Extending Experimental Control

The Use of Porcelain in Flaked Stone Experimentation

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ABSTRACT

One of the biggest problems faced by archaeologists engaged in flaked stone experiments is that of control. Controls are universally accepted as a way of ensuring reliability of experimental results used to interpret the archaeological record. Here, the use of a new and tightly controllable material in flaked stone experiments is proposed: porcelain. Unlike traditional approaches using stone, porcelain—while demonstrating comparable properties and fracture mechanics—can be more tightly controlled. As such, we suggest that its use ensures greater reliability in results derived from studies of tool manufacture and use and more potential for repeatability of experimental studies. A critique of previous approaches is followed by an assessment of porcelain as a suitable material for experimentation, in which two case studies that piloted the material are discussed. The first demonstrates its use in experiments regarding tool manufacture and skill. The second demonstrates its success in experiments dealing with observations of use-wear, such as projectile point impact fractures. The varied nature of these two studies aptly demonstrates the benefits of using porcelain as a controllable, moldable material.

Uno de los problemas más grandes a los que se enfrentan los arqueólogos que se dedican a la talla lítica experimental es el del control. El control es aceptado universalmente como una forma de asegurar la confiabilidad de los resultados utilizados para interpretar el registro arqueológico. Aquí, se propone el uso de un material nuevo y altamente controlable: la porcelana. A diferencia de los estudios tradicionales que utilizan lítica, la porcelana, al demostrar propiedades y mecánica de fractura comparables, puede controlarse más estrictamente. Por lo tanto, sugerimos que su uso asegura una mayor confiabilidad a los resultados derivados de los estudios de producción y uso de herramientas y un potencial mayor para la repetibilidad de los estudios experimentales. A la crítica de propuestas previas, le sigue una evaluación de la porcelana como material apropiado para la experimentación en la que se discuten dos estudios de caso que ponen a prueba el material. El primero demuestra su uso en experimentos relacionados con la manufactura de las herramientas y la habilidad. El segundo demuestro su éxito en experimentos relacionados con las observaciones de huellas de uso, tales como, las fracturas de impacto en puntas de proyectil. La naturaleza variada de estos dos estudios demuestra acertadamente los beneficios del uso de la porcelana como un material controlable y maleable.

Since the advent of experimental archaeology, investigation into the manufacture and use of stone tools has been the focus of many studies. Knapping skill, mode of manufacture, context of use, and depositional impact are among the many hypotheses tested within the literature. However, if advances are to be made in archaeological experimentation, the limitations of previous studies must be addressed. Of these, access to consistent raw material types for testing, the availability of required knapping expertise, sustainable project funding, and time are selected for further analysis as we highlight the benefits of the use of molded porcelain in flaked stone experiments.

Porcelain shows properties similar to traditional lithic materials, but as a synthetic material that can be shaped with a mold, porcelain can be more tightly controlled than any natural stone. Previous studies that have looked into using tightly controllable material have often used molded or cut glass and focused on gaining a greater understanding of the fracture mechanics of materials that break conchoidally, such as flint, cherts, porcelain, and glass. The work in this area of Dibble, Pelcin, and Faulkner, among many other researchers, placed strict controls on material shape, size, and consistency, which allowed for a greater understanding of the laws that govern conchoidal fracture and the effect core morphology has on flake formation (e.g., Dibble and Pelcin 1995; Dibble and Rezek 2009; Faulkner 1973; Rezek et al. 2011; Speth 1975).

Similarly, when substituted in stone tool experiments, porcelain can be tested with a much higher degree of consistency and comparability than naturally occurring and highly variable raw materials. While some may debate whether this level of control is necessary (for inconsistencies in materials would inevitably have existed in the past), control over specific variables can be of great assistance in experimental hypothesis testing. This

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is particularly important when comparisons are to be made between the work of a number of knappers and when an experiment requires manufacture of a large number of near-identical pieces to ensure a sufficiently large sample size for statistical significance. The use of molded materials such as porcelain or glass increases the control we have over some specific variables such as size, shape, and consistency of material. It is true that such tight controls are not necessary or desirable in all experimental work, for instance, work that focuses on testing the properties of a specific material type or assessing workability across different material types. These controls have, however, proven to be of great benefit in specific experimental studies, such as the two case studies presented below, and they have the potential to be more widely applied in cases where variables other than material type are subject to analysis.

ASSESSING PREVIOUS APPROACHES TO LITHIC EXPERIMENTATION

In order to assess the usefulness of porcelain within lithic experiments, we must first address some of the main limitations of previous approaches and the attempts that have been made to overcome them. Each of the points addressed below can be seen to relate directly or indirectly to raw material variability in terms of consistency of form and features within and between pieces.

Material Attributes

Suitable knapping material requires several attributes: it must be homogenous, brittle, elastic, and isotropic, and it must fracture conchoidally. When choosing a raw material type for use in an experiment, the hypothesis that is to be tested is the most important factor for consideration. If a particular artifact is to be manufactured that was made exclusively from one raw material type, in many cases this material, if available, would be the ideal choice for use in experiments. Many experiments, however, are not testing such specific hypotheses. Some seek to answer wider questions about fractures seen in stone tool technologies or to assess performance across a large number of individual knappers. Traditionally, natural stone types have been used in experimental studies; however, to gain a greater understanding of the mechanics of flake formation, more control is needed over initial material shape, size, and consistency to successfully address hypotheses (Rezek et. al. 2011:1346). By using molded or cut glass cores and controlling the force applied by using ball bearings or fixed hammers, a fuller understanding of the mechanics of flake formation and the factors that affect this has been achieved through a number of experiments (i.e., Dibble and Pelcin 1995; Faulkner 1973; Rezek et. al. 2011; Speth 1975).

In recent years, homogenous manufactured material types have been used in a wider range of experimental studies: for instance, bricks in studies of skill and learning (Geribàs et al. 2010) and glass in impact fracture studies (Iovita et al. 2013). The advantages of porcelain are that it can be acquired readily and inexpensively, molded into whatever shape is required by a particular experiment, and fired with a standard electric kiln, without requiring any specialized skills or equipment. Very few natural raw materials used in experiments are homogenous, come in uniform shapes, and are widely available. For this reason, in this paper we hope to encourage methods of testing that allow greater control of vital knapping attributes and are widely accessible, without compromising the validity of the resulting data.

Sample Size

Perhaps the most common approach to addressing consistency in results has been the use of large sample sizes (e.g., Eren 2008; Eren et al. 2011; Fischer et al. 1984). Increasing the sample size essentially lowers the effect of anomalies and ensures that any patterns noted in the results can be viewed with greater reliability. However, the main problem here is with the time and cost associated with obtaining large samples. These can often be excessive and, particularly for small-scale experiments, exceed the resources available. Furthermore, some natural materials are scare and their availability limited, which may constrain the number of experimental specimens that can be manufactured. While large samples are always preferable, they are only a viable mechanism for controlling raw material variability when dealing with low cost, easily accessible materials, and where there is an extended timeframe available for research. Rarely is this the case.

Choice of Material

Another approach to dealing with material variability has been to incorporate the participants' choice of material as an assessed variable in an experiment (e.g., Finlay 2008). This approach cannot, however, be applied beyond assessments of skill. Even in the case of skill experiments, this approach has its limitations. Individual pieces of stone can have internal flaws that are not always apparent externally, making it difficult, even for highly skilled individuals, to select pieces of consistent structure. This constrains the useful results that can be derived from such a project. The use of a consistent material whose properties can be tightly controlled would enable greater comparability of results and allow more scope for repeating the experiment.

Raw Material Depletion

Another consideration when selecting flakeable materials for experimentation is the availability and current state of natural raw material resources. There are ethical issues to be addressed when using a non-renewable resource for archaeological experiments, particularly if there are options to use an alternative renewable resource. The continued use, for experiments and by modern flintknappers, of natural flint and other flakeable rocks is having a negative impact on the quarries and sites where they occur and, more importantly, can cause destruction of archaeological contexts where these were also exploited in prehistoric periods.

PROPOSING AN ALTERNATIVE METHODOLOGY

Development

In order to address the problems of raw material variability in flaked stone experiments, it seems clear that an alternative methodology should be established. This approach was applied in the Learning to Be Human Project, a study, funded

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by the Leverhulme Trust, which used experimental archaeology to answer questions about skill and learning in Lower and Middle Paleolithic technologies. For this long-term project, natural raw materials of sufficient consistency were not available in the quantity required, and a method had to be developed that would ensure the reliability of the results. To this end, one of us (Bradley) developed the use of porcelain as a material for blanks and cores knapped during skill assessments throughout the experiment. The use of porcelain as a knapping material has been known ethnographically from the nineteenth century, when Australian aborigines would take the porcelain insulators from telegraph lines (Cotterell 2010:95). In such cases, it proved itself a good substitute for natural stone.

Porcelain was first developed in China around 1,200 years ago (Savage 1963:25). Modern porcelain is commonly made from a mixture of white china clay known as kaolin (an aluminum silicate), feldspar (a silicate of potassium and aluminum), and quartz or alumina (Carty and Senapati 1998:5). When heated to temperatures in excess of 1,200°C, the feldspar vitrifies, giving the porcelain its glass-like features, while the kaolin allows it to remain plastic and thus moldable before firing (Savage 1963:26). Due to this vitrification, porcelain has the same conchoidal fracture properties as flakeable stones such as flints or cherts; indeed, conchoidal fracture is one of the features that is used in identifying hard paste porcelains (Bengisu 2001; Polehampton 1815; Ramsay and Ramsay 2008). In addition to its use by Australian aborigines, porcelain has also been used by modern knappers as a substitute for natural stone. Whittaker (1994:68) suggests it as a tougher alternative to glass for knapping practice and compares its quality to coarser cherts, agates, and jasper, among other natural stones (Figure 1). While he refers to industrial porcelain, the hard paste, fine variety available from pottery suppliers falls more closely into the finer flints and cherts category. Porcelain clearly will not have the same material properties as an individual natural material type in a similar way that flint does not have the same material properties as obsidian or basalt or any other raw material that is known to have been knapped prehistorically. However, the suitability of the material for knapping, due to its conchoidal fracture, homogeneity, moldability, and commercial availability, makes porcelain an ideal substitute for natural stone in many flaked stone experiments that are not reliant on the use of a specific material type.

Methods and Materials

The methodology for creating porcelain blanks for experimentation was initiated by Bradley and adapted and developed by Antony Whitlock at the University of Exeter as part of the Learning to Be Human Project. In their experiments, Royale porcelain from the Valentine clay range was used. This material is widely available from ceramic suppliers in the UK and is relatively inexpensive. The chemical composition of this substance is shown in Table 1. One of the major advantages of using porcelain is that the unfired material can be pressed into a mold, meaning that an unlimited number of blanks or pre-cores can be made to the same mass and dimensions. This is a significant consideration when trying to ensure consistency in a controlled experiment, especially where results between knappers are being evaluated. One- or two-piece molds can be used as required by the experimental conditions. In initial experiments, plaster molds were made around a model core, but soap stone molds were

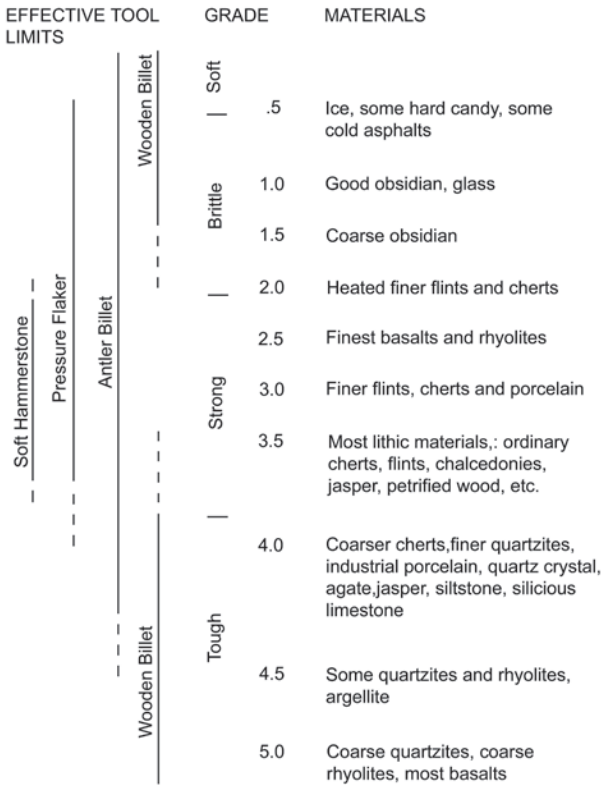


FIGURE 1. Raw material types and their properties based on ease of working (adapted from Whittaker 1994).

also used (Figure 2). After shaping, the porcelain is left to dry (depending on the size of the pieces, this can be for a period of a few days to several weeks). This is an essential part of the process, as improperly dried pieces are liable to crack on firing, ruining the homogeneity of the material. After a piece has dried, it can be trimmed, if necessary, to remove any overhang from the mold and smooth the edges. When fully dried, the piece can then be fired in a pottery kiln. We fired our pieces in an electric kiln at a temperature of 1,250°C, which produced pieces that

TABLE 1. Chemical Composition of Royale Porcelain Used in Lithic Experiments.

Chemical	Percent
SiO_2	64.83
TiO_2	0.04
Al_2O_3	23.41
Fe_2O_3	0.36
P_2O_5	0.10
CaO	0.45
MgO	0.26
K_2O	3.07
Na_2O	1.31

Source: CTM Potters Supplies 2013.

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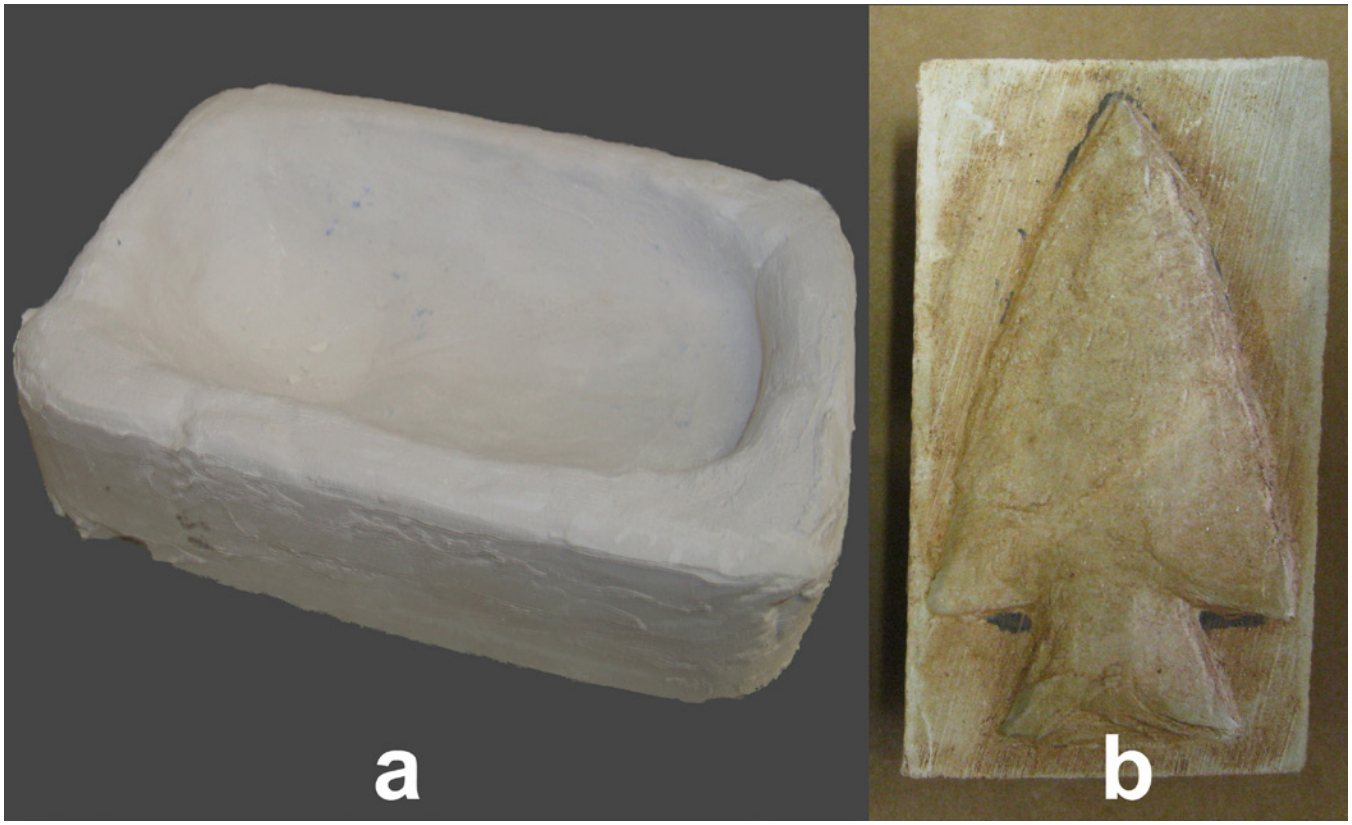


FIGURE 2. Plaster (a) and soapstone (b) molds used to shape the porcelain preforms.

sufficiently replicated the fracture found in knappable stone such as flint or chert.

Results

Some of the resulting blanks and pre-cores can be seen in Figure 3. Once fired, samples were flaked by an expert knapper (Bradley) to test their suitability as a substitute for natural stone. The material was found to be knappable by both antler soft hammers and stone hard hammers, such that Bradley was able to create handaxes, Levallois cores, and thin bifaces, as well as pressure blades (Figure 4) and pressure thinned bifaces, using both antler and copper flakers. The flakes that were produced showed the same characteristic flake features as those created from flint, chert, or other natural material types. The flakes also showed the same range of termination types (the form of the distal end of the flake showing how the impact force exited the piece), comprising feather, hinge, step, and overshot or plunging terminations (Odell 2003:56–57). On the basis of these samples, the material was deemed suitable for use in archaeological experiments as a substitute for natural stone.

THE CASE STUDIES

The case studies that follow provide brief descriptions of the first two experiments using molded porcelain. The descriptions are by no means a complete account of each experiment, for these will be the subjects of later publications. In this case, the purpose of their inclusion is to demonstrate the use potential of a tightly controlled stone substitute in archaeological experimentation.

CASE STUDY ONE: EXPERIMENTS IN SKILL AND LEARNING

Background

One of the major applications of the use of porcelain is in experiments that are focused on assessing flintknapper skill. This is particularly the case when skill needs to be determined across a large number of flintknappers in an experiment. While there have been attempts to use a preshaped material in skill experiments (Geribàs et al. 2010), the majority of such experiments use naturally occurring stone (e.g., Eren et al. 2011; Ferguson 2008; Finlay 2008; Shelley 1990; Winton 2005). If natural stones are used as initial raw materials in such an experiment, variability in material, hidden material flaws, and poor availability of similar materials can cause problems when assessing skill between individuals based on the products of their knapping. The Learning to Be Human Project was a flintknapping experiment that studied a group of 16 volunteers over a period of nearly two years as they learned to make Oldowan style tools, Acheulean handaxes, and Levallois preferential flakes. As the project involved studying a considerable number of people across a wide geography and over a relatively long period of time, issues of raw material availability and variability had to be addressed. To this end, the decision was made to use porcelain pre-cores in the skill assessments throughout.

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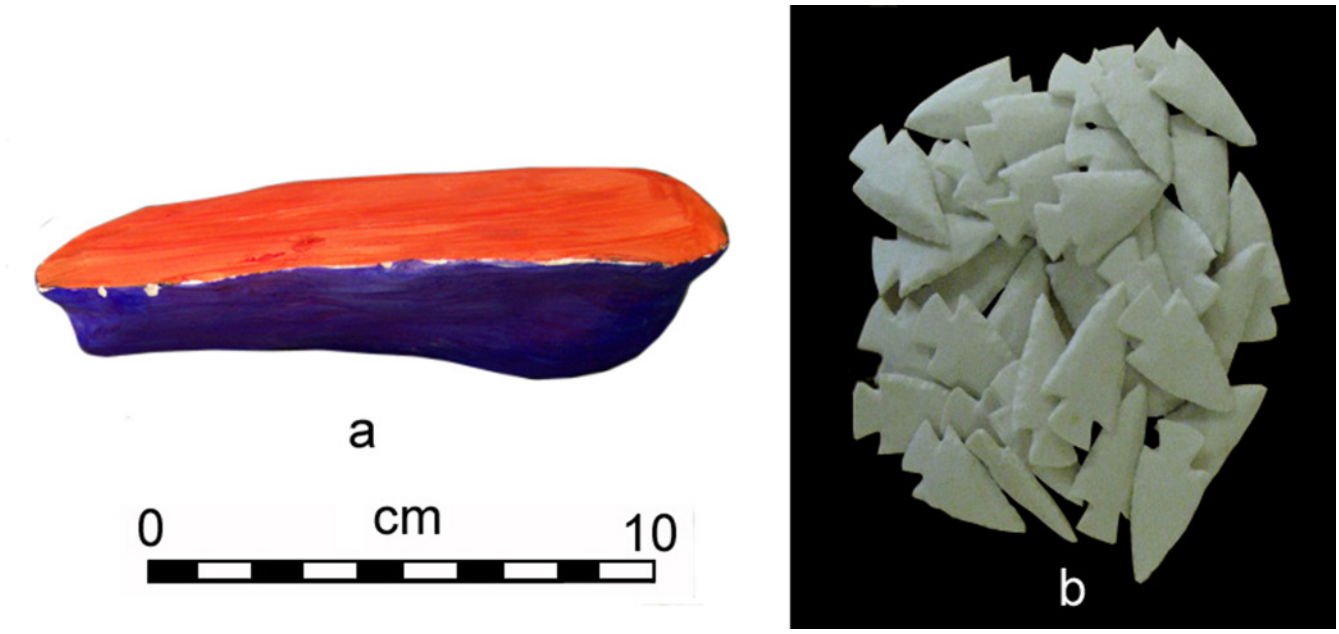


FIGURE 3. Porcelain blanks and preforms used in skill experiments, showing red ventral and blue dorsal surfaces (a) and use-wear experiments (b).

Methodology

One-piece plaster molds were made to a size and shape that would be suitable to allow both handaxes and preferential flake Levallois cores to be made (Figure 2a). As this experiment dealt with knapper skill, elements of difficulty were introduced into the design that would also be seen on natural stone flakes used as blanks in these technologies and that often cause novices trouble. These comprised a simulated bulb of percussion, flat striking platform, and a hinge fracture style rounded edge at the distal end of the piece (Figure 3a). After firing, the ventral (flat) and dorsal (rounded) surfaces were colored using marker pen. This aided analysis of results in a number of ways. First, the colored area on the dorsal surface could simulate cortex, indicating how much of this "cortical" area was removed by the knapper when their products were analyzed. Second, the



FIGURE 4. Pressure blades and cores of different raw material types showing comparable features. From left to right, greensand silicate, porcelain, Norfolk flint, and obsidian.

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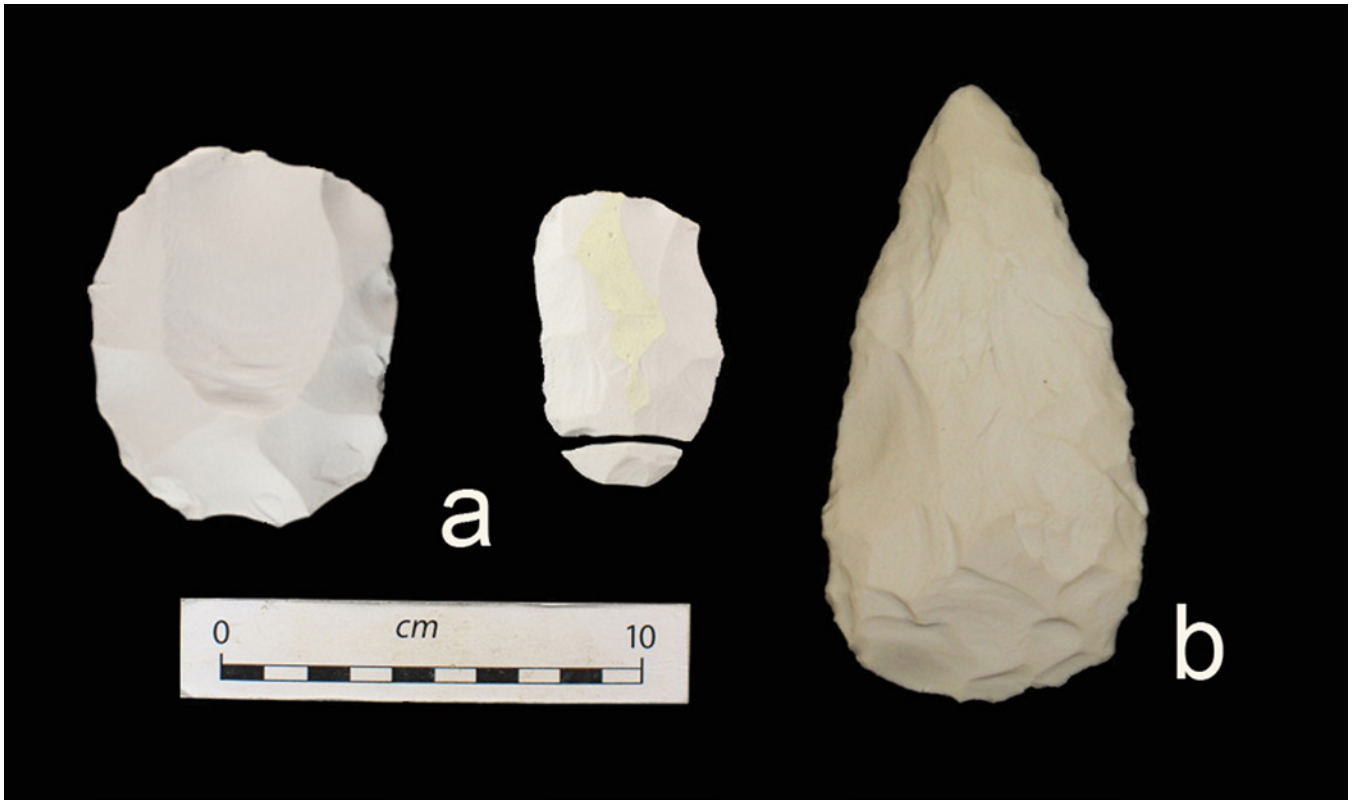


FIGURE 5. Levallois core and flake (a) and handaxe (b) knapped from porcelain by an expert knapper (photographs by Antony Whitlock and Nada N. Khreisheh, 2012).

two different colors on the dorsal and ventral surfaces allowed debitage, which showed these colors to be assigned to the face from which they were removed in the early parts of the reduction sequence. This permitted counts of dorsal-ventral flakes to be made. These counts are of interest when considering knapper skill, especially when Levallois technology is being attempted (Eren et al. 2011:237). It also often allowed the original dorsal and ventral surfaces to be identified on the finished products, which gave information on the technical strategy of the knapper, another aspect of their skill. The finished pre-core shape was first knapped by an expert knapper (Bradley) into a Levallois core and flake (Figure 5a) and a handaxe (Figure 5b) to ensure that the shape of the porcelain pre-core was suitable for these technologies and the purposes of the experiment.

During the Learning to Be Human Project, skill was assessed by authors Bradley and Khreisheh at a number of points during the experiment. The assessment results were related to data from initial aptitude tests, counts of hours spent practicing, and time in taught sessions. The skill assessments consisted of two parts. First, participants were given flint examples of a generic flake core, handaxe, or Levallois core at different stages of reduction and asked how they would remove a number of flakes from these pieces to advance the technology. Flake scars were drawn with chalk on the pieces rather than removed, allowing each individual to be given the same piece. The level of skill assessed in this part of the experiment relates to *connaissance* (knowledge and understanding of how to flake). The knapper was then given a porcelain pre-core and asked to make a handaxe or Levallois core, depending on the technology assessed. The skill assessed in this part of the project relates to their *savoir-faire* (know-how and physical ability to flake).

Results

The results of the first Levallois assessment are shown below (Table 2). In this case, skill in Levallois technology was not simply determined by the number of hours practiced. For instance, knapper H (Figure 6a) had the lowest number of practice hours, yet received a higher score for *savoir-faire* than knapper C, who practiced for nearly twice as long (Figure 6b). This indicates that a level of initial aptitude is also involved. It was only by using a controlled initial raw material shape and quality that these direct comparisons could be made. Having used data from aptitude tests conducted at the start of the experiment, it is hoped that the area of aptitude that is most significant for determining skill in Levallois and handaxe manufacture will be identified. This may allow for an understanding of the abilities that were most significant for our hominid ancestors in permitting early technologies to be realized.

The use of porcelain allowed standardized cores to be used for each individual and across each *savoir-faire* evaluation in the project. This allowed errors identified in knapper performance and the cores and debitage they produced to be attributable to their skill in the technology, rather than the result of material variability. This provided a clearer understanding of the true abilities of individual knappers.

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TABLE 2. Scores for Levallois Evaluation and Number of Hours Practiced Prior to Assessment.

Knapper	Connaissance Score	Savoir-Faire Score	Number of Knapping Hours
A	4.5	3	103.75
B	2	2	41.25
C	4.5	3.5	85.25
D	4.5	3.5	119.5
E	4.5	4	89
F	4	3	117.5
G	5	4	99
H	3	4.5	36.75

CASE STUDY TWO: OBSERVATIONS OF USE-WEAR

Background

Projectile point use-wear studies, at both the micro and macro scale, commonly involve the use of experimental approaches (e.g., Barton and Bergman 1982; Bergman and Newcomer 1983; Fischer et al. 1984; Odell and Cowan 1986). In such cases, the researcher requires a sample of comparable finished products for testing. Traditionally, this has required a knapper with enough expertise that he or she could produce large quantities of points within a suitable time frame, with as low a level of variability as possible. Even in the few instances where pieces are consistently made, ultimately, the internal structure of individual pieces of stone (i.e., inclusions and irregularities) is left to chance (there are some exceptions, for example the glass points used by Iovita et al. [2013]). For experiments which deal directly with interpreting forms of use-wear such as impact fractures, any anomalies caused by irregularities in testing material might be seen to limit the comparability of results. As such, experimentation with hafted porcelain points was carried out by one of us (Davies) in an attempt to assess the merits of a more tightly controlled material substitute. In this case, initial observations were limited to macrofracture patterns produced upon impact, though future work could extend this to include traces of microwear (polish, striations, etc.) and forms of damage associated with non-projectile use-contexts.

Methodology

As with the core method, the porcelain points were manufactured using a single mold (Figure 2b) to ensure that all were alike. However, unlike the cores, the experimental points were bifacial and lenticular in cross section, meaning that the clay needed to be formed in a two-piece mold to shape both ventral and dorsal surfaces. By using the same mold for each of the 50 points in this pilot study, the size and shape variables were kept to a minimum, with a maximum weight range of .3 g.

To maintain a close comparison with flaked stone projectile points, the lateral edges of each were consistently pressure-flaked after firing, taking care not to adjust the desired dimensions (Figure 7). As with the handaxe pre-cores, each of the porcelain points were colored using a marker before hafting; an initiative that would later prove useful for studying flake remov-

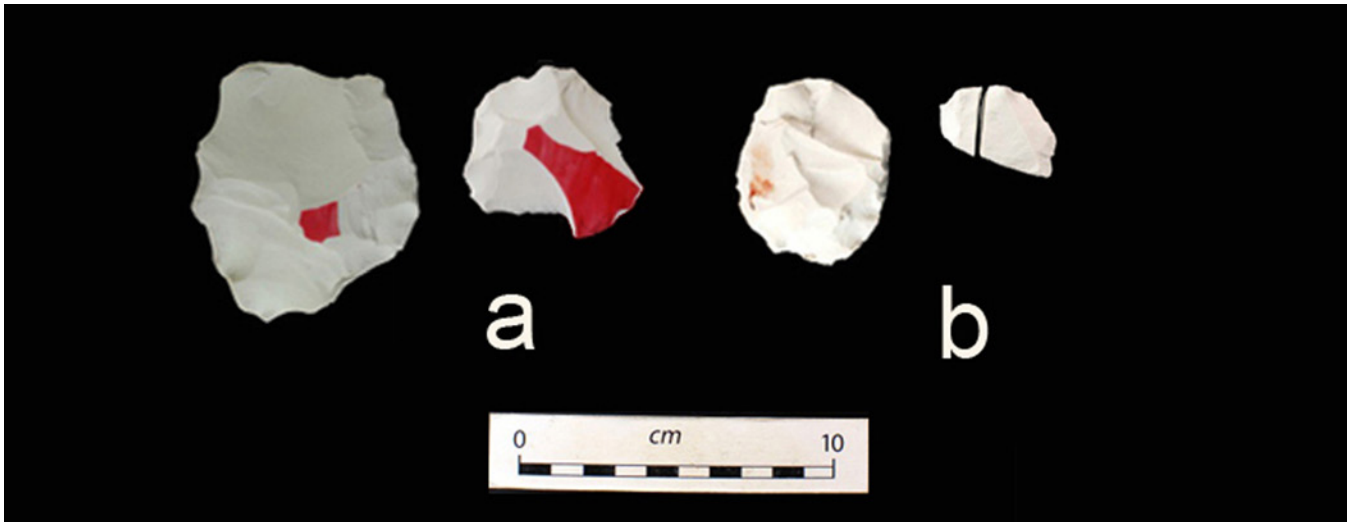


FIGURE 6. Levallois core and flake knapped by knappers H (a) and C (b) (photographs by Antony Whitlock, 2012).

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FIGURE 7. Pressure-flaking the porcelain points.

als caused by impact damage. Just as the molded points were carefully controlled to maintain consistency, so too was the hafting for which commercially available materials were used.

Each of the points in the sample was shot by Davies at a controlled target, in this case an industrial plastic water pipe, to initiate use-damage. The uniform properties of the pipe made it a suitable and consistent substitute for representing impact against hard objects such as bone, wood, or rock. After each projectile had been shot, the points were removed from their hafts and studied for signs of impact.

Results

During the analysis of the porcelain points, the ease with which use damage could be identified was immediately apparent. The artificial color applied to the exterior of each point meant that any form of damage, whether minimal tip crushing or significant breaks, was macroscopically very clear. Unlike in the case of points made of material such as obsidian, the extent and direction of flake removals on the porcelain points are clearly defined, making recording and photography easier.

The types of damage present in the tested sample were consistent with those reflected in the archaeological record (Figure 8a-d). Among these, impact fluting (e.g., Frison et al. 1976) and breaks that occurred in the haft were the most common, though each of Dockall's (1997) longitudinal, transverse, lateral, and spin-off fractures were also present, providing additional evidence that porcelain promises to be a suitable material for testing hypotheses associated with tool use.

In essence, the only real differences between stone and porcelain points in experimental archaeology are those of consistency, accessibility, and time. Where the internal structure of individual pieces of stone can be difficult to predict, the consistency of porcelain can be controlled. Where comparable stone points require highly-skilled knappers, porcelain points simply require a mold (and a basic ability in pressure-flaking) and thus provide a more widely accessible methodology. Finally, where tight controls on stone point manufacture may mean that preparation takes days or even months, large numbers of molded points (or other finished/near finished forms) can be made in a much shorter time-frame. When taking these considerations into account, it seems that molded porcelain holds great potential for controlled experiments in some types of use-wear studies.

DISCUSSION

Major Advantages

Of the many advantages of using porcelain, consistency in replication, flexibility in sample type and size, and widespread commercial availability of the same material are some of the most important for promoting its use in archaeological experimentation. While flakeable stone can often be hard to find, difficult to collect and preshape, and expensive to transport, porcelain offers an excellent substitute for testing, especially in allowing repeatability, one of the key tenets of scientific experimentation (Coles 1973:15–18).

Drawbacks and Limitations

While porcelain may be usefully applied in most experiments, there are some occasions where it cannot be substituted. For example, experiments investigating the properties of specific material types, such as the effects of heat treating upon various flints, can only be conducted using those specific materials. While the fracture properties of porcelain are similar to flint, it is not a perfect replica of any individual material type, which can be highly variable.

Furthermore, shrinkage during the drying and firing processes mean that a mold made from an original artifact would not produce an identical piece, although any alterations would likely be negligible and proportional. Moreover, the edges of porcelain blanks tend to be rounded when removed from a mold. While these may be modified before firing, where finer details including flake scar patterning are desirable, these pieces must still be knapped subsequent to firing. This would, however, remain an easier task than that of starting with varied pieces of stone.

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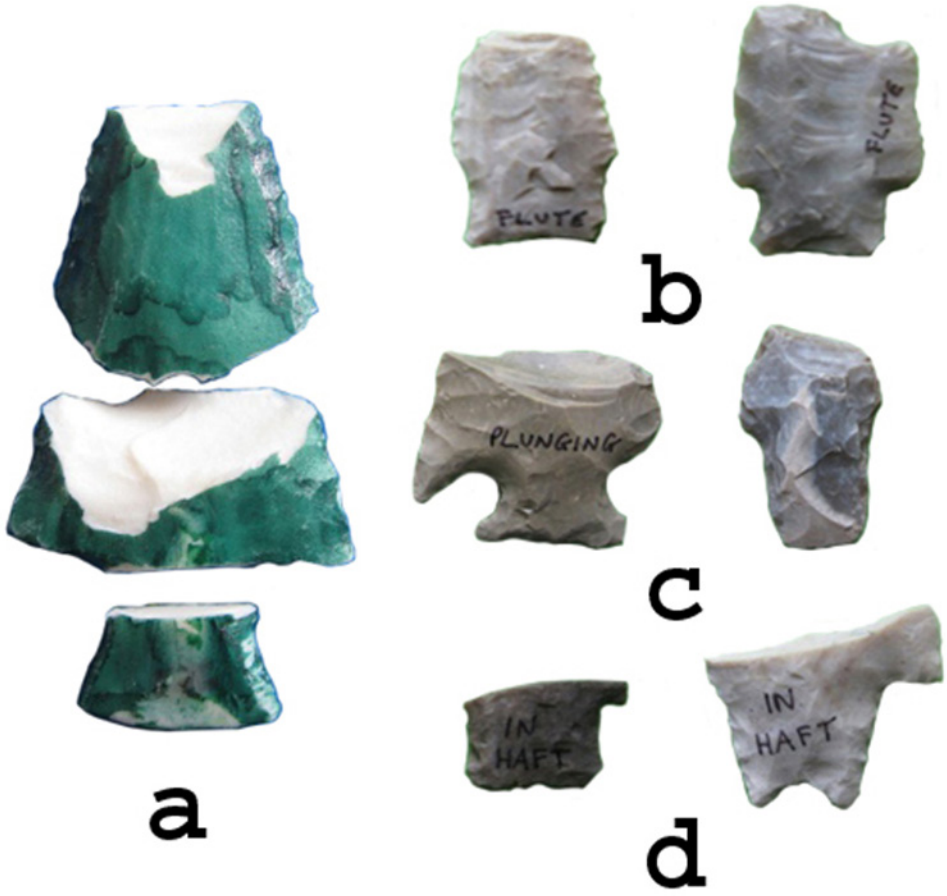


FIGURE 8. Three types of fracture noted on one of the porcelain points (a), each of which can be directly compared to archaeological specimens from the Gault site, Texas. This comprises impact fluting (b), a longitudinal or "plunging" macrofracture (c), and a transverse macrofracture (d) that occurred in the haft.

Other Applications and Future Refinements

The use of porcelain in archaeological experiments is still at an early stage of development, but it has already produced promising results in a number of experiments. Following the success of those experiments discussed above, porcelain has also been used in experiments investigating blade and handaxe transmission chains (Stuart Page, personal communication 2012), snapped Clovis blades (Klemenic 2012), and the edge angles of Clovis adzes (O'Leary 2012). Current work is also looking into the use of liquid porcelain for pouring into molds, which would increase the range of shapes available for experimentation. Further development and refinement of the techniques will allow porcelain to be applied more widely to archaeological experiments, improving their consistency and repeatability, and thus increasing the utility of these experiments for interpreting the archaeological record.

CONCLUSION

Experiments in archaeology are plagued with drawbacks and limitations, particularly in the field of stone tool studies, where materials can often be inconsistent, expensive, and difficult to source. The skills required to manufacture replica tools and preforms used in experiments means that many are restricted by both the investigator's ability and the time available. Due to these constraints, we have proposed the use of molded porcelain. Easily controlled, manipulated, and widely accessible, we suggest that this material has the potential to extend the comparability of stone tool studies internationally for current and future experimental archaeologists. It has the potential to become a standard medium that will allow direct comparisons through time and space.

Acknowledgments

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