CHEMICAL AND METALLOGRAPHIC ANALYSES OF SOME ROMAN IRON OBJECTS EXCAVATED FROM THE ARCHAEOLOGICAL SITE OF DOHALEH/JORDAN

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Abstract

A collection of various Roman tools excavated from the archaeological site of Dohaleh was analysed using metallographic examination and chemical analyses. Metallographic results prove that these objects were forged from wrought iron with a very low carbon content. The obtained microstructures and microhardness values of the tested objects show no evidence of intentional carburisation or hardening since no quenching or tempering was detected. The chemical analyses results show that these objects were mainly made of pure iron with very little impurities indicating almost complete separation between the metal and the slags during the smelting and smithing processes.

Historical background

It is not known for certain who began to smelt iron from its natural ores. It could have happened in Anatolia where the earliest man-made iron daggers were found. It seems that the supply of man-made iron in the second millennium BC was small and spasmodic, but it gradually increased until it was being used on quite a large scale for weapons in about 1200-1000 BC. Because of its rarity, iron was used during these early periods in small items of jewellery and for daggers' blades. The superiority of iron in serving as blades for weapons over ductile cast bronze and leaded bronze was obvious (Tylecote, 1976).

Iron was beginning to appear in quantity by the 8th century BC in many areas especially the Anatolian-Iranian region. Iron transferred from there across parts of
Europe, Asia and Africa in the period of 1000-500 BC. Soon after 1000 BC, iron reached the coast of Palestine. At around 900 BC it entered Greece via Anatolia and from there entered Egypt. In the period of 200 BC-500 AD, iron reached central and east Africa and some parts of Asia (Coughlan, 1956).

It is quite certain that iron entered Jordan as early as the bronze age. Iron artefacts dated to that period were excavated from various sites. This includes a Middle Bronze Age iron blade from Pella (Smith et al., 1984), an unidentified fragment from an LB II tomb on Jebel al-Nuzha near Amman (Dajani, 1966) and part of an anklet/bracelet from an LB II burial cave in the Baq'ah valley (Piggot et al., 1982).

In his surveying of iron artefacts recovered from Eastern Mediterranean excavations, Waldbaum (1978) mentioned a pair of bracelets and a pair of rings excavated from a late Bronze/Early Iron Age tomb at Madaba. McGovern described the discovery of a group of eleven complete pieces of iron jewellery, eight anklets and three rings, together with forty additional fragments (McGovern, 1979, 1981).

It is obvious from the size of the found iron artefacts and their nature that iron during these periods was rare and precious. Due to its rarity, it was mainly used for the manufacturing of the small items of jewellery.

The scale of iron production and the nature of its use had been dramatically changed during the Roman period. The military and civil needs of the Roman civilisation created a considerable demand for iron. Therefore, this period witnessed large scale smelting and smithing of iron (Jones, 1964). Iron was extensively used for manufacturing various types of weapons and cutting tools. Various types of arrow heads, spear heads, daggers, knives, axes, sickles and other items were excavated from Roman sites all over Jordan. The same applies to Byzantine and Islamic sites.

**The Present situation of studying iron artefacts in Jordan:**

Despite the enormous increase in the amount of excavated iron artefacts from Jordan in the past few decades, very little is known about the techniques of production and fabrication of iron acquired by the ancient blacksmith in Jordan. This could be mainly attributed to two factors: the first is the poor corrosion resistance of iron. Very few of the earliest iron objects could survive the burial environments in a sufficiently good condition to give information. Most of the excavated iron objects have been found in a completely mineralised state with no metal left and in some cases the original shapes of these objects cannot be identified. Moreover, in the rare cases where iron objects in good conditions are found, their survival is highly doubtful. This is because of the post excavation corrosion that the excavated iron objects suffer from. Due to the lack of facilities and expertise for iron preservation and stabilisation in Jordan, excavated iron objects are usually dumped untreated in
stores without any environmental control. This initiates very rapid cycles of corrosion sufficient to convert the objects into the mineralised state in a short time. This means that even future analyses of these objects will not be possible. The second factor is the methods and approaches used by most Jordanian archaeologists for studying excavated iron artefacts. In most cases these objects have been approached from a stylistic point of view only. Such descriptive studies do not go beyond what is present on the surface of the studied objects ignoring the intrinsic value of these objects. Knowing that most of these objects are abandoned under uncontrolled environments after finishing these preliminary studies, the chance of doing future scientific analyses on these object is severely limited. Therefore, invaluable information regarding the techniques of manufacturing and the subsequent treatments of these objects is overlooked. Very little scientific analyses were done on iron objects excavated from Jordan and even these analyses were done outside the country (Pigott, 1982 et al.; Smith et al., 1984).

An overview of the methods used for studying iron artefacts:

There are three main approaches for studying archaeological iron objects. The first is the traditional typological method. This method is based on the classification of the metal artefacts based on their visible forms and presumed function. This is, at best, a severely limited approach and can lead to erroneous conclusions when non-metallurgical criteria are the main classification feature. Iron artefacts cannot always be identified without a technological examination and the meaningful characteristics of a weapon or a tool is its strength, hardness, resistance to wear, etc. Details such as these cannot be sought by the typological analyses (Coghlan, 1959).

The second approach is based on the study of primary extractive metallurgy includes extracting and smelting of iron in antiquity. This is the most rewarding approach that will ultimately answer most of the questions posed by those concerned with early metallurgy such as types of ores, smelting techniques, etc. However, this approach requires the co-operation of specialists from many fields and is not practical on small scale archaeological investigations.

The third approach is the chemical analyses and metallographic examination of the iron artefacts (Brandon, 1966; Phillips, 1971; Scott, B. G, 1977). This approach can answer questions regarding the techniques used by the blacksmith in iron alloying and fabrication.

It is clear that these three techniques are complementary and not in conflict with each other. Therefore, for maximising the quantity and quality of information regarding ancient iron, a comprehensive approach that utilises all the mentioned approaches should be used. However, in some cases where specific questions regarding ancient iron are sought, one or more of these approaches that can answer such questions can be used.
Fig. (1): Geographical map showing the location of the archaeological site of Dohaleh.
In this study the typological approach coupled with the chemical analyses and metallographic examination approach will be used to analyse some iron objects excavated from the archaeological site of Dohaleh/ northern Jordan dated to the Roman period. It is hoped that some light may be shed on the technical competence of the blacksmith of that period and on his knowledge of iron alloying, fabrication and working.

**Theory behind metallographic examination and chemical analyses of ancient iron objects:**

Metallographic study is concerned with the crystal structure of metals as this enables identification of the phases present in the metal alloy. By knowing what phases are present, it is possible to give an account of the work carried out on the metal object during its manufacture. Interpretation of metallographic results can provide invaluable information that is very important in the assessment of the technological sophistication acquired by the ancient metal smith. Information regarding the nature of the metal or alloy used to make the artefact, the manufacturing processes, subsequent heat treatment and quality control of an artefact can be gained from studying its microstructure.

Metallography is based on the study of polished sections of metallic materials using a special metallurgical microscope. Reflected light microscopy is used for metallographic examination because metals cannot transmit light in thin sections since metals are opaque substances. This microscope can reflect the light passing through the objective lens onto the specimen surface. The reflected light passes back through the objective lens to the eye piece that enables the surface structure of the section to be studied (Hendrickson, 1967; Scott, 1991).

In order to view the metal grains microscopically, a flat section of the metal must be prepared so it can be viewed by reflected light. The section is polished on several stages of fine abrasive until it is scratch free. When the sample is viewed in this condition little will be visible except for the non-metallic inclusions such as slags. To examine the grain boundaries, other phases, and effects of alloying additions the polished metal surface must be attacked with selected chemical reagents (etchants) that will reveal differences in grain orientation and microstructure.

The hardness of a metal object is a function of the nature of metal or alloys that the object was made of and the subsequent treatments and shaping that the object was
subjected to. Therefore, invaluable information regarding the object composition and manufacturing technology can be obtained by the determination of the hardness of the metal object. Since Moh's scale of hardness cannot be used accurately to assess the hardness of a metal, other methods should be employed. The most common methods of assessing metal hardness are based on deforming the metal in a hardness-testing machine under a certain load employing a specially sharpened indenter to press into the surface of the metal. Therefore, hardness is a measure of the metal resistance to permanent or plastic deformation. It is a function of the deforming force and is therefore a relative measurement only. Microhardness may differ significantly from one location to another within the sample due to the inhomogeneity of the metal sample. The results from the indenter on one or two grains may not compare with a reading that averages the results of deformation over many grains and grain boundaries.

The first hardness testing method that found a universal acceptance is the Brinell hardness testing (HB). In this technique, a steel ball of known diameter is forced into the metal surface under a certain applied load. The diameter of the impression left on the surface can be measured accurately and a scale of harness calculated. Subsequent industrial developments have brought another method known as Vickers method (HV). The Vickers method utilises a four-sided diamond pyramid indenter and the results of the scale are sometimes quoted as DPN numbers (from Diamond Pyramid Number) (O'Neill, 1934; Scott, 1991). This is the same as the HV, merely being a different abbreviation for the result. In most ancient metals, sound metal is not found at the immediate surface and hardness testing must usually be carried out on a micro rather than a macro level on a polished and mounted section using a special microhardness testing machine.

Unlike other metal artefacts, the compositional analyses of iron artefacts are not much of a guide to the type of ore used in producing these artefacts or their provenance. Iron being a relatively base metal will take up any more noble elements such as nickel or copper from the ore, but will leave behind in the slags elements such as manganese and zinc. However, some elements are of some value in assessing the provenance within a small area and the manner of manufacture of iron implements. These elements are mainly carbon, phosphorous, sulphur, silicon, nickel, manganese and calcium.
Materials and methods:

Materials:
The archaeological context of the studied objects:

This study is concerned with a collection of different iron artefacts unearthed during the excavation works at the archaeological site of Dohaleh/northern Jordan (see map). The excavations were undertaken by a Yarmouk University team under the supervision of Dr. Sari of the Institute of Archaeology and Anthropology (Sari, 1991, 1992). A large collection of various iron artefacts was excavated from areas A and C. On the basis of the stratigraphy and the typological analysis of the excavated archaeological materials, especially pottery and coins, that were found in the same context the iron objects could be dated to the late Roman period, probably the third century AD.

When excavated, most of the iron objects were satisfactorily preserved. After two years of improper storage due to lack of facilities, investigations revealed that most of these objects were in a complete mineralised state with no metal left. Fortunately, seven objects were found in a satisfactory condition for metallographic and chemical analyses. These are:

(a) A socketed spear head: this has a length of 27 cm and a weight of 322 grams. The object has a thick layer of corrosion but with a sound metal core. Textile remains were found preserved within the corrosion products. The shaft was filled with compact soil and this was mechanically removed.

(b) Two tanged arrow heads: the first has a length of 9.2 cm and a weight of 21 grams while the second has a length of 10.2 cm and a weight of 20.6 grams. Both are in good conditions with sound metal core left. Extraneous concretions were mechanically removed.

(c) A tanged knife: this has a length of 18 cm and a weight of 36.5 grams. This object was in a fragmentary condition. However, X-Ray examination revealed that some metal was still left in the blade and the tang areas. Remains of the wooden shaft were found preserved within the corrosion layers.

(d) Three nails: these objects were found in a very good condition. Removal of a thin layer of concretions and corrosion revealed solid and sound metal cores.
A photograph of all these objects is given in figure (2).

Preparation of the samples for metallographic and hardness studies:

The artefacts were prepared for metallographic and hardness examination using the following method:

The extraneous soil and sand material and concretions adhered to the surfaces of the objects were mechanically removed using an air abrasive. Then the areas of special interest on each object were identified. Samples from these areas were cut using a jeweller’s saw. The cut samples were then oriented as desired and mounted using a 20-8130-032 Epoxide with hardener 20-8132-008. This is a cold-mounting epoxy resin system that adheres well to the samples and shows a very low shrinkage rate during curing.

Fig. (2): Photograph of the iron objects

The grinding of the samples was done by using water-proof silicone carbide paper discs secured to metal wheels. Consistent grinding leaves a series of parallel scratches on the surface of the sample. When using a smaller grit size, the samples
were turned so that the new scratches were perpendicular to the extant ones. Grinding continued until most of the earlier scratches disappeared. To achieve that, grit sizes 220, 320, 400 and 600 were used.

Polishing of the grinded samples was achieved by using 6, 1 and 1/4 micron diamond pastes spread on a lapping wheel. The samples were frequently examined under the microscope during the polishing operation to monitor the progress. When there was a high shine on the surface and no scratch marks were visible, the polishing operation was stopped.

The polished samples were then examined under the metallographic microscope (Nikon Optiphot) and photographed. After that, the samples were chemically etched using 2% Nital (nitric acid diluted with ethanol). A small quantity of the etching solution was poured into a small crystallising dish and then the specimen to be etched was immersed for a few seconds in the solution. After etching, the specimen was washed under running water and then rinsed with acetone and then dried using an air dryer. The samples were then examined again under the metallographic microscope and microphotographs were taken.

Microhardness testing was carried out on a Vickers M 129 hardness tester. A 20 g load was applied to the diamond indenter. Microhardness results are based on the average of four tests.

**Preparation of the samples for Atomic Absorption analyses:**

The samples were prepared by a modified method of Hughes et al. (1976). Care was taken to obtain representative samples of the studied objects. Therefore, surface concretions and corrosion products were mechanically removed from specific areas from which the samples were taken. Samples were taken with a portable hand-held mini drill. One mm tungsten carbide drill bits were used to minimize the possible contamination of the taken samples. The surface metal was drilled until shiny metal turnings appeared. This part of the sample was discarded and then the drilling continued deep into the objects until sufficient samples of clean and shiny metal turnings were obtained. Then 10-25 mg of the drillings from each sample was weighed to an accuracy of ± 0.01 mg using an analytical balance. The sample was then transferred to a 250 ml beaker. Twenty five ml of aqua regia (1 volume of concentrated HNO₃ and 3 volumes of concentrated HCl) was added to each sample. The sample was then placed on a hot plate at 60 °C until it was completely
dissolved and after that it was removed from the hot plate and left to cool at room temperature. A further 1 ml of aqua regia and 10 ml distilled water were then added. The sample was transferred to a 25 ml Erlenmeyer flask and distilled water was added to the mark. The analyses were carried out for Fe, Cu, Mn, Ni, Si and Al using a Perkin-Elmer Atomic Absorption Spectrometer, model SP9 stationed at the Geology Department, Yarmouk University.

**Calorimetric Determination Of Phosphorous:**

This was done by a modified method of Westwood and Mayer (1960). Around 0.5 gram of finely ground sample of iron drillings was accurately weighed and transferred to a 150 ml beaker. To the sample 25 ml of concentrated HCl and 10 ml of concentrated HNO₃ were added. The beaker was then covered and heated on a hot plate at 80 °C for 30 minutes. Then the cover was removed and the solution was evaporated till a volume of 5 ml was left. The beaker was removed from the hot plate and the solution was allowed to cool. Five ml of concentrated perchloric acid (HClO₄) were added and the solution was heated until HClO₄ refluxed down the sides of the beaker for 10 minutes. After the solution was cooled, 50 ml of distilled water were added and the solution was heated to near boiling for 25 minutes. The solution was then filtered and diluted to 250 ml. Twenty millilitres were then pipetted and transferred to a 100 ml volumetric flask. Twenty millilitres of vanadomolybdate were then added and the flask was filled up to the mark with distilled water. After 30 minutes the optical density of the solution was measured at wave length of 460 nm using a Spectronic 2000 spectrophotometer. Five readings were taken for five different samples and the average value was used in the calculations. A series of standard solutions were prepared and their absorbencies were measured and used for drawing a calibration curve. The absorbance value of the solution was used to determine the concentration of phosphorous using the calibration curve. The percentage of phosphorous in the sample was then calculated.

**Results and discussion:**

**Metallographic interpretations:**

*The socketed spear head:*

This object was sampled in three areas, the positions of which are shown on the drawing of the object in figure (3). The first sample was removed from the blade edge and mounted to expose the lateral direction. The microstructure contains numerous slag inclusions. The central area is composed of small α-grains of ferrite.
with some small amount of lamellar pearlite (fig. 4). It has an estimated carbon content of 0.2-0.3%. The outer edges were all decarburised. Toward the surface the grains are larger, ragged and permeated by degenerated pearlite (figure 5). The hardness values range from 173 HV in the core to 108 HV at the decarburised edge.

The second sample was removed from the solid portion of the socketed area. The core is composed of larger equiaxed ferrite grains and less pearlite than the outer area that has a 0.1% carbon content and smaller grains (fig. 6). The core has a microhardness value of 90 HV and the higher carbon area a value of 133 HV.

The third sample was a cross section through the socketed area. The microstructure consists of layers composed of pearlite in a matrix of α-grains, with an estimated carbon content of 0.4%, alternating with layers of coarser ferrite grains (fig. 7). A microhardness of 145 HV in the higher carbon area was obtained while in the ferrite layers the value was 102 HV.

Metallographic examinations indicate that the socketed spear head had been forged from a faggot of piled carburised wrought iron. It might have been made by rolling over the faggot to form a forge-welded tubular section which was then completely collapsed at one end but retained its tubular form in the socket portion. Alternatively, the faggot might have been flattened out to form the blade at one end while the other was folded to form the socket. The spear head appeared to have been cooled in the air, with the blade area cooling more rapidly than the socketed area. Some final shaping of the blade had been carried out at very low temperature. Microstructure and microhardness examinations indicate that the blade had not been hardened.

**Fig. (3):** Drawing of the socketed spear head showing the locations of the taken samples
Figure (4): Photomicrograph (100x) of sample 1 (central area) of the socketed spearhead showing slag inclusions and small size ferrite grains with a small amount of lamellar pearlite indicating minimal carburisation.

The tanged knife:

Two samples were taken from the cutting edge and from the non-working area of the knife for comparison (fig. 8). The photomicrograph of an etched sample of the blade (fig. 9) shows numerous slag inclusions which had not been expelled during forging. The blade was forged from a piled structure with layers of varying carbon content. There is no indication of quenching and tempering of the blade. The carbon content close to the edge of the blade is extremely low (below 0.04 %). This probably resulted from prolonged heating which had decarburised the thin portion of the cutting edge. Figure 9 shows that the microstructure of the blade is typical of material that had been air cooled from above 850 °C. Neumann bands are distributed among large ferrite grains indicating that heavy cold hammering had occurred during the final stages of the manufacture process. The micro hardness value of the cutting edge is only 159 HV due to decarburisation.
The microstructure of the sample taken from the tang is composed of large grains of pure ferrite as shown in figure 10. The hardness value of 104 HV suggests that no work-hardening had been tried on the tang.

The tanged arrow heads:

Two samples were taken from the tang and from the blade area of one of these arrow heads as shown in figure 11. The microstructure of the tang sample (fig. 12) contains numerous slag inclusions. It is composed of small equiaxed α-grains with small amounts of lamellar pearlite. The hardness value in the high carbon area is 165 HV while the value is 150 HV in the low carbon area. The sample cut from the blade area was mounted to expose the lateral direction. The microstructure of the blade sample (fig. 13 and 14) is composed of small equiaxed α-grains with spheroidised pearlite. The carbon content is around 0.2 %, though partial spheroidisation of pearlite makes an accurate estimation of the carbon content difficult. At the cutting edge the carbon content is higher and the structure is composed of large patches of pearlite. The hardness value of the cutting edge is 174 HV and of other areas is 167 HV.

The metallographic examination indicates that this tool appeared to have been forged from wrought iron with a low carbon content. The blade had been worked during the final stages of the manufacturing process. Reheating to below 720 °C had possibly occurred during sharpening of the edge. This had removed the low carbon area.

Fig. (5): Photomicrograph (400x) of sample 1 of the socketed spearhead (outer edge) showing larger grains of ferrite with pearlite.
Fig. (6): Photomicrograph (100x) of sample 2 of the socketed spearhead showing layers of different sized equiaxed ferrite grains.

Fig. (7): Photomicrograph (100x) of sample 3 of the socketed spearhead showing layers of ferrite grains that contain pearlite.
**Fig. (8):** drawing of the tanged knife showing the locations of the taken samples.

**Fig. (9):** Photomicrograph (200x) of the tanged knife blade (sample 1) showing ferrite grains containing Neumann bands.
Fig. (10): Photomicrograph (400x) of the tang of the knife (sample 2) showing large equiaxed ferrite grains.

Fig. (11): Drawing of the tanged arrow head showing the locations of the taken samples.
Fig. (12): Photomicrograph (200x) of the tang of the tanged arrow head (sample 1) showing small equiaxed ferrite grains with some pearlite.

Two samples were taken from the second arrow head (one from the tang and one from the blade). The microstructures and the hardness values obtained are very similar to those of the first arrow head implying that these two objects were made from the same raw material using the same fabrication and shaping techniques.

The nails:

One sample was cut longitudinally through the head of the nail shank from each nail (fig. 15). The microstructure of the first nail indicates that the head and the shank appear to have been made by forging one piece of wrought iron. The photomicrograph of the etched section (fig. 16) consists of ferrite grains with no indication of carburisation, the grain size getting smaller in the head area due to heavy working. The hardness of the shank area is 112 HV while the head area is a bit harder with a value of 125 HV. Similar results were obtained by examining the two other nails indicating that the same raw materials and manufacturing techniques were employed in the manufacture of these nails.
Compositional Analyses:

Table (1) provides the elemental composition of the studied objects. The high percentage of iron indicates that these objects were made mainly of pure iron. It is noticed that elements that might have affected the composition and functional behaviour of iron are not present in high concentrations. Phosphorous, an element which can harden or embrittle iron, occurs at a uniformly low concentration. It seems that during the Roman period there was a move away from the nodular carbonate ores of the pre-Roman with their high phosphorous content, to a better class of ore such as limonite or hematite. Phosphorous iron is cold short, which means that it is brittle when bent cold, and although strong, is not attractive to those who understand well the technique of carburisation (Tylecote, 1962). What is very noticeable is the uniformly low manganese and silicon contents. These elements are present in the iron ores in most cases. However, they are not reduced during the normal smelting process and find their way almost exclusively into the slags. The low concentration of these two elements might indicate that the separation between the metal and the slag was efficient. The low concentrations of impurities detected in the analysed objects may indicate that these objects were made of iron smelted from a high purity ore.

The determination of the provenance of metal objects is a very complicated task. This is mainly due to the large variety of impurities that might enter the metal structure during the smelting, smithing and fabrication processes (Tylecote, 1970). However, the slight variation in the concentrations of impurities suggests that the objects under investigation were probably obtained from the same ore. The proximity of iron ore deposits of limonite and hematite in the Wadi Zarqa and Ajlun regions (Basha, 1968; Bender 1974) suggests nearby production. Despite the fact that archaeological investigations conducted by Coughenour (Coughenour, 1976) at the sites of Mughar el Wardet and Abu Thawab have thus far only been able to substantiate medieval Islamic smelting activities, the presence of large amounts of pottery sherds of Roman origin points to a possibility of smelting operations during that period. However, before these and other sites of iron ores are fully surveyed, well dated and studied, the precise determination of the provenance of these objects is not possible.
Fig. (13): Photomicrograph (200x) of the blade of the tanged arrow head showing small ferrite grains with spheroidised pearlite.

Fig. (14): As in figure (13) but with a higher magnification (500x).
Fig. (15): Drawing of one of the nails showing the location of the taken sample.

Figure (16): Photomicrograph of the nail showing the slag inclusions and the ferritic grains.
Table (1)

Elemental composition of the iron objects (% by weight)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Ni</th>
<th>P **</th>
<th>Si</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socketed Blade</td>
<td>99.30</td>
<td>0.016</td>
<td>0.020</td>
<td>0.032</td>
<td>0.11</td>
<td>0.142</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>Socket</td>
<td>99.50</td>
<td>0.015</td>
<td>0.022</td>
<td>0.037</td>
<td>0.13</td>
<td>0.163</td>
<td>0.059</td>
<td></td>
</tr>
<tr>
<td>Tanged Blade</td>
<td>99.32</td>
<td>0.019</td>
<td>0.031</td>
<td>0.042</td>
<td>0.092</td>
<td>0.120</td>
<td>0.062</td>
<td></td>
</tr>
<tr>
<td>Knife Tang</td>
<td>99.51</td>
<td>0.021</td>
<td>0.034</td>
<td>0.033</td>
<td>0.095</td>
<td>0.110</td>
<td>0.071</td>
<td></td>
</tr>
<tr>
<td>Tanged Blade</td>
<td>99.41</td>
<td>0.020</td>
<td>0.031</td>
<td>0.037</td>
<td>0.11</td>
<td>0.092</td>
<td>0.066</td>
<td></td>
</tr>
<tr>
<td>Arrow head Tang</td>
<td>99.55</td>
<td>0.018</td>
<td>0.030</td>
<td>0.034</td>
<td>0.10</td>
<td>0.091</td>
<td>0.073</td>
<td></td>
</tr>
<tr>
<td>Nail Head</td>
<td>99.60</td>
<td>0.015</td>
<td>0.027</td>
<td>0.031</td>
<td>0.089</td>
<td>0.110</td>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>Shank</td>
<td>99.64</td>
<td>0.014</td>
<td>0.024</td>
<td>0.030</td>
<td>0.078</td>
<td>0.100</td>
<td>0.068</td>
<td></td>
</tr>
</tbody>
</table>

** Phosphorous was determined by a calorimetric method.

Conclusion:

The specimens used in this study are too few to permit accurate conclusions concerning the technical competence of the blacksmiths working in northern Jordan during the late Roman period. However, these analyses could be considered a step forward in the reconstruction of iron production and fabrication techniques in this part during the Roman period.

The metallographic examinations show that the investigated objects do not show evidence of highly sophisticated iron metallurgy. Perhaps one would not expect much attention to harden a spear head, but had the skills of the smith been high, one would expect some endeavour to be made to harden a knife cutting edge. It was hoped that a fine specimen like this would exhibit the techniques of quenching and tempering. However, this was not the case. Moreover, the cutting edge of the knife had been spoiled through excessive decarburisation resulting from heavy cold hammering. Cold hammering was probably an attempt by the smith to render an unsatisfactory tool in some measure serviceable. This might indicate that the smith
had no high skills of proper methods of iron alloying and fabrication. No attempt had been made to harden the arrow heads, nor would hardening be possible with such low carbon material. This specimen is a poor piece of work, although no doubt quite good enough for an arrow, but of little interest in terms of sophistication of iron fabrication.

The results of this study are entirely agreed with the well established fact that Roman smiths do not appear to have made very marked progress in actual technology, but were rather satisfied to retain the old and well-established techniques, while much increasing the scale of iron production (Tylecote, 1962, 1976).

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