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## Reviewed Article:

# Cross-Contamination via Stone Tool Use: A Pilot Study of Bifacial Butchery Tools

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The pathogenic environment has been a constant shaping presence in human evolution. Despite its importance, this factor has been given little consideration and research. Here, we use experimental archaeology and microscopic analysis to present and support a novel hypothesis on the pathogenic properties of bifacial butchery tools during the Middle Pleistocene. Use-wear evidence from the Acheulean site of Boxgrove, Sussex suggests that a sample of flint bifaces were used for butchery tasks for a remarkably limited duration. Circumstantial evidence from other Acheulean sites, such as the apparent discard of bifaces at single-episode butchery sites, and biface caching sites, also suggest limited-use, and extend this interpretation beyond Boxgrove. There is no current utilitarian explanation for why such an apparently over-engineered tool would be discarded after such a limited duration of use. This pilot study demonstrates, via experimental investigation, that residual biological matter from performing butchery tasks cannot be completely removed from the flake scars of flint bifaces using prehistorically available cleaning methods. It is argued that the biological matter is likely to begin spoiling within hours of butchery, which poses a significant risk of introducing pathogens into foodstuffs if the biface is reused, resulting in foodborne illness. Subsequently, hominins likely learned to minimise this risk by discarding each flint bifacial tool after a single episode of butchery.

> Experimental archaeology has revolutionised our understanding of lithic technology specifically in terms of its manufacture and practical use, and the skill and expertise required for some of the more elaborate items. Likewise, microscopic analysis has begun to indicate the materials with which some of these tools were used. However, these approaches, with their focus on the moment of action, have missed what may be one of the most significant aspects of hominin life, the pathogenic environment that is created when biological

## Introduction

The recent global COVID-19 pandemic placed renewed attention on the effects of pathogens. Archaeologists have long been interested in such punctuated type events, such as the 14th Century Black Death, or the 6th Century Justinian plague. As well as the pathogen itself, *Yersinia pestis*, being directly detected (Bos, et al., 2011), the effects of the 14th Century Black Death can be seen in everything from regional changes in land use (Izdebski, et al., 2022), to increases in animal protein consumption (Zechini, et al., 2021), and an increase in higher value items being more widely recovered, all reflecting changes in the social landscape (Oksanen and Lewis, 2023).

It has long been thought that human concern with pathogens appeared with the Holocene, linked to the emergence of agriculture and the possible spread of zoonotic diseases from domesticated animal species, along with increased population densities resulting from sedentism and urbanisation (Karlen, 1996; Barrett, et al., 1998; Armelagos and Harper, 2005). Recent genomic work, however, reveals that many modern pathogens have a Pleistocene origin (Houldcroft and Underdown, 2016) requiring us to change focus from large-scale, punctuated "plague" type events to a more gradualist type relationship with pathogens as a constant shaping presence in human evolution. Despite the importance of this pathogenic environment to human evolution, it remains chronically under-theorised, often without any consideration matter adheres to lithic tools after use.

in syntheses of the archaeological record except when visible as pathologies preserved on fossilised skeletal remains (Odes, et al., 2016).

We believe that experimental archaeology and microscopic analysis has much to offer here. Modern biomolecular methods can be used to sample and characterise the pathogenic profile of an experimentally recreated activity, such as food storage using ceramic containers, or experimental butchery. This extension of the concept of 'tool use-life' to include the pathogenic profile resulting from use can then be operationalised within the *chaîne opératoire* to help understand possible design features, use-cycles, and eventual discard behaviours that might be explained through pathogenic considerations.

To demonstrate the importance and utility of an experimental approach we present a pilot study - 'The *Pathogenic Hypothesis*' - which shows that the re-use of Acheulean bifaces for butchery may have unrealised pathogenic consequences. By way of a specific example, we focus on the British Middle Pleistocene site of Boxgrove with its abundance of bifaces (Roberts and Parfitt, 1999), which use-wear analysis suggests that these tools had a very short 'use life'. (Mitchell, 1998).

## The *Pathogenic Hypothesis*

The *Pathogenic Hypothesis* proposes that the risks of cross-contamination between butchery episodes may explain the observed discard patterns of Acheulean bifaces which appear to only have been minimally used. Many Acheulean bifaces show no signs of use (Potts, Behrensmeyer and Ditchfield, 1999; Goren-Inbar, et al., 2018; Méndez-Quintas, et al., 2018), which could be explained by them being used as a 'single-use' butchery tool. Microscopic wear from butchery is very slow to form (Keeley, 1980), with a single short-duration butchery episode being unlikely to leave any evidence that could be confidently interpreted. A use-wear study by Mitchell (1998) on the Acheulean bifaces from Boxgrove concluded that these bifaces were used for roughly 15 minutes of butchery.

During stone tool manufacture, many of the retouch scars terminate in steps, hinges, and fissurated flakes, which together we call micro-niches (See Figures 1 and 2). On a bifacially worked tool, like the Acheulean biface, such micro-niches are abundant on both faces and often concentrated near the edges as a result of final shaping. These act like a physical trap where biological matter from butchery can become lodged and accumulated. Trapped material, such as this, is very difficult to remove even with laboratory cleaning methods involving corrosive reagents. If the trapped biological matter cannot be removed from these micro-niches using cleaning methods available during the Middle Pleistocene, then safe decontamination of Acheulean bifacial butchery tools was likely not possible. Re-use of a contaminated butchery tool for future food processing poses a risk of severe foodborne illnesses which still pose a lethal threat today (https://www.who.int/health-topics/foodborne-diseases#tab=tab_2). The *Pathogenic Hypothesis* proposes that hominins may have minimised the health risk associated with contaminated tools by discarding them following a single episode of butchery.

Circumstantial archaeological evidence supports this hypothesis, including (a) discard patterns and (b) biface 'caches'. Acheulean butchery sites across Eurasia have yielded bifacial tools in association with the cut-marked faunal remains, which suggests the tools were discarded after being utilized for butchery tasks, rather than being retained and transported for future use (e.g., Piperno and Tagliacozzo, 2001; Solodenko, et al., 2015). Additionally, multiple Acheulean sites across Afro-Eurasia have yielded dense accumulations of *in situ* bifacial tools, which do not show evidence of use (Potts, Behrensmeyer and Ditchfield, 1999; Goren-Inbar, et al., 2018; Méndez-Quintas, et al., 2018), which are often interpreted as 'tool caches' (e.g., Potts, Behrensmeyer and Ditchfield, 1999). This is also enigmatic, as manufacturing such large surpluses should not be necessary if each tool can be reused multiple times.

## Methodology

### Experimental bifaces

To test our *Pathogenic Hypothesis*, nine replica flint Acheulean bifaces were manufactured by one of the authors (CS). The manufacture included both hard and soft hammer percussion, to produce tools technologically and morphologically similar to those found in the Middle Pleistocene (See Figure 3).

Prior to experimental butchery, the tools were cleaned using a five-minute soak in 1m NaOH and inspected using a Meiji techno RZ binocular microscope with an LED ring light. All tools were clear of any adherent residues and, from this point on, handled only with unused nitrile gloves and stored in unused resealable plastic bags.

### Butchery

Commercially available chicken carcasses (from Aldi supermarket) were chosen for the butchery since they offer a ready supply of biological matter that is consistent in nature for the purposes of the experiment. The carcasses used had already undergone the initial stages of butchery, having had the feathers, head, feet, and organs removed. While a commercially available chicken carcass has little recognisable ecological authenticity to the period, the low-fat content and lack of fur on such animals are likely to reduce the level of contamination described below.

Each of the bifaces was used to butcher half of one chicken carcass. The butchery episode lasted approximately ten minutes and involved the use of the lateral edge of the biface in a sawing action to remove the breast, along with the use of the tip and butt of the tool in a percussive action to remove the legs and wings (5 minutes duration). This was followed by dicing the breast meat and de-fleshing the bones (5 - 8 minutes duration), using the lateral edge with the lowest handling resistance.

### Middle Pleistocene decontamination experiments

Three decontamination methods were used to test experimentally the likely effectiveness of decontamination processes available to Middle Pleistocene hominins in Europe: the water, soapwort, and ash methods. These methods were chosen based on their known utility in decontamination and the ready availability of suitable materials to perform each one in the Middle Pleistocene (Hosfield, 2022). Each method was used on three experimental bifaces.

### Water method

The water method is the most readily available method to decontaminate a bifacial butchery tool, submerging and/or rinsing it in a body of freshwater. In this cleaning method, bifaces were rinsed under a domestic tap for 60 seconds, whilst being rotated and wiped with gloved fingers to remove any macroscopically visible biological matter. The biface was then soaked in a container of clean room-temperature tap water for 30 minutes, before being rinsed again for a further 60 seconds. The *water* method was performed with experimental bifaces #01, #02, and #03. The use of English tap water slightly reduces the ecological validity, being filtered and chlorinated, and having a different chemical and biological content to natural freshwater sources (i.e., a stream).

### Soapwort method

This is a more aggressive cleaning method than water whilst still using available Middle Pleistocene materials. It uses a soap-producing plant - soapwort, high-temperature water, and an animal hide 'cloth'. Water is more effective at removing residue at a higher temperature; however, whether Acheulean populations had the technology to artificially raise water temperature is unclear (Speth, 2015). Soapwort (*Saponaria officinalis*) is a contemporary plant documented as a cleaning agent in ethnographic literature (Thompson, 2019) and in ancient history (Cropley, 2020). The roots of soapwort contain the compound saponin at concentrations of up to 20%, which produces a soapy lather when agitated by water (Nowrouzi, Mohammadi and Manshad, 2020). Soapwort is likely an effective and ecologically valid decontamination method, and it is distributed across contemporary Europe. It may well have been available to the Middle Pleistocene inhabitants of Boxgrove and other European Acheulean populations.

The cleaning solution was produced using ten grams of commercially available dried and crushed soapwort roots, which were mixed into 300ml of tap water heated to 100°C. The solution was stirred for five minutes to agitate the saponin compound and produce a lather.

The solution and the contaminated biface were placed into a sealed plastic container for 30 minutes. The biface was removed from the solution for ten minutes whilst a hide cloth, itself soaked and continuously dampened in the solution, was used to scrub the surface and working edges of the biface. After this, the biface was resealed in the solution for a further 30 minutes, before again being removed and scrubbed for ten minutes. The soapwort method was performed with experimental bifaces #04, #05, and #06.

### Ash method

The ash method utilises the chemical properties of biological matter itself to decontaminate the biface. The high alkaline content of wood ash causes it to react with lipids in the biological matter and saponify (i.e., turn into soap), allowing it to be easily rinsed off with water. Ash also works as a mechanical cleaning agent by agitating and absorbing potential contamination. European holly (*Ilex aquifolium)* wood was chosen to produce the ash for this experiment; it is exceptionally high in alkaline content with a distribution across Northwest Europe.

For this method, the biface was entirely submerged in a deep container of holly ash to ensure maximum coverage. The biface was then thoroughly rinsed off under a water tap for one minute. This process was continuously repeated for 30 minutes. The ash method was performed with experimental bifaces #07, #08, and #09.

### Storage

After each of the cleaning experiments, the bifaces were left to air-dry on a clean surface before being stored in a new sterile bag. The duration of storage between cleaning and later microscopic analysis was roughly 12-24 hours.

### Microscopic analysis

Experimental bifaces were analysed using a Meiji techno RZ binocular microscope using an LED ring light to identify sites containing biological matter. Each biface was primarily analysed at a 7.5x to locate potential micro-niche traps, followed by the use of a higher magnification (up to 75x) to investigate any traps detected. The full investigation and recording of micro-niches with biological matter took approximately one hour for each experimental biface.

The frequency and location of individual micro-niche traps of biological matter - hereafter 'sites' - were recorded on an RTI (Reflectance Transformation Imaging) image for each biface. RTI images were selected as a rapid and accurate recording method: they allow key features, such as flake scars, to be easily located. For this preliminary study, the recording of an individual site does not vary according to the size or nature of the deposit of biological matter: it simply records the existence of a surviving continuous deposit of biological matter. Images of micro-niche sites were captured using a Keyence VHX-7000 digital microscope.

## Results

Microscopic analysis of the experimentally used bifaces reveals the presence of surviving biological matter on 100% of the bifaces exposed to the water and soapwort methods (#01 - #06), suggesting they were ineffective at decontamination (See Figure 4). Microscopic analysis identified biological matter on none of the bifaces exposed to the ash method (#07, #08, #09), but extensive contamination with ash was present on 100% of these bifaces (See Figure 4). It is unclear whether the ash had removed the biological matter before contaminating the biface, or whether deposits of biological matter remain underneath the ash. This requires further experimental investigation to determine, however, as the tool is still contaminated with biological material, bifaces #07, #08, and #09 are, for the purpose of this experiment, treated as contaminated, and the ash method as ineffective. A record of the frequency and location of contamination sites for each experimental biface is illustrated in *supplementary material 1* (for example, See Figure 5 and 6).

## Discussion

The results of this study suggest that each of the three potential decontamination methods used was ineffective for the removal of biological matter from the micro-niches present on bifaces following an episode of butchery. Biological matter remains present on every one of the bifaces used in this experiment.

It might be argued that alternative decontamination methods would be more effective, which will be further explored in future research. One alternative cleaning method might be sterilisation; applying extreme heat to the tool to neutralise any pathogens. Two possible sterilisation methods might have been possible: placing used tools directly in a fire, or placing used tools into a container of boiling water. However, extended direct heating of stone leads to diagnosable macroscopic patterns (i.e., reddening, lustre increase, and thermal shock breakages (Domanksi and Webb, 2007), and such evidence has not been observed in the archaeological record before the Mousterian (Copeland, 1998). It might be possible that short periods of exposure to fire, which does not leave obvious signs of heating, could be an effective decontamination method. The sterilisation method - placing contaminated bifaces into boiling water for extended periods - would not produce the same macroscopic evidence on the lithics as exposure to fire since the temperatures do not exceed 100°C. Despite there being no ceramic vessels known for the Middle Pleistocene (Hommel, 2014), boiling has been experimentally demonstrated through the suspension of a hide over a fire, or through the addition of heated rocks as "potboilers" (Langley, et al., 2023). The evidence for directly heated rocks also first appears in the Mousterian (Speth, 2015). Suspension in boiling water potentially offers a decontamination method from that time period onwards, but it should be remembered that the soapwort decontamination method employed in the experiments recorded here also used boiling water, and this method appears to have had no success in removing the adherent biological matter following butchery.

### Implications of the re-use of butchery tools

The presence of surviving biological matter on the experimentally cleaned bifaces following a single episode of butchery makes it clear that archaeologists of even the earliest periods need to consider the implications of the reuse of contaminated tools more rigorously. Contemporary bacteria commonly associated with spoiled biological matter and foodborne illness (e.g., *Campylobacter jejuni*) often cause debilitating symptoms of diarrhoea and vomiting which last roughly five days (Young, Davis and DiRita, 2007). There are multiple hypothetical scenarios in which the reuse of a contaminated biface could result in foodborne illness during the Middle Pleistocene (See Figure 7).

### Scenarios 1 and 2: Bacteria cross-contamination

Using contaminated butchery tools to process food likely results in cross-contamination: analogous to the situation controlled by modern regulations on cutting board use (Cliver, 2006). If food is fully cooked after cross-contamination (scenario 1), bacteria will be neutralised and not result in foodborne illness. However, if food is not fully cooked after (e.g., processing of readily edible plantstuffs), then bacteria introduced into the food will likely cause foodborne illness.

### Scenario 3 and 4: Preservation and storage

Methods of preserving and storing meat used by recent hunter-gatherers, include drying, smoking, or freezing, which inhibit bacterial growth and toxin release. Middle Pleistocene hominins may have used such preservation techniques to extend the calorific yield of large game (e.g., Piperno and Tagliacozzo, 2001; Solodenko, et al., 2015; Pope, Roberts and Parfitt, 2020). In hot climates, meat can be preserved by sun-drying in thin strips (Hawkes, O'Connell and Blurton Jones, 2001; Wiessner, 2002), whilst the same process can also be replicated in cold climates using fire (Soffer, 1989), in addition to smoke-drying (e.g., Duffy, 1995). Finally, freezing meat is possible at extremely high latitudes, either by burying the meat in snow or similarly cutting it into thin strips, allowing the cold arid air to freeze the meat (e.g., Giddings, 1967).

Fire-drying, smoke-drying, or freezing meat to preserve it may have been in the behavioural and technological repertoire of Middle Pleistocene hominins suggesting that, if preservation was performed successfully, any bacteria introduced by the contaminated biface might have been inhibited with no later foodborne illness. However, research into modern drying preservation methods (Little, 1998), suggests that many strains of pathogenic bacteria can often survive the preservation process. Therefore, the preserved meat would still need to be cooked to be safe. In recent hunter-gatherer groups, dried meat becomes a 'jerky' which is typically consumed without cooking (Hawkes, O'Connell and Blurton Jones, 2001; Wiessner, 2002) whereas smoked or frozen meat is still typically cooked before consumption (Duffy, 1995).

### Scenarios 5 and 6: Toxin volume

Modern food safety regulations (Collins, 1997) state that raw meat begins to spoil (i.e., accumulate bacteria and toxins) after 4 hours. This suggests that an Acheulean biface may safely be reused within a 4-hour time window before a harmful volume of toxins in the biological matter adhering to the tool is reached. It has been proposed by archaeologists, however, that the time interval between butchery events for the inhabitants of Boxgrove was more likely days, not hours, due to an exclusive exploitation of megafauna, based on the Boxgrove faunal assemblages (Pope, Roberts and Parfitt, 2020) and this also tallies with the subsistence practices of ethnographic analogues (e.g., the Cree, Lee and Daly, 1999). The Cree people of Canada are an appropriate contemporary ethnographic analogue for the inhabitants of Boxgrove during interglacial, due to affinities in latitude (i.e., Hayden, 1981) and palaeoenvironment (Böhme, 2010), who historically hunted megafauna (Leeand Daly, 1999). Megafauna, such as a horse, (Pope, Roberts and Parfitt, 2020), could likely feed a band of 12 individuals for roughly two days (See Appendix 1). This would allow two days for bacteria to accumulate and release toxins onto the biological matter on the butchery biface, thus creating a risk of foodborne illness.

### Hominin response: single-use

The most severe possible outcome from foodborne illness is fatality. For those that survive, the severity of the symptoms from foodborne illness would produce strong selective pressure for the development of mechanisms to avoid it. It may be that this adaptive response was partially biological in nature with Middle Pleistocene hominins becoming able to tolerate greater toxicity than modern *Homo sapiens.* While this might be true, by the Middle Pleistocene, hominins have begun to develop sophisticated cultural adaptions to their environment (Hutchence and Scott, 2021) and we might examine the possible existence of cultural responses to major problems. Since neither decontamination nor sterilisation are likely solutions, the *Pathogenic Hypothesis* raises the possibility that hominins might have learned to discard bifaces after single episodes of butchery to avoid foodborne illness.

We are not proposing that such hominins possessed a modern understanding of contamination and disease, but that such a form of discard behaviour would have become enculturated in a manner consistent with each group's cosmology and other cultural norms as is frequent in recent hunter-gatherer groups (e.g., Marshall, 1962).

This discard behaviour has parallels with non-human primates, which do not practice scavenging behaviour, and are observed to self-medicate through the consumption of specific plants (Huffman, 1997). These behaviours, however, have proximal cues, such as the scent of rotting meat, or the sensation of being unwell. The discard of bifaces used in butchery to prevent future illness requires mental time travel (Suddendorf and Busby, 2003; Suddendorf, Addis and Corballis, 2011) to recall past events which have a causal relationship to those in the present (Shipton and Nielsen, 2015) and project this 'historical' understanding to the future. Such evidence for mental time travel and understanding causality adds to the growing evidence for cognitive complexity which appears to have expanded rapidly during the Middle Pleistocene (e.g. Twomey, 2014; Joordens, et al., 2015; Barham, et al., 2023).

## Conclusion

Experimental archaeology has revolutionised our understanding of lithic technology specifically in terms of its manufacture and practical use, and the skill and expertise required for some of the more elaborate items. Likewise, microscopic analysis has begun to indicate the materials with which some of these tools were used. However, these approaches, with their focus on the moment of action, have missed what may be one of the most significant aspects of hominin life, the *pathogenic environment* that is created when biological matter adheres to lithic tools after use.

We hope to have demonstrated that experimental approaches offer a further opportunity to examine this forgotten environment. This pilot study has shown that an appreciation of potential pathogenic risks may explain specific patterns in the archaeological record by demonstrating that safe decontamination of flint bifacial butchery tools is likely to be not possible, and their later re-use poses the risk of foodborne illness. The most likely occasions for the transfer of foodborne illness would occur during the processing of foodstuffs without later cooking, preserving meat by drying, or introducing toxins, which cannot be neutralised by high temperatures.

Finally, we have also suggested that Middle Pleistocene hominins were likely cognitively capable of identifying a cause-and-effect relationship between the re-use of bifaces for butchery tasks and later symptoms of foodborne illness, contributing to the archaeologically-evidenced behaviour of bifaces discarded after a single episode of butchery. This learning process would not need to be repeated each generation, as social mechanisms would likely enforce the behaviour throughout generations, resulting in it becoming integrated into Acheulean cultures.

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## Statements and Declarations

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### Attachment(s)

Supplementary Information 1: Microscopic Data - Biface #01 (water) (1.25 MB)
Supplementary Information 1: Microscopic Data - Biface #02 (water) (1.18 MB)
Supplementary Information 1: Microscopic Data - Biface #03 (water) (1.16 MB)
Supplementary Information 1: Microscopic Data - Biface #04 (soapwort) (1.17 MB)
Supplementary Information 1: Microscopic Data - Biface #05 (soapwort) (1.11 MB)
Supplementary Information 1: Microscopic Data - Biface #06 (soapwort) (1.25 MB)
Supplementary Information 1: Microscopic Data - Biface #07 (ash) (1.09 MB)
Supplementary Information 1: Microscopic Data - Biface #08 (ash) (1.13 MB)
Supplementary Information 1: Microscopic Data - Biface #09 (ash) (1.08 MB)

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# Appendix 1

1. Deer carcass provides 60,000 calories.
2. A band of 12 individuals, with an average daily calorie consumption of 2500 calories, amounts to 30,000 calories (2500 x 12 = 30,000).
3. Deer carcass would last two days (60,000 / 30,000 = 2).

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## Gallery Image

FIG 1. EDGE OF EXPERIMENTAL TOOL SHOWING HIGH DENSITY OF 'MICRO-NICHES' TERMINATIONS (20X). SOURCE: WHITEHEAD

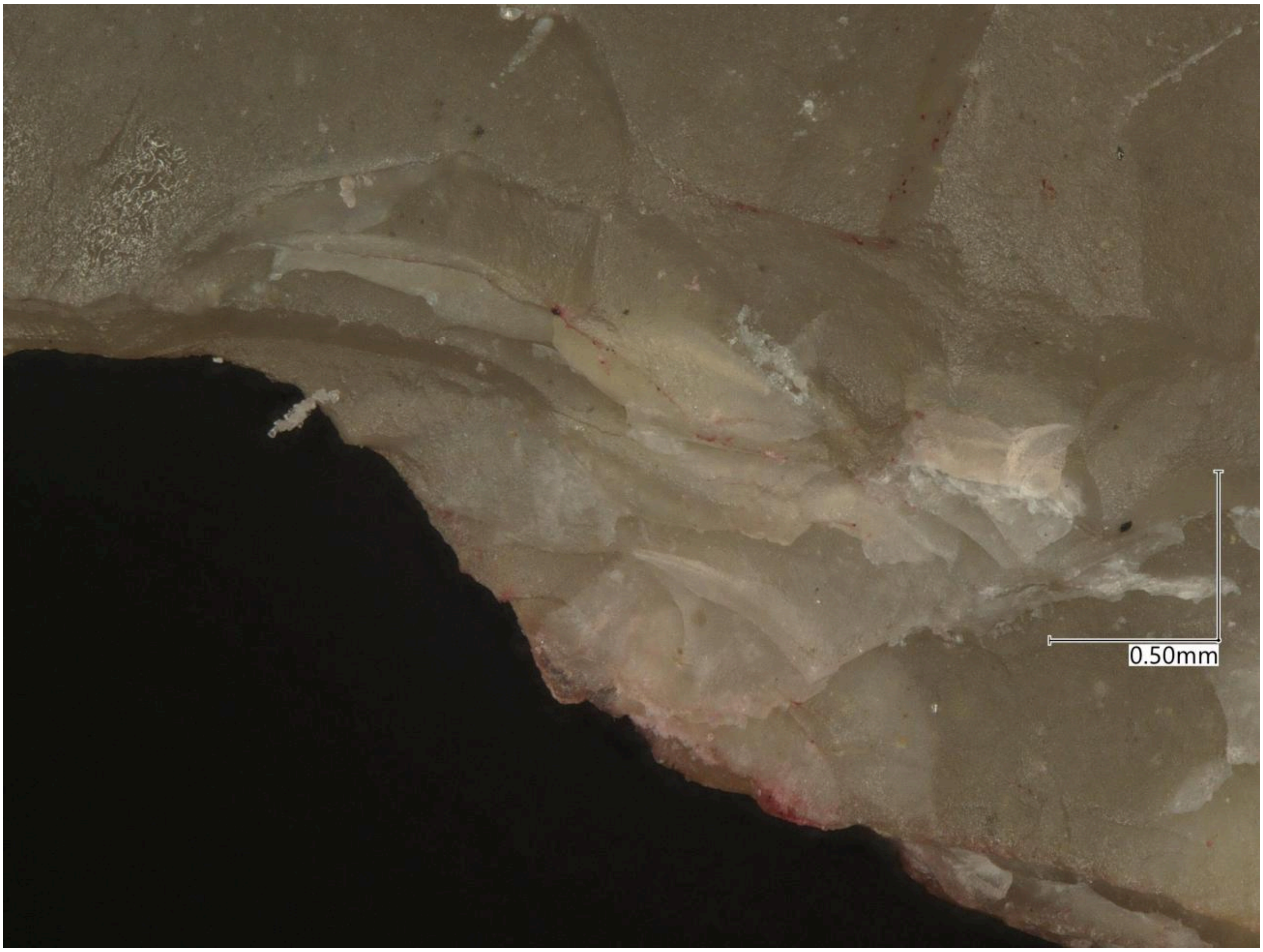


FIG 2A. CLOSE-UP VIEW OF EDGE WITH HIGH AMOUNTS OF FISSURATED FLAKES AND ADHERENT BIOLOGICAL MATTER (80X). SOURCE: WHITEHEAD


FIG 2B. CLOSE-UP VIEW OF EDGE WITH HIGH AMOUNTS OF FISSURATED FLAKES AND ADHERENT BIOLOGICAL MATTER (80X). SOURCE: WHITEHEAD


FIG 2C. CLOSE-UP VIEW OF EDGE WITH HIGH AMOUNTS OF FISSURATED FLAKES AND ADHERENT BIOLOGICAL MATTER (80X). SOURCE: WHITEHEAD

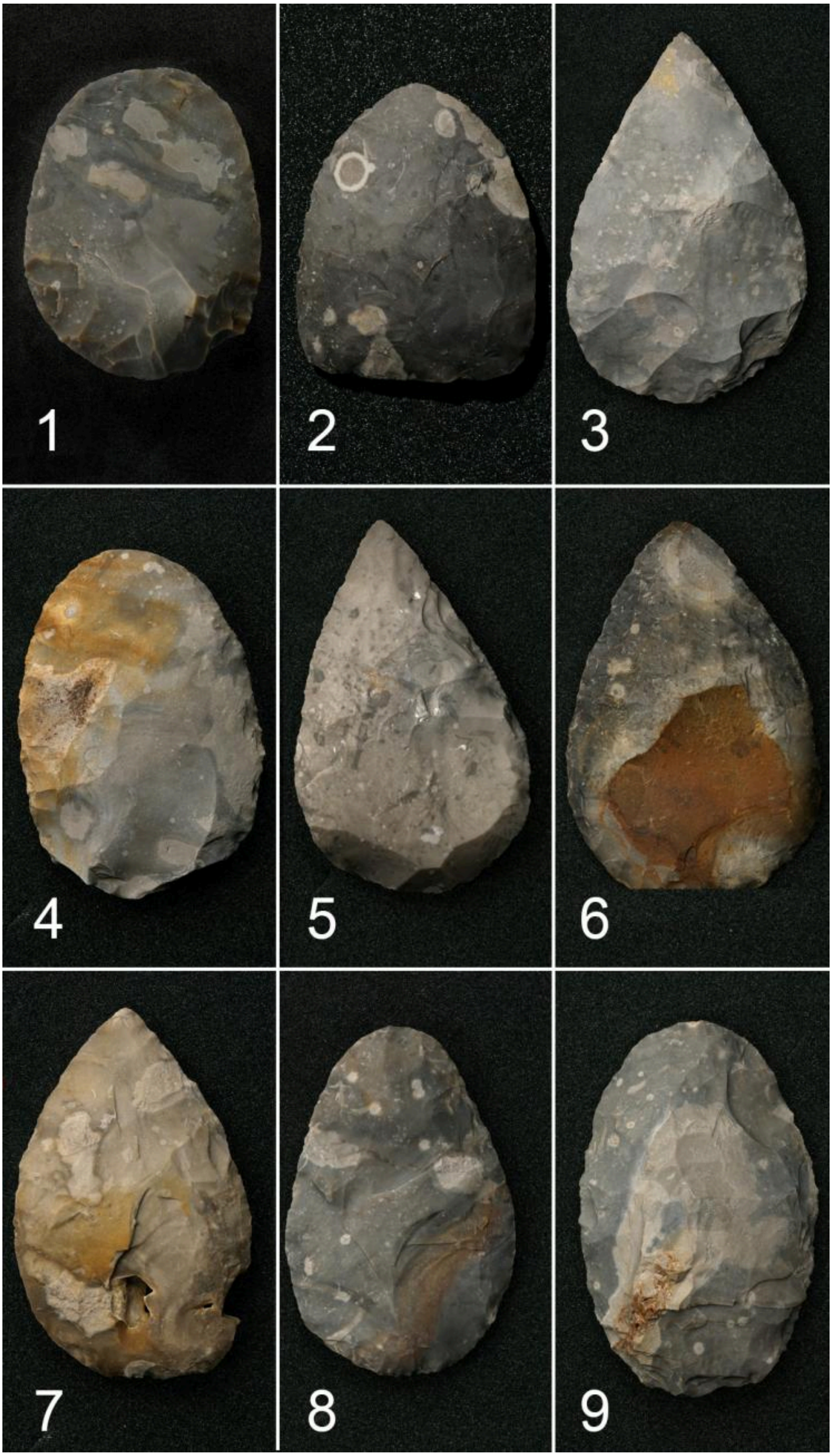

FIG 3. EXPERIMENTAL TOOLS USED. SOURCE: WHITEHEAD

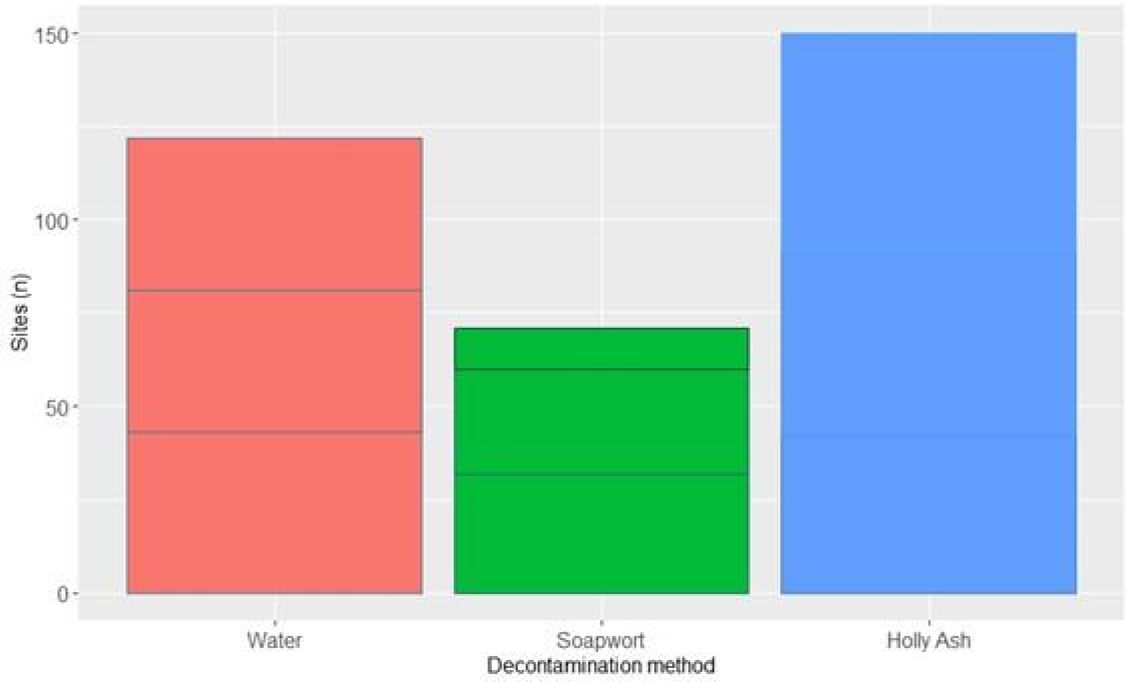


FIG 4. FREQUENCY OF BIOLOGICAL MATTER SITES ACROSS EACH OF THE EXPERIMENTAL BIFACES BY DECONTAMINATION METHOD. SOURCE: WHITEHEAD

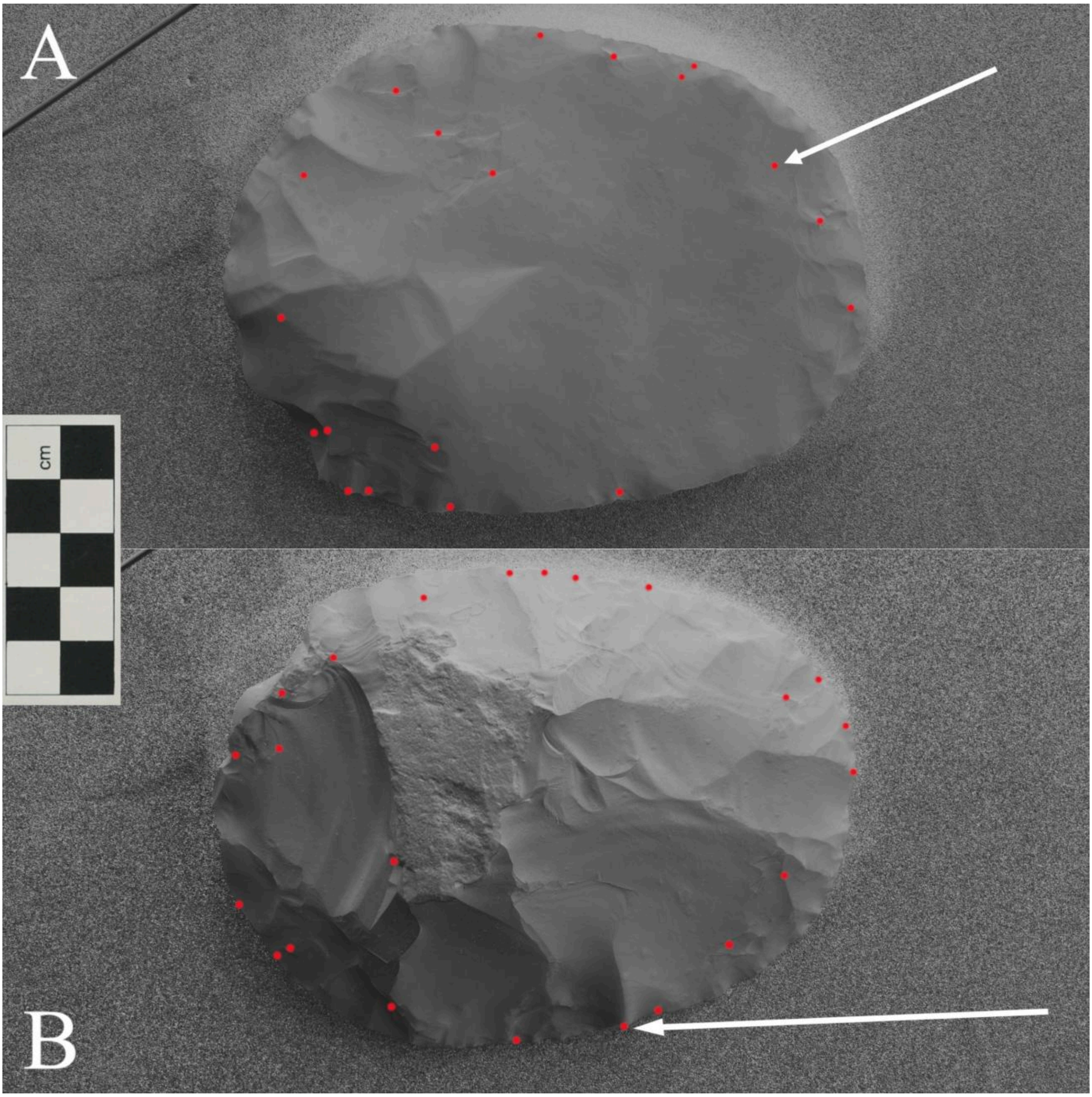


FIG 5. DIGITAL MAP OF BIFACE #01, SHOWING FACE A (TOP) AND FACE B (BOTTOM). RED DOTS MARK BIOLOGICAL MATTER SITES. ARROW POINTS TO THE EXAMPLE IMAGE FOR EITHER FACE. SOURCE: WHITEHEAD

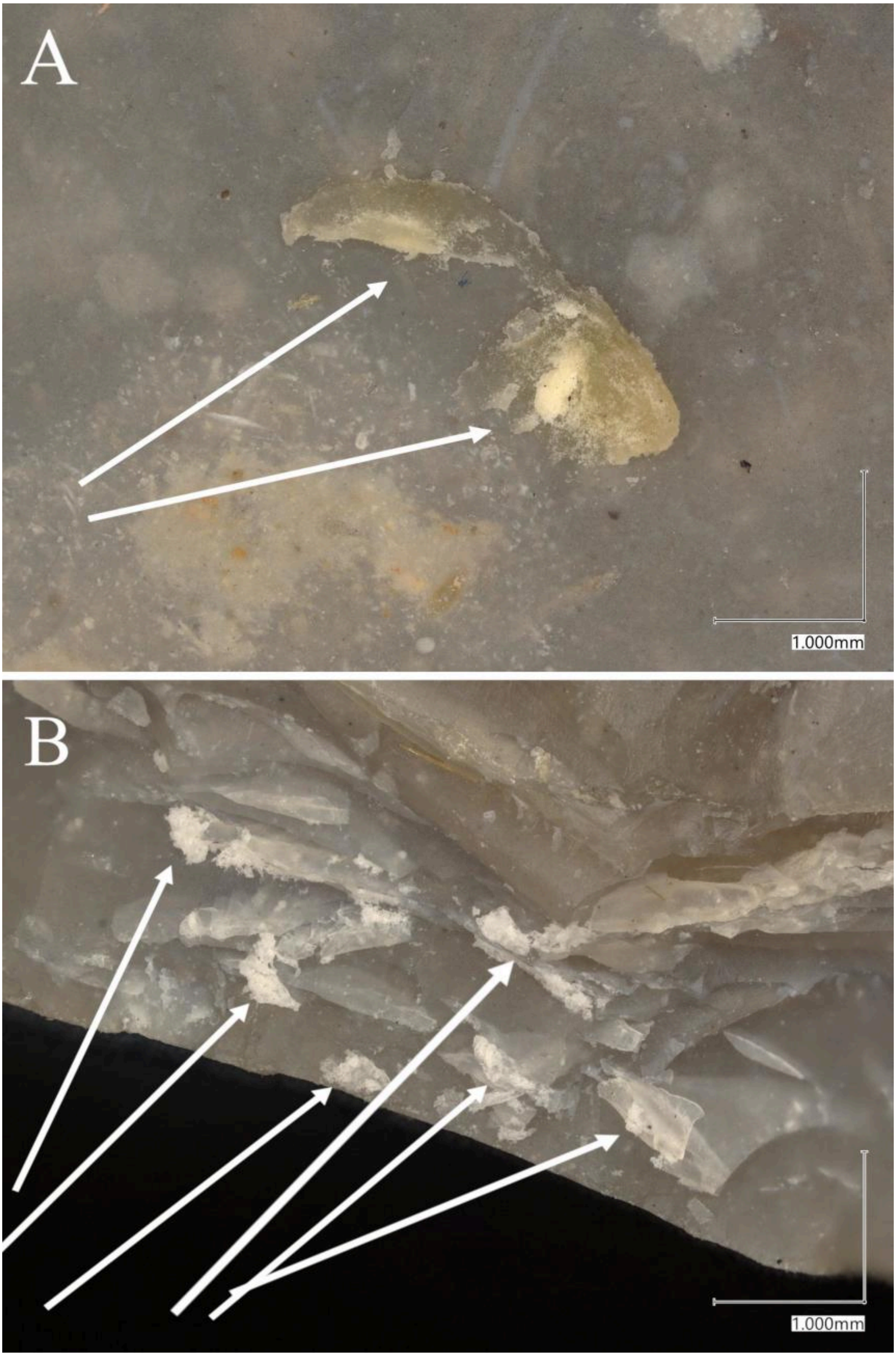


FIG 6. PHOTOGRAPHIC EXAMPLE OF BIOLOGICAL MATTER ON EITHER FACE OF BIFACE #01. ARROWS POINT TO DEPOSITS OF BIOLOGICAL MATTER. SCALE ON THE BOTTOM RIGHT-HAND CORNERS. SOURCE: WHITEHEAD

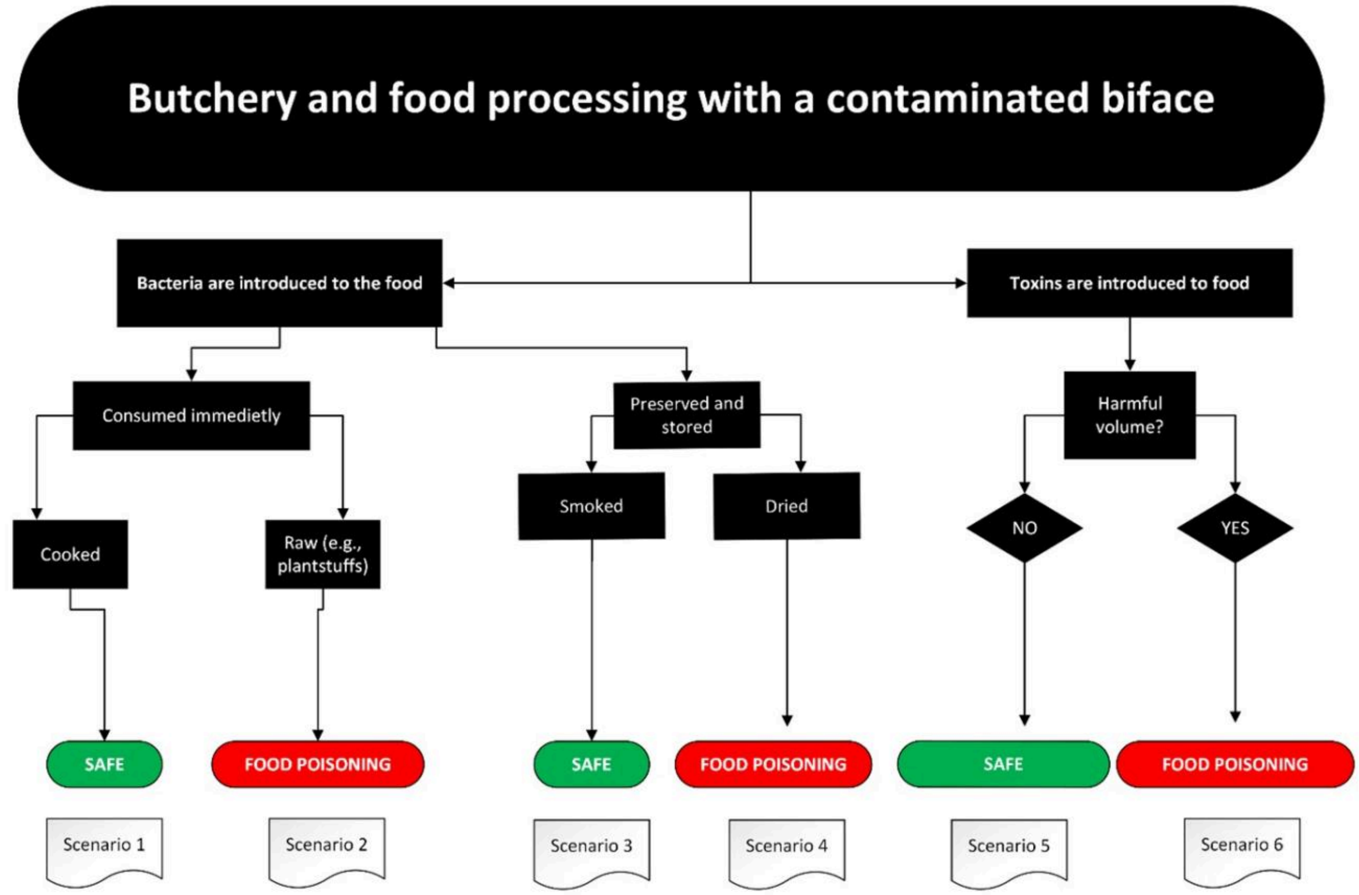


FIG 7. FLOW CHART OF HYPOTHETICAL OUTCOMES OF USING A BUTCHERY-CONTAMINATED BIFACE FOR FURTHER FOOD PREPARATION. SOURCE: WHITEHEAD