Экспериментально-трасологические исследования в археологии

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TRACEOLOGY ON METAL. EXPERIMENTS AND INTERPRETATION OF THE ARCHAEOLOGICAL ITEMS

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Traceology on metal has been one of the last specialities to join the world of functional studies of prehistoric materials. That is why its experimental base is still scarce and should be developed in the future. Its methodology corresponds to that of the Traceology on flint or other rocks and materials such as bone, antler, shell and several others, with special interest in systematic and replicative experimental designs, taking into account all the independent variables that intervene in the experimentation and a careful characterization of the traces obtained. In the case of metal, the raw material and post-casting processes are important because they will determine that the tool is softer and ductile or more hard and brittle. Thus, a metal weapon or tool will develop traces of use that will be different qualitatively and quantitatively also in function of these technical elements. A second aspect that determines the study of traces on metal objects is the presence of various types of corrosion with different intensity that may cover some traces and limit the interpretation, as we will see in the experimental examples that we present. Traceology on metal has a very recent development, there are still few works carried out, but future experiments and new techniques of treatment, observation, and analysis of archaeological pieces will be able to increase our knowledge on it.

Keywords: archaeology, traceology, functionality, use wears, experimentation, metal tools, Palmela points.

La Traceología sobre metal ha sido una de las últimas especialidades en incorporarse al mundo de los estudios funcionales de materiales prehistóricos. Es por ello, que su base experimental es aún escasa y deberá ir desarrollándose en el futuro. Su metodología corresponde a la propia de la Traceología sobre sílex u otras rocas y materias como hueso, asta, concha y varias más, con especial interés en los diseños experimentales. En ellos es preciso tener en cuenta todas las variables independientes que intervienen en la experimentación y una cuidadosa caracterización de diversa tipología de huellas obtenida. En el caso del metal es importante considerar la influencia de la composición específica de la materia prima y de los procesos postfundición porque ambos determinarán la dureza y capacidad de deformación del útil frente al uso. Un segundo aspecto que condiciona el estudio de huellas sobre los objetos metálicos es la presencia de corrosiones diversas con distinta persistencia, puesto que cubren algunas de las huellas previas de tecnología y uso limitando la interpretación. La Traceología sobre metal tiene un desarrollo muy reciente y aún son pocos los trabajos realizados, pero los futuros experimentos y nuevas técnicas de tratamiento, observación y análisis de las piezas arqueológicas podrán ampliar este panorama.

Palabras clave: arqueología, traceología, funcionalidad, huellas de uso, experimentación objetos metálicos, puntas de Palmela.

Introduction. The metal problematics.

Several are the causes of the later development of the Traceology on metal. Firstly, most of prehistoric metallic objects are configured in known morphologies that have reached our days. Arrowheads, axes, chisels, knife/daggers, awls, etc., there is a whole range of objects of which "supposedly" we know the function. This has led researchers of prehistoric metallurgy to focus more on aspects related to the composition of the pieces, the origin of raw materials or technological processes for the production of the piece, obviating the specific functional aspect. In fact, it has even reached the point of assuming an exclusively value of prestige, denying the practical functionality of some types of weapons (Ó Ríordáin, 1946, for the halberds, Delibes de Castro and Santiago Pardo, 1997, for Palmela points), alleging the scarce hardness of pieces in copper, arsenic copper or low tin bronzes. Now, what happens if we compare these metals with our current steels or equivalent weapons in flint and other rocks? In the first case, there is a difference of objective hardness against the weapons manufactured with this first metallurgical technology. However, if we compare it with the raw materials contemporaneous with those first metals, the scarce hardness seems to be relativized taking into account the rest of the advantage offered by these first metallic objects (Gutiérrez Sáez et al, 2010).

We can attribute as a second cause the complexity and cost involved in its technology, compared to the lithic industry. Related to the experimentation, it is necessary to obtain the mineral, transform it into metal, melt it, pour it into a mould and finally forge and polish it. This process requires specific knowledge and a relatively expensive infrastructure, by comparison with lithic or bone technology. To carry out the study and interpretation of copper-based prehistoric metal objects, we need a good understanding of the type of metal – pure copper, arsenic copper, bronzes with different percentages of tin – and of the technological processes that take part on it, since the mechanical properties vary greatly depending on these aspects. For example, a good forge will get a harder edge than a process consisting of an annealing followed by a slight forge.

Because of the plastic capacity of this metal, copper-based objects have important differences in their response to use, if we compare them to the lithic industry. The edges of the lithic tools break with the effort, they are known as chipped, while the metal tend to deform losing edge but, on the contrary, it admits a greater capacity of repairing and recycling. The set of mechanical traces that will be developed on the active edge of an instrument with the same use will be very different in a flint or obsidian tool than in other object made in copper or bronze. On the first it will appear blunt and various types of chipping, while on metal, in addition to bluntness, we will find a greater diversity of plastic deformations and rarely diagnostic polishes of the worked material or striations that can be clearly attributed to use.

Thirdly, the metallic objects found in archaeological sites present a state of conservation with different degrees of alteration that can range from a light dark layer, a copper oxide known as tenorite, to a substitution of the metal by ore in the worst cases. As the usual tendency of the metal to return to its mineral phase, being connected in greater or less intensity to its active life and the sedimentary process suffered; we could add the traces, added or eliminated, during the restoration work. All these topics contribute to the fact that the use wear analysis, already complex itself, becomes unfeasible in a high number of pieces.

The experimentation.

The experimentation methodology in Traceology is well explained and determined in previous works (Semenov, 1964; Keeley, 1980; González and Ibáñez, 1994; Gutiérrez Sáez, 1996). In the case of metal, we appeal to the same methodology with special attention to the technological process because the hardness of the object determines, to a greater or lesser extent, its response to use (Kamphaus, 2007; Gutiérrez Sáez and Soriano Llopis, 2008; Gutiérrez Sáez and Martín Lerma, 2015).

The condition of creation and use of the objects in prehistoric times have been able to vary widely throughout space and time due to diverse causes such as technical condition and knowledge, access to raw materials or due to different cultural nuances of each group. An experimentation that includes all these aspects is immeasurable, so it is necessary to combine two types of experimentation. A basic one that focuses on the response to the interaction of the different variables involved such as the types of tools/weapons, raw materials, metallurgical processes, materials worked and actions. With it, we will have a general reference corpus of response to use in various circumstances. However, to get closer to the functional analysis, it would be necessary to complete this knowledge with replicative experiments on each type of weapon or tool, taking into account the specific conditions of the objects of the sites to be studied; especially concerning the composition of the raw materials, their technology and metal morphologies.

The independent variables that make up experimentation are common in functional studies on lithic industry. As it is also the case here, it must be remembered that, although in experimental metal pieces the traces derived from these variables can be relatively well isolated; in the archaeological pieces it is more difficult. This occurs because of the influence of other factors such as resharpening or consecutive varied uses, to which they have been added other possible causes of generating traces such as technological processes and especially corrosion (Gutiérrez Sáez and Soriano Llopis, 2008).

Raw materials and technological process. Copper (Cu) is relatively abundant in nature. In spite of appearing sometimes in its native state, it is more common to obtain it from oxides (tenorite and cuprite), carbonates (azurite and malachite), silicates (crisocola) and sulphides (chalcopyrite, covellite, chalcocite and bornite). The reduction process of copper to pass from ore to metal and its subsequent melting at 1083ºC, gives us a relatively soft object (3.0 on the Mosh scale) that will be transformed into an object – weapon or tool – more or less effective depending on post-casting treatments. Even with these treatments, it will remain tenacious and ductile, with a plasticity that will allow it to deform instead of breaking during use. If we need a tool with a greater resistance capacity we will alloy the copper with another metal, usually tin (Sn). The addition of this material not only achieves harder objects with tenacious edges, but also lowers the temperature of the melting between 880ºC and 920º. In addition, the casting will be more fluid distributing better by the mould and leaving objects with a better-defined morphology.

In the early European metallurgical phases, it was very common to use arsenical copper. Arsenic (As) that is a semimetal with scarce hardness 3.5 on the Mosh scale – which volatilize easily during the reduction and melting. The resulting objects have a percentage of arsenic generally less than 3%, but this small amount gives greater hardness to the pieces and also, a more fluid melting.

Although there has been a lot of discussion about whether arsenic was an intentional addition or not, when it appears in such small amounts it is accepted that it comes from the ore (Montero

Ruiz, 2010, p. 162–172). Therefore, in most cases it does not seem to be an intentional alloy, but instead sulphide ore would be collected where copper and arsenic appeared together. In fewer cases natural bronzes were used, namely ores composed of copper and tin.

The operational chain of the copper-based objects begins with the obtaining of the ore. Although it can be used copper and tin in their native state, its weirdness caused that in prehistoric times they appealed to obtain it from diverse ores, by the outcrops on the surface or through mining.

The mineral, when it is not a native metal, must be reduced in a furnace to extract the pure metal, discarding the bargain. This process could be done with ores of copper and tin separately or with both at the same time in a co-reduction to obtain an already alloyed metal (Rovira Lloréns, 2007, p. 27). The reduction process could be done in a furnace, in a smelting crucible or even on outdoor fires. With the sulphide minerals, it needs to be toasted before the reduction since an oxidation of the ore is needed to obtain the metal.

Copper, more or less pure, is introduced into a crucible and melted, either alone or with the addition of tin. When it reaches the melting point, it is poured into the moulds with the proper shape. These moulds can be of different shapes, univalves (open or closed), bivalves and multiples (Fraile Vicente, 2008), made in materials such as clay (Doonan et al, 2007), stone (Rovira et al, 2007) or metal (García Vuelta et al, 2014). Another option, difficult to find in the archaeological record, could be the use of sand moulds with a percentage of clay that when moistened can be compacted (Ottaway and Seibel, 1998), either to make simple or complex moulds.

Once the piece is obtained from the mould, the post-casting works gives the final form to the metallic objects. Cold hammering and annealing are the most characteristic treatments involved. With the first one the metal gain hardness due to be hammered over an anvil as it was demonstrated with Vickers Hardness tests over experimental pieces (Dungworth, 2013, p. 151), although it adds more frailness. The annealing would be the opposite, softens the metal decreasing the hardness and returning the initial plasticity to homogenize the internal crystalline structure (Dungworth, 2013, p. 151), but without changing the external shape. A difficult process to document in the ancient examples would be the hot forging, which join the previous processes. In this case, the mechanic deformation of the hot metal would not produce the pungency described, since the material would be modified, decreasing the fracture risk, but adding hardness with the compacting of the internal crystalline structure of the metal. The use of hot forging is under discussion for ancient times due to the absence of tongs in the archaeological record to hold the hot objects (Montero Ruiz, 2010, p. 181), an aspect that should not be ruled out given the obvious capacity of the prehistoric metallurgists to take the crucibles out of the fire at a very higher temperatures.

All the steps involved in the operational chain of metal are no more than modifications of the mechanical properties of the objects, which will be applied according to the tool that will be done. Sequential combinations of cold hammering-annealing-cold hammering-annealing make up more or less long operational chains according to whether the type of object is, for example, a bracelet, a sword or an awl.

The second step of the post-casting treatment is the regularization of the surface, in which we distinguish between the polishing or roughened of the surface, which more than providing the characteristic metallic shine removes the roughness resulting of the casting, the marks produced by the forge and the superficial alterations formed during the annealing. Finally, the edges or active parts of the objects could have a carefully and specific polishing or sharpening. These polishing phases generate a field of striations that it is before any use and which must be taken into account. This is a common characteristic to other materials such as bone industry or polished stone.

Copper is a plastic material, but the copper-based objects will vary its plasticity, that is, their ability to deform before use, depending on two main factors. The first one is the composition of the metal, pure copper is easily deformed and it acquires hardness with the addition of tin or arsenic. In the case of bronze, the ideal ratio in the plasticity/hardness balance is between 8 and 12% of tin (Montero Ruiz, 2010, p. 171), above 13–14% tin the objects become more brittle, and we have experimentally verified that it is easy to break during forging, especially if there are bubbles inside the piece. In fact, bronze with a tin content between 10–12% is superior in hardness to arsenic copper with an arsenic content between 2–4% (Montero Ruiz, 2010, p. 171). Thus, it would be something indirectly proportional, if there were more tin; there would be less plasticity of the metal and greater hardness/fragility, which could facilitate the rupture of the material, but decreasing its capacity of deformation during use.

The second factor that takes part in the mechanical properties derives from post-casting treatments, especially cold hammering and its combination or not with annealing. At this point, it should be added that the intensity of the forge can also significantly influence the development of the use wears and we will talk about it later. Experimentally we have been able to verify that, if in a piece a forge has been made very shallow, the hardness of the edge is much smaller and, with the same use, it allows a greater development of traces than in the opposite case.

The last step of the technological process of the item, being a weapon or a tool, usually requires its assembly in a handle or grips through extensions of the metal blade as tangs, perforations in it for the rivets or its insertion in a hole, what is the case of the axes. The traces in this area can come from the insertion in the shaft itself, from the effects of a counterstrike of the blade on it, or of the un-hafting one. It is also well-known in the lithic industry that when the handles are not perfectly adjusted and slack is created, not only does it increase the possibility of generating use wears in this area, but the effectiveness of the tool is reduced.

<u>The objects.</u> The design of the object conditions it is effectiveness during use. Although in the early phases the basic technology of reduction and smelting is limited, prehistoric metallurgists have sometimes shown strong empirical knowledge in post-casting treatments to obtain more resistant tools and weapons. The first copper-based metal assemblies have a limited typological diversity of objects and their morphologies come from lithic models (bifacial knives, polished axes, arrowheads, denticulate) or bone (awls). They are simple pieces that are improving their design as technological knowledge evolves. But the design itself goes beyond the technology and we perceive them, for example, in the change of shaft types (passing from tanged daggers to those with rivets) or in the appearance of thickenings in the central areas of the blades. This is the case of plateaus or central thorns in the blades of many types of daggers, halberds or Palmela points to avoid bending during use. Although metallic objects respond to apparently well-known functional types, their limited typological diversity leads us to ask ourselves if some of them could respond to multiple uses and even to double functions, such as axes and knives – are they weapons or tools? – awls – are they drill-bits, awls or perforators? – or are they chisels?

<u>The worked materials and actions.</u> Those are two of the fundamental elements in functional analysis because the basic aim is precisely their identification. This is because we already know the other variables about archaeological objects, raw material, work processes and morphology.

The worked materials on which a metallic instrument can act are diverse and concern a wide number of aims. These materials interact with the weapon or tool in different ways according to their belonging – animal, plant, mineral – and composition, their hardness, degree of rigidity/flexibility, degree of humidity, etc. This diversity itself prevents to propose an experimentation that includes all the possibilities systematically. It is usual in lithic Traceology to use those materials supposedly within the reach of prehistoric man: meat, skin, bones or antlers derived from animal carnage, wood, vegetable fibres … However, the extent of the resources potentially exploited in the past, and the specific way to do it, are too large to be included in a single experimentation program. For this reason, the experimentation in metal has been articulated from the specific types of pieces – knifes/daggers, awls, projectile tips, halberds, saws ... – trying to exploit its potential functionality in relation to different raw materials and actions. In the lithic industry, the identification of the worked materials is made from the whole set of use wears but among these; the type of polish has a lot of importance. Experimentally we have obtained polishment identical to flint, in copper saws that have worked on materials such as bone, antler and wood. However, after a few weeks of use, a layer of tenorite covered this polishment hiding it completely. This limited its attributes and, consequently, the possibility of identification. Bearing in mind that most of the metal from archaeological sites usually has significant layers of corrosion, in addition to tenorite; the determination of the material worked is not viable. Now we can only try to determine the degree of hardness of the material worked in correlation with the hardness of the piece, considering that, in the latter case, it is determined by the composition and intensity of post-casting works.

One advantage of metal is that when it corrodes and releases copper oxide, it can trap organic substances that would otherwise have disappeared. These substances – wood, bone, fabric, leather ... – usually come from shafts, sheaths and other elements of configuration of the tool or weapon, perhaps also from the material worked or even, have adhered during the sedimentation process if the piece is together with organic materials such as woods, cloth, bones or others.

The action, on the other hand, is been defined by a specific set of gestures. Each type of action responds to different subvariables such as the way of application of force (pressure, direct percussion, thrown percussion), displacement in space (directional or rotary), directionality (longitudinal or transverse), the angle of work (perpendicular or oblique) or the sense of work (unidirectional or bidirectional), (Gutiérrez Sáez and Soriano Llopis, 2008). However, from the functional point of view, we must bear in mind that actions are not the same as activities, for example, the action of cutting wood with an axe can be aimed at activities as diverse as creating support poles from a hut, make a wheelbarrow or configure shafts and handles for weapons and tools. Thus, the context could sometimes help us to determine the activity, but in the majority of cases, we will only be able to determine the action.

Likewise, the easy way to renew the blunted edges by a light filing or even by a soft forge, introduces us to the ticklish field of resharpening. The need to resharpen the tool for better maintenance destroys the previous use marks and prevents us from determining the function of the tools in similar cycles of use or not. To discern this aspect, in some types of objects it may be helpful to consider the relationship between the width of the head and the total length of the object, within broad and homogeneous series of typologies such as daggers or halberds. Thus, we have observed in some cases that small knives of a few centimetres in length maintain the same proximal width as others with a longer blade length, which a priori could be interpreted as the consequence of successive resharpening of the piece in a long/intense cycle of use.

Time and other aspects to consider. It is a slippery variable since its effect on the traces can overlap with the aforementioned variables. To this, it could be added successive uses, interspersed or not with resharpenings, which make it extremely difficult to specify the duration of use. For this, we must discriminate between the possible time/intensity of the last use and in some cases the total duration of the use of the tool, as, for example, in the daggers mentioned above, where the relation between the width of the head and the total length of the piece indicate constant resharpenings. Likewise, the asymmetries of both the silhouette and the edges help us to qualify if it has been able to have previous resharpenings. Other aspects to consider are laterality, or the muscular strength of the users, facts that we know at an experimental level, but that are also difficult to determine on archaeological pieces due to the interaction of the different variables that make up the traces.

The traces.

The traces on metal tools or weapons reveal the different response to the use of metal, compared to stone. In addition, along with them it is common to find other traces produced by different causes to the use itself, such as the technological process, which includes the configuration of the piece, the hafting or decoration, postdepositional alterations and the manipulation of archaeologists/restorators in the cleaning and restoration process of the piece.

The plastic capacity of the metal, also variable in relation to its exact composition and the intensity of the post-casting processes, makes the tendency of the metal to deform before breaking. This fact causes that during the experimentation we have been able to detect an increasingly wide field of plastic deformations on the edges and the surfaces of the metallic tools. There are also some breakages, equivalent to the chipping on lithic, which in the metal can arise from the fatigue of the material after an intense forge, especially when there is a melting bubble inside. In many other cases, the breakages may correspond to corrosion mineralization suffered during the deposition.

We have classified the traces on metal in three major categories and each, in turn, in different types for better understanding, also adding the probable causes.

From the successive experimental works carried out we have obtained a wide set of traces that, except for the polishment, have also been identified in various archaeological objects. From these traces there is an extensive description in Gutiérrez Sáez and Martín Lerma (2015), so we will not go in depth into this work. But we would like to insist that, unlike the lithic industry where polishment has an important value, different aspects are observed over the metal. Firstly, we have not yet detected polishment more than in experimental pieces for the aforementioned corrosion problems. On the other hand, the capacity of plastic deformation of the metal gives us a rich set of traces in the form of mechanical deformations that, depending on the type of piece and its location in it, give us valuable indications of use.

We will allude to some of them in this work from the examples of a characteristic model of well-known type of projectile in the peninsular territory during Bell Beaker period and early Bronze Age known as Palmela points.

A case of study: Palmela points.

The Palmela points are prototypes manufactured from arsenic copper; they appear from 2,500 cal BC. These pieces are typical of the Bell Beakers grave goods of the Iberian Peninsula, although they also extend to the south of France. In the Iberian Peninsula they have been used up to the last periods of the Bronze Age, especially in the Spanish Plateau, and from these moments they are replaced by metal peduncle and fins arrowheads, because they are smaller and lighter weapons. The Palmela points, are integrated into the so-called "warrior grave goods" of the Bell Beaker world of Western Europe (2500–1800 cal BC). They usually appear within funerary contexts, along with flint arrowheads, V-perforated buttons, sometimes gold and/or ivory ornaments, as well as the well-known Bell Beaker ceramics.

They have a lanceolate blade shape more or less wide and it ends in a very narrow and long peduncle with quadrangular section. Although there are some ones that reach sizes of 183×22 mm and others are smaller (54×12 mm). The average size ranges from 7 to 12 cm in length by 1.5 to 2.5 cm in width and 2 mm in thickness. The weights are also varied, from 3.9 gr of the lightest whole point to the 35.6 of the heaviest, although most of them oscillate between 9 and 22 grams (Gutiérrez Sáez et al, 2014).

Table 1.

Types of traces on metal

CATEGORY	DESCRIPTION	TYPE OF TRACES	CAUSES
Plastic deformations	Massive depressions	Varied imprints	Technological processes Use/handle Post-depositional alterations
	Lineal depressions	Incisions Striate Fissures Band of fissures	Technological process/decoration Use / Handle/ Revived Post-depositional alterations Mechanical cleaning
	Rounding	Dulling	Technological processes Use/Handle Post-depositional alterations
	Blade deformation	Breakage Notch Flanges Flattering Thickening Edge asymmetry Stepped undulation	Technological processes Use/Handle/ Revived Mechanical cleaning Post-depositional alterations
	Deformation of the silhouette	Folding Lateral folding Microfolds Torsion Morphological asymmetry	Technological processes Use/Handle Intentional destruction/ritual
Physic-chemical deformations	Surface physic-chemical alterations	Corrosions Polishment Gloss bands Differential alterations	Technological processes Use/Handle Post-depositional alterations
Added elements	Adhering materials	Residues	Use/Handle Post-depositional alterations

Manufacturing and planning of the experimental program:

We manufactured 37 experimental Palmela points of three different sizes: 13 small ones (40–50 mm in length × 12–15 mm in width and 0.8–1.8 mm in thickness with a weight between 3.5–6 gr), 16 medium (90–115 mm long × 20–28 mm wide and 1.8–2.8 mm thick with a weight between 18–22 gr) and 9 large (130–150 mm long × 30–40 mm wide and 1.2–2.5 mm thickness with a weight between 30–41 gr).

The points were used on three different types of weapons. The small ones were used as arrowheads and javelin heads; the medium points were used in the three types of weapons such as arrowheads, javelin head and spearheads. Finally, the large ones were only used as spearheads and javelins. An ash wood bow with linen bowstring and a power of 35 pounds was used. Javelins and spears were used on pine shaft measuring 16.3×2 cm in the first and 20.0×2.8 cm in the second. For their part, the arrows were made of fir wood and were feathered with goose feathers, their measurements were 81.5 cm long and 1 cm thick.

From the three types of weapons, 24 points were thrown towards a dead sheep; with 9 arrows and javelins were carried out distance tests, and with 4 arrows were made a ballistic study. The pieces were very effective with the three types of weapons, except those points that had been annealed and that were bent after the first impact. The ballistic results showed a speed of 41.20 m/s for a small Palmela point (3.77 gr of the metal tool and 46.62 gr of the total arrow) and 28.34 m/s for a medium point of bronze whose total weight was of 73, 96 gr and which tool weight was 23.41 gr.

We find different types of microwears, although some impact diagnostic traces were developed at both apical ends of the point, as well as in intermediate areas. The microwears were similar with the three types of weapons and, for the moment, we have not found differences in this aspect (fig. 1, 2 and 3) (Gutiérrez Sáez et al, 2014).

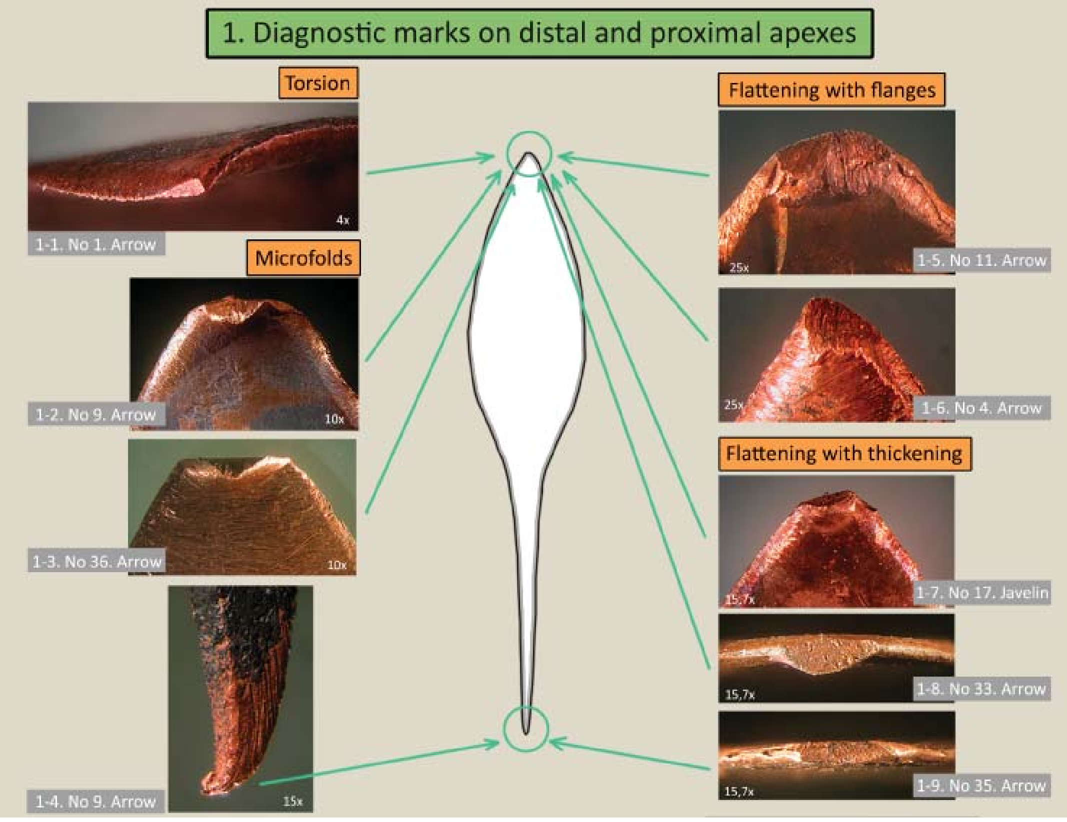


Fig. 1. Diagnostic marks on distal and proximal apexes.

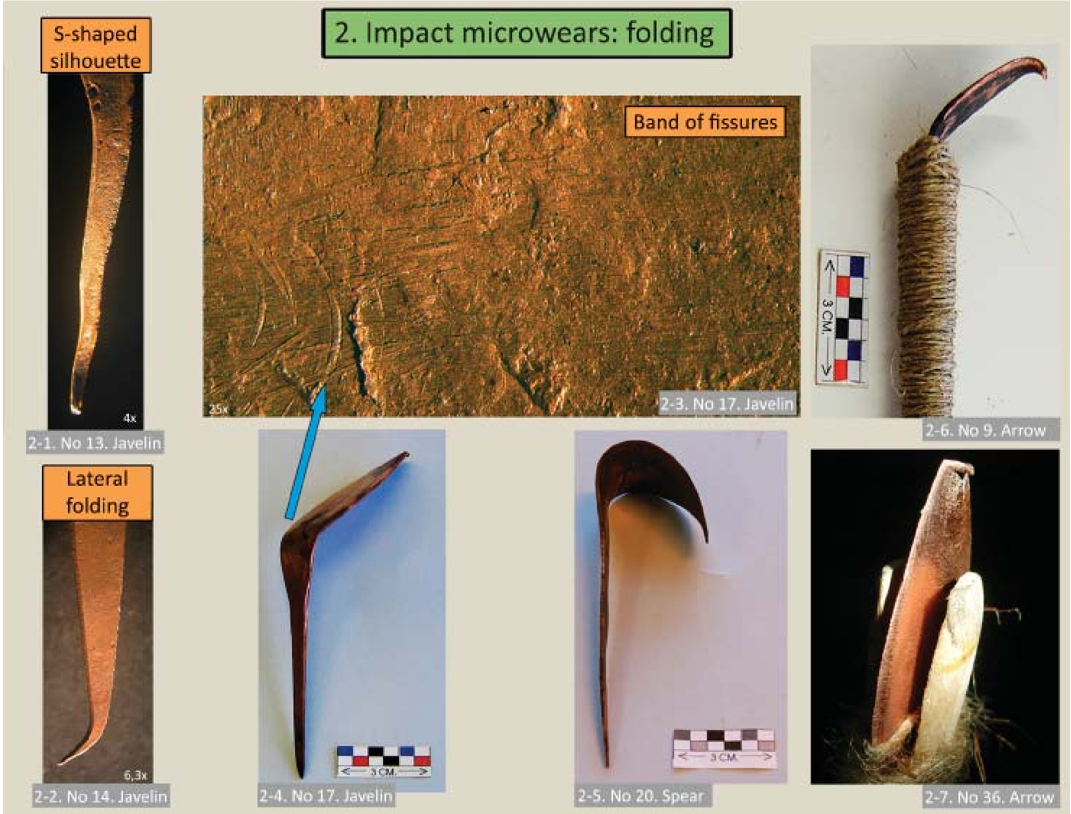


Fig. 2. Impact microwears: folding.

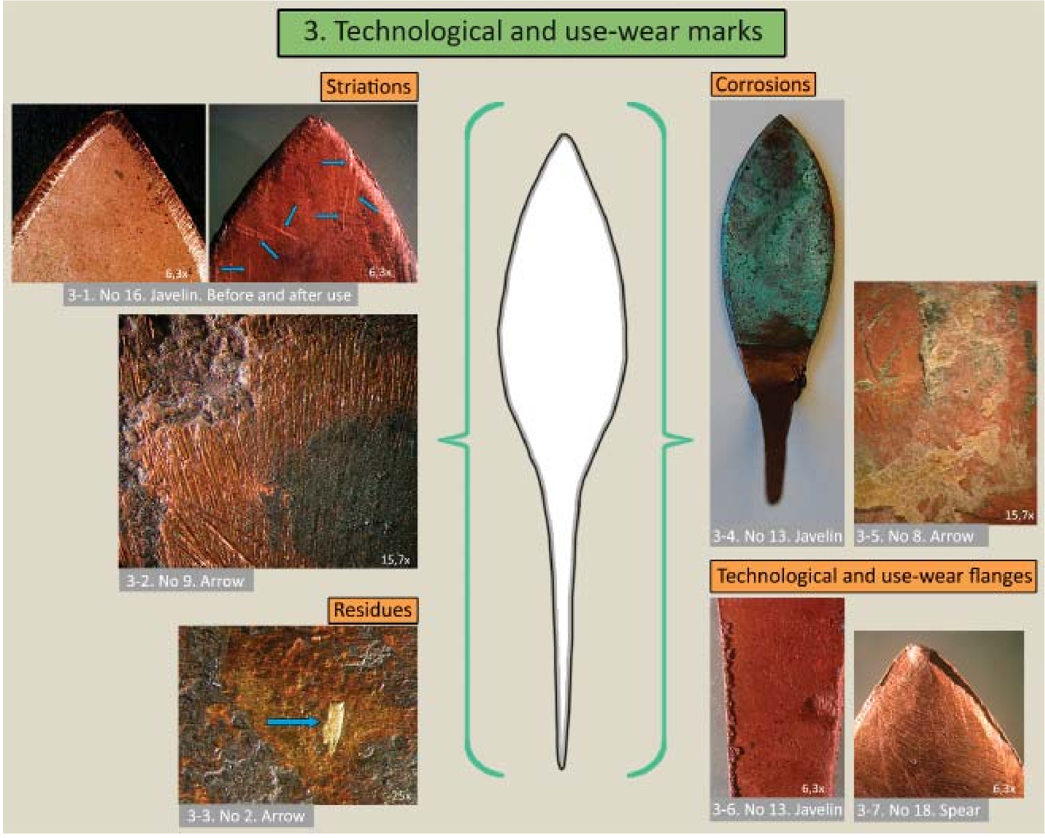


Fig. 3. Technological and use-wear marks.

Diagnostic microwears

Table 2.

Percentage of diagnostic microwears on experimental specimens depending on its situation

EXPERIMENTAL TOOLS	MICROWEARS	DISTAL APEX	BLADE/PEDUNCLE	PROXIMAL APEX
Impact diagnostic	Flattening	66,6%	-	45,54%
	Microfolding	12,1%	-	15,1%
	Torsion	9,1%		9,1%
	Folding	-	57,5%	-
	Lateral folding	-	12,5%	-
	S silhouette	-	4,16%	-
	Striations	-	8,33%	-
Diagnostic repair	Band of fissures	-	4,16%	-

We have been able to specify the mechanical deformations derived directly from the violence of the impact (fig. 1). They are located at the apical ends, although in those of the proximal area they are by counterstrike against the shaft during the impact. On both apices, the point often recedes and flattens leaving two characteristic microwears of this fact. The most common is the flattening with flange (fig. 1: 5 and 1: 6) and the other a flattening with thickening of metal on one of the faces (fig. 1: 7, 1: 8 and 1: 9). Also, depending on the angle of attack, the point bends and can be stuck on one of the faces (microfolding) (fig. 1: 2 and 1: 3). In some cases, the apical end can be deflected by turning slightly and forming torsion (fig. 1: 1).

The force of the impact also affects the blade and the peduncle, especially at the point of attachment with the handle. In these areas, we find pieces bent towards one of the faces in angles up to 45º, what we call folding (fig. 2: 4, 2: 5, 2: 6 and 2: 7). When it affects the peduncle, it usually deviates laterally (lateral folding) (fig. 2: 2). Finally, in pieces of little thickness, a series of waves can affect the edges or the whole silhouette and we have called it silhouette in S (fig. 2: 1).

The striations of use can be considered impact traces, but they appear in very small amount.

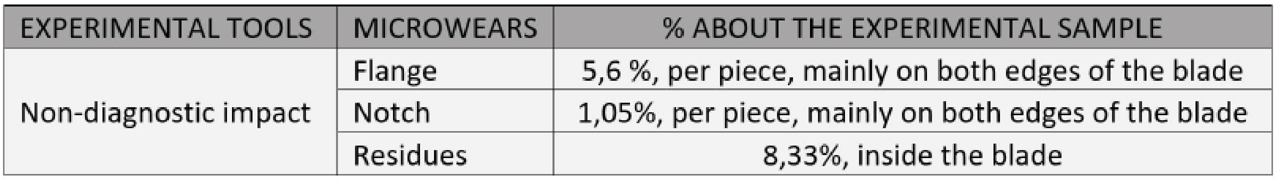
They were interpreted thanks to the photographic documentation of the Palmela points done before use (fig. 3: 1). In this way, it was possible to distinguish it from the technological striations (fig. 3: 2), but this fact is very difficult to assess in the archaeological pieces. In the few pieces in which they appear, they develop from the edges of the distal end towards the interior of the blade, they are wide and with oblique direction to the major axis.

Some pieces that were bent due to the impact were forged and slightly filed until they recovered their original silhouette. On one of them a band of small fissures developed in the same area where it had been bent (fig. 2: 3). This microwear indicates a repair work on the damaged object.

Non-diagnostic microwears:

Table 3.

Percentage of non-diagnostic microwears on experimental specimens



EXPERIMENTAL TOOLS	MICROWEARS	% ABOUT THE EXPERIMENTAL SAMPLE
Non-diagnostic impact	Flange	5,6 %, per piece, mainly on both edges of the blade
	Notch	1,05%, per piece, mainly on both edges of the blade
	Residues	8,33%, inside the blade

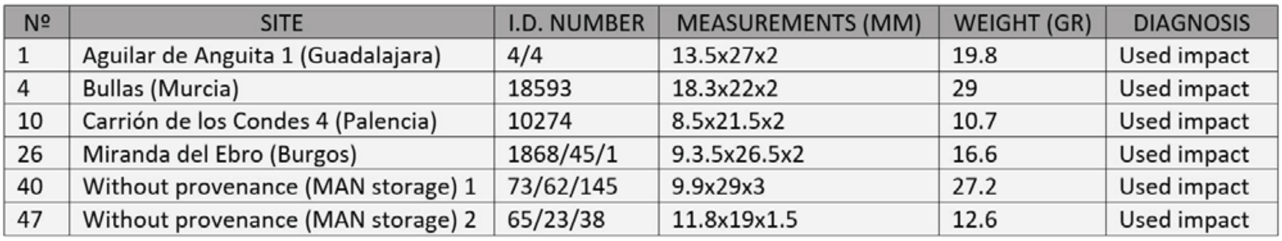
We have also detected other microwears on the experimental Palmela points. Two of them, like the flanges and notches, constitute the most abundant repertoire of metal microwears. They are found throughout the piece, but preferably along the edges of the blade. A few, flanges and notches, come from the manufacturing processes, especially if a little careful filing has been carried out (Soriano Llopis and Gutiérrez Sáez, 2007) (fig. 3: 6 and 3: 7). The impact caused that the irregular and raised on the edge previous flanges, were later flattened and smoother. The rest of the flanges and the few notches come from the manipulation for the hafting and also from the impact of use, either against the sheep or earth and stones when the point did not hit the prey.

Small pieces of wood from the shaft itself were embedded in the blade during the impact (fig. 3: 3). Finally, some pieces that penetrated inside the sheep developed a rapid and strong corrosion by contact with stomach acids (fig. 3: 4 and 3: 5).

Examples of archaeological Palmela points

Table 4.

Archaeological Palmela points studied



№	SITE	I.D. NUMBER	MEASUREMENTS (MM)	WEIGHT (GR)	DIAGNOSIS
1	Aguilar de Anguita 1 (Guadalajara)	4/4	13.5x27x2	19.8	Used impact
4	Bullas (Murcia)	18593	18.3x22x2	29	Used impact
10	Carrión de los Condes 4 (Palencia)	10274	8.5x21.5x2	10.7	Used impact
26	Miranda del Ebro (Burgos)	1868/45/1	9.3.5x26.5x2	16.6	Used impact
40	Without provenance (MAN storage) 1	73/62/145	9.9x29x3	27.2	Used impact
47	Without provenance (MAN storage) 2	65/23/38	11.8x19x1.5	12.6	Used impact

Here we present an analysis of 6 archaeological pieces conserved in the funds of the National Archaeological Museum (MAN) of Madrid that have been interpreted to have been used as projectiles. We know the composition of some of these tools and it is, in general, almost pure copper with a low natural percentage of arsenic (0.477% as in Bullas and 0.12% as in the one from Carrión de los Condes) or tin (Miranda de Ebro 0.67 Sn) (Rovira et al, 1997). On the other hand, the technology used generally in the Palmela points is very simple, reduced in casting in a mould with a subsequent treatment of cold forging. Only a small part of the set of Palmela points analysed throughout the Iberian Peninsula shows a longer technological process that introduces an annealing after the first hammering, followed by a second forging applied to the edges (Rovira Lloréns and Gómez Ramos, 2003, p. 168–170). Consequently, we are faced with metal pieces with low hardness and high deformation capacity.

We have found the same impact microwears as in the experimental series (figs. 4 and 5). These are microfolding and flattening at the apical ends, both distal and proximal, derived from the force of the impact against the prey (distal ends) or against the shaft (proximal ends). On the distal apexes of points 1 and 47, there are microfolding

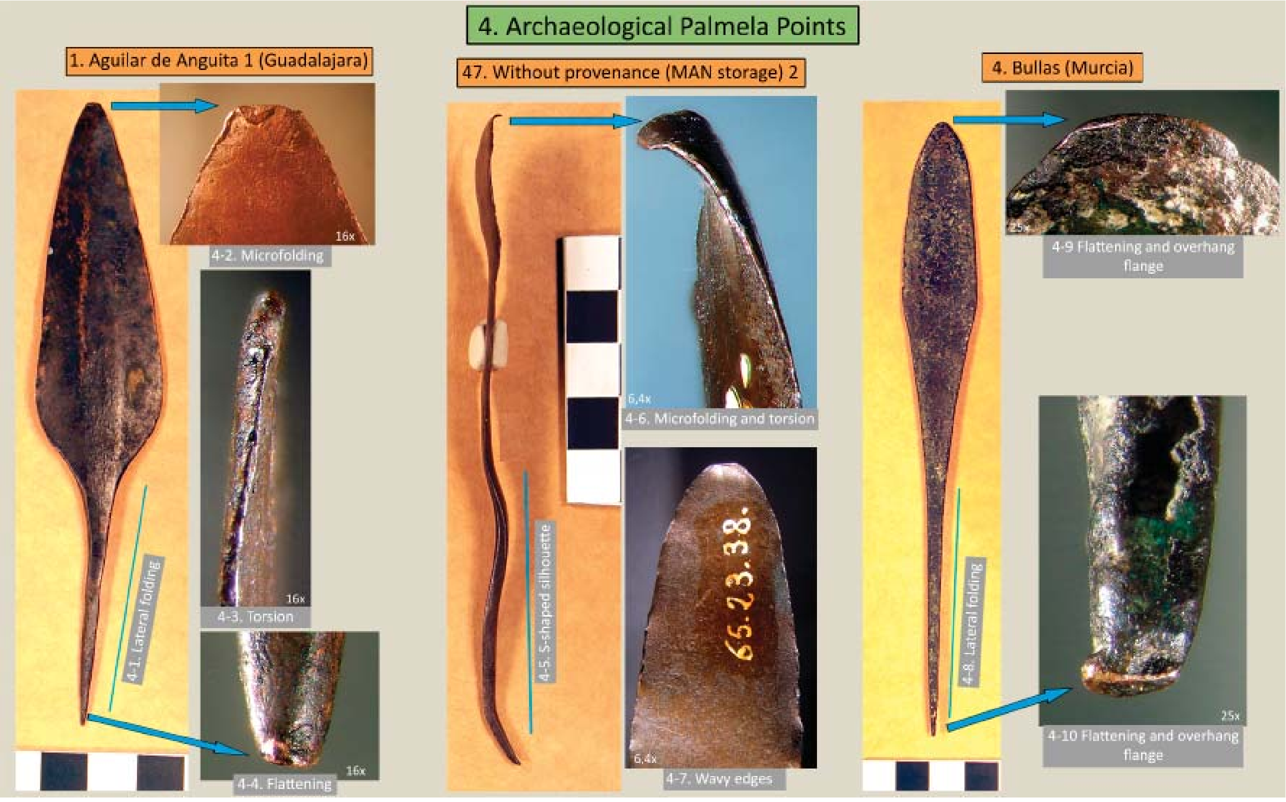


Fig. 4. Archaeological Palmela points.

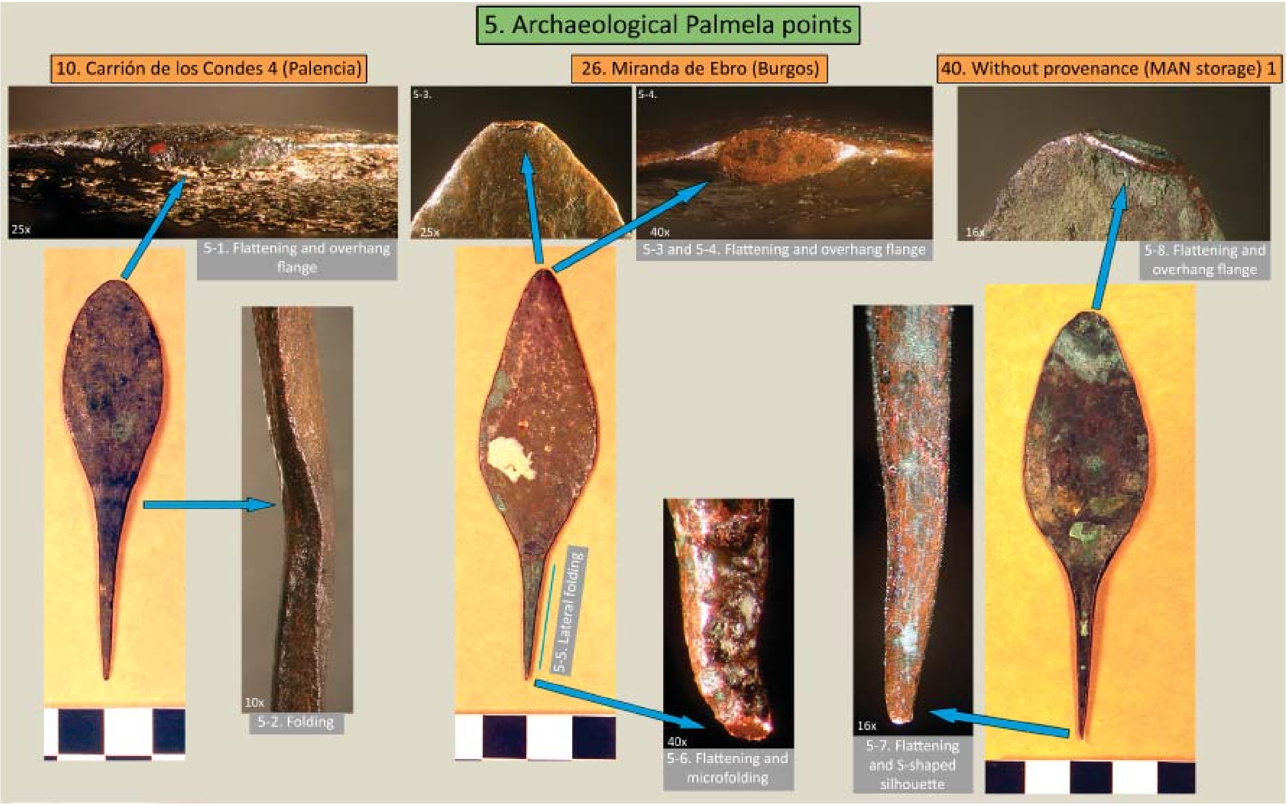


Fig. 5. Archaeological Palmela points.

(fig. 4: 2 and 4: 6), which in the first Palmela is not visible to the naked eye. Likewise, at the remaining points (4, 10, 26 and 40) the impact has retracted the distal apex, converting it into a flattened area with a small overhang flange of metal (fig. 4: 9, 5: 1, 5: 3, 5: 4 and 5: 8). In all the examples there are also clear flattenings of the proximal apexes by counterstrike against the shaft (fig. 4: 4, 4: 10, 5: 6 and 5: 7).

There are other evidences of the force of the impact that are visible along the silhouette of the pieces such as torsion of the distal third (nº. 1 and 47, fig. 4: 3 and 4: 6), folding at the junction of the blade with the peduncle (nº. 10, fig. 5: 2), S silhouette (nº 40 and 47, fig. 5: 7, 4: 5 and 4: 7) and lateral folding of the peduncle (nº 1, 4 and 26, fig. 4: 1, 4: 8 and 5: 5).

We have not observed any striation clearly attributable to use, since those that we have found on the pieces mainly seem to come from sharpened in the phase of manufacture, repaired in a few cases, and as a result of the processes of cleaning and restoration in the archaeological treatment.

Discussion and Conclusions.

Regarding this work we have tried to offer the possibilities of development that Traceology currently has, applied to the prehistoric copper-based metals. As traceologists, our work focuses on the identification and interpretation of traces in archaeological objects from an experimental base where various variables are contemplated.

In this aspect, there are several authors working on different metallic types: Kienlin and Ottaway, 1998; Soriano Llopis and Gutiérrez Sáez, 2007; Gutiérrez Sáez and Soriano Llopis, 2008; Dolfini, 2011; Can Aksoy, 2018, for axes, Gutiérrez Sáez et al, 2010; Gutiérrez Sáez et al, 2014; Muñoz et al, 2018; Can Aksoy, 2018, for projectile points, Dolfini, 2011; Muñoz et al, 2018, for knifes/daggers, Brandherm, 2011; Brandherm et al, 2011; O'Flaherty et al, 2011; Dolfini, 2011; Horn, 2017; Lull et al, 2017; Muñoz et al, 2018, for halberds, Anderson, 2011, for spearheads or Kristiansen, 2002; Quilliec, 2007a, 2007b and 2008; Molloy, 2011 for swords. Traceology on metal is still in an initial moment and there are a big lack of experimental series that would allow us to fit the identification of the action and the function of the metallic specimens. This is because some works cited, focus on the analysis of traces on archaeological pieces with a limited experimental base or, even, a total absence of it.

The experimentation not only provides us with a reference collection for the recognition and formation of the traces. In addition, it has a precious value by allowing us to calibrate the functional value of the tool from its production to its final consumption.

However, the metallurgical process has its complications. Firstly, due to our own lack of experience as metallurgists, which we must develop in theory and practice from our own experimentation. From this point of view, we note that it is not easy to achieve the necessary expertise until a wide series of experiments are carried out. Aspects such as casting or, especially, post-casting treatments, such as forging, are not easy to learn in order to obtain the necessary balance between hardness and malleability. This is very important to get edges on the objects that reach an optimal balance before use.

For example, some time ago we proposed a slight experimental program in which we tried to assess the influence of the raw material and the post-casting processes of forging and annealing (Soriano Llopis and Gutiérrez Sáez, 2007). Through an experimental collection of axes cutting wood, we considered that the composition of metal did not respond equally neither to post-casting treatments nor to use. For instance, the 5% of tin bronzes resulted more effective than pure copper or higher percent of tin bronzes (12% of Sn). But at that moment we did not contemplate the differences due to the different post-casting treatments like the use of short operational chains (casting, cold hammering) or long ones (casting, cold hammering, annealing and selective cold hammering). Subsequent analysis, not published yet, showed us that neither annealing nor cold forging had the necessary intensity to be recognized on metallographic analysis, which could explain the homogeneity of the traces derived from the different treatments.

Following experimental works are warning us about the different behaviour of the edges related with these aspects, so it is necessary to work on this specific aspect experimentally and with the help of the appropriate analysis like XRF to know the composition, metallographic analysis to know the manufacture processes and Vickers Hardness tests to determine the hardness.

Regarding the development and intensity of the traces we can shade, at this moment, that the post-casting processes are aspects directly implicated in it. Specifically we refer at this point to several technological aspects of the configuration of the pieces, such as their morphology, the forge that is applied to them and the sharpening to which they are putting through.

- If the object does not have rectilinear morphology in its active part before starting the hammering process, the different irregularities present at the active part could lead to an irregular expansion of the metal in the process. Although this irregularity can be fixed by filing after hammering, it is a very problematic circumstance, since these alterations are tension areas that could end up forming microbreakages, fissures and cracks in the edge that internally expand through the active part of the piece. By sharpening after hammering these alterations could be fixed and it is possible to make a functional active part, but not to a completely optimal level, since these tension areas could not guarantee the absence or apparition of breakages or fissures that make the edges useless.

- The forging process is another critical treatment. Although the copper-based metals have a very high level of deformation under hammering, in a practical point of view the apparition of fissures and cracks on the worked areas establishes the limit. This is the matter of the problem, if it is not forged enough, metal do not get the appropriate hardness and toughness, not being, in this case, good enough. There is an indirect relationship between the degree of hammering and the development of the microwears appeared during use. The more forging, the less development of the traces and vice versa.
- The last point is a technological aspect that is practically ignored in the bibliography. The sharpening of the active edge is something crucial that also conditions not only the finishing of the tool, but also the functionality and the use of it. If a sharpening is not performed correctly, the sharp bevel of the cutting edge will present irregularities as deformations, for instance such as flanges, and unsuitable delineation before its use, which will reduce the suitability and durability of the object's useful life.

These technological peculiarities indicate the need of a strong knowledge of the processes to be carried out. The specialization necessary to create truly optimal objects is reflected in the exact understanding of the technological gestures that can be relatively simple a priori. For instance the morphological configuration prior to the forging or the correct sharpening. Other processes are more complicated and necessarily known through the experience as the level of forging needed before the metal begins to develop cracks and fissures, which could make the pieces useless. Thus, the crafts necessary for the creation of the tools is a fundamental factor that necessarily should be taken into account, since it will determine not only the functional optimization of the tool, but the development of the traces with greater or lesser intensity too.

The second problem, which we alluded to before, is related with the precise lack of knowledge we have of the specific procedures carried out by the prehistoric metallurgist on many archaeological collections not yet analysed, which deprive us of reliable data to design replicative experiments. We can add that, in many cases the metal could be recasting many times with the consequent losses of volatile elements such as tin or arsenic (Montero Ruiz 2010: 165), elements which add better characteristics to metal when they are in the appropriate proportions. Is this the case of the analysed Palmela points that we have described before, whose minimum percentage of arsenic and tin was perhaps higher in origin, even when it comes from the same mineralization as the copper ore? Or is it a lack of knowledge about the conditions of reduction of the metal by the prehistoric metallurgist? Questions like these do not have an appropriate answer by the research yet.

Related to the specific characterization of the function of an object (weapon or tool), some types are more accessible in its identification due to their highly specialized morphology, which does not allow other diversified functional options. For example, the Palmela points, as arrowheads, saws or the well-known swords and spearheads of a later Bronze Age period. In these cases, the interpretation focus on the perception of use and, in some circumstances, of previous resharpenings.

With other objects like knifes/daggers, the functionality could be double, either as weapon – distal use – or as tool – use of one or both sides. Axes, on the other hand, could show the same functional ambivalence, although its use will be distal in both circumstances. Even types such as halberds, a specialized weapon, could lend to a subsequent use as knife/dagger (Bradherm, 2011, p. 27). Other examples are even more ambiguous from the point of view of the functionality, such as awls, whose functional possibilities are very wide.

All this greatly limits the functional interpretation. At least in the polyvalent tools it is still early in the investigation to be able to determine elements as important as the specific action carried out or the exact worked material. We are deprived of this by the poor access to polishes and striations, hidden beneath layers of corrosion. In some circumstances we cannot go beyond checking if the tool was used, what is the case of awls or axes, although the intensity and position of the traces on the lateral and/or distal edges could discriminate between a tool, a weapon or both.

We must add the ticklish subject of successive resharpening obvious in some asymmetries and reconditioning of the active area. These maintenance treatments are very necessary with a raw material such as copper-based objects relatively soft, which deforms and erases their edges easily. Two important aspects derive from this the first, being that identification always refers to the last function and, secondly, that the absence of traces does not mean the absence of use, especially when there is evidence of resharpening.

Finally, the archaeological metal give us in many cases a difficult problematic to overcome. The growth of corrosion over the object could provoke effects such as the substitution of the metal by mineral and/or the breakage of the edges or even parts of the pieces. We often find a smaller number of traces on archaeological items that are very altered, than we expected from the experimental programs. Frequently these microwears are so small that they are not always visible to the naked eye and they even need many magnifications to be observed. We suspect that these small traces could be covered and overcast beneath strong layers of corrosion, so these objects could often not been evaluated functionally with precision.

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ТРАСОЛОГИЧЕСКИЙ АНАЛИЗ МЕТАЛЛА. ЭКСПЕРИМЕНТЫ И ИНТЕРПРЕТАЦИЯ АРХЕОЛОГИЧЕСКИХ НАХОДОК

К. Гутьеррес Саес, П. Муньос Моро

Трасологический анализ является одним из последних разработок в области функциональных исследований доисторических материалов. Именно поэтому его экспериментальная база все еще является недостаточной и требует дальнейшего расширения. Его методология соответствует методологии трасологического анализа кремня и прочих горных пород и материалов, таких как кость, рог, раковины и некоторые другие, и особое внимание в ней уделяется систематическим и репликативным схемам экспериментов с учетом всех независимых переменных, имеющим отношение к экспериментам, а также тщательной классификации определяемых следов. Для металлов большую важность имеют процессы обработки сырья и последующего литья, поскольку они определяют мягкость и пластичность, или же твердость и ломкость инструмента. Таким образом, на поверхности металлического оружия и инструмента содержатся следы использования, которые различаются с качественной и количественной точек зрения, а также в зависимости от функционального предназначения данных технических элементов. Вторым аспектом, определяющим изучение следов на металлических объектах, является наличие отдельных видов коррозии различной интенсивности, способных покрывать некоторые следы и ограничивать возможности интерпретации, что также характерно для примеров экспериментов, рассматриваемых в данной работе. Трасологический анализ металла в последнее время получил активное развитие, но еще предстоит выполнить большой объем работы, связанной с будущими экспериментами и новыми методами обработки, наблюдения и анализа археологических находок для получения новых сведений по данному вопросу.

Ключевые слова: археология, трасология, функциональность, следы износа, эксперимент, металлический инструмент, точечная коррозия.

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