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ROMAN SHEARS: METALLOGRAPHY, COMPOSITION AND A HISTORICAL APPROACH TO INVESTIGATION

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ABSTRACT

The earliest archaeological finds of shears are documented by Petrie, and are attributed to the Roman period in Central Europe. Although some catalogues from museums display pictures of scissors or shears, to date there have been very few analytical studies examining Roman iron scissors or shears. The current study investigates two Roman shears housed in the Royal Ontario Museum, Toronto, and focuses on the technological aspects of their production and the knowledge possessed by ancient smiths concerning the material they used.

Metallographic studies and microchemical analysis have been performed on these artifacts in order to better understand the material used and the production of the objects. Several unique features were found, including the presence of precipitates within ferrite grains. Using advanced compositional mapping techniques on the electron microprobe, we were able to identify the microchemistry of these precipitates and relate their presence to the fabrication processing.

This project serves as an example of how advanced modern analytical techniques can be used within an archaeological/anthropological context to enhance and expand on our knowledge of ancient materials and the peoples who produce and use them.

KEYWORDS

Shears, Technology, Iron, Metallography, Electron Microprobe, Roman, Design.

INTRODUCTION

Scissors and shears seem so commonplace today that we take for granted the technological achievement in their construction and implementation in ancient times. Although there have been many recorded instances of scissors and shears in the literature, there has been only limited detailed investigation done to understand how these objects were produced and what skill level and knowledge those that made them possessed. In order to complete a truly inclusive study we have attempted to integrate metallurgical techniques to investigate the microstructures of these objects with research into what scissors and shears really are, and when they appear in the archaeological and historical record. To this end, the authors will present concise definitions of scissors and shears, give some background as to the historical uses of shears, their ergonomics and what has actually been uncovered and reported in the archaeological record. Only after we have provided these details will we address the evidence from the microstructural analysis of the objects, including microscopy, chemical analysis, hardness testing and electron microprobe mapping.

DEFINITION OF SCISSORS AND SHEARS

The definition of what scissors and shears are and the distinction between them can be confusing. The Oxford English Dictionary (OED) defines a *pair of scissors* as "a cutting instrument consisting of a pair of handled blades, so pivoted that the instrument can be opened to a shape resembling that of the letter X, and the handles then brought together so as to cause the edges of the blades to close on

the object to be cut. The larger instruments of this kind, especially those which are too large to manipulate with one hand, are called **shears**. Tailors call the large size *shears*, the medium size *trimmers*, and the small size *scissors* or *cuts*". The OED defines **shears** as "originally and still = scissors....The various kinds of shears fall into two principal classes: those which are worked in the manner of scissors, and those in which (as in ordinary sheep-shears) the bringing together of the blades is effected by pressure on their stems between the blades and the arched spring by which the stems are connected...". The OED also defines a **forfex (from the Latin)** as "a pair of scissors". This overlap in definition between scissors and shears is what has caused the confusion in distinguishing between the two.

In terms of simple machines, a pair of scissors is really two knife blades joined together to form a double lever. Each blade operates as a lever of the 1st class (with the fulcrum between the load and the effort). A pin or bolt holds the blades together and acts as the common fulcrum. The lever action starts by squeezing the open scissor handles together, applying pressure against both sides of the object placed between. On the other hand, a shears would be classed as a lever of the 2nd class (with the load between the fulcrum and the effort); a wheelbarrow would also fall in this category (a lever of the 3rd class has the effort between the fulcrum and the load, for example, the muscle in an arm used to lift an object).

In the present context the authors define scissors, as does the OED, which, when opened, resembles an X; while shears most resembles what is commonly known as sheep shears, a set of blades which are squeezed together in a cutting action. It is important to differentiate scissors from tongs as well, since we have many good visualizations in the archaeological record of tongs in association with metal production [1]. A pair of scissors is functionally different from tongs in that their intended purpose is to cut, while tongs are intended to hold an object tightly.

HISTORY OF SCISSORS/SHEARS

The origins of shears and scissors appear to be lost in the shroud of history. Forbes [2] writes that "shears are mentioned for the first time in a Neo-Babylonian text" [3]. This clay tablet is part of a group called the Nabonidus Chronicles, held at the British Museum, and only partially translated. In any event it appears that #667 talks about sesame for a confectioner [4], and is probably a misprint error in Forbes. However, the Assyrian Dictionary of the Oriental Institute of the University of Chicago [5] translates *sirpu* as shears or scissors. The references given there for *sirpu* indicate that they were made of iron (*sir-pu parzilli*) and confirm that they were used for shearing (*si-ir-pi AN.BAR ana gi-zu*). All references given in [5] are Neo-Babylonian, with dated texts from the reigns of Nabonidus and Cambyses. Thus it appears that shears, in some form, may originate in the Near East, but no existing archaeological objects are known to the present authors.

Shears do not appear in Egyptian wall paintings or carvings until the Roman Period - on a wall relief from the Temple of Sobek and Horus at Kom Ombo (ca.100 CE), which shows about 40 different medical implements [6].

The Greek sources are also unclear. *The Feast of Peleus* by Edward Burne-Jones [7] shows the three fates spinning the web of mortal destiny, with one of the fates (Atropos) holding a pair of shears to cut short the thread of life. Atropos is often described as holding "the abhorred shears", but this phrase comes from *Lycidas*, Line 70, by Milton (1608-1674). The classic sources are unclear as to the implement that Atropos used, but Liddell and Scott [8] indicate the word ψαλις ("psalis") to mean shears, and list its occurrence in a number of classic sources.

Although there are no attic vase paintings showing a set of shears, there are a number [9-13] showing the use of pivoted tongs in conjunction with foundry practice. More commonly, Hephaistos, the builder and craftsman for the Greek gods (Hephaestus and Vulcan, Roman), is often pictured with an

axe and pivoted tongs, as in [13]. Thus pivoted tongs, the predecessor of scissors, are usually associated with metalworking. Wells [14] indicates that the Greeks were aware of the elastic behavior of both copper alloys and of iron for use in springs, for which he quotes a German translation of Pliny's (~300 BCE) text on missile weapons [15].

Tylecote [16] points out that withies (flexible wood branches), not tongs, are shown as the implement to lift smelting crucibles in a wall painting from a tomb at Thebes c.1500 BCE [17]. Zwicker, *et. al.* [18] note a similar wall painting from the same location showing a worker using a blowpipe and a simple non-pivoted spring pincers [19].

Pivoted instruments appear in Roman context in many forms. Copper alloy instrument segments could typically be cast and then assembled using pivot pins. However, fabrication of iron objects consists of taking each longitudinal segment of wrought iron and forming the ends as needed, possibly hardening one end in the smiths' charcoal hearth, piercing the mid-section of the heated rod with a cold piece of iron, and joining with a pivot pin. This conceptual design approach is a fundamentally different process than that used for elastic shears, where the development moves from multiple piece mechanical assembly to fabrication in a single piece as efficient lap welding technology develops, as will be described in this paper.

Petrie [20] states the origin of shears or scissors to be in Roman Italy circa 300 BCE, in disagreement with the textual evidence from Mesopotamian and Greek sources. However, his observations are based only on archaeological finds. The Petrie Museum collection at University College London holds a large number of Roman shears, almost all of which are made of iron, and which the present authors have had an opportunity to study.

A beautiful mosaic [21] showing "Nymphs punishing a Satyr" by threatening with a pair of shears was found in the Roman Domus [town house] situated in the Roman capital city of Malta - Melite. It was functional about the 1st century BC and continued for about a century later. It was discovered and excavated in 1881 and is now held on a site protected by the Museum of Roman Antiquities at Rabat. A number of stone carved reliefs, one at Ostia [22], one in Malta [23], and the carving mentioned above from Kom Ombo show collections of Roman surgical instruments and include shears. However, Kunzl [24] has made a survey of 69 archaeological sites at which collections of Roman instruments have been found, with the total number of objects near a thousand, only six of which are shears. Bliquez [25] has examined the Roman surgical instruments held at the National Archaeological Museum in Naples, which includes the instruments from Pompeii, and of the hundreds of instruments examined, only one pair of copper alloy (bronze?) shears is identified as a surgical implement. Bliquez points out that this is a small pair of shears as opposed to a few other larger ones in the collection, and he mentions the possible viticulture use of shears such as these [26]. It thus appears that very few shears have been found in the context of other medical instrument finds, and of the shears that are held in museums the vast majority are made of iron rather than bronze. These generalized observations are confirmed by Bliquez [27], and Jackson [28]. There have been no shears found in context with other medical instruments used by the Greeks [29].

DESIGN AND PRODUCTION

The relevant aspects of the production of iron shears lie in the different properties desired for the blade and in the spring. Blades should be hard, in order to maintain a sharp edge without bending; it appears that this was clearly understood by Roman smiths, as evidenced by the many blades that have been studied and which show a martensitic structure caused by rapid quenching of the blade. On the other hand, the spring needs to be flexible and cannot be brittle or it will break. Producing soft iron was also not a problem for Roman smiths. Thus, it is not the ability to produce these two separate materials that is in question here, but rather it is the ability to combine both into a one piece metal object that requires great skill and was difficult to manufacture at the time. Different microstructures

could be developed in the blade and spring regions by a number of conceptually different fabrication approaches: 1) carburize the blade starting from low-carbon iron, 2) decarburize the back spring region starting from higher carbon iron, 3) forge-weld a high carbon blade to a low carbon spring, or 4) fabricate the entire shears from low carbon iron except for a small high carbon insert at the blade edge.

Piaskowski reports metallographic study of three pairs of Roman single piece shears found in Poland, and dated to the 3rd-4th century CE [30, 31]. Pleiner reports the study [32] of a single piece elastic shears, from the La-Tene period in Bohemia, which was indicated to consist of ferritic iron in all but the tip regions where they were found to be martensitic steel. One piece shears from medieval London have been well documented and analyzed by Wilthew [33]. Although Wilthew published schematic descriptions of the blade construction, the report did not include any actual micrographs of the samples and did not perform analyses in the spring section of the shears, an important aspect for understanding the technology of these objects.

Petrie [20] notes that "In Pompeii blades of iron riveted to a bronze spring were not uncommon (Q12, Plate LVIII)". Bronze technology was well developed at the time that experimentation with iron was taking place, so it is understandable that the critical needs of the spring would be the limiting design issue. Although today spring steel is a more appropriate choice than any copper alloy, in ancient times the residual slag inclusions present in iron made fabrication very difficult and the product prone to failure. This was attested to when we had opportunity to examine a multi-section shears from the Petrie collection which was cracked across the back of the spring ([20] item Q14, Plate LIX, now identified as item UC63499 in the museum). It is apparent that it was very difficult to provide the blades with high hardness at the same time as providing good spring quality in the most critical location. Thus bronze in this critical location was initially a good choice. Therefore in order to obtain optimum properties in both the spring and the blade areas it was necessary to use different materials linked mechanically, because the wrought iron (that might make a good spring if clean) would crack because of elongated slag inclusions contained in the iron. Once this design, using mechanical linkage, was developed it was logical to try replacements with individual parts made of iron as improvements in iron technology took place. Finally, as efficient forge -welding developed it became possible to manufacture the final product in one piece.

As we will show, the typological transition in shears construction appears to have first started with a three piece shears having two blades attached to a spring, with one blade hard riveted to the spring, and a pivot joint rivet used to attach the other removable blade. This design was likely followed by a two piece shears, with one side having one of the blades and the spring made from a single piece of metal, and a pivot joint used on the other side of the spring to connect the second blade. In both of these designs the pivot joint would enable the blade to be removed from the shears in order to allow for the sharpening of both blades. This transition would have been a significant challenge in the production of multi-functional metal for the Roman smiths in the production of shears. The final stage used in shear design and production is the one piece shears.

Other aspects of design can be noted. Many of the shears (both multi-section and single piece) have a simple **U** shape to the spring section while others (almost always single piece shears as in Q21-Q26, Plate LVIII in [20]) have a **C** shaped back spring. This ring shape towards the back positions the parallel sides of the shears closer together and this changed shape reduces the stress on the central part of the spring, resulting in reduced breakage associated with the previous design seen in the shears from the Petrie Museum collection, as described above. Gaitzsch [34] catalogues the various types of iron tools manufactured in Roman Europe and includes a section on shears in which he attempts to classify shears by the shape of the rear spring section including the **U** and **C** shaped springs. Also, most of the shears have overlapped blades, but many have an open design with separated blades (as in Q24 and Q25, Plate LVIII in [20]); the open end makes it easier to sharpen the blades but increases the stroke needed for closure and therefore increases the load on the spring. It is possible that the **C** shape and the open designs appear only in later shears as they are correlated to improvements in the spring made possible as better material becomes available.

PRESENT METALLURGICAL INVESTIGATION

The specimens of Roman scissors and shears that the Royal Ontario Museum kindly allowed us to sample were all fabricated of iron and are dated to the Roman period in Egypt. The ROM obtained their collection of Roman shears in the early 1920's and as such, the excavated context of the objects is unknown but their value for providing technological information is still valid. We sampled four shears and one pair of scissors from the collection, and of the four shears sampled from the ROM we present two in the present paper. Sample 910.175.89 is a three piece shears and sample 910.175.487 is a two piece shears which comprise both stage one and stage two in the technological development sequence that we propose. Samples were taken from both the cutting blade and the spring to compare their microstructure.

Based on the presence of obvious weld laps indicated by visual examination of the Petrie pieces, and the absence of such laps in the ROM pieces, our tentative assumption is that none of the ROM pieces have been fabricated by forging the blade section to the spring section. At this point in time we have not yet had the opportunity to check for such welds using x-ray radiography, nor are we able to section samples from the mid-regions along the shears where weld laps might be present. These weld laps and their location are very different from the forge welded inserts in the blade section of medieval single piece shears (as found by Wilthew [33]).

METHODOLOGY

Samples were cut from the shears in the metals conservation laboratory of the Royal Ontario Museum under the supervisor of the metal conservator, Susan Stock. Samples were cut with a jewelers saw at right angles to the cutting blade and at the back of the spring. Samples were then mounted in epoxy resin and ground and polished to 0.3 μm alumina and finished with colloidal silica. The samples were all etched with 2% nital and digitally photographed. Hardness testing was done using a Vickers microhardness tester with a load of either 10, 25 or 50 grams for 15 seconds. Subsequent microchemical analysis and qualitative X-ray mapping was performed using a JEOL 7300 electron microprobe with a 4 spectrometer WDS system equipped with LDE2, LDE1 and TAP crystals to identify C, N, and Fe respectively.

RESULTS

Sample 910.175.89 (3 piece shears, fig 1)

This is a three piece shears with a solid rivet joint attaching a blade to the spring on one side and a pivot joint attaching the second blade to the other side (fig 1 photo A). The blade is comprised mainly of spheroidized carbide in a ferrite matrix (fig 1 photo B) with an average hardness of VHN 275 over 6 tests. This structure is surprising because most other shears that have been studied (although of a later period) appear to be comprised of tempered martensite [30-33].

The spring shows clear indication of forging with several extended slag stringers all in the same direction. Heavy corrosion is apparent on both edges of the sample. The slag is a two phased slag of wustite and iron silicate (also containing Ca and P as verified by SEM). The metal microstructure is comprised of coarse grained ferrite on about half the sample cross-section; the other half of the sample area consists of a finer ferrite microstructure with small pockets of slightly spheroidized pearlite (fig 1 photo C). Small slag inclusions are also present. There are small grain oriented precipitates (fig 1 photo D) present in both ferritic regions. The nature of these precipitates will be discussed below. The average hardness in the spring is VHN 114 over 5 tests.

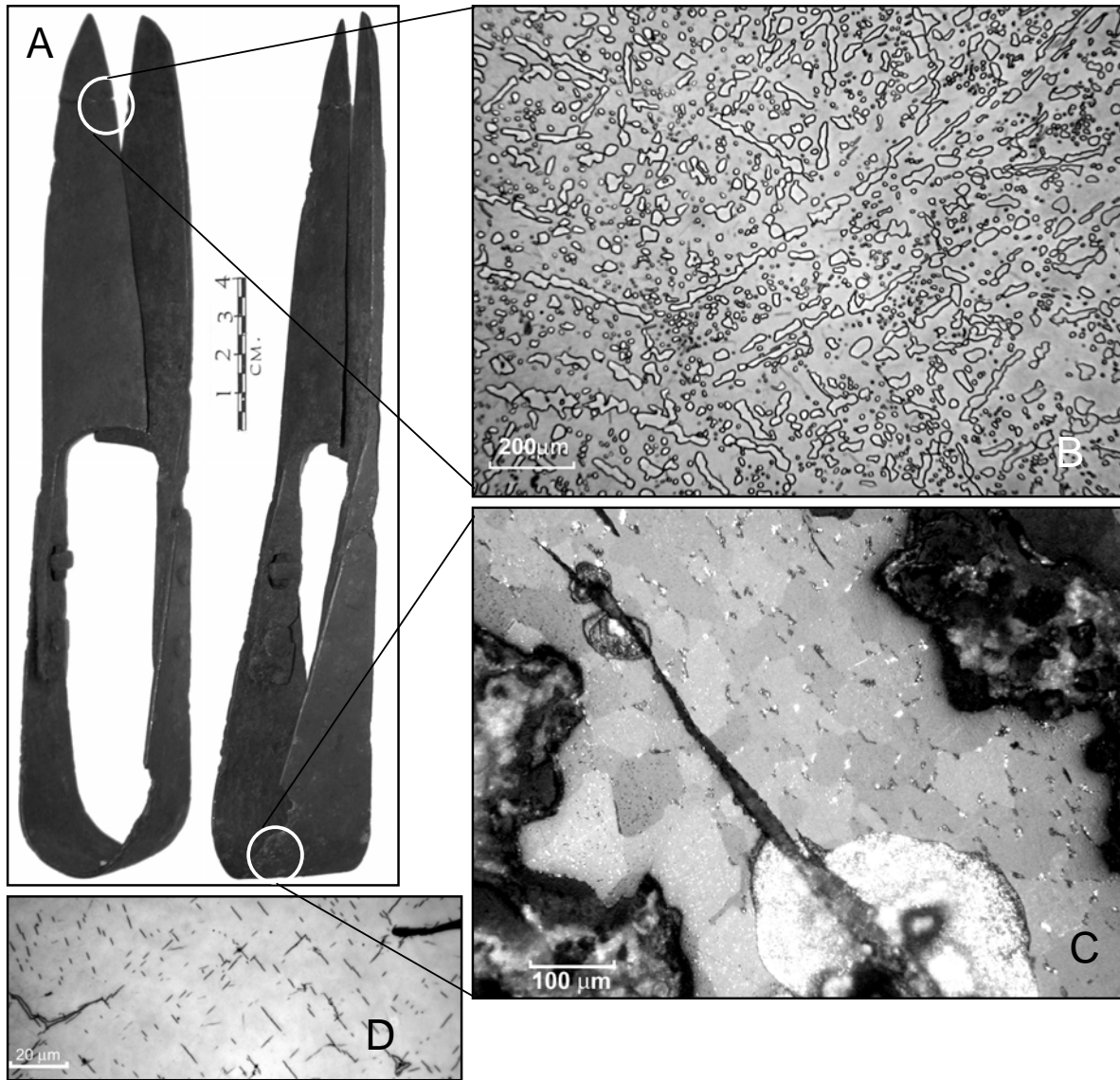


Figure 1: Roman Shears (910.175.89). Photo A is a macrograph of the shears showing the location of sampling. The pivot joint is clearly seen. Photo B shows the spheroidized carbide/ferrite matrix microstructure of the blade. Photo C shows the ferritic microstructure in the spring. The light specks recognizable in the ferrite grains are precipitates (see enlargement, Photo D). The photo was taken using cross polarizers. Photo A is the property of the ROM.

Sample 910.175.487 (2 piece shears, fig 2)

This specimen is part of a 2 piece shears (fig 2 photo A) with one blade and spring comprising one piece and having a pivot joint with which to attach the second blade. This blade has a more complex microstructure than the previous sample, made even more complicated by extensive regional corrosion. The microstructure consists mainly of ferrite with large pockets of martensite, carbides and precipitates similar to those found in the spring on sample 910.175.89 (fig 1 photo B). The corrosion within the body of the remaining metal is closely linked to the precipitates. The ferrite grains have an average hardness of VHN 137 over 5 tests. The martensite has an average hardness of VHN 712 over 6 tests

The spring (fig 2 photo C) contains slag stringers indicative of forging. The slag is a two phased slag of wustite and iron silicate (also containing Ca and P as verified by SEM). The metal microstructure consists of ferrite with a line of small pockets of martensite inclusions running along the center. Some larger pockets of martensite are distributed throughout the cross-section. Once again there are

precipitates present in the ferrite grains. In some cases the precipitates show signs of bending which may be an indication of mechanical deformation once formed.

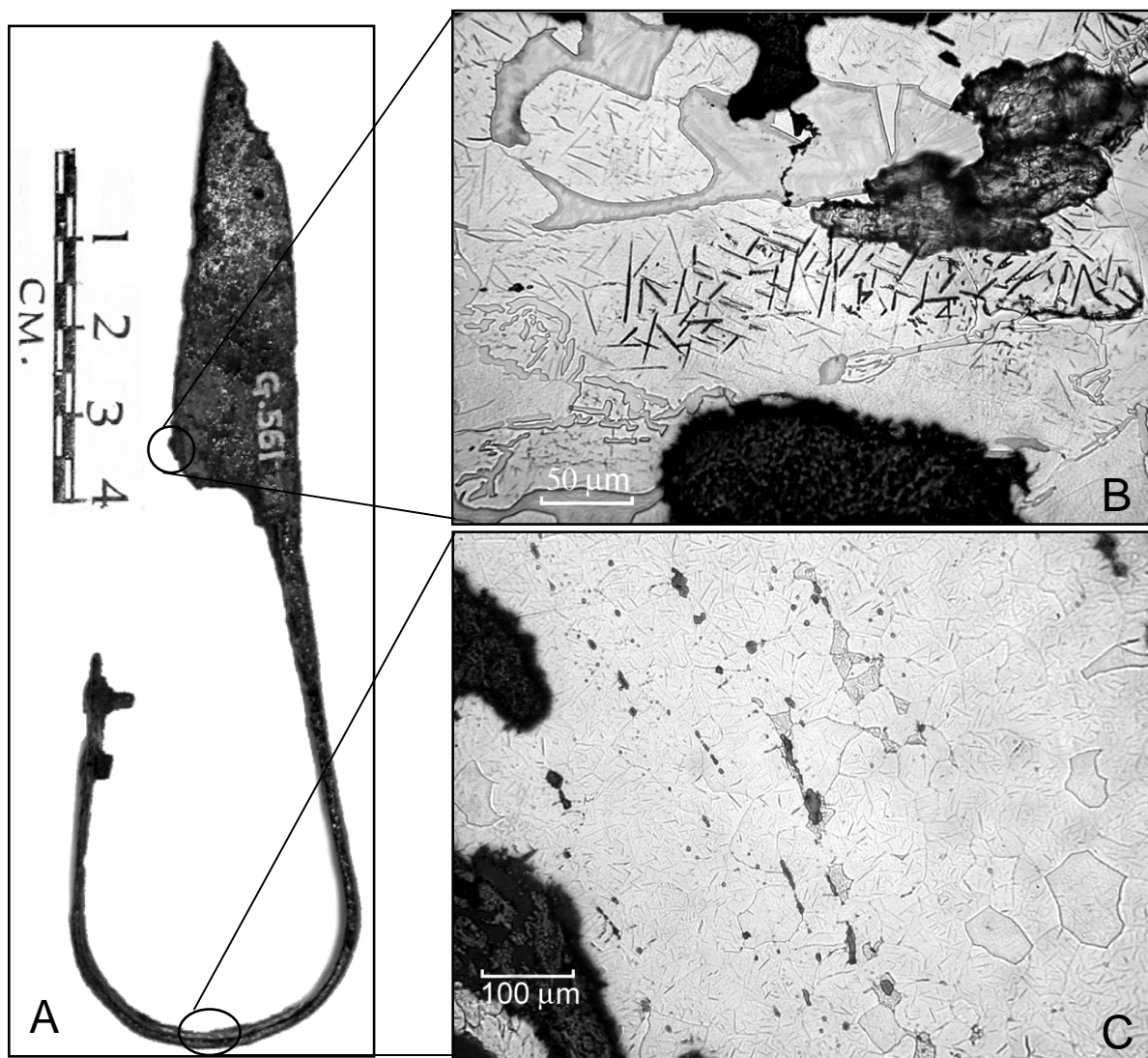


Figure 2: Roman Shears (910.175.487). Photo A is a macrograph of the shears showing the location of sampling. Photo B is a micrograph showing the microstructure of the blade, consisting mostly of ferrite (f) with pockets of martensite (m), carbides (c), and precipitates. The corrosion path follows the precipitates. Photo C is a micrograph showing the microstructure of the spring. Photo A is the property of the ROM.

These fine needle-like precipitates are observed in the ferrite matrix of both shears. In the three piece shears (910.175.89) they are relatively small, measuring less than a micron across and approximately $5 \mu\text{m}$ in length. In the two piece shears (910.175.487) the precipitates are longer, often up to $30 \mu\text{m}$. In an attempt to elucidate the nature of the precipitates found in the ferrite matrix, the two piece shears (910.175.487) shown in fig. 2 was examined using x-ray mapping in the electron microprobe (fig. 3). Light optical micrographs showing these precipitates are presented in fig.3 photo A (spring region, normal reflected light) and in fig.3 photo B (blade region, cross-polarizers). Fig.3 photo C is a composite of the Fe, N, and C maps produced by microprobe analysis. Comparison of the maps indicates the precipitates to be iron carbonitrides. This result is consistent with other studies performed in our laboratory on comparable objects [35]; in this previous study using EELS (Electron Energy Loss Spectroscopy) when examining the sample by transmission electron microscopy. Earlier reports in the archaeological literature (for example, Piaskowski [31, fig. 28] using only light microscopy) indicate

precipitates with this morphology to be complex iron nitrides, and often incorrectly associates them with the fuel source used by the smith. In fact, these precipitates are associated with "quench-aging", i.e., rapidly quenching from a temperature where ferrite would be stable and then holding at a low temperature for a long period of time, or cooling very slowly, to allow the supersaturated carbon (or nitrogen) to precipitate out.

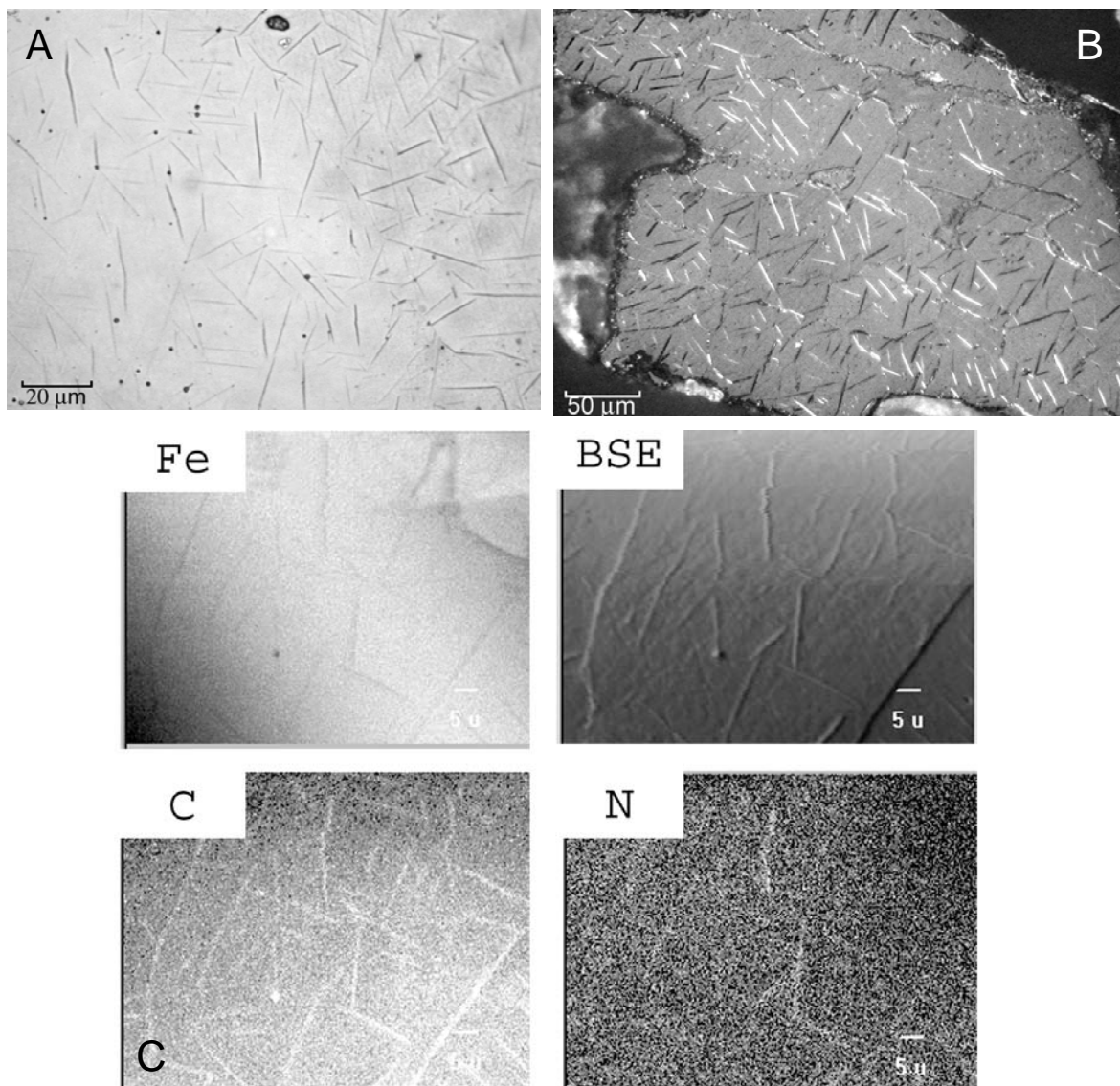


Figure 3: Precipitates in the ferrite regions of the spring (A, normal reflected light) and blade (B, cross-polarizers) of the two-piece shears (910.175.487). A composite of the x-ray maps for Fe, N, and C obtained from this region by electron microprobe analysis is shown in photo C.

It is interesting to compare the microstructures present in blade regions of the three-piece and two-piece shears. The blade of three-piece shears is composed of spheroidized carbides in a ferrite matrix. Although such a microstructure does have good strength and wear resistance, it is not a quenched martensitic structure and therefore does not indicate development of optimum properties from the available material. On the other hand, the lack of slag inclusions in this region indicates extensive forging and improvement in the quality of the available iron through this processing. The two-piece blade was composed of ferrite with only pockets of martensite, meaning that it was made of only a low carbon iron rather than a higher carbon material which would be more optimal for development of high hardness in the blade. Most reports in the literature [30-33] indicate a true martensitic structure in

the blade region of later period blades, although Piaskowski reports that a shear blade he investigated from the 3rd-4th century AD had a structure of ferrite and troostite (upper bainite) [31], also indicating non-optimal selection of material and treatment. In both of the present cases under investigation the predominantly ferritic structures in the spring regions, with the carbonitride precipitates indicating very low residual carbon in the remaining ferrite, do represent appropriate material and treatment choices in the spring region.

Logical process sequences for both shears may be inferred from their microstructures. In both cases the piece was shaped from wrought iron, heavily forged in the blade region such that slag was eliminated and carbon was picked up during processing. The three-piece (spheroidized carbide structure) had to have been developed by cooling below the pearlite transformation temperature (727^oC) and holding below that temperature for a long period of time. In the two-piece blade the presence of martensite pockets in the ferrite matrix is consistent with heating from a region where both ferrite and austenite are both present (below 910^oC) and quenching to form supersaturated ferrite and martensite from the austenite. This would be considered a relatively inefficient heat-treatment and quench, indicative of poor furnace temperature control or lack of knowledge by the smith. It would however produce a microstructure that could be manipulated to produce better properties in the spring region.

CONCLUSIONS

Examination of a three-piece and a two-piece iron shears indicates these objects to be consistent with early experimentation with iron technology attempting to match object design requirements with available technology. Metallurgical study of the blade region of the three-piece shears shows it to consist of spheroidized carbides in a ferrite matrix, i.e., it is not quenched and tempered martensite. The blade of the two-piece shears is composed of ferrite plus martensite, indicative of an attempt to quench this blade. Ferrite regions in both shears contain carbonitride precipitates related to a quench-ageing treatment. Based on visual examination of a considerable number of shears we propose a design development sequence starting with three-piece or two-piece construction and terminating with a single-piece design as improvements in iron materials and forge-welding technology were accomplished. A clear definition of scissors and shears, and the distinctions between them, are provided together with the historical and anthropological background concerning the development of shears and its use as an indicator of technological achievement in iron working in the ancient world.

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