Early iron objects of Southwest China: A case study of iron objects excavated from Qiaogoutou cemetery site, Sichuan Province

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Abstract: Iron objects excavated from the Qiaogoutou cemetery site provides an opportunity to study iron-making technology during the late Warring States period and the early Western Han dynasty in Southwest China. Five metallographic samples were prepared and analysed. The results are discussed in relation to other studies of iron objects discovered in Southwest China.

Keywords: Iron object analyses; early Han dynasty; Qiaogoutou cemetery site; Southwest China.

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Introduction

The aim of this paper is to understand the early iron-making technology of Southwest China through the metallographic study of the excavated iron objects from Qiaogoutou. The result is compared with other early iron objects discovered in Southwest China to generate discussion on the origin and development of the iron objects of Qiaogoutou. It addresses the gaps left by the limited previous metallurgical studies of early iron objects of Southwest China.

According to archaeological discoveries, cast iron and steel making technologies were established and consolidated in China in the Warring States period (475-221BCE) and the Qin (221-206BCE) and Han dynasties (206BCE-220CE), when iron and steel products were used in many areas (Bai 2005, 116; Han and Ke 2007, 440; Wagner 2007, 115).

Southwest China was a separate region distinct from the Central Plain before the Qin conquest of China (221BCE). It was the territory of the Ba, Shu, Dian, Bo, Yelang, and Julan states. Its cultural and technological developments lagged behind but were influenced by the powerful states of the Central Plain. The Qin state conquered the Ba and Shu states in 316BCE, and brought advanced agricultural technology to develop the area so that it could supply its strategic needs. In *Shiji*[1], it records that the Qin forced the ancestors of the *Zhuo* family, smelters from the north of China, to move to Shu when Qin conquered the Zhao state in 222BCE (SiMa 1982, 3277; cf. Wagner 2007, 140-144). This suggests that there was a close connection in both cultural exchange and technology development between Southwest China and the Central Plain during the Warring States period and the Qin and Han dynasties.

In the published excavation reports, there are over 5,100 iron objects excavated from Southwest China of all periods, and 2,490 of these are from over 130 sites dated before 200CE. In the past decade, 75 iron smelting related sites and locations in the Chengdu plain and Chongqing area have been surveyed or reinvestigated, and 5 among these have been systematically excavated (Ma 2011).

However, the scientific analysis and study of excavated iron objects from Southwest China have been limited in comparison with the analysis of material from the Central Plain and northern areas, for example the Mancheng Han tomb (Lu et al. 1980, 369-389), tomb 44 of Yanxiadu (Anonymous 1975), Dabaotai Han tomb (Beijing 1989), and the Dongheishan site (Liu et al. 2014). The location of the

[1] 'Records of the historian', by SiMa Qian, who died 90BCE. This great book tells the history of the known world from mythical beginnings to SiMa Qian's own time.

Qiaogoutou site during the Warring States period was near the border of both Shu and Bo states (southern Sichuan and northeast Yunnan provinces). The scientific analyses of its excavated iron objects can provide great value to the study of iron smelting technology of southwest China.

Qiaogoutou

The Qiaogoutou site is located in Yibin city, Sichuan province, China (***Fig. 1***). It is on the banks of the upper Yangtze River, about 290 km southeast from Chengdu. The site was discovered by the Sichuan Provincial Cultural Relics and Archaeology Research Institute during fieldwork associated with the construction project of the Xiangjiaba dam in 2006, 2007 and 2009 (Liu 2012). Part of the site, a total area of 2,650 m^2 cemetery, was excavated by the Sichuan University in 2011. The site was long occupied from the Neolithic to the Qing dynasty (1644-1912CE), and the primary remains are from the Warring States period (475-221BCE) to the Qin and Han dynasties (221BCE-220CE). There are 20 pit burials dating from the late Warring States to the early Han dynasty (ca.300-140BCE) which contained gravegoods consisting of assemblages of pottery, bronze and iron objects.

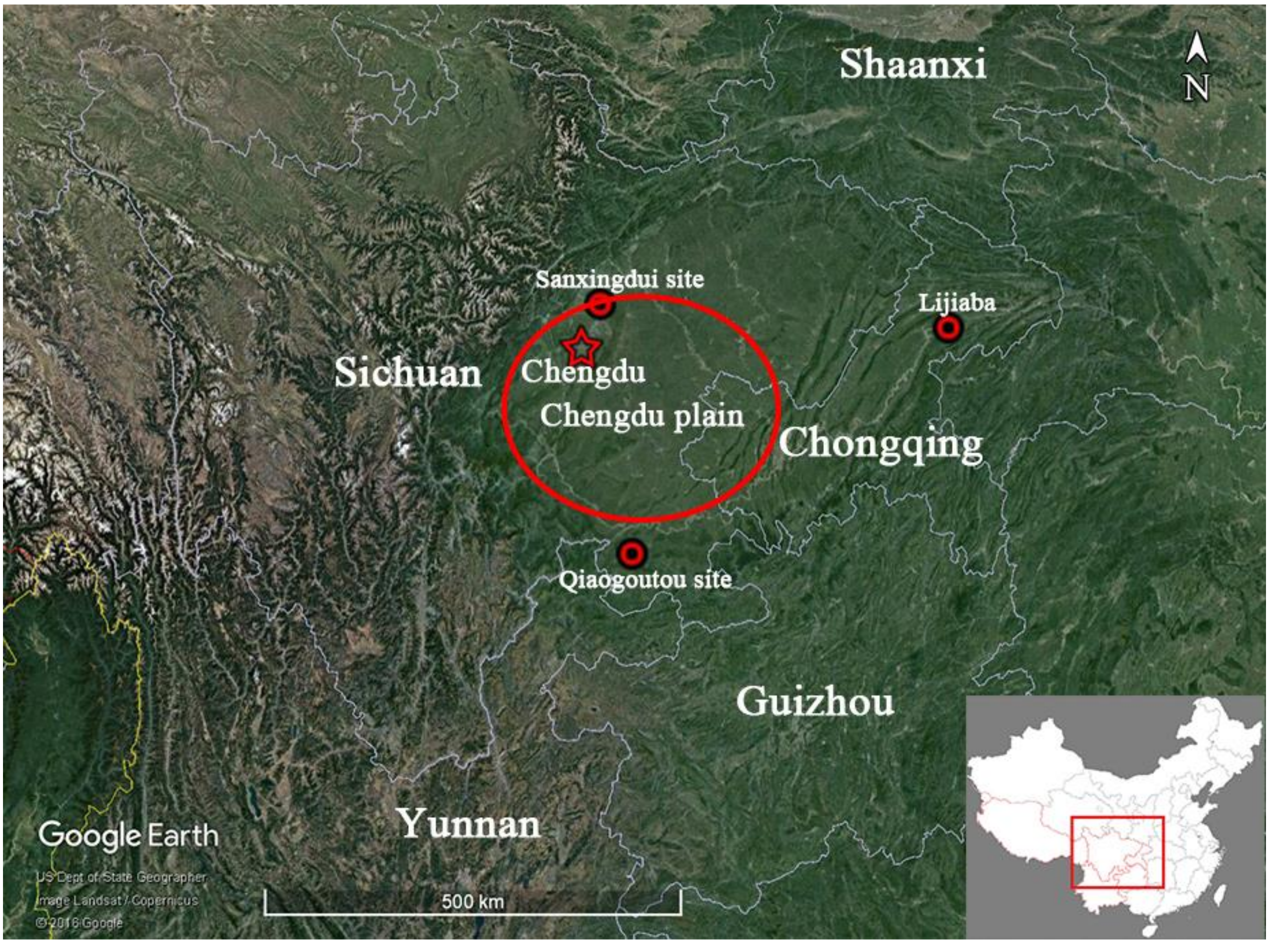

***Fig. 1** Location of the Qiaogoutou site*

A total of 52 iron objects were excavated from 17 tombs, including categories of domestic objects, weapons, tools, accessories and some unidentified (***Table 1***, ***Fig. 2***). Dating was based on the typical local ceramic assemblage and excavated bronze coins which were retrieved from almost every tomb. All the bronze coins were *Banliang* coins of the Qin state. '*Banliang*', a weight unit of 8g, these typical coins were circulated in the Qin state between 336-206BCE. The ceramics were dated as early as the late Warring States period to the mid-Western Han dynasty (400-140BCE, Liu 2013, 35-37). Bronze coins were discovered in every tomb in which iron objects were excavated. Therefore, the iron objects excavated from Qiaogoutou could be dated to 336-140BCE.

Table 1 ***Iron objects excavated from Qiaogoutou***

Category	**Type**	**Count**	**Percentage**
Domestic objects	*mou* (caldron)	2	*4%*
Weapons	sword	10	*27%*
	spearhead	4	
Tools	axehead	12	*46%*
	implement cap	8	
	sicklehead	2	
	knife	2	
Accessories	belt hook	1	*2%*
Others	unidentified	11	*21%*
	Total	**52**	

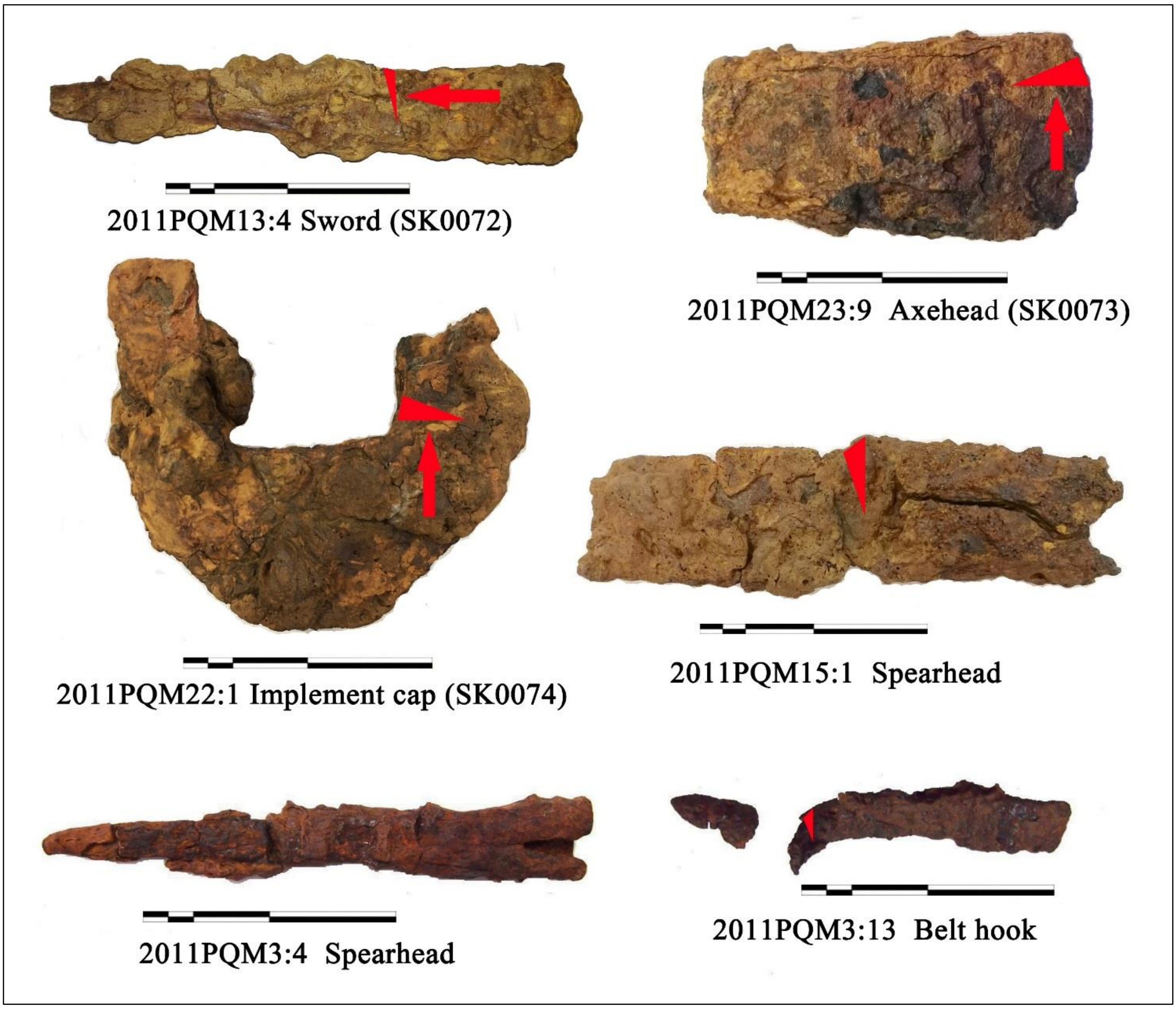

***Fig. 2** Examples of iron objects from Qiaogoutou cemetery showing sampling positions*

Methodology

Five samples were prepared and analysed, of these two were fully corroded with no metal remaining. The samples were taken by making two cuts inward to meet close to the central area of the object. The specimens were compression mounted at 30±5MPa and 130±5°C, ground and polished. The polished sections were examined using a Leica CM6000M optical microscope before and after etching with 2% nital. SEM-EDS analyses were carried out with an Oxford X-Max^{N}50mm2 EDS system at the Jinsha Museum in Chengdu, China, and the acceleration voltage was set to 20kV (***Table 2***). The points/areas analysed are labeled in the figures and the results were shown in ***Table 3***. We acknowledge the limitation that only 3 samples were studied, but the excavated iron objects from Qiaogoutou were badly corroded and the density of most of the iron objects was very low. Two cuts were made on two of these low density objects but there was no metal remaining, thus we stopped cutting these low density objects. Fortunately, three higher density objects were found to have enough metal remaining for metallographic examination.

Table 2 ***Sample analysis details from Qiaogoutou.***

Artifact No	Type	Laboratory No	Metallographic analysis	SEM-EDS
2011PQM15:1	spearhead	-	NO	NO
2011PQM3:13	belt hook	-	NO	NO
2011PQM13:4	sword	SK0072	YES	YES
2011PQM23:9	axehead	SK0073	YES	YES
2011PQM22:1	U-shaped implement cap	SK0074	YES	YES

Results

A summary of the metallographic analysis of the three samples is given in ***Table 4*** and more detailed descriptions are given below.

Sample SK0072

This sample is cut from the cross section of an iron sword. The sword is almost fully corroded with very little metal remaining in the core (about 0.6cm wide and 0.1-0.2cm thick). Some slag inclusions, single-phased, could be seen in the unetched section. Most were seen as narrow stringers aligned in a direction parallel to the surfaces (***Fig. 3***).

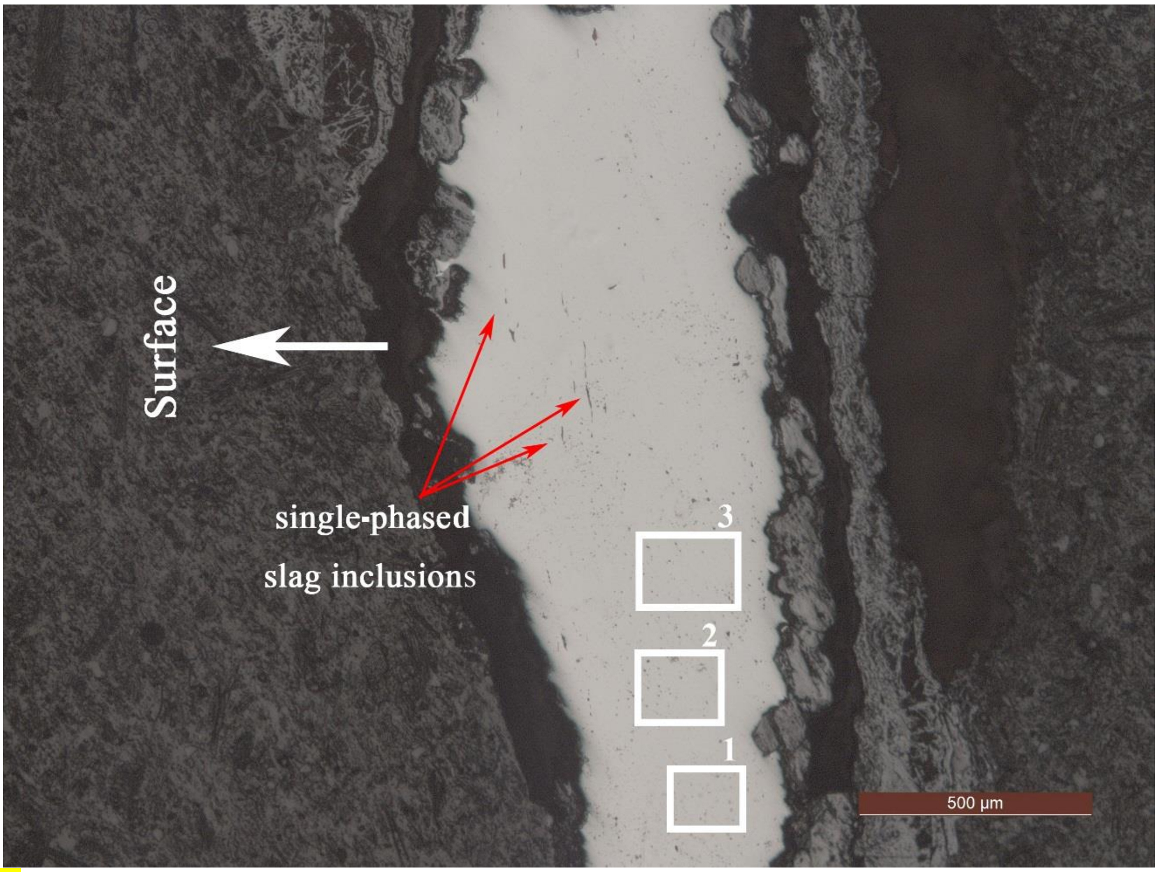

***Fig. 3** SK0072 showing the remaining metal, the distribution of the inclusions, and areas for composition analyses. Unetched. Scale bar 500µm.*

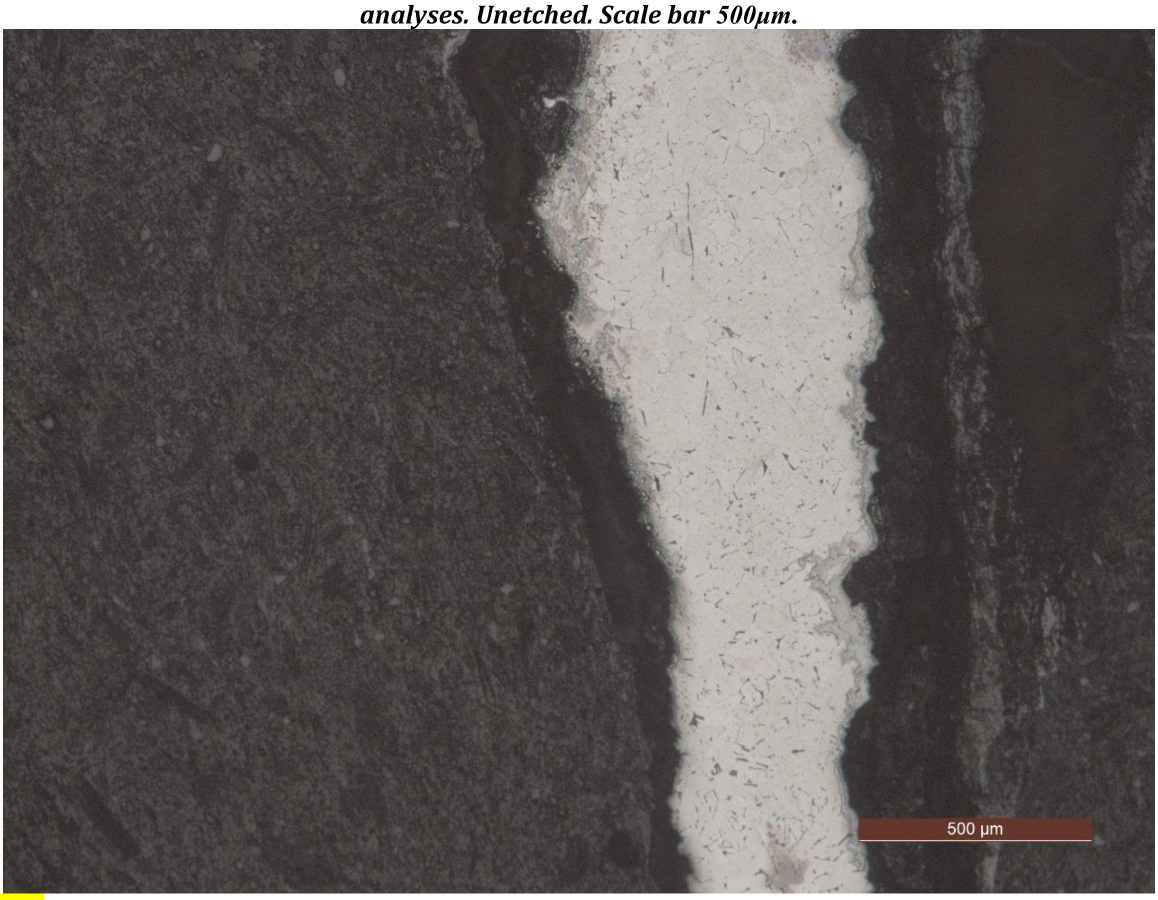

***Fig. 4** SK0072. Small grains, not very clear grain boundaries. Ferrite with a slightly uneven response, suggesting phosphorus, grain boundary pearlite and stringers. Etch 2% nital.*

At low magnification, etching revealed a ferrite matrix with small grain size, and some light precipitates within the ferrite grains. The grain boundaries are faint, and a slightly uneven response to etching was visible throughout the section (***Fig. 4***). It is of low carbon content, 0.1%, with grain boundary cementite and a little pearlite (***Fig. 5***). Grain sizes and orientation are even and give no obvious clues of working deformation.

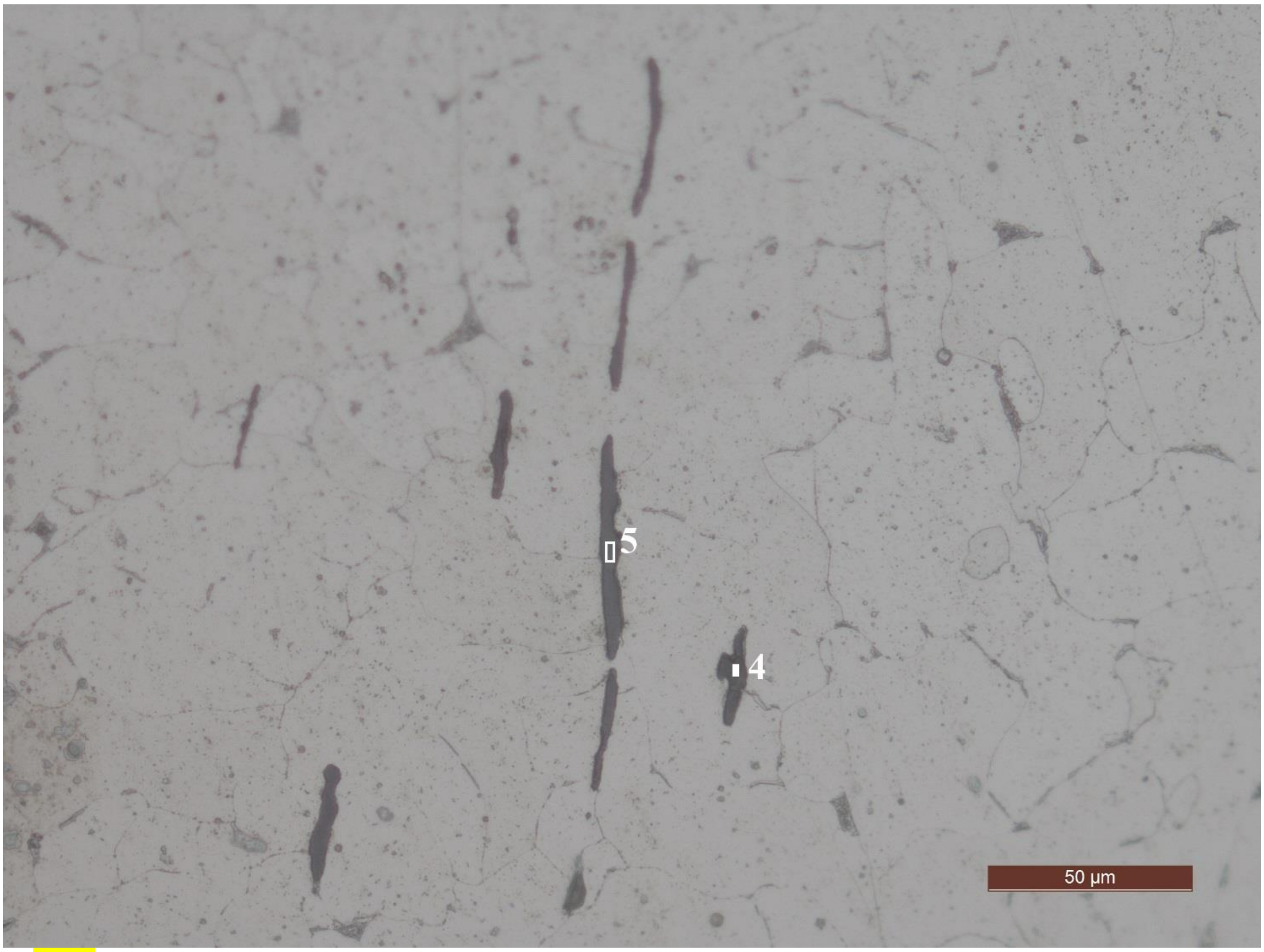

Fig. 5 ***SK0072 showing the distribution of the stringers, low occurrence of carbon distributed along with grain boundaries, and areas for composition analyses. Etch 2% nital.***

Sample SK0073

This sample is cut from the cutting edge of an iron axehead. One side of the sample shows a band of corrosion within the remaining metal. The corrosion is dark and light grey in colour. Both single and double-phased slag inclusions could be seen before etching (***Fig. 6***). The single-phased slag inclusions are relatively small, elongated, and distributed in groups parallel to the surface. The double-phased slag inclusions are larger, mainly elongated with some irregular exceptions, and also distributed parallel to the surface. The double-phased slag inclusions have dark and light grey phases which could be identified as an iron silicate (fayalitic) matrix with wüstite dendrites (***Fig. 8***).

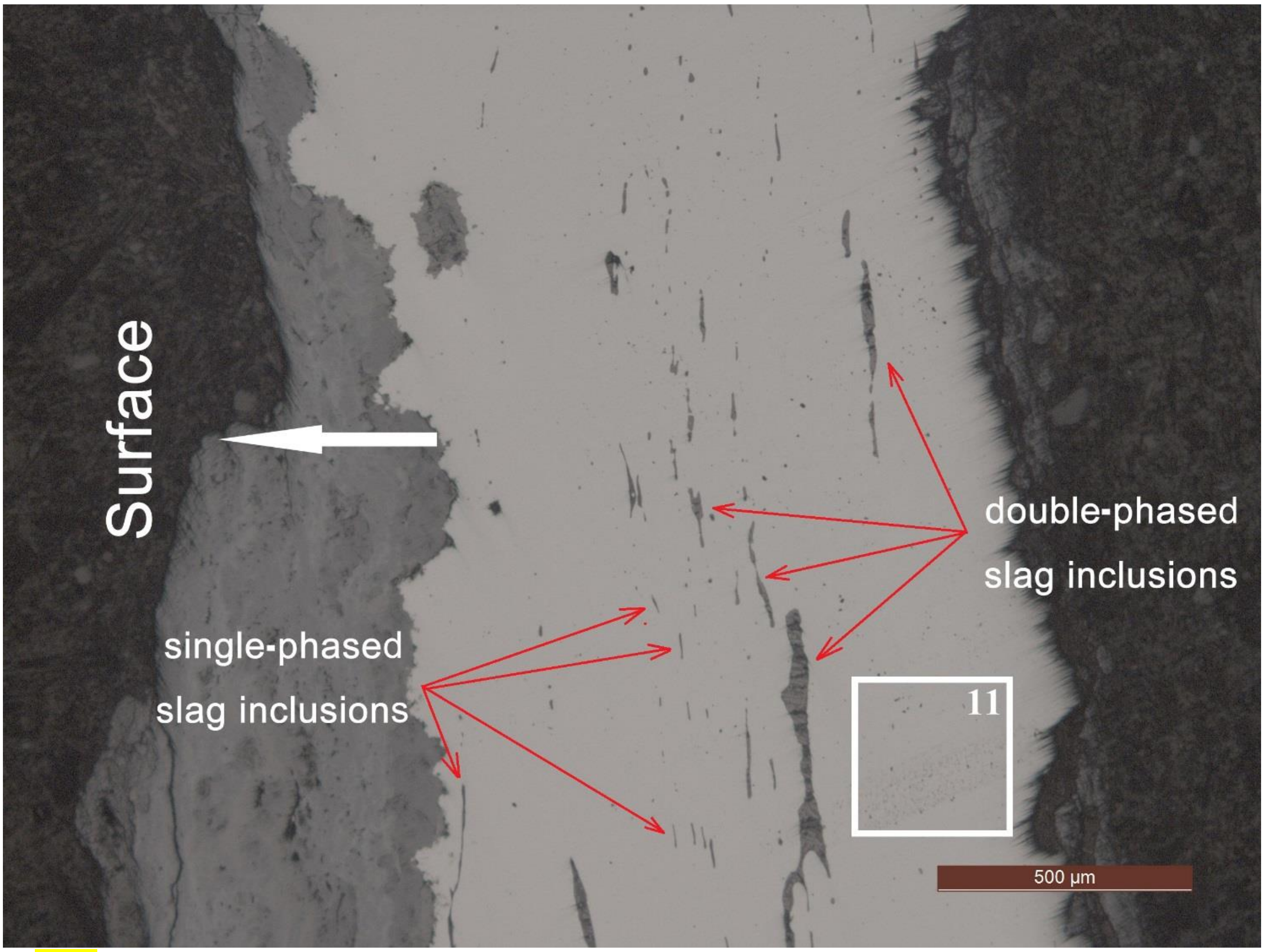

Fig. 6 ***SK0073 showing the remaining metal, the distribution of the inclusions, and area for composition analysis. Unetched. Scale bar 500µm.***

At low magnification, etching revealed a fine pearlite matrix. The structure near the tip area is pure pearlite. Ferrite started forming on the edge of the grain boundaries away from the tip area. The amount of ferrite increased from the tip to the middle and from one surface to the other surface of the axehead. The carbon content is ca. 0.2% - 0.4% in the top right corner in ***Fig. 7***. Needle-like ferrite structures extend inwards from the grain boundaries, indicating a Widmanstätten structure. The grains are equiaxed without distortion (***Fig. 8***).

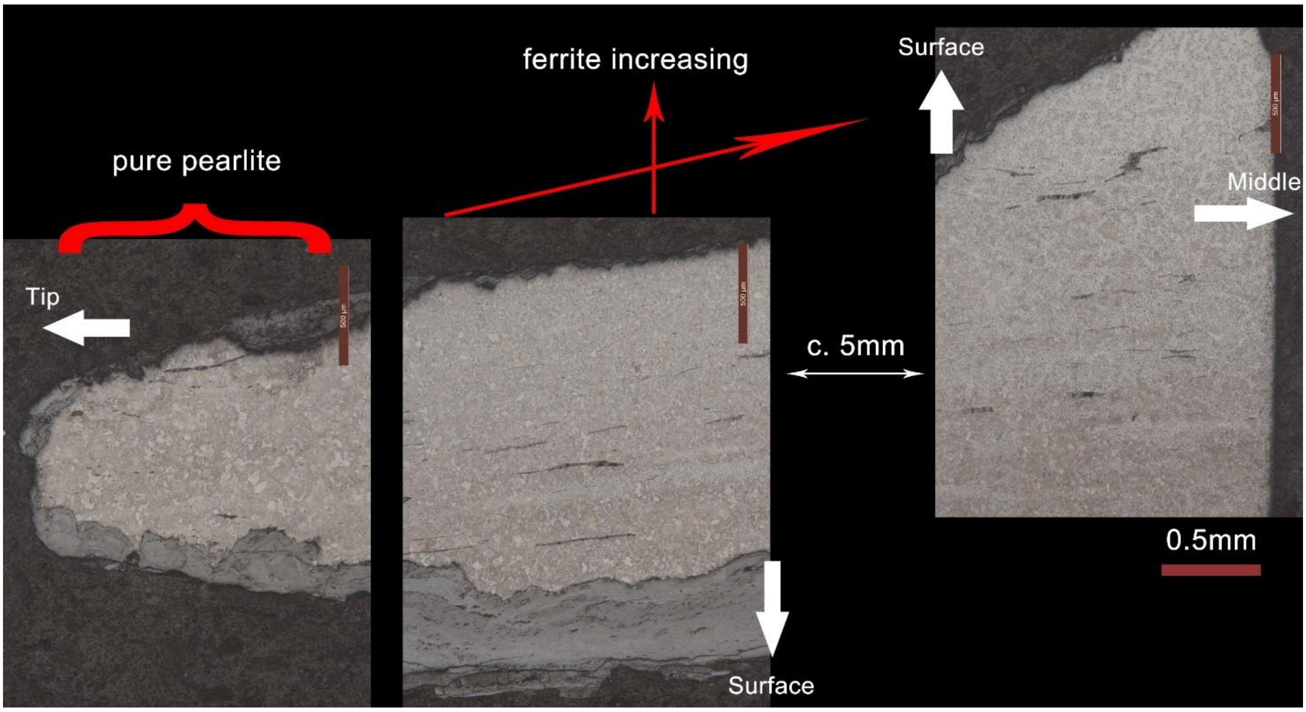

***Fig. 7** Montage of the section from SK0073 showing the difference of carbon content in different areas of the object. Etch 2% nital.*

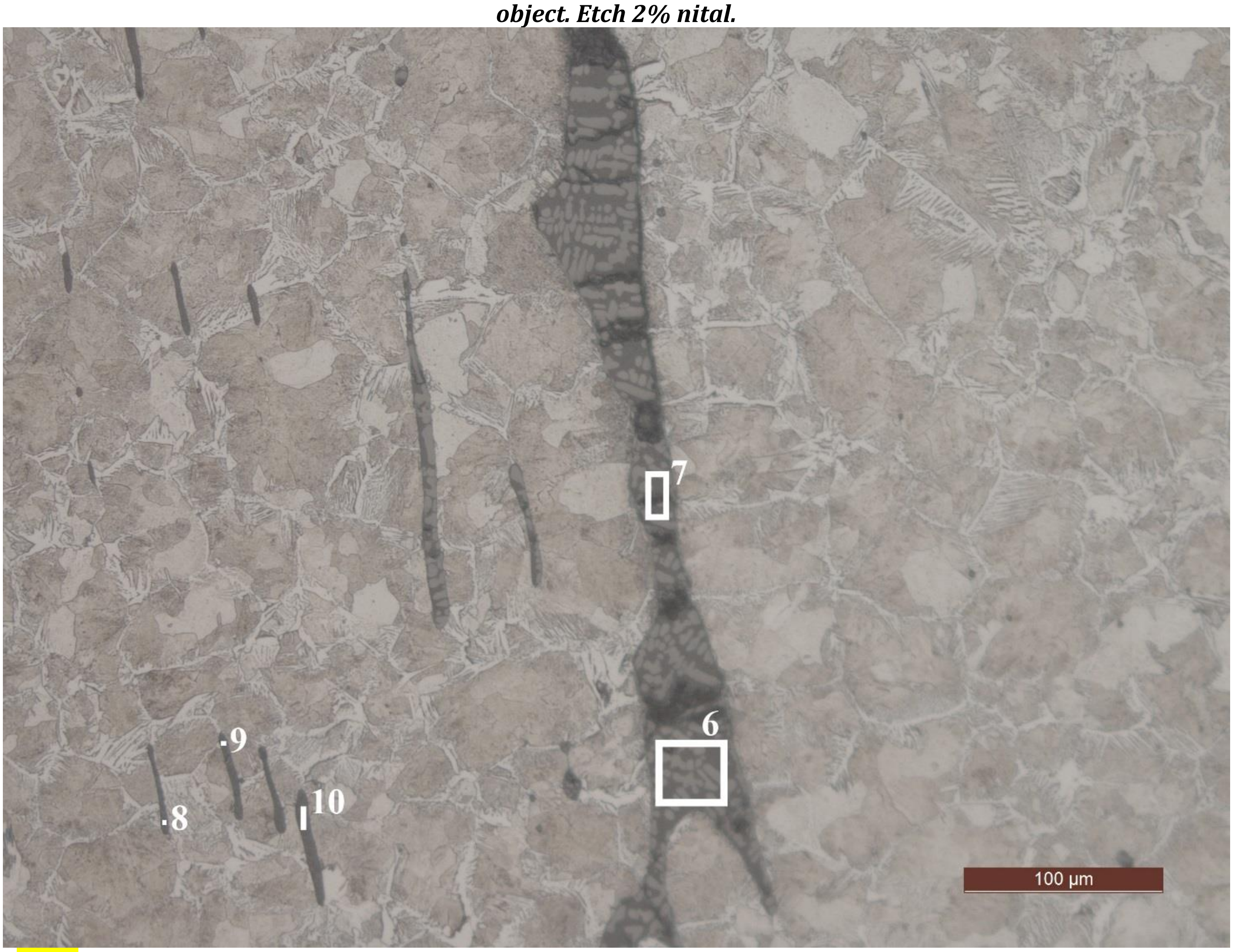

***Fig. 8** SK0073 showing the ferrite and pearlite matrix, the distribution of the inclusions, a Widmanstätten precipitation of ferrite into pearlite containing grains, and areas for composition analyses. Etch 2% nital.*

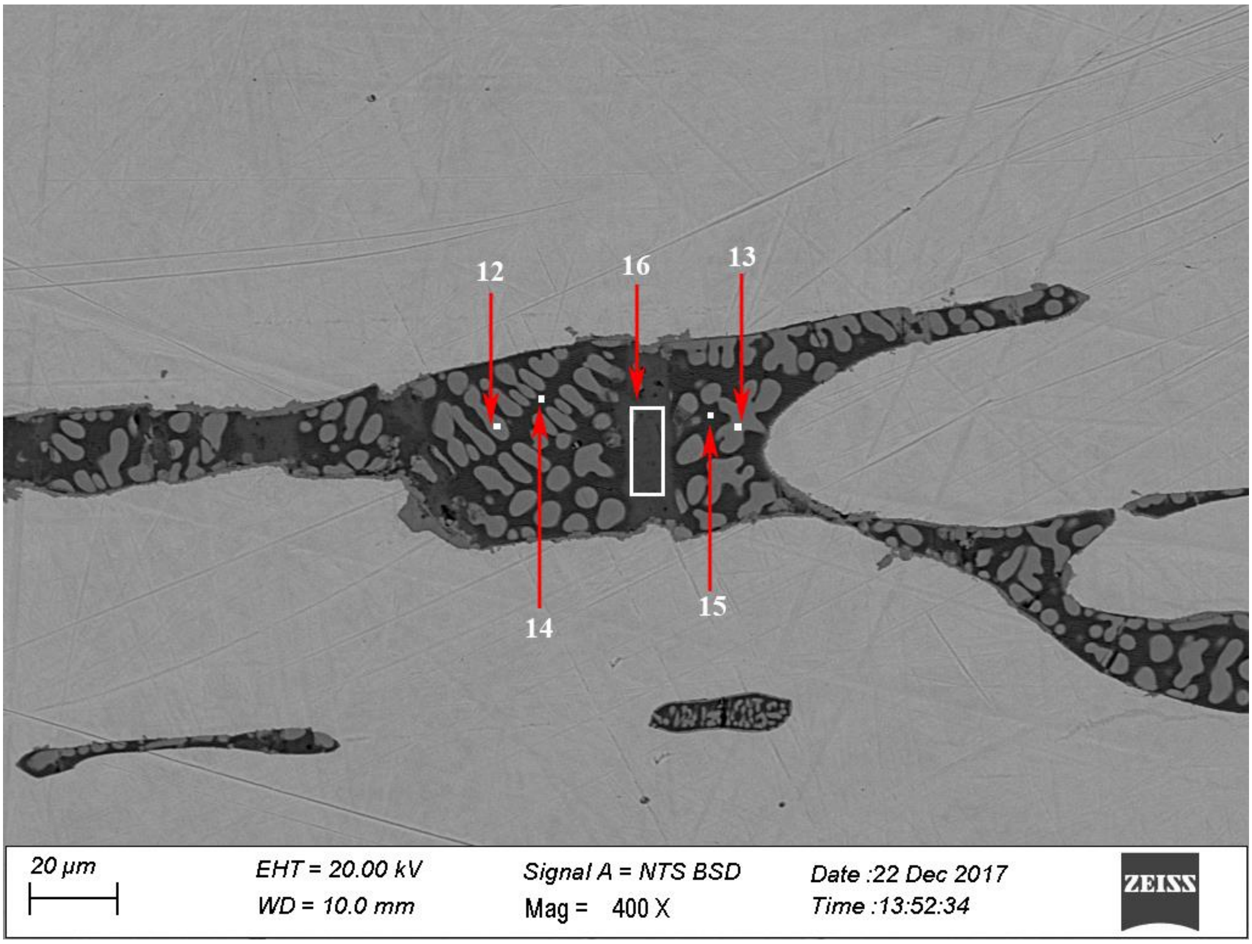

***Fig. 9** SK0073 showing the double-phased slag inclusions and areas for composition analyses.*

Sample SK0074

This sample is cut from the edge of a U-shaped iron implement cap. The sample is badly corroded with very little metal left in the centre.

At low magnification, etching revealed a ferrite matrix and clear grain structure with different size grains. The rust in the middle of the sample was from imperfect drying during sample preparation. There were no visible slag inclusions or grain distortion that might indicate forging. There are some graphite-like structures throughout the section (***Fig. 10***).

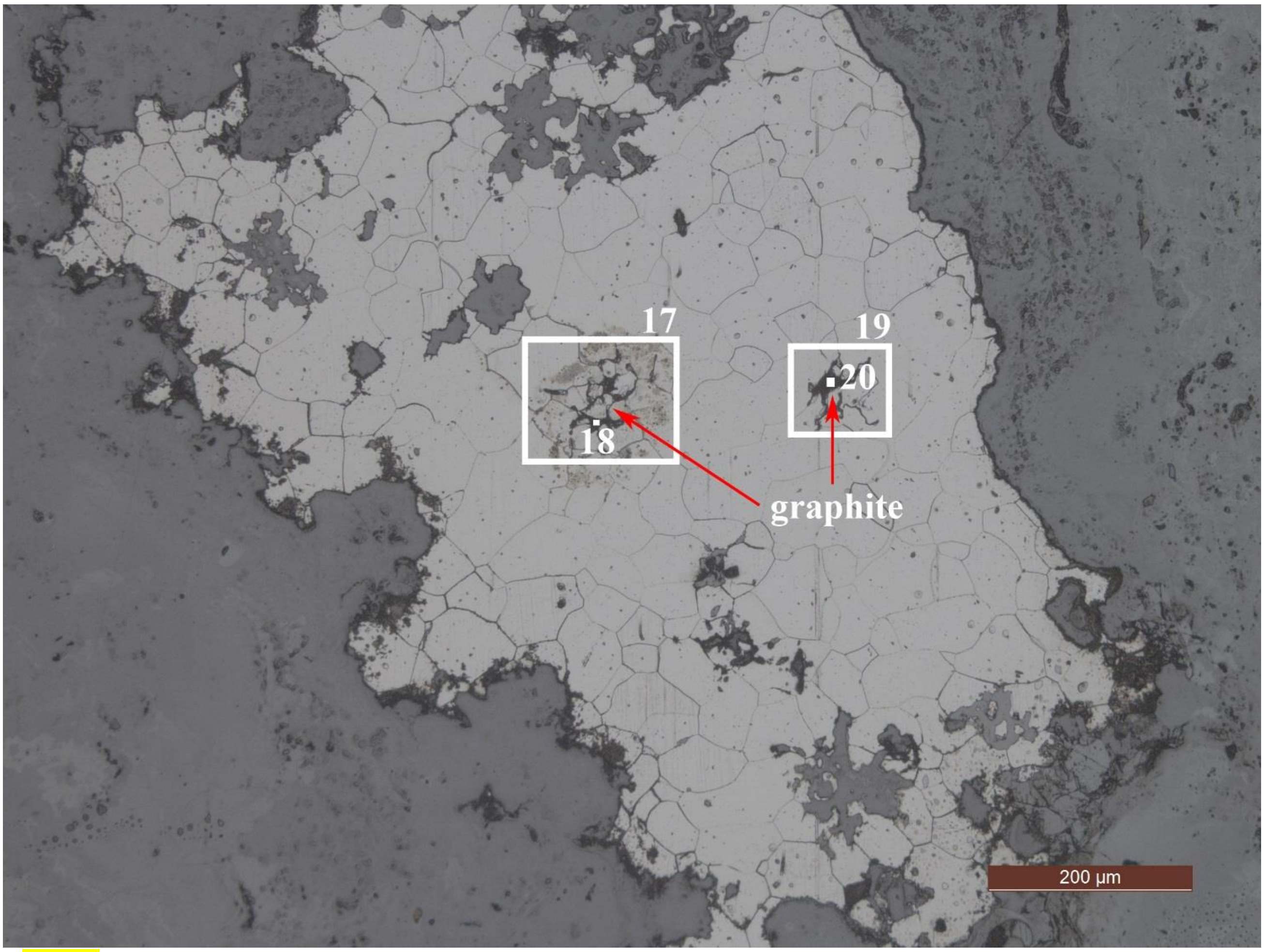

***Fig. 10** SK0074 showing the ferrite matrix, clear grain crystal in different sizes, and areas for composition analyses. Etch 2% nital.*

***Table 3** Result of chemical compositions (normalized wt%)*

Sample no.	Analysis no.	C	O	Na	Mg	Al	Si	P	Cl	K	Ca	Ti	Mn	Fe
SK0072	1	3.3	-	-	-	-	-	-	-	-	-	-	-	96.7
	2	3.8	-	-	-	-	0.5	-	-	-	-	-	-	95.7
	3	3.8	-	-	-	-	-	-	-	-	-	-	-	96.3
	4	5.6	24.3	0.5	1.8	3.1	16.9	-	-	1.7	6.0	0.6	2.3	37.3
	5	4.3	41.0	-	1.0	2.2	22.9	0.1	-	2.3	5.0	0.4	2.9	17.3
SK0073	6	12.8	25.3	-	-	1.0	5.2	0.5	0.4	0.6	1.1	-	-	53.1
	7	23.0	22.5	-	0.4	1.0	4.9	0.6	0.1	0.7	1.1	-	-	45.9
	8	27.4	26.2	-	0.7	1.3	8.1	1.3	-	1.7	5.1	-	1.0	27.3
	9	36.6	24.1	-	0.5	1.3	7.9	1.3	-	2.1	4.2	-	0.8	21.3
	10	26.2	23.9	-	0.6	1.6	8.6	1.3	-	2.0	6.2	0.2	1.0	28.6
	11	4.1	-	-	-	-	-	-	-	-	-	-	-	95.9
	12	5.0	23.2	-	-	0.5	2.2	0.3	-	-	0.4	-	-	68.3
	13	9.3	24.6	-	0.6	1.3	6.8	0.7	-	0.5	1.1	-	-	55.2
	14	11.1	31.6	-	0.6	2.0	11.9	1.3	-	1.5	2.8	-	-	37.2
	15	11.4	29.9	-	0.7	2.0	10.6	1.3	-	1.2	2.4	-	-	40.5
	16	5.3	32.8	-	-	-	-	-	5.0	-	-	-	-	56.9
SK0074	17	5.0	-	-	-	-	0.4	0.4	-	-	-	-	-	94.2
	18	29.0	9.8	-	-	-	0.5	0.3	-	-	0.2	-	-	60.2
	19	6.6	-	-	-	-	0.3	0.5	-	-	-	-	-	92.7
	20	60.3	18.8	-	-	-	0.6	0.1	-	-	0.6	-	-	19.6

Notes: '-' means below detection limit.

Discussion of the results

The slag inclusions in SK0072 are fewer and smaller than the slag inclusions in SK0073. The acicular phases in the ferrite grains of SK0072 are either carbides, nitrides or carbide-nitrides (Scott 2013, 167). The carbon content is very low in SK0072, less than 0.1%. The single-phased slag stringers and undistorted grains in SK0072 suggests that the object was forged and annealed from wrought iron. When making iron swords, the blacksmiths of ancient China probably started with wrought iron, and carburized the sword during the forging process. In ancient China, wrought iron could have been produced in a number of different ways - by a bloomery process, a crucible process, by the fining of pig iron from a blast furnace, or by solid-state decarburization of pig iron from a blast furnace (Wagner 1993, 288). There is still insufficient evidence of a crucible process for iron smelting in China before 200CE (Zhou et al. 2016, 363), and we might expect more and larger slag inclusions if the wrought iron was from a bloomery process. It is possible to produce wrought iron by fining pig iron from a blast furnace although the primary purpose of this process was to produce carbon steel. In addition, the high silica single-phased slag inclusions may indicate the wrought iron used to forge this sword was probably from solid-state decarburization of pig iron, which the iron was cast into a plate or rod and annealed in an oxidizing atmosphere, decarburizing it in the solid state.

The slag stringers and the decreasing pearlite from the tip to the middle of SK0073 suggest that the object was forged from wrought iron and then carburized to a medium-high carbon steel. Some scholars believe slag inclusions can be used to identify the material is either bloomery iron or fined iron (Chen and Han 2007, 37; Liu 2014, 60). According to their definition and the SEM-EDS result of SK0073 (***Table 3***, analysis no.6-16), the material could be identified as bloomery iron because the clear eutectoid phase-separated microstructure as in bloomery iron's high Fe and low Si double-phased inclusions, however, it could also be identified as fined iron (or puddled steel as defined by Liu 2014) because there are also many single-phased inclusions. Therefore, in this case this method may not yet be a sufficient way to identify bloomery iron and fined iron.

There is only very little metal left in the center of SK0074. No conclusive evidence of either forging or casting was discovered. However, this type of implement is usually believed to be cast rather than forged in ancient China. The SEM-EDS result indicated that the graphite-like structures are very possibly graphite (***Table 3***, analysis no.17-20). The artefact was possibly made from whiteheart malleable cast iron, being cast in white cast iron and then decarburized in the solid-state. A small amount of pearlite and more graphite could be expected in a larger sample.

Table 4 ***Iron objects from Qiaogoutou. Summary of metallographic analysis.***

Artifact No	Laboratory No	Phases	Carbon	Material and techniques
2011PQM13:4	SK0072	ferrite	some carbon on grain boundary	wrought iron, solid-state decarburized, forged, annealed
2011PQM23:9	SK0073	ferrite, pearlite	decreasing from tip to middle, and one surface to the other. Low to 0.2-0.4%, and high to 0.6-0.77%	wrought iron, hypo-eutectoid steel, forged
2011PQM22:1	SK0074	ferrite	some graphite	whiteheart malleable cast iron

Discussion

Metallographic studies of iron objects dating to the 5th century BCE or earlier have concluded that the blades of iron swords (with bronze or jade handles) were made from carburized bloomery iron with a carbon content up to 0.5% (Han 1998, 92). Other metallographic studies of iron swords, axeheads, and U-shaped implement caps from the 4th century BCE to the 4th century CE are listed in ***Table 5***. However, most of the analyses were published a long time ago, and it remains unclear how the investigators arrived at their conclusions. Many also have no illustrations of the microstructures. Therefore, it is preferable to exclude the conclusions and only focus on their descriptions.

From these descriptions (***Table 5***), the materials used to make these iron swords were hypo-eutectoid steel with carbon content usually higher near the surface from 0.3% to 0.8% and lower in the core from 0.1% to 0.3%, and sometimes quenched. The axeheads were made of decarburized steel from white cast iron with a carbon content between 0.2% to 0.4%, and the earlier two (the 4th to 2nd century BCE) were forged and the later (200-350CE) were cast. There are only few single-phased slag inclusions found in these axeheads. The U-shaped implement caps were made of varied materials including white cast iron, decarburized steel from white cast iron, and malleable cast iron.

As we know now, the iron objects excavated at Qiaogoutou were made from wrought iron and whiteheart malleable cast iron. It is interesting that wrought iron tools were found in Sichuan. Wagner (1993; 2007) has pointed out in his works that in early times in China, weapons were wrought and tools were cast, and that this began to change in the Tang dynasty (618-907CE). There are some exceptions, for example, an iron scythe-blade from a Han tomb excavated in Mianyang (near Chengdu), Sichuan province (Wagner 1993, 212), a similar scythe-blade of Han dynasty was excavated at Lijiaba, Chongqing, and the iron axehead (SK0073) from Qiaogoutou were all wrought iron tools. These exceptions might be helpful in studying the differences in policy and management of the central government and the frontier areas relating to iron production technology.

Up to now, there have been very few metallurgical studies of excavated iron objects from Southwest China. Li Xiaocen (2011) analyzed some iron objects from Yunnan, and the results show that there were both forged and cast iron in use. The forged iron objects appeared no later than the mid-late Warring States period (ca.340-200BCE). The quantity and type of both are few and include iron bracelet, iron knife, iron sword (bronze handle) and iron chisel (bronze socket) indicating iron may have been regarded as a precious material at the time. In addition, hypo-eutectoid steel objects were also in use. However, there is no evidence of iron smelting activities in ancient Yunnan before the mid-Western Han dynasty (ca.140-50BCE), and the iron objects and primary material were possibly imported from Sichuan or further afield. Iron was widely applied in the making of tools and weapons in ancient Yunnan during the mid-late Western Han dynasty (ca.140BCE-9CE). Many puddled steel, quenched steel and cast iron objects were discovered in tombs indicating a big improvement of iron making technology (Li 2011, 99).

Chen Jianli et al. (2008a, 195-206) analyzed 11 iron objects (one iron sword with bronze handle) excavated from Kele, Guizhou province. The objects are dated from the late Warring States period to the early Han dynasty (300-150BC). The result shows that the objects were both forged and cast, and the materials and included white cast iron (decarburized to steel and wrought iron), malleable cast iron, bloomery iron, and fined iron. They concluded that iron production technology of Kele, Guizhou, derived from the Central Plains technology system (Chen et al. 2008a, 206).

Li Yingfu (2016) analyzed a bridge pier weighing 1.38 tons and dated 96BCE, discovered in Guanghan, Sichuan. The metallographic results show the artefact is grey-cast iron, and nearby were found fragments of the mould in which it was cast. It is direct evidence indicating that the ancient Sichuan was capable of casting big iron objects at least by 96BCE.

The Qiaogoutou site is located in the south of Sichuan province close to Yunnan province. The iron objects analyzed here were dated to the late Warring States period and early Western Han dynasty (336-140BCE). The metallographic characteristics of these objects are similar to the ones discovered in Yunnan of the same period, but in larger quantity and more types including weapons, tools and domestic objects. However, it is still too early for conclusions to be drawn about the iron production technology until more samples can be studied.

Conclusion

The iron objects excavated from Qiaogoutou are abundant both in quantity and type. Three metallographic samples, one each from a weapon, a wood working tool, and an agricultural implement were analyzed. The analysis provides valuable data for the study of iron making and smelting in southwest China. According to the metallographic results, during the Warring States period and the Western Han dynasty the primary use of iron at Qiaogoutou is forged wrought iron objects. There is also evidence that cementation, annealing (SK0072) and decarburization (SK0074) were used. However, it is worth mentioning that these artefacts were all excavated from cemetery contexts, which could not be fully representative of daily use situations. In addition, there is no evidence of iron smelting in this area. To address the question whether they were made locally or imported from other places will require more samples to be studied in the future. Qiaogoutou is a large cemetery site, the richness of the object types and its production level is greater than in the Yunnan area generally, but lower than the contemporary discoveries from the Chengdu plain and Lijiaba (author, manuscript in preparation). The emerging picture is that Qiaogoutou was possibly an important routeway of contact between the Shu and Ba regions and areas further southwest.

***Table 5** Metallographic studies of iron swords, axeheads, and U-shaped implement caps in China, from the 4th century BC to the 4th century AD*

No.	Lab No.	Context	Cutting point	Type	Date	Area	Description *	Conclusion	Source
1	7117	M374:15	cutting edge	sword	200-350 CE	Liaoning (northeast)	pure pearlite in the cutting edge area, 0.8% carbon; core area about 0.3% carbon with a Widmanstätten structure; slag stringers, carburized on the edge.	fined steel, forged	(Chen et al. 2001)
2	7118	M218:10	cutting edge	sword	200-350 CE	Liaoning (northeast)	uneven carbon content distribution, higher on the edge with a Widmanstätten structure, 0.3% carbon, carburized. Core area is ferrite and small amount of pearlite on the grain boundaries, 0.1% carbon, single and sub-double phases inclusion stringers mostly in the core area.	fined steel, forged	
3	7119	M309:13	cutting edge	sword	200-350 CE	Liaoning (northeast)	uneven carbon content distribution, higher side is ferrite+pearlite on the grain boundaries, 0.1% carbon, lower side is ferrite, single-phased inclusion stringers.	fined steel, cold forging	
4	7112	M4:46	cutting edge	axehead	200-350 CE	Liaoning (northeast)	even carbon distribution, pearlite+ferrite, 0.4% carbon, few inclusions.	decarburized steel from white cast iron	
5	7131	M205:11	cutting edge	axehead	200-350 CE	Liaoning (northeast)	ferrite+pearlite, pearlite precipitated on the ferritic grain boundaries, 0.2% carbon, very few inclusions, shrinkage cavities or gas hole in casting.	decarburized steel from white cast iron, cast	
6	7134	M20:4	cutting edge	U-shaped implement cap	200-350 CE	Liaoning (northeast)	white cast iron, casting flaws.	white cast iron	
7	FWC01	③:18		U-shaped implement cap	-4th/-2nd century	Fujian (southeast coast)	badly corroded, trace of white cast iron structure in the corrosion.	white cast iron	(Chen et al. 2008b)
8	FWC02	T13II③:4		U-shaped implement cap	-4th/-2nd century	Fujian (southeast coast)	badly corroded, little metal left, which is pearlite with 0.8% carbon content, no inclusion.	decarburized steel from white cast iron, forged	
9	FWC03			U-shaped implement cap	-4th/-2nd century	Fujian (southeast coast)	pearlite+ferrite matrix with graphite.	malleable cast iron	
10	FWC05	T287 ③:39		axehead	-4th/-2nd century	Fujian (southeast coast)	ferrite, grain size grade 5, some carbides precipitated in the ferritic grains, few single-phased inclusions.	decarburized steel from white cast iron, forged	

No.	Lab No.	Context	Cutting point	Type	Date	Area	Description *	Conclusion	Source
11	FWC06	T287 ③:34		axehead	-4th/-2nd century	Fujian (southeast coast)	ferrite+pearlite in the cutting edge area, 0.2% carbon, few single-phased inclusions. Ferrite in the socket area, grain size grade 5.	two pieces of decarburized steel from white cast iron, forged	
12	FWC16	T8III③:1		sword	-4th/-2nd century	Fujian (southeast coast)	martensite, some bandings caused by trace element, single-phased inclusion stringers.	fined steel, forged	
13	FWC17			sword	-4th/-2nd century	Fujian (southeast coast)	uneven structure, 3-5 layers of differnet carbon content, Widmanstätten structure in high carbon content area, 0.7% carbon with some spheridized pearlite, ferrite+pearlite in lower carbon content areas, 0.4% carbon, some single-phased inclusion stringers.	fined steel, forged	
14	1:4249	Tomb of Liusheng	body?	sword	165-113BCE	Hebei (Central Plain)	5 layers for the central ridge, and 4 layers in the blade areas. Higher carbon layer about 0.6-0.7% carbon, and lower carbon layers about 0.3% carbon. Martensite on the cutting edge. 'carbon-free bainite' (lower bainite) on the surface.	carburized steel from bloomery iron, quenched	(Yu and Qian 2011)
15	1:5105	Tomb of Liusheng	section	sword	165-113BCE	Hebei (Central Plain)	lower carbon content layer about 0.1-0.2%, higher carbon content layer about 0.5-0.6%, surface carburized, higher than 0.6% carbon, martensite observed. Layers are thin due to the repeatedly forging process. Inclusion size is small, the biggest is 0.05-0.1mm.	carburized steel from bloomery iron, partially quenched	
16	HXS-4	M37:4	broken section	sword	202BCE - 20CE	Henan (Central Plain)	trace of forging, indistinct pearlite, forged from eutectoid steel.	decarburized steel from white cast iron, forged	(Rong et al. 2013)
17		M311:2		sword	300-221BC	Guizhou (southwest)	badly corroded with no metal remaining, some trace of ferrite and pearlite can be seen in the corrosion with single-phased slag stringers.	decarburized steel from white cast iron	(Chen et al. 2008a)
18		M284:3		U-shaped implement cap	202-150BC	Guizhou (southwest)	badly corroded, ferrite matrix with cotton-like graphite can be seen in the corrosion in the core, a decarburization layer on the edge.	malleable cast iron, decarburized from white cast iron	
* these were translated directly from the descriptions in Chinese									

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