Hafting and raw materials from animals. Guide to the identification of hafting traces on stone tools

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ABSTRACT

Stone tool hafting has been a widely discussed topic, but its identification on a prehistoric level has long been hampered. Given the organic nature of hafting arrangements, few remains are generally preserved. An overview is presented of animal materials that can be used for hafting stone tools, and examples are provided of preserved hafting arrangements made out of animal raw material. Based on the same principles as those determining the formation of use-wear traces on stone tools, it is argued that hafting traces are formed and can be identified. The variables influencing the formation of hafting traces are discussed. Specific wear patterns and trace attributes are provided for different hafting arrangements that use animal raw material. It is concluded that the provided referential data allow for the identification of hafted stone tools on prehistoric sites and the identification of the hafting arrangement used.

KEY WORDS
Stone tools,
use-wear,
hafting,
wear pattern,
experiments,
animal raw material.

RÉSUMÉ

Emmanchements et matières premières animales. Un guide pour l'identification des traces d'emmanchement sur des outils de pierre.

Le sujet des emmanchements des outils de pierre a été largement discuté, mais leurs identifications à un niveau préhistorique ont longtemps été difficiles. Compte tenu de la nature organique des emmanchements, peu de vestiges sont généralement préservés. Une vue d'ensemble des matières animales qui

1. A slide show with Hide Processing may be viewed on the DVD attached at this volume.

peuvent être utilisées pour emmancher les outils de pierre sera présentée et des exemples de conservation d'emmanchements faits de matière première animale seront fournis. Fondé sur les mêmes principes que ceux qui déterminent l'observation des traces d'usure sur des outils de pierre, on procédera à l'observation puis montrera que la détermination des traces d'emmanchement est possible. Les variables qui influencent la formation de traces d'emmanchements seront discutées. Les formes spécifiques des traces et leurs particularités seront présentées pour différents emmanchements en matières premières animales. Les données obtenues créent un véritable référentiel pour permettre l'identification des outils en pierre emmanchés et les matières animales utilisées pour les emmanchements issus de sites préhistoriques.

MOTS CLÉS
Outils de pierre,
usures,
emmanchement,
organisation des traces,
expérimentation,
matières premières animales.

INTRODUCTION

Since the beginnings of prehistoric research, people have been interested in what stone tools were used for. Semenov (1957, english translation 1964) was the first to systematically deal with this question and to come up with a technique that made answers conceivable. Starting from the observation that stone tool use results in wear traces visible on a tool's edges, he explored the possibilities of interpreting them with the aid of a microscope. Up to recently, microscopic functional research has mainly been centred on use-wear traces visible on working edges (active tool parts). Non-active parts were largely neglected, although these parts may also carry traces worthwhile exploring: not only technological traces, but also prehension or hafting traces. Hafting has always been a problematic issue in functional studies. While hafting was considered an important topic (Keeley 1982), the systematic formation of hafting traces and the possibility to interpret them was seriously doubted. The idea was that hafting could only be investigated based on preserved remains of hafting arrangements. Since hafts (or handles) are fabricated out of organic matter, their preservation depends on climatic conditions and the resulting corpus of preserved hafting arrangements is biased. The only valid procedure to gain a more adequate insight in the existence and use of hafts is through the detailed examination of hafting wear on the remaining stone tools. Such an investigation requires a methodology, based on which hafting traces on archaeological assemblages can be identified and interpreted (Rots 2002a, 2003). The methodology necessarily relies on extensive experimentation in order to examine the characteristics of hafting traces and the variables that may influence their formation (Rots *et al.* 2001). Both direct and indirect evidence of hafting on stone tools need to be considered, while also ethnographic material can be informative (Rots & Williamson 2004).

Given the focus of the volume, this article discusses the use of raw material from animals for the hafting of stone tools in prehistoric periods and the resulting microscopic traces on the stone tools. More details concerning the use of other raw materials, such as wood or plant materials can be found in Rots (2002a).

HAFTING AND HAFTING ARRANGEMENTS

Haft type, hafting method, stone tool placement, stone tool direction and orientation of the active part are the main features defining the way in which a tool is hafted; they define the type of hafting arrangement used (Stordeur 1987: 11-34). Haft types can be sub-divided in 'female' (or juxtaposed hafts), 'male' referring to the way in which contact is made between the stone piece and its handle: a handle can be inserted in the stone tool ('female'), and a tool can be placed next to a handle (juxtaposed, Fig. 1); the stone tool can be inserted in a handle ('male', Figs 2 & 3). Bindings of some sort — animal-derived or made from plant fibre — are necessary in the latter case. In 'female' arrangements, the stone tool needs to be hollowed out. Since this is only possible for ground stone tools, this arrangement is not further considered here. The contact between tool and handle can be direct or indirect, depending on whether or not the stone tool was wrapped for a closer fit. This defines the hafting method. A wrapping may consist of a piece of leather (or other) folded around the stone tool (Fig 4). The wrapping is only partial when the tool is wrapped after being placed on a handle resulting in direct contact between the stone tool and the haft, but an indirect contact with the bindings. The stone tool can be placed at the end of a straight (or slightly curved) handle (terminal), at the side of a handle (lateral), or at the end of a bent (or elbow) handle (latero-distal). The tool direction can be parallel to the axis of the haft (axial) or perpendicular/oblique to it (transversal). And finally, the active part can be oriented parallel, perpendicular or obliquely to the axis of the handle.

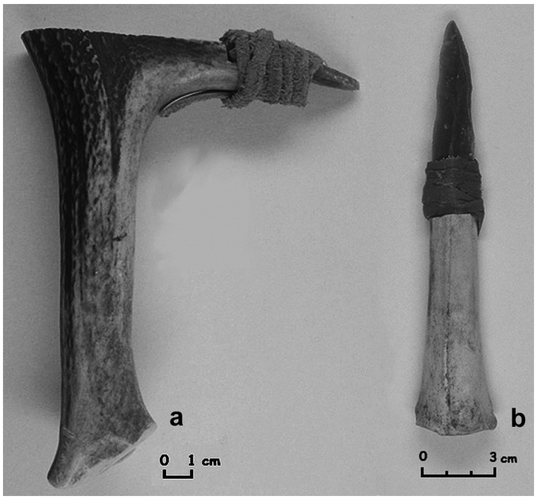

FIG. 1. — **a.** Juxtaposed latero-distal hafting arrangement on antler; **b.** Juxtaposed terminal hafting arrangement on bone. Photographer: Ludo Cleeren (K.U.Leuven).

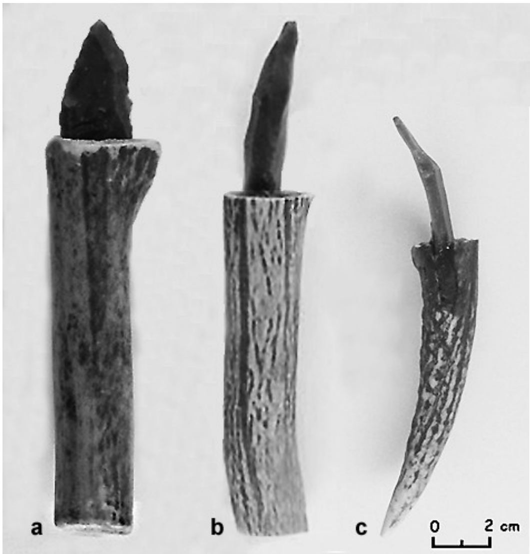

FIG. 2. — **a.** & **b.** Male terminal hafting in antler; **c.** Male split terminal hafting in antler. Photographer: Ludo Cleeren (K.U.Leuven).

THE USE OF RAW MATERIALS FROM ANIMALS FOR HAFTING PURPOSES

Raw materials from animals are readily available, suitable for the fabrication of hafts and for providing all kinds of fixative materials. Below, the available data concerning preserved archaeological examples, characteristics and fabrication procedures are summarized.

HAFTS MADE FROM OSSEOUS MATERIALS

Osseous materials include bone, antler, horn and ivory, all of which can be used to fabricate hafts. Bone and antler are the most relevant ones given their wide availability in prehistoric times. In general, osseous materials from animals have frequently been used to produce hafts up to the present day. The major advantage is that few adaptations are generally required to transform animal matter into suitable hafts. Two basic types are relevant to prehistoric material: 'male' hafts in

FIG. 3. — Male lateral hafting arrangement in antler. Photographer: Ludo Cleeren (K.U.Leuven).

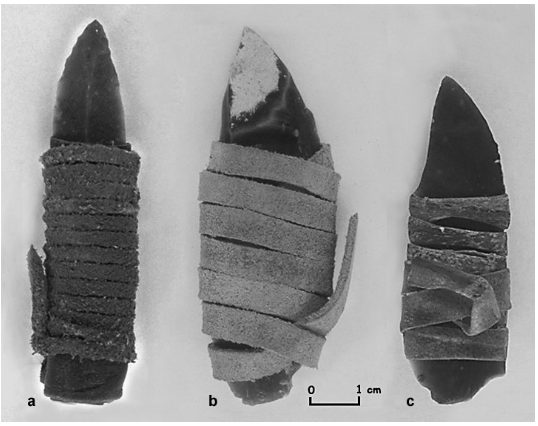

FIG. 4. — **a.** Leather wrapping with leather bindings; **b.** Leather bindings; **c.** Wet leather bindings. Photographer: Ludo Cleeren (K.U.Leuven).

which the stone tool is inserted in a hole, a groove or a cleft ("split") in the haft as well as juxtaposed hafts in which the stone tool is fixed next to the haft. Both straight and angled (latero-distal) hafts occur. Examples are common for the Palaeolithic and the Final Neolithic period (Barge-Mahieu *et al.* 1993).

On a mechanical level, bone and antler have distinct characteristics, as demonstrated by Currey (1979), MacGregor and Currey (1983) and MacGregor (1985). Their bending strength varies depending on their state (fresh/moist or dry). It is lowest in wet conditions, in particular for antler. In dry conditions, the bending strength of antler is higher than bone. Secondly, the bending strength differs in the longitudinal versus the transversal axis. Overall, bone is much more resistant to bending in its longitudinal axis than in its transversal axis, but this varies according to the state of the bone. The bending strength of antler is highest in dry conditions and in the longitudinal in comparison to the transversal axis. It is, therefore, better to cut bone and antler with the grain instead of at right angles to the grain as the end result will be far more resistant. Thirdly, bone is more elastic than antler, but based on the stress-strain curve, antler breaks less easily than bone, implying that antler has a better capacity to absorb shocks and sudden impact loads (MacGregor 1985: 29) and is therefore a very suitable haft for percussion activities.

Bone

While bone tools are regularly recovered (*e.g.* Clarke 1936, Allain *et al.* 1993, Camps-Fabrer 1982, 1985; Averbouh *et al.* 1995, Camps-Fabrer *et al.* 1998), bone hafts remain rare. Most of them were found in the Near East and date to the Neolithic period (*e.g.* El Ouad, Jarmo, Kebara, Oumm ez-Zoueitina, Tell Sawwan: Cauvin 1983), but some older European examples exist (Barge-Mahieu *et al.* 1993). The large majority of these hafts were used for mounting sickle blades. Exceptions for the Magdalenian are a bone handle for the lateral hafting of microliths (Allain & Descouts 1957) and a burin hafted in the extremity of a bone handle (Grotte de Pekarna (Moravia): Jelinek 1982). Other exceptions are a certain number of Mesolithic bone handles, used for terminal hafting and generally recovered in the peat bogs of Denmark (*e.g.* Mullerup: Sarauw 1903; Refsvindinge: Müller 1917; Svaerdborg: Friis-Johansen 1918-1919; Holmegaard: Broholm 1926-1931), but also elsewhere, for instance Germany (Hohlen Stein: Andree 1932). In order to mount a tool, the bone was cut laterally, a technique also used in later periods for the hafting of retouched blades (Camps-Fabrer & Ramseyer 1993: Fig. 2). Bird bone fragments proved to be used for the mounting of microliths as demonstrated by examples recovered at Ensdorf, in Northern Europe (Clarke 1936). A microlithic triangle set into a short tubular bone was also found at Tebessa (Algiers) (Menghin 1927). Even after the Neolithic period, bone hafts or bone inlays were frequently used for different tool classes (*e.g.* MacGregor 1985, Sampson 1993).

If bone working existed at Blombos Cave (South Africa) as early as the Middle Stone Age (around 70,000 years ago) (d'Errico *et al.* 2001b, Henshilwood *et al.* 2001), the first bone hafts may be much older than is known archaeologically. Evidence of intentional bone use was even found much earlier at for instance Swartkrans (South Africa; 1.8 – 1 million years ago) and Sterkfontein (South Africa, 1.7 – 1.4 million years ago) (Backwell & d'Errico 2001, d'Errico *et al.* 2001a, d'Errico & Backwell 2003). For the European Old Palaeolithic period, possible bone artefacts have been recovered, such as the bone tip from Bilzingsleben (Fundstelle Steinrinne, Germany), fabricated out of the split middle part of a straight metatarsus of a large wild horse (Mania & Cubuk 1977), even though the human modification of many bone pieces from Bilzingsleben has been doubted (Steguweit 2003). Early bone tools were also discovered in Italy, for instance at Castel di Guido (Villa 1991).

Bone is one of the easiest available haft materials, a trait that may have largely stimulated its use. Furthermore, it can be obtained in all sizes and weights allowing the hafting of a large variety of tools. One disadvantage may be the fact that all bone hafts must be straight and are therefore impossible to use in percussion (i.e. hoeing, adzing). The extensive evidence for the working of bone and antler during the Late Palaeolithic and Mesolithic period may witness a large-scale use of bone hafts.

Appropriate Parts

Bone has a homogeneous and compact appearance, but remains porous on a very fine scale. It is strong under tension whilst remaining flexible thanks to the presence of collagen (O'Connor 1987: 6). Based on the negative effects that heating or cooking may have on the mechanical properties of bone, bones were probably used while fresh and an occasional heat treatment must have been partial only. This is demonstrated by the heating of the extremity of bones used in hide scraping among the Inuit of Arctic Canada (for strengthening purposes) (Beyries 1997).

The internal structure of bone can be quite varied, depending upon the species, the part of the skeleton, and the age of the individual (O'Connor 1987). Long bones may have been used preferentially because of the presence of the medullary cavity that greatly facilitates male hafting. This preference is also visible in later periods, as demonstrated by the Roman finds in the rubbish pits of Augst (Switzerland) (Schmid 1968) and the Saxon examples from Southampton (England) (Holdsworth 1976). Also for tool production, long bones are preferred (*e.g.* Beyries 1993). Apart from these, the ribs of big mammals may have been used. They can function as hafts after being split laterally (Allain *et al.* 1993: 23).

Haft Manufacture

Male arrangements necessarily dominate among bone hafts. Long bones are hollow and do not require much adaptation to be suitable as hafts (*i.e.* terminal hafting), unless a split is made. They do, however, demand at least a minimal morphological adaptation of the stone tool to be hafted. This is not necessary for a juxtaposed bone haft, in which the stone tool is placed next to the handle, even though a complete or partial split can be made. Bones can also be cut laterally in the longitudinal axis to create a groove in which a stone tool can be inserted.

This ease in production is a great advantage for bone hafts and compensates for the restricted variety in hafting arrangements. It is sufficient to select an appropriate size of bone and saw (or break) off one extremity, or hollow out the bone from the extremity onwards. Fresh bone is a sufficiently soft material to be cut, but as soon as it dries, working it becomes far more difficult (unless weathered bone is used).

Depending on the exact characteristics of the prepared bone haft, it makes different demands on the tool's morphology. Hafting a tool in a cut-off bone extremity requires a tool with a, more or less, oval cross-section. When hollowed out from the extremity onwards the tool needs to be more trapezoidal in cross-section.

Antler

The relatively large number of preserved antler hafts suggests that antler was frequently used in haft production. Shed antlers must have been sufficiently available and were probably predominantly used (Arbogast & Pétrequin 1993), next to cut-off antlers (Voruz 1997). A piece of antler can serve as a complete haft, or it can be used in combination with wood, as demonstrated by preserved axe handles (*e.g.* Guilaine 1976, Ricq-de-Bouard 1996). Its great flexibility and strong resistance to shocks make antler a preferred material for manufacturing hafts, as evidenced by its frequent use as tools used in percussive activities (*e.g.* Voruz 1984, Winiger 1985).

Antler hafts have been recovered more frequently than bone hafts, but this may be a result of differential preservation qualities. While most finds date from the Neolithic period, Upper Palaeolithic examples have been recovered at, for instance, l'Abri de la Fru (France) (Pion 1987). The latter yielded an example of a "male" haft without a stone tool. Magdalenian male split hafts in reindeer antler have been recovered frequently, for instance at La Garenne (France) (Allain & Rigaud 1993). For the Mesolithic period, some Northern European finds can be mentioned, such as the latero-distal "male" haft from Nórre-Lyngby (Clarke 1936: 80), or the numerous intermediate pieces (Friis-Johansen 1918-1919). The latter are generally combined with "female" wooden handles, such as the partially preserved example at Holmegaard (Broholm 1926-1931). The distal part of the wooden handle is usually thicker in order to be able to secure it in the antler piece. For the Neolithic period, the preserved examples consist of sickle hafts (*e.g.* Mikov 1959, Cauvin 1983, Bar-Yosef 1987), intermediate pieces, generally for axes (*e.g.* Ricq-de Bouard 1996, Voruz 1997), complete "male" axe or adze hafts (Giot 1958a, 1958b; Mellaart 1970, Chastel 1985, Voruz 1997) and some rare examples of other tool types (*e.g.* Cauvin *et al.* 1987, Egloff 1987).

It is clear that antler is less readily available in comparison to bone: only a restricted number of animals possess antlers, such as deer (roe deer, red deer, reindeer, etc.) and elk, and the supply of shed antlers is seasonal. Given that shed antlers deteriorate if not collected, people must collect seasonally. Rodents and deer may gnaw the antlers, and weathering and frost may eventually totally destroy them.

Based on the fact that reindeer was one of the main animals hunted during the Upper and Late Palaeolithic period (Benecke 1995: 77), one may expect antler to have functioned as hafts in those time periods. Also during the Mesolithic period, reindeer antler may have been frequently used. During the Neolithic, hunting generally remained important and antler could still be gathered easily.

Appropriate Parts

Depending on the intended use, almost any part of antlers can be used for the manufacture of hafts (Billamboz 1977, Allain *et al.* 1993: 23). For hafts from a single piece, the tines may have been preferentially used. For hafts combined with other materials, the attachment zones of tines may have been preferred thanks to their greater strength. For a latero-distal haft, the staving with a part of the tines is required.

Haft Manufacture

Like bone, antler does not require an important investment for a transformation into an appropriate haft (Billamboz 1977). However, the varia-

tion in size and morphology is restricted. "Male" hafts must have been common, as they are straightforward to produce by removing the spongeosa within the antler compacta (Billamboz 1977, Beugnier 1997). The stone tool to be hafted necessarily needs to be adapted to the produced hole. Among the Caribou Inuit, both "male" and juxtaposed antler hafts are in use, for instance for adzes (Birket-Smith 1929). "Male" hafts are most frequent and all stone tools are adapted proximally before insertion. Juxtaposed hafts were used for the larger and cruder blades.
From historical sources (*e.g.* Roman and Medieval periods) and experimentation, antler is known to be difficult to saw because it is solid in cross-section. Therefore, the antler has to be rotated periodically during sawing in order to reduce the friction that results as the area and depth of the cut grows (MacGregor 1985: 55, Greep 1987: 3). The final separation is usually done by breakage. Soaking in water or in an acid solution (MacGregor 1985) can largely facilitate the processing of antler (Billamboz 1977). It temporarily changes the physical properties of antler and makes it easier to saw. Żurowski (1974) demonstrated that red deer antler could be cut like wood after six weeks of immersion and that it regained its hardness within four days. Immersion softens the spongeous mass inside the antlers to the extent that it can be removed without sharp tools.
Except a few parts of reindeer antler, most antler pieces are curved. This characteristic may sometimes be unfortunate in view of haft production, but antler can be reshaped (straightened) after soaking. Casseyas (pers. comm.) obtained good results after heating it above a fire. Straightening or reshaping antler obviously facilitates its use as hafting material.

Horn

The processes in working horn are different from bone and antler. Pawlik (1993) did not experience many problems during his horn experiments and he considered horn to be relatively soft, elastic and easy to work. Working dry horn appeared to be ineffective and quickly dulled the tool's edge. Horn is generally worked when heated, for instance after immersion in a warm solution or applying delicately controlled heat (MacGregor 1985: 66), since this softens the horn and largely facilitates processing.
It seems unlikely that horn was frequently used as haft before the start of the Neolithic period. It could only be obtained from the woolly rhinoceros (*Coelodonta antiquitatis*), present in Western Europe during colder periods, and aurochs (*Bos primigenius*), which were regularly available. In the Neolithic period, however, the availability of horn significantly increased (cattle, sheep, goat) and probably stimulated its use as haft.

Ivory

Nowadays, ivory is extremely difficult to obtain. Based on its morphology, "male" hafts are expected to be frequent. Ivory has excellent working properties (MacGregor 1985: 38), but it is not as widely available as bone or antler. Only a few animals possess ivory and these are restricted to certain regions and periods. In Western Europe, it may have been used for hafts in colder periods in which the presence of, for instance, mammoth (*Mammuthus primigenius*) has been demonstrated. But similar to antler, the amount of potential haft material that can be obtained per animal is limited. Together with its large size and low manageability, the large-scale use of ivory seems doubtful. Governed by size, only the extremity could function as a male haft, all other parts would have had to be used in a juxtaposed fashion, if used at all. The tendency of ivory to split into cones (MacGregor 1985: 17) may have been considered as a great advantage for "male" hafts.

HAFTS MADE FROM SOFT ANIMAL MATERIALS (WRAPPINGS)

Soft animal materials such as leather, sinew and guts, or soft plant fibres can be used as a special kind of haft, in particular wrappings. Given the protection from sharp edges that a wrapping provides and the slight augmentation in pressure that can be exerted, a wrapping should be considered as a special type of hafting. An example is the scraper wrapped in a piece of hide fixed with a plant binding recovered at Guitarrero Cave (Peru) (Lynch 1980: 239-241). The use of wrappings has been documented archaeologically (*e.g.* Stordeur 1987) and ethnographically (*e.g.* Tindale 1983, Beyries 1997). The bindings or wrappings can also be immersed in resin to fix them more strongly (Tindale 1983, Bocquet 1984).

Hafts made from adhesives

In some cases, the non-active part of a lithic tool may be covered with a ball of resin, similar to some preserved bone awls (Müller-Beck 1965, Stordeur 1987: fig. 6). Just like a wrapping or bindings, resin protects the hand from the sharp edges and prevents it from being cut.

Fixation agents

Adhesives have been used extensively in the past and are still in use today on a very large scale (*e.g.* Barquins 1993). In general, adhesives (used as fixation agent) do not resist high pressure well: they crack or shatter. However, if special care is given to increasing their flexibility (*e.g.* by adding beeswax), the resulting tool may potentially be used in high-pressure motions, such as adzing. Several types of adhesives can be used. The most well known is resin or tar, but also hide and blood (Birket-Smith 1929) can be transformed into an adhesive.

Resin, which is a plant exudates, can be used as such, it can be loaded (addition of sand, earth or other abrasives), or one can obtain tar by the destructive distillation of resinous wood or bark. Pure natural resins are actually too brittle to serve as good bonding agents. Pure resin is a lustrous translucent brown substance, softening at 60°C and becoming a viscous fluid around 120°C. Upon further heating it changes irreversibly to a hard black mass, which is brittle and unsuitable for hafting purposes. Consequently, fillers are required (loading). The spinifex resin prepared by Australian Aborigines contains about 80% fillers by weight in the form of vegetal fibre, ochreous dust and sand (Dickson 1981: 163-167). Birch tar is most commonly used for hafting. It is assumed that birch bark is heated in order to produce a sticky tar. This assumption was guided by the discovery of large amounts of birch bark at various sites (Mercier & Seguin 1939, Vogt 1949, Clark 1954) and is supported by chemical analyses (Binder *et al.* 1990, Heron *et al.* 1991, Charters *et al.* 1993, Pawlik 1996, Regert & Rolando 1996, Regert *et al.* 1998). In many cases, however, secure identifications are lacking (Albasini-Roulin 1987, Egloff 1987, Ramseyer 1987, Anderson *et al.* 1992). In the beginning, mainly infrared spectroscopy was used for discovering the composition of adhesives (Funke 1969), but later on gas chromatography and mass spectrometry have proven more successful and allowed the characterisation of biomarkers (Regert *et al.* 1998). Lupeol, lupenone and betulin are the principal identified components (Binder *et al.* 1990, Hayek *et al.* 1991, Heron *et al.* 1991, Charters *et al.* 1993). Latter analyses are only possible when sufficient adhesive material is available. If not, one has to rely on an analysis with the scanning electron microscope in combination with an energy dispersive analysis of X-rays (*e.g.* Pawlik 1996). Most of these studies concerned Neolithic and protohistoric adhesives (Binder *et al.* 1990, Regert 1996, Regert *et al.* 1998).

The earliest evidence of resin use was discovered at the late Middle Pleistocene site of Campitello (Italy) (Mazza *et al.* 1996). For the Mousterian, evidence was discovered at Königsaue and Kärlich (Germany): resin fragments as well as resin with imprints of both a wooden haft and a stone tool were found (Mania & Toepfer 1973). The resin remains from Königsaue have been AMS dated to 43,800 ± 2100 BP and 48,400 ± 3700 BP (Hedges *et al.* 1998: 229). At Bocksteinschmiede (Germany) hafting resin was also found (Bosinski 1985). Evidence for the use of adhesives is more numerous for the Upper Palaeolithic (*e.g.* Leroi-Gourhan & Allain 1979, Leroi-Gourhan 1983), Late Palaeolithic (*e.g.* Rekem (Belgium): Lauwers 1985, Caspar & De Bie 1996) and Mesolithic period, especially for projectiles (*e.g.* Star Carr (United Kingdom): Clark 1950, 1954). For the Neolithic period, evidence is abundant and mainly concerns sickle blades and knives, but also awls (*e.g.* Charavines: Mallet 1992), projectiles (*e.g.* Burgäschisee-Südwest BE: Wyss 1973; Chalain, Clairvaux: Beugnier 1997) and sidescrapers (*e.g.* Clairvaux, Chalain: Baudais 1987).

While adhesives used in Europe mostly come from plants (resin, tar or fruit juice), bitumen (natural petroleum tar) is often used in the Near East (Coqueugniot 1983, Bar-Yosef 1985, Connan & Deschene 1991, 1992; Barquins 1993) where it is widely available in solid and liquid form (Schwartz and Hollander 2000). The oldest evidence for the use of adhesives, in particular bitumen, dates back to the Middle Palaeolithic, at least to 42,500 years ago (Boëda *et al.* 1996, 1998). Evidence for its use was recovered at the site of Umm el Tlell and Hummal (Syria) (Boëda *et al.* 1996, 1998). Traces of bitumen were discovered away from the cutting edge on 15 artefacts and one artefact respectively. The artefacts (including different tool types) are associated with Neanderthal remains. Bitumen was apparently most often used in its pure state, although sporadic additions of proteinaceous materials have been documented (Connan 1999). Collagen was occasionally used as evidenced at the Neolithic site of Nahal Hemar Cave (Connan *et al.* 1995). Collagen is the structural fibrous protein of tissues in humans, animals, and fish. It gains adhesive properties when degraded into gelatine by treatment with hot water.

Instead of resin, loaded beeswax (70% fillers by weight) can be used, which softens at a lower temperature than resin and is more pliable (Dickson 1981). Beeswax has a rather definite melting point, about 65°C, above which it is highly fluid. Pure wax shrinks considerably upon cooling and, for this reason, as well as for added mechanical strength it should always be used with loading. When used as a bonding agent, the stone head should be warmed to the melting point of the wax (or higher to remove surface water) (Dickson 1981). The wax is soft enough to penetrate small interstices and is easier to finish off than resin. The mechanical behaviour of loaded wax is different from loaded resin. Wax is much softer and more pliable than resin, making it more resistant to shocks and thus suitable for hafting percussion implements. As long as it is not left lying in direct sunshine, it performs very well. It behaves as a rigid body with no observable tendency to crack. When signs of loosening occur after prolonged use, it is sufficient to add a bit of wax into the groove, making sure it penetrates.

There are not many references to the use of hide as adhesive (*e.g.* Witthoft 1958). There is one clear description of its production process through the Primitive Skills Group, where Ball describes the process as follows: shredded bits of deer hide are placed in a crock-pot, covered with water, and cooked for 24 hours. The liquid then needs to be poured off through a cloth and placed in a shallow pan where it simmers until it has reduced in volume and attained a consistency of thin warm syrup. This syrup can be used as glue and if necessary dried into a kind of gelatine and kept for years.

Bindings

Bindings are primarily made from bark (*e.g.* Danish and Alpine Neolithic), ochred leather (*e.g.* Capsian), leather immersed with adhesives, or simple leather (*e.g.* recent Neolithic, Near East) (Stordeur 1987: 15).

Hide and leather

First of all, the exact meaning of the terms hide, skin and leather should be highlighted. Hide refers to the pelt of large animals (*e.g.* cattle, horses), while skin refers to the pelt of small animals (*e.g.* sheep, goat, rabbit). Leather refers to animal pelt that has been preserved or dressed for use. Several processes can be used: tanning, curing, smoking, etc. Within the group of tanned leathers, one can make further distinctions on the level of the tanning agent used. In vegetable tanning, bark, flower, gallnut, etc. are used. Curing refers to a treatment with oil or fat. No chemical transformation takes place; it is a conservation treatment that allows the hides to be used in clothing, etc. Smoking is used to fix tanning agents. Here, a distinction is only made between hide and leather. More details concerning different processes of hide working can be consulted in Audouin-Rouzeau and Beyries (2002).

Hide or leather bindings can be used in various states, independent of their processing. Dry and moistened hide/leather are considered. The main difference between them is the strength of the fixation and the amount of potential friction in the haft. Both aspects are related. For dry bindings, the strength of the fixation depends on how tight the bindings can be attached. In practice, it is impossible to eliminate all friction. When bindings are moistened they expand and they contract again upon drying. Consequently, if bindings are applied when moist, the shrinkage secures the tool against its haft and little friction is possible thereafter. Thanks to their adhesive character, moist bindings are easier to attach and they stick to each other when dried, reducing the risk of loosening during use. Re-moistening the bindings facilitates de-hafting.
Hide and leather were readily available throughout prehistory. Scavenged, hunted or domesticated animals all possess hides that can provide good quality bindings. The manufacturing process of bindings is straightforward and does not demand a lot of skill or a highly specialised hide treatment. Ethnographically, the use of hide/leather bindings is widely documented. However, the manufacturing process is only described in a few cases. Birket-Smith (1929) relates from the Caribou Inuit that bindings should not be fabricated out of belly hide because it is too thin. The fresh hide that is to be transformed into bindings is cleaned of flesh and hair remains, but not scraped thin. The Inuit cut out their bindings in a spiral when the skin is frozen. The bindings are then briefly immersed in water, stretched with the hands and dried.
Only few examples of preserved hide/leather bindings can be noted (Groenman-van Waateringe 1992), such as an adze mounted in a wooden handle with the aid of leather bindings from the Neolithic site of *Byblos* (Cauvin 1968). Hide/leather degrades far more rapidly than hard animal matter and the preservation chances are slim. This is exemplified by the experimental construction of a leather tent (Jourdan & Leroy 1987). The leather cover was completely degraded after only one year, in this case obviously while being exposed to air and varying weather. Buried conditions can be expected to favour preservation, in certain (stable) conditions. Waterlogged environments, for instance, are favourable for leather preservation, but not for hide (Van Driel, *pers. comm.*).

Guts and sinews
The characteristics mentioned above for moist bindings count for guts or sinew as well. Both should be applied when wet and contract upon drying. The strength of the fixation and the amount of potential friction is equal to that of moist hide. Intestines and tendons were widely available throughout prehistory. No special treatment, apart from cleaning, is required.
In comparison to hide, guts and sinew are less versatile. Sinew for instance, can only be used as binding or as thread for sewing and snares (*e.g.* Van Gijn 1990: 41), while hide is highly functional and can be used for clothing, tents, etc. It is not excluded that hide is curated and that other materials are chosen as bindings, if possible. Due to their equal efficiency and performance in securing lithic tools to hafts, guts and sinew may be preferred to hide.
The fabrication of sinew thread is described for the Caribou Inuit (Birket-Smith 1929). The sinew is softened in water and scraped free of flesh remains. It can be spread out on a board to dry, in order to facilitate the splitting process. If one wants a thicker cord, several sinew threads are plaited.
Just as with leather, there are few preserved examples of bindings made from guts or sinew because these materials degrade easily under normal dry-site conditions. One example is a hafted arrow (Müller 1917).

Fibres and strings
Early evidence for the production and use of fibres and strings is scant. Figurines can be considered the oldest indirect evidence of fibres in the form of represented woven skirts etc. These date back to about 25,000 years ago (Soffer *et al.* 2000). More evidence was recovered in Russia and consists of lines impressed in bits of clay that

date to about 22,000 years ago. Similar impressions of wavy lines in bits of clay were discovered in Moravia and were attributed to a woven rope (Soffer *et al.* 2000). Also for the Mesolithic period, there is indirect evidence: remains of a fishing-net were found at *Korpilathi* (Finland) (Pälsi 1920). More recently, direct evidence is available from the *Lascaux* cave, where fragments of rope were sticking to the cave wall and date to at least 15,000 years ago (Glory 1958, Leroi-Gourhan & Allain 1979). In Israel, evidence was discovered that dates to about 19,000 years ago. For the Mesolithic period, the use of bast fibre in hafting arrangements is documented for arrows (Evans 1897). For the Neolithic period, more evidence is available. The hafted parts of some awls from Charavines were first covered with birch tar after which vegetal fibres (roots or twigs) were secured in the tar. In some cases, a wooden haft is added, which is fixed with pine twigs and blocked with fine thread (*e.g.* Bocquet 1984, Pétrequin & Pétrequin 1988, Mallet 1992). At Clairvaux Station III (Jura, France), the use of flax for the production of cords and fibres is documented, as well as oak bark thread for plaiting (Pétrequin 1986).
Several tree and plant species possess materials — *e.g.* bark, fibres — suitable for the production of strings and rope. Lime tree (*tilia*) is often used for fibre production. Yew has also been documented, for instance at Seeberg-Burgäschisee-Süd (Müller-Beck 1965), as well as flax (Pétrequin & Pétrequin 1988: 22-23). Agave and yucca fibre have been identified by residue analysis (Sobolik 1996). The production process of cord has regularly been described ethnographically (*e.g.* Dickson 1981, Stewart 1984). Generally, the fibres are twisted in order to increase strength.

DESIGN THEORY AND HAFTING MATERIALS

The manufacturing process of handles can demand an important investment depending on the raw material choice and the requirements of the intended use. It is likely that the decision to haft a tool is determined by the importance and/or frequency of a task within a society. Only for functions necessitating hafting is the situation likely to differ, but even then one can opt for a very simple and straightforward arrangement (*e.g.* a direct juxtaposed lateral hafting on a straight wooden handle) instead of a very complex arrangement demanding an important investment. The simplicity or complexity of the hafting arrangement both depend on the haft type and on the fixation method opted for. In terms of their design, different criteria can be compared between the hafting arrangements.

Reliability

The reliability of a haft depends on the hafting arrangement and the intended use. The more pressure is exerted on the tool, the higher the risk of failure. Few problems generally occur with hafts used in low-or moderate-pressure tasks. Hafts rarely split or fracture. This contrasts with high-pressure tasks, such as hoeing or adzing, during which cleavage occurs far more frequently. For such actions it is important to choose a hafting arrangement, and in particular a haft material, that is resistant to shocks. Therefore, bone is less suitable than wood or antler. If resin is used, it has to be made more flexible than in the case of low-pressure activities. Several attempts were made in prehistory in order to reduce the chances of haft fracture, which is exemplified by the evolution of wooden Neolithic axe handles (Schibler 1981, 1997; Pétrequin 1986, Pétrequin & Pétrequin 1988): an intermediate piece of antler was one of the solutions to reduce the chance of cleavage. Antler is actually frequently used as a way to protect wooden hafts (*e.g.* spears, axes) from damage (*e.g.* Caribou Inuit: Birket-Smith 1929, Schibler 1981, 1997; Pétrequin 1986; Pétrequin & Pétrequin 1988).
The reliability of hafts does not only depend on the raw material, it also differs between the different haft types. Male hafts have a higher chance of splitting than juxtaposed hafts, as the pressure on the haft is directed from inside towards the outside and around most of its circumference. This

makes this haft type particularly vulnerable. Juxtaposed hafts are rarely damaged. If no stopping ridge is present, hardly any haft damage occurs, be it that the fixation is less secure. If a ridge is present, this part may split off after extensive use, but a binding may prevent this. Next to head fractures, also proximal fractures should be considered, but such fractures seem unlikely if the tool is not used in a violent way. In ethnographic accounts, haft fractures seem to occur regularly, but on the other hand, hafts are often used for decades and inherited from one generation to the other (*e.g.* Beyries 1997, Brandt & Weedman 1997, Rots & Williamson 2004).

Maintainability

When a haft splits, little repair is usually possible. The temporary solution is to tie both parts together with leather or vegetal bindings, but the haft will need to be replaced at one point. If the haft is secured with bindings as soon as a fissure is visible, haft cleavage can be delayed. The possibility of adapting a broken or damaged haft into another functional haft depends on the haft type and haft material in question. When a male haft splits, it may be transformed into a juxtaposed haft (with stopping ridge). Bone is the least maintainable as a result of its size and restricted morphological variety. When it breaks or splits it is difficult to repair or transform into a functional haft.

Flexibility

On the level of haft flexibility, the haft material seems the main determining factor. Bone is less flexible than wood with a limited number of possible haft morphologies. Latero-distal hafts are not possible and one is restricted on the level of size and weight. The only possibility to introduce a larger variety is to use animal bones from animals of different ages or species. One advantage of bone is the ease to produce male hafts thanks to the hole present in long bones. The flexibility of antler is more important than bone. Although one is restricted in terms of size and weight, all morphologies are theoretically possible. Occasionally, the original morphology of the antler needs to be transformed. The use of resin for fixation purposes can extend the flexibility of a haft, as it allows the hafting of a wider variety of tool morphologies. One simply needs to adapt the amount of resin and make sure it fills all cavities.

Flexibility is, however, also important on the level of the stone tool morphology. A juxtaposed haft allows for more varied tool morphologies than a male haft. For the latter, the stone tool generally needs to be adapted in order to fit the haft.

Versatility

If versatility is interpreted as “multifunctionality” as proposed by Hayden *et al.* (1996: 13), then hafts may potentially restrict the amount of possible uses. After all, some haft materials are not suitable for certain functions. A tool hafted in bone is less versatile due to the difficulty of high-pressure motions, while antler is less restrictive.

Also, the haft morphology has an impact on the tool’s versatility. Straight hafts with a terminal hafting do not allow adzing or chopping, while latero-distal hafts do not allow cutting. With regards to haft type, more functions are possible with a male haft than with a juxtaposed one.

It is clear that the versatility of a tool is influenced by several parameters and that it can only be adequately judged based on the individual case.

Transportability

The hafting arrangement itself does not have an important influence on the transportability of a tool, mainly the size (length) and weight are decisive. Latero-distal hafts can be balanced on the shoulder and easily transported (*e.g.* Pétrequin & Pétrequin 1993).

Longevity

Longevity refers to use life, which is an aspect that is difficult to evaluate. There are two major components for each hafting arrangement, the stone tool and the haft, both of which should be evaluated separately. The use life of a stone tool is very short, in spite of resharpening possibilities, in comparison to the potential use life of a handle. The short use life of a stone tool is less important when the fixation procedure is straightforward allowing easy replacements. After all, most stone tools are quickly made and stocks can be prepared if necessary. Hafts on the other hand are only discarded when they are no longer functional due to intensive wear or breakage (beyond repair). Based on ethnographic data, it is known that hafts are often inherited from one generation to another (*e.g.* Konso (Ethiopia): Brandt & Weedman 1997, Rots & Williamson 2004) confirming their extensive use life. Hafts are thus considered as valuable items that are carefully curated. The long use life immediately compensates for the required investment, which is probably an important factor in the decision to haft a tool.

THE HAFTING WEAR PATTERN FOR HAFTING MATERIALS OUT OF ANIMAL MATTER

Given the doubts concerning the formation of hafting traces and the possibilities to derive valid inferences from them, an extensive experimental program was launched in order to examine the issue of hafting wear in more detail (Rots *et al.* 2001, Rots 2002a, 2002b, 2003, 2004, 2005). More than 400 experimental tools were produced that were used on various worked materials (earth, hide, wood, bone, antler, etc.), with various actions (adzing, grooving, scraping, drilling, etc.) and that were hafted with different hafting materials (wood, bone, antler, etc.) in various hafting arrangements or were used in the hand. Different variables were isolated that proved to influence the formation process of hafting traces. Dominant variables determine the hafting trace formation process while secondary variables only cause variations on the existing pattern (Rots & Vermeersch 2004). Dominant variables are the tool's use and the hafting material and arrangement used. Secondary variables are the raw material coarseness, the presence of retouch, the tool's morphology, etc. In order to test the impact of each variable, experiments were performed in which all other variables were kept constant.

The resulting wear pattern was systematically compared, which allowed the proposition of distinctive criteria, useful for archaeological determinations. It proved possible to distinguish between hand-held and hafted tools and between different hafting arrangements (Rots 2004, 2005). Blind tests were performed in order to, amongst others, examine the applicability of the experimental framework to archaeological conditions (Rots *et al.* 2006).

The main results concerning the exact characteristics of hafting wear produced in the case of a contact with hafting materials out of animal matter are summarised below. Data are organised according to the determining dominant variable.

Haft material impact

Similar to the formation of use-wear traces, the haft material influences the trace morphology (*e.g.* polish: morphology, brightness, linkage, etc.; scarring: morphology, size, distribution, etc.). Given the high similarity of bone and antler on a use-wear level, there are few differences what the hafting trace pattern concerns. In general, a bone/antler haft polish is not very intrusive and it remains restricted to the higher zones of the microtopography (Fig. 5c, d). Scars frequently have a narrow initiation, abrupt terminations and a good definition. The ease of determining the exact haft material depends on the intensity of the hafting traces and obviously increases the better developed the hafting traces are. For short uses or low-pressure actions, a distinction between different haft materials, in particular between wood and bone/antler, is generally difficult. The traits of bone/antler haft wear are summarised in Table 1.

Haft type impact

The haft type determines the distribution of the hafting traces over the stone tool. Depending on the haft type, the haft material makes contact with both faces and the edges ("male"), both faces only ("male" split), or one face only (juxtaposed). The remaining tool parts are in contact

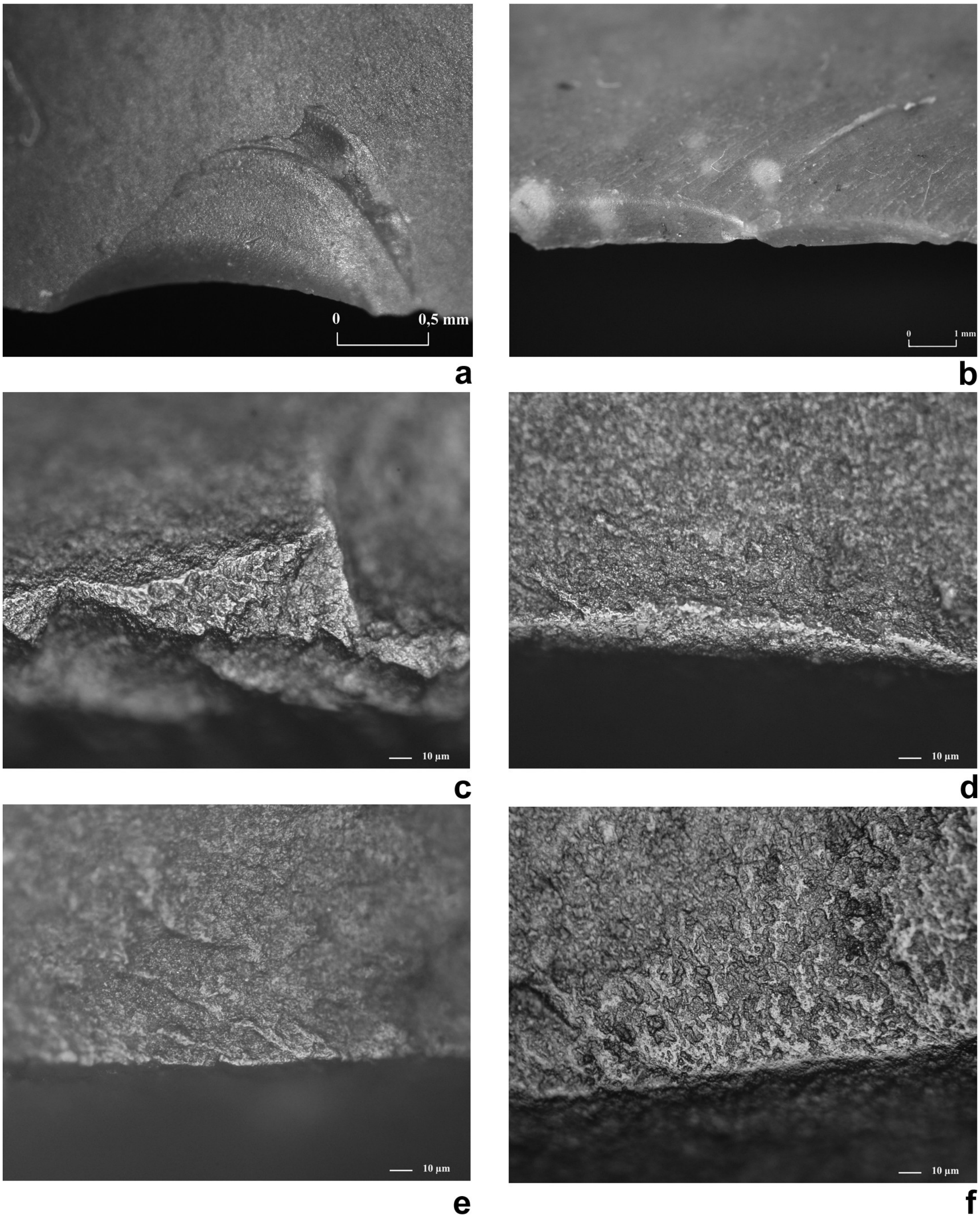

FIG. 5. – **a.** Sliced into scalar scar; **b.** Sliced scar; **c.** Antler haft polish on dorsal ridge; **d.** Well-developed antler haft polish on dorsal ridge; **e.** Leather bindings polish on dorsal ridge; **f.** Well-developed leather wrapping polish (indirect contact with wooden haft) on dorsal ridge. Photographer: Veerle Rots (K.U.Leuven).

with bindings. This differential distribution of a particular kind of traces over the stone tool is an important distinctive criterion to distinguish between haft types. In addition, the impact of a particular haft type on a tool's edges differs greatly resulting in quite distinctive scarring patterns. A "male" hafting obviously has the most important impact on the tool's edges, given that the stone tool is often blocked in the haft under pressure and that the edges are in contact with a hard material. Any pressure resulting from use results in an important pressure on the edges within the hafting arrangement. Consequently, scarring is generally important in the case of male-hafted tools. This contrasts with juxtaposed hafting arrangements in which the pressure on the edges is significantly reduced on the condition that the edges do not protrude from the haft (haft width is larger than tool width). If the edges protrude, scarring will be more intensive. However, bindings result in very typical scarring (*e.g.* sliced scars, sliced into scalar scars, scars with bent initiation, Fig. 5a, b) allowing straightforward distinctions. "Male" split hafting arrangements are grouped in between male and juxtaposed arrangements. What the pressure on the lateral edges concerns, the result is similar to juxtaposed arrangements. What the faces concerns, the pattern is similar to "male" arrangements: there is only one kind of polish on both faces.

The impact of leather bindings or a wrapping on a stone tool is limited. The hafting wear pattern is therefore a mixture between a distribution that is guided by the position of the hand during use and trace characteristics that are reminiscent of binding use (*e.g.* sliced scars). Polish is on average poorly developed and scars are generally small. A clear limit in the trace pattern, representing the boundary of the wrapping, is often visible.

A scheme that summarises the most valuable attributes for an interpretation of the hafting arrangement is always a compromise. Nevertheless, an attempt is made in Table 2: it includes the main traits and can form a useful aid for making hafting inferences. As is clear from this table, polish and scarring form the main trace types that allow a distinction between different haft types.

TABLE 1. — Distinctive trace attributes of bone/antler haft wear.

Trace attribute	Hard animal matter
Polish	
polish morphology	*cf.* usewear
typical morphology	appears at moderate development
polish development	quickly moderately developed
polish extension	low presence tends to be concentrated on outer edge/ridge
Scarring	
scar initiation	narrow = present
scar termination	abrupt
scar definition	moderate to well
Bright spots	
bright spot amount	few to moderate
bright spot size	moderate
Striations	
striation amount	few to moderate
striation orientation	perpendicular
Rounding	insignificant

BINDING MATERIAL IMPACT

The binding material impact is highly similar to what was noted for the haft material impact. The binding material determines the hafting trace morphology, similar to use-wear formation. For bindings, polish is the most distinctive trace type (Fig. 5e), while scarring serves as supportive evidence. Wet leather bindings and intestines lead to the poorest polish development. This is a consequence of the shrinkage upon drying resulting in a strong fixation with little friction. One could pose that these bindings allow the most "efficient" fixation, but this is not entirely correct, as not each function demands a well-secured tool. On the contrary, some movement in the haft often prevents fractures. It largely depends on the tool's use: in high-pressure motions, a strong fixation may be a drawback and favour fractures, while for mechanical drilling a strong fixation is a necessity for efficient tool use. Wet leather bindings or intestines are an advantage when well-secured tools are

TABLE 2. — Distinctive traits per hafting arrangement.

Trace attribute	Juxtaposed hafting	Male split hafting	Male hafting	Leather wrapping
Polish				
number of polishes	two: haft + bindings	two: haft + bindings	one: haft	one: bindings; sometimes two: prehension polish
polish frequency	haft = bindings	haft > bindings	only haft	only bindings (> prehension polish)
polish morphology	*cf.* usewear	*cf.* usewear	*cf.* usewear	*cf.* usewear
opposition	dorsal versus ventral	centre tool versus edges	no opposition	no opposition (only with butt: prehension polish)
concentration haft polish	ventral contact: most proximal & haft limit	dorsal medial ridge, bulb	dorsal ridges, medial edges, ventral butt	none
concentration binding polish	dorsal contact: dorsal ridges	edges	none	no real concentrations
Scarring				
Scar morphology				
* sliced	present	present	absent (exception: perforating, drilling)	present
* crushing	low	low	high	low
Morphological detail				
* sliced into scalar scars	present	present	absent (exception: perforating, drilling)	present
Scar initiation				
* straight into curved	present	present	absent (exception: perforating, drilling)	present
* curved	present	present	absent (exception: perforating, drilling)	present
* twisted	present	present	absent (exception: perforating, drilling)	present
Scar termination				
* snap	present	present	tends towards « rare »	present
* feather	present	present	tends towards « rare »	present
* hinge	tends towards « rare »	tends towards « rare »	present	tends towards « rare »
* step	present	present	present	limited presence
* vertical	present	present	tends towards « rare »	present
* superposition	tends towards « rare »	tends towards « rare »	present	tends towards « rare »
Scar size	not distinctive	not distinctive	not distinctive	not distinctive
Scar depth	not distinctive	not distinctive	not distinctive	not distinctive
Scar intrusiveness				
* intrusive scars	present	present	tends towards « rare »	present
Scar definition	not distinctive	not distinctive	not distinctive	not distinctive
Scar distribution				
* alternating	tends towards « rare »	rare	present	absent
* bifacial	absent	absent	present	absent
* continuous	rare	rare	present	rare
Scar pattern				
* crushed initiations	rare	rare	present	rare
* (inverse) skewed saw pattern	present	present	present	absent
* clear intrusion/notch	rare	rare	present	rare
Scar interpretability	moderate	moderate	high	high

required. It is clear that care should be taken with linking fixation to "efficiency", the demands of each task are different and need to be judged independently. The main differences in wear characteristics caused by the binding material are summarised in Table 3.

Impact of wrapping use

The use of a leather piece in which the tool is wrapped before being mounted in or on a haft influences the subsequent formation of hafting traces. The use of a wrapping has several advantages, as it reduces the amount of friction in the haft and enhances fixation, it reduces the chance of bindings being cut, etc. For male hafts, it allows the use of tools with some size differences in one and the same haft. A small tool size can be compensated by a larger piece of leather, which ascertains that the tool remains well fixed in its haft. Its use on an ethnographic level is attested. In Siberia for instance, scrapers are often fixed in the hole of a wooden haft with the aid of a piece of leather (Beyries 1997).

The use of a wrapping has a notable impact on the formation of hafting polish and scarring, and to a more limited extent also rounding, largely independent of the haft type used. In general, a wrapping reduces the amount of trace formation following the reduced friction that takes place within the haft. The effect on polish is mainly morphological, resulting in a kind of mixed polish depending on the hafting material surrounding the wrapping. When the secondary contact is with a hard haft material, the polish will have a morphology corresponding to the material out of which the wrapping is made, while the polish distribution will be determined by the secondary contact with a hard haft (Fig. 5f). The effect on scarring concerns both its intensity and morphology. On a morphological level, the use of a wrapping has a smoothening effect on the resulting scars, while their intensity significantly decreases. Rounding is slightly increased when a wrapping is used. The impact of wrapping use for juxtaposed arrangements is summarised in Table 4.

Table 3. — Distinctive traits for binding material identifications.

Trace attribute	Leather bindings	Wet leather/ intestines
Polish		
polish morphology	*cf.* usewear, but slightly brighter	*cf.* usewear
polish development	tends to be moderate to well	tends to be low
polish linkage	tends to be well	tends to be low
polish extension	several extensions, preferentially border and inner surface	tends to be concentrated on outer edge
polish interpretability	tends to be moderate	tends to be low
Scarring		
Scar morphology		
* sliced scars	present	present
* crushing	present	present
Scar initiation		
* straight into curve	present	present
* curved	present	present
* twisted	present	present
Scar termination		
* superposition	frequent	present
Scar definition	not significant	minor tendance to frequent well-defined scars

THE IMPACT OF TOOL USE (WORKING ANIMAL MATTER) ON THE FORMATION PROCESS OF HAFTING TRACES

Worked material

The influence of the worked material on the formation of hafting traces rests within the trace intensity mainly. The harder or more resistant the worked material, the better developed the hafting traces will be. This implies that hafting traces will be less developed when working hide than when working bone or antler, following a reduced pressure that is exerted on the stone tool by the haft.

This worked material impact is independent of the action, hafting material and hafting arrangement used. Only for polish, a change in hafting

Table 4. — Distinctive traits for the identification of a wrapping use (for juxtaposed arrangements).

Trace attribute	Wrapping
Macroscopic	
scarring	decrease
gloss	decrease
Microscopic polish	
polish morphology	mixed polish
polish development	not significant
polish extension	slightly more extensive (and intrusive)
Microscopic scarring	
Number of damaged tool parts	decrease (significant)
Scar intensity	minor decrease
Scar morphology	
* sliced	minor decrease (insignificant)
* nibbling	increase
* crushing	decrease (significant)
* elongated	absent (needs confirmation)
Scar initiation	
* narrow	decrease
Scar termination	
* non-abrupt (snap, feather)	increase
* abrupt (hinge, step)	decrease
* superposition	decrease
Rounding	minor increase

arrangement obliterated worked material-induced patterning. This stresses the importance of examining all trace types for making valid interpretations.

Action

The action undertaken has a notable impact on the hafting trace pattern, which is largely independent of other variables. Its impact is situated on the level of the hafting trace distribution within the hafted area, *i.e.* in longitudinal and transversal section. High-pressure motions, like adzing, hoeing or chiselling, result in wear traces over most of the hafted part. By contrast, moderate-pressure actions involving a kind of lever effect, like scraping and grooving, result in two main concentrations: one around the haft limit and one in the most proximal zone of the stone tool. In between these two areas, few hafting traces are formed. This is a consequence of the named lever effect, resulting in a back-and-forth pressure in the two mentioned zones. For rotating actions such as drilling or perforating, there is also a clear opposition in the wear pattern, but in this case between the centre of the stone tool and the edges, independent of the location in longitudinal section. This opposition is formed by a concentration of different trace types. Polish dominates the centre of the stone tool, while hardly being present on the edges, while scarring is only concentrated on the edges.

The most important distinctive traits are summarised in Table 5. The identified impact of the action does not influence the general interpretability of the traces or the distinction between haft types, even though it is obviously true that hafting traces are generally best developed in the case of high-pressure actions.

CONCLUSION

Animal material has formed an important raw material for hafting from the start, depending obviously on the environmental context. Next to several archaeologically preserved examples, a hafting wear study allowed the identification of the use of animal matter in other archaeological cases, where no hafts were preserved (*e.g.* Rots 2005). Animal matter has the major advantage of being easily available, flexible and useful in different ways, *i.e.* for the fabrication of hafts as well as for fixation purposes. In addition, the procurement and preparation of animal matter for hafting does not demand an excessive amount of skill. Some animal parts can be used with minimal preparation.

While hafting has been a largely neglected topic in functional studies, the archaeological data left no doubt about the existence of hafting, at least from the Upper Palaeolithic onwards. A more detailed study of hafting traces was urgently needed. The experimental part of this research indubitably demonstrated that distinctive, inter-

TABLE 5. — Distinctive traits per action.

Trace attribute	Action		
	Adzing & Chiselling	**Scraping & Grooving**	**Perforating & Drilling**
Macroscopic			
Scarring	intense	moderate	moderate
Gloss	insignificant		
Microscopic			
Polish			
* intensity	high	moderate	moderate
* pattern	triangular	inverted or double T	concentration on ridge
Scarring			
* intensity	high	moderate	high
* pattern	V-shaped	inverted or double T	all edges
* number of damaged tool parts	high	moderate	high
* morphology	larger variety	insignificant	insignificant
* terminations	step & hinge most important	insignificant	insignificant
* size & depth	large & deep dominate	small & superficial dominate	small & superficial dominate
Bright spots			
* frequency	high	low to moderate	low
* characteristics	large, well-developed	small, moderate development	small, moderate development
Striations			
* frequency	high	moderate	moderate
* orientation	parallel dominates	perpendicular (and oblique for grooving) dominates	–
Rounding	slightly more intense	low	–
Overall pattern			
* opposition	no true opposition, especially not on edges; on other parts some concentration around haft limit and butt	haft limit versus most proximal; especially on edges	ridges versus edges

pretable hafting wear patterns are formed. The created experimental framework and methodology allows for a distinction between hand-held and hafted tools as well as a distinction between different hafting arrangements (*e.g.* Rots 2002a, 2003, 2004). An archaeological application of this methodology allowed the identification of hafting and hafting arrangements in several cases, which demonstrated that hafting extends further back in time than the archaeological remains allowed to assume up to now (up to 200.000 BP: Rots & Van Peer 2006). In addition, it could be demonstrated that the integration of hafting within functional studies has an important impact on the kind of interpretations that can be obtained (*e.g.* Rots 2005). Insight is possible in the entire life cycle of a stone tool (Rots 2003), which largely improves adequate interpretations of archaeological assemblages. The identification of used hafting arrangements and materials also allows for an investigation of past technical choices. The importance of including all kinds of trace causes in functional studies is therefore stressed. If future functional studies need to remain reliable and methodologically sound, a systematic integration of hafting wear (next to production, use and post-depositional wear) is essential.

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