Ironworking in ancient China: a review of two recent publications

Brian Gilmour

Iron and steel in ancient China by Donald B Wagner. *E J Brill (Handbook of oriental studies Vol 9), Leiden, 1993. ISBN 90 04 09632 9. Price not stated.*

The traditional Chinese iron industry and its modern fate by Donald B Wagner. *Nordic Institute of Asian Studies Report 32, Curzon Press, Richmond, 1997. xii+106pp, 225x145mm, 29 figs, index. ISBN 0 7007 0951 7. £35-00.*

The aim of the first of these publications, a large and excellent book, is to study this industry in its main formative phase in the pre-Han period, between the beginning of the Iron Age in China and 206 BC, which saw the fall of the short-lived Qin Dynasty. Inevitably much material from the Han period (from which much more survives) have been included and the book is the richer for it.

It is well known that what marks out the Chinese iron industry is its very early adoption of cast iron and its main derivative, wrought iron; although steel was made from cast iron as well. During the Han period this industry reached a scale unsurpassed in the ancient world, which meant that China was the largest producer (if not exporter) of iron before the Western Industrial Revolution in the 18th century. This has meant that rather than the early iron industries in other parts of the world being carefully compared with that in China with all the underlying factors and evidence considered, including what might be missing, there has been a tendency to consider early iron industries outside China as primitive by comparison, which accumulating evidence is slowly disproving.

In the introductory Chapter 1 the development, organization and scale of the preceding bronze industry in the heartland of ancient China (the north-eastern part of central modern China) is examined, as this is important in showing the conditions which allowed the iron industry to develop. The bronze industry reached its height during the Shang period (*c*1500-1122 BC) and the better known Zhou dynasty (1122-771 BC). Like the iron industry which followed, the scale of this industry was unprecedented. This was made possible by a single geological freak, an enormous, sulphur-free copper (oxide) ore deposit at Tonglüshan in Daye County, Hubei Province. Estimates of the output of these workings (which covered an area two kilometres long by one kilometre wide) vary between 40,000 and 100,000 tons of copper. Curiously the source of the corresponding 4,000 to 10,000 tons of tin, with which this must have been alloyed, is not mentioned. Most if not all the bronze produced by this centrally controlled industry was used in the production of ritual vessels and of weapons, its use for other things being prohibited. This industry resulted in a great variety of bronze vessels, often very large, which in turn demanded a well developed bronze casting technology.

Copper smelting remains at Tonglüshan include a series of shaft furnaces, as much as 2m high with a maximum shaft diameter of 60cm. These are dated around 6th century BC on stratigraphic grounds and are essentially blast furnaces for the production of copper. They are similar in size to the dwarf blast furnaces of the Dabieshan region of southern Henan, eastern Hubei and western Anhui which were part of a traditional cast iron industry which survived well into the present century (see below) and which were as little as 30cm and up to about 2m high. Fragments of raw copper found at Tonglüshan were high in iron, indicating the use of iron oxides as fluxes and, as is pointed out, it is not hard to see how by having a more reducing blast, the same furnaces, using much the same charge and operating at similar temperatures, could produce molten iron as well as copper.

The earliest use of iron in China is discussed in Chapter 2. When this was written it was not known whether or not the production of bloomery iron in China predated that of cast iron as there was no definite evidence for either before the 6th century BC. Different early written sources which appear in the Shu jing, a collection of ancient texts, suggest that iron was known in China in the period before 600 BC. At the time this book was written the earliest reliably dated iron artefacts were a lump of cast iron and a wrought (?bloomery) iron rod of *c*500 BC (found in a tomb in the eastern province of Jiangsu but in the independent state of Wu at the time). This area produced iron artefacts (a knife and sickle) possibly as early as the 9th century BC, but the dating of these is controversial. Another interesting early artefact is an iron-bladed sword with a cast-on bronze hilt (p 94; Fig 2.42) probably dating to the 8th century BC, found further west in a Qin tomb in the province of

Shaanxi, suggesting, at least, an earlier familiarity with iron in this western part of early China.

The iron used for this sword is as yet unidentified and the author suggests that there is a real possibility that the iron used here is meteoric in origin citing the three other cases where meteoric iron has been reported with bronze cast-on in a similar way. Given the importance of trying to sort out both the chronology and stages through which the introduction of iron in China might have gone, it seems important that the occurrence of other iron objects, particularly swords, with cast-on bronze parts in the Bronze Age-Iron Age overlap period should be mentioned. Examples include the Luristan sword hilts from western Iran, arguably dated to around 12th-11th centuries BC, and long, iron-bladed swords from eastern Europe which have both cast-on bronze and skeumorphic iron hilts (in this case forged iron copies of contemporary cast bronze examples) — which can be seen in the Ashmolean Museum, Oxford.

The earliest iron finds in this region of eastern or south-eastern China form part of a thesis which the author floats in Chapter 3, that iron was first used and probably discovered in the early, non-Chinese state of Wu most probably in the 6th century BC and that cast iron might even have preceded wrought or bloomery iron. Here the author was very unlucky for no sooner was the book submitted for publication than more secure evidence for bloomery iron artefacts — a jade hilted sword and a cast-on bronze hilted dagger — dating 9th-8th centuries BC were found near the Yellow River at Sanmenxia in Henan province (and reported by Han Rubin at the BUMA III conference in May 1994, and again at the BUMA IV Forum meeting at Matsui in January 1996, but unfortunately not published in the proceedings from that meeting).

It is clear however from the evidence presented here that there have been other early cast iron finds from much further afield, notably from tombs in the Qin state which lay in the area straddling parts of the modern provinces of Gansu and Shaanxi, some 600 miles (1000km) or so west of the state of Wu. For instance, also reported (on p 92-3) is the find of a cast iron spade head in the backfill of one enormous (undisturbed) tomb, tentatively identified as that of Duke Jinggong of Qin (d 537 BC).

There seems to be no evidence for cast iron production before this time and the scattered early evidence, presented here, suggests that cast iron technology developed in this general region of China in the 6th century BC. The rest of this chapter is devoted to the background events that may have led to this technological breakthrough which so completely changed the face of Chinese iron technology, setting it apart from that of the rest of the world for most of the next two thousand years. It is argued that much greater Chinese influence in the early eastern states of Wu and Yue followed the Zhou conquest of Shang (traditionally) in 1122 BC. During the first part of the period following this, Chinese bronzes were exported into Wu from Chinese regions to the north-west where bronze production was a very tightly controlled, centralized industry, this being easier to achieve given that the large scale production of this industry centred on the huge, non sulphide (therefore easier to produce) copper deposit at Tonglüshan. This and the lack of central control in Wu led to the development of a local bronze casting technology based on much smaller scattered copper sulphide ore deposits, identifiable amongst other things by the adoption of lost-wax casting and the use of stone moulds, rather than a reliance on multi-part piece moulding.

Some of these sulphide copper ore deposits are also very high in iron which would soon have led to the accidental production of cast iron. Given a low silicon content and likely contamination by sulphur, this would have consisted of white cast iron — this being borne out by metallographic analysis of early cast iron pieces — which is much more difficult to cast successfully than bronze as it shrinks (up to about 5%) on solidification as well as being very brittle and extremely hard. This is likely to have been mastered in Wu with its smaller scale, more basic casting technology and the greater freedom for experimentation which led amongst other things to the use of bronze for agricultural implements, exceptional (as Wagner points out) anywhere in the Bronze Age.

The author however recognizes problems with this argument, such as the lack of iron implements in tumuli of the Chu period of the 4th century BC in this region, when they are common elsewhere in China. It is pointed out that this is only a working hypothesis awaiting revision in the light of further archaeological discoveries, although there seems little doubt that the revolutionary breakthroughs, which soon led to the adoption of a cast iron, blast furnace-based technology across ancient China, had been made by sometime in the 6th century BC. This may well have started in Wu with the unusual combination of local circumstances.

The most predictable of these archaeological developments has of course already been made with the discovery that directly smelted bloomery iron was known and used in the ancient heartland of China as early as the 9th century BC. It seems that the final impetus for the adoption of iron casting technology could have been provided by knowledge that iron artefacts could be desirable or useful.

This hardly affects the surviving body of surviving pre-Han Chinese ironwork, the greater proportion of which belongs to the 5th-3rd century BC period. Chapter 4, much the longest in the book, is a detailed and well illustrated description and discussion of all the important cast iron, wrought iron and steel finds known from this formative period of early Chinese iron technology and these findings are set into a general historical framework or matched with specific events known from written sources. Although the focus is on pre-Han contexts, Han period material is brought into the discussion where this sheds light on what happened earlier.

Various interesting things, and sometimes only further interpretation problems, emerge from this survey of early iron artefacts. For instance it turns out that bronze continues to be the material of symbolic importance for weapons: the army of terracotta soldiers, found in the grave of the first Emperor (d 206 BC), are nearly all armed with bronze weapons, the only exceptions being one iron and five bronze-iron crossbow bolts compared with 6,806 made of bronze. Set against this is the case of the mass grave of fallen soldiers in the northern state of Yan (60 miles or 100 km south-west of Beijing, in Yixian County, Hebei) probably in the early 3rd century BC. Here 22 graves (out of an original probable total of 30) were found with 15 swords and 19 spearheads made of iron or steel together with 12 halberd heads which were the only bronze weapons. Quench-hardened steel is reported for at least some of these weapons showing a familiarity with steel heat-treatments by this time.

It appears that long swords, typically 70 to 100cm long and both of bronze and iron or steel, make their appearance in China in the mid 3rd century BC but the author makes the point that it is not even understood to what extent, or even if any of these were intended as practical weapons. The situation seems confusing but he also emphasises that most of what survives has been found in graves which are likely to contain material of symbolic importance. He goes on to point out that advances of the Qin state during the 3rd century BC are likely to be partly the result of the mastery of iron and steel technology, and partly good centralized organization of the state, and if a minor state like Yan had a well developed iron and steel industry, the same must have been true for the dominant Qin state.

Chapter 5 covers the ironworks and iron-masters of the 3rd century BC although it is clear that not much is known in detail of the period up to the imposition of the Han state monopoly on ironwork in 117 BC, by which time large scale ironworks had been established. It is not at all clear how typical they are of the industry over the preceding two centuries, although it seems very likely that it was dominated by a series of wealthy ironmasters. The scale of the industry is hinted at by the probable use of water power as early as the 3rd century BC, this being suggested by the siting of some iron-making sites on rivers a relatively long way from the nearest ore source.

The following two chapters cover metallographic studies of early ferrous objects, those made of wrought iron or steel (Chapter 6) and those made of cast iron (Chapter 7). He begins with a good introduction to the metallography and basic metallurgy of iron and steel and goes on to describe the forging techniques used by iron smiths, including hammer (solid-phase) welding, plus heat treatments for hardening (quenching) and softening (annealing), all of which are encountered in early Chinese ferrous artefacts. This part of the book reveals some interesting parallels with techniques used by medieval and earlier ironsmiths in the West.

Of particular interest is the ‘hundred-fold [or similar] refined’ steel which is mentioned in poetry as early as the 3rd or 2nd century BC and is found inscribed on swords and knives of the 1st century AD and later. Two which have been metallographically examined are a ring pommel ‘thirty-fold refined’ sabre of 112 AD and a ‘fifty-fold refined’ long sword (p 283-4; Figs 6.24-7). The etched sections of these are reported as showing up 30 and 60 layers respectively and in the case of the sword (micrograph 6.27) there are clearly alternating higher and lower carbon laminations which also show higher and lower phosphorus contents. These are essentially piled or laminated structures made up (certainly in the case of the sword) from what started as two different pieces of metal hammer-welded together then either folded and welded again, or cut and stacked and welded together, the process being repeated until the intended number of layers was achieved.

Han Rubin and Ke Jun (?Ko Tsun) have suggested (p 285) that ‘refining’ (*lian*) specifically refers to this laminating process and the number quoted would have shown (in round terms) the number of layers represented. It seems that techniques such as these may have been developed as a way of evening out the carbon contents of steels which were inhomogeneous when first made, irrespective of whether bloomery, crucible smelting, or finery production techniques were used. The laminated structure of the fiftyfold-refined sword described here would have produced a very striking surface appearance if this had been polished and etched, and I think this could be an early Chinese version of pattern-welding.

Before leaving this suggestion I would refer the reader back to the example of the early-mid 3rd century BC find of the mass grave (M 44) of the fallen soldiers of the early northern state of Yan. Two relatively low magnification micrographs plus a sketch of the complete macro-structure of the section from one of the 15 ferrous swords (M 44.100) from this grave are shown (p 299). These show an uncanny resemblance to very early examples of pattern-welding used for at least some late Iron Age swords in England (perhaps two to three centuries later than their

Chinese counterparts and with no conceivable connection). Again, could this be a pointer towards the independent development of a form of pattern-welding in China in this period, to my mind a much less unlikely development than the independent discovery of iron in China.

Another surprise with this sword (M 44.100; see p 462-463) from the fallen warrior tomb is that it seems not to be a finery product but to be made of bloomery metal or possibly the product of crucible smelting. Much of the blade is made of steel (see Fig 6.7) and more recently it has been reported (by Han Rubin in her unpublished paper 'The Development of the Chinese Ancient Blast Furnace' presented at the BUMA IV Forum meeting at Matsui, Japan in January 1996) that the bloomery process continued to be used in China for making steel until the 1st century BC. This is yet another indication that during the bloomery era in different parts of the world steel was produced as a bloom product, not by a subsequent carburisation process. Presumably this was superceded in the production of steel by developments in cast iron decarburisation, and possibly crucible processes, which has obvious implications for the origin and development of crucible processes in the Fergana region (formerly) of north-eastern Iran in the Parthian period.

Finally in Chapter 7 we come to cast iron technology, which again is very well covered. Cast iron technology became widely used during the 4th century BC, one of the more striking early developments being the making of 'malleable' cast iron, the product of an annealing treatment of white cast iron, the (almost) invariable end product of the blast furnace smelting process in early China, given that the metal was very low in silicon. The author mentions that malleable cast iron is unknown before an English patent of 1671 and not important in the Western iron industry before the 19th century.

This 17th century reference is to a patent granted in May 1671 to Prince Rupert, who dabbled in metallurgy in Restoration England, and claimed to have developed a process for annealing cast iron ordnance '…for preparing and softening all cast or melted iron so that it may be fyled and wrought as forged Iron is…' (Barter-Bailey; *Prince Rupert's Patent Guns*; Royal Armouries, forthcoming monograph). Over the following 10 years (according to Samual Pepys) Prince Rupert was paid about £52,000 (an enormous sum in the 17th century) for processing thousands of tons of 'Neal'd and Turn'd' pieces of ordnance (*ie* cannons) by a so-called annealing process which he claimed to be a success, although there is no significant evidence for this. I have looked at a few samples from cannon that were put through Prince Rupert's 'annealing' process and not surprisingly they consist of unaltered grey cast iron, invariably the form of cast iron found in the kind of guns he was dealing with. The annealing process used in early China was successful because it was carried out on relatively small castings, low in silicon which therefore solidified as white cast iron. It was already in decline as a technique by the 4th century AD in China, only finally dropping out of use around the 9th century. It seems that the period between the 6th and 2nd centuries BC was one of innovation and rapid progress in the iron industry in China, for instance with the introduction of waterpower for iron-making being used by about the 3rd century BC. All the main technological advances seem to have been made before the end of the Han Dynasty and that it was during this latter period that the scale of the industry rose to a point unsurpassed until the 18th century Industrial Revolution in the West.

The author was attracted by the idea that the use of bloomery iron might have developed independently from that of the West, although it seems to me that five centuries is a believable time for it to have filtered though to western China given that it may have reached northern Iran as early as the 14th or 13th century BC. It seems to have taken about this long before its use was established in western Europe, a broadly comparable distance. It also appears from the researches of Han Rubin and others that bronze-hilted objects using meteoric iron (assuming it was this rather than iron smelted from nickel rich ores, which are admittedly rare) had appeared in central and western China as early as the 14th century BC and so iron must have been a familiar material by the 9th century.

One criticism of this book is the lack of a good general map to show, even approximately, the areas covered by the early states, particularly Wu, Chu and Qin (running east to west in northern central China) and Yue to the south of Wu, in the area of Zhejiang province, south of Shanghai. This seems surprising given the inclusion of a map (p 17) showing seven of the most important city sites in the Shang era, positioned in relation to the modern states, although there is no scale shown either in this map or the introductory maps (preceding p 1).

It would have been instructive to have included illustrations, preferably schematic reconstructions, of the types of furnaces that might have been used for the early iron-making discussed, even if examples from the Han period (206 BC to AD 220) had to be used (much other Han period evidence having been drawn in) for want of earlier evidence. For example a diagrammatic summary of the different stages in the iron-making cycle found at the Han No 1 Ironworks ? at Tieshengg, Gongxian County in the province of Henan, would have served very well as the information is virtually unknown in the West. A list of illustrations would have been helpful. This is a heavy weight book (in every respect) but expensive (now at £100), although likely to remain the standard work on the subject until the author can complete what should be a truly monumental book, the volume in the Science and Civilisation series which adds the Han and later period to the earlier industry which is covered by the present book. Don Wagner skilfully puts together a very readable and cohesive account of the known remains of the early Chinese iron industry from very scattered and scanty evidence. He was unlucky that the definite evidence for bloomery iron reaching China a good three centuries before the development cast iron technology was found so soon after the completion of this book although the warning signs were already there, particularly the bronze-hafted iron sword (Fig 2.42) found in a Qin tomb.

The traditional iron industry of China that survived into modern times looks as if it gradually evolved to suit the needs of local areas or wider regions. Hopefully Don Wagner will fill in the gaps in this story with the more complete volume on the iron industry in the Science and Civilization in China series. The earliest use of iron in China is further discussed in a forthcoming paper of that name of which Don Wagner was kind enough to send me a copy, and in this he examines in detail the more recent evidence and its implications.

The more recent of these two books describes the final phase of Chinese traditional iron-making during the 19th and early 20th centuries. A very short general summary (Chapter 3) of traditional Chinese iron production techniques is followed by a chapter each (Chapters 4 to 7) on the four production areas. Finally in Chapter 8 the main factors which governed the survival, decline or disappearance of the traditional Chinese iron industry are summarised.

The regions were chosen on the basis of availability of information as well as the variety of traditional iron technologies represented. The fortunes of the four geographically separate regions were very different, as they reacted to changing economic circumstances, brought about firstly by increasing foreign competition and the Opium Wars of the 19th century, but later also by successive political upheavals — World War I, the Sino-Japanese War, and China's isolation after the revolution of 1949. The final dramatic phase came with the Great Leap Forward of 1958-1960, when a massive expansion of the traditional iron industry was launched, doomed to end as a failure except in a few instances. This was because the traditional iron industry had long ceased to operate in most areas. Only in the remote, poorer regions like Dabieshan were there still people who knew traditional iron production techniques.

One statement in Peter Nolan's Foreword, which introduces the study of the iron industries, now requires correction. This is that the Chinese began to 'cast iron almost as soon as they knew about it at all', around the 6th century BC; in fact, the use of bloomery iron in China is now known as early as the 9th century BC in Henan province. The introduction of cast iron production may have marked the point at which the Chinese iron industry began to expand, growing to become the leading producer of iron for over two millennia, until the Industrial Revolution in the West altered the picture the 18th century.

The first area described is Dabieshan, an isolated mountainous region spanning the provinces of southern Henan, north-western Hubei and western Anhui. The traditional iron industry here had evolved into a distinctive form, based on many very small blast furnaces mostly about 2.2m in height. The walls were made of a mixture of loess subsoil, sand and straw, lined inside with a refractory mixture of about 60% charcoal, the whole construction reinforced with iron bands. A rich iron sand (of 49-65% Fe) recovered from river deposits was used with charcoal as fuel. Tapping of both iron and slag was achieved by tipping the whole furnace (by 20-30% to judge from Fig 4). The cast iron smelted in these furnaces was converted to wrought iron in small fusing hearths often operated in pairs, blown by a single traditional (double acting) windbox bellows, the same type as used to provide the blast for the furnaces. These small and rather primitive-seeming furnaces evolved in a way which suited the needs of this region and, unlike many others, survived well into the 20th century. This was partly because of the small scale on which they operated and partly because the area was so remote, that imported iron had much less impact than elsewhere.

The Red Basin of Sichuan province, 500 miles (800 km) to the west-south-west, is a complete contrast to Dabieshan. Over the past few centuries this has mainly been due to a large population, good transport systems within the region, and relative isolation from rival iron industries further afield. Such factors led to the development of the largest blast furnaces to be found anywhere in China, typically stone built and about 9m (30ft) high and 6m (20ft) square at the base. Several descriptions mention the use of water power to drive the bellows which, in at least one case, was a cylindrical version of the traditional box (or in this case, piston) but much larger, 1m across by 3.5m long. A wider variety of ores seems to have been used, sometimes (before 1900) with limestone as a flux, but almost invariably charcoal was used as the fuel. Curiously, after 1815 only people power is mentioned for the driving of the bellows. This seems to be one of the signs of the gradual impoverishment, during the 19th and 20th centuries, of what earlier had been a highly developed industry. Sand moulds were used to produce rectangular cast (pig) iron plates, typically about 80–100cm long, 50-60cm wide by 2cm thick, weighing 60kg or more. These were broken up for conversion to wrought iron by a method very similar to the 'puddling' process patented by Henry Cort in 1784.

In north-eastern China about 420 miles (650 km) north-west of Dabieshan,a different traditional iron industry developed, mostly in Shanxi province. Here smelting was carried out in crucibles described in 1870 as being 15 inches (38cm) high by 6 inches (15cm) wide, filled with a mixture of crushed anthracite and crushed iron ore. 150 or more such crucibles were packed in anthracite and arranged in successive layers for firing. The arrangements and procedures were varied depending on whether cast or wrought iron was wanted. This area was known for its export of speciality products such as scissors, mentioned by a Tang poet (many centuries before scissors were known in the West), and was for centuries the main supplier of needles used in China. Production declined in the face of competition, and crucible smelting finally ceased at the time of the Great Leap Forward in the late 1950s.

1000 miles (1600km) away in south China in the mountainous, sub-tropical province of Guangdong, the traditional iron industry had both large and small-scale furnaces. The latter were similar to those in Dabieshan, and were also tipped to enable the slag and iron to be tapped. These furnaces were used not only for smelting but also as cupola furnaces to melt pig or scrap iron for casting. The small scale ironworks supplied the local needs of the region while much larger ironworks produced for export, mainly through Guangzhou (Canton). Less is known about how this industry operated, although it is clear that fining or puddling hearths were also used. The region's position made its traditional iron industry vulnerable to foreign competition and it was already in decline by the late 19th century, by which time the large furnaces had ceased production, although small-scale production survived into the 1950s and beyond.

The author has presented his material in a meticulous, methodical way, producing a readable, interesting and informative account.

Address: 20, Squitchey Lane, Summertown, Oxford OX2 7LB