



Putting ochre to the test: replication studies of adhesives that may have been used for hafting tools in the Middle Stone Age

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Abstract

Substantial frequencies of Middle Stone Age (MSA) lithics from Rose Cottage and Sibudu Caves in South Africa have red ochre on their proximal and medial portions. Residue studies suggest that the tools were hafted and that the ochre may be part of the adhesive used for hafting the tools. Replication studies show that ochre is indeed a useful loading agent for adhesive; however, there are other potential loading agents. It is also possible to use unloaded plant resin, but this agent is brittle and difficult to work with. It appears that people living in the MSA had wide knowledge of ingredients suitable for hafting tools, and that they chose different adhesive recipes because of the required properties of the adhesive. Brittle, unloaded adhesive allows a projectile head to disengage its haft and implant itself in an animal; robust adhesive keeps a spearhead safely in its shaft.

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Introduction

This study has its roots in the observation, made some years ago, that many stone tools from Rose Cottage Cave, South Africa, have red ochre on them. Residue and macrowear studies of these MSA tools and similar tools from Sibudu Cave, also in South Africa, are described in this paper.

The positions of the ochre suggest at least three reasons for its presence: (1) some pieces are ochre-covered because they fortuitously rested on ochre-stained ground, (2) others seem to have been used to cut or scrape ochre, and (3) numerous tools have ochre on their bases. It is this latter group that I concentrate on in this paper. My working hypothesis is that many tools were hafted using an adhesive in which red ochre was an ingredient. My hafting replication studies were thus designed to investigate

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the usefulness of ochre as an ingredient in natural adhesives. If the ochre can be shown to have little purpose, then it is feasible that it was added to the adhesive for the sake of its color and possibly for symbolic purposes. Naturally, a symbolic role cannot be totally excluded if the ochre is found to be an advantageous additive to adhesives, but this scenario will suggest that it is unwise to automatically assume symbolism when ochre is present.

Coloring material is present early in African living sites: it was used systematically by about 285 ka at GnJh-15, Kapthurin Formation, Kenya (McBrearty, 2001), and possibly even earlier at Twin Rivers, Zambia, where pigments were found associated with a Lupemban Industry, dating to about 300 ka (Barham, 2002). Barham (2002: 186–187) estimated that about 60 kg of coloring material were recovered from the 1950s excavations. This large quantity of coloring is overshadowed by the tons of specular hematite that were mined from iron pods at Lion Cavern, in the eastern part of South Africa, perhaps earlier than 40,000 years ago. Mining hammers in the form of grooved, heavy-duty stones were found alongside Middle Stone Age (MSA) tools in one of the Lion Cavern adits (Beaumont, 1973: 140). It is difficult to imagine what people were doing with this amount of coloring material, but it looks as if the demand for coloring material increased between the Lupemban and the final MSA. I address the issue of densities of coloring material at the end of this paper.

Not only does the Lupemban Industry document the earliest substantial use of ochre in Africa, but it also has the earliest backed tools. At Twin Rivers, backing accounts for up to 15% of the retouched tools in the Lupemban Industry (Clark and Brown, 2001; Barham, 2002). It might not be coincidental that backed tools and quantities of ochre are found together; the reason for this comment will be made clear below. The Lupemban industry appears to be associated with fossil remains of *Homo heidelbergensis* (elsewhere called *Homo rhodesiensis*) at Kabwe, Zambia (Barham, 2002). There are important implications if these anatomically pre-modern humans were the makers of the backed tools and the users of ochre at Kabwe and at Twin Rivers (and possibly Kalambo Falls). Some archaeologists believe that ochre is always associated with

symbolic behavior (e.g., Knight et al., 1995; Deacon, 1995; McBrearty and Brooks, 2000; Watts, 2002), and others (e.g., Deacon, 1995; Wurz, 1999) consider backed tools to be hallmarks of modern behavior, embodying symbolic expression. If the ca. 300 kyr-old ochre and backed tools are indeed attributes of a symbolic system, then symbolism is not the exclusive property of anatomically modern humans, and archaeologists will need to redefine what it means to be a culturally modern human.

The common assumption about the use of large quantities of ochre in the MSA is that red coloring was used for symbolic body decoration. This conjecture is based on analogy with modern hunter-gatherers living tens of thousands of years later. For example, red body-paint was used for puberty and marriage rituals by !Kung girls in northwestern Botswana in historic times (Marshall, 1976: 277). There is, however, no way of testing whether ancient people practiced body painting, and the application of hunter-gatherer ethnography to the deep past can be problematic; as pointed out by Hovers et al. (2003), ethnographic analogy cannot be used as both a building block of a model and a test of the same model.

Powdered ochre was sometimes placed on the bodies of the dead in southern African Later Stone Age (LSA) sites dating to within the last 10,000 years (Wadley, 1997), but symbolic behavior is already well-documented by this time. In my opinion, the earliest unequivocal evidence for symbolic behavior in Africa comes from Blombos Cave, in the Western Cape, where shell beads were found in a layer that is dated to approximately 77 ka (Henshilwood et al., 2004). These beads are symbolic because they had the potential to play an active role in the articulation and manipulation of social relationships (Wadley, 2001, 2003). As personal ornaments, they were an index of social identity—either group or individual identity. Such expressions of identity are always symbolic. The earliest use of ochre for no clear functional reason comes from the same 77 kyr-old layer in Blombos Cave (Henshilwood et al., 2002). Here, several pieces of engraved ochre were found. The larger Blombos ochre tablet has a crosshatched design engraved inside several broken boundary lines. The decorated ochre was interpreted by

Henshilwood et al. (2002) as evidence for the presence of symbolic behavior and, therefore, cultural modernity at 77 ka. The engraved tablets are certainly compelling evidence for new types of behavior in the MSA. Since the shell beads are already evidence for symbolism at 77 ka, we know that the engraved ochre was made by people who used symbolism. This means that the ochre may have had a symbolic function, but, in my view, the meaning of the engraved ochre remains ambiguous. More than 8000 unworked pieces of ochre were recovered from the same site, so ochre production was common at Blombos (Henshilwood et al., 2002). If the ochre was not always for symbolic purposes, what could the non-symbolic functions have been? In particular, what could red ochre's functions have been before 77 ka, i.e., at 300 ka when quantities of ochre were being brought back to living sites like Twin Rivers?

Henshilwood and Marean (2003: 635) stated that Watts (2002) had effectively critiqued the suggestion that ochre was utilitarian. This opinion is shared by several archaeologists, notwithstanding the evidence from several continents that ochre has properties that make it useful for practical tasks, such as hide-working and adhesive manufacture. This claim does not detract from ochre's worth as a symbolic agent, and it does not deny that, in the recent past, many tasks that on the surface appear practical (such as hunting) can be imbued with symbolism (Wadley, 1987). This claim also does not mean that other substances cannot be used equally well for hide-working or adhesive manufacture. People in the past, like people today, probably chose from a variety of materials when they were carrying out tasks.

Little has been written about the functional uses of ochre, but ochre has been shown to have properties that make it an antibacterial agent (Mandl, 1961: 196; Velo, 1984). In desert Australia, fruits of *Solanum* sp. and the wild fig were packed into balls of ochre the size of a basketball and were stored in trees to conserve them (Flood, 1995: 264). This practice confirms a preservative role for ochre. Red ochre reduces collagenase and is therefore perfect for processing hides (Audouin and Plisson, 1982). Watts (2002) argued that ochre is not needed for tanning, and that there is no practical

reason for the use of red rather than other colors of ferruginous material. The extinct /Xam from the northwestern part of South Africa used red ochre to color leather bags (Bleek and Lloyd, 1911); the custom of coloring some leather bags red continues in parts of Botswana and Namibia (personal observation). It is also correct to say that there are several methods for successfully tanning leather and that ochre is not necessarily a requirement. Southern Ethiopian hide workers, for example, use plain water on their skins (Kimura et al., 2001). Nonetheless, ochre is a valuable tanning agent. Steinman observed Tehuelches in Argentina tanning guanaco hides with ochre and fat in 1906, and Sollas described ochre-assisted hide tanning in Tasmania (in Audouin and Plisson, 1982: 57). Audouin and Plisson (1982) were able to demonstrate that hide processing with red ochre is beneficial, particularly for preventing or reversing decomposition. They treated a three-day-old moose skin when it was already in the first stages of putrefaction. The skin was scraped with flakes, and red ochre was then applied everywhere, except the tail. The hide dried quickly and became thinner and softer, but the tail section that was not covered in ochre rotted. Thus, red ochre seems to be especially desirable for tanning leather where there is a risk of decay.

Another of Audouin and Plisson's experiments involved tanning two pieces of skin from the same ox hide. The piece tanned with yellow ochre (goethite) stayed stiff, thick, and rough, whereas the piece worked with red ochre dried rapidly and became pleasingly thin and soft. Audouin and Plisson deduced that red ochre stops hide from rotting, assists it to dry rapidly, and produces superior leather compared to yellow ochre. Goethite is a hydrated iron oxide, and therefore has higher moisture content than red ochre.

Replication work (Allain and Rigaud, 1986; Wadley et al., 2004) and microscopy (Williamson, 1997, 2004; Gibson et al., 2004; Lombard, 2004, 2005; Wadley et al., 2004) have demonstrated that ochre has at least one other function in addition to its effectiveness as a preserving agent and a tanning agent. Replication studies in France by Allain and Rigaud (1986: 715) demonstrated that successful adhesives depend on a loading agent in the form of an inert powder, such as ochre. Wax and resin do

not mix well without a loading agent, which also encourages the hardening of the adhesive while it dries. The combined ingredients prevent adhesives from becoming brittle. Allain and Rigaud's recipe uses one part beeswax, four parts resin and one part yellow ochre, and the mixture is heated in order to melt the components. A well-known property of goethite is that it readily dehydrates and transforms to hematite with a corresponding color change when it is heated at temperatures as low as 250 °C (Pomiès et al., 1999). This means that archaeologists can expect to find red rather than yellow adhesives when ochre has been used as a loading agent. Pomiès et al. (1999) suggested that yellow ochre that is transformed through heat to a darker color can be structurally distinguished from its unheated hematite counterpart, even when the color is identical. Such a study could be profitable on archaeologically recovered tools.

The French adhesive replication experiments were initiated because some French Paleolithic tools have ochre on them and this required explanation (Audouin and Plisson, 1982; Beyries and Inizan, 1982). A backed blade with ochre on its backed edge was recovered from the Magdalenian Gouy in northern France and, at Lascaux in southwest France, adhesive containing red ochre was noticed on backed bladelets (Audouin and Plisson, 1982: 52). Ochre has been found on stone tools from a further eight French sites, but the position of the ochre is not documented (Allain and Rigaud, 1986).

In a preliminary residue analysis of artifacts from Rose Cottage Cave, South Africa, Williamson (1997) detected the presence of red ochre on many stone tools. A subsequent study of Howiesons Poort Industry backed tools from the MSA of the same site showed that ochre and plant material were often concentrated together on or near the backed edges (Tomlinson, 2001; Gibson et al., 2004). This coincidence suggested that ochre might be part of the hafting process, but the sample was small and was not ideal for residue work because the Rose Cottage tools had been handled and labeled after excavation in the 1980s. It was therefore decided to study untouched MSA stone tools from Sibudu Cave.

Sibudu Cave is approximately 12 km inland from the Indian Ocean and about 40 km north of Durban in KwaZulu-Natal, South Africa. The

surface of the site contains debris from Iron Age occupations; immediately below this are multiple MSA layers containing final MSA dating to about 40 ka (Wadley, *in press*), late MSA dating to between 60 ka and 40 ka (Villa et al., 2005), Howiesons Poort (Wadley and Jacobs, 2004), and pre-Howiesons Poort MSA industries. In a preliminary analysis of 412 late MSA tools (no backed tools were represented here), Williamson (2004) discovered that 29 out of 104 points from the late MSA layers had ochre residues on them, 30 out of 83 scrapers, 23 out of 77 pieces of "other" retouch, and 26 out of 113 flakes had ochre on them. Although the percentages of ochre in each tool class are similar, the position of ochre on tools within the various classes is not the same. For example, only 3% of scrapers have ochre on their working edges, whereas 27% of flakes have ochre residues on their working edges (Wadley et al., 2004). Some flakes may have been used for processing ochre and, in some instances, for processing items such as leather together with ochre. Some flakes appear to have been hafted because 47% have ochre on their proximal and/or medial portions. The proximal end of a tool incorporates the platform and bulb of percussion. In contrast to flakes, 80% of scrapers and 68% of points have ochre on their proximal and/or medial portions. The microscopic analysis of the Sibudu tools with ochre residues shows that, on retouched tools of all classes, the majority of the ochre residues occur on proximal, medial, or a combination of these two positions.

The tools for residue analysis were usually taken directly from their excavated position with sterilized tweezers, and a small soil sample was taken at the site where the tool was recovered. The soil samples were analyzed so that it can be seen whether residues on the tools could have resulted from soil contamination (Williamson, 2004). The tools used for the residue analyses presented here were not contaminated with ochre from the soil. However, patches of ground ochre were sometimes found in Sibudu MSA deposits, and fortuitously ochre-impregnated tools and bones were always recovered from these patches. Such tools were never used for residue analysis. When conducting residue analyses, it is important to understand the

exact provenience and the context of the collection that is being studied.

With only a few exceptions, there are more plant residues on tools that have ochre on their bases than on tools without ochre. This may imply that the tools were secured with plant twine in addition to adhesive.

In a detailed analysis of 24 whole points with ochre residues from the late MSA of Sibudu, Lombard (2004, 2005; Wadley et al., 2004) observed clusters of bending fractures on the laterals within the ochre-stained proximal and/or medial portions of the points. Such fracture damage is consistent with hafting, and it probably results, in part, from the use of binding materials. Unfortunately no tools from Sibudu have been found with large lumps of adhesive on them, but we believe that the multifaceted evidence from the residue and macrowear analyses provide compelling circumstantial evidence for hafting. The combination of ochre and damage to the lower half of the points, sometimes in combination with resin and other plant residues, implies that these tools were hafted and that ochre was one of the ingredients of the adhesive (Wadley et al., 2004). While I assume that the staining of red ochre on the bases (as opposed to the working edges) of stone tools is most often the result of incorporating ochre into adhesives that were used to mount the tools onto handles, this may not always have been the case. Other methods of hafting with ochre are possible: Büller (1988), for example, suggested that tools in the Near East were ochre-stained because they were wrapped in ochre-stained hide and then hafted to bone handles. Not all tools with evidence for hafting in the form of edge damage have ochre traces on their bases; this suggests that adhesive recipes without ochre also existed in the past.

Ochre has been observed on some stone tools from other sites, such as the MSA site of Die Kelders, Western Cape, South Africa (Thackeray, 2000: 157). In Kenya, backed blades from Enkapune Ya Muto, dated to between 50,000 and 40,000 years ago, have red ochre residues on their backed portions (Ambrose, 1998). Historical records suggest that ochre was also recently used as a loading agent for adhesives in Australia, where aborigines combine vegetal fiber and

ochreous dust and sand with their resins (Rots, 2002: 60). San from Namaqualand used “euphorbid milk and red clay” as “cement” for attaching feathers to arrows according to Doctor Atherstone, who made the observation in 1854 (Webley, 1994: 61–62). The red clay may have been ochre. These ethnographic records should not be used as supportive evidence for similar ochre use in the past, but the cross-continental use for ochre in adhesives is, nonetheless, interesting.

Red ochre was sometimes replaced with other ingredients that acted as loading agents. Later Stone Age (LSA) adhesives are not recorded as having ochre in them (Phillipson, 1976; Schweitzer, 1979; Deacon, 1979; Deacon and Deacon, 1980; Binneman, 1983; Binneman and Deacon, 1986; Mitchell, 1995; Jerardino, 2001). Jerardino (2001) noted that the adhesive used for the mounting of a stone adze from Steenbokfontein Cave contained plant fiber (Jerardino, 2001: 862), but no ochre was observed.

As a preliminary observation, it therefore seems that ochre is a useful loading agent for adhesive manufacture, but that it can be replaced with other ingredients. My replication studies, which I shall now describe, were designed to investigate whether the addition of ochre to local resin is as constructive as it was shown to be in France.

Methods

Nodules of hematite (approximately three kilograms of nodules) and coarse sandstone slabs were collected from a quarry in the Wildlife Sanctuary, Moletadikgwa, Limpopo Province, South Africa. Resin from *Acacia karoo* trees and branches from *Grewia flava* shrubs were collected from the same sanctuary. Fibrous leaves of the plant *Hypoxis rigidula* were picked to use for binding material.

Wooden hafts were prepared by cutting a split in the haft or by cutting an L-shaped platform of about 12 mm in width and 18 mm in height. Replicated flakes were made from a variety of local rock types, and 38 flakes were hafted with replicated adhesives.

The hematite formed a centimeter thick crust, as the result of weathering, around an inner core of

ironstone. Powdered coloring material was produced by rubbing each nodule on a sandstone slab. The nodule is most easily worked by rotating it so that several faces are ground. This method produces ground, striated facets on the nodule, which is worked to the inner core until no further coloring can be ground. Consequently, much of each nodule is discarded, even though it still looks red. The three kilograms of nodules produced sufficient hematite powder (about 70 ml) to make adhesive for 28 flakes. The grinding process results in widespread reddening of everything in a meter-wide radius of the activity. Hands, arms, clothing, work surface, and anything lying nearby become covered in fine, red dust.

Each tool was attached to its haft with approximately 5 ml of adhesive. Four basic adhesive recipes were used:

1. *Acacia karoo* resin (5 ml per tool)
2. *Acacia karoo* resin (2.5 ml) mixed with equal quantities of red coloring powder (2.5 ml)
3. *Acacia karoo* resin mixed with equal quantities of red coloring powder and beeswax
4. *Acacia karoo* resin mixed with equal quantities of red coloring powder and a few drops of water

Acacia resin was selected because it is widely used as adhesive in Africa (Grant and Thomas, 1998; Van Wyk and Gericke, 2000); in southern Ethiopia, stone scrapers for hide-working are still mounted in adhesive that contains hardwood resins (Kimura et al., 2001). *Acacia* spp. occur near Sibudu Cave today and they also occurred in the area in the MSA (Allott, 2004; Wadley, 2004), so their resin would have been available throughout MSA occupation of the site.

The processing of the adhesive recipes varied. In all cases adhesive was mixed with a stirring stick. Thereafter, the methods differed.

1. The adhesive was used to mount the stone flake on the haft, and the finished tool was air dried.
2. The adhesive was used to mount the stone flake on the haft, and the finished tool was dried close to a fire.

3. The adhesive was used to mount the stone flake on the haft, the finished tool was heated in the fire, and was then air dried.
4. The adhesive was used to mount the stone flake on the haft; the finished tool was heated in the fire, and was then dried close to a fire.
5. The adhesive was heated on the stirring stick over the fire. The adhesive was used to mount the stone flake on the haft, and the finished tool was air dried.
6. The adhesive was heated on the stirring stick over the fire. The adhesive was used to mount the stone flake on the haft, and the finished tool was heated in the fire and then air dried.
7. The adhesive was heated on the stirring stick over the fire. The adhesive was used to mount the stone flake on the haft, and the finished tool was heated over the fire and then dried close to the fire (Fig. 1a).

Some of the air-dried tools had *Hypoxis* twine wrapped around the adhesive while it was still wet, but most were unbound (Fig. 1b, c). All of the completed tools were photographed, and were subsequently used for the same task of chopping bark from branches for six minutes. The surfaces of the various adhesive recipes were microscopically examined at magnifications ranging from 50× to 500× under incident light.

The hafting experiments were carried out on four separate occasions (in June, August, and December 2003, and January 2004), and the hafting techniques varied according to the results obtained and lessons learned from each set of experiments. Methods used are listed in Table 1.

Results

Both split hafts and L-shaped hafts were used in the first replication. Although it is counterintuitive, the L-shaped hafts were far more successful, even without binding. The split hafts were unsuccessful because pressure on them extended the split and the tool then fell from the haft (only one tool on a split haft did not break). Consequently, all split-haft results were excluded from the calculations in this section. Extensive binding can

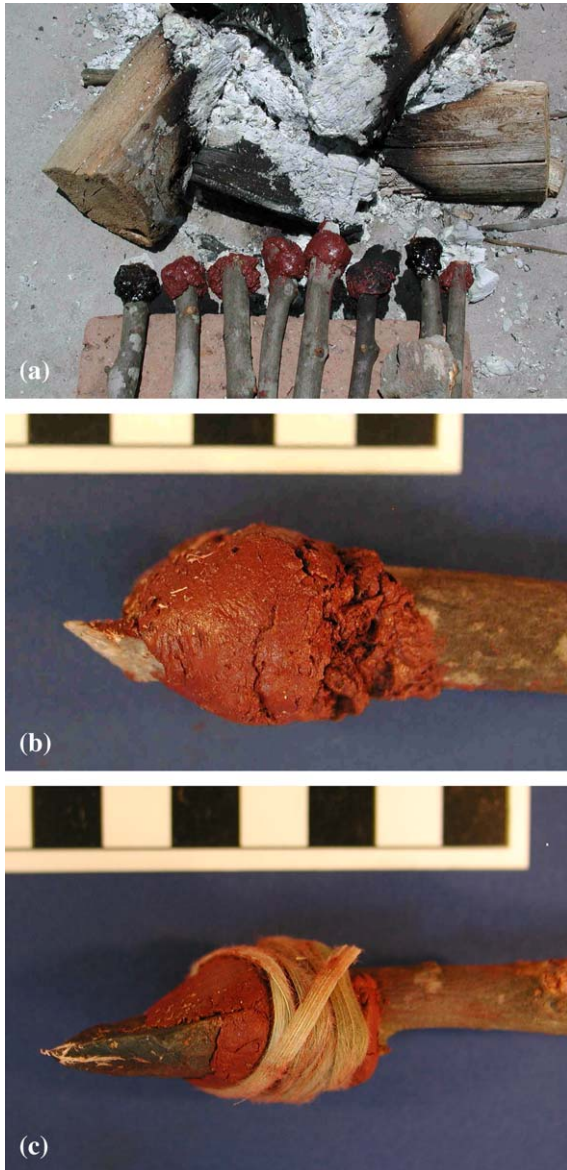


Fig. 1. (a) Hafted tools drying near a fire; (b) Haft 40 (resin and ochre mastic); (c) Haft 24 (resin, ochre and wax mastic, bound with *Hypoxis* twine).

sometimes prevent the split from developing, but split hafting was nevertheless abandoned after the first replication. The purpose of the study was to examine the strength of various adhesive recipes; varying the haft design introduced unwanted variability into the experiments. For the same

reason, binding the tools with *Hypoxis* twine was also discontinued by the fourth experiment. Apart from the issue of unwanted variability, the marks made by the twine on the adhesive interfered with microscopic analysis of the adhesive. Twine is, however, most likely to have been used to strengthen hafts. Lombard's (2004, 2005) microscopy showed wear traces on a sample of points from Sibudu Cave that are most likely to have resulted from binding with twine.

Adhesive recipes

1. *Natural plant resins.* The quality of *A. karoo* resin seems to be variable, but it is difficult to quantify this suggestion. Certainly, drier gums are easier to work with than runny ones, which are very sticky. Unloaded resin is difficult to control during the hafting process: when it is the consistency of honey it requires constant attention to prevent it from dripping off the haft. For the same reason, the stirring stick must be rotated constantly and quickly while the resin is being dried over the fire. Even after the moisture content of the resin has been sufficiently reduced to allow the resin to be molded around the stone and its haft, the tool must be turned every half minute while it is drying next to the fire. If this is not done, the adhesive oozes off the haft.

Natural plant resin dries slowly and the end product is brittle, full of cracks and air bubbles, and sometimes crumbly. Under the microscope, natural resin adhesive has a glassy, brittle appearance (Fig. 2). Woody and other plant inclusions are also apparent in the resin; some of these inclusions are unintentional and are from the scraping of gum from the bark of *Acacia* trees. Thus, plant inclusions in the hafting area of archaeologically recovered stone tools need not imply the deliberate use of non-resinous plant material in the adhesive recipes.

Natural resin is water-soluble, and hygroscopic and damp conditions will cause adhesive to become tacky, with the result that the lithic insert will fall from its haft. Haft 7 is a good example. When the tool broke from its haft, it was put into a plastic bag together with its haft. Within two days the resin had become damp and sticky.

Table 1
Hafting replication methodology and results

Haft#	Haft type	Resin	Ochre	Wax	H ₂ O	Heat/stove	Heat/fire/stirring stick	Tool heated on fire	Dried next to fire	Bind	Description of mastic	Task time	Status
1	Split	Yes	Yes	—	—	Yes	—	—	—	—	crumbly	1 min	broke
2	L	Yes	Yes	—	—	Yes	—	—	—	—	—	1 min	broke
3	Split	Yes	Yes	—	—	Yes	—	—	—	—	—	5 min	OK
4	L	Yes	Yes	—	Yes	Yes	—	—	—	Yes	—	5 min	OK
5	L	Yes	Yes	—	Yes	Yes	—	—	—	—	didn't set	—	—
6	Split	Yes	—	—	—	—	—	—	—	—	brittle	1 min	broke
7	L	Yes	—	—	—	—	—	—	—	—	—	5 min	broke
11	Split	Yes*	Yes	—	Yes	Yes	—	—	—	—	—	—	split
12	Split	Yes	Yes	—	—	Yes	—	—	—	—	—	—	split
13	Split	Yes*	Yes	—	—	Yes	—	—	—	—	crumbly	—	broke
14	Split	Yes	—	—	—	—	—	—	—	—	—	—	—
15	L	Yes	Yellow	—	Yes	Yes	—	—	—	—	—	<1 min	broke
16	L	Yes	Yes	—	—	Yes	—	—	—	—	—	6 min	OK
17	L	Yes	Yes	—	—	Yes	—	—	—	—	—	—	—
18	Split	Yes	Yellow	—	—	Yes	—	—	—	—	crumbly	—	—
19	Split	Yes	Yes	—	—	—	—	—	—	—	sticky	—	—
21	L	Yes	Yes	—	—	—	Yes	Yes	—	Yes	crumbly	1.5 min	broke
22	L	Yes	Yes	Yes	—	—	Yes	Yes	—	Yes	elastic	6 min	OK
23	L	Yes	Yes	Yes	—	—	Yes	Yes	—	Yes	elastic	6 min	loose
24	L	Yes	Yes	Yes	—	—	Yes	Yes	—	Yes	elastic	6 min	OK
25	L	Yes	Yes	—	—	—	Yes	—	—	Yes	hard	6 min	OK
26	L	Yes	—	—	—	—	Yes	Yes	—	Yes	crumbly	6 min	OK
27	L	Yes	Yes	—	—	—	Yes	—	—	Yes	hard	6 min	OK
28	L	Yes	—	—	—	—	—	Yes	—	Yes	brittle	6 min	crumbly
29	L	Yes	Yes	—	Yes	—	Yes	Yes	—	Yes	hard	6 min	OK
30	L	Yes	Yes	—	—	—	Yes	Yes	—	Yes	hard	6 min	OK
31	L	Yes	Yes	—	Yes	—	Yes	Yes	—	Yes	hard	6 min	OK
32	L	Yes	Yes	—	—	—	Yes	Yes	—	Yes	hard	6 min	OK
33	L	Yes	Yes	—	—	—	Yes	Yes	—	Yes	hard	6 min	OK
34	L	Yes#	—	—	—	—	—	—	—	Yes	hard	6 min	OK
40	L	Yes	Yes	—	—	—	—	Yes	Yes	—	hard	5 min	OK
41	L	Yes	Yes	—	—	—	—	Yes	Yes	—	hard	5 min	OK
42	L	Yes	—	—	—	—	—	Yes	Yes	—	hard	5 min	OK
43	L	Yes	Yes	—	—	—	Yes	—	Yes	—	hard	5 min	OK
44	L	Yes	—	—	—	—	Yes	—	Yes	—	hard	5 min	OK
45	L	Yes	Yes	—	—	—	Yes	—	Yes	—	hard	5 min	OK
46	L	Yes	Yes	—	—	—	Yes	Yes	Yes	—	hard	5 min	OK
47	L	Yes	Yes	—	—	—	—	—	Yes	—	hard	5 min	OK

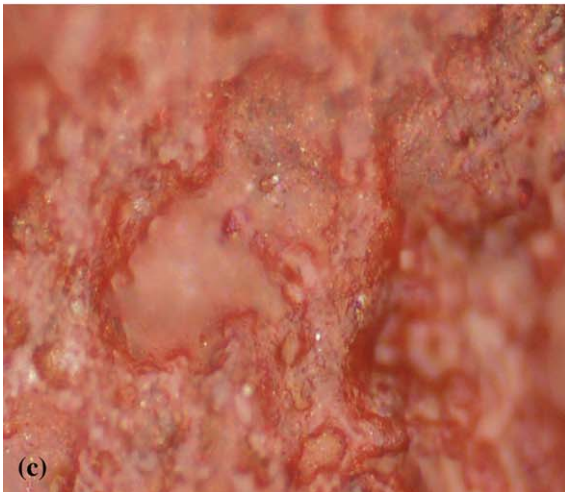
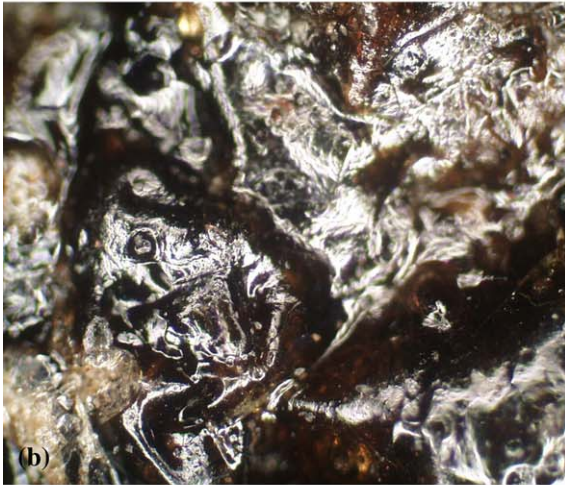
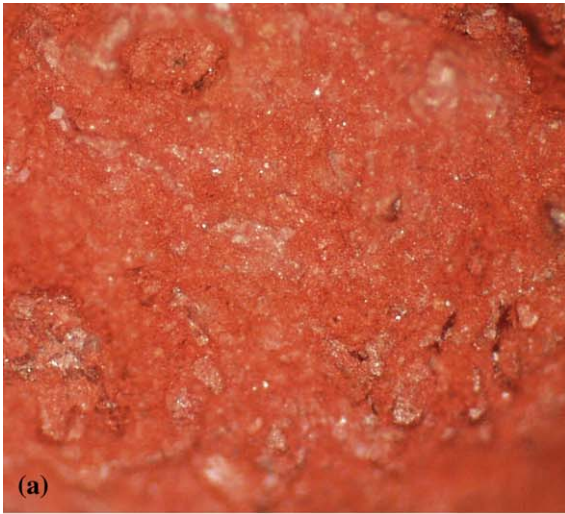
* *Elephantorrhiza* resin.

Ozoroa resin.

Notwithstanding the problems that I have outlined, the replications show that *A. karoo* resin can be used alone as adhesive for attaching tools to their hafts. Of the five tools mounted with *Acacia* gum, four were successful for cutting tasks that lasted five or six minutes (Table 1). This corresponds to an 80% success rate, but the sample may be too small to be representative. One of the tools labeled

successful (Haft 28) survived the tasks, but lost so much of its brittle adhesive that it cannot be used for any further work. Other vegetable resins, e.g., *Ozoroa paniculosa*, are also successful adhesives; Haft 34 demonstrates this. *Elephantorrhiza burkei* gum was very crumbly and was not successful.

2. *Plant resin mixed with red ochre*. Fifteen of the red ochre and *Acacia* gum adhesives on L-hafts



were successful, while three were not. This represents an 83% success rate. One broken tool (Haft 21) was air dried and had not set sufficiently before it was used; when it broke, the inner adhesive was still wet. I comment on correct drying methods later. The other two unsuccessful adhesives had water mixed with them during manufacture. As a result, the adhesive on Haft 5 did not set and it could not be used. This happened because, in my first set of experiments, I mixed and heated more adhesive than was needed for the hafting of a single tool. When molding of the first tool was finished, the remnant adhesive was crumbly, so a few drops of water were added to moisten the mixture. Although the reconstituted adhesive was reheated and initially appeared successful, it never dried. The addition of water to the adhesive was not, however, always unsatisfactory. When water was mixed with fresh *Acacia* gum and red coloring in the first stage of manufacture, it formed successful glue after it was heated. Indeed, this combination held tools so well during scraping and cutting of wood that the stone inserts could not be pried from their hafts (Hafts 29 and 31). Thus, all three of the unsuccessful resin/ochre adhesives appear to have failed because of a recipe error. Because the natural plant resins vary in their moisture content, a set recipe cannot be prescribed for the addition of a loading agent. Wet resins require more loading agent than drier resins in order to make them manageable. Thus, the making of adhesive is more complex than might be expected, and experience is required to get an acceptable outcome.

When red ochre/resin adhesive has been properly dried, it does not seem to be adversely affected by damp conditions or by storage in plastic. In this respect, it also has a big advantage over pure resin adhesive. The adhesive is, however, water-soluble when soaked for several hours.

Under the microscope, the adhesives loaded with red ochre appeared homogeneous (Fig. 2), although cracks sometimes developed; fine “mud cracking” (Fig. 1b) occurred as the result of slow drying next to the fire.

Fig. 2. (a) Ochre and resin mastic (Haft 30); (b) heated *Acacia* resin; (c) ochre, resin, and wax mastic (Haft 24).

3. *Plant resin mixed with red ochre and wax.* Only three tools were made using a combination of equal quantities of resin, red ochre, and natural beeswax. All three tools were successful, although Haft 23 became loose after it was used for six minutes. The addition of wax made the adhesive especially easy to work with; it had the consistency and flexibility of plasticine. The waxy adhesive used in my experiments never set completely hard; a fingernail could be pushed into the adhesive several months after its manufacture. The wax-impregnated adhesive was also very homogeneous and had few cracks. The disadvantage of using wax is that shrinkage occurs within a period of several weeks, and this caused the adhesive to loosen from its haft. Shrinkage could possibly be avoided by using less wax. Allain and Rigaud (1986) used less wax than I did and they had better results.

This adhesive is distinctive under the microscope; at 500× magnification, it is possible to see the fatty globules of wax in an otherwise homogeneous mixture (Fig. 2c). The wax leaves a fatty stain on the stone insert, and this is visible even to the naked eye.

The branches that were scraped with these tools became reddened from the greasy coloring material that rubbed against them.

4. *Plant resin mixed with yellow coloring.* Two adhesives were manufactured using a yellow coloring material together with resin. When the adhesive was heated, it turned dark brown, not red. No elemental analysis was attempted on the yellow coloring, but it is possible that it is not an iron-rich mineral. Several coloring materials from the Sibudu area were analyzed by S. Schiegl (by FT-IR; personal communication), who found that some of the local yellow coloring material contained no iron and yielded no infrared spectra information.

Neither of the tools hafted with adhesive made from yellow coloring and resin was successful.

The role of heat in the production of adhesive

In the initial stages of adhesive manufacture, heating the adhesive helps to drive off excess moisture and make the mixture pliable. The use of

fire for creating and “cooking” the adhesive is as much an art as the mixing of ingredients. On my first attempt at “cooking” a newly hafted tool over the fire, the adhesive swelled and the outer crust became hard and charred, leaving an air-filled hollow under the hard crust. Even without this incompetent handling, heating of adhesive over the fire can introduce charcoal into it. This may account for the charcoal that is sometimes observed (B. Williamson, personal communication) on the bases of tools during microscopy. There is, however, another important application for heat in the next stage of adhesive production. The slow drying of the completed tools near a moderate fire makes the drying process considerably quicker than drying with no additional heat. The difficulty experienced with air drying alone is demonstrated by tools manufactured on 9 December 2003. Adhesive was placed on a stirring-stick and heated directly over the fire; next, the warm, pliable adhesive was used to attach the tools to their hafts, and the compound tools were heated directly over the fire for a few minutes. The mounting process was complete by 13:00 on the same day and the tools were thereafter allowed to air-dry naturally. Twenty-four hours later Haft 21 (with adhesive made from 2.5 ml resin and 2.5 ml red ochre; see Table 1) was used to scrape bark. The stone tool dislodged from its haft immediately, revealing wet adhesive. The stone tool was pressed back into its haft and the exercise was repeated on 12 December. The stone broke from its haft after 1.5 min, once again revealing tacky adhesive. The other tools from this experiment were allowed to dry for a few more days before they were used. This exercise demonstrates that air-drying requires longer than four days, and probably as long as six days, for the tools to become set in their adhesive, and for the adhesive to dry and harden properly.

Tools mounted in adhesive on 6 January 2004 were processed differently after the first stage of heating the adhesive on a stirring-stick and mounting the stone on the haft. They were slowly dried near a fire for between three and four hours. They were then used immediately to remove bark and chop wood. All the tools were successful and none broke.

When using fire to dry adhesive, the tools' distance from the fire must be judged carefully. When tools are too close to the fire the adhesive begins to boil. This creates cracks and weakness and eventually the overheated adhesive produces a huge bubble of air under the dry surface adhesive crust. The adhesive can be rescued if it is quickly remolded and the tool placed next to a cooler part of the fire. Slow drying in the vicinity of the fire produces distinctive microscopic "mud cracking" on adhesive loaded with red ochre.

Residue distribution on replicated tools

All the replicated tools were hafted in such a way that their proximal (thick, basal) ends were secured to the hafts with adhesive. In most cases, the medial portions of the tools also contained adhesive. During the manufacture of the adhesive and mounting of the tools, my fingers became stained with ochre and everything that I touched was marked with superficial red blotches. Thus, the distal (tip) portions of the tools outside of the hafted areas obtained ochre stains during the tool manufacturing process (see Fig. 1c). When the tools were used for chopping the bark off of branches, the superficial ochre stains on the distal portions of the tools disappeared. They were rubbed off through use, though the occasional spot of ochre remained.

If the tool was placed on an L-shaped haft before adhesive was applied, the tool did not acquire ochre-staining on the surface placed against the haft. This observation is important because it means that archaeologically recovered tools with ochre on only one tool face should not be discarded as unhafted. Other evidence for hafting does, however, need to be sought.

Discussion

My preliminary replication work on adhesives and hafting confirms some of the observations made by other researchers. The work corroborates, for example, the proposal by French researchers that ochre is excellent filler for use with resins and with resin and wax mixtures.

Ochre-loaded adhesive is far easier to work with than sticky resin alone; it dries faster than unloaded resin and, intuitively, it looks stronger, more homogeneous, and less brittle. Loaded resin can be more easily molded to a tool and it is less likely to fail during the drying process than natural resin. In addition, unloaded adhesives are hydroscopic and become tacky under damp conditions; ochre-loaded adhesive is not hydroscopic after it has been properly dried.

The strengths of my adhesives have not been empirically measured because the available meters are designed to measure the strength of metals without organic inclusions. At this stage, I also do not have chemical or molecular results to explain why the combination of iron-rich inorganic ochre with organic, carbohydrate-rich resin is an effective bonding agent, but the tasks successfully completed by tools mounted with ochre-loaded resin are proof of this. One clue to the success of the ochre as a loading agent may be in nature: iron oxide minerals act as cementing agents in some sedimentary rocks, such as banded ironstone; the iron oxide is chemically deposited from solutions containing the mineral. Since quartz (SiO_2), like iron oxide, is a cementing mineral in sedimentary rocks, it (or quartz-rich sand) should also prove to be a good loading agent for adhesives. Empirical research into the properties of ochre will be done by T. Hodgskiss, who will also experiment with other loading agents because ethnographic and archaeological data imply that alternative loading agents can be and have been used. Williamson (1997, 2004) occasionally observed fat, charcoal, and even blood together with resin on the bases (proximal ends) of both LSA stone tools from Rose Cottage and MSA stone tools from Sibudu Cave, and plant material was a frequent inclusion in both instances. The Steenbokfontein Cave LSA adhesive used for mounting a scraper contained plant fiber, but no ochre (Jerardino, 2001).

My replications imply that artisans in the MSA had considerable technical skill and that they understood the properties of the ingredients that are suitable for adhesive manufacture. They probably manipulated ingredients knowingly, according to their needs. Their complex technical knowledge in all probability included an understanding of

the individual properties of ochre and resin and the combined property of these inorganic and organic materials. The adhesive makers would have needed a good intuitive understanding of how the adhesive should look and feel: experience is required for successful adhesive manufacture because the recipes are not an exact science. Texture and viscosity must be gauged while the adhesive is being mixed because the moisture content of resin varies from tree to tree and season to season. The artisans also needed to understand the effects of various types of heating on the adhesive recipes that they used. Furthermore, the creation of the hafting pastes needed planning to ensure that all the necessary ingredients were simultaneously available. This behavior is undoubtedly technically advanced.

In the same way that it is possible to tan hide in different ways, it is also possible to haft tools in different ways. Thus, several different types of adhesive recipe could have been used for mounting tools into hafts. To some extent, this variability may have depended on the local or seasonal availability of ingredients. However, there is a strong possibility that some adhesive recipes were deliberately varied to accommodate the type of task to be performed and the type of haft to be used. Microscopy on Rose Cottage and Sibudu tools suggests that, on some occasions, the early artisans loaded their resins, but under different circumstances, they used resin alone. As I have shown, resin can be used alone, even though it is difficult to manipulate when it does not have the addition of a loading agent. Unloaded resin has advantages as well as disadvantages. When resins are heated alone, they are brittle and do not resist high impact pressure (Rots, 2002: 57–59); they therefore allow arrow barbs to become dislodged in animal carcasses (Crombé et al., 2001: 260). This effect is desirable when projectile weaponry is used because it causes fatal hemorrhages. It is not desirable when hand-held stabbing tools are used; here the requirement is different and points or other spearhead inserts need to remain firmly in their hafts so that the hunter can, when necessary, make repeated thrusts at prey. Securely fastened spearheads may have depended on bindings as well as loaded adhesives. The well-preserved Adam's

Kranz Cave LSA arrowhead is a good example of the use of plant fiber for binding a tool to its haft (Binneman, 1994). Lombard's (2004, 2005) microscopy showed that binding was almost certainly also used on the Sibudu late MSA points because it caused characteristic damage to the tool laterals. Plant residues at the base of tools might also indicate that binding was used, but it is feasible that fragments of plant were intrinsic components of the glue that once attached the stone tool to its handle or shaft. The replication work described here suggests that plant residues can be unintentionally incorporated into resins during their collection and processing.

A comparison of the position of residues on the ancient tools from Sibudu Cave and on the replicated hafted tools is informative. As mentioned above, the majority of the scrapers and points examined had high frequencies of ochre residues on their proximal and medial portions, although, in addition, small amounts of ochre are sometimes present elsewhere on the tools. Almost half of the flakes examined also had ochre residues on their proximal and medial portions. It must be pointed out that the ochre residues on MSA tools are often too small to be seen with the naked eye and are detected under a hand lens or binocular microscope. The replicated hafted tools and the archaeologically recovered tools that are assumed to have been hafted have identical spatial distributions of ochre residues. The replicated tools do, however, have heavier ochre stains around their proximal and medial portions, so that the staining can be seen with the naked eye. The better visibility is presumably because the replicated tools have not been buried; future work could involve experimental burying of tools with ochre residues.

Archaeologists who believe that the mere presence of ochre signifies symbolic behavior will probably contend that the use of ochre in adhesive is another example of ritual in the MSA. I cannot prove that this was not the case; they may be right. For example, Hovers et al. (2003) argued persuasively for the early symbolic use of ochre by modern humans at Qafzeh. I do not yet have answers to all the questions about adhesive use and hafting practice. Nonetheless, there are data from several continents that verify that ochre has

properties useful for the manufacture of adhesive for hafting stone tools. This claim does not detract from ochre's capacity as a symbolic agent, yet I urge archaeologists to make interpretations that are sensitive to ochre's versatility. Since ochre *does* have practical merit under certain circumstances, it seems unwise to *assume* ritual use from its mere presence in archaeological sites.

At the beginning of this paper, I commented that it is difficult to imagine what people living in the MSA would have done with the large quantities of coloring material that have been found in some sites. The study reported here suggests that hafting adhesives may account for a large proportion of the coloring. Some simple calculations demonstrate the point. The three kilograms of coloring nodules used for my replications produced sufficient hematite powder (about 70 ml) to make adhesives for 28 flakes. Thus 107 g of geological parent rock were required to produce enough ochre powder for adhesive for one tool and 60 kg of parent rock would provide enough powder for adhesive to haft 560 tools. Williamson's (2004) study of more than 400 Sibudu stone tools (including flakes) showed that 11% had ochre on them. Even if only 5% of stone tools (including flakes) were hafted using ochre-rich adhesive, then 1000 tools from a collection of 20,000 might be hafted. This would require 107 kg of parent rock of the type that I used for my experiments. The issue suggests that there is potential for further research into the amounts of usable coloring material from a variety of iron-rich geological rocks. The issue also raises the need for standardization in the reporting of coloring material from archaeological sites. Weights seem necessary, as well as fragment frequencies, because it is hard to compare 60 kg of material with 10,000 fragments. Another matter that seems important to research is the reason for the appearance of large quantities of unmodified coloring at MSA sites. Watts (1998), for example, analyzed 4053 pieces of ochre from sites south of the Limpopo and found that only 384 pieces of ochre were definitely ground. We need an investigation of the unmodified pieces from MSA sites. Are they unmodified because they are unusable or because they were simply not used? Some unmodified

pieces might, on the one hand, have been smashed open to extract good quality coloring material and there may be damage marks on the rocks that would confirm this practice. If, on the other hand, large quantities of unused iron-rich rocks still retain good quality coloring material, we may be witnessing behavioral patterns that are not easily explained outside of a symbolic model. Ochre research is by no means exhausted.

At Rose Cottage and Sibudu Caves, it is perhaps unremarkable to find advanced technical knowledge, and possibly even symbolic behavior, in Howiesons Poort and post-Howiesons Poort industries within the MSA. Such a comment is, however, inappropriate when considering Lupemban sites in Zambia, where quantities of coloring materials appeared at 300 ka together with the first evidence for the presence of backed tools. Residue analysis results are not yet available for these Lupemban backed tools, which Barham (2002) believes may be the first examples of hafted tools. It would be truly remarkable if hafting with ochre is discovered on these 300 kyr-old Twin Rivers backed tools. While the presence of ochre-loaded tools may arguably represent symbolic behavior at 300 ka, it would certainly represent considerable and unexpected technical skill by *Homo rhodesiensis*.

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