The morphological identification of micro-residues on stone tools using light microscopy: progress and difficulties based on blind tests

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Abstract

Fifty-three stone flakes were knapped for a series of four blind tests on replicated flakes with residues derived from the processing of plant and animal products. Some flakes were hafted before use. Tests 1 and 2 were pioneering efforts published in 2004; lessons learned from these early studies shaped the new research reported here and lead to improved methodology and interpretive skills. A high level of accuracy was obtained for test 4. Test 3 showed that the rock type of a tool could influence the ability of the analyst to recognize and interpret residues. Test 4 in the series resulted in the most accurate interpretations because, prior to Test 4, identification difficulties experienced during the first three blind test sessions were addressed by examining many stone tools that had been used for various replicated tasks. The preparatory exercise was particularly useful for resolving issues that had previously caused problems for correctly identifying animal residues. The new work reported here highlights some of the difficulties that can be experienced in the morphological identification of microscopic organic residues, particularly the distinction between animal and plant residues. Some solutions for these problems are suggested.
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Keywords: Stone tools; Residue analysis; Blind tests; Animal residues; Contamination; Problem solving; Reference collections

1. Introduction

In 2004 we reported on two blind tests (Tests 1 and 2) that were designed to test an analyst's ability to identify and differentiate between an array of plant and animal residues produced under field conditions, based only on the microscopic morphological characteristics of such residues using light microscopy [29]. Since 2004, we have conducted two more blind tests (Tests 3 and 4) to address some of the lessons we learned during the previous tests and to identify other areas that need work. This contribution discusses the progress made in the morphological identification and interpretation of microscopic use-residues. It also provides the protocols and results of the two new blind tests (Tests 3 and 4) designed by L.W. (examiner) and conducted by M.L. (analyst).

The first blind test, Test 1, was initially designed to test the skills and confidence of the residue analyst for the archaeological research she was involved with at the time, namely the analysis, through light microscopy, of residues on a sample of Middle Stone Age points from Sibudu Cave, KwaZulu-Natal, South Africa (see [17,18,30]). Test 2 was aimed at investigating the effects on residues of burying replicated stone tools in organic-rich, slightly acidic soil. A number of predicaments were encountered during Test 2. Amongst these was degradation of residues, which is one of the most pressing problems of residue analysis. Other researchers have addressed aspects of residue diagenesis: Jahren et al. [12], for example, conducted experiments with bamboo and bone residues on replicated stone tools to simulate processes of diagenesis. The simulated diagenesis had no effect on the morphological characteristics of the bamboo, and although the bone residue

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was reduced, no significant morphological changes were observed. However, the chemical compositions of the residues changed slightly, and potassium and iron were particularly affected. Further aspects of diagenesis and decomposition of organic residues that are being researched include the decomposition of starch grains [10], and the potential misidentification of starch grains as a result of fungal activity on tool surfaces [11]. The issue of whether or not residue degradation takes place is likely to depend on site-specific conditions (temperature, moisture, pH, soil characteristics etc.). It is therefore not always possible to make generalizations about its effect on residues, and blind tests such as Test 2 are not the best way to investigate this process. Well-designed and controlled research programs need to be constructed to address particular questions about diagenesis in archaeological sites.

In the case of Sibudu Cave, Williamson [34] argues that the slightly acidic nature of the soil may have contributed to the preferential preservation of organic plant residues over faunal residues on stone tools. Abundant traces of wood ash, carbonized plant cell walls, silica skeletons, degrading bone and burnt bone occur in the sediments of the site [23]. The presence of large quantities of degrading and burnt bone suggests that microscopic faunal residues should also be preserved on Sibudu Cave stone tools. This is indeed the case, as was shown by the analysis of residues on 50 stone points from the site. Although plant residues were more prolific than faunal residues, a range of animal residues could be identified on the points, including animal tissue, collagen, fat, hair and blood [17,18].

Our pioneering blind tests (Tests 1 and 2) were hampered by a number of methodological and identification obstacles that were reported in the publication [29]. However, as so often happens with research, mistakes and subsequent efforts to overcome these lead to valuable insights in addition to improved methodology. This feedback approach to blind testing is underscored by sophisticated studies carried out by other researchers (e.g. [21]). The main residue identification problem highlighted in Test 1 was the tendency to confuse certain faunal and plant residues. The reality that animal residues may be difficult to distinguish is acknowledged by Hardy [7], and was anticipated by Briuer [3] in one of the first residue studies. Another error was that shell residues were not recognized because they had not previously been worked with. Shell residues will form the focus of future investigations and they are not dealt with here. Because Sibudu Cave (see [26,28] for site details) has excellent bone preservation indicating efficient hunting [20], we decided to focus our present study on improving the recognition and interpretation of faunal residues and on distinguishing these residues from those of plant material. Thus, after our first blind tests, M.L. worked extensively on faunal residues and on distinguishing faunal and plant residues. Notwithstanding the presence of some animal residues on Sibudu points [17,18], animal products appear to be under-represented in the residues on archaeological stone tool samples [6,7,17,18,33]. This may be a result of diagenesis as implied by Test 2 [29], and by a washed control sample [7,9]. However, we now consider that a number of faunal residues may previously have been misidentified as plant residues, or may simply not have been recognized for what they were.

An important outcome of Test 1 was the confirmation that birefringence (the double refraction of incident light) is not an exclusive characteristic of cellulose plant residues, as suggested by some analysts [24,32,33]. Certain faunal tissues are also highly birefringent [13,18,29]. Another problem may arise from the morphological similarity between a few plant and faunal residues, such as relatively rectangular and ordered cell structures. In Fig. 1, selected images of modern replicated vegetal and faunal residues are compared to highlight possible complications that may be encountered in their differentiation. We show how the longitudinal view of muscular tissue (Fig. 1b) has an ordered structural appearance with rectangular cells that could possibly be mistaken for plant or wood cells (Fig. 1a). The potential for interpretive error is exacerbated when the residues are degraded so that only minute fractions of such structures are preserved, for example, on archaeological tools. Fig. 1c and d illustrate the similarities between some plant and animal fibers; both can appear birefringent and translucent during the cross-polarization of incident light. The angle at which residues are observed can also affect the accuracy of interpretations; for example, longitudinally viewed surfaces of dry wood and dry, muscular tissue (dried meat) may appear very similar with regard to color and striations. This does not mean that residue analysts are unable to distinguish between these plant and animal residues, but they must exercise caution. We provide suggestions for solving some of the identification problems later in the paper.

2. Blind Test 3

2.1. Preparation by the examiner

The examiner, L.W., knapped and prepared 16 stone flakes for this test (Table 1). Quartz, quartzite, hornfels and dolerite rocks were knapped. Some tools were hafted using mostly *Grewia flava* (velvet raisin bush) branches. This species was once widely used by Bushmen (southern African hunter-gatherers) for arrow shafts [25,27]. Several different adhesives were used for hafting the tools (Table 1); for example, one of the recipes used *Acacia karroo* gum mixed with red ochre that had been ground into powder on a sandstone slab. All the tasks were field-based, not laboratory-based. Processes were replicated as closely as possible to plausible prehistoric conditions. Several tools were used to process animal material obtained from an impala (*Aepyceros melampus*) carcass (the impala was killed by a leopard on the farm Moletadikgwa, in Limpopo Province, South Africa). The partially consumed animal was butchered where its remains were found, on the ground, amongst grass. Tracks showed that the body had been dragged by the leopard for some distance. On another occasion, elsewhere in the field, other tools were used to process ochre or plant material. Some tools were not used at all. After the residues were dry, the tools were placed individually in sterile airtight plastic bags, labeled with the test number. Hafted stone
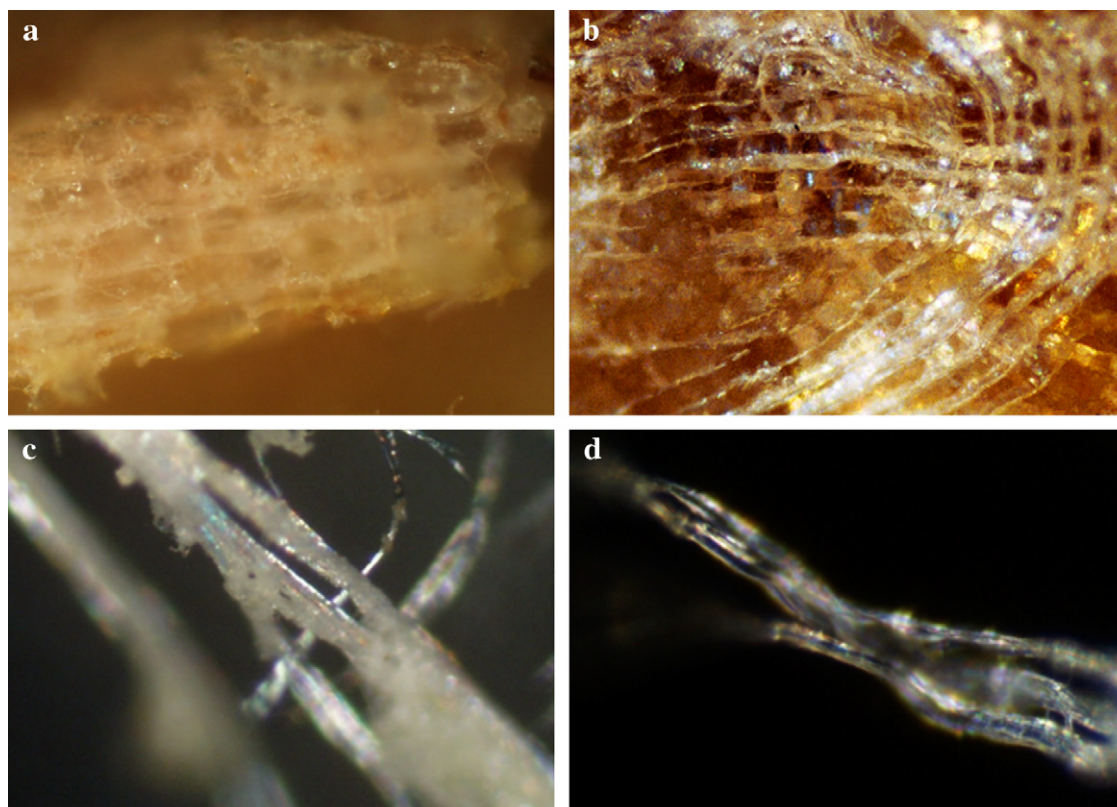
Fig. 1. Selected images of modern replicated vegetal and faunal residues highlighting identification complications (color images are available in the electronic version of this publication). (a) Inner epidermal cells of wet wood (*Combretum zeheri*) on the edge of a replicated tool used to scrape the bark off a green stem photographed at 200×, Tool #23 Test 3. The small white spots in the residue could be identified as starch grains in the wood at 500×; this feature may be used to distinguish between plant and animal material that may appear very similar based on cellular structure. (b) Longitudinally orientated, striated muscle tissue deposited on a tool as a result of cutting beef, photographed at 200×, Tool #10 Test 1. Note the birefringence of the residue in the color version. (c) Plant fibers on the edge of a replicated tool used to scrape a fibrous leaf, *Sanseviera pearsonii,* photographed at 200×, additional replication as preparation for Test 4. (d) Collagen fiber on the edge of a replicated tool used to cut fatty cartilage of an *Aepyceros melampus* carcass, photographed at 200×, from Tool #9 Test 3.

tools were removed from their shafts before being bagged. The tools were transported to the laboratory where they were subject to controlled laboratory conditions. The tools were analyzed about five months after preparation. The analyst had no insight whatsoever into the preparations of the stone tools by the examiner.

2.2. Preparation by the analyst

M.L. prepared for the test by examining images from Tests 1 and 2 and, as explained earlier, by paying particular attention to residue types that caused difficulties in these initial tests. Images from residues documented on the 42 replicated tools from hunting and butchery experiments [19] were also examined carefully.

2.3. Results

The same methodology and equipment were used for the light microscopy of Test 3 as for the previously described tests [29]. The complexity of residue combinations and interpretive variables may not allow for accurate scoring on each detail, but we believe that our scoring system provides an adequate

impression of the results. Although 16 tools were examined for this test, the score is out of 20. This is because scores were given for hafting residues as well as for use-residues, so that two points were allocated for each of the hafted tools, numbered 20, 21, 22 and 23 (see Table 2), while one point was allocated for each of the other tools. The residues on the tools were scored separately from the hafting interpretation, because correct identification of the residues does not inevitably result in the correct hafting interpretation for example Tool #23 (Table 2). A score of 85% was obtained for the identification of the residues (4th column of Table 2), and 94% (last column of Table 2) accuracy was obtained for the interpretation of whether the tools were handheld or hafted. Scores in the 4th column were allocated according to a simple scoring system (plant, animal, unused), this system will be refined for future tests where we will focus more on functional interpretation, as opposed to the identification of individual residue types. Functional and hafting interpretations (see comments of the analyst in Table 2) are based not only on the presence of the identified residues, but also on their frequency, distribution patterns, layering, orientation, association with other residues and the way in which they adhered to a tool. This is standard practice when M.L. interprets residues on archaeological tools.

Table 1
Inventory of the residues, hafting materials and tasks performed with replicated tools for Blind Test 3

Tool #	Inventory of residues, hafting and tasks	Raw material
2	Scraped hair from *Aepyceros melampus* leg	Hornfels
3	Cut bone and cartilage of *Aepyceros melampus* leg	Quartzite
4	Cut bone and cartilage of *Aepyceros melampus* leg	Hornfels
6	Cut fatty cartilage of *Aepyceros melampus* leg	Hornfels
9	Cut fatty cartilage of *Aepyceros melampus* leg	Hornfels
11	Scraped inside of the *Aepyceros melampus* hide	Quartzite
13	Tool picked up with hands used for ochre grinding	Quartzite
16	Cut and scrape ochre	Hornfels
17	Cut and scrape ochre	Hornfels
18	*Acacia karroo* gum smeared on tool platform	Hornfels
19	Yellow ochre and *Acacia karroo* gum heated and hafted on split mount of *Grewia flava*	Hornfels
20	Hafted to *Ficus* sp. Split haft with *Acacia karroo* gum. Cut *Ozoroa paniculosa* stick	Quartz
21	Hafted to split *Grewia flava* stem with *Acacia karroo* gum and ochre (heated). Cut *Ozoroa paniculosa* stick	Hornfels
22	Hafted to split *Grewia flava* stem with *Acacia karroo* gum and ochre (heated). Tried to cut *Ozoroa paniculosa* stick, but stone was dislodged after one motion	Quartzite
23	Hafted to *Grewia flava* stem as angle mount with *Acacia karroo* gum. Cut *Combretum zeyheri* branch	Quartzite
24	Hafted to *Grewia flava* split haft with red ochre and *Elephantorrhiza burkei* gum (heated)	Hornfels

2.4. Lessons learned from Test 3

The main difficulty documented during Test 3 was that rock types affected the analyst's ability to recognize residues accurately. White or translucent quartz and quartzite flakes were included for the first time during the test series in Test 3. For Tests 1 and 2 only darker opaque materials such as hornfels, dolerite, chert and chalcedony were used. The breakdown of the Test 3 results reveals that all the errors occurred on the light reflective and refractive rocks such as quartz and quartzite. The comments by the analyst on tools numbered 3 and 11 (Table 2) reflect the visual difficulties of interpreting residues on this type of raw material. Colored inclusions or impurities in the raw material may also be misleading.

We now report on some observations about recognizing hafting residues that other analysts may find useful. First, the mere presence of resinous deposits (we use the term 'resin' for describing the micro-residues resulting from plant gum and plant resin—at this stage we cannot tell the difference between gum and resin under the microscope) on the stone tools cannot be interpreted as evidence of hafting because activities such as the processing of green wood and bark also often result in resinous deposits. When identifying hafting on archaeological tools, M.L. looks for an association between a number of residues and characteristic wear damage [18], but usewear was not examined during this test because our emphasis was solely on residues. Where *Acacia karroo* gum was used on the test tools as an ingredient in the hafting adhesive, woody residue could be seen adhering to the surface of the resinous deposit on the

proximal and medial portions of the flakes (Fig. 2a2). This signifies that the gum was layered between the woody residue and the stone flake. Secondly, where a resinous substance was present, but had not been used as an adhesive, the residue surface remained continuous, smooth and glass-like. Where gum functioned as an adhesive, portions of the resinous surface were dull (Fig. 2a1), showing where the shaft was detached from the tool. This layering of residues and the dulling of resinous surfaces may thus be seen as residue evidence for wood hafting on the test tools. However, in an archaeological context, these indicators may be affected by taphonomic factors, and can be expected to be much less obvious. Thirdly, where *Acacia* gum was merely smeared on the surface of the tool (for example, Tool #18) and was not used as an adhesive, the other plant residues recorded are covered with a resinous film (Fig. 2b1). This suggests that plant residue types associated with wood are to be expected as an integral part of resin or gum from trees such as *Acacia karroo*. Fragments of bark, woody residue, wood fibers and plant tissue are invariably incorporated into gum scraped from an *Acacia* tree.

An additional outcome of Test 3 is that the analyst established her ability to identify, contamination in the form of plant residues (see comments on Tools #9 and #13 in Table 2). 'Dust' is always in the atmosphere, and plant material such as starch grains, spores, pollen, plant fibers or tissue are invariably part of this dust and may be present on tools as a result of accidental contact or contamination, for example Rots and Williamson [22], Hardy and Garufi [8] and our own observations on replicated material. When tools are used to process 'wet' material it can be expected that 'dust' will adhere to them. Such contaminants seldom occur in high frequencies or with distinct and repetitive distribution patterns on the tools. They are generally on top of the use-related residues and, in the case of fibers and tissue; they often seem to adhere loosely to the tool. Of course, where plant material was intentionally processed or used for hafting, plant material contaminants may not be so easily recognized. Most important though, is the influence that contaminants might have on functional interpretations of stone tools. Our results show a relatively small margin of error due to contaminants. Feather, down and hair fragments are some of the non-plant residues that we have thus far experienced to be airborne as 'dust'; we establish a dust-accumulation record by deliberately leaving microscope slides with a strip of double sided tape in the open.

Since our test tools were used in the field (in an attempt to replicate prehistoric conditions) it is obvious that contaminants will be present on them. Contaminants of ancient origin will almost certainly be present on archaeologically recovered tools and this complication needs to be factored into the residue analyst's examination of these old tools. We believe that we can only securely interpret general plant tissue, fibers and especially starch grains as use-residues on archaeological tools when there are supportive strands of evidence from a variety of plant residue types [5,17,18]. From a residue perspective, supportive evidence includes: distinctive distribution patterns and clear and repetitive clustering of tissue, fiber and starch grains in association with other plant residues such as

Table 2
Results and analyst's comments for Blind Test 3

Tool #	Documented residues	Comments	Score residues	Score hafting
2	Hair, collagen, faunal tissue	Used to process animal material. Most probably the scraping of hide. Handheld	1	1
3	Red ochre or crystals, maybe wax with dull surface	First impression: relatively equal distribution of red pigment. A waxy substance may have been applied to one facet of the dorsal side. Handheld Second interpretation: red pigmentation probably in raw material. Facet with dull surface may be weathered raw material NOTE: Identification of residues very difficult because of the reflective nature of the raw material	0	1
4	Faunal tissue, bone, collagen, muscle tissue, fat	Used to process animal material. Handheld	1	1
6	Faunal tissue, hair, collagen, bone, muscle tissue	Used to process animal material. Handheld	1	1
9	Faunal tissue, fat, collagen, muscle tissue. Some plant tissue	Used to process animal material. Handheld. Accidental contact with plant material	1	1
11	Plant fibers, plant tissue. Red ochre/crystals	Possible brief processing of plant materials. Ochre probably coincidental or in raw material. Very difficult to see residues on the reflective surface of the raw material. Handheld	0	1
13	Red ochre. Plant tissue, starch grains	Handled with ochre stained hands. Accidental contact with plant material	1	1
16	Red ochre	Processing of red ochre with edge. Handheld with ochre stained hands	1	1
17	Red ochre	Processing of red ochre with edge. Handheld	1	1
18	Resin, plant tissue, woody residue in resin, plant fibers, plant tissue, starch grains	Resin applied to bulb of percussion, not hafted. Very little plant material and resin on edge. Probably not used, contamination while applying resin to bulb.	1	1
19	Resin, plant fibers, woody residue, yellow ochre	Hafted to wooden haft with resin mixed with yellow ochre	1	1
20	Resin, plant tissue, plant fibers, woody residue, epidermal cells. Animal tissue	Hafted to wooden haft with resin. Possible processing of animal material	1 out of 2	1
21	Woody residue, resin, plant fibers, plant tissue, macerated plant tissue, starchy residue. Red ochre	Hafted to wooden haft with resin mixed with red ochre. Processed resinous plant material	2 out of 2	1
22	Resin. Red ochre. Plant fibers	Hafted with resinous glue, no supporting vegetal residues to indicate haft material (maybe due to the nature of the raw material). Few plant fibers on edge, brief plant processing. Accidental contact with resin and red ochre	2 out of 2	1
23	Resin, plant fibers, woody residue, epidermal cell tissue	Resin applied to bulb of percussion. Processing of woody/fibrous plant material No additional evidence for hafting, possibly not hafted	2 out of 2	0
24	Plant tissue, starchy residue, starch grains, plant fibers. Red ochre	Contact with red ochre and starchy plant material. Hafted to wooden haft. No use established	1	1

wood, bark cells, resin or plant exudates. Test 3 shows, clearly, that the preferred means of reliably identifying residues and interpreting tool function is through the documentation of combinations of residues. This also applies to faunal residues that can be most confidently identified when hair, animal tissue, fat, blood, bone and collagen (or several of these elements) are found as associated residues. Single faunal elements, such as collagen fibers alone, provide less confident identifications. It is furthermore useful to use multi-stranded evidence from a combination of residue and use-wear analyses [7–9,14,18] when archaeologically recovered tools are being examined.

Residues from Test 3 are illustrated in photographs to show residue combinations that contributed to specific identifications and interpretations. The residues illustrated in Fig. 3a resulted from using the hafted Tool #23 from Test 3 to cut a branch of *Combretum zeyheri* (the large-fruited bushwillow). Residues that can be expected as a result of cutting wood may include resin, bark fragments, plant fibers, and woody residues. Additional evidence may be gathered using higher magnifications under which structures such as plant vessels and starch grains are visible (Fig. 3a, insert). The fact that both the vessel and the grain are simultaneously in focus at this high magnification indicates that the starch grain is inside
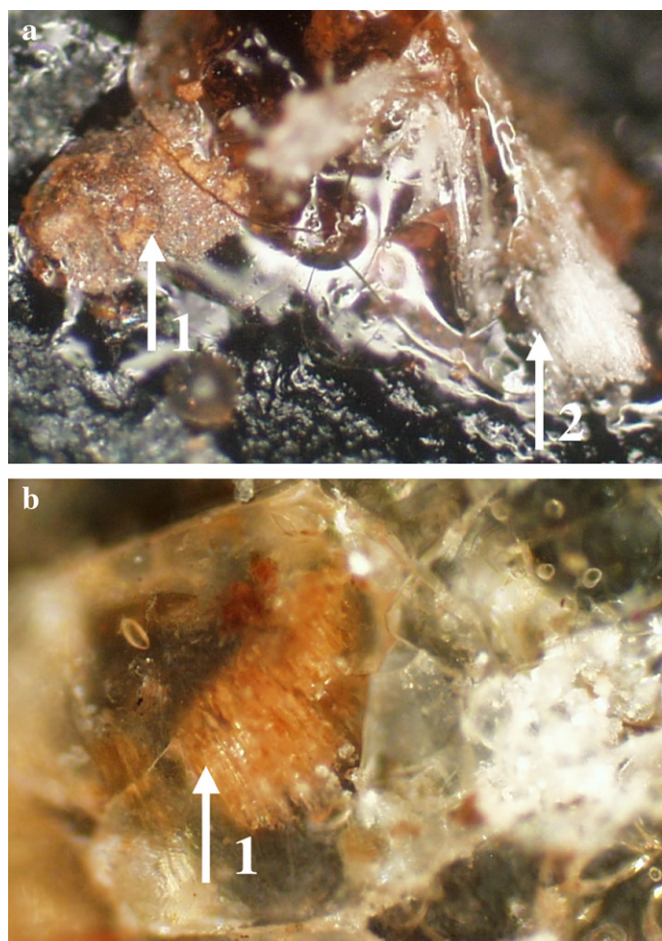
Fig. 2. Selected images from Test 3 with *Acacia karroo* resin (color images are available in the electronic version of this publication). (a) Resin with dulled surface (a1) and woody residue (a2) on the surface of the resin, photographed at 200×, from Tool #23 Test 3; (b) Woody residue (b1) in the resin photographed at 100× from Tool #18 Test 3.
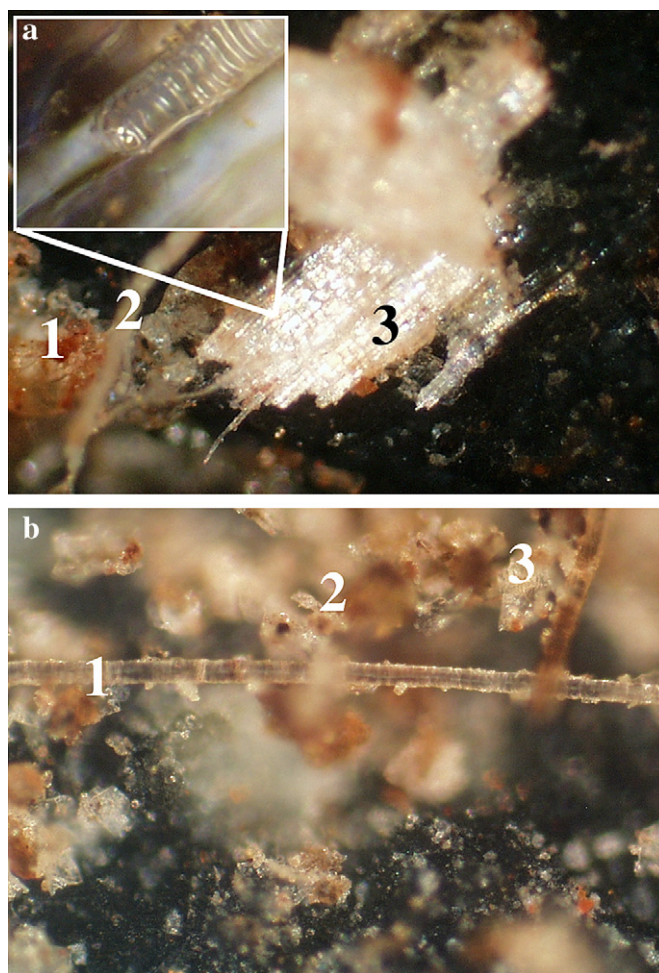

Fig. 3. Examples of residue combinations resulting from replicated tasks (color images are available in the electronic version of this publication). (a) Residue combination as a result of cutting a *Combretum zeyheri* branch: (a1) resinous accretion, (a2) plant fiber, (a3) woody residue (photographed at 100×), (insert) wood vessel in woody residue with embedded starch grain photographed at 500×, from Tool #23 Test 3. (b) Residue combination as a result of scraping the outside of an *Aepyceros melampus* hide: (b1) hair, (b2) animal tissue, (b3) collagen photographed at 200× from Tool #2 Test 3.

the vessel itself, eliminating the possibility that the grain can be the result of contamination. Fig. 3b illustrates the combination of residues that can result from scraping the outside of an animal hide (Tool #2, Test 3); these include animal hair fragments, animal tissue and collagen.

3. Blind Test 4

3.1. Preparation by the examiner

The examiner assembled the tools and performed tasks for this test during the preparation of tools for Test 3, but the analyst was unaware of this. Identical protocols were used for both sets of tools. Ten tools were used for various activities including the butchery of an impala and the processing of plant materials and ochre (Table 3). None of the Test 4 tools was hafted. Test 4 was administered six months after Test 3 and about a year after the tools were prepared. The main objective was to establish whether the lessons learned from previous tests resulted in more accurate residue identifications and functional interpretations.

3.2. Preparation by the analyst

During the time between Tests 3 and 4 the analyst prepared 15 microscope slides with residues, and used 25 modern stone flakes to replicate various activities. Together with the 42 experimental hunting weapons and butchery tools mentioned earlier, the slides and replicated flakes were intensely scrutinized two days before Test 4 was carried out. Time spent examining known residues before test sessions or before the analysis of archaeological residues is considered crucial preparation.

3.3. Results

During this test, the observed residues were noted in a table and were also plotted on line sketches of the tools, as is standard procedure during the analysis of archaeological tools in

Table 3
Inventory of the residues and tasks performed with replicated tools for Blind Test 4

Tool #	Inventory of residues, hafting and tasks	Raw material
1	Scraped hair from *Aepyceros melampus* leg	Quartzite
5	Cut bone and cartilage from *Aepyceros melampus* leg	Hornfels
7	Cut fatty cartilage from *Aepyceros melampus* leg	Hornfels
8	Cut fatty cartilage from *Aepyceros melampus* leg	Hornfels
10	Scraped the inside of *Aepyceros melampus* hide	Quartzite
12	Scraped the inside of *Aepyceros melampus* hide	Quartzite
14	Tool picked up with hands that had been grinding ochre	Hornfels
15	Tool picked up with hands that had been grinding ochre	Hornfels
25	Stripped bark off *Grewia flava* stem	Hornfels
26	Stripped bark off *Grewia flava* stem	Hornfels

a non-test situation. The functional interpretation provided by the analyst for all 10 tools were correct (Table 4). We want to draw attention to the fact that comprehensive interpretations of tool use could be made (see comments in Table 4). For example, hide processing could be correctly identified as opposed to the processing of other animal material, and it was possible to interpret correctly the processing of fatty animal tissue. The processing of green wood with resinous bark could also be recognized. This is exceptionally detailed functional information.

4. Discussion and conclusion

4.1. Raw materials and residue analysis

Test 3 highlighted problems associated with rock types on which residues may occur. It illustrates that whitish, light

reflective and refractive rocks in an archaeological sample may reduce the accuracy of residue identifications. Residues with dark colors like ochre, animal tissue, resin and bark are clearly visible on these raw materials, but colored inclusions in the rocks may be misleading. Another observation made during the analysis of quartz tools is that some residues tend not to adhere to the smooth glass-like surfaces, but instead accumulate only in cracks and crevices. This makes detailed plotting and 'quantification' of the residues on these rock types challenging. The difficulty of detecting whitish, translucent and birefringent residues such as fat, bone, silica skeletons or starch grains on quartz and quartzite should be acknowledged; such residues can easily be overlooked if the analyst is not aware that extra care should be taken. More analytical work is needed on these rock types, but until this has been done, we shall approach archaeological tools made on these rocks with caution.

4.2. Implications for the interpretation of organic residues

The ongoing blind tests for the morphological identification of residues on stone tools have created increasing awareness of the problems involved in distinguishing plant and animal residues. We demonstrate here that faunal residues may, in some past instances, have been erroneously interpreted as plant material. Such interpretive errors possibly contributed to the perception that plant materials were processed more often than animal materials at some archaeological sites, or that animal residues did not preserve well. Although this may be true for some sites, it cannot be the case for all sites and all tool types. Contradictory evidence in the form, for example, of large faunal assemblages and few animal residues on stone tools should sound a warning

Table 4
Results and analyst's comments for Blind Test 4

Tool #	Documented residues	Comments
1	Thick white hair, thinner brown hair, fibrous sheet collagen, animal tissue	White/gray quartzite may prove difficult to recognize certain residues such as fat, bone, collagen and starch. Residues are concentrated along one edge. The residues are very fragmented and 'dirty'. The presence of small dust particles, few starch grains and very small and fragmented plant material is seen as the result of processing 'dirty' animal material. The hairs indicate hide processing. Handheld
5	Striated muscle tissue, animal tissue, hair, sheet collagen, fibrous collagen, bone, fat	Residues concentrated along one edge. Some of the striated muscle tissue and collagen fibers are longitudinally deposited indicating a cutting motion. Tool probably used to process (cut) bony/fatty animal material. Handheld
7	Striated muscle tissue, animal tissue, sheet collagen, collagen fibers, bone hair, red stains, fatty residue	Residues concentrated along one edge. The tool was used to process fatty animal material. Handheld
8	Animal tissue, fat, cartilage, bone, collagen sheets, collagen fibers, hair	Residues concentrated along one edge. The edge was used to process fatty animal material. Handheld
10	Animal tissue, collagen, fat	Residues concentrated along one edge. Not many residues detected probably based on raw material. Edge used to process animal material. Handheld
12	Animal tissue, hair, collagen, striated muscle tissue	Raw material very reflective, colorful and grainy. May be very difficult to identify residues. Very few residues identified. Tool possibly used to process animal material. Handheld
14	Red ochre. One plant fiber	Tool handled with ochre stained hands. Accidental plant fiber. Handheld
15	Red ochre	Tool handled with ochre stained hands. Handheld
25	Woody residue, plant tissue, plant fibers, epidermal cells, resin starch grains	Edge used for the processing of green wood with resinous bark. Handheld
26	Woody residue, plant fibers, resinous plant material, epidermal cells, macerated wood	Plant residues concentrated along the edge. The edge was used to process green wood with resinous bark. Handheld

signal and, under such circumstances, residue analysts need to accept that residues may not be telling the full story. For instance, the presence of large quantities of comminuted animal bone with accompanying stone tool cut marks at the Middle Palaeolithic site of La Quina (France) enabled Hardy [7] to conclude that, despite the relative lack of identifiable animal residues, the occupants of the site were exploiting a broad range of resources, including mammals, birds and bone or antler.

When animal residues are preserved and correctly identified where they are not to be expected, surprising results can be obtained. Babot and Apella [1] showed that, in addition to maize, burnt bone was ground on lower grinding stones during the pre-Hispanic period in north-western Argentina. Such projects not only give direct and reliable clues to what substances were really processed with stone tools, but also serve to correct erroneous assumptions about the functions of tools. Analyses of stone artifacts from sites like Rocky Cape, Tasmania (about 8000 years old) [4], Starosele and Buran Kaya III, Crimea (about 46,000 years old) [9] and Sibudu Cave, South Africa (from about 33,000 to about 61,000 years old) [17,18] testify to the preservation of a variety of identifiable faunal residues over long periods under various conditions.

During the analysis of archaeological tools, the potential for the presence of faunal residues should be thoroughly investigated. In order to do this, analysts need a good database of modern reference material. The importance of replication work undertaken by the residue analyst cannot be overstressed. The value of reference collections for the identification and interpretation of archaeological faunal residues is illustrated in Fig. 4 where we compare residues documented on stone points from Sibudu Cave dated to older than 50,000 years [17,18] (Fig. 4b,d,f) with modern replications (Fig. 4a,c,e). Microscope slides and residues on replicated stone tools are ideal for three-dimensional collections, and residues stored in this way are better for reference purposes than photographs. Thus, the tools made and used for our blind tests and other replication work have become valuable reference material within our existing comparative collection. Further, we monitor the condition of these replicated specimens at regular intervals to study the potential degradation or preservation of residues. This practice has helped us to record fungal growth on animal residues. Fungi are growing on some of the tools used for experimental hunting and butchery activities in 2003 [19]. These tools were never buried; they were curated in their individual bags in a cool, dark, laboratory storage facility. They were only removed from their sealed plastic bags for the original macro-fracture and residue recording, then almost a year later for the analyst's preparation for Test 3, and more recently when the fungal growth was documented. Currently we perceive of fungal growth as a decomposition contaminant. However, some fungi feed off specific sources [15]. It is thus conceivable that, if the fungi can be identified, they can be used as an additional strand of evidence for archaeological use-interpretation.

Although microscope slides and replicated tools provide the best reference material, it is inevitable that photographs will also form part of comparative collections. These are seldom as clear as the original residues because photographs are one-dimensional (grayscale/black and white), or two-dimensional (color) and because the equipment used to observe and photograph residues cannot always cope with the depth of field required for properly recording associated residues. Where it is necessary to use photographs alone, color aids the identification of animal residues; an attempt to identify such residues without colored images is not advised.

Of necessity most published micrographs of residues are in gray scale; this publication serves as a point in case. The hardcopy is printed in grayscale, but the electronic version contains full color images, and readers are encouraged to compare the quality of information represented in the two sets of figures. In whatever form images are published, clear, morphological definitions, or references to such definitions, are seldom provided so that readers cannot assess the criteria by which microresidue identifications were made. We therefore urge analysts to publish, at least once, their micro-residue descriptions, so that published descriptions [17,18,29] can be continuously updated and corrected.

The interpretation of plant residues on stone tools is not necessarily easier than that of animal residues. Interpretative ability is improved when analysts are familiar with incidental residues. This can be achieved by recording 'dust' samples and archaeological soil samples prepared on microscope slides and scrutinizing these prior to residue analysis. The results of Test 3 together with the work of others [22] illustrate that vegetal residues such as plant tissue, starch and fibers on replicated or ethnographical stone tools do not always indicate use-behavior. Barton et al. [2] demonstrated that residues, especially starch grains, should not be analyzed in isolation, but together with sediment samples and use-wear traces, and Haslam [10] warns against the assumption that large clusters of starch grains on stone tools might indicate use. Detailed spatial analysis of residue types on a sample of ten or more tools of similar type may be a solution for this problem, if there is evidence and statistical support to show that the distribution pattern on the whole tool sample could not have happened accidentally [17,18]. Another resolution, which we recommend, also for smaller samples or single tools, is the consistent use of multi-stranded evidence.

4.3. Conclusion

A high level of accuracy was obtained for the recognition of residues and tasks performed for the new blind tests reported here. Our pioneering blind tests [29] singled out potential problems with some residue identifications and our subsequent research has begun to address these issues. In particular, the early test results highlighted some difficulties in making morphological distinctions between animal and plant residues. We have resolved some of these issues now, but Test 3 taught us even more about the intricacies of residue analysis because it showed that the rock type of a tool can influence the ability of the analyst to correctly recognize and interpret residues. Reflective rocks such as quartz and some types of quartzite need to be scrutinized with particular care. However, by painstakingly inspecting the microscopic
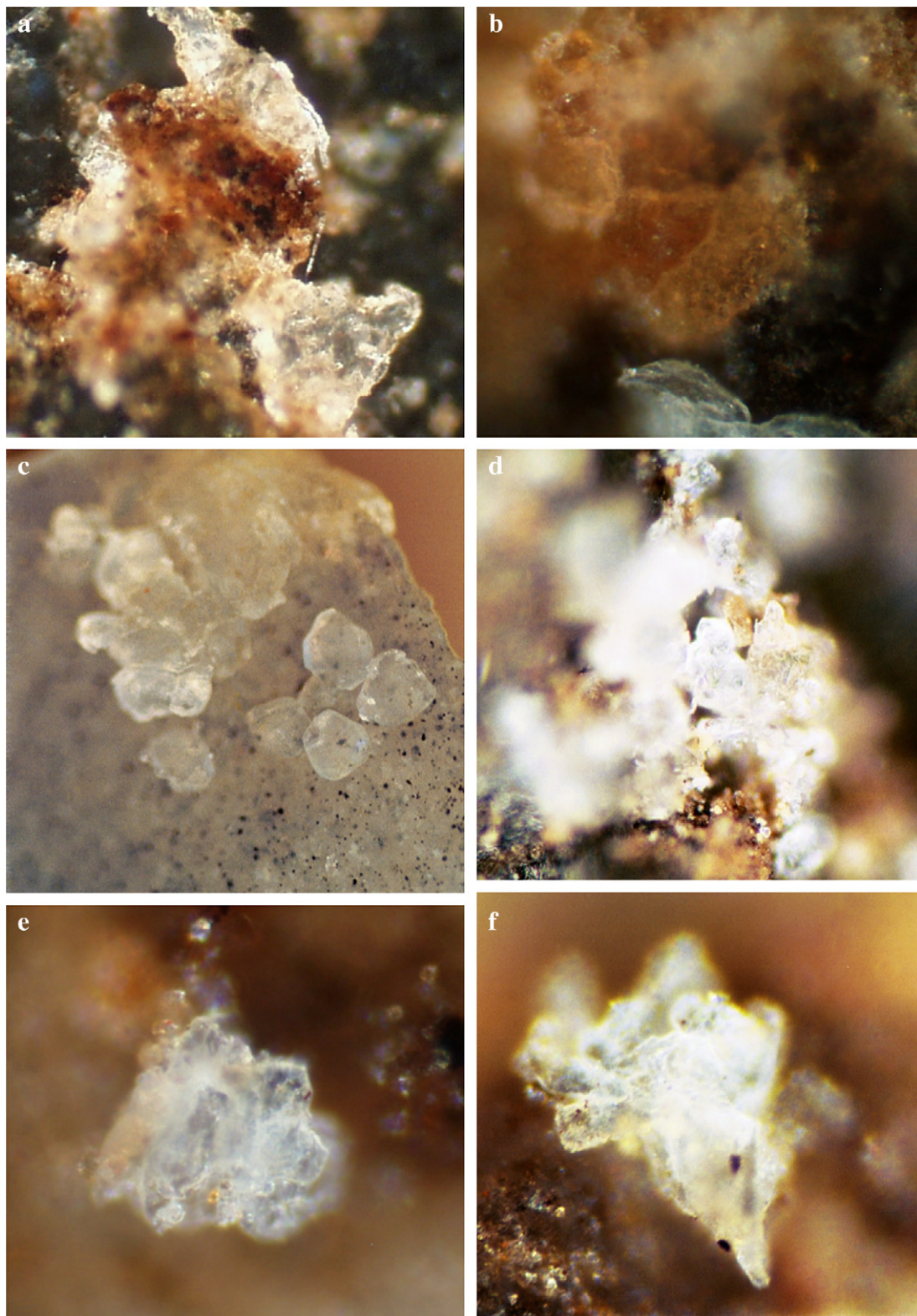
Fig. 4. The value of replication, is to a great extent the building of a reference collection to help interpret archaeological residues. The purpose of this figure is to provide a glimpse of how effective this is by comparing replicated residues with residues documented on archaeological tools (all older than 50,000 years) from Sibudu Cave. (a) Faunal tissue and collagen on a replicated spearhead used to stab a *Connochaetes taurinus* carcass, photographed at 200×, from hunting experiments [18]. (b) Faunal tissue and collagen on a convergent tool from Sibudu Cave, photographed at 500×. (c) Fat cells from modern beef, photographed at 100×, from additional replication work. This residue has a translucent, whitish appearance and become opaque, though often highly reflective, when the light polarizer is rotated. It may also display a rainbow-colored surface reminiscent of birefringence, but unlike some plant residues the birefringence is only superficial and usually does not continue through the depth of the residue. (d) Dehydrated fat cells on a convergent tool from Sibudu Cave, photographed at 100×. (e) Rumpled bone/sheet collagen on a replicated tool used to cut bone and cartilage of an *Aepyceros melampus* carcass, photographed at 500×, from Tool #5 Test 4. Bone consists mostly of collagen, and M.L. is not yet sure whether it is possible, or advisable to differentiate between bone and sheet collagen fragments. (f) Rumpled bone/sheet collagen on a convergent tool from Sibudu Cave, photographed at 500×.

appearance of residues on quartzite after Test 3 was completed, mistakes were avoided in Test 4.

Test 4 in the series resulted in the highest score. This was because, prior to Test 4, the predicament associated with distinguishing plant and animal remains was directly addressed through a series of replications. Replicated plant and animal residues were curated as micro-slides, replicated stone tools with use-residues, and as a set of colored photographs; this created both three-dimensional and two-dimensional records of residues that could be used for comparative purposes. Particular care was taken to create suites of related residue types, thus the collection of animal residues includes examples of fat cells, collagen, muscle tissue, bone, blood and hair; the plant residue suite includes starch grains, resin, wood, bark, fibrous leaf and silica skeletons. A careful study of the differences between plant and animal residues was made and some photographic evidence is provided here, together with some examples of comparable archaeologically recovered residues. An important issue has arisen from our recent study: we believe that because of the challenging nature of distinguishing some plant and animal residues, analysts should consistently seek multi-stranded evidence for the identification of either category of residue. Attendant residues, for example, the combination of fat, bone and animal tissue on a tool provides a far more secure interpretation of an animal residue than a single residue type such as hair. This is particularly relevant in archaeological contexts where some residues may be partially degraded.

Notwithstanding the demanding nature of residue analysis using light microscopy, the morphological identification of residues remains one of the most reliable sources of use-information, especially because changes in chemical composition, as a result of diagenesis, may confound results from other methods [12]. We find blind testing to be of unequivocal value for isolating problems, particularly those that arise during the examination of archaeologically derived residues. Analysts should not be inhibited in their experimental work because of a fear of making mistakes, a comment that has also been made by Rots et al. [21]. Lessons learnt from deficiencies in Tests 1, 2 and 3 advanced our knowledge of residues considerably and helped the analyst to avoid errors in Test 4. Thus, blind tests are a highly effective means of skills development.

There are several ways in which blind tests for residue analysis using light microscopy can be constructed. For some analysts it might be preferable (and, indeed, it is essential for novices) to perform blind tests on micro-slides of single, simple residue types prepared under controlled laboratory conditions. This type of test can successfully build the confidence of an analyst because 'safe' conditions are reassuring. However, the analyst who is interested in investigating archaeologically recovered residues eventually needs to move beyond this phase into a situation that more realistically emulates prehistoric conditions. We believe, perhaps controversially, that field-based tasks are preferable for creating replicated residues for the testing of experienced analysts. Tasks performed in the field are more likely to imitate situations in antiquity than laboratory-based replications. Ancient tools were used in field situations and were subject to 'contamination' (in that incidental residues adhered to the tools) and perhaps to multi-purpose use. Consequently, we choose to fashion our blind tests to suit our particular archaeological enquiries.

As has been frequently discussed, the ideal archaeological sample for residue analysis is one that has been taken directly from the ground to controlled laboratory conditions [31–33]. Inevitably though, an analyst will, at some stage, be asked to examine tools that have been collected from, or stored under, less than ideal circumstances [16]. If the collection is of specific archaeological value it is worth making the effort to examine it, but it is important that publications record the conditions under which the tools were excavated, curated, and handled prior to residue analysis, or whether such conditions are unknown to the analyst. Sometimes residues are studied on tools that have been handled during technological studies [6] or have been retrieved from surface collections [31]. Tools collected from the surface or from open sites may have been exposed to contamination of many kinds for centuries. Tools subjected to potentially destructive analyses are also occasionally examined [31]. If anything useful is to be gained from collections drawn from such unfavorable circumstances, the analyst requires familiarity with a broad spectrum of contaminants. These include residues that can arise from undue handling, from exposure to dust and to the general effects of the elements. Residues that are considered to be contaminants should be incorporated into reference collections and, in our opinion, should be used in blind tests, too. Collections of such residues can also be part of studies of diagenesis, such as those discussed earlier in this paper.

Although a 100% score was attained for Test 4, using tools that had been worked with in the field, it does not follow that archaeological residues can necessarily be interpreted with the same accuracy. A margin of error must be expected, but we consider that this margin has been reduced through our explorations during the set of four tests. Nonetheless, much work remains to be done on the morphological identification of specific faunal and vegetal residues and we hope that our experience and observations will stimulate further research in other laboratories.

Acknowledgements

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