Jr. et al. 2021](#_ENREF_80); [Selden Jr. 2023](#_ENREF_78); [Selden Jr. and Dockall 2023](#_ENREF_79)), and the next generation of archaeologists are learning those tools and methods needed to reproduce and/or replicate research results ([Marwick et al. 2019](#_ENREF_61)). 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](#_ENREF_67)).

AUTHOR CONTRIBUTIONS

Not applicable—single authored paper.

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