Journal of Archaeological Science (1998) **25,** 177–184

Identification of Woodworking on Stone Tools through Residue and Use-Wear Analyses: Experimental Results

Bruce L. Hardy

Department of Anthropology and Sociology, Olof Palme House, Kenyon College, Gambier, OH 43022, U.S.A.

Gary T. Garufi

Department of Anthropology, Student Building 130, Indiana University, Bloomington, IN 47405, U.S.A.

(*Received 10 December 1996, revised manuscript accepted 18 March 1997*)

Microscopic analysis of stone tools has traditionally relied upon the analysis of wear patterns to provide clues for tool function. However, actual residues of the material on which a tool was used may also survive to provide identification of the use-material. A series of replication experiments were conducted to observe the patterns and types of residues produced in processing wood with stone tools. Fragments of wood preserving diagnostic features of microscopic anatomy were observed and allowed identification of the residue to species in some cases. Distribution patterns of residues, together with use-wear patterns, allow the identification of the use-action. The methods described here will aid in recognition of woodworking tools in the archaeological record, thereby expanding the types of ecological and cultural data available which have been traditionally overlooked.

Keywords: STONE TOOL FUNCTION, RESIDUE ANALYSIS, EXPERIMENTAL ARCHAEOLOGY, WOODWORKING.

Introduction

Functional analysis of archaeological stone tools frequently involves the examination of use-wear patterns including microflake scars, microfractures, striations and micropolishes. The types and patterns of use-wear are correlated with different use-actions and different use-materials (e.g. Keeley, 1980; Moss, 1983; Vaughan, 1985; Shea, 1992). However, more direct evidence of prehistoric tool use is sometimes preserved in the form of residues of the material on which a tool was used. Microscopic examination of tools prior to washing can potentially allow the recognition and identification of these materials (e.g. Briuer, 1976; Anderson, 1980; Anderson-Gerfaud, 1990; Loy & Hardy, 1992; Loy, 1993).

Microwear analysis of stone tools typically involves cleaning of artefacts with a variety of solvents (i.e. water, potassium hydroxide, hydrochloric acid, etc.) in order to see more clearly the wear patterns on a tool. Normally, one of the goals of this cleaning process is actually to remove the organic residues on the tool surface. Despite the fact that these residues have often been observed and recognized (e.g. Semenov, 1964; White, 1969; Brose, 1975; Briuer, 1976; Keeley, 1980; Anderson, 1980; Anderson-Gerfaud, 1981), systematic investigation into the identification of use-residues is still rarely attempted.

The earliest attempt at systematic microscopic examination of use-residues was undertaken by Briuer (1976). Animal residues identified through microscopic analysis include: blood (Briuer, 1976; Loy, 1983, 1985, 1986, 1987, 1993; Loy & Nelson, 1987; Loy & Wood, 1989; Loy & Hardy, 1992), hair (Loy, 1985, 1986, 1987, 1993; Loy & Nelson, 1987; Loy & Hardy, 1992), feathers (Loy, 1985, 1993; Loy & Nelson, 1987), and collagen and muscle tissue (Loy, 1993; Loy & Nelson, 1987; Loy & Hardy, 1992). Plant residues identified microscopically include: stellate hairs, pollen grains, calcium oxalate crystals, raphides, cell walls, cell lumen, tracheids, fibre tips, spiral vessels, and hair vessels (Briuer, 1976); plant fibres, including epidermal fragments, starch grains, raphides, and phytoliths (Shafer & Holloway, 1979); parenchymous tissue and vessels of poplar and hazelnut origin and tracheids of pine and spruce (Anderson, 1980; Anderson-Gerfaud, 1981, 1986, 1990); starch grains and raphides (Loy, Spriggs & Wickler, 1992), starch grains and plant fibres (Fullager, Meehan & Jones, 1992); fragments of reeds (Hurcombe, 1988, 1992); and tracheids (Hardy, 1994).

The identification of plant residues on stone tools is a potentially valuable source of information since macroscopic plant remains rarely survive in archaeological contexts, particularly in earlier time periods. There are several notable exceptions that demonstrate that plant remains can survive in a wide variety of

0305–4403/98/020177+08 $25.00/0/as970234

contexts. For example, preserved wooden spears are known from the Lower Paleolithic site of Schöningen, Germany (*c*. 400 kya, Thieme, 1997), the Middle Paleolithic site of Lehringen in Germany (*c*. 110–130 kya, Movius, 1950) and the Middle Pleistocene site of Clacton-on-Sea, England (*c*. 350 kya, Oakley *et al*., 1977). A variety of wooden artefacts were preserved in a water-logged context at the Middle Pleistocene Acheulean site of Kalambo Falls, Zambia (Clark, 1974). A wooden plank with man-made polish and other possible wooden artefacts have been found at the Acheulean site of Gesher Benot Ya'aqov in Jordan dating from the Middle Pleistocene (0·24–0·75 mya, Belitzky, Goren-Inbar & Werker, 1991; Goren-Inbar *et al*., 1994). Wooden artefacts and pseudomorphs have recently been reported from Middle Paleolithic levels at Abric Romani, Spain (Carbonell & Castro-Curel, 1992; Castro-Curel & Carbonell, 1995). In addition to these more dramatic finds, Mason, Hather & Hillman (1994) have recently reported the recovery of plant macroremains from the sediments at the Upper Paleolithic site of Dolní Vestonice in the Czech Republic. These recent findings suggest that plant remains may be more common at Paleolithic sites than was previously thought and that they are not often recovered (Mason, Hather & Hillman, 1994).

Possible Mechanisms of Wood Residue Preservation

Despite this generally held notion that plant remains do not survive archaeologically except under conditions of exceptional preservation, a growing literature indicates that plant remains can survive in a wide variety of contexts. For example, microscopic woody plant remains have been reported to survive on the surfaces of tools from the Middle Paleolithic (Anderson-Gerfaud, 1990; Hardy, 1994). Why do these microscopic woody plant remains survive when most or all macroscopic traces are gone?

Wood decays through a variety of biological and chemical processes. Fungi, bacteria, and insects can all cause mechanical breakdown of wood through attack and use of cell wall components (Blanchette *et al*., 1990). Microorganisms and insects break down the structural polymers of wood into simpler molecules and finally to CO_2 and water. Chemical degradation can occur in a variety of ways, including enzymatic hydrolysis caused by anaerobic microorganisms, adsorption of ultraviolet light by photochemically sensitive chemicals, and interactions with ground water. These and other methods of degradation are influenced by the particular burial environment. Temperature, pressure and water content play important roles, as do many other factors. However, despite the wide range of possible mechanisms of breakdown, wood can survive in archaeological contexts ranging from wet to dry (Florian, 1990). When wood does survive, it is because it is somehow protected from these processes of degradation due to some combination of factors of the unique burial environment (Florian, 1990). The preservation of microscopic fragments of wood on stone tools may not only be a product of the general burial environment, but also of the particular microenvironment immediately surrounding the tool. Anderson-Gerfaud (1990) has also pointed out that wood microfibres contain silica in their cell walls, which is more resistant to decay than organic material. These fibres and other microscopic plant fragments may be trapped in depressions on the tool's microsurface which further protect them from the action of decay. Finally, she suggests that residues can adhere to the tool edge due to ''dissolution of small areas of the flint micro-surface from friction in the presence of water and abrasives'' (Anderson-Gerfaud, 1990: 395; see also Kamminga, 1979; Anderson-Gerfaud, 1981). These and other factors may help protect residues and allow them to survive on tool surfaces when they do not survive macroscopically.

Despite the paucity of identifiable plant remains from the Early and Middle Pleistocene, microscopic examination of tools from these time periods suggests that the processing of woody plants may have been more common than the surviving examples indicate. The earliest artefacts showing evidence of processing of wood come from the Middle Paleolithic. Artefacts showing use-wear patterns indicative of plant processing have been reported from the Middle Paleolithic sites of Pech de l'Azé IV, Combe Grenal, and Corbiac (Anderson-Gerfaud, 1990), and Corbehem, Grotte Vaufrey, Combe-Grenal, Pié-Lombard, Marillac, and Arcy-sur-Cure (Beyries, 1987, 1988). Anderson-Gerfaud (1990) has further observed plant residues on tools from the Middle Paleolithic sites of Combe-Grenal (siliceous plant epidermis) and Corbiac (plant, probably wood fibre). Microscopic wood fragments have also been found on stone artefacts from the Middle Paleolithic site of La Quina in south-western France and have been identified to class level (Gymnospermae, see Figure 1(a, b)) (Hardy, 1994). These results suggest that microscopic wood fragments may survive on stone tools when no macroscopic plant remains are found. This paper, therefore, is concerned in particular with the identification of wood remains on stone tools and the identification of use-actions based on residue and wear patterns observed on tools.

Establishing that Residue is Related to Use-Patterning and Experimentation

One of the difficulties of interpreting evidence from residue analysis is establishing that the residue seen

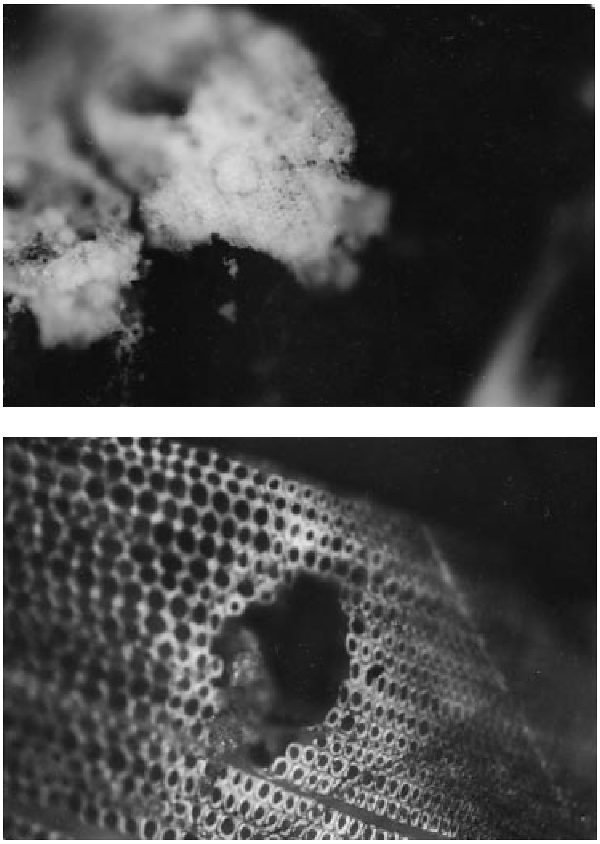

Figure 1. (a) Fragment of gymnosperm tissue on flake QE5-234 from the Middle Paleolithic site of La Quina, France. Tracheids are visible in cross-section. Original magnification 100 ×. (b) Cross-section of modern pine tissue showing tracheids and resin canal. Original magnification 100 ×.

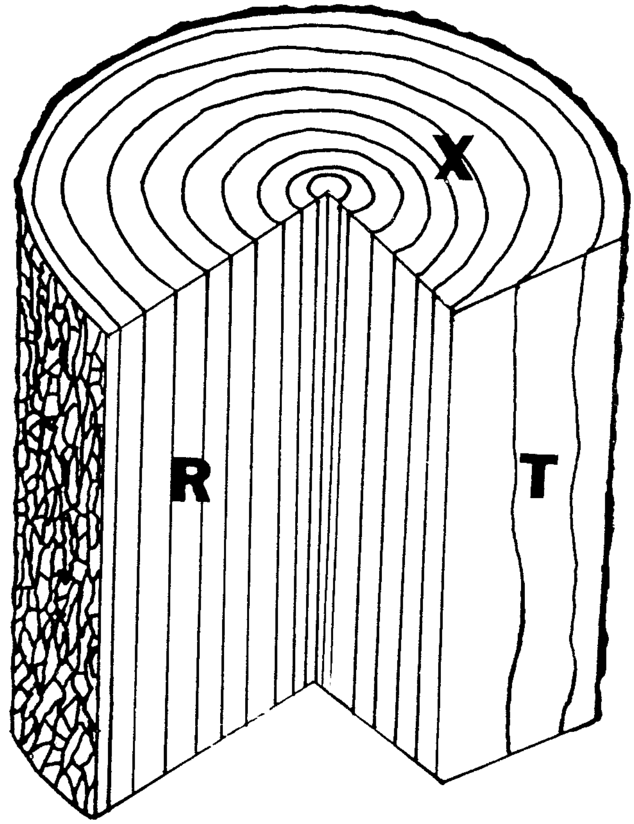

Figure 2. Drawing showing planes of cut used in wood identification. X = cross-section, R = radial, T = tangential.

microscopically is related to the use of the tool. Connections between residues and use can be established in three ways. The first involves the examination of the soil at the site. If residues found on a tool are also scattered through the soil, then they are more likely to be a contaminant not related to tool use. Conversely, if residues are not present in the soil, then it is likely they are related to tool use.

However, even if the residue is not present in the soil, it is possible that its presence on the tool occurred prior to burial but is nevertheless coincidental. The second way to establish that residues are use-related, and perhaps the most reliable, is to examine patterning on the tool surface. If the residue is concentrated in particular areas on the tool, i.e. in areas which have been modified by use, it is more likely to be use-related. If the residue is scattered over the surface of the tool with no discernible pattern, it is less likely to be related to use. Finally, in order to corroborate the evidence provided by patterning of the residue, use-wear patterns should also be examined. If the use-wear patterns are consistent with the distribution of residue on the tool surface, then the case for a residue being use-related is further strengthened.

Methods

Identification of microscopic wood fragments

A series of replication experiments were performed on a variety of woods to determine if consistent patterns were observable and to test the possibility of specific identification of wood residues. Identification of wood residues was based on standard anatomical features (Hoadley, 1990). Wood is defined as secondary vascular thickening in plants and can be found in trees, vines and shrubs (Fahn, 1982). Features of microscopic anatomy can allow classification of wood fragments as angiosperm (hardwood) or gymnosperm (softwood). In some cases, microscopic features allow identification of wood fragments to species. Identifiable features of wood anatomy, including characteristic cell types, pits, resin canals, etc., are best seen along three axes of the wood (Figure 2). Wood features are more easily identified on cross-sectional (X), radial (R), and tangential (T) axes than on oblique cuts cross these axes. Planes which are oblique to these axes cut diagonally across cells making diagnostic features more difficult to see.

Wood residues were examined using reflected light microscopy on an Olympus BH2 microscope with magnifications ranging from 50–500 ×. Anatomical features were identified by comparison with published materials and comparative wood samples. Descriptions of the anatomical features diagnostic of different wood types can be found in Friedman (1978), Core, Côté & Day (1979), Barefoot & Hankins (1982) and Hoadley (1990).

Experiments

A series of 100 replication experiments involving wood processing was undertaken by the authors. Stone tools were manufactured from flint and used to work wood with six different use-actions: whittling, slicing, incising, scraping, planing, and boring (Keeley, 1980; Mansur-Franchomme, 1986). The tools used were unmodified flakes for the use-actions whittling, slicing, and incising. For the use-actions scraping and planing, the tools were unifacially retouched flakes with steep working edges. Tools used for boring were bifacially retouched into an elongated point.

The use-materials included six species of wood, three hardwoods and three softwoods. The hardwoods included sugar maple (*Acer saccharum*), persimmon (*Diospyros virginiana*) and oak (*Quercus coccinea*). These woods represent the three major anatomical divisions of hardwood, ring-porous, semi-ring-porous, and diffuse porous. The softwoods included red spruce (*Picea rubens*), eastern white pine (*Pinus strobus*), and eastern red-cedar (*Juniperus virginiana*). These represent the three major anatomical divisions of softwoods, large resin canals, small resin canals, or no resin canals. Each experiment consisted of performing the use action on a new piece of wood for 5 min with no resharpening. All wood was gathered from live trees and worked in a fresh condition. Once an experiment was completed, the tool was placed in a plastic bag until microscopic analysis.

Microscopic analysis

Microscopic analysis was conducted as described above using both bright and dark field illumination. Experimental tools were examined and patterns of wear and residue distribution recorded. Artefacts were not cleaned prior to analysis in order to avoid loss of residues. Identification of wood residues to class or species level was based on observation of diagnostic anatomical features.

Blind tests

In addition to the 100 original experiments, G.T.G. conducted a further 50 experiments on the same species of wood for use as a blind test for B.L.H. to test for accuracy in identification. The 50 experiments were arbitrarily distributed among the six use-actions in proportions unknown to B.L.H. The experiments were conducted without B.L.H. present and were passed to a neutral third party, who recoded and renumbered them, before being given to B.L.H. for analysis. B.L.H. examined the tools using the methods previously described and then gave G.T.G. a list of his identifications for scoring. B.L.H. recorded presence/absence of wood residue and use-action for all tools. When possible, he also identified class of wood (hardwood/softwood) and species.

Results

Use-actions

Microscopic examination of the experimental tools yielded clear patterning of use-wear and residues associated with different use-actions. The distribution of the wood residues observed along with planes of cut visible in microscopic wood fragments were diagnostic of use-actions performed. Planes of cut were observable in the residues through recognition of cell types and cellular structures. Observations of the angle and trajectory of a tool in relation to the wood allowed predictions of the planes which would be cut by a given use-action. Although a stone tool is rarely held at a constant angle, certain planes are more likely to be cut with each use-action.

Slicing The only plane cut with a slicing motion is cross-sectional. However, the edge of a stone tool is not uniform and often undulates at a microscopic level. Therefore, radial sections are sometimes torn loose and adhere to the tool. Striations are parallel to the working edge.

Incising Incising cuts primarily along a radial plane. Striations are parallel to the working edge.

Whittling At the beginning of cutting, the fragments produced are tangential. As more wood is removed, radial and even cross-sectional planes may appear. Striations are perpendicular to the working edge.

Scraping The residues produced with scraping are similar to those of whittling. Tangential planes dominate. Striations are perpendicular to the working edge.

Planing See scraping.

Boring The planes cut when boring are mostly oblique. Occasionally radial sections are visible. Striations are perpendicular to the long axis of tool and confined to the tip.

Specific identification of residues

In some cases, it was possible to recognize diagnostic elements of wood anatomy on tools which allowed the identification of the origin of the residue. Most fragments of wood residue seen on tool surfaces have no visible diagnostic anatomical features. On those

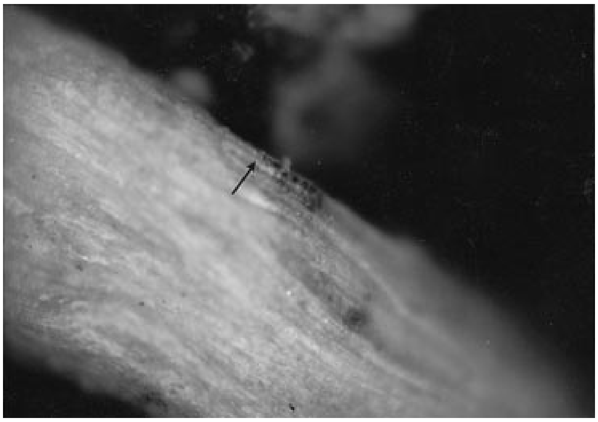

Figure 3. Ray cells in tangential view on an experimental tool used to whittle cedar. Original magnification 200 ×. Diagnostic level: wood.

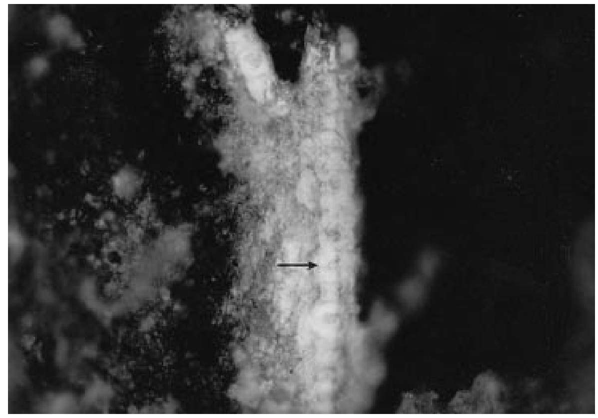

Figure 5. Bordered pits in radial view on an experimental tool used to incise spruce. Original magnification 500 ×. Diagnostic level: gymnosperm, number of pits can separate species.

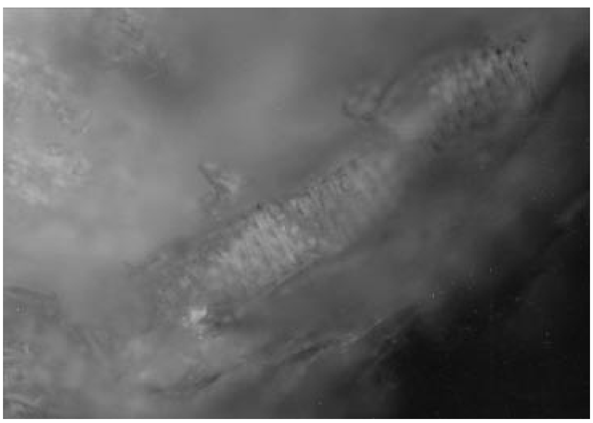

Figure 4. Alternate intervessel pitting in tangential view on an experimental tool used to plane maple. Original magnification 200 ×. Diagnostic level: angiosperm, type of pitting can identify species.

Figure 6. Amorphous debris and hard/high silica polish on an experimental tool used to scrape pine. Original magnification 100 ×. Amorphous fragment is identifiable as wood based on morphology of the fibre indicated by the arrow. Diagnostic level: wood.

tools which were identifiable to class or species level, the number of fragments with diagnostic anatomy was usually a very small amount of the overall residue (<10%). Figures 3–7 show examples of wood anatomy and use-wear visible on experimental tools. The ray cells in Figure 3 are diagnostic of wood, but do not permit more specific identification. Rays are found in both hardwoods and softwoods. This particular view of the ray does not allow any further distinctions.

Figure 4 shows intervessel pitting which indicates that this residue derives from hardwoods. Hardwoods possess pitting between vessel elements which is visible in radial view. The type of pitting (alternate, opposite or scalariform) can be further diagnostic of species. Because the range of species in the experiments was known, it is possible to identify this species as maple. Even if the range of species had not been known, it would still have been possible to narrow down the residue's origin to a handful of hardwood species with alternate intervessel pitting.

Figure 5 shows bordered pits in radial view on a tool used to incise spruce. Bordered pits are only found in the tracheids of softwoods and are among the most common and easily identifiable residues. The number of pits across an individual tracheid can be useful in distinguishing between species. For example, spruce rarely has more than one pit across a tracheid while redwood may have as many as four (Hoadley, 1990). However, with the range of species used here, it is only possible to identify this residue to softwood.

Figure 6 shows amorphous wood fragments in association with a hard/high silica polish. Amorphous fragments with no diagnostic anatomy are usually produced when a tool cuts obliquely through the wood. These residues are sometimes identifiable as wood which is used in an archaeological context, but they do not allow any more specific distinctions.

Figure 7 illustrates well-developed striations on a tool used to incise pine. The presence of striations on tools can provide support for an identification of wood residues.

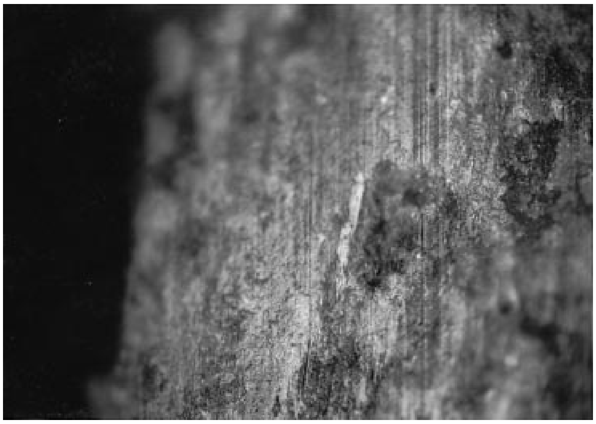

Figure 7. Striations parallel to working edge on a tool used to incise pine. Original magnification 100 × .

Table 1. Results of blind-test identifications

	Use-action	Presence absence of wood	Class	Species
No. correct	49	50	13	1
No. of attempts*	50	50	15	2
% correct	98	100	86·7	50
Indeterminate	0	0	35	48

*In the case of determining use-action and presence of wood, number of attempts equals 50, the global sample of experimental tools. In the case of determining class and species, No. of attempts refers only to those tools upon which diagnostic anatomy was identified which would allow these determinations.

More than one kind of evidence (residue, polish, striations, and edge damage) strengthens an interpretation of a tool as wood-processing. Although there is a temptation to attempt class or species identification, archaeologists should remember that the identification of wood alone is important for behavioural reconstruction.

Blind tests

Wood identification The results of the blind test identifications are given in Table 1. B.L.H. correctly identified that all tools exhibited wood residue. Of the 50 tools, B.L.H. attempted to identify 15 to class level. He correctly identified the class on 13 out of 15 tools (86·7%). On two specimens, the residue contained cellular structures which were potentially diagnostic of species. One of these was correct and was identified as cedar on the basis of bordered pits (softwood) and pinoid cross-field pitting (characteristic of cedar). The other attempt was incorrect at both the class and species level because unknown structures were mistakenly identified as cuppressoid pits.

Use-actions B.L.H. correctly identified 49 out of 50 tools to use-action (98%). Identifications were based on tool morphology, direction and extent of striations, and patterning of residues on the tools.

Discussion

The experiments in this study form a comparative base for the interpretation of residue and use-wear patterns on tools used to process wood. Examination of the experimental tools has allowed the prediction of certain patterns which are associated with different use-actions. These patterns were observed consistently on the experimental tools and were successfully used to identify use-action in the blind tests. The results indicate that these patterns may be used as a model for the prediction of prehistoric use-actions of woodworking tools. Experiments in this study were limited to one use-action per tool and may therefore be more accurate in modelling expedient tool use. If a tool were used to perform multiple use-actions, the predicted patterns might be masked or confused.

In addition to the prediction of use-actions, these experiments have demonstrated that microscopic residue analysis can allow the identification of fragments of wood adhering to tool surfaces. Because many archaeological sites do not preserve macroscopic plant remains, microscopic wood fragments may be the only reflection of wood processing activities at a site. It has also been possible to identify residues to class or species level in some cases. This level of specificity is not available with other techniques. Furthermore, blind tests demonstrate that these identifications can be made from unknown material. The specific identification of wood residues, to class and possibly species, can further aid in the reconstruction of prehistoric plant exploitation.

Conclusions

In this study, we have outlined a technique which allows the detection and identification of wood residues on stone tools. Through experimentation and blind testing, we have shown that it is possible to identify wood residues, sometimes to class or species level, and use-actions of woodworking tools with a high degree of accuracy. It is becoming increasingly apparent that some of the more perishable items at archaeological sites may sometimes survive in a detectable form. While plant remains may not be visible macroscopically at an archaeological site, it is possible that microscopic traces may be preserved. Microscopic analysis of stone tools is one method which can be used to detect these remains. In order to perform the analysis properly, stone artefacts must be examined prior to washing. For this reason, microscopic residue analysis should be included in the original research design of a project. Microscopic residue analysis can potentially identify classes of remains which are otherwise undetected. It is even possible in some cases to make identifications of the particular species being exploited. However, microscopic residue analysis should not be performed in isolation. It should be supported and corroborated by evidence from use-wear studies to help establish that the residues observed are related to tool use. Finally, as with all specialized techniques, it should be placed into the broader archaeological context before functional and behavioural interpretations are made. This technique should be applicable to a wide range of time periods and may help to elucidate the traditionally underrepresented role of plants in prehistoric human behaviour.

Acknowledgements

We would like to thank Nick Toth, Kathy Schick, and the CRAFT Research Center at Indiana University for access to facilities, and Mohammed Sahnouni for assistance in blind tests. Leslie Bush and Mohammed Sahnouni provided helpful comments on earlier versions of this paper. Thanks to Arthur Jelinek of the University of Arizona and André Debénath of the Université de Bordeaux for access to the La Quina material. The La Quina International Cooperative Project of the University of Arizona, Université de Bordeaux I, University of Pennsylvania and the Musée des Antiquités Nationales à Saint-Germain-en-Laye was supported by funding from the Wenner-Gren Foundation for Anthropological Research, the National Geographic Society, the National Science Foundation, the University of Arizona, the University of Pennsylvania, and private donors.

References

Anderson, P. C. (1980). A testimony of prehistoric tasks: diagnostic residues on stone tool working edges. *World Archaeology* **12(2),** 181–194.

Anderson-Gerfaud, P. (1981). *Contribution Méthodologique à l'Analyse des Microtraces d'Utilisation sur les Outils Préhistoriques*. Thèse de Troisième Cycle. Bordeaux: Université de Bordeaux.

Anderson-Gerfaud, P. (1986). A few comments concerning residue analysis of stone plant-processing tools. In (L. Owen & G. Unrath, Eds) *Technical Aspects of Microwear Studies on Stone Tools, Part II*. Tubingen: Early Man News, pp. 69–81.

Anderson-Gerfaud, P. (1990). Aspects of behaviour in the Middle Paleolithic: functional analysis of stone tools from southwest France. In (Paul Mellars, Ed.) *The Emergence of Modern Humans*. Ithaca, New York: Cornell University Press, pp. 389–418.

Barefoot, A. C. & Hankins, F. W. (1982). *Identification of Modern and Tertiary Woods*. Oxford: Oxford University Press.

Belitzky, S., Goren-Inbar, N. & Werker, E. (1991). A Middle Pleistocene plank with man-made polish. *Journal of Human Evolution* **20,** 349–353.

Beyries, S. (1987). *Variabilité de l'Industrie Lithique au Moustérien: Approche Fonctionelle sur Quelques Gisements Français*. London: British Archaeological Report, International Series **S238**.

Beyries, S. (1988). Functional variability of lithic sets in the Middle Paleolithic. In (H. Dibble & A. Montet-White, Eds) *Upper Pleistocene Prehistory of Western Eurasia*. Philadelphia: University Museum Press, pp. 213–224.

Blanchette, R. A., Nilsson, T., Daniel, G. & Abad, A. (1990). Biological degradation of wood. In (R. Rowell & R. J. Barbour, Eds) *Archaeological Wood: Properties, Chemistry, and Preservation.* Washington, D.C.: American Chemical Society, pp. 141–176.

Briuer, F. (1976). New clues to stone tool function: plant and animal residues. *American Antiquity* **41(4),** 478–484.

Brose, D. (1975). Functional analysis of stone tools: a cautionary note on the role of animal fats. *American Antiquity* **40,** 86–94.

Carbonell, E. & Castro-Curel, Z. (1992). Paleolithic wooden artefacts from the Abric Romani (Capellades, Barcelona, Spain). *Journal of Archaeological Science* **19,** 707–719.

Castro-Curel, Z. & Carbonell, E. (1995). Wood pseudomorphs from Level I at Abric Romani, Barcelona, Spain. *Journal of Field Archaeology* **22,** 376–384.

Clark, J. D. (1974). *Kalambo Falls Prehistoric Site, Volume II*. Cambridge: Cambridge University Press.

Core, H. A., Côté, W. A. & Day, A. C. (1979). *Wood Structure and Identification*. Syracuse, NY: Syracuse University Press.

Fahn, A. (1982). *Plant Anatomy*. Oxford: Pergamon.

Florian, M. E. (1990). Scope and history of archaeological wood. In (R. Rowell & R. J. Barbour, Eds) *Archaeological Wood: Properties, Chemistry, and Preservation.* Washington, D.C.: American Chemical Society, pp. 3–34.

Friedman, J. (1978). *Wood Identification by Microscopic Examination*. Heritage Record Series No. **5**. Victoria: British Columbia Provincial Museum.

Fullagar, R., Meehan, B. & Jones, R. (1992). Residue analysis of ethnographic plant-working and other tools from Northern Australia. In (CNRS, Ed.) *Préhistoire de l'Agriculture: Nouvelles Approches Expérimentales et Ethnographiques*. Monographie du CRA No. **6**, pp. 39–53.

Goren-Inbar, N., Lister, A., Werker, E. & Chech, M. (1994). A butchered elephant skull and associated artifacts from the Acheulean site of Gesher Benot Ya'aqov, Israel. *Paleorient* **20(1),** 99–112.

Hardy, B. L. (1994). *Investigations of Stone Tool Function through Use-wear, Residue and DNA Analyses at the Middle Paleolithic Site of La Quina, France*. Ph.D. Thesis, Indiana University.

Hoadley, R. B. (1990). *Identifying Wood: Accurate Results with Simple Tools.* Newton, CT: Taunton.

Hurcombe, L. (1988). Some criticisms and suggestions in response to Newcomer *et al*. (1986). *Journal of Archaeological Science* **15,** 1–10.

Hurcombe, L. (1992). *Use Wear Analysis and Obsidian: Theory, Experiments and Results*. Sheffield: J. R. Collis.

Kamminga, J. (1979). The nature of use-polish and abrasive smoothing on stone tools. In (B. Hayden, Ed.) *Lithic Use-Wear Analysis.* New York: Academic Press, pp. 143–158.

Keeley, L. H. (1980). *Experimental Determination of Stone Tool Uses*. University of Chicago, Chicago.

Loy, T. H. (1983). Prehistoric blood residues: detection on tool surfaces and identification of species of origin. *Science* **220,** 1269–1271.

Loy, T. H. (1985). Preliminary residue analysis: AMNH specimen 20.4/509. In (D. H. Thomas, Ed.) *The Archaeology of Hidden Cave, Nevada*. Museum of Natural History, New York, pp. 224–225.

Loy, T. H. (1986) Recent advances in blood residue analysis. In (J. Olin & J. Blackman, Eds) *Proceedings of the 24th International Archaeometry Symposium*. Washington, DC: Smithsonian Institution Press, pp. 57–65.

Loy, T. H. (1987). Appendix I: Elk Creek Lake Project: residue analysis of 50 artifacts from three sites. In (R. Pettigrew & C. Lebow, Eds) *Data Recovery at Sites 35JA27, 35JA59, and 35JA100, Elk Creek Lake Project, Jackson Co., Oregon, Volume 2*. Eugene, OR: Infotec, pp. I.1–I.7.

Loy, T. H. (1993). The artifact as site: an example of the biomolecular analysis of organic residues on prehistoric tools. *World Archaeology* **25(1),** 44–63.

Loy, T. H. & Hardy, B. L. (1992). Residue analysis of 90,000-year-old stone tools from Tabun Cave, Israel. *Antiquity* **66,** 24–35.

Loy, T. H. & Nelson, D. (1987). Potential applications of the organic residues on ancient tools. In (W. Ambrose & J. Murray, Eds) *Archaeometry: Further Australasian Studies*. Canberra: The Australian National University, pp. 179–185.

Loy, T. H. & Wood, A. R. (1989). Blood residue analysis at Çayönü Tepesi, Turkey. *Journal of Field Archaeology* **16,** 451–460.

Loy, T. H., Spriggs, M. & Wickler, S. (1992). Direct evidence for human use of plants 28,000 years ago: starch residues on stone artifacts from the Northern Solomon Islands. *Antiquity* **66,** 898–912.

Mansur-Franchomme, M. (1986). *Microscopie du Matériel Lithique Préhistorique: Traces d'Utilisation, Altérations Naturelles, Accidentelles et Technologiques, Exemples de Patagonie*. Paris: CNRS.

Mason, S. L. R., Hather, J. G. & Hillman, G. C. (1994). Preliminary investigation of the plant macro-remains from Dolní Vestonice II, and its implications for the role of plant foods in Paleolithic and Mesolithic Europe. *Antiquity* **68,** 48–57.

Moss, E. (1983). Some comments on edge-damage as a factor in a functional analysis of stone artefacts. *Journal of Archaeological Science* **10,** 231–242.

Movius, H. L. (1950). A wooden spear of third interglacial age from lower Saxony. *Southwestern Journal of Anthropology* **6,** 139–142.

Oakley, K. P., Andrews, P., Keeley, L. H. & Clark, J. D. (1977). A reappraisal of the Clacton spear point. *Proceedings of the Prehistoric Society* **43,** 1–12.

Semenov, S. (1964). *Prehistoric Technology*. Trans. M. Thompson. London: Cory, Adams and Mackay.

Schafer, H. J. & Holloway, R. G. (1979). Organic residue analysis in determining stone tool function. In (B. Hayden, Ed.). *Lithic Use-Wear Analysis*. New York: Academic Press, pp. 385–399.

Shea, J. J. (1992). Lithic microwear analysis in archaeology. *Evolutionary Anthropology* **1(4),** 143–150.

Thieme, H. (1997). Lower Paleolithic hunting spears from Germany. *Nature* **385,** 807–810.

Vaughan, P. (1985). *Use-Wear Analysis of Flaked Stone Tools*. Tucson: University of Arizona Press.

White, J. (1969). Typologies for some prehistoric flaked stone artefacts of the Australian New Guinea Highlands. *Archaeology and Physical Anthropology in Oceania* **4(1),** 18–46.