# A QUANTITATIVE ASSESSMENT OF PERCUSSION-INDUCED MODIFICATION TO BONE SURFACES

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## RESEARCH QUESTION

Can variations in 3-D micromorphological features discriminate between the anvil and hammerstone percussion marks on bone and the raw material of the hammerstone?

## BACKGROUND

The presence of percussion marks on faunal remains demonstrates that hominins used a hammerstone-on-anvil technique to process animal carcasses with the intention of extracting and consuming fat-rich bone marrow. The analysis of such marks holds important implications for both the evolution of stone tool technologies, as well as hominin encephalization, which roughly coincides with the appearance of percussion marks in the archaeological record [1,2]. Zooarchaeologists have typically utilized low-power hand lenses or 2-D microscopic techniques to discern percussion marks on faunal remains [2,3], but these methods are difficult to reproduce between researchers and are limited in the behavioral inferences they can produce [4]. Here, we provide a new approach that applies high-resolution 3-D scanning to identify the unique characteristics and quantify the micromorphology of percussion marks inflicted on limb bones.

## METHODS

- Experimental percussion marks were produced by MCP with raw materials from Olduvai Gorge, Tanzania using a hammerstone-on-anvil technique controlling for animal species, bone type, and raw material of the lithics used to break the bones [5].
- 3-D reconstructions of percussion marks were produced using a Nanovea ® ST400 white-light confocal profilometer.
- Percussion marks were processed and measured using Digital Surf's Mountains® software.

| Tool Type | | 3-D MEASUREMENTS | | | | | | PROFILE MEASUREMENTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SURFACE AREA (µm²) | VOLUME (µm³) | MAX DEPTH (µm) | MEAN DEPTH (µm) | MAX LENGTH (µm) | MAX WIDTH (µm) | MAX DEPTH (µm) | AREA (µm²) | WIDTH (µm) | ROUGHNESS ($R_a$) | ANGLE (°) | RADIUS (µm) |
| ANVIL | Mean | 8852865.7 | 891098390666.7 | 563.8 | 212.8 | 4603.9 | 2628.8 | 494.1 | 1315098.6 | 3781.0 | 17.2 | 140.2 | 7396.3 |
| | Median | 6387949.7 | 1090000000.0 | 476.3 | 181.9 | 3450.3 | 2840.2 | 398.1 | 435078.8 | 2860.0 | 16.8 | 144.8 | 2673.6 |
| | Standard Deviation | 8875084.6 | 3443886249967.5 | 386.4 | 134.1 | 3463.9 | 929.5 | 331.6 | 2303604.6 | 3625.7 | 8.3 | 36.6 | 10071.2 |
| HAMMERSTONE | Mean | 5832391.7 | 1186666551.7 | 540.9 | 182.9 | 4746.5 | 1893.6 | 469.2 | 1221554.8 | 4166.9 | 14.0 | 151.5 | 22326.3 |
| | Median | 4573099.8 | 802300000.0 | 387.1 | 145.4 | 4199.1 | 1712.2 | 330.2 | 627018.8 | 3600.0 | 10.5 | 154.7 | 5711.7 |
| | Standard Deviation | 4636507.4 | 1541566529.9 | 384.0 | 104.6 | 2577.8 | 746.4 | 345.2 | 2047950.9 | 2468.4 | 11.7 | 18.7 | 49030.0 |
| *p-value (Mann-Whitney)* | | 0.17 | 0.29 | 0.67 | 0.37 | 0.36 | <0.01* | 0.54 | 0.44 | 0.11 | 0.10 | 0.29 | 0.17 |

Table 1) Mean, median, and standard deviation for anvil and hammerstone percussion marks. Mann-Whitney test used due to non-parametric distribution. * indicates statistical significance.

| Raw Material | | 3-D MEASUREMENTS | | | | | | PROFILE MEASUREMENTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SURFACE AREA (µm²) | VOLUME (µm³) | MAX DEPTH (µm) | MEAN DEPTH (µm) | MAX LENGTH (µm) | MAX WIDTH (µm) | MAX DEPTH (µm) | AREA (µm²) | WIDTH (µm) | ROUGHNESS ($R_a$) | ANGLE (°) | RADIUS (µm) |
| QUARTZITE | Mean | 6186911.5 | 1004257142.9 | 443.6 | 181.0 | 4812.1 | 1802.4 | 372.2 | 698627.5 | 4069.3 | 11.3 | 156.4 | 36672.4 |
| | Median | 4338299.8 | 866200000.0 | 377.0 | 145.1 | 4123.3 | 1682.9 | 319.9 | 612136.5 | 3800.0 | 9.1 | 155.2 | 9163.7 |
| | Standard Deviation | 4770735.5 | 743998481.9 | 271.4 | 106.2 | 1714.6 | 707.8 | 244.0 | 485087.6 | 1379.6 | 6.0 | 16.4 | 68172.8 |
| BASALT | Mean | 5501506.5 | 1356915333.3 | 631.8 | 184.6 | 4685.4 | 1978.6 | 559.8 | 1709620.2 | 4258.0 | 16.5 | 147.0 | 8936.5 |
| | Median | 4727862.3 | 802300000.0 | 507.8 | 177.5 | 4622.2 | 1744.1 | 408.4 | 1250881.3 | 3600.0 | 12.4 | 147.5 | 4755.5 |
| | Standard Deviation | 4649430.5 | 2043166890.7 | 456.3 | 106.7 | 3248.5 | 795.6 | 406.0 | 2764240.9 | 3225.0 | 15.1 | 20.1 | 9716.7 |
| *p-value (Mann-Whitney)* | | 0.63 | 0.71 | 0.45 | 0.98 | 0.47 | 0.50 | 0.31 | 0.68 | 0.71 | 0.37 | 0.12 | 0.13 |

Table 2) Mean, median, and standard deviation for basalt and quartzite hammerstone percussion marks. Mann-Whitney test used due to non-parametric distribution.

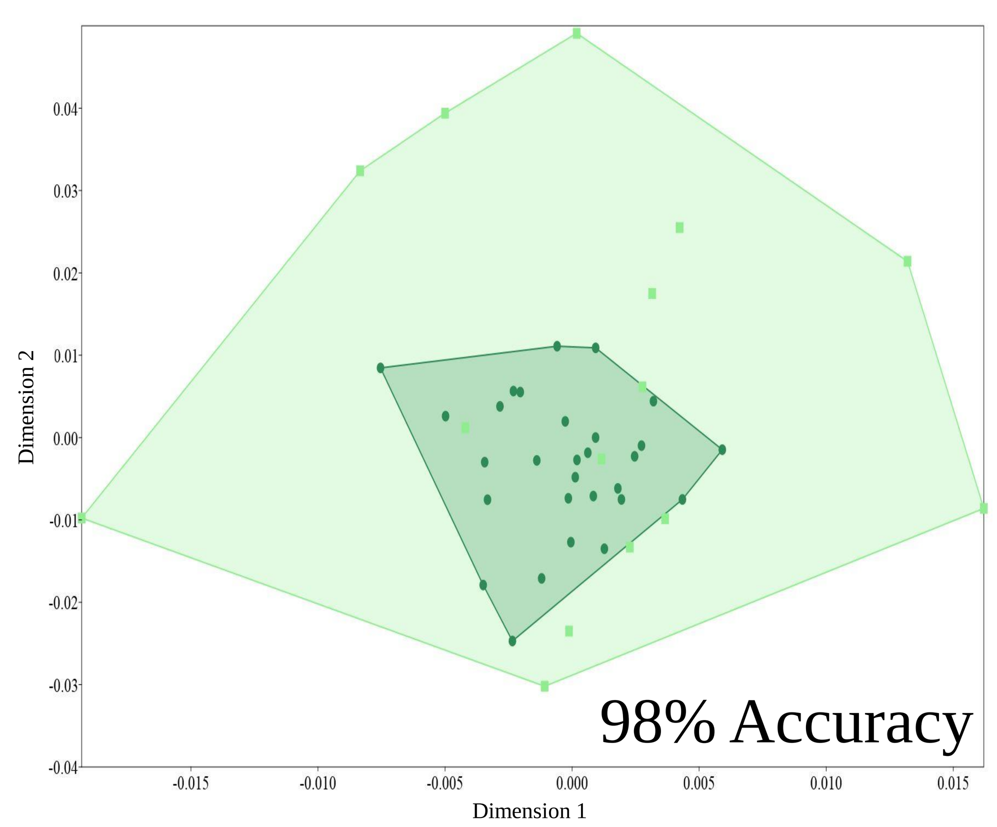


Figure 1) Discriminant analysis of anvil and hammerstone percussion marks. Light green represents marks made by the anvil. Dark green represents marks made by the hammerstone.

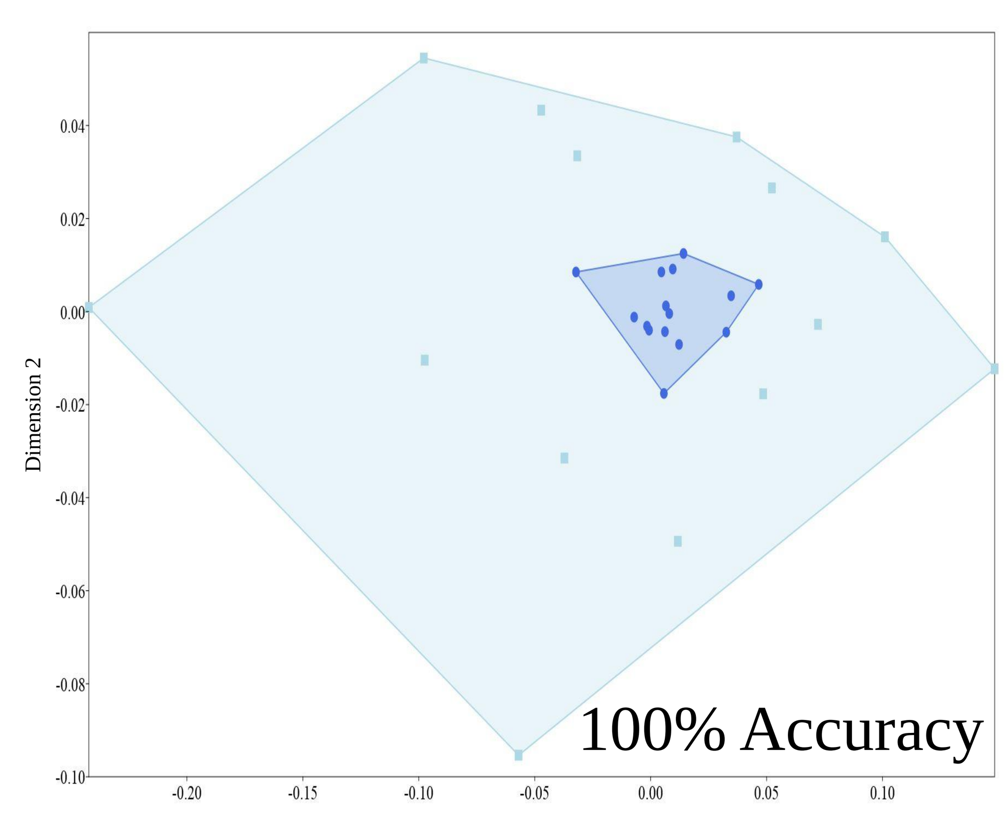


Figure 3) Discriminant analysis of percussion marks produced by basalt and quartzite hammerstones. Light blue represents marks made by the quartzite hammerstone. Dark blue represents marks made by the basalt hammerstone.

## DISCUSSION AND CONCLUSIONS

- Quadratic discriminate analysis was capable of distinguishing between percussion marks produced by the anvil and hammerstone with 98% accuracy and between percussion marks produced by basalt and quartzite hammerstones with 100% accuracy.
- Future research will increase the size and diversity of the sample to include a broader array of animal species, bone types, and raw materials. When applied to the fossil record, this experimental database may allow percussion marks to be identified and analyzed with greater accuracy, which would provide a better understanding of hominin behavior and evolution during the Early Stone Age.

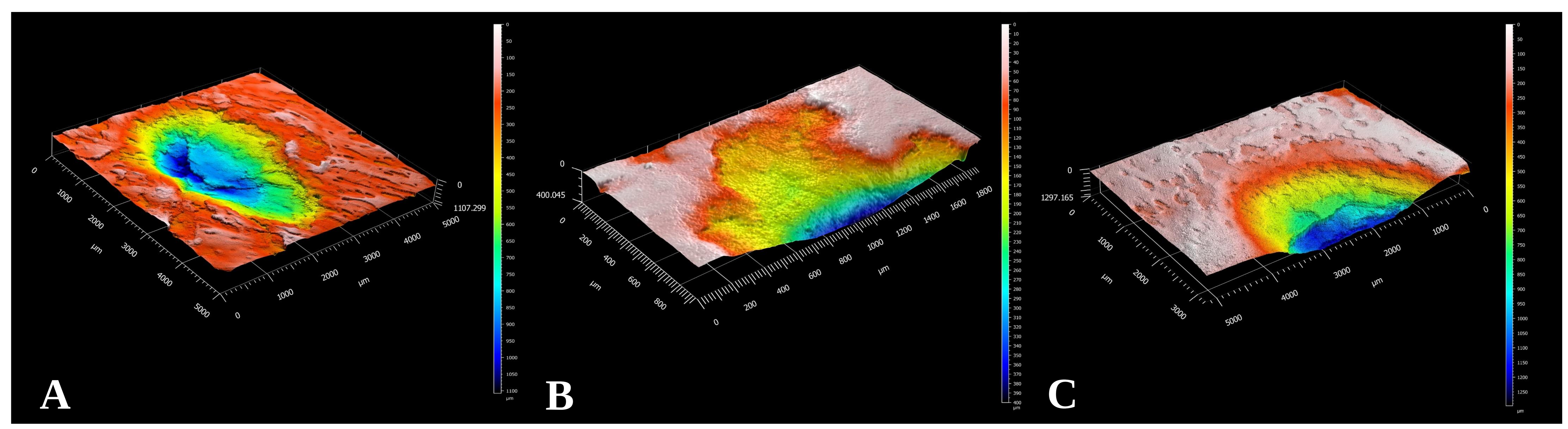


Figure 2) 3-D images of percussion marks. Image A is an anvil mark. Image B is a basalt hammerstone mark and the only mark to be misclassified as an anvil mark. Image C is a quartzite hammerstone mark.

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