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Determining the Reduction Sequence of Hawaiian Quadrangular Adzes using 3D Approaches: A case study from Moloka‘i

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Abstract

Hawaiian adze manufacture requires a great deal of skill and undoubtedly required long apprenticeships to achieve the finesse seen in many finished prehistoric adzes. Despite the presence of more than two dozen adze quarries in Hawai‘i and previous attempts at replicating adze preforms and positing reduction sequences in Polynesia, there is no detailed study that clearly defines the steps and stages of quadrangular adze preform manufacture (the most common form in Hawai‘i), and the resulting characteristic debitage. In this paper we examine the sequence of adze production for a population of 109 adzes from Moloka‘i, documenting the transition from blanks to preforms to the finished objects that were transported away from quarries. Reduction intensity is measured using the Scar Density Index (Clarkson 2013) calculated from 3D scans. We document the sequence of cumulative additions of characteristic features to adzes (e.g. bidirectional edges, bevel, poll and tang) as reduction intensity increases. We also note the reasons for adze rejection at each stage of reduction. Our study provides the first detailed analysis of adze reduction in Polynesia facilitated and standardised by 3D scanning technology. Hopefully, it will serve as a useful benchmark for objectively and systematically comparing adze technology in other parts of Hawai‘i and across Polynesia, leading to a better understanding of regional and temporal variation in adze technology.

Introduction

Hawaiian quadrangular adzes are among the most difficult stone technologies to reproduce in the world, requiring precise bidirectional flaking of four right-angled edges and creating flat faces on tough volcanic fine-grained basalt. These are requirements that defy novice knappers and push the possibilities of direct percussion knapping to the limits. The extremely refined examples of prehistoric Hawaiian adzes indicate very high levels of skill and suggest long apprenticeships were required to attain these skills. Cleghorn (1982, 1986) stated that master craftsmen and apprentices worked different parts of the huge ~20 km^2 Mauna Kea adze quarry complex on Hawaiʻi Island (McCoy 1977, 1990, et al. 2012) and that high quality basalt outcrops were restricted for use by master knappers. The high levels of skill, huge quantities of debris and restricted use of valued and difficult to access sources (such as the barren, high altitude quarries on Mauna Kea above 3500 m), point to at least part-time specialists and raise the possibility of state level control of adze manufacture (Bayman et al. 2001; Cleghorn 1986; Hommon 2013:107-109; McCoy 1977).

Unfortunately, little early ethnography exists detailing the methods, tools or cultural practices of master adze makers in Hawaiʻi (Malo 1951:51). For this reason experimental replication of adzes is essential to model the stages from raw material selection to finished adze, to reconstruct manufacturing techniques, to better understand the technological problems encountered, as well as to identify the characteristic debitage produced. Cleghorn (1982) replicated 10 quadrangular adze preforms to model reduction strategies at the Mauna Kea adze quarry, while Williams (1989) used the resulting debitage to link characteristic flakes to specific stages of reduction. Turner (1992, 2000, 2005:58-60; Turner and Bonica 1994) conducted extensive replication experiments with her craftsman-colleague Dante Bonica in New Zealand using basalt and argillite (a highly indurated mudstone). Because New Zealand adzes made from these materials display a huge variety of types (with varying cross section forms, reduced butts, lugs, etc) and include hammer-dressing which is not used in Hawaiʻi, the reduction models for these adzes are not considered here further. A similar situation holds true for Samoa, where replication and technological studies identified at least four blank types to make a broad range of adzes (Leach and Witter 1987).

There have been several technological studies of Hawaiian adze manufacture using quarry assemblages (Bayman and Moniz-Nakamura 2001; Cleghorn 1982; Dixon et al. 1994; Dye et al. 1985; Kahn et al. 2008; McCoy et al. 1993; Mintmier 2007; Weisler 1990, et al. 2013, in press; Williams 1989). Many of these studies lament the difficulty of clearly defining adze blanks and preforms so they can be objectively separated prior to analysis. In this regard, Dye *et al.* (1985: 11) defined a stage between the blank and preform called a ‘preform?’. However, McCoy *et al.* (1993: 123-124), questioning the usefulness of the blank-preform continuum, suggested using a ‘techno-morphological’ approach that proposed four ‘types’ where Type 1 was the least refined and Type 4 was a preform. Criteria used to separate his types were based largely on distinguishing the front, back and sides, as well as discerning regular profiles along the length and midpoint width. No matter how many stages are suggested, it still requires that each stage be clearly and objectively defined—and that similar technological attributes are reported (Weisler 1990:39)—so other researchers can replicate a typical study. The lack of consensus in clearly defining stages along the blank-preform continuum has hindered archipelago-wide comparisons of adze production and estimates of output. The absence of an objective measure of reduction continuums has also precluded opportunities for comparing skill levels within and between quarries. For example, are there areas within a quarry where there is a high percentage of early stage rejects, implying low levels of skill (see also Cleghorn 1986)? Once clear and objective criteria for separating the steps in adze production are determined, it should then be possible to identify intra-site spatial variability in the stages of production.

Here we present for the first time a study of changing Hawaiian quadrangular adze morphology as reduction progresses, from blank to preform to completed adze. We focus on the quadrangular adze as it was the overwhelmingly dominant type throughout prehistory (Cleghorn 1992), although trapezoidal, circular and triangular adzes have also been documented. We use 3D scans of adzes to facilitate the objective capture of variation in shape and surface area that aids in the definition of stages. We examine quadrangular adze manufacture in relation to increasing reduction intensity using a measure of reduction called the Scar Density Index (SDI) that is suited to nucleii such as cores and bifaces. The index is further described below and in detail in Clarkson (2013).

For this study we analysed a sample of 109 complete and broken blanks, preforms and finished adzes, encompassing the manufacturing continuum. These were mostly collected from three quarries on Molokaiʻi: Kaʻa (N = 15), Kaʻeo (N = 63) and Kealapūpūakiha (N = 5) (Weisler 2011), shown in Figure 1. Complete adzes and preforms were obtained from private collections with known Molokaʻi provenance and surface sites across the island (N = 4), as well as local collections donated to the Molokaʻi Museum (N = 17).

The Sites

The three archaeological sites sampled in this study are described in detail by Weisler (2011). Relevant information is summarised below.

Kaʻeo Complex

Two hills, the highest at 178m asl, sit either side of an un-named gulch that drains west into the bay at Kawākiu Nui. The hills are late-stage cinder and spatter cones, the eastern one of which has a flow of dense, fine-grained rock on its western slopes and immediately east of the drainage that was first reported by Stearns and Macdonald (1947: 25; Summers 1971: 45). The raw material consists of rounded to sub-angular cobbles and boulders up to 80cm in diameter; most rocks, however, range from 30 to 40cm. This main quarry area (State of Hawaiʻi site number, 50-60-01-32) consists of two low stone-faced terraces at the north end of the flow with dense concentrations of debitage and adze blanks and preforms (Weisler 2011:Plate 2, Figure 3). Immediately south of the stone-working area, the land slopes more steeply to the west where stone-faced earthen terraces (for habitation and gardening) check the slope that descends into level land with numerous stone piles and other gardening modifications just above the drainage. There is a clear separation of activity areas with adze manufacturing at the north end of the site and habitation and gardening along the southern half. A test pit in the northern adze-making area revealed extremely dense debitage to 30cm below the surface, while two test pits in terraces within the southern extent confirmed habitation functions including a hearth and sparse food remains. Within the larger complex there is a substantial gardening enclosure, three C-shaped habitation shelters atop the hill, and several isolated outcrops with debitage.

Kaʻa

Like Kaʻeo, Kaʻa is a late stage cinder cone; it has a small plug of dense basalt in the north end (Stearns and Macdonald 1947: 25, plate 1) that was used for adze manufacture (50-60-01-806). At 200m asl, there are commanding views from the summit of Kaʻa along the north coast past the Kalaupapa (Makanalua) peninsula and across the Hoʻolehua plain. Near the top of the level summit, on the east side, is a shrine with an upright elongate stone, associated with a flat slab that may have served to hold offerings. About 75m west is a low shelter associated with debitage, adze blanks and preforms, and a single hammerstone, all scattered over an area ~200m^2.

Kealapūpūakiha

There is a dense layer of basalt exposed just above the rocky shore where the medium-grained rock forms a scree down-slope (50-60-01-100). Only a few adze blanks and flakes of this material are found around the habitation complex situated along the cliff edge.

Adze Terminology and Reduction Stages

Best (1912) was the first to recognise the need for standardised terminology when describing stone adzes, and, after the publication of several area-specific studies with slightly different terminologies (e.g., Emory 1924:78-79; Hiroa 1927:213-220), Buck (et al. 1930) defined terminology that is widely used today and adopted here. Hawaiian adzes are typically elongate flaked stones made from basalt flakes, tabular clasts, or sub-rounded cobbles and small boulders. They display a range of characteristic features, as illustrated in Figure 2. The main divisions of the adze are the front, back, blade, bevel and butt. The distal margin of the bevel is the cutting edge of the adze and is usually flaked then ground. The bevel is typically fashioned on the back of the adze and is asymmetrical when viewed from the side (Figure 2). The butt includes the tang and the poll and slopes downward on the front face on tanged adzes, or is straight (parallel to the back) in untanged forms. The front face of the butt is usually flat, whereas the back face may be slightly concave or flat. The poll is a flat surface at the end of the adze. The tang begins at the intersection between the blade and the butt and is formed by reducing the butt on the front face, often creating a distinct ridge at the point of intersection between the butt and the blade. The tang is a hafting innovation unique to East Polynesia.

Our observations of quadrangular Hawaiian adzes indicated that all examples examined could be classified into two morphological groups (square-sectioned and rectangular-sectioned), defined according to cross-sectional shape at the midpoint along the length, as well as a third group referred to here as a ‘micro-adze’ on account of its small size and less standardised reduction trajectory. These groups are further defined below.

Square-Sectioned Adzes

These are typically large and robust adzes with the best examples displaying very skilful squaring of all four sides and neat, acute bidirectional edging. They are literally ‘square’ in cross-section, over most of their length, hence the name we apply to this type. They also tend to be parallel-sided along their length when viewed from above, unlike rectangular-sectioned adzes that often expand towards the cutting edge (Figure 3A; Cleghorn 1992:140). The tangs on square-sectioned adzes tended to be more pronounced than the rectangular-sectioned ones. Emory referred to these adzes as ‘a narrow, heavy, pick-like adz’ (1924:78), while Weisler (1990:41, Figure 5) defined these adzes as having a thickness >50% of the width, as taken at the midpoint along the length.

The impression gained from the robust cross-section, large size, and pronounced tang, is that these were heavy duty chopping tools and the square section was intended to add strength through resistance to end-shock, and perhaps also a narrower bit. We hypothesize these adzes may have been used in tree-felling and heavy duty shaping of trunks and slabs (see also Best 1977). Complete examples of these adzes all exhibit a well-formed bevel, poll, tang and butt, and fully invasive flaking on all surfaces. Grinding can be extensive, but is minimal on very well-flaked adzes that lack humps or protruding sections (e.g. Figure 3A).

Rectangular-Sectioned Adzes

These adzes have a considerably greater width to thickness ratio than square-sectioned adzes with a characteristic rectangular cross-section (Figure 3C). Rectangular-sectioned adzes also expand slightly along their length, with a wider blade than butt, and their tangs tend not to be as pronounced as the square sectioned adzes. The rectangular adzes were intended to have a broader blade than square-sectioned adzes, and are perhaps not quite as robust and as well-suited to very heavy chopping tasks as their thinner blade would make them more vulnerable to end shock. The broad blade would have suited intensive, fine adzing tasks, rather than heavy duty chopping. Such hypotheses require experimental testing with faithful replicas (Best 1977).

Micro-Adzes

These adzes tend to weigh less than 300g and can be very small. They exhibit greater variation in production technique and refinement than the larger adzes. Micro-adzes display the same constellation of morphological features as the larger adzes; however, they tend to be rectangular in cross-section and can be very thin. Generally these micro-adzes are made from small flakes with the unretouched ventral surface forming the front of the adze (Flake 3B). The shaping is not as precise or refined as for the larger adzes with often unidirectional flaking of the sides using the ventral surface of the flake as a platform. The back of microadzes is often quite irregular and concave along its length, and may lack 90 degree edge angles as a result of the unidirectional flaking. The tang is often created by removing a series of flakes from the butt of the adze, while the poll is usually not as well formed as for the larger adzes. Imperfections tended to be removed and overall shape obtained by grinding on microadzes, whereas more precise flaking and less non-bevel grinding are evident in the larger adzes.

The distinctiveness of the two large adze cross-sections is confirmed metrically by plotting histograms of width/thickness for each type for complete adzes. There is a clear separation in width/thickness values for each type, indicating that two discrete populations exist rather than a continuum in shape variation. Interestingly, there is also a third mode, seen to the right of the histogram for rectangular adzes (Figure 4). This suggests a third group of adzes exists that are very thin relative to width. We have not identified this population as a separate type, as they are still rectangular in cross-section; however, it seems the upper peak represents the combined contribution of the rectangular and micro-adzes.

Reduction Stages

The reduction sequence and techniques of Hawaiian adze manufacture were first experimentally tested by Cleghorn (1982). Our own replicative experiments using unmodified fine-grained basalt source rock from the Ka‘eo quarry and local hammerstones are to be published in detail elsewhere. To summarize briefly, our experimental adzes are typically made from large basalt flakes or tabular pieces, first by flaking a 90 degree bidirectional ridge at the intersection of the upper surface and first side. Then anvil resting is used to help generate hinge or step terminations along the lower side of the first edge, to generate platforms with appropriate angles (i.e. <90 degrees) for flaking onto the lower surface, in order to create the second 90 degree bidirectional edge. We use the terms upper and lower surface here as the front and back of the adze may not yet be determined in the earliest stages of production, as noted also by McCoy et al. (1993:123). The same process is repeated on the opposite edge of the upper and lower surfaces.

At the completion of this ‘edging’ stage, a quadrangular shape is achieved, but may not yet display a true square or rectangular cross-section or regular profile. Anvil resting is then used to ‘square the edges’ as the final step in this process, using oblique blows and soft stone hammers to create flat, 90 degree, bidirectional edges. We define a blank as a peice that has attained up to two bidirectional edges and a preform as one that has attained three or more edges. A complete adze preform will have four properly squared edges, a bevel, a finished poll and can be tanged or untanged. Complete adzes are also more likely to display some grinding. We define the cut off blank and preform at three edges as the act of creating the third edge requires the much more difficult process of creating new bidirectional edge on the opposite face, and is a common point of failure in adze manufacture, as further discussed below. Adzes also tend to more readily take on their ‘final shape’ after completion of the third edge.

Mistakes or lumps can be flaked off during the sequence by way of elongate flakes struck from the butt end onto the front, back, or sides at any point in the process (Figure 5). Such ‘flattening flakes’ (recognised in archaeological debitage) also help create suitable platforms for edging as well as to move onto a new face. The reduction process creates distinctive debitage at each stage in terms of technological characteristics and size.

Quadrangular adze reduction is extremely difficult and requires very high levels of skill to achieve the masterpieces of ancient Hawaiians, and large numbers of adzes were broken at all stages of the process–mostly by end shock–as attested by the large quantities of broken blanks and preforms at quarries. Indeed, whole and finely flaked preforms are extremely rare at quarries (see also McCoy et al. 1993:124).

Measuring Adze Reduction

Scanning Methods

Adzes were scanned using a Next Engine 3D laser scanner at resolutions of 1,100 (for larger adzes), or 10,000 (for smaller adzes), dots per inch. Each complete 3D model is made of nine separate scans with the adze rotated 40° on a turntable between each scan. Scanning and processing time is approximately half an hour for each adze. Surface areas were measured in square inches in the program ScanStudio, while the adze illustrations used here were generated from Scan Studio screen shots. Scanning technology has made determinations of specimen surface area, volume and cutting edge angle more accurate and objective (e.g. Weisler et al., 2013).

Scar Density Index (SDI)

The Scar Density Index was proposed by Clarkson (2013) as a standardised and systematic means of determining the extent of flaking on a nucleus, and by Shipton (2011) as a means of determining the extent of flaking on shaped bifaces. It is calculated as the number of flake scars divided by surface area, where flake scar counts omit very small edge trimming flakes (<1cm long) or edge damage, and surface area is accurately determined from the 3D scan. Flake scars are counted manually.

SDI has been shown experimentally to be a robust and widely applicable measure and was tested on a wide range of experimentally reduced cores. It also performed well in an archaeological test case (Clarkson 2013) by showing marked increases in SDI in archaeological layers where reduction was expected to increase.

SDI can also be applied to Hawaiian adze blanks and preforms to assess degree of reduction using exactly the same measurement techniques as described above. This can be demonstrated by examining the relationship between SDI and % mass remaining for five replicated Hawaiian adzes as shown in Figure 6. The scatter plot shows a strong correlation between increasing SDI and decreasing % original mass for the experimental adzes, with an R^2 of 0.967. The sample size is small, but given that Clarkson (2013) earlier demonstrated that the SDI performs well across a wide range of core forms, and that our experimental results corroborate this pattern, we think the SDI is a useful and appropriate measure of reduction for Hawaiian adzes.

Using the criteria adopted above, of treating blanks as those artefacts with two or less bidirectional edges, and preforms as those with three or more bidirectional edges, and completes as unbroken adzes that have all four edges as well as poll, butt, and bevel, we see in Figure 7 that each stage in the process of reduction and refinement equates to significant increases in SDI (ANOVA, df = 2, F = 56.06, p = <0.0005). These stages of production also equate to decreases in mean mass for complete artefacts, from 1742g for blanks, to 717g for preforms, and 638g for completes.

Increasing SDI and decreasing mean mass are changes consistent with the pattern of increasing reduction intensity we would expect to be associated with the continued shaping and refinement of blanks into preforms, and preforms into finished forms. We can examine this process more closely by plotting the SDI against a larger set of technological features that are added over the course of adze manufacture. These are the seven elements listed below, although the numbering used here is not meant to represent the order in which these features were added. We explore that issue separately below.

1. The first edge
2. The second edge
3. The third edge
4. The fourth edge
5. The bevel
6. The tang
7. The poll

Figure 8 shows that the progressive addition of these technological features corresponds to a gradual and continuous increase in SDI. The addition of adze elements also equates to a statistically significant increase in SDI (ANOVA, df = 7, F = 21.966, p = <0.0005)

The Adze Manufacturing Sequence

Bidirectional Edges

The creation of bidirectional edges (i.e. alternate flaking away from ridges) that run the length of the adze is a fundamental requirement for successful adze manufacture, and is the most common way of generating four right angled edges and four flat surfaces on elongate objects such as these. Natural right angles may also be exploited to some degree and hence not every complete adze has four bidirectionally flaked edges (note also that microadzes often did not have four bidirectional edges), but the great majority do. Bidirectional flaking is also usually applied to some degree even to naturally steep edges, probably in order to remove step terminations created from the opposite edges—which at some quarries is a reason for rejection (Kahn et al. 2008:146)—as well as other irregularities, or to create suitable platforms for flaking back across an adjacent surface.

Experiments indicate that the creation of each bidirectional edge is increasingly more difficult than the last. This is because platforms become harder to create and exploit on each new surface, often resulting in failed attempts, heavily stepped edges, lumps, and overshots, with high rates of end shock resulting from attempts to remove intractable lumps, leading ultimately to rejection of the blank or preform. We can explore the gradual addition of bidirectional edges to adzes by plotting the mean number of bidirectional edges found on adzes as reduction increases, as measured using intervals of SDI. Figure 9 plots the results of this test and shows that edges are gradually added to adzes as reduction continues, with three and four edges typically found only at late stages in the reduction sequence. It makes sense, then, to include the number of bidirectional flaked edges, along the length of the specimen, as one criterion to separate the multiple stages along the continuum from blank to preform manufacture. Figure 10 shows the progression of adze form for square and rectangular adzes as SDI increases.

Bevel Formation

The bevel forms the cutting edge of the adze and is often ground on completed specimens. Bevels have a mean angle of 68.5±13.8 degrees. A total of 45 of 109 complete and broken adzes in our sample have a bevel. Broken adzes with a poll (butt fragments) were excluded from this analysis as these naturally would not have a bevel. Our results indicate that bevels can be added very early in the reduction sequence, but are more commonly present at later stages (Figure 11). This is somehwat different to the Nu‘u, Maui adze quarry where bevel formation was considered the last step in quadrangular adze preform manufacture from flake blanks (Kahn et al. 2008:152).

Poll Formation

Much like the previous two characteristics, the poll is increasingly likely to be added at later stages of reduction, as shown in Figure 12. Nevertheless, some adzes exhibit a well-formed poll quite early in the reduction sequence. In most cases the poll appears to be created by deliberately end shocking the preform once the final form is nearly achieved, removing irregular flaking on the end and creating a flat surface (Figure 5C). Further trimming of the poll from the sides or front and back was necessary where the result was not as flat as desired. In some cases, end shocking a small piece from the end of the adze earlier in the sequence was a useful means of creating a steep-angled platform for striking invasive flakes along the faces or sides to flatten the adze (Figure 5D), or create platforms with which to form or improve the bidirectional edges. Almost all late stage adzes have a well-formed poll.

Tang Formation

The tang is an East Polynesian technological innovation that adds extra stability to the adze while in the haft by creating a ridge near the midpoint of the length of the adze that facilities tight diagonal lashing to the haft. Not all finished adzes, however, have tangs. This may relate to adze function or even skill level of the knapper. Like most other features discussed above, the tang is clearly added at mid to late stages in the sequence (Figure 13).

Discard Criteria

The SDI can also be used to examine a number of possible reasons why adzes were discarded at various stages of reduction. These include end shock, as well as failure to create bidirectional edges on new faces (Figure 14). In some cases it is unclear why adze blanks were rejected at quarries, as they are complete and at early stages of reduction with no obvious blemishes, and we have included these as ‘unknown’. We have also included complete adzes that were transported away from quarries, presumably ready for grinding and use. This is useful for determining the stages of reduction at which adze preforms might be deemed ‘finished’.

Figure 15 indicates that the most common reasons for rejection at early stages of reduction are the failure to create second, third and fourth bidirectional edges. This is usually indicated by overshot flaking that has removed the possibility of creating a steep platform for use in forming a subsequent edge. Another common sign of failure to create edges is a short line of heavily stepped retouch, or a battered and rounded ridge on the new edge prior to discard, as these represent failed attempts to strike the invasive flake scars necessary to create a flat adjoining surface. Numerous blanks were also rejected at quarries for unknown reasons – perhaps because they were too thin, or the interior of the raw material was of poor quality (e.g., unseen vesicles, large phenocrysts or minute fracture lines), although a host of other reasons is possible. The reasons for rejection at the middle stages of reduction are typically end shock or failure to create the fourth and final edge. All adzes in the sample with an SDI >3.0 were ‘finished’ and had been removed from quarries.

Discussion

Based on the results presented here we can now propose a new sequence of quadrangular adze preform manufacture with each of four stages clearly and systematically defined along the continuum from blank to finished form ready for grinding. We have found it convenient to define each stage in terms of the number of bidirectional right-angled edges running the length of the specimen, and this system accords well with marked increases in reduction intensity. While some overlap exists in SDI between blanks, preforms and finished adzes, we can nevertheless define six stages in adze manufacture as follows:

Stage 1 Unworked Blank: Raw material in the form of loose tabular pieces, cobbles or sub-rounded boulders is selected. Large flakes might be struck from larger clasts with very large hammerstones, while smaller ones might themselves be flaked into blanks.

Stage 2 Lightly Worked Blanks: A single bidirectional edge is formed on the blank. These early stage blanks typically have an SDI of between 0.01 and 0.5 (mean = 0.48),

Stage 3 Heavily Worked Blanks: These are flakes or cobbles exhibiting two bidirectional edges and an SDI of 0.5 – 1.0 (mean = 0.88),

Stage 4 Preforms: These are well-defined adze preforms with three bidirectional edges and SDI values of 1.0 – 2.0 (mean = 1.8),

Stage 5. Finished Adzes: These are adzes with four properly squared edges, and typically have a bevel, a finished poll and can be tanged or untanged. Finished adzes general have SDI values of 2.0 - >3.0 (mean = 2.8).

Stage 6: Ground Adzes: These are adzes with four properly squared edges, a bevel, a finished poll and tang that have SDI values of 2.0 - >3.0 and exhibit varying levels of grinding on the bevel and/or body of the adze.

We believe these stages will prove useful in analyses of the frequency of various production at quarries or the transport of adzes at various stages of manufacture away from quarries. They will also prove useful where access to 3D scanning is not possible and measurement of continuous variables such as SDI is not possible. It is yet to be determined whether the same adze reduction sequence exists on other Islands in Hawai’i.

In the case of the Scar Density Index (as well as other metric measurements), we believe that the use of scanning technology enhances the ability to obtain values easily and objectively. Recording SDI and the number of bidirectional flaked edges together make it possible to objectively and systematically separate blanks and preforms along the manufacturing continuum. Armed with a reliable measure of reduction intensity we may go to the archaeological record to compare variation within and between quarries and perhaps differential skill levels, and formal organisation of adze production. Importantly, the use of scanners has also created a permanent archive of each specimen in our study. This is an archive that can be utilised by other researchers without accessing the original artefacts. As stone adze quarries are highly visible on the landscape and thus more likely to attract unauthorised artefact collectors, a permanent digital record is one way to ensure long-term, economical access to study collections.

Conclusion

Hawaiian adze manufacture has long been recognised as a highly skilled activity that mostly took place only where high quality raw materials were available. In some cases, ancient Hawaiians went to enormous lengths to procure the best stone available. The degree of skill and the quantity of adze production evident at places such as Mauna Kea, for instance, indicates a very high value was placed on well-made adzes. Some have also raised the possibility of state control over adze production and distribution (e.g. Bayman et al. 2001; Cleghorn 1986; Hommon 2013:107-109; McCoy 1977).

To properly investigate the nature and scale of adze production across the Hawaiian Islands, a robust method for determining the stages of adze production is required. This enables analysts to determine the differential stages of reduction present at quarries and across the landscape or in different site types. Our approach first divided adzes into three types – blanks, preforms and finished adzes according to the number of bidirectional ridges present. We then tested these stages against the SDI as an independent measure of reduction. We found that each type corresponds to a marked increase in reduction intensity. We also found that increasing SDI corresponds with the cumulative addition of key design elements characteristic of completed adzes. Defining and testing the reduction sequence for adzes has allowed us to explore the stages of adze manufacture on three quarries on Moloka’i as well as determine the most common reasons for rejection at quarries over the sequence of reduction. This approach is portable and can be easily applied to adze assemblages from other islands and across the Pacific. Adopting this approach in future will allow adze manufacturing techniques to be determined and compared between islands and through time. Our approach adds a powerful new set of observations and analyses to Hawaiian adze studies that will hopefully see application throughout the Pacific.

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Figure Captions

Figure 1: The Hawaiian Islands, Molokaʻi and the~20,000 hectare study area of Kaluakoʻi (literally, the ʻadze pit')–a traditional land unit (*ahupuaʻa*) that encompasses nearly the entire leeward expanse of the west Molokaʻi volcano (from Weisler 2011). The three quarries are shown (Kaʻa, Kaʻeo and Kealapūpūakiha) as well as several sites mentioned in the text.

Figure 2: 3D scan of a typical quadrangular Hawaiian adze showing the main technological characteristics and naming conventions.

Figure 3: Examples of the three different adze types shown alongside 5cm scales. A: square-sectioned, B: Micro-adze, C: rectangular-sectioned.

Figure 4: Histograms of width / thickness values for complete square-sectioned and rectangular-sectioned adzes.

Figure 5. A, B and D, examples of adzes with elongate flakes struck along the face of an adze to flatten one side. C is an adze butt with the pole created by deliberate end-shock.

Figure 6: SDI versus mass lost for replicated adzes.

Figure 7: 3D scans of adzes at various stages of reduction, as measured by the SDI. Early, SDI <1 (scars per square inch); Middle, SDI = 1-3; and Late, SDI >3 stages of reduction.

Figure 8. Increases in SDI as the seven technological elements are added to adzes. The seven completed elements may be present in different combinations.

Figure 9: Mean number of bidirectional edges found on adzes at different stages of reduction, as measured using intervals of SDI. It can be seen that edges are gradually added to the adze as reduction continues, with three and four edges representing the latter stages in the sequence.

Figure 10. The progression of adze form with increasing SDI. Above: a square-section adze sequence starting with a cobble blank. Below: a rectangular-section adze sequence starting with a flake blank. A and D have SDI of <1, B and E have SDI of 1-3, while C and F have SDI of >3.

Figure 11: Proportions of adzes at each stage of reduction that have a completely formed bevel. Note that while bevels are more commonly added at later stages of reduction they can also appear very early in the sequence (i.e. the blank stages).

Figure 12: Proportions of adzes at each stage of reduction with a well-formed poll. Broken adzes with a bevel, i.e. those lacking the butt portion, were excluded from this analysis.

Figure 13: Proportions of adzes at each stage of reduction with a well-formed tang.

Figure 14. Examples of rejected adzes. A, B, and C were rejected because they were unable to create four bidirectional edges, while D and E were rejected due to end-shock, or double end-shock in the case of E.

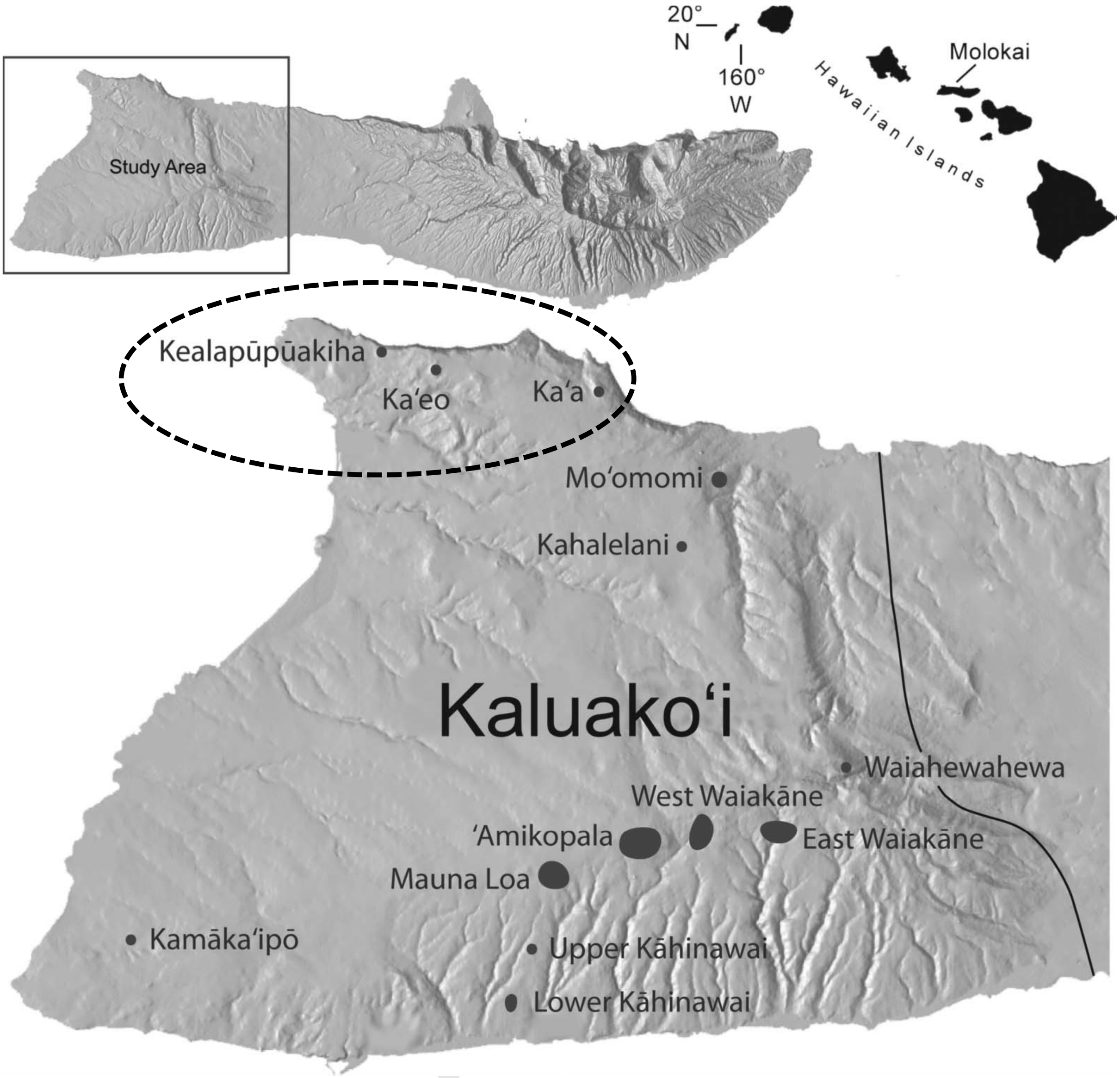
20°
N
160°
W
Molokai
Hawaiian Islands
Study Area
Kealapūpūakiha
Ka'eo
Ka'a
Mo'omomi
Kahalelani
Kaluako'i
Waiahewahewa
West Waiakāne
'Amikopala
East Waiakāne
Mauna Loa
Kamāka'ipō
Upper Kāhinawai
Lower Kāhinawai

Figure 1:

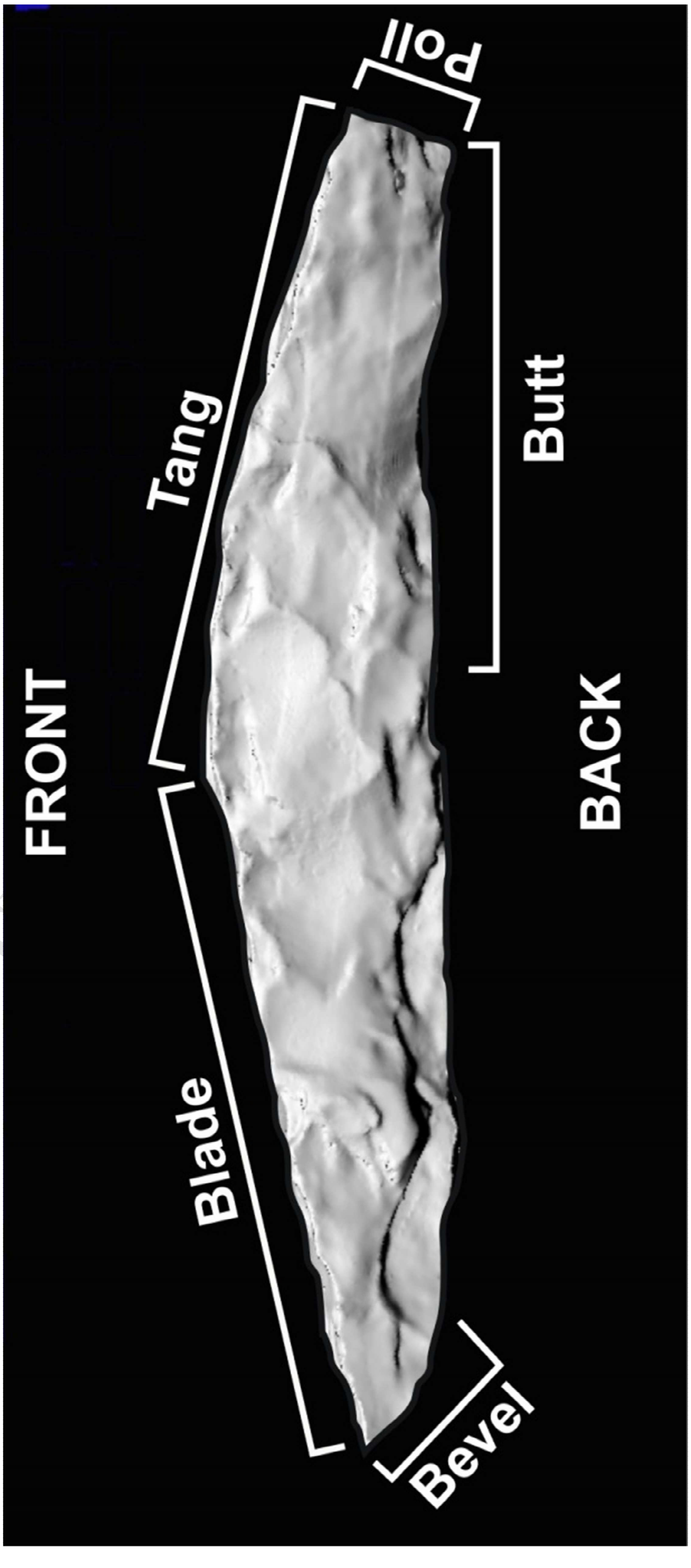

Figure 2:

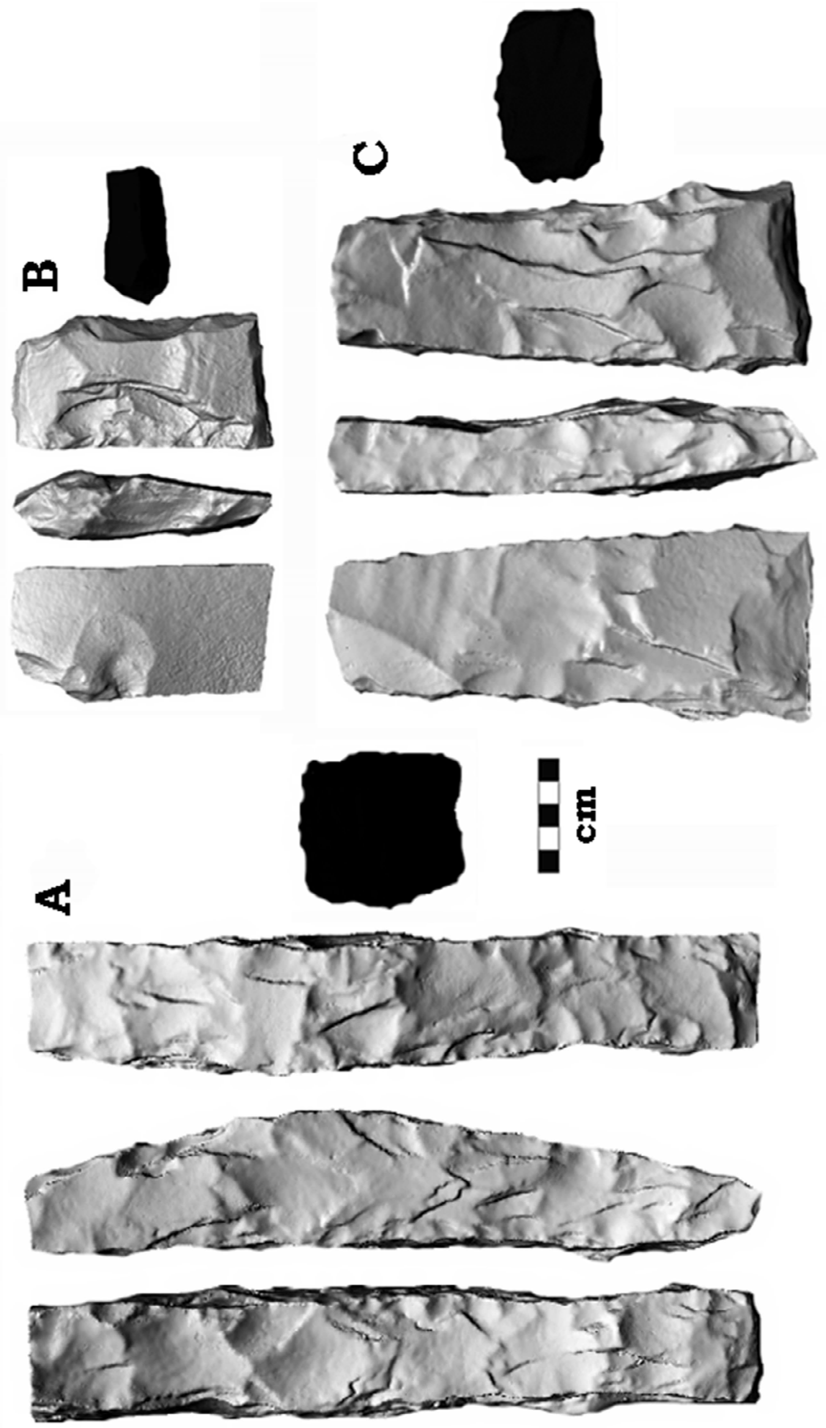

Figure 3:

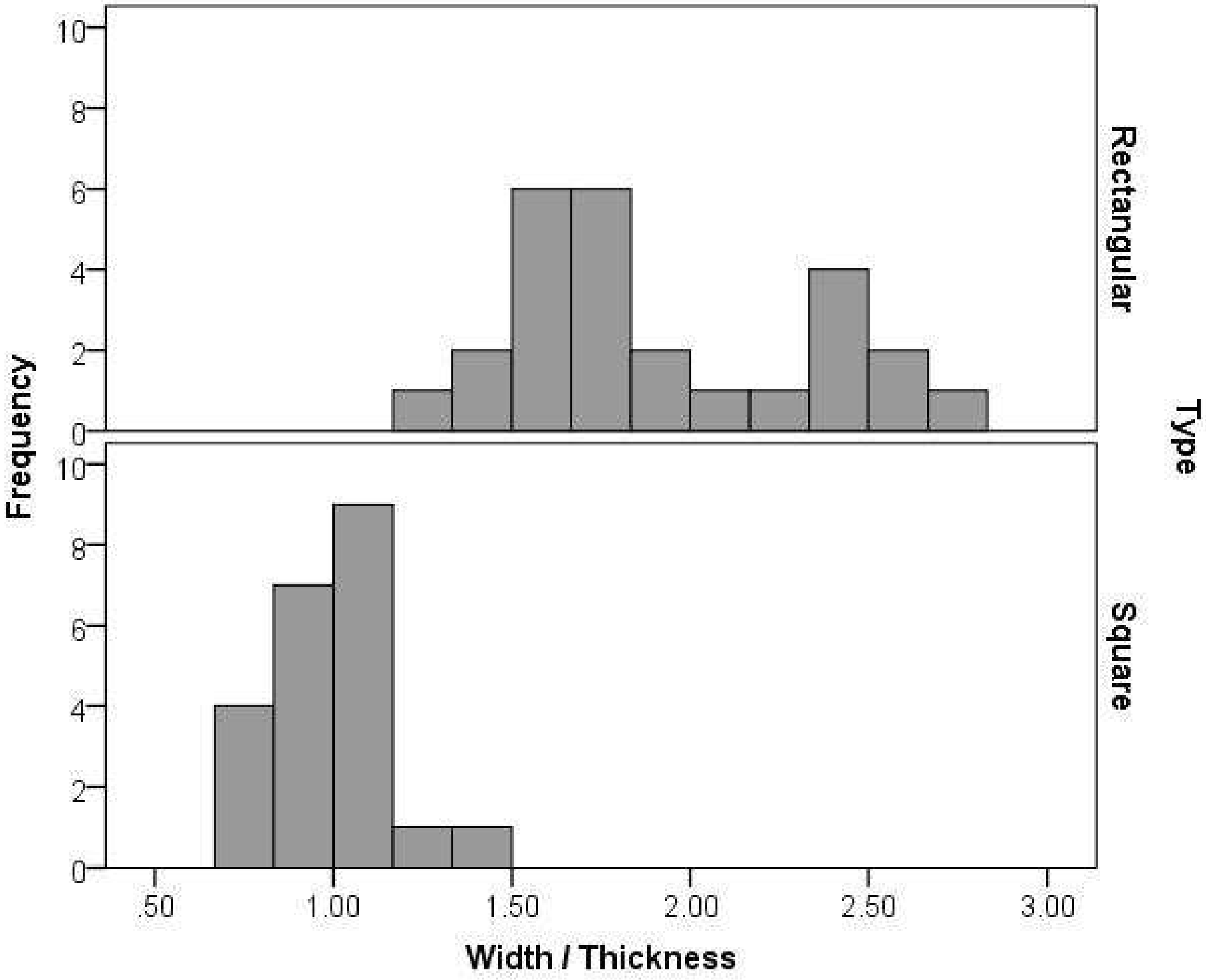
Frequency
Type
Rectangular
Square
10
8
6
4
2
0
.50
1.00
1.50
2.00
2.50
3.00
Width / Thickness

Figure 4:

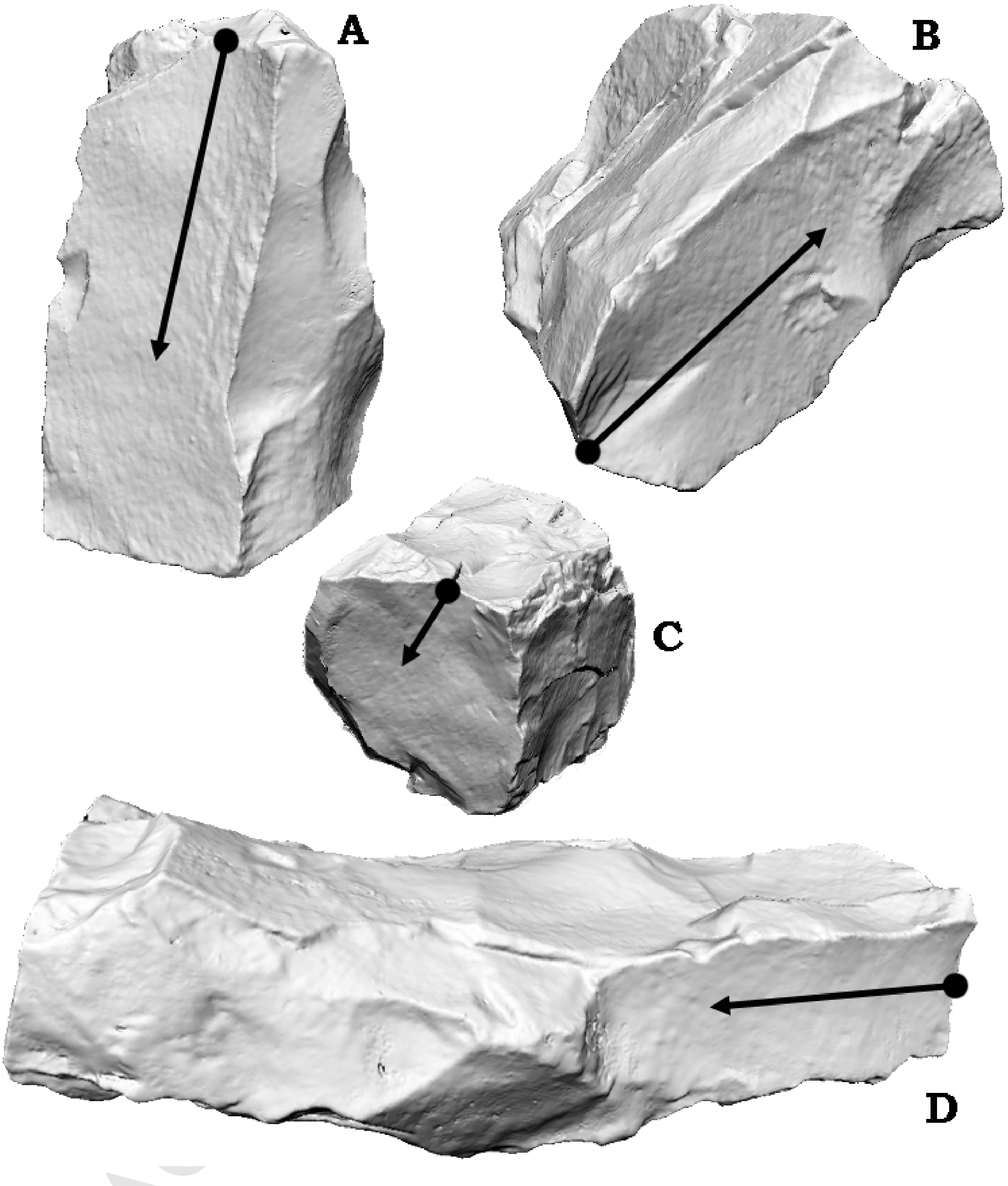

Figure 5.

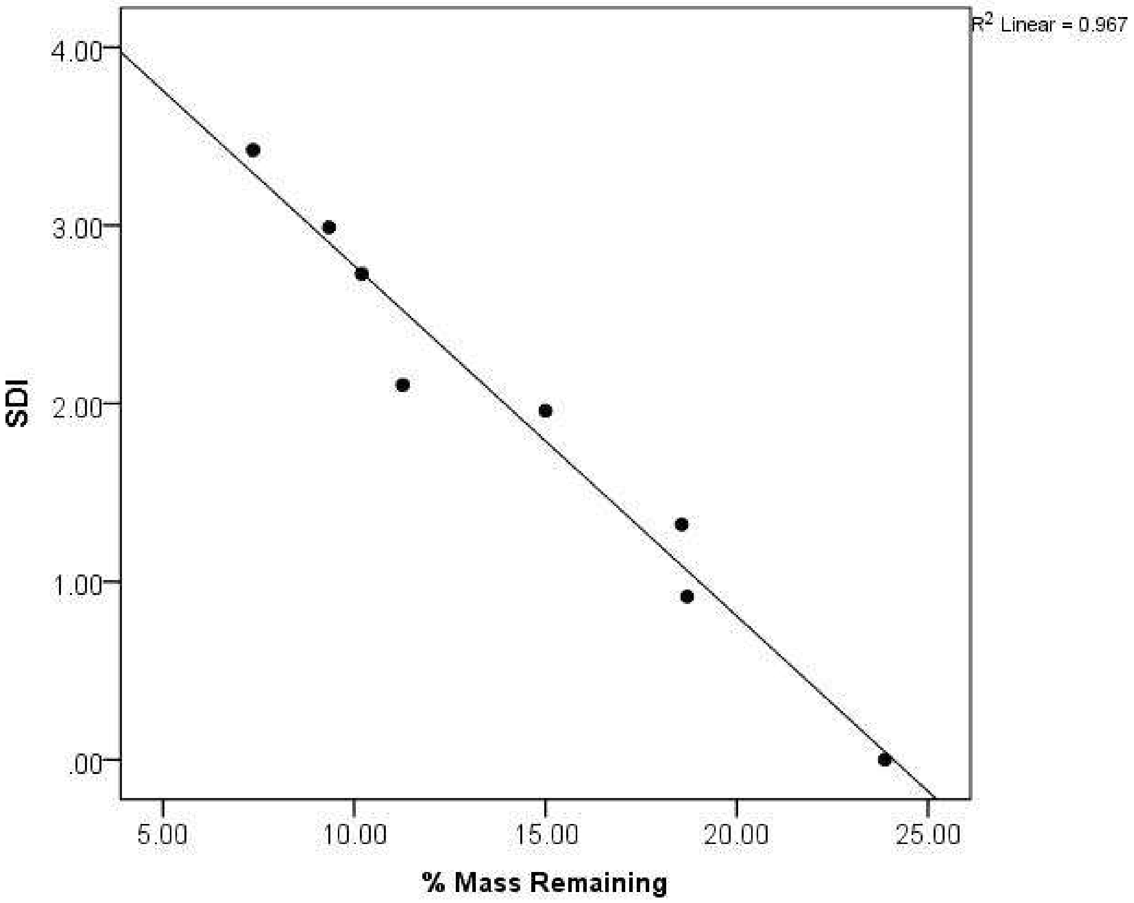
R² Linear = 0.967
SDI
4.00
3.00
2.00
1.00
.00
5.00
10.00
15.00
20.00
25.00
% Mass Remaining

Figure 6:

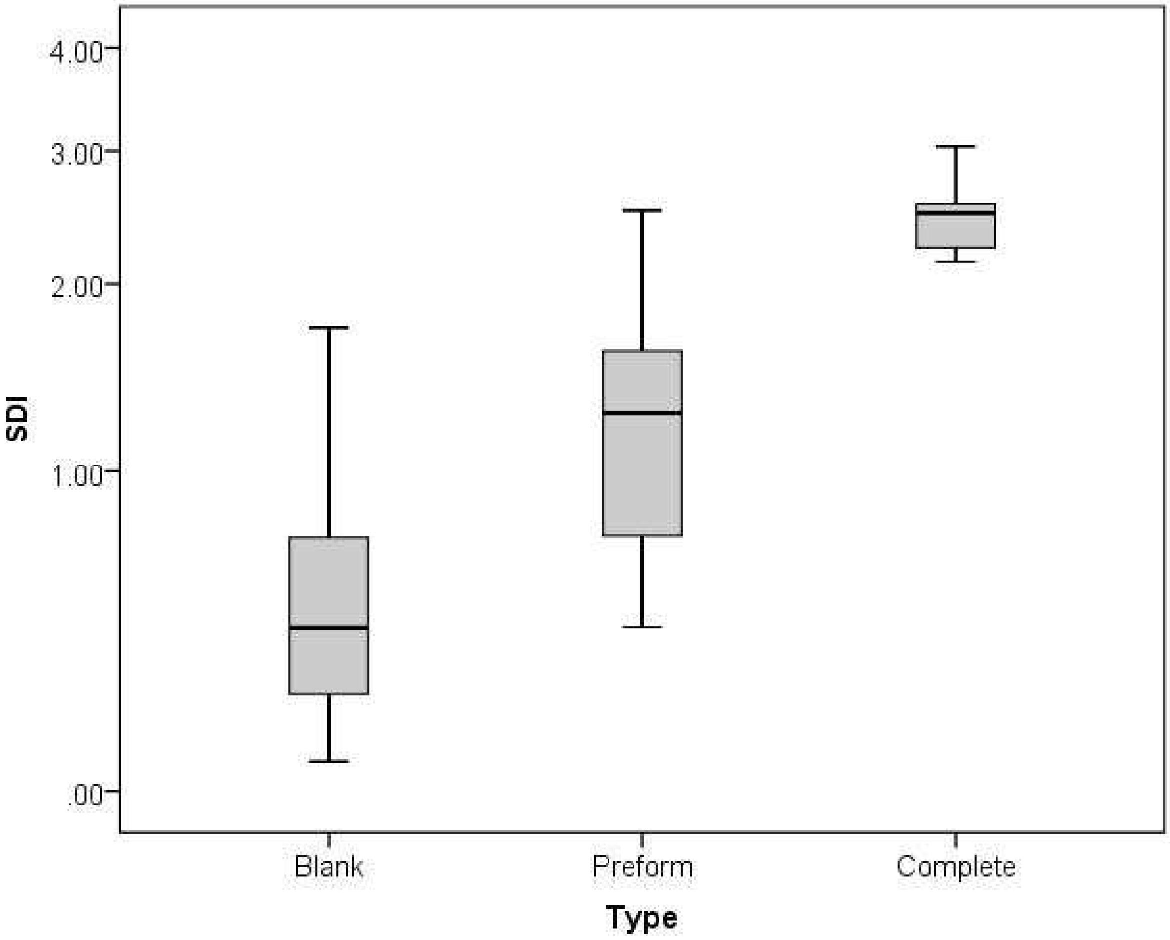

Figure 7:

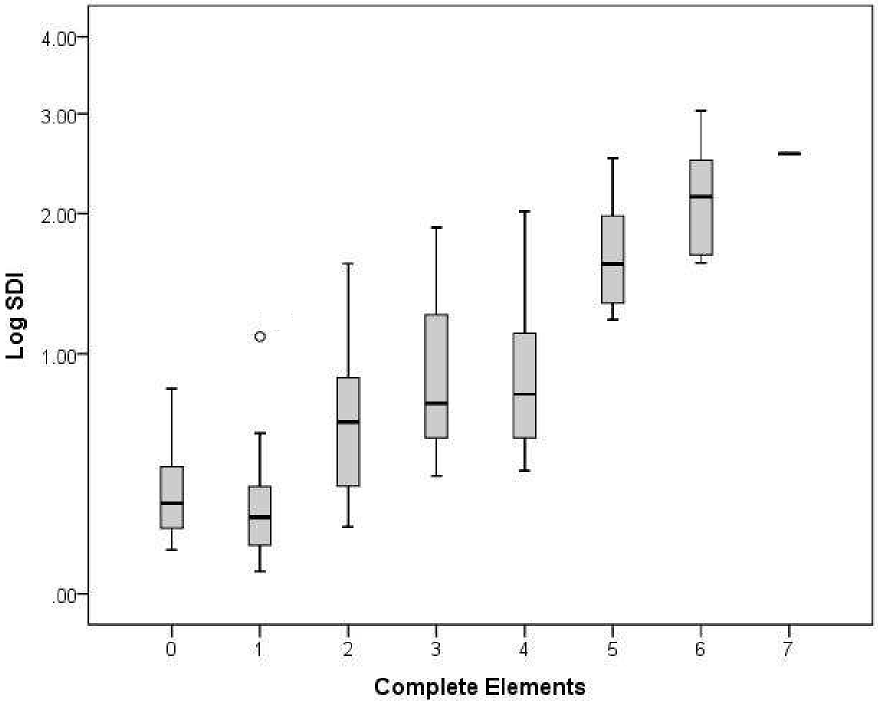

Figure 8.

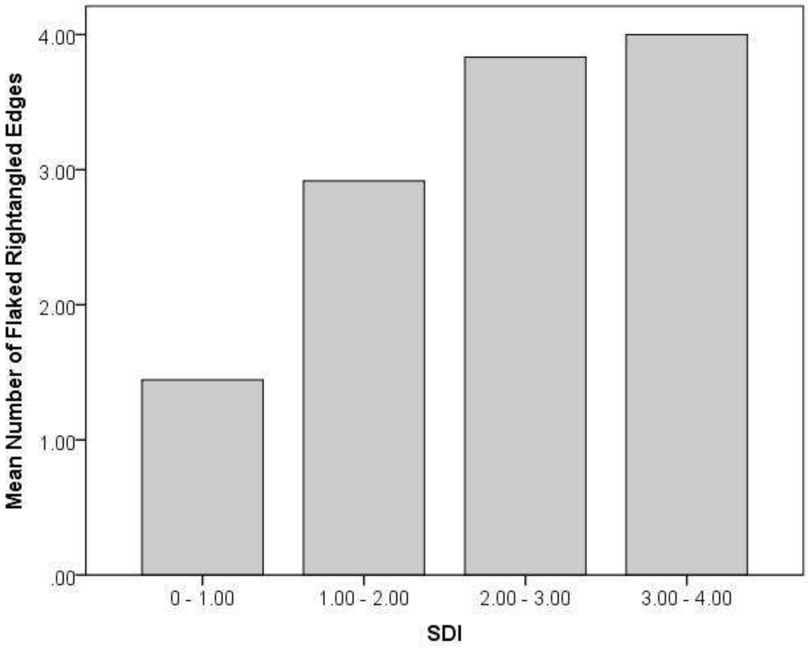
Mean Number of Flaked Rightangled Edges
4.00
3.00
2.00
1.00
.00
0 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 4.00
SDI

Figure 9:

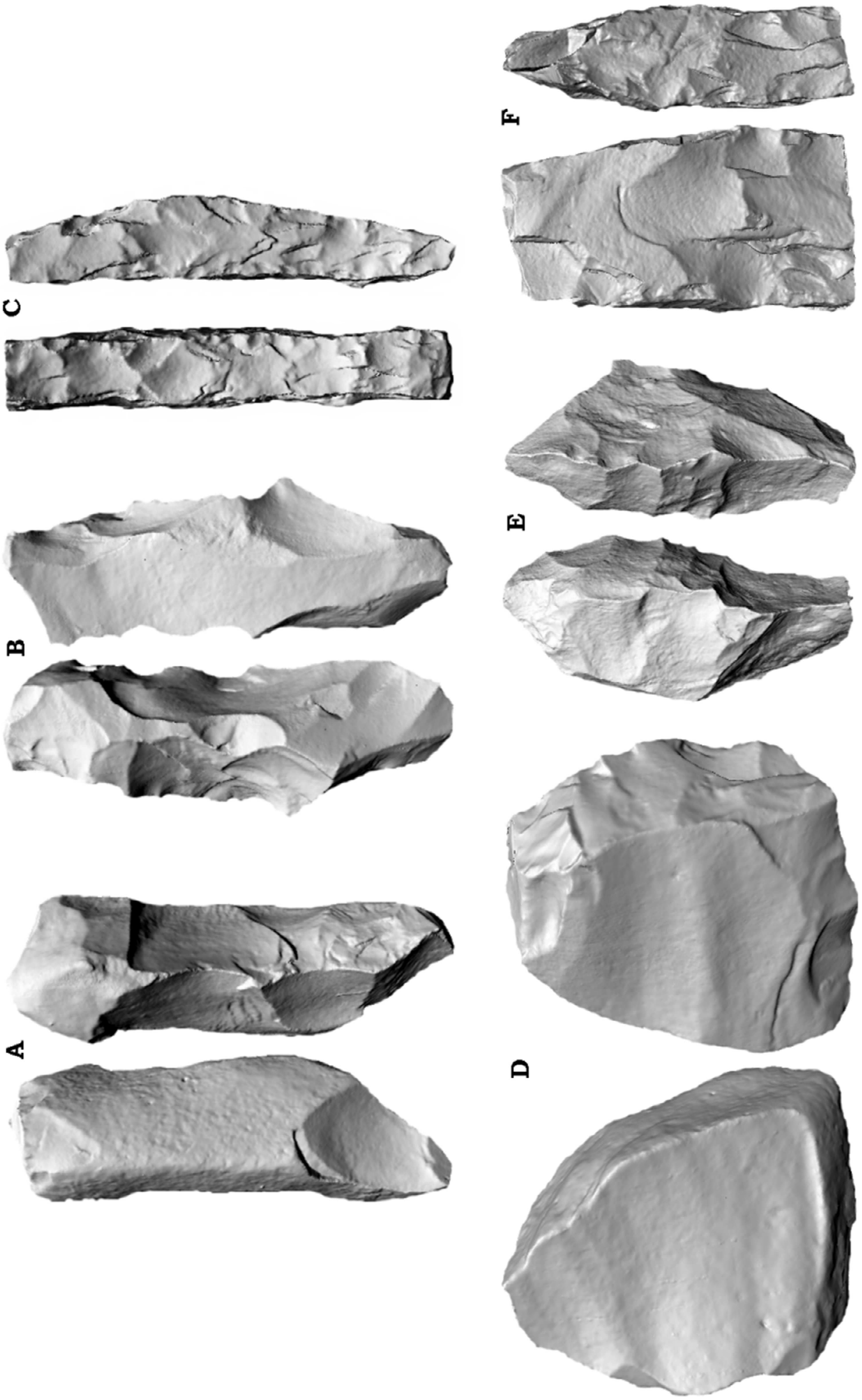

Figure 10.

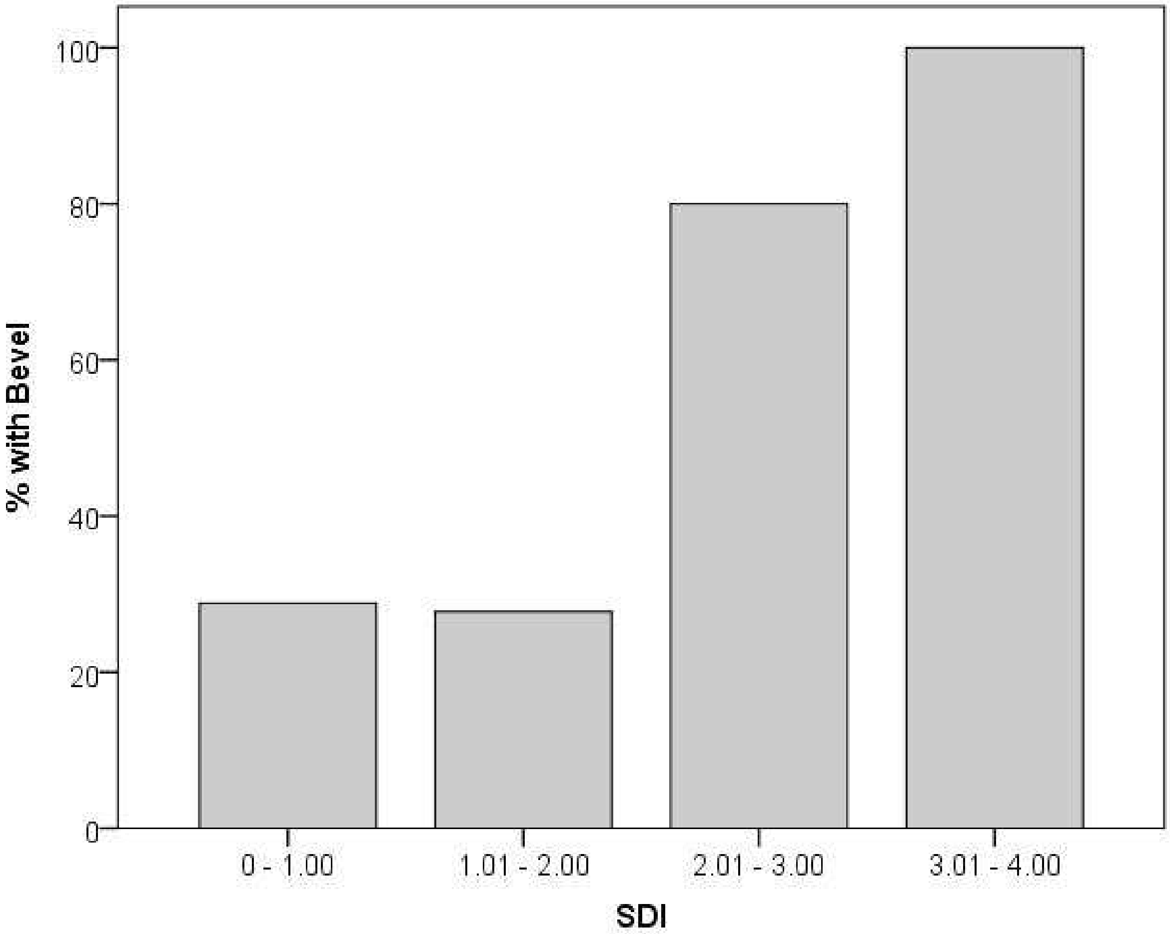

Figure 11:

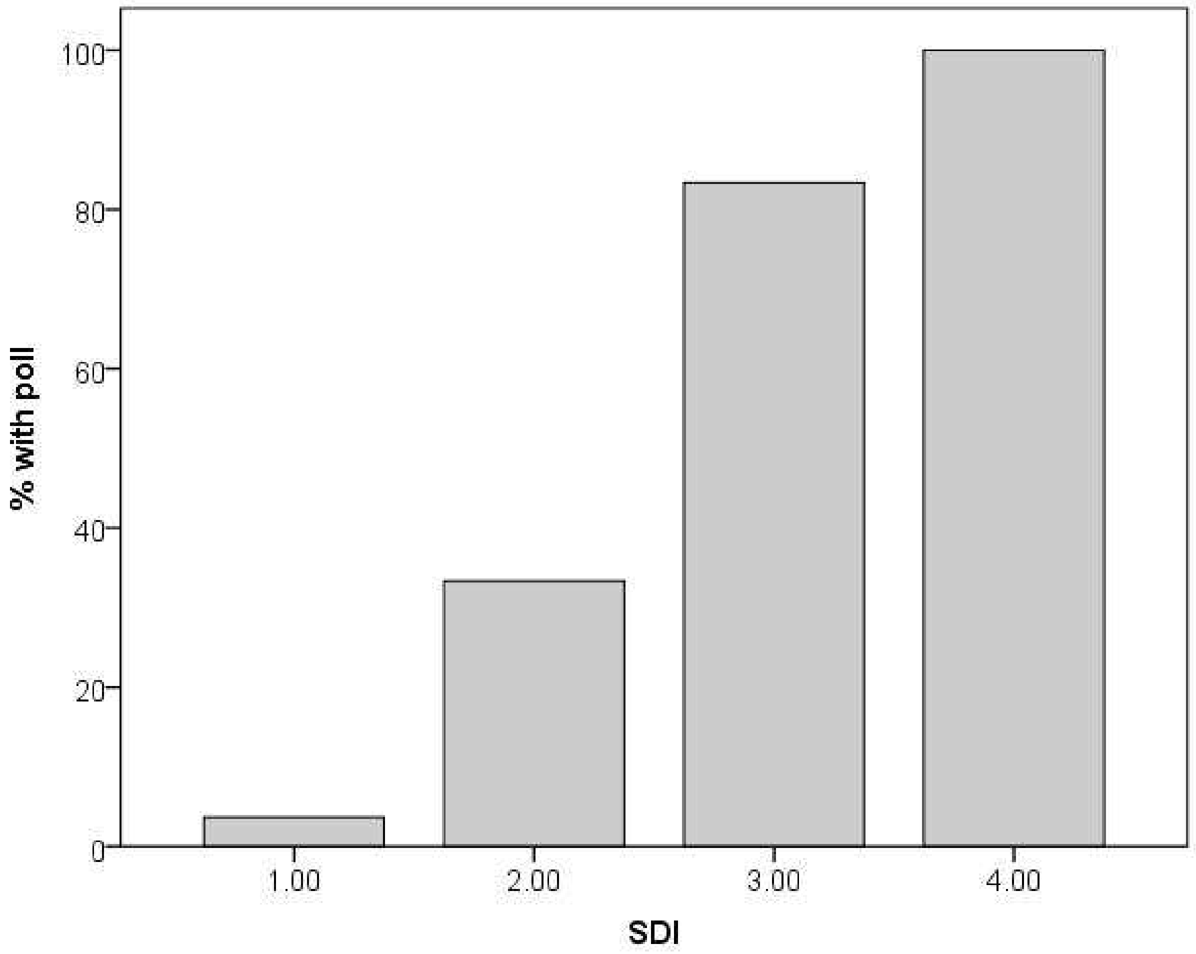

Figure 12:

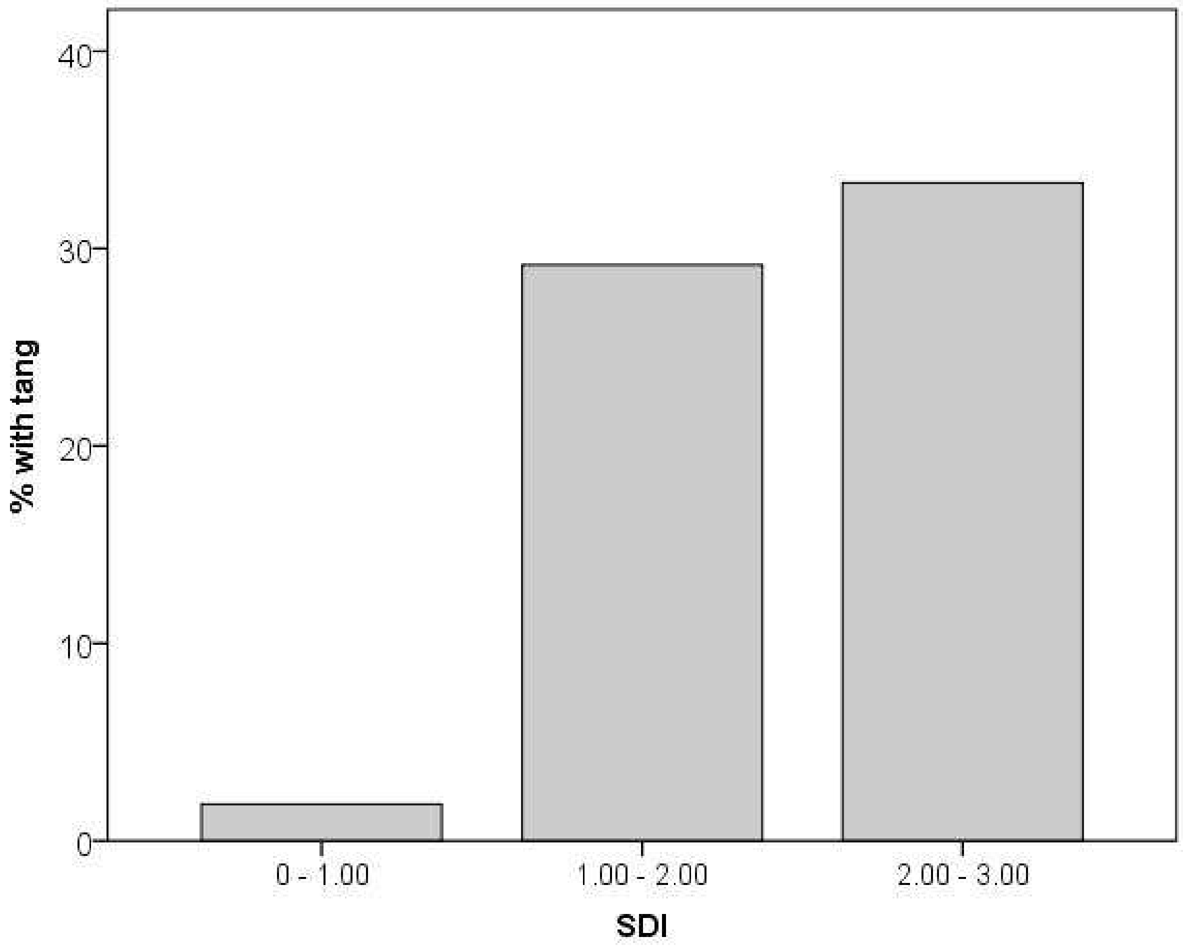

Figure 13:

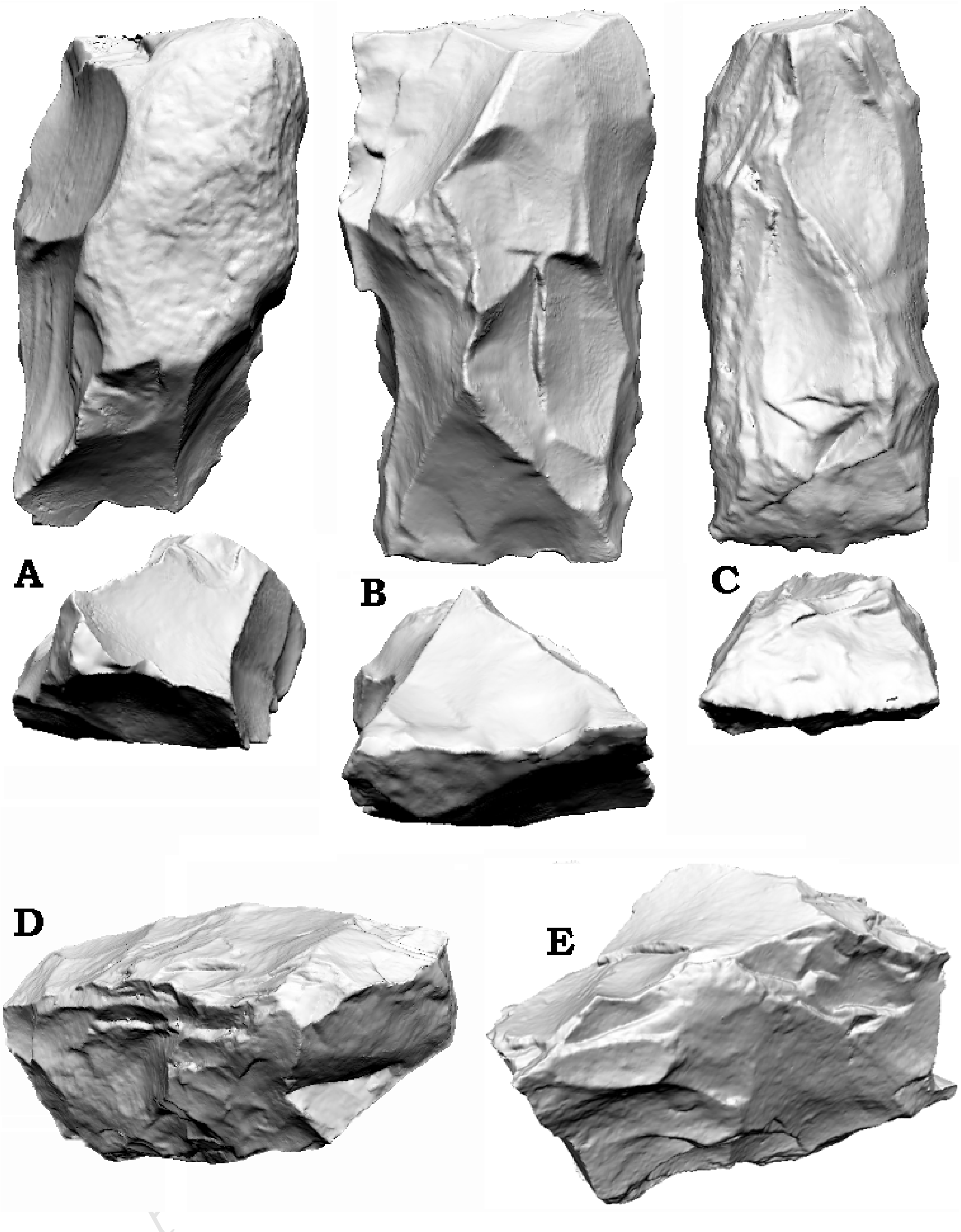

Figure 14.

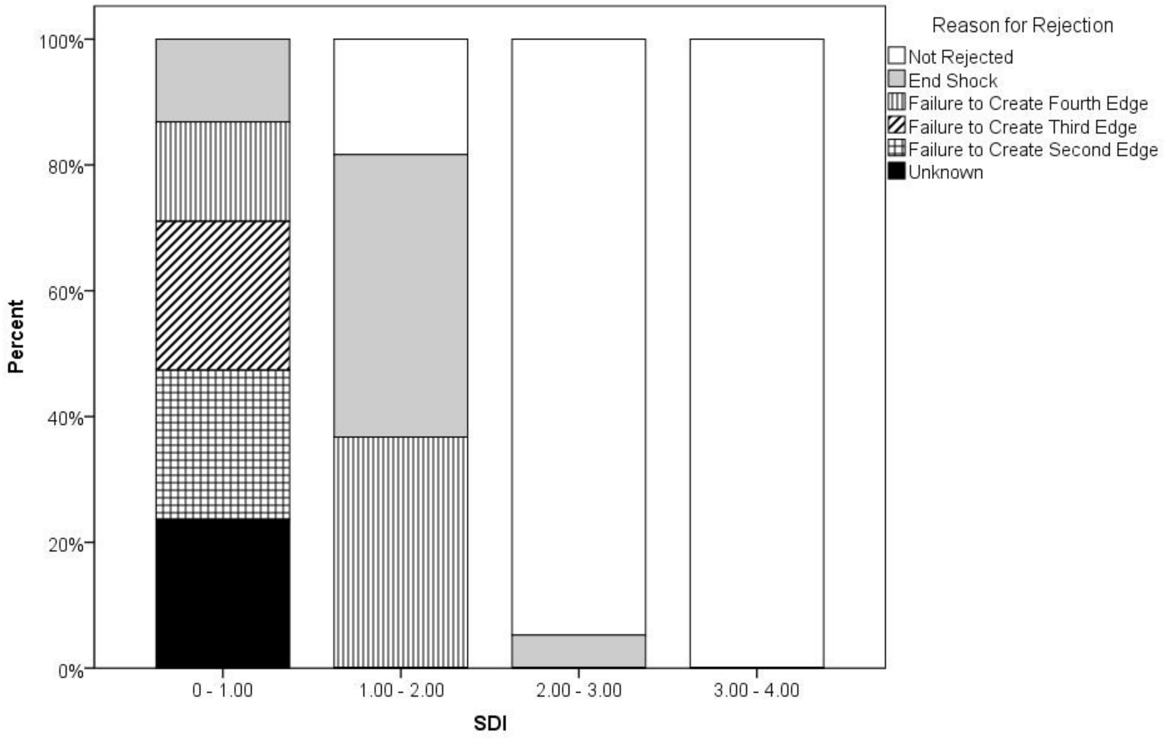

Figure 15. Reason for rejection by SDI. This figure shows only unground adzes.

- The SDI is employed on Hawaiian quadrangular adzes to determine reduction stages
- 109 complete quadrangular adzes are analysed from several quarries on Moloka'i
- A new reduction sequence is proposed for Hawaiian adzes, comprising six stages
- The order in which each adze element is added as well as the discard criteria for adzes is determined