# The manufacture techniques and dates of iron objects found at several Chinese archaeological sites in recent years

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*ABSTRACT*: This paper is a survey of the development of iron and steel technologies in ancient China based upon new archaeological findings and laboratory research. Man-made iron produced by the bloomery process was first used around the 14th century BC in Gansu province, and by the 9th-8th century BC or earlier in the Central Plains and Xinjiang areas. The earliest cast iron fragment, dated to the 8th century BC, was found in the Central Plains. From the 5th century BC cast iron was widely used and a sophisticated cast iron technological system was established during the period between the 3rd century BC and the 2nd century AD. Cast iron technologies were spread widely from Central China into neighbouring areas.

*Keywords*: Radiocarbon dating; iron; steel; inception.

## Introduction

It is generally accepted that the Iron Age began in Asia Minor, where iron-using people have occupied the area from about 2000 BC (Tylecote, 1992, p.47). A dagger with copper handle and iron blade, unearthed in a tomb of Hittites (2500 BC), was thought to be a man-made iron object. It indicated that iron smelting technology had emerged in Anatolia during that period; however, the dagger might just be an accidental result. After 1500 BC, artificial iron objects became more and more common in Mesopotamia, Anatolia, and Egypt. The trade of iron objects between Hittites and Assyrians was recorded in documents. Between 1500 and 1000 BC, iron techniques were diffused throughout Europe, Asia, and Northern Africa. Tylecote (1992, pp.47-48) pointed out that ironworking spread to India and China from Iran around 400 BC. Bennet Bronson (1999) also pointed out that the making of iron emerged late in China, later than in many other parts of Eurasia.

The origin of iron smelting technology in China has puzzled us for a long time, from as early as the 1920s. Significant archaeological fieldwork and scientific investigation on iron and steel has been carried out in China since the 1950s, and there is now a considerable amount of literature on the topic. As a result, scholars have already achieved some preliminary understandings regarding the development, characteristics, and organisation patterns of early Chinese iron production (Yang Kuan, 1955; Chinese Archaeometallurgy Study Group at Beijing University of Iron and Steel Technology, 1978, pp.148-50; Li Jinghua and Chen Changshan, 1995; Hua Jueming, 1999, pp.303-5; Bai Yunxang, 2005; Chen Jianli and Han Rubin, 2007; Han Rubin and Ko Tsun, 2007, pp.357-358,383; 377-378; Wagner, 2008).

However, due to the vague descriptions in historical documents and the lack of archaeological evidence from early periods, the origin of the iron smelting technology in China is still under debate among scholars. Some think it emerged no later than the Erlitou culture, 1500 BC (Zhang Binglin, 1925), while some others believe it began in later periods, such as the Shang Dynasty, 1600-1046 BC (Tong Shuye, 1955; Xia Xiangrong, 1980, pp.212-13), the Western Zhou Dynasty, 1056-771 BC (Guo Moruo, 1976, p.313; Yang Kuan, 1982; Tang Jigen, 1993; Bai Yunxiang, 2005, p.9; Zhao Huacheng, 1997; Hua Jueming, 1999, pp.303-5), or even the Spring and Autumn Period, 771-476 BC (Li Jiannong, 1962, p.42). In addition, whether smelting techniques were introduced from the west or invented indigenously within China is an issue that has not yet been determined clearly. Therefore, systematic studies of early Chinese iron artefacts and smelting technology, as well as their careful dating, are essential for our understanding of the origins of the Chinese Iron Age.

Although the currently available data suggests that the development of iron and steel technologies varies from culture to culture, the technology of cast iron production and steel made from cast iron in ancient China represents a unique approach that differs considerably from the ferrous technologies of West Asia and Europe (Han Rubin and Ko Tsun, 2007, pp.357-358,383; 377-378.). The distinguishing characteristics which can be used as the criteria for differentiating between puddled steel, decarburised steel, and carburised steel produced in the solid state were previously discussed by Chen Jianli and Han Rubin (2007). Over the past several years, many new iron smelting sites and archaeological iron objects have been excavated in China, providing new information for the study of the development of iron and steel technologies in ancient China. More than 500 samples of slag, iron objects, furnace walls, ores, charcoal, bones, etc. were collected by the authors from archaeological sites in central, north-east, north-west, and south China, as shown in Fig. 1. These samples were analysed by metallographic microscopy, SEM-EDS, and AMS-$^{14}$C dating methods. This paper is a survey of the iron objects and their chronology based on these new findings and our laboratory research results.

## The radiocarbon dating of iron objects

Because sometimes iron objects are separated from related archaeological materials that would permit assigning them an absolute date, direct radiocarbon dating of iron materials is a desirable approach to ascertaining their ages. The radiocarbon dating of iron objects was first proposed and carried out by van der Merwe in 1969 (van der Merwe, 1969). Later, AMS-$^{14}$C dating was used by researchers to obtain dates for iron objects (Creswell, 1991, 1992; Eylon, 2002; Cook, et al., 2003). In order to verify whether ancient Chinese iron can be successfully used for radiocarbon dating, several iron objects with definite dates, including one coin dating to the 6$^{th}$ century AD, 12 coins dating to the 11$^{th}$-12$^{th}$ century AD, seven iron bridge fragments from the Pujindu site of the 8$^{th}$ century AD (Chen Jianli, et al., 2008), as well as 15 iron objects without definite dates (Chen Jianli, et al., 2008; Chen Jianli and Ma Qinglin, 2009), were examined using metallographic methods, and dated using AMS-$^{14}$C methods. The results are listed in Table 1.

The 13 coins are made from white cast iron. The calibrated radiocarbon dates obtained for four coins (laboratory codes BA05680, BA05684, BA06516, and BA06518) are approximately one century earlier than the dates displayed on the surface of the coins. The reason is probably that older carbon was introduced from the fuel during the process of iron smelting and casting. This problem has been discussed previously (Craddock, et al., 2002) and we do not believe that there are any reasons to doubt the reliability of the methods of radiocarbon dating of Chinese cast iron objects. Six samples are noted as containing fossil carbon, and these samples also contained FeS slag inclusions. It can therefore be inferred that coal was used in the iron smelting process during the Chongning Period (1102-1106 AD) of the Northern Song Dynasty (960-1127 AD). The radiocarbon dates of iron coins BA06511, BA06521, and BA06522 are 1950±35, 4255±35, and 2260±35BP respectively, much earlier than the dates shown on the coins (1102-1110 AD), which could indicate that coal and charcoal may have been used together during the smelting or melting process. This possibility creates some problems for radiocarbon dating research on iron objects.

The Pujindu is a famous ancient ferry on the Yellow River, located in Yongji county, Shanxi Province. Four iron 'tractors' (each 3.3m long and 1.5m high, weighing about 50 to 70 tons), four iron men (positioned next to each tractor, about 1.9m high and weighing about 3 tons), and other iron objects were found at the site. The records showed they were cast during the Kaiyuan period (about 724 AD) of the Tang Dynasty (618-907 AD). As for the iron samples from the Pujindu site,

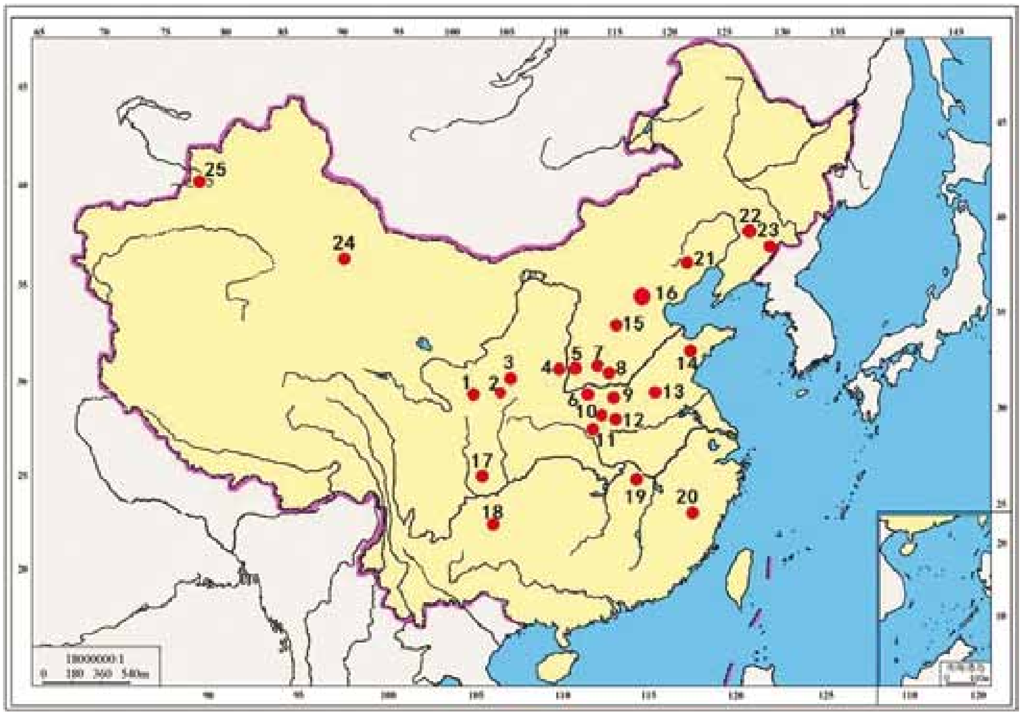


**Figure 1**: Map of China showing the archaeological sites mentioned in the paper. 1. Mogou site, Lintan county; 2. Li county; 3. Majiayuan site, Zhangjiachuan county; 4. Liangdaicun site, Hancheng; 5. Pujindu site, Yongji county; 6. Sanmenxia; 7. Tianma-Qucun site, Quwo county; 8. Maijiehe and Beiyecun site, Jiaozuo; 9. Zhenghan old city, Xizheng; 10. Wangfangzhuang site, Nanyang; 11. Yangying site, Laohekou county; 12. Five iron workshops in Tongbai county; 13. Shizishan tomb in Xuzhou; 14. Dongpingling site, Zhangqiu city; 15. Dongheishan site, Xushui county; 16. Shuiquangou site, Beijing; 17. Iron workshops in Chengdu; 18. Hezhang; 19. Ezhou; 20. Chengcun site, Wuyishan; 21. Lamadong site, Beipiao county; 22. Erlonghu site, Tongyu county; 23. Goguryeo tombs, Ji'an; 24. Dongheigou site, Balikun county; 25. Tombs in Ili Valley.

**Table 1: The AMS-$^{14}$C dates of iron objects with definite ages***

| | | | | |
|---|---|---|---|---|
| BA06521 | Yuanyou Tongbao | 4255±35 | 2930 BC (75.3%) 2850 BC<br>2810 BC (17.3%) 2750 BC<br>2720 BC (2.8%) 2700 BC | Huayin, Shaanxi province, 1086-1094 AD |
| BA06522 | Yuanyou Tongbao | 2260±55 | 410 BC (95.4%) 190 BC | |
| BA05684 | Yuanyou Tongbao | 1045±50 | 880 AD (88.1%) 1050 AD | |
| | | | 1060 AD (7.3%) 1160 AD | |
| BA06523 | Chongning Tongbao | 39985±235 | Not calibrated for fossil carbon | Huayin, Shaanxi province, 1102-1106 AD |
| BA05681 | Chongning Tongbao | 39130±220 | | |
| BA05682 | Chongning Tongbao | 38140±180 | | |
| BA06511 | Daguang Tongbao | 1950±35 | 40 BC (95.4%) 130 AD | Yuncheng, Shanxi province, 1107-1110 AD |
| BA06513 | Daguang Tongbao | 25720±95 | Not calibrated for fossil carbon | |
| BA06514 | Daguang Tongbao | 15275±55 | | |
| BA06515 | Daguang Tongbao | 37000±235 | | |
| BA06516 | Daguang Tongbao | 1060±35 | 890 AD (95.4%) 1030 AD | |
| IAAA31134 | No.1 iron man | 1530±40 | 420 AD (95.4%) 610 AD | Iron bridge at the Pujindu site, Shanxi province, 724 AD |
| IAAA31135 | No.1 iron man | 1460±40 | 530 AD (95.4%) 660 AD | |
| IAAA31136 | No.1 iron man | 1430±40 | 550 AD (95.4%) 670 AD | |
| IAAA31137 | No.1 iron man | 1430±40 | 550 AD (95.4%) 670 AD | |
| IAAA31138 | No.2 iron man | 1370±40 | 590 AD (90.1%) 720 AD | |
| | | | 740 AD (5.3%) 770 AD | |
| IAAA31139 | Iron stick under the No.3 iron man | 1410±40 | 560 AD (95.4%) 680 AD | |
| IAAA31140 | Iron pillar besides the No.4 iron man | 1910±40 | 0 AD (95.4%) 220 AD | |
| BA07335 | Adze | 2320±45 | 518 BC (73.3%) 349 BC | Yangying site of Laohekou City, Hubei province, about the 5th century BC |
| | | | 309 BC (22.1%) 208 BC | |
| BA07336 | Sickle | 2330±30 | 507 BC (7.8%) 437 BC | |
| | | | 420 BC (85.9%) 359 BC | |
| | | | 273 BC (1.7%) 259 BC | |
| BA07337 | Adze | 2300±35 | 409 BC (66.6%) 351 BC | |
| | | | 296 BC (28.8%) 209 BC | |
| BA07338 | Fragment | 2310±35 | 415 BC (74.2%) 350 BC | |
| | | | 299 BC (21.2%) 209 BC | |
| BA07542 | Tripod caldron | 2525±35 | 800 BC (95.4%) 530 BC | Li county of Gansu province, about the 5th century BC |
| BA07543 | Sword | 2380±50 | 760 BC (12.7%) 680 BC | Lingtai county of Gansu province, from 5th century BC to 1st century AD |
| | | | 670 BC (4.0%) 630 BC | |
| | | | 600 BC (78.7%) 370 BC | |
| BA07544 | Tripod caldron | 2240±40 | 400 BC (95.4%) 200 BC | |
| BA07545 | Ploughshare | 2105±35 | 350 BC (2.7%) 320 BC | |
| | | | 210 BC (92.7%) 40 BC | |
| BA07546 | Sword | 2315±40 | 510 BC (73.5%) 340 BC | |
| | | | 300 BC (21.9%) 200 BC | |
| BA06507 | Iron blade | 2150±45 | 360 BC (95.4%) 50 BC | Chengcun site in Wiuyishan city, Fujian province, about the 3rd-2nd century BC |
| BA06508 | Iron blade | 2240±35 | 400 BC (27.1%) 340 BC | |
| | | | 330 BC (68.3%) 200 BC | |
| BA06509 | Iron blade | 2180±40 | 380 BC (92.2%) 150 BC | |
| | | | 140 BC (3.2%) 110 BC | |
| BA07548 | Knife | 2220±35 | 390 BC (95.4%) 200 BC | Suizhou Museum of Hubei province, about the 2nd century BC |
| BA07549 | Knife | 2100±35 | 350 BC (1.3%) 320 BC | |
| | | | 210 BC (94.1%) 30 BC | |
| BA07550 | Knife | 2100±40 | 350 BC (3.2%) 310 BC | |
| | | | 210 BC (92.2%) 0AD | |

"*Tongbao*" is the name of the coins during the Tang and Qing dynasties. "Xining", "Yuanyou", "Daguan", and "Chongning" are the names of the coins corresponding to different emperors' periods of reign. For example, "Chongning Tongbao" was one such example, cast during the years of rule of the emperor Zhao Ji (Huizong) Chongning of the Song Dynasty (1102-1106 AD).

the metallographic results show that six of them, the No.1, No.2, and No.4 men (laboratory codes IAAA31134-31138 and IAAA31140) are made of grey cast iron and the iron pillar beside the No.3 iron man (IAAA31139) is made of middle carbon steel. The dates of these six grey cast iron samples are almost the same, while their calibrated dates are also about one century earlier than indicated by the records. However, the date of the iron pillar was older than that of the other six samples. It is possible that older iron materials were used to build the bridge. The archaeologists also pointed out that the pillar is older than the other parts of the iron men. As a result, the radiocarbon dates obtained for the iron men are in agreement with the dates indicated in the historical records.

The radiocarbon dates of iron objects from the Chengcun site of Fujian province, the Li and Lingtai counties of Gansu province, the Yangying site and Suizhou Museum of Hubei province are in good agreement with their archaeologically estimated ages. The results obtained for these archaeological artefacts indicate that the iron objects can be used as materials for $^{14}C$ dating credibly in some cases, and that, rust does not add a significant amount of contaminant carbon. The radiocarbon dates together with the carbon extraction yields from iron objects indicate that much of the original carbon is retained. However, the influence of old carbon used during the smelting, annealing, and forging processes should be considered. When the age of the iron object is approximately known archaeologically, as in the case of the objects discussed in this paper, the contemporary technology by which the iron is likely to have been produced can be considered. Here, the analysis of the microstructures of the iron objects and a consideration of manufacturing techniques provide a better interpretation of the radiocarbon dates. For example, in the case of cast iron and decarburised steel, it may be useful to study their smelting or casting dates. However, when considering carburised steel, because some carbon from different sources may have been introduced to the iron objects, investigating and exploring the dates may prove less reliable. Therefore, the selection of iron objects and the decision as to which part of the object can be radiocarbon dated should be decided based on investigation of the microstructures.

Because of the relative lack of data pertaining to the direct radiocarbon dating of iron materials, it can be suggested that it is better to select short-lived plant and bone samples for AMS-$^{14}C$ dating. The radiocarbon dates mentioned in this paper are mainly measured from organic materials rather than iron objects.

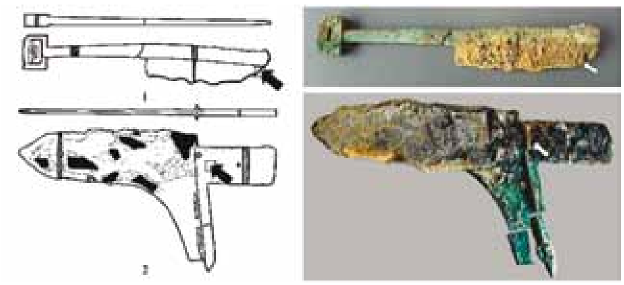

**Figure 2**: Two copper-iron bimetallic wares excavated from the Liangaicun site, Shaanxi province.

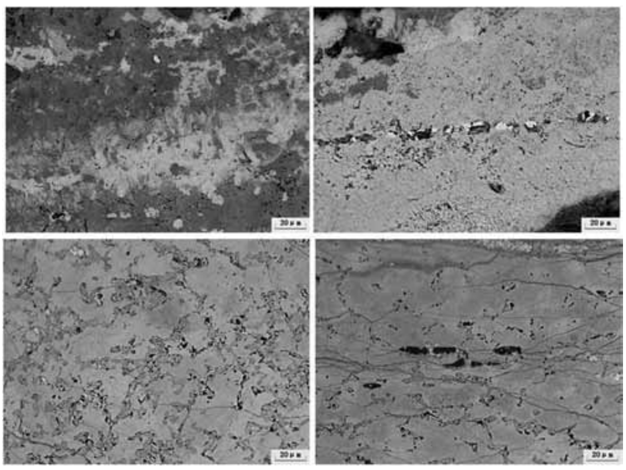

**Figure 3**: The microstructures of two copper-iron bimetallic wares excavated from the Liangaicun site, Shaanxi province.

## The beginning of the use of iron in China

Presently there is no definitive conclusion regarding the time and place of the origin of iron smelting in China. Three meteoritic iron objects and three bloomery iron objects excavated in the Guo State cemetery at Sanmenxia, Henan Province, dated to the 9th century BC, belong to the late Western Zhou Dynasty (1046-771 BC) (Han Rubin, et al., 1999). Two shapeless remnant pig iron fragments and a triangle-shaped iron fragment date back to the middle of the Spring and Autumn period (770-476 BC) were excavated in Qucun village, Quwo county, Shanxi Province (Han Rubin, 2000). They are dated to around 800-600 BC. The fabrication technology of two copper-iron bimetallic wares (a bronze knife with an iron blade and a bronze *ge*戈 with an iron blade, Fig. 2), excavated in tomb M27 of the Liangdaicun site, Hancheng of Shaanxi province, was analysed by metallography, EPMA, and AMS-$^{14}C$ dating methods. The microstructures of the two samples are typical of wrought bloomery iron containing a substantial amount of carbon, i.e. carburised steel made from bloomery iron by cementation in the solid state (Fig. 3).

The objects can be dated back to the early Spring and Autumn period (770-476 BC). Thus, the study of these objects provides new evidence regarding the beginning of iron smelting in Central China. Most of the previously known iron objects dating from the period between the late Western Zhou Dynasty and the early Spring and Autumn period were excavated in the region at the junction of the Henan, Shanxi, and Shaanxi provinces, in the middle reaches of the Yellow River, suggesting that this region might have been one of the earliest centres of iron smelting technology in China and thus deserves further archaeological investigation (Chen Jianli, et al., 2009). In the late Spring and Autumn period, the iron smelting industry in this area developed rapidly. For instance, Han Rubin studied the fabrication technology of approximately 4000 iron objects dated to about the 3rd century BC and earlier in China and found that the area of the Shanxi province was the area where most of the iron objects dating to the period between the 5th and the 3rd centuries BC were excavated. This area became the centre of iron smelting during the Warring States Period (Han Rubin and Duan Hongmei, 2009). The nearby area of western Henan also yielded a large number of excavated iron objects. The fact that most man-made objects from the western Zhou and early Spring and Autumn periods have been excavated in this area is important evidence in the effort to locate the origins of iron working technology in China. Due to the potential for finding more early Spring and Autumn period iron objects in this area, further archaeological excavations and laboratory research are necessary.

More than 50 iron objects dated to the $5^{th}$ century BC or earlier were excavated in Baoji, Shaanxi, and the neighbouring Gansu and Ningxia provinces (Han Rubin, 1998). It is worth exploring the relationships between these iron objects and those in the area at the junction of the Henan, Shanxi and Shaanxi provinces. Among the 50 iron objects, nine of them belong to the early Spring and Autumn period and the others belong to the end of the Spring and Autumn period and the early Warring States period (475-221 BC). One carburised steel sword with a gold handle excavated in Cemetery No.2 in Yimencun, Baoji City, was analysed by metallographic methods (Bai Chongbin, 1994). No differences were found in terms of production technology between the early iron objects in this area and those in Sanmenxia, Quwo, or Liangdaicun, located about 300-370km to the east. The dates of the iron objects from these two areas were almost the same, and consequently an investigation of the communication and transportation of the iron objects and smelting technologies in the two areas could provide some very important results.

The early iron objects excavated in Xinjiang have caused great interest among academics because they provide a clue about the beginning of the use of man-made iron in Central China. Some scholars believe that the iron smelting technology in Central China originated in Xinjiang, but there are still debates about the date of early iron objects excavated in Xinjiang. Iron objects in Yanbulake, Subeixi, Chawuhugoukou, Ili River, and other areas of Xinjiang included small iron knives, swords, sickles, finger rings, arrowheads, thimbles, needles, residual iron blocks, and other small tools and weapons, which may indicate that there was no large-scale iron production before the Han Dynasty. To date, only three iron workshops dating to the time of the Han Dynasty have been found. Details about the sites and tombs where the iron objects were excavated are generally not fully released and few $^{14}C$ dates of these objects were obtained. So far, there are only six $^{14}C$ dates from samples taken directly from tombs where ironware was found, and the dating error is significant. Therefore, the framework of $^{14}C$ dates for the early iron objects in Xinjiang needs further research. A total of 32 iron objects and ten radiocarbon dating samples (bones) were collected from the Ili River reaches of Xinjiang for metallographic and AMS-$^{14}C$ dating analysis by Chen Jianli. The results show that objects made of bloomery iron and carburised steel were mainly found in the early period (Fig. 4); decarburised steel made from cast iron (Fig. 5) was first used during the Han Dynasty. The beginning of the use of iron in the Xinjiang area can be dated back to the $9^{th}$-$8^{th}$ century BC.

In 2009, an iron bar excavated from tomb M444 at the Mogou site, Lintan county, Gansu province, was analysed

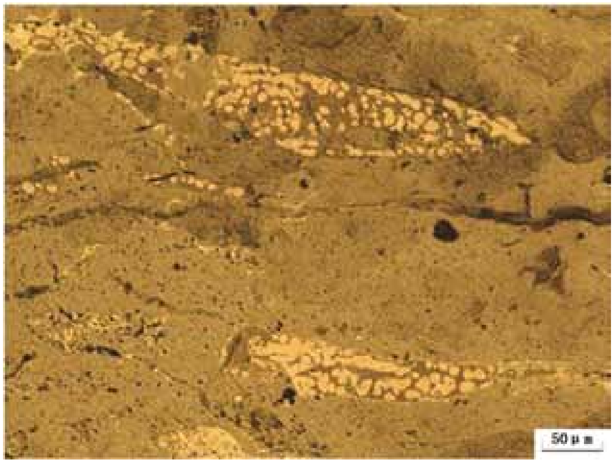


**Figure 4**: The microstructure of a bloomery iron object excavated from the Ili Valley, Xinjiang

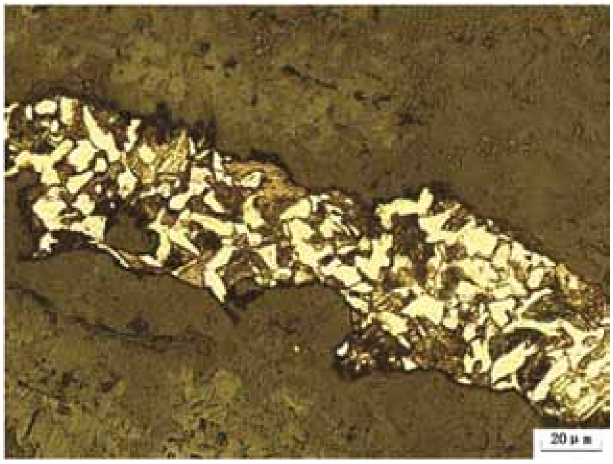


**Figure 5**: The microstructure of a carburised steel object excavated from the Ili Valley, Xinjiang.

**Figure 6**: Iron bar excavated from tomb M444 at the Mogou site, Lintan county, Gansu province.


**Figure 7**: The microstructure of the iron bar excavated from tomb M444 at the Mogou site, Lintan county, Gansu province.

by metallographic techniques and SEM-EDX by Chen Jianli. The AMS-$^{14}C$ analyses of charcoal and human bones from this tomb and from another tomb containing corroded iron artefacts revealed that both of these tombs can be dated to the 14th century BC. They should thus belong to the local Siwa culture (14th century BC to 11th century BC). The technical study of this artefact showed that it was made with carburised bloomery iron and shaped by forging (Figs. 6 and 7). This new finding may be able to push back the date of the earliest use of anthropogenic iron in China from the 9th century BC to the 14th century BC and provide significant information for the discussion regarding the origin of iron metallurgy in China. Based on current evidence, the use of smelted iron in the Central Plains of China emerged later than in northwest China, but its technology is unique and may indicate an indigenous invention.

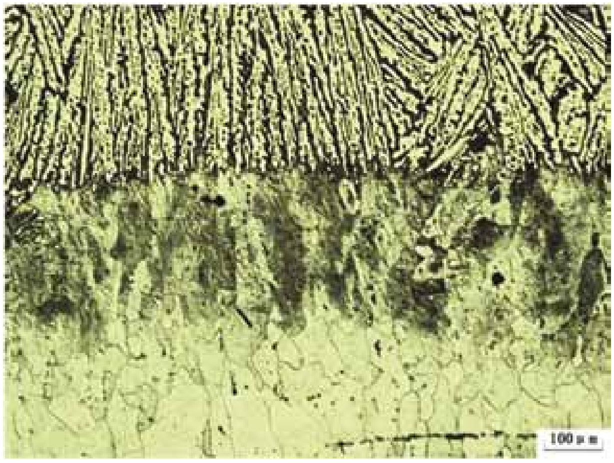

**Figure 8**: The microstructure of decarburised iron unearthed from the Yangying site, Hubei province.

## New findings of cast iron and of steel made from cast iron

One of the most significant developments in ancient Chinese metallurgy was the production and use of cast iron, which became the main focus of the iron making technology following invention of an annealing process for toughening white cast iron and the making of steel from cast iron. The earliest white cast iron fragments in Tianma-Qucun, Shanxi province, were dated to the 8th-7th century BC (Han Rubin, 2000). The annealing process was invented in the early 5th century BC. Several annealing furnaces from the Han Dynasty (Western Han Dynasty 202 BC – 9 AD, Eastern Han Dynasty 25-220 AD) have been excavated at several sites in Henan province, such as Tieshenggou (Archaeology Team of Henan Province, 1962), Guxing (Zhengzhou Museum, 1978) and Wafangzhuang (Henan Provincial Archaeology Institute, 1991).

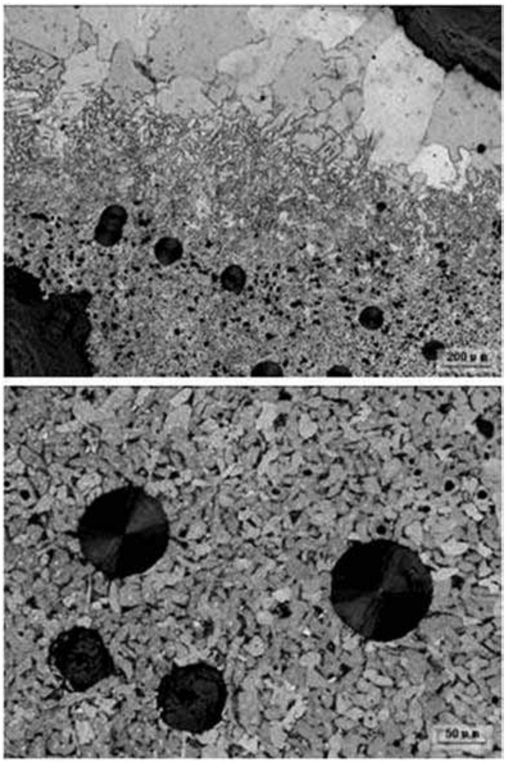

**Figure 9**: Spherical graphite in a malleable iron object excavated from Xinzhen, Henan province.

More than 40 iron objects were found at the Yangying site in Hubei province. Their radiocarbon dates and microstructures show that cast iron, decarburised iron (Fig. 8), and decarburised steel were used at this site. This is one of the earliest pieces of evidence in China that the annealing process was conducted so as to make good use of white cast iron around the 5th-4th century BC. The typical microstructure of decarburised iron consists of ledeburite in the centre of the casting and decarburised layers on the surfaces, i.e. white cast iron encased in steel surface layers. Three iron tools from the Yanying site, Laohekou of Hubei province, and one iron object from Linzi, Shandong province (Chen Jianli, 2007), have this same structure.

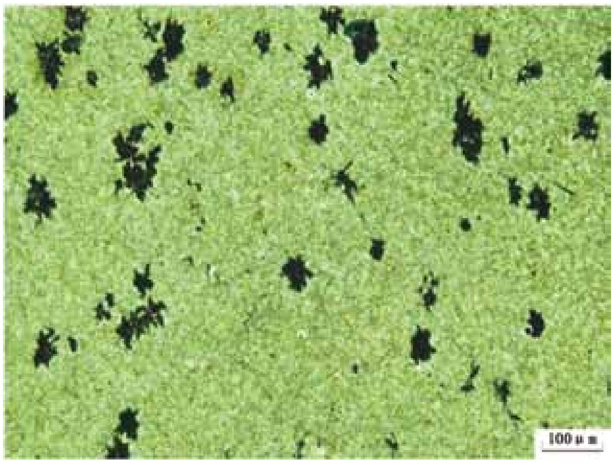

**Figure 10**: The microstructure of a malleable iron tool excavated from Chengcun, Fujian province.

Malleable iron can be forged to a certain extent; this aspect was revealed within several analysed objects, which show broken graphite elongated in the direction of working. A shovel excavated at the Luoyang Cement Factory has the typical structure of black-heart malleable iron, and this is the earliest such example found to date, dating to the 5th century BC (Li Zhong, 1975). It should be noted that spherical graphite was produced during annealing in the course of malleable iron production, which also appeared in the 5th-4th century BC in Xinzhen of Henan province (Fig. 9). An arrowhead and an axe excavated from the Lamadong graves of Liaoning province, dated to the 3rd-4th century AD, were made from black-heart malleable iron, with some snowflake graphite embedded in the ferrite matrix visible in the microstructure (Fig. 10). This represents direct evidence that the Xianbei people living in North China had acquired the annealing techniques by this time (Chen Jianli, et al., 2003).

The examination of ferrous artefacts showed that a simple, economical process of steel making was in use by the 5th century BC in China; thin or narrow plates or tools were cast and then annealed into steel. This type of steel contains little spheroidised carbide without graphite and inclusions (Han Rubin and Ko Tsun, 2007, pp.357-358,383; 377-378.), as visible in the samples of six pairs of scissors from Zhengzhou, a pickaxe from Dengfeng, a ring handle knife from Changzhi, an arrowhead from Mancheng, and objects from the Wangchenggang iron smelting site (Chen Jianli and Han Rubin, 2007), the Shizishan tomb of Jiangsu province (Chen Jianli and Han Rubin, 1999), the Lamadong tombs of Liaoning Province, Tianshui of Gansu (Chen Jianli and Ma Qinglin, 2009), and the Balikun tombs of Xinjiang. Although they were found in different localities, the objects had similar structure (Fig. 11), and mould joint marks still remained on some of them.

The making of steel from cast iron by decementation was simple, economically viable and easily available in adequately high quality. The plates could be transported, traded, and then forged directly into tools and weapons. Some cast iron plates, clay mould materials and objects forged from steel plates dated to the 3rd century BC and the 2nd century AD have been discovered in ancient iron workshops such as Dengfeng, Guxing, Tieshengou, Nanyang in Henan province (Li Jinghua and Chen Changshan, 1995), Dongpingling in Shandong province, and Taicheng in Shaanxi province. New field excavations are being carried out at the Dongpingling and Taicheng sites, and these will be continued for several years by Peking University and other institutions.

A more advanced steel making process, producing 'puddled steel', first appeared in the 2nd century BC and was very popular by the 2nd century AD. Several furnaces used to produce puddled steel in the Han Dynasty were excavated in Tieshenggou, Wafangzhuang, and Zhaohe of Henan province (Li Jinghua and Chen Changshan, 1995). Five pieces of puddled steel objects excavated from the tomb of Shizishan indicate that ironsmiths in the earlier period of the Western Han Dynasty had produced this type of steel (Chen Jianli and Han Rubin, 1999). They were made from steels with different carbon content, produced by puddling followed by forging until the desired content was achieved. A large number of inclusions elongated in the direction of working are present in the matrix of the steels (Fig. 12).

This was the earliest finding in China that confirmed that the puddling technique had been used by the middle of the 2nd century BC. More than 10 pieces of steel weapons made of puddled steel during the Han Dynasty, excavated from tombs at Suizhou, Hubei province; Hezhang, Guizhou province (Chen Jianli, et al., 2008a);the Chengcun site of Fujian province (Chen Jianli, et al., 2008c), and other sites in Gansu province indicate that puddled steel technology was widely used during that time. A puddled steel plate originating from the Lamadong graves contains large quantities of inclusions and has a non-uniform structure with different carbon distribution and grain size. It is possible that the raw output of the puddling process was exchanged between different areas (Chen Jianli, et al., 2003). *Hundredfold Refined steel* (*Bailiangang steel)* 百炼钢 was developed after the spread of puddled steel during the 1st-2nd century AD.

Grey cast iron objects appeared in the Warring States period (475-221 BC) at the Yangying site in Hubei province (about the 4th century BC), the Yanxiadu site in Hebei province (about the 3rd century BC) (Li Zhongda, et al., 1996) and the Tonglushan site of Hubei province (about the 3rd century BC) (Ye Jun, 1975). More grey cast iron was produced after the Western Han Dynasty, as indicated by the objects found in the Mancheng tomb (113 BC) of Hebei province (Optical Microscopy Laboratory at Beijing University of Iron and Steel Technology, 1980), the Wangchenggang iron-making site (Fig. 13) (Chen Jianli and Han Rubin, 2007), the Lingtai site of Gansu province (Chen Jianli and Ma Qinglin, 2009), and the Chengcun site of Fujian province (Chen Jianli, et al., 2008c). Many large objects, such as the iron lion of Cangzhou (953 AD) (Song Wei, et al., 2009) and the iron men and oxen of Pujindu (Chen Jianli, et al., 2008b), were made from grey cast iron.

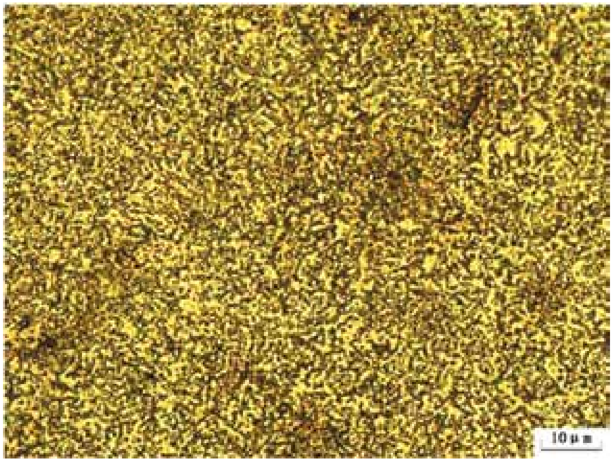


**Figure 11**: The microstructure of decarburised steel objects excavated from Hezhang, Guizhou province.

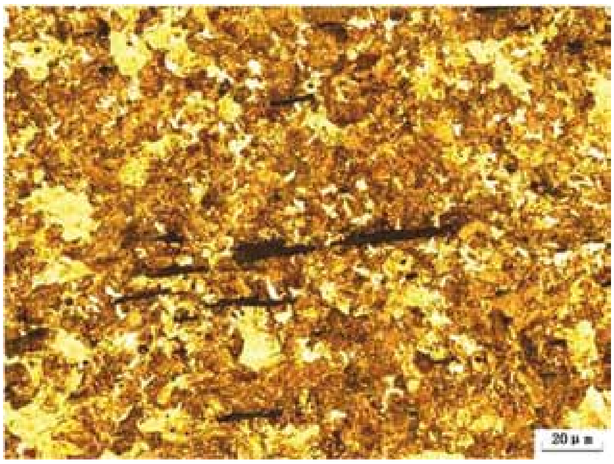


**Figure 12**: The microstructure of a puddling steel sword excavated from Suizhou, Hubei province.

Based on these results, a brief schematic system of iron- and steel-making techniques in ancient China can be illustrated in the following diagram (Fig. 14).

The history of iron and steel technology in ancient China and its neighbouring countries is of great importance and relevance for the study of the development of the politics, economy, and culture of these countries. In recent years, researchers from many countries have published books and papers that discuss the development of iron and steel technologies in China, employing archaeological, typological, and archaeometallurgical methods. Scientific research on iron and steel artefacts and smelting methods in China, however, has so far focused on objects and sites from Central China, with little attention being paid to the metal findings in other areas.

Microstructural analyses of iron and steel artefacts excavated from Laoheshen and Lamadong, two important sites in Northeast China, show that pig iron, decarburised cast iron, malleable iron, puddled steel, *nip steel* 夹钢, and *Guangang steel* 灌钢 were widely used. The *Guangang* process is to seal pieces of cast iron and wrought iron layer by layer and heat them; the carbon within cast iron will diffuse into the wrought iron, and all the parts will become steel. This procedure indicates that these artefacts were made by workers with relatively high-level skills. It is possible that the raw steel materials came from the Central Plains, as one piece of puddled steel bar was found in the tombs. Comparative studies on materials and manufacturing techniques of iron artefacts between northeast China and Central China show that the beginning of the use of man-made iron in northeast China was later than that in Central China, and the techniques and styles of iron objects in Northeast China were strongly influenced by the latter. The appearance of ironware, raw iron and steel materials, and iron smelting did not occur at the same time in northeast China. First, iron objects brought from other areas were used, followed by raw materials for making implements, and finally the skills of iron smelting were mastered. We suggest that war, migration, robbery, and other actions among people living in different areas accelerated the spread of advanced iron technology from Central China to northeast China (Chen Jianli, et al., 2005).

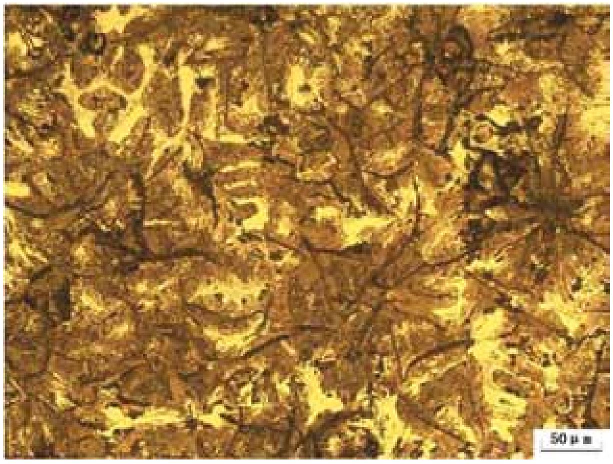


**Figure 13**: A grey cast iron object excavated from the Chengcun site, Fujian province.

## Conclusions

This study provides new evidence for understanding the beginning of iron smelting in China. Most of the previously-known iron objects of the period between the late Western Zhou Dynasty (the Western Zhou Dynasty, 1050-771 BC) and the early Spring and Autumn period were excavated in the region at the junction of the Henan, Shanxi and Shaanxi provinces, in the middle reaches of the Yellow River. This suggests that this region might be one of the earliest centres of iron smelting technology in China and deserves further archaeological research. As early iron products were also

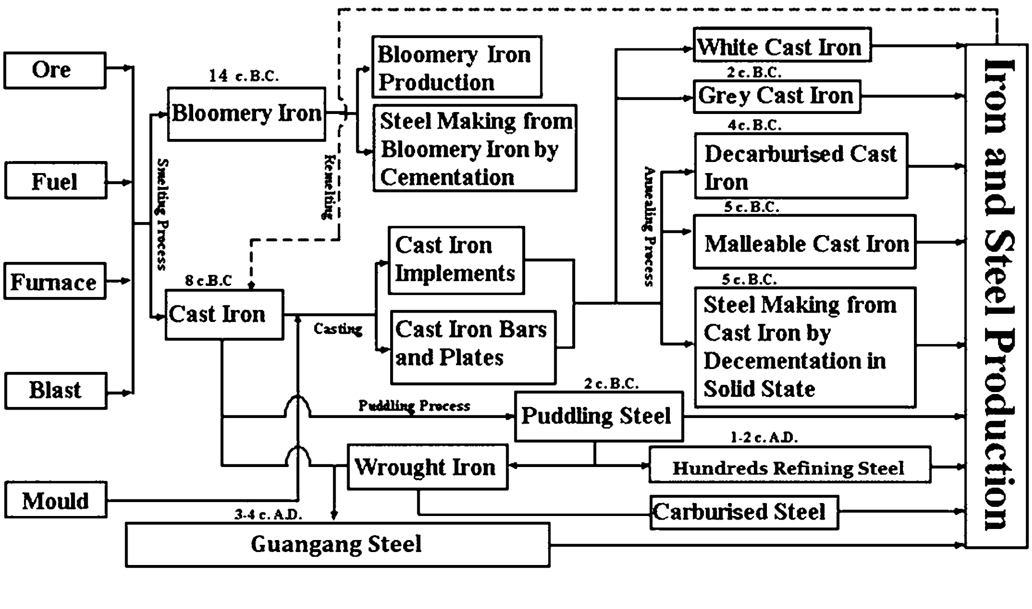


**Figure 14**: The system of iron and steel production techniques in ancient China.

discovered in the upper reaches of the Yellow River and in Xinjiang, appropriate attention should also be paid to the relationship between these two areas in terms of the origin of iron smelting. New findings at the Mogou site may be able to push back the date of the earliest use of anthropogenic iron in China from the 9th century BC to the 14th century BC and provide significant information for the discussion regarding the origin of iron metallurgy in China.

This paper also provides new evidence for understanding the wide use of cast iron and of steel made from cast iron. From the 8th-7th century BC, the Chinese began to use cast iron, and cast iron objects were used to a larger degree from about the 6th century BC onwards. Around this time, annealing processes were developed to produce decarburised cast iron, malleable cast iron, and decarburised steel. During the 2nd century BC, puddled steel objects appeared in Central China and soon the technology was widely spread into neighbouring areas. Coal was used as fuel for mould baking at the iron foundry sites of the Han Dynasty, but not for iron smelting until the 11th century AD.

## Acknowledgements

This research was supported by NSFC (No.51074010) and the State Administration of Cultural Heritage of China. We are especially grateful to Professors Ko Tsun, Sun Shuyun, Li Yanxiang, and Mei Jianjun from the University of Science and Technology Beijing, and Professors Chen Tiemei and Wu Xiaohong from Peking University for their useful supervision, advice and help with the research.

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