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An Archaeometallurgical Study of Medieval Knives from Kinet Höyük, Turkey

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Keywords
Archaeometry, Kinet Höyük, medieval iron smithing, knife, crucible steel

Abstract

This paper examines the knives of the medieval period (13th -14th century AD) from Kinet Höyük in Cilicia, one of the most important areas of Anatolia for the history of iron production. The materials and production processes of 12 knives were revealed using archaeometry methods, such as Optical Microscopy (OM), Scanning Electron Microscope-Energy Dispersive X-Ray Spectrometer (SEM-EDS) analyses, and micro-hardness tests. An examination of the relationship between the shape and size of these knives was undertaken, along with a discussion of the factors involved in the manufacturing techniques.

Among the medieval knives from Kinet Höyük that were analyzed, the results of the study indicate that besides blades made entirely of steel or wrought iron there are examples of forge-welding steel to wrought iron in a variety of ways. The largest group of knives is composed of small blades made only of steel. A particular example of this group is a blade made of crucible steel, which was skillfully forged and heat-treated. The medieval blades from Kinet Höyük exhibit a direct relationship between their shapes and their dimensional proportions. A specific production method, however, seems not to have been chosen in accordance with a given shape. The dimensions of the knives were more significant, particularly when only steel or only wrought iron was used. Based on the historical iron-producing activities in the region and the traces of intense blacksmithing practices found in the medieval layers of Kinet Höyük, it is argued that these knives are remnants of a skilled metal production culture.

Introduction

In the history of iron, tools have been manufactured using a variety of materials and thermo-mechanical processes that enhance their performance to withstand the specific forces and stresses that evolve due to their functions, such as cutting, piercing, crushing, and hammering. Knives, for instance, should be hard and sharp at the cutting edge, since they were designed to be used (mostly) for cutting. They should keep their sharpness for a reasonable time and be available for re-sharpening. In addition, their material features should minimize the risk of cracks forming during usage. In order to meet these expectations, blacksmiths generally implemented a combination of materials and manufacturing techniques for the production of knives.

As the cutting edge is responsible for the cutting function of a knife, its quality is determined by the production techniques and materials used. This part of the blade must have the necessary mechanical properties for this, such as strength and toughness. To achieve the required performance characteristics, knives are best made of steel, an alloy comprised of iron and carbon that can be subjected to a variety of mechanical and heat treatments. However, the price of steel was up to five times that of wrought iron during the medieval period (Tylecote, 1981, p.46). Due to the importance of knives as tools for work or for the household, blacksmiths attempted appropriate forging techniques that were also economically feasible. The simplest method was to place steel only at the cutting edge of the blade. At the time of medieval Anglo-Saxon settlements in Britain, for example, knives were often made in such a way, using steel for the cutting edge and wrought iron for the back (Blakelock and McDonnell, 2007, p.52). High-quality steel with a homogeneous carbon content and as few slag inclusions as possible was generally selected for the cutting edges. Wrought iron and steel parts were welded either with blunt ends (also called butt welding) or tapered ends (also called scarf welding). Provided that the welding was performed properly, no weakness would be experienced at the joining line during use. There was a significant disadvantage

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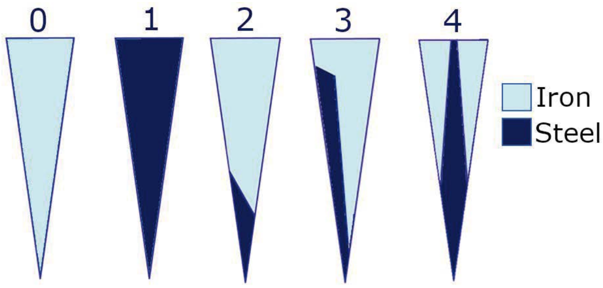


Figure 1. Knife production techniques are illustrated using a schematic representation of blade cross-sections. Graphics: Ü. Güder.

to butt-welded or scarf-welded knives, however: a short service life. When the steel at the cutting edges was worn off, the knives were either discarded or re-welded. If a longer service life was desired, steel layers were placed along one side of the wrought iron layer or in between two wrought iron layers, a challenge that required skill.

Figure 1, which illustrates production techniques applied to medieval knives, is adapted from McDonnell's work (1989, p.377), a simplified version of the classification by Tylecote and Gilmour (1986). Using this illustration, the cross-section of the knives is depicted as a triangle where the sharp tip at the bottom is the cutting edge, and the flat one at the top is the back of a knife. The use of different types of materials is indicated by different colors.

Type 0 blades were manufactured solely from wrought iron. Due to the high ductility of wrought iron, the blades were inefficient and quickly lost their sharpness. With Type 1, the entire blade was made of steel. By taking advantage of the ability of steel to harden, quenching may have been applied to increase the performance of the cutting edge. With Type 2, steel was forge-welded only to the cutting edge of knives of this type, which kept the cost of the materials low. An inclined weld-line can be observed between two materials with this technique, which is also known as scarf-welding. A steel layer was welded to a flank of the wrought iron body to Type 3 knives, which were intended to be more durable than scarf-welded knives. Type 4, commonly referred to as core or sandwich welding, combines the desirable features of iron and steel. On both sides, ductile wrought iron layers supported the steel layer in the middle, which hardened after the quenching process. A Type 4 production knife required advanced iron smithing skills due to its complexity compared to the others.

As the variety of materials and production techniques indicates, ancient knives have a greater potential for providing information about the technological knowledge and skills of craftsmen than other utilitarian iron objects. However, it is crucial to note that the term "knife" refers to a highly heterogeneous group of objects when considering their form and function. The biggest obstacle to comparing an ancient knife with other finds from the same group is to regard it solely as a cutting tool, as Sigaut (1991) has pointed out. As an example, both a shaving blade and a butcher knife perform cutting, but their functioning and primary function is different. One cuts facial hair by sliding gently over the skin, while the other slices by running the sharp edge through the meat. The units of a knife and their relationships may assist with understanding the function of a knife, such as the length of the blade and tang, the width of the blade, the straightness of the cutting edge, etc. In order to make a comprehensive analysis of archaeological knives, it is necessary to examine their structure, function, and functioning from a holistic perspective, which takes into account archaeological context, stylistic specifications, and material characteristics. Several studies have adopted this perspective, including the analysis of pattern-welded medieval knives (i.e. Thiele, et al., 2017) and long-blade weapons (i.e. Hošek and Haramza, 2018; Žákovský, Hošek and Bárta, 2013).

Following a similar methodology, the objective of this study is to present the results of archaeometric analyses, including OM, SEM-EDS, and microhardness tests, performed on 12 medieval knives recovered from Kinet Höyük, and to interpret these findings from a shape and function perspective. After presenting the location of the archaeological site, its history, and the significance of the region in terms of iron mining and smithing, the knives are described, including their shapes, dimensions, and distinctive elements such as their hilts. Analytical results include metallography examinations of samples that reveal the materials used, production methods, and thermal-mechanical treatments applied to the knives from Kinet Höyük. The discussion section of the study focuses on the metallurgical knowledge and skills of the craftsmen who made these knives, the constraints affecting their material and technical preferences, and the relationship between the material characteristics of these knives and their shapes and functions.

History and geography of medieval Kinet Höyük

The archaeological site of Kinet Höyük (ancient Issos) is located in Cilicia on a narrow corridor between the seacoast of the Eastern Mediterranean and the Amanos Mountains (Nur Dağları) (Figure 2). Excavations conducted at Kinet Höyük between 1992 and 2012 by a scientific team led by Prof. Marie-Henriette Gates from

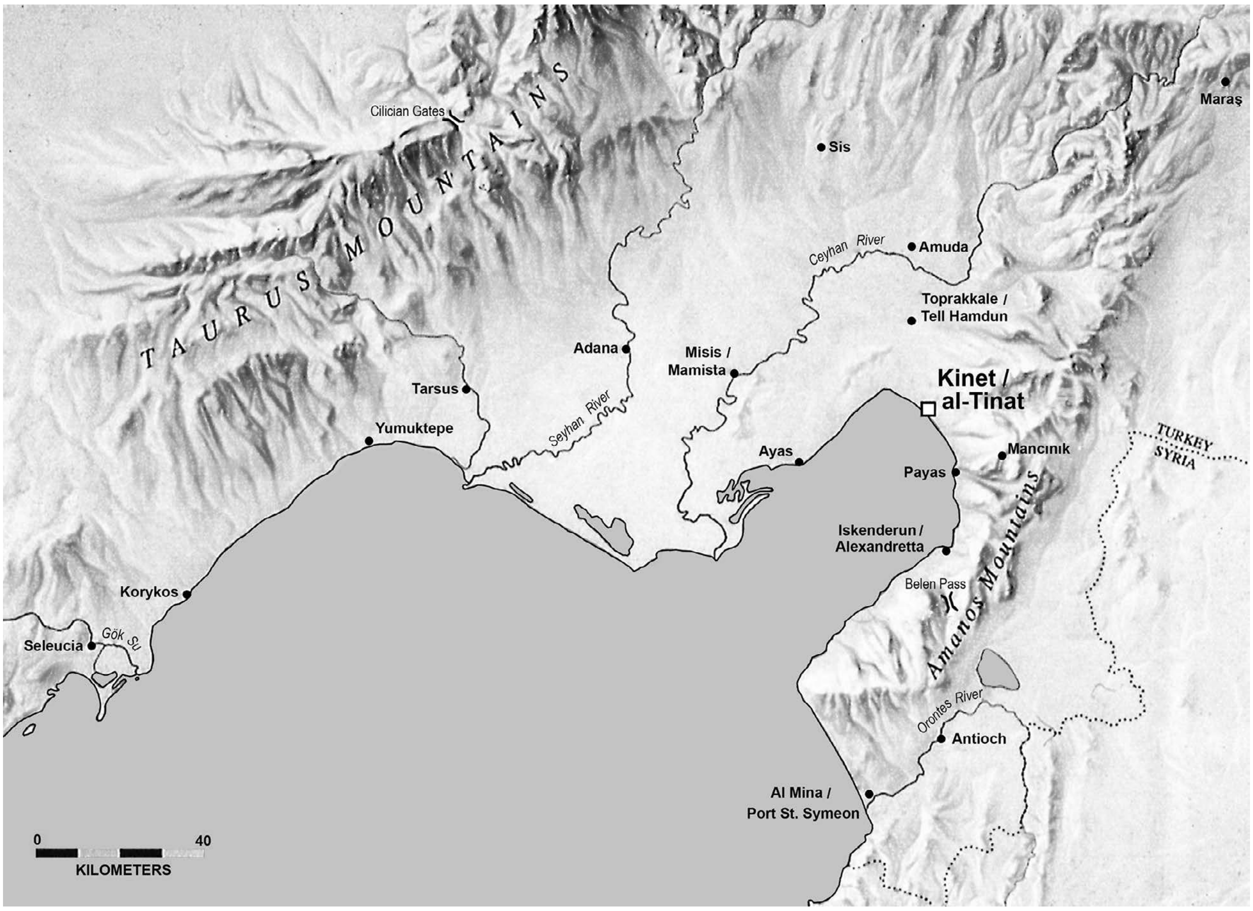


Figure 2. The location of the site of Kinet Höyük (Kinet/al Tinat) can be seen on this map of the northeastern corner of the Mediterranean. The site was referred to as al-Tinat by Arabic chronicles of the 13th and 14th centuries. Map with permission of Redford, et al., 2001.

Bilkent University, Ankara, revealed 29 occupation phases[1]. Due to its strategic location with access to both maritime and land routes, as well as the availability of rich mining and forestry resources, Kinet Höyük hosted successive settlements, the earliest dating back to the Early Bronze Age and continuing through the late Hellenistic Period (Gates, 2013). For over a millennium, the mound of Kinet was abandoned before being reinvested in the twelfth century. This was in keeping with the trend of fortified settlements being built upon mounds during this period in the region. A port that could accommodate maritime trade and the Deli Çay, a nearby stream, which probably served as a transport route for carrying lumber from the Amanos Mountains to the mound, must have inspired the medieval settlers to invest the mound again (Redford, et al., 2001). Strategic concerns must have also been considered, as the major commercial and military road linking Anatolia and Syria through Cilicia passed close to Kinet Höyük.

It is believed that the driving force of the local industry contributed to the development of a thriving economy in medieval Kinet, with products such as iron implements, glazed ceramics, and foodstuffs exported from the port. Although logs were not found in the archaeological record, sources of the time mention the site as a port exporting timber. As evidenced by ceramic finds imported from the Aegean, Cyprus, Italy, and inland Syria, the medieval inhabitants of Kinet were successfully integrated into international maritime trade networks as well.

Medieval habitation at Kinet (from the 12th until the beginning of the 14th century) can be divided into four primary phases, all of which ended with a destructive fire, with the exception of the first. The first medieval inhabitants reused the foundations of earlier levels. Initially, the site was settled in an organized and methodical way around the beginning of the 12th century. One of the most remarkable features of the first phase (Phase 1) is an ironmongery recovered on the northern edge of the top of the mound (Operations G and G2). Some pits full of iron slag, a stone pavement which was covered with smithing residues (spheroidal hammer scales, corroded metal, etc.), and pyrotechnic features in Operation G2 might be interpreted as evidence of a small-scale industrial workshop rather than a simple smithy. Other than smithing slags, iron finds that would provide insight into iron production during Phase 1 are rare, since it is likely that the inhabitants of this first settlement had sufficient time to gather all of their valuable items before abandoning the site. Phases 2 and 3 involved the construction of casemate defensive walls encircling the mound. Consequently, the mound top was fortified, possibly housing a garrison. Furthermore, recovered coins identify Phase 2 with the Principality of Antioch, and historical factors connect it with the protectors of this territory by the middle of the twelfth century, the Frankish military order of the Knights Templar. In spite of the difficulties with identifying the exact origin of the settlers of Phase 3, its onset coincides with the start of the reign of the first Armenian Cilician king, Levon I – at the turn of 12th/13th century. The eastern terraces of the mound (Operation K2) contained evidence of iron smithing and ceramic production during Phase 3. This side of the mound, sheltered by the mound from the prevailing sea breezes, yielded a large quantity of slags; however, no pyrotechnic features related to ironworking were recovered, unlike Operation G2 of Phase 1. Following the sacking of the site, which marked the end of Phase 3, the site became a domestic settlement with a village-like appearance. Iron smithing and ceramic production continued at the site, as indicated by smithing slags found on the eastern terrace, until it was burned and abandoned sometime in the first decades of the 14th century. The knives examined in this study are among the finds recovered in Kinet Höyük's Phases 3 and 4 which are associated with the rise of the Kingdom of Armenian Cilicia (and its fall in the region). The majority of the knives were found on the eastern terrace, where ironworking activities during these periods were concentrated.

Iron mining and metallurgy in the region

According to ancient sources, the Cilicia region, where Kinet Höyük is located, played a significant role in the history of iron mining and metallurgy since the early stages. It is highly likely that the iron smelting activities described in the famous Kizzuwatna letter, which is regarded as proof that the Hittite Empire monopolized iron production (Yalçın, 2005), were conducted somewhere in Cilicia. A previous archaeometry study of the finds from Kinet Höyük documented evidence of iron smithing at the site during the Iron Age (Güder, Gates and Yalçın, 2017). This detailed analysis revealed that Kinet's ironsmiths appreciated the heterogeneity of the material and successfully adapted the thermal and mechanical processes available in this period. In this sense, they were part of a broad community of contemporary craftsmen with a common level of technological expertise.

Similarly, the treaty of 1285 between Mamluk Sultan Qalawun and King Leon III of Armenian Cilicia demonstrates the region's importance on the medieval iron metallurgy scene. As part of this agreement, the Kings of Armenian Cilicia agreed to furnish 10,000 iron plates (i.e. horseshoes with their nails) annually to the Mamluks (Redford, et al., 2001). Hence, the medieval population of the region was not only capable of operating the existing iron deposits, but also of processing the iron in large scale obtained by smelting the ores. Specifically, the ironmongeries of Kinet, bearing the traces of intensive metallurgical activity especially during the first phase of medieval Kinet, illustrate the relevance of iron smithing in the region as an economic driver (Redford, 2012).

According to mining research, iron-rich metallogenic zones are located between the western slopes of the Amanos Mountains and the coastal zone (Engin, 2002). The nearest known ore occurrence to Kinet is in Payas-İslahiye region, approximately 10 km to the south. The deposit type of Payas was identified as iron-rich bauxite, which is seen as having no economic value for today's steel industry because of its high alumina and silica content (Tuncer, Altınova and Yıldız, 2001). Yet, according to recent research conducted in the Payas region, pure iron ore, reddish-blue oxide lenses (hematite), can be found embedded within the bauxites (Öztürk, et al., 2021). The mining capacity of the past cannot be compared to the large scale of today's industrial production. Resources that are not considered exploitable today may have been utilized efficiently in the medieval period. Consequently, the iron oxide formations of Payas may have been identified based on their distinctive color and used for iron production. Payas was not the only option for mining in the past, since the Amanos Mountains also contain similar occurrences of limonite and goethite, which result from the oxidation of long pyrite veins (pers. comm. Prof. Özdemir). To determine exactly which iron sources were used by the Kinet blacksmith forges from the Iron Age onwards, further archaeometallurgy studies are required. A research project focused on the determination of the isotopic ratios of Osmium in slag, tool and ore samples from the archaeological contexts in the region is currently underway.

Material

The majority of the medieval iron artifacts found at Kinet Höyük were heavily corroded due to the humid climate of the region. In the study, we selected 12 knives from those that were not damaged by corrosion to the

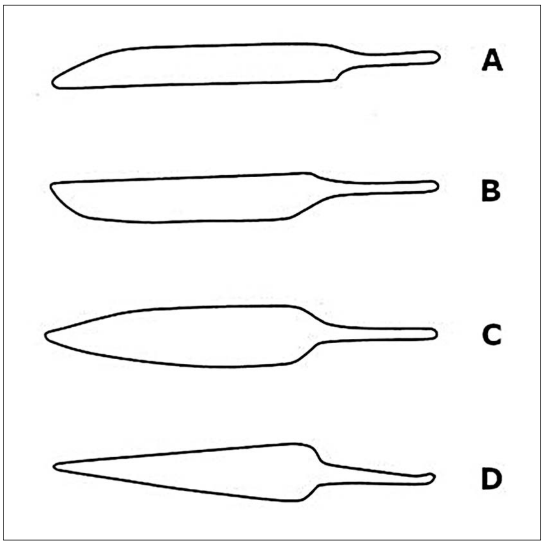
Figure 3. a) KT 13597 is a spear blade. b) Side view of KT11992 shows how the hilt plate was formed. Photos: Ü. Güder.

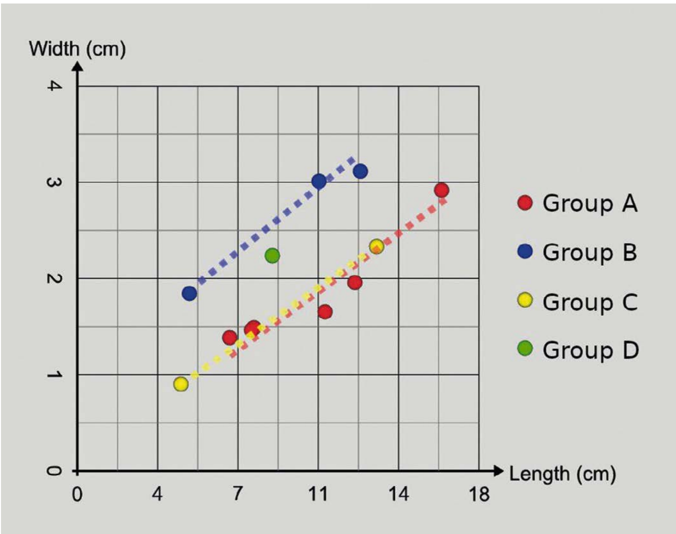
extent that their type and size could not be determined (Figure 3a). Blade sections of those knives survived in various lengths, ranging from 5 cm to 16 cm. Nearly all of the tang sections of the knives were intact. They were mostly identified as whittle tangs that were inserted into wood or bone handles without the need for rivets. Hilt plates were discovered on three knives (KT 9401, KT 10363 and KT 11992). One example is the hilt plate of KT 11992, which was formed by forging a thick iron rod around the back part of the blade (Figure 3b).

Kinet knives can be divided into four main groups based on the relationship between the back and the cutting edge (Figure 4). With Group A, the cutting edges are slightly curved before rising to a point. However, the blade backs of these knives are straight. In addition, the tip point lies on the same axis with the blade back. Knives of Group B have a blade back that is parallel to their straight cutting edge. The blade back angles down to meet the cutting edge at the tip. Group C blades are characterized by their parallel back and cutting edges, which taper toward the tip. This group of knives has tips aligned with the central axis. As the spear blade (KT 13597) is of a special form, it is placed in Group D, which can be identified by having equally tapering edges to its tip.

Within each group, the ratios between maximum width and length of the blades show a correlation (Graph 1). Knives of Group B have proportionally wider blades than those from the other groups. While the trend lines of Group A and Group C are similar, the only member of Group D sits between Group B and Group A and C. This separation provides clues about the intended use of the knives. Generally, wear and sharpening losses were observed with most Group B knives, which might have been used for food preparation or daily use. Small Group A and C knives, on the other hand, might have been used to assist with eating. It is apparent from the distinctive shape of Group D that it was manufactured for military purposes.

Figure 4. Simplified drawings of knife design groups (left). Group A: KT 7594, KT 9570, KT 10363, KT 13596, KT 18027, KT 18028. Group B: KT 9401, KT 11992, KT 16482. Group C: KT 7351, KT 22446. Group D: KT 13597.
Graph 1. The graph shows the proportions of blade length versus maximum width (right). Graphics: Ü. Güder.





Sampling techniques and analytical procedures

A rotary tool equipped with air-cooled diamond discs was used to cut metallography samples from all the objects. Low rotational speeds were used for the cutting process to prevent any distortion of microstructures due to heat generation. Samples were taken from both the blades and the tangs of the knives, whenever possible. From the blades, a slice was taken to be able to observe the entire cross section. Wet silicon carbide papers with grit sizes ranging from 240 to 1200 were used to grind the samples, which were mounted in epoxy resin. The final preparation stage involved polishing the samples with diamond pastes of 6, 3 and 1 micron particles, respectively.

We observed samples at different magnifications under a light microscope, a Nikon E-Pol 200, before and after etching them with 1 % Nital etchant. Micro-hardness measurements were conducted using the Vickers method on an HV-1000Z model hardness tester of Pace Technologies. For the purpose of testing the precision of the device, we measured two standard samples (with 468 and 712 HV0.2 hardness) by using 200 and 500 grams load that showed a maximum of 4 % error rate. While mainly 200 grams were used during the measurement of sample hardnesses, for hard structures, such as martensite, a 500 grams load was occasionally used. For each sample, the micro-indenter was positioned on at least five uncorroded and slag inclusion-free areas. We used a Zeiss Sigma 500 scanning electron microscope (SEM) to identify microstructures that were not clearly visible under a light microscope. Additionally, we measured the chemical composition of bulk metal and inclusions for KT 9401 with an EDAX energy dispersive X-ray spectrometry (EDS) instrument attached to an SEM. The chemical composition measurements were processed by the APEX software.

Analytical results

Table 1 summarizes the results of metallography analysis and micro-hardness tests conducted on knives. The results are explained in detail based on the manufacture types.

Manufacture Type 0

In addition to having a heterogeneous composition of low carbon steel and predominantly iron (ferrite) structures, the wrought iron contains several slag inclusions. This characteristic feature corresponds to the microstructural features identified in KT 13596. The entire cross-section displays similar structural features, indicating that no special treatment was applied to the cutting edge. At the cutting edge, equiaxed ferrite grains and a few fine-sized pearlite microstructures between them were observed (Figures 5a and b). Microstructural observations were consistent with the hardness mea-

Table 1. General overview of the results of the analysis of the knives

Manufacture type	Find code	Notes on microstructures	Min-max hardness	Average hardness
			(HV0.2 or HV0.5)	
Type 0	KT 13596	Ferrite	138.9 - 168.4	152.3
Type 1	KT 7594	Quenched – Martensite	556.6 - 736.7	648.9
	KT 9401	Fine Pearlite + Martensite (cutting edge was quenched) crucible steel	236.3 - 975.4	375.4
	KT 18028	Tempered Martensite	205.4 - 262	220.2
	KT 22446	Tempered Martensite	147 - 158	152
Type 2	KT 9570	Ferrite + Pearlite + Martensite	148 - 442.9	253.4
	KT 10363	Ferrite + Pearlite + Martensite	102 - 291.2	262
Type 3	KT 7351	Ferrite + Pearlite + Martensite (cutting edge was quenched)	131.8 - 846	285.7
	KT 16482	Ferrite + Pearlite + Martensite (cutting edge was quenched)	111.7 - 753.4	205.3
	KT 18027	Ferrite + Pearlite (cutting edge is missing)	92.7 - 160.2	122.6
Type 4	KT 13597	Fine Pearlite (the middle layer) + Ferrite	181.7 - 244.7	198.6
	KT 11992	Ferrite + Pearlite + Martensite (cutting edge was quenched)	129 - 196	166

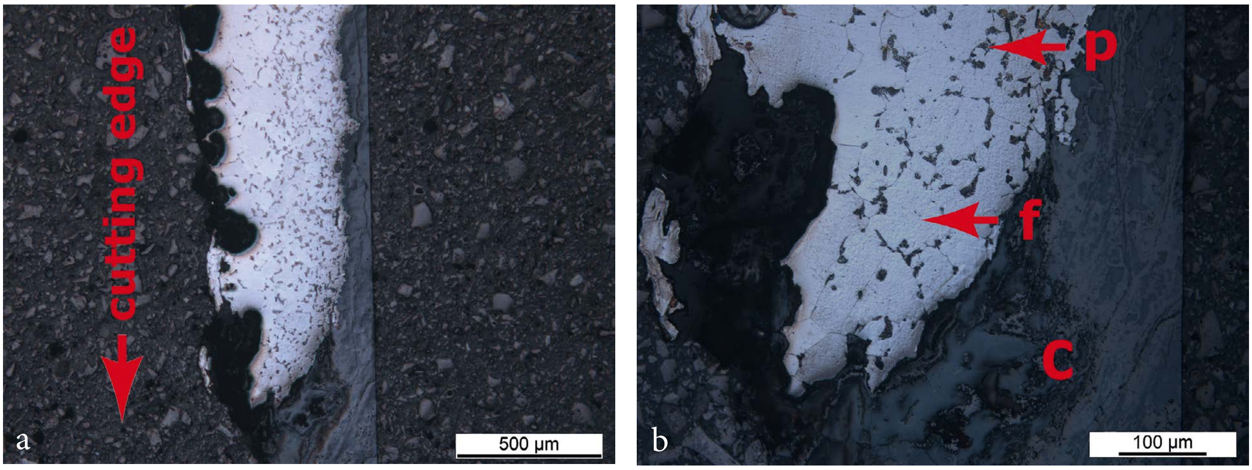


Figure 5 (a and b). Equiaxed ferrite grains (f) dominate the microstructure at the cutting edge of KT 13596. Additionally, small pearlite grains (p) at the grain boundaries were observed. A thick corrosion layer (c) surrounds the sample. The sample represents a typical wrought iron material. Photos: Ü. Güder.

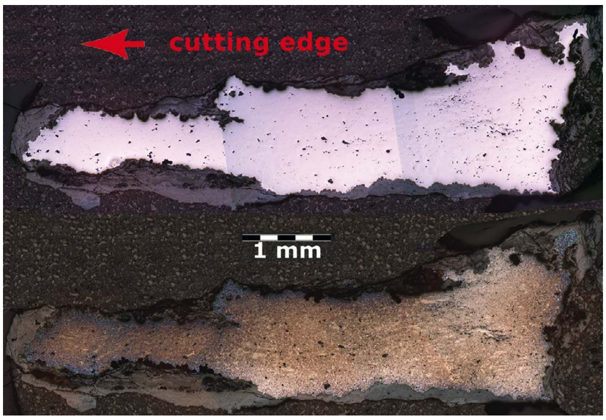
surement, which indicated a low hardness of around 140 HV0.2 at the cutting edge.

Manufacture Type 1

In the course of the light microscope examination of the samples taken from the knife KT 22446, microstructures of medium-carbon steel were observed both at the cutting edge and at the back of the cross-section (Figure 6). The amount of carbon appears to decrease at the sides close to the back, however the overall microstructural distribution can be assessed as homogeneous. A large number of slag inclusions and porosities were observed all over the sample, which indicates that the material was poorly refined.

Since light microscopy alone was not sufficient for identifying the microstructural composition of the samples from KT 22446, images with higher magnification were obtained by scanning electron microscopy (SEM). SEM images indicate some fine pearlite localized areas, semi-globular cementite blocks, and small cementite particles (spheroidized) in the ferrite matrix (Figure 7a). Pearlite structures in this microstructure may have degraded as a result of the tool being exposed to the blacksmith's forge for an extended period during the forging process. However, martensite may also take this form because of excessive tempering. The purpose of tempering is to reduce the stress in the martensitic structure in order to prevent brittleness. As brittleness decreases, so may hardness. However, the material's hardness was measured throughout the entire cross-section of this sample between 147 - 158 HV0.2. These values obtained also from the cutting edge indicate that the material was too soft to serve as a functional knife. Accordingly, it is highly likely that it was exposed to heat unintentionally, resulting in the alteration of its original microstructure. This hypothesis is supported by archaeological data, since in the daily reports of the excavation it was mentioned that the object was found in an ash layer within the remains of a domestic hearth structure in 2005. In its original state, possibly, this knife was martensite throughout the entire cross-section prior to this unintentional heat treatment.

Figure 6. With the unetched sample of the cross-section from KT 22446 (top), various slag inclusions are visible. The image from the nital-etched version of the same sample (bottom) demonstrates the steel microstructures. Photo: Ü. Güder.



Furthermore, KT 18028 also shows micro-structural constituents that are likely to be related to over-tempered martensite (Figure 7b). Another knife (KT 7594) supports the interpretation that knives (KT 22446 and KT 18028) were originally martensitic and were unintentionally over-tempered. The microstructure of KT 7594 was found to be martensite throughout the cross section (Figure 8). Thus, it appears that it survived with-

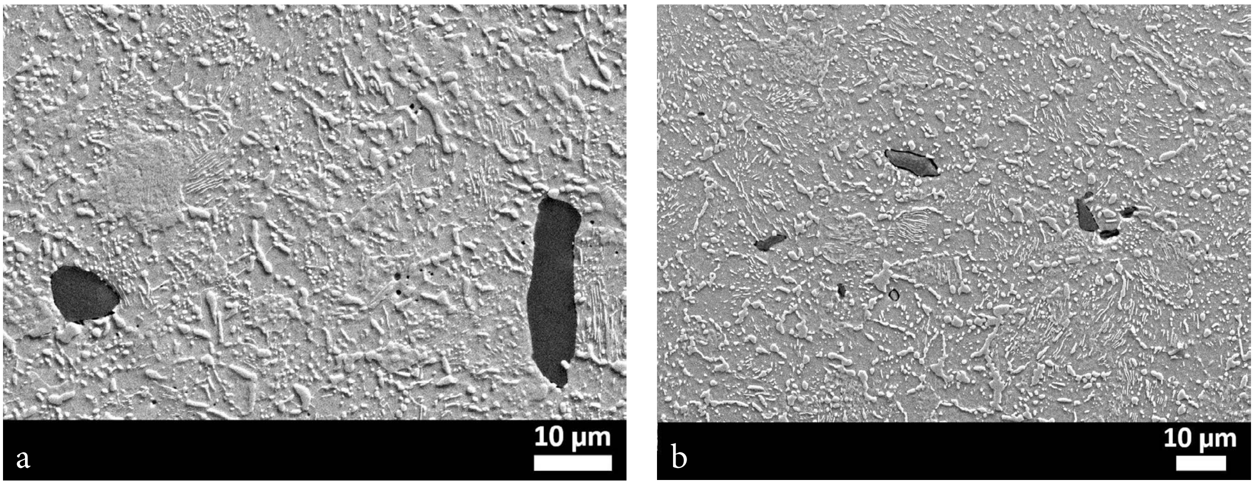


Figure 7. a) An SEM image of sample KT 22446 demonstrates microstructural characteristics (cementite blocks and spheroidized cementite) that resemble over-tempered martensite (left). b) An identical microstructural composition can also be observed with a SEM image of KT 18028 (right). Photos: Ü. Güder.

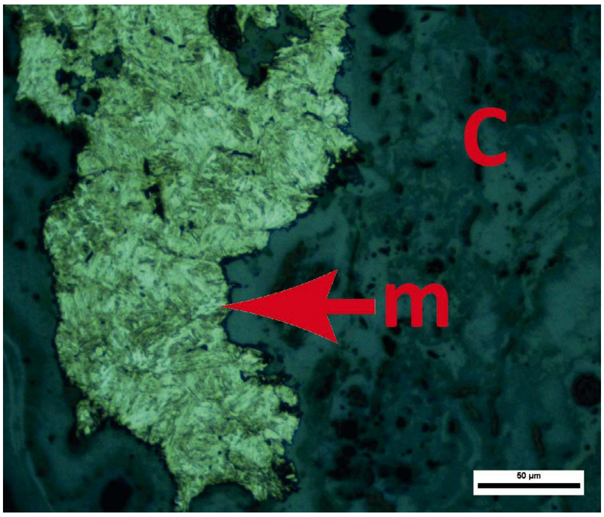


Figure 8. Lath martensite (m) in association with corrosion (C) in KT 7594. Photo: Ü. Güder.

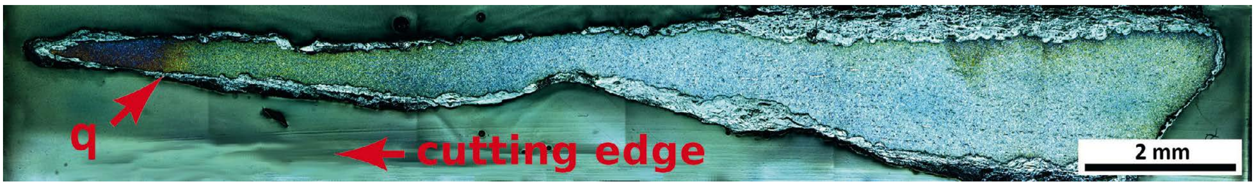
out being exposed to fire. According to the light-microscope images, the type of micro-structure was identified as lath martensite, and the material was characterized as medium-carbon steel. Hardness values range from 556.6 to 736.7 HV0.2.

KT 9401 is another knife manufactured from one type of steel. However, it shows a number of distinctive characteristics in comparison to other knives. Firstly, as can be seen from the cross-section image (Figure 9), quenching was limited to the cutting edge only. This selective quenching procedure allowed for hardening at the cutting edge while protecting the overall durability of the knife. This technique offered the blacksmith the option of forging a wider shape (Group B) than the full martensitic Group A blades.

The light microscope could not differentiate the micro-constituents of the structure, apart from a mottled pattern displayed in lighter elongated areas against a darker background (Figure 10a). SEM analysis revealed that the cutting edge and back of the blade show different microstructural compositions (Figures 10b and c). Additionally, a mixture of both microstructural constituents was observed in the transition zone between these two sections (marked with q in Figure 9 and shown in Figure 10d). The microstructural composition of the back part of the blade was characterized by exceptionally fine pearlite, small amounts of spheroidized carbides, and pro-eutectoid cementite along the edges of pearlite grains, which are indicative of hypereutectoid steel compositions (over 0.8 %) (Figure 10b).

While hardness ranges from 230 to 270 HV0.2 in most parts of the cross-section, it increases significantly to

Figure 9. The etched sample illustrates the cross-section of blade KT 9401. There is a visible quenching border at the cutting edge (q), due to the color change of the microstructures. Photo: Ü. Güder.



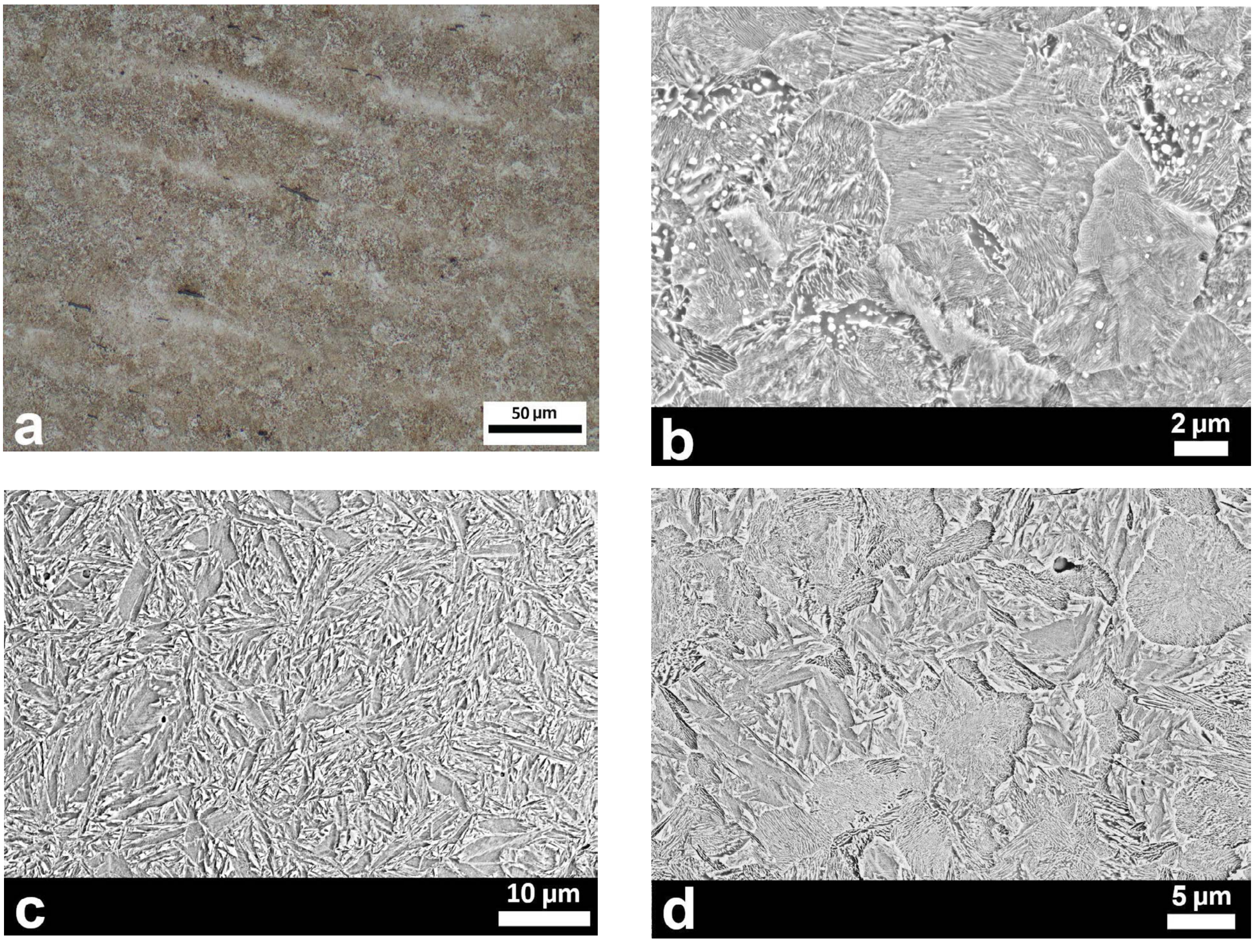


Figure 10. a) A mottled pattern is evident in the light microscopy image of KT 9401. b) An SEM analysis of the location corresponding to the back of the same blade reveals densely packed lamellar structures of fine pearlite grains. c) The cutting edge of the blade displays a mixture of lath and plate martensite. d) There are pearlite nodules together with martensite within the transition zone. Photos: Ü. Güder.

975 HV0.5 at the tip where quenching was applied. Regarding plain carbon steels, it appears that the martensite region of the cutting edge shows a high degree of hardness.

Based on the results of the OM, SEM examination and micro-hardness testing, the knife KT 9401 shows a remarkable homogeneity, clean microstructure, and high degree of hardness at the cutting edge. Similar microstructures were observed throughout the cross section of the blade, except the cutting edge. Moreover, very few inclusions were detected. In addition, the fine craftsmanship employed for the manufacturing process is evident from the hilt of the knife (Figure 11). As indicated by the knife's extended whittle tang and wear loss at the cutting edge, it might have been used daily.

Figure 11. KT 9401 with intact whittle tang. Photo: Ü. Güder.

Table 2. Average chemical compositions of bulk metal and inclusions in KT9401 as determined by EDS measurements.

	Si %	Mn %	Fe %	
Metal composition (average)	0.8	1.0	98.2	
	Si %	**S %**	**Mn %**	**Fe %**
Inclusion composition (average)	0.2	27.5	51.7	20.6

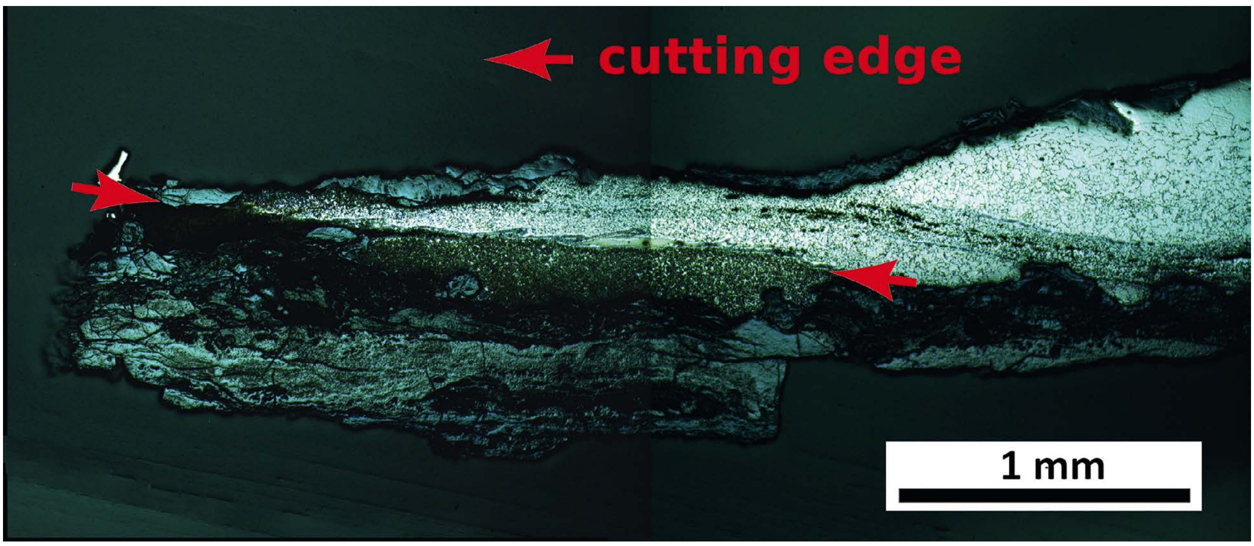
The chemical compositions of metal and inclusions within KT 9401 were measured using the EDS attachment of the SEM in order to gain a detailed understanding of its properties. The results of the EDS analysis revealed that the steel contained approximately 1 % manganese as an alloying element. Additionally, the inclusions were characterized as manganese sulphide (Table 2). With bloomery iron, manganese levels are generally not expected to exceed 0.50 % (Rostoker and Bronson, 1990). As an alternative, a higher amount of manganese containing steel alloys can be produced via crucible steel technique. Historically, some crucible steel recipes contain inorganic substances including manganese oxide (Said, 1989). The type and amount of manganese added to the crucible charge were, among others, identified in the small-scale medieval crucible steel production workshop discovered in Kubadabad (Güder, et al., 2022). Additionally, metallographic studies of crucible steel have revealed objects with a mottled appearance, similar to those observed in the examination of KT 9401, shown in Figure 10a (Lang, Craddock and Simpson, 1998, p.9; Allan and Gilmour, 2000; Feuerbach, 2006, p.14).

Manufacture Type 2

Forge-welding is a process that involves forging hot metal parts one above each other that are intended to be joined together. Metal parts need to be heated above a normal forging temperature prior to welding, and the ideal temperature for forge welding depends on the carbon content of the metals. Since iron and steel parts have different carbon ratios, adjusting the welding temperature required experience (Pleiner, 2006, p.59). Additionally, sand was thrown onto the surfaces to prevent excessive oxidation, since a good bond requires a clean surface between the welded parts. Due to the high temperatures and use of fluxing sand with forge welding, ironworking residues called hammer scales were produced with some unique characteristics (Dungworth and Wilkes, 2009, p.35). Hammer scales were formed as flakes during forging, but they took on a spherical appearance and a slaggy composition during welding, accumulating on the ground together with corroded smithing materials around the anvils (Bayley, Dungsworth and Paynter, 2001, p.14). From medieval Kinet, a Phase 1 stone pavement covered with congealed spheroidal hammer scales must be related to such high temperature smithy operations. Among the knives examined in this study, including the Type 2 examples, forge-welding was evident with more than half of them. As a consequence, such advanced smithing techniques may have existed not only during Phase 1 but also during other medieval phases.

Knives of Type 2, known as scarf-welded knives, are manufactured by forge-welding steel only to the cutting edge of the blade. Forge-welding opposing tapering ends of the steel and wrought iron parts creates an inclined

Figure 12. The beginning and end of the forge welding line, which shows the interface between steel and wrought iron at the cutting edge of the blade KT 9570, are indicated by two red arrows. Photo: Ü. Güder.



welding line in the cross-section. With the examinations of two Kinet Höyük knives (KT 9570 and KT 10363), a thin layer of steel was observed on the cutting edges of both knives. A microscope image in Figure 12 shows the steel part at the cutting edge of KT 9570 as well as a clearly visible welding line. The microstructure of steel appears darker at the end of the cutting edge, as a result of intense martensite transformation. These observations indicate that the blade was only quenched along the edge.

Manufacture Type 3

An excellent example of Type 3 production is KT 7351, in the case of which a thick layer of steel was welded onto one flank of the wrought iron section. Images from the light microscopy examination of KT 7351 illustrate how this technique was applied. Towards the back of the blade, in the cross-section, pearlite grains can be identified adjacent to the wrought iron (Figure 13a). On the other hand, through the cutting-edge pearlite changes into martensite, which means selective quenching took place (Figure 13b). It appears that the welding process was relatively high-quality, as the welding line can be barely seen. The hardness varies depending on the location at the cross-section: 150 HV0.2 was measured with the wrought-iron section, 260 HV0.2 in the pearlite region, and over 700 HV0.5 with the cutting edge.

A knife like KT 7351 was manufactured in this way because the size of this knife is almost double that of a Type 1 knife. It was therefore more economical to produce the knife using less steel. Additionally, this type of knife could be sharpened multiple times because the steel layer extends longer into the cross-section of the blade. It was, of course, necessary to quench the knife again after sharpening.

Manufacture Type 4

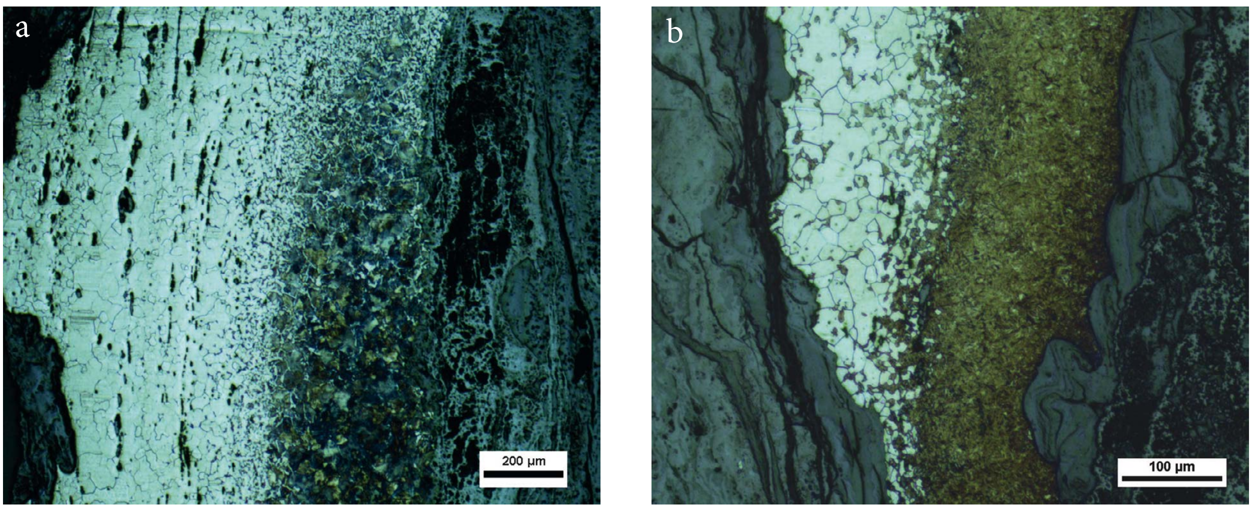
The metallography of the spear blade (KT 13597) revealed fine pearlite structures in the middle of the cross-section, as well as acicular ferrite structures on both sides (Figure 14a).

The microstructure of the object suggests that it was manufactured in the style of a sandwich, that is, a layer of medium carbon steel was placed between layers of wrought iron. The manufacturing process involved forge-welding a steel strip onto a wrought-iron strip, then folding it over the steel side.

Considering that the sample was taken somewhere in the center of the blade and that the material at the edges had been corroded, no hardening treatment could be detected. The measured hardness ranged between 181.7 and 244.7 HV0.2. Given its function, it is likely that this spear blade was quenched at least at the tip, in order to improve its penetration capability.

When the forge-welding was done correctly, the Type 4 manufacturing technique offered exceptional results. In other cases, oxidizing products or voids could develop in the structure, affecting drastically the knife's mechanical properties. The other Type 4 blade KT 11992 illustrates this risk very well. It appears that the crack which propagated along a welding line happened as a result of thermal shock during quenching (Figure 14b). However, as indicated by the wear and sharpening loss at the cutting edge, this fault did not cause any problems for the users.

Figure 13. a) Microscope image shows the back part of the cross-section of KT 7351: the light portion represents ferrite and slag inclusion stringers - wrought iron, the darker portion represents pearlitic steel (left). b) Transformation of pearlite to martensite (dark brown portion) at the cutting edge in the same sample (right). Photos: Ü. Güder.



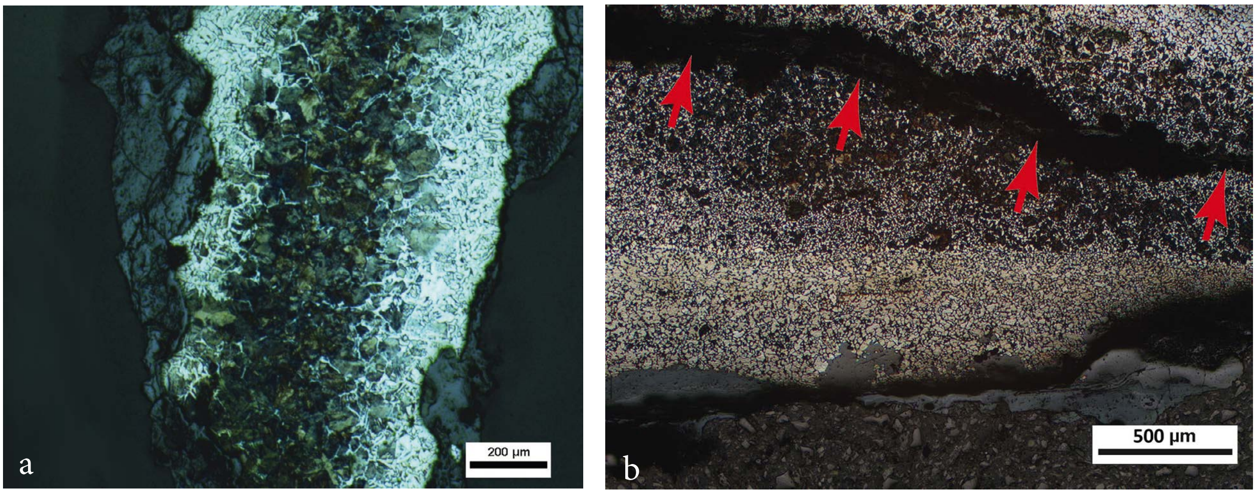


Figure 14. a) A thick steel layer in the middle surrounded by ferrite layers displays a sandwich cross-section with KT 13597 (left). b) Red arrows indicate the path of a crack which runs along the folding line in the steel portion in KT 11992 (right). Photos: Ü. Güder.

Discussion of the results

The analysis of 12 medieval knives from Kinet revealed a variety of different types of manufacturing techniques. Steel was used for the cutting edges of all knives, with the exception of one (KT 13596). The steel cutting edges of knives were obtained in four different ways. We have found that the most preferred production technique relies on the use of only mid-carbon steel (Type 1) for the complete blade and the application of heat-treatments; such as quenching and tempering. Knives made exclusively of steel were uncommon in medieval times. Based on the analysis of 12 medieval knives discovered during archaeological excavations in London, it was determined that although a wide range of manufacturing techniques were evident, none of the knives were entirely manufactured of steel (Cowgill, Neergaard and Griffiths, 2000, p.11). Similarly, only one of 19 Anglo-Saxon knives analyzed from medieval York was found to be made entirely of steel (Blakelock and McDonnell, 2007). Due to the contribution of steel to the edge performance and toughness, four Kinet knives (KT 7594, KT 9401, KT 18028 and KT 22446) can be considered to be of high quality. A further analysis was undertaken on one of them (KT 9401) which shows the highest hardness value at the cutting edge. We conclude that this knife was produced from crucible steel based on the chemical analysis revealing an unusual quantity of manganese as an alloying element in the structure and manganese sulphide inclusions. It should be noted that to date archaeological remains of historical crucible steel production centers have been recovered in Central Asia, Southern Iran and Southern Asia (Feuerbach, 1997; Wayman and Juleff, 1999; Rehren and Papachristou, 2000; Alipour and Rehren, 2015). Crucible steel knives and tools were extensively used in medieval Anatolia (Güder, Yavaş and Yalçın, 2015; Güder, Taşan and Yavaş, 2018; Yavaş, et al., 2018) and a crucible steel production workshop in Kubadabad in Central Anatolia has recently been discovered (Güder, et al., 2022). Despite the similarity in chemical composition between the Kinet Höyük knife (KT 9401) and Kubadabad crucible steel objects, there is a marked difference in microstructure. Possibly, this difference is due to the variations in smithing techniques, indicating a distinct metalworking tradition. KT 9401 stands out from other knives from Kinet Höyük, due to its exceptional material and distinctive design. It was therefore likely to have been imported.

Three knives (KT 7351, KT 16482 and KT 18027) were found to be of Type 3 (with a layer of steel welded along one flank of the blade), whereas only two (KT 9570 and 10363) had been scarf-welded (Type 2). While using steel only at the cutting edge was the most economical and practical method for producing functional tools, there are relatively few examples of this type among Kinet knives. However, blades with a welded steel edge have been the most commonly encountered type from medieval British archaeological sites (Blakelock and McDonnell, 2007; Goodall, 2011). In addition, medieval Bohemian knives also exhibited primarily steel cutting edges and iron backs (Hošek, et al., 2007, p.281).

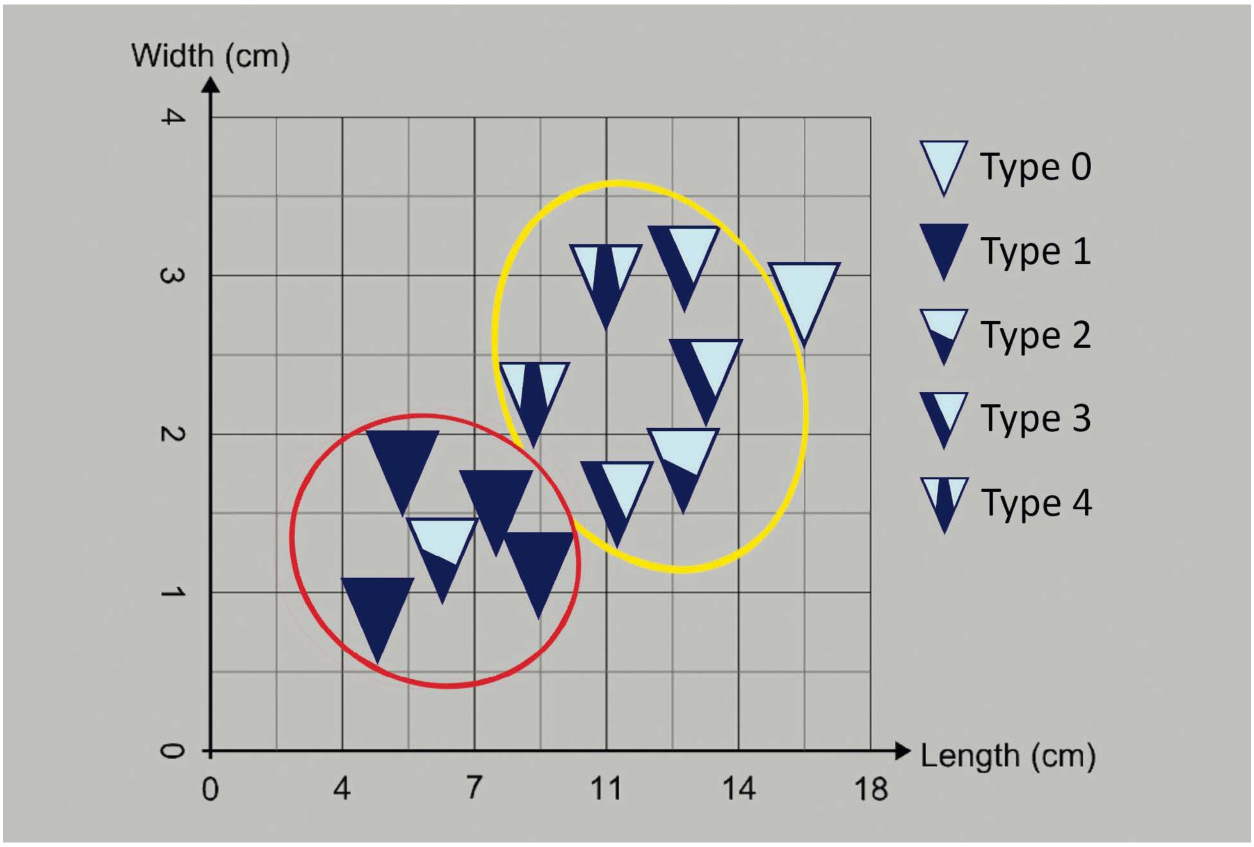
Core welding (Type 4) was employed with the production of a spear blade (KT 13597) and a knife with a thick hilt plate (KT 11992). Due to the fact that KT 11992 was recovered together with several armor piercing arrowheads, it may have belonged to the military occupants of Phase 3. The core-welding technique, which required expertise in smithing, provided a thick layer of steel in the middle of the cross-sections of blades and was used to produce blades that were strong and durable. Thus, the battle blades might have been better manufactured this way.

Aside from crucible steel, one of the manufacturing techniques used for luxury knives during the medieval period was pattern welding, which was not found with Kinet knives. In case of this technique different alloys, such as steel and phosphoric iron, were twisted together and welded into the blade. The final step consisted of polishing and etching dissimilar metals, providing a distinctive appearance of the surface of the blade. Phosphoric iron has been known by metalworkers since ancient times, but it was used for the manufacturing of small items, due to its hard but brittle character (Piaskowski, 1989). Due to the limited amount of phosphoric iron used for a pattern welded blade, the blade was not adversely affected by the material weaknesses associated with phosphoric iron. The analysis of several iron tools found in medieval Kinet revealed only one carpenter's adze made of phosphoric iron welded to wrought iron (to be published by Güder). Therefore, despite having access to phosphoric iron, medieval blacksmiths in Kinet preferred to use wrought iron and steel for their work. Moreover, pattern welding was not unknown in this region, since a pattern-welded knife dating from the 10th to the 11th century was found in Hisn al-Tinat, a fortified stronghold located approximately 500 meters to the north-east of Kinet Höyük (Güder, 2015). Due to the limited number of samples, we were unable to determine whether pattern-welding was performed at Kinet workshops.

Comparing manufacturing techniques and blade forms does not provide a correlation between the two characteristics. There are, for instance, one Type 0, two Type 1, two Type 2 and one Type 3 knife in Group A, which is the largest. Therefore, the design of the blades was not an influential factor for determining the method of manufacturing. Graph 2 indicates, however, that the size of a knife was the most important factor to consider when selecting a production method.

Out of the five knives shown in the red circle in Graph 2, four were produced using Type 1 manufacturing technique. These blades range in length from 4.6 to 7.9 cm, and in width from 0.9 to 1.8 cm. For three of the blades with a smaller width the entire blade was submerged in water during the quenching process. In the case of the crucible steel knife, the quenching medi-

Graph 2. Manufacturing methods of Kinet knives are shown in the length vs. maximum width graph. Graphics: Ü. Güder.



um was applied only to the cutting edge. It is likely that there are different reasons why steel was the only material used for the production of these knives and why different quenching techniques were employed. In the first instance, because martensite structures are extremely brittle, it was likely that relatively small dimensions were selected to minimize this risk. Additionally, as the size of the product decreases, techniques such as forge-welding become more challenging to control. Anatolian Seljuks possessed knives with blade lengths of less than 7 cm, which were manufactured with more advanced material designs; however, these knives were most probably the products of special workshops affiliated with the palace (Güder, Taşan and Yavaş, 2018). Since completely quenched Type 1 knives were not capable of performing heavy-duty tasks, this technique might have been used to manufacture tools with functions such as cutlery or shaving. Knives of this group were found in domestic structures, supporting the idea that they were used as household knives.

The Type 1 blade made of crucible steel, KT 9401, on the other hand, exhibited an extremely thin quenching line. This knife is therefore an exceptional example, due to its combination of both skilled craftsmanship and special material.

With slightly longer knives, indicated by the yellow circle in Graph 2 and ranging in size from 1.7 to 3.1 cm in width and 8.7 to 13.4 cm in length, different manufacturing techniques were observed. The manufacturing technique for these knives might have been determined by their function and the availability of materials. Most pieces of this group were produced according to Type 3 (a steel layer was welded to one side of the blade).

In the case of the largest knife, KT 13596, only wrought iron was used, possibly due to economic considerations. Furthermore, the majority of the large iron tools analyzed from medieval Kinet were made of wrought iron (to be published by Güder). Similar to KT 13596, no steel material was applied to the cutting edges of agricultural tools such as sickle blades, weed hooks and carpentry tools. Therefore, KT 13596 can be regarded as a simple tool designed for rough work, such as agricultural or carpentry tasks.

Conclusion

The current study provides new data concerning the metallurgical skills and practices of medieval blacksmiths in the Cilician area, which is well known for its strong metalworking traditions and abundant ore sources. This archaeometry research focused exclusively on knives, one of the most important group of metal finds, due to the variety of techniques and materials that were used to manufacture them. Analyses for material characterization were conducted with knives from Kinet Höyük, a multi-period harbor site in the northeastern corner of the Mediterranean. These knives were selected from Kinet Höyük's third and fourth medieval phases, which were dated between the second half of the thirteenth century and the beginning of the fourteenth century. Based on the results of the analytical study, a variety of manufacturing methods have been identified. Blacksmiths who forged the Kinet Höyük knives considered several factors, including the availability of materials and functionality, when determining the production method. In terms of their preferences, the dimensions of knives were more important than their shapes. Small knives made of steel alone, including crucible steel blades, can be classified as quality knives based on the characteristics of their cutting edges. Among the knives produced by forge welding steel and iron in numerous ways, it was observed that more advanced methods, such as core welding, were used for the tools considered to be part of the military items in the settlement. The difference in manufacturing methods between some exclusive blades (such as the spear blade and the crucible steel knife) and utilitarian knives might be indicative of an origin other than from local workshops for those blades.

Although this study has highlighted several interesting trends, additional studies on more knives are necessary to gain a better understanding of the knife making traditions of the period and geographical area. The number of studies conducted on the production of iron tools in medieval Anatolia is extremely rare. Therefore, even though this study covers a relatively small sample size, it intends to contribute comparable data for future research on medieval ironworking.

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Note

1 S. Redford served as a project associate focusing on the medieval period during the Kinet excavation project. Ü. Güder, as an archaeometallurgist, has analysed iron objects, slags, and remains of pyrometallurgical settings from the Kinet Höyük excavations.

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