To determine the origin of the perforations in the Petersfels Glycymeris shells, whether they were caused by abrasion or occurred naturally, we employed a rigorous analytical approach. We conducted a comprehensive 2D shape analysis complemented by metric measurements and multivariate statistical methods. Our study utilized a Hirox HRX-01 3D digital microscope set at a consistent 20X magnification. This enabled us to capture both experimentally abraded perforations and intact or nearly complete archaeological ones. Additionally, we included a set of shells with naturally occurring perforations to compare and analyze metric and shape variations among the three groups.

For the shape analysis, we applied Elliptic Fourier Analysis (EFA) (Rohlf, 1990) to the 2D outlines of the perforations, extracted from high-resolution images using *DiaOutline* software (Wishkerman & Hamilton, 2018). The raw 2D coordinates were processed and analyzed in R (Posit team, 2023; R Core team, 2023) using the *Momocs* package (Bonhomme *et al.*, 2014), following standard procedures (Falcucci *et al.*, 2024; Leplongeon *et al.*, 2020; Matzig *et al.*, 2021). Before EFA, we standardized the outlines by centering, scaling, and rotating them. EFA was performed with harmonics capturing 99.9% of cumulative harmonic power (n = 56). Subsequently, we conducted Principal Component Analysis (PCA) to explore shape variability across the dataset, categorizing perforations into archaeological, experimental, and natural groups.

To investigate the relationship between size and shape, we conducted another PCA using the main Principal Components (PCs) derived from the 2DGM analysis (n = 3), along with area (in mm²) and diameter (in mm) measurements obtained from the 3D digital microscope. We further assessed inter-group variability through non-parametric MANOVA (PERMANOVA) with 10,000 permutations, using the vegan package (Oksanen *et al.*, 2022) and *pairwiseAdonis* for Euclidean distance calculations (Martinez Arbizu, 2017). Finally, to quantify morphological and metric variations across archaeological, experimental, and natural perforations, we conducted disparity tests (Guillerme, 2018), bootstrapping the PCA data 1,000 times as per Matzig *et al.* (2021).

This approach allowed us to document the area and circumference of the holes. To compare the morphology of the holes, we divided the perforations into four quadrants and took four measurements (ray and diameter, in mm). Since the holes are rarely perfectly round, the center was determined at the intersection of the lines calculated at the maximum length and maximum height of each hole. (Fig. X and Tab.).

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