Cast Iron Smelting and Fining: An Iron Smelting Site of the Eastern Han Dynasty in Xuxiebian, Sichuan Province, China

Yuniu LI*
Sichuan University
Chunyan MA
Chengdu City Institute of Cultural Relics and Archaeology
Yasuyuki MURAKAMI
Ehime University
Zhiqing ZHOU
Chengdu City Institute of Cultural Relics and Archaeology
Yingdong YANG
Chengdu City Institute of Cultural Relics and Archaeology
Yingfu LI**
Sichuan University

ABSTRACT

In this article, we introduce the excavation of an iron smelting site at Xuxiebian, Pujiang County, Sichuan Province in the PRC. Two excavations were carried out in 2007 and 2011, and a total of four bowl-shaped furnaces, five pits, two trenches, and one posthole were excavated. The site is dated from the mid-late Eastern Han dynasty to the Jin dynasty (ca. AD 150–420) according to the local pottery assemblage. It is possible that the sole functions of the Xuxiebian site were the production of pig iron ingots and the conversion of pig iron to wrought iron. The iron ingots were likely transported to areas with stronger administrative control by the central government near the ancient city of Chengdu or even to the Central Plains, where they were then cast into different objects.

Keywords: Iron smelting site; Eastern Han dynasty; fining process; bowl-shaped furnace; Southwest China.

Introduction

According to archaeological discoveries, cast iron and steel making technologies were established and consolidated in China during the Warring States period (475–221 BC) and the Qin 秦 (221–206 BC) and Han 汉 dynasties (202 BC–AD 220), when iron and steel objects were used in many areas (Bai 2005, 116; Han et al. 2007, 440; Wagner 2008, 115).

Sichuan Province is regarded as the most important area for iron smelting
and production in Southwest China during the Qin and Han dynasties. The Shiji 史记 records that the Qin government forced the ancestors of the Zhuo 卓 and Cheng 程 families, the smelters from north and northeast China, to move to the state of Shu 蜀 (modern-day central Sichuan) when Qin conquered the Zhao 赵 state (located in parts of modern Shanxi 山西, Shandong 山东, and Hebei 河北) in the third century BC (Sima 1982, 3277–3278; translated in Wagner 1993, 165). According to the Shiji, in 117 BC, salt and iron production were monopolized by the government, and fifty government-controlled offices responsible for iron smelting and production activities, called Tieguan 鐵官, were set up in different counties and prefectures by Emperor Wu 汉武帝 of the Western Han, with three being established in the prefectures of Linqiong 临邛 (modern Pujiang and Qionglai 邛崃, Sichuan), Wuyang 武阳 (modern Pengshan 彭山, Sichuan), and Nan'an 南安 (modern Zigong 自贡, Sichuan). In addition, in the Hanshu 漢書 (The history of the Former Han dynasty, 206 BC–AD 23), compiled by Ban Gu 班固 (AD 32–92) in AD 80, Tieguan were divided into two classes, large and small, depending on whether or not iron resources could be found within the county where the Tieguan was situated (Ban 1999, 976). The one in Linqiong prefecture was a large Tieguan that included mining, smelting, and selling in one operation.

The iron production of Southwest China has become a topic of interest in recent years. There are studies on the characteristics of both the bowl-shaped

Figure 1. Map of the distribution of the iron smelting sites discovered in Southwest China

* First author.
** Corresponding author.
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(Li 2014a, 2014b) and blast furnaces (Liu et al. 2017). Metallographic analyses of iron objects excavated from Southwest China have been conducted (Chen et al. 2008; Li 2011; Li et al. 2016; Li et al. 2018), along with compositional analyses of slag discovered at iron smelting sites (Chen et al. 2009; Huang et al. 2011, 2012a, 2012b, 2012c). However, there is a lack of systematic studies of iron smelting sites in Southwest China. Two excavation reports of the Tieniucun 铁牛村 iron smelting site were published, but they only provided a cursory examination of the functions of the features and the sites that were discovered (Zhou et al. 2008; Zhou et al. 2011).

From 1981 to 1985, fifty-seven iron smelting-related sites in Pujiang County were discovered and recorded in the second National Survey of Cultural Relics of China (He 1986). Based on this evidence, from 2005 to 2010, Chengdu City Institute of Cultural Relics and Archaeology (China), Sichuan University (China), and Ehime University (Japan) carried out a regional archaeological survey of ancient metallurgical sites in Pujiang and Qionglai Counties, Sichuan Province. A total of seventy-four sites related to iron smelting were reconfirmed or newly discovered (Figure 1). In this paper, we provide a systematic study of the Xuxiebian iron smelting site discovered in Pujiang, Sichuan, and discuss its function and the structure of the late Eastern Han (ca. AD 150–220) iron industry in Southwest China.

Technological Background

Two routes to producing iron, the direct and indirect, are recognised in iron metallurgy. The direct route is often called the “bloomery process” and the indirect route is that which utilizes a blast furnace. The differences between the two processes are many, but the most significant is that direct or bloomery smelting produces a soft, heterogeneously carburized, solid-state mass of iron known as a “bloom,” while the indirect or blast furnace process produces a hard, high-carbon but brittle molten iron that can then be cast. Both products then needed further fining treatments.

Bloomery smelting was the main method used in early Europe, India, and the Near East (Jobey 1962; Deo 1985; Khakhutaishvili 2009). According to Tylecote (1976, 40–41), ironworking of the early European Iron Age focused on smelting and hot forging. The latter could have been known first and practised on meteoric iron. In China, the earliest evidence of bloomery iron production are two unidentified objects dated to the fourteenth century BC that were excavated in Gansu Province (Chen et al. 2012), but no actual evidence of bloomery smelting before the fifth century BC has been discovered in China (Li 2014a, 65).

In ancient China, it was the blast furnace, cast iron method that was the primary means of iron and steel production. The earliest cast iron objects appeared in China no later than the Spring and Autumn period (eighth-century BC) (Han 2000, 1178). In contrast, for example, to family-based iron smelting activities in Britain in the second century BC (Cunliffe 1991, 454), in ancient China, ca. 117 BC, salt and iron production were monopolized by the state (Wang 1958; Wagner 1993, 2008). The iron smelting activities in ancient China at this time were large-scale and well controlled by the central government.
Tylecote (1976, 41) indicated that if the ratio of fuel to ore is substantial and the bellows are efficient, iron can be made to absorb so much carbon that it forms an alloy of iron and carbon or “cast iron,” which melts at 1,150°C and forms pools at the bottom of the furnace. When cooled, these liquated lumps can be broken up and re-melted in a crucible in a hot smithing forge and then cast like bronze.

The furnaces that produced cast iron in ancient China are called “iron blast furnaces” or “blast furnaces.” A blast furnace produces iron with a high carbon content and therefore a lower melting point. The iron forms in the furnace in the molten state and is then cast, either as “pigs” (ingots) for later remelting, or, as in early European practice, directly into moulds of the intended products. A blast furnace is vastly more efficient than a bloomery furnace, and in modern industry virtually all iron is produced in blast furnaces (Wagner 1993, 178).

The blast furnaces discovered in China have been dated to as early as the third-century BC, and are inherently oriented towards large-scale production. It is almost technically impossible to produce less than perhaps a half-ton of iron per day, and efficiency rises dramatically as production increases. Efficiency also requires that the furnace be operated continuously over long periods; under pre-modern conditions, perhaps a week or a month at a time. The operation of a blast furnace thus requires a greater degree of reliability in all aspects of production, especially with respect to fuel and ore sources, labour, markets, and transportation (Wagner 1993, 239). The original size of the Western Han blast furnace from Guxingzhen, Zhengzhou, Henan Province was reconstructed according to the ruined foundation as being about 2.7 to 4 meters in diameter and over 6 meters high (Yang 1982, 87).

Percy (1864, 579) applied the word “fining” to the operation of converting cast iron into malleable iron by a specific process, or series of processes—in a hearth or open fire, or driven by a blast of air with charcoal as the fuel. The products obtained from the fining process are called fined iron. Post-smelting, the fining process involved liquifying cast iron in a fining hearth and removing carbon from the molten cast iron through oxidation (Pigott 1999, 186–187). This process produced different qualities of steel and wrought iron in a small furnace, usually a bowl-shaped furnace in the Han dynasty (202 BC–AD 220), and possibly a square furnace in the Ming dynasty (AD 1368–1644, Song 1933, 98).

**Geographic Background**

Of the four biggest geographic basins in China, the Sichuan Basin has the southernmost latitude and the lowest altitude. It is densely populated and relatively developed in terms of transportation and economy. The basin is located at the upper stream of the Yangtze River 长江, and has a total area of about 260,000 km². To the west of the Sichuan Basin is the Tibetan Plateau and the Hengduan Mountains 横断山脉, to the north are the Qinling Mountains 秦岭 and the Huangtu Plateau 黄土高原, to the east is the mountainous region of the west of Hunan 湖南 and Hubei 湖北 Provinces, and to the south is the Yungui Plateau 云贵高原. The basin can be divided into two parts: the mountainous margin and the central basin (Chengdu Plain). The altitude of the margin is mostly between 1,000 and 3,000 meters and
the altitude of the central basin or Chengdu Plain is between 250 and 700 meters (Zhongguo 2009, 127). Pujiang County is located in the southwest of Chengdu Plain, west of Meishan 眉山 and Pengshan, east of Mingshan 名山, north of Danling 丹棱, south of Qionglai counties, and about eighty-three kilometers from Chengdu. The total area of Pujiang is 582.86 km². The Pu and the Linxi Rivers 临溪河 are the main rivers flowing through Pujiang, covering an area of 435.3 km² and providing the convenience of the use of water for ancient iron smelting activities.

**Xuxiebian**

The Xuxiebian site is located on the top of a hill at Group 4 of the Ma'nan village 马南村, Shouan Town 寿安镇, Pujiang County, Sichuan Province. The site is 37 meters E-W and 45.5 meters N-S, for a total area about 1,700 m². Slag, refractory material, and iron sand (residue from the ore crashing and selection processes) can be found all over the ground within the site area.

**Table 1.** Details of the excavated trenches at Xuxiebian

| Year | Context number | Size (m) |
|------|----------------|----------|
| 2007 | 07PSXTG1       | 4 x 2    |
| 2007 | 07PSXTG2       | 4 x 2    |
| 2007 | 07PSXTG3       | 4 x 2    |
| 2011 | 11PSXT1 (T1)   | 4 x 4    |
| 2011 | 11PSXT2 (T2)   | 4 x 4    |
| 2011 | 11PSXT3 (T3)   | 4 x 4    |
| 2011 | 11PSXTG1 (TG1) | 2 x 4    |
| 2011 | 11PSXTG2 (TG2) | 2.5 x 6  |

**Figure 2.** Map showing contours and the excavated trenches at Xuxiebian in 2007 (red squares) and 2011 (black squares)
Two excavations were carried out during May and June of 2007 and December of 2011. Details of the excavated trenches are shown in Table 1. A total of four furnaces, five pits, two trenches and one post-hole were discovered in the two excavations. A total of 408 coordinate data were collected by using a total station. A 0.5 meter contour map was produced of the Xuxiebian site and the nearby area (Figure 2). In labeling the excavated trenches and features, the first two digits represent the excavation year, followed by three letters “PSX” indicating the excavation location, and in which P means Pujiang County; S means Shouan Town, and X means Xuxiebian. The excavation year and location are usually omitted in the figures.

Stratigraphy and Deposits of the Site
The stratigraphy and deposits of the site are indicated by using the north section of 11PSXTG2 as an example (Figure 3). There are four layers in total that have been excavated, and below the fourth layer is virgin soil. Layer ① is a modern agricultural layer 5-18 cm thick composed of yellow and brown clay and which has a loose structure. The inclusions consist of plant roots, modern porcelain sherds, rocks, iron ores, and slags. Layer ② is a modern disturbed layer 14–36 cm thick composed of reddish brown clay with a loose structure and about 5–18 cm to the ground surface. The inclusions are plant roots, rocks, blue and white porcelain sherds, furnace bricks, charcoal, and slags. Layer ③ is a Tang and Song Dynasties layer 6–16 cm thick (ca. seventh to fourteenth centuries AD), composed of brown sandy clay with a loose structure, and about 20–42 cm to the ground surface. The inclusions are slags, charcoal, porcelain sherds of the Tang and Song Dynasties, and furnace bricks. Layer ④ is the Eastern Han dynasty (AD 25–220) layer up to 10 cm thick composed of yellow clay with a tight structure, 27–46 cm to the ground surface. The inclusions are iron ores, refractory materials, a small amount of charcoal, clay pottery, and slags.

Archaeological Features
In the excavations of 2007 and 2011 the following features were excavated: five pits, two trenches, one foundation pole, and four furnaces (Figure 4).
Pits:
1) 07PSXH1 was located in the north of 07PSXTG3, and sealed by layer ③. This pit was rectangular in plan and contained large amounts of pottery, porcelain sherd, and smelting remains, including charcoal debris, burned soil, and slags. This pit was discovered in the trial excavation in 2007 and was not excavated completely in order to preserve it for systematic excavation in the future.

2) 11PSXH1 (H1) was located to the north of 11PSXT2 and the south of 11PSXT3, and was sealed by layer ③. This pit was irregular in plan, slightly U-shaped in section, with straight walls, and a flat bottom (Figure 5). The pit was 28–59 cm in depth and 10–28 cm from the surface. The deposit of the pit had three layers: the first layer is reddish brown clay with inclusions 5–10 cm in size, and included irregular slags, small limestone fragments, furnace bricks, and cylindrical charcoal fragments. The second layer was a charcoal deposit with most of the charcoal fragments up to fifteen centimeters long and four centimeters in diameter. One of the charcoal...
fragments had a diameter of eight centimeters. The inclusions of the third layer were similar to the first layer except that the furnace bricks found in this layer had a more intact square shape with a diameter of about thirty cm. There was a rectangular-shaped foundation discovered on the east side of the pit.

3) **11PSXH2 (H2)** was located in the southwest of 11PSXT1 and sealed by layer ②. Elliptical in plan, the pit was U-shaped in section, with a curved wall, and flat bottom. The pit was 10–12 cm in depth and 11–13 cm from the surface. The deposit was a dark grey sandy soil with a loose structure. The inclusions were 5 cm-sized slags, and 5–15 cm-sized broken furnace bricks with different colours of red and grey.

4) **11PSXH3 (H3)** was located in the northwest of 11PSXTG2, and sealed by layer ③. This pit was irregular rectangular in shape, with a slightly U-shaped section, straight wall, and flat bottom. The pit was 9–20 cm in depth and 40–42 cm from the surface. The deposit consisted of grey and yellow clay with a tight structure. The inclusions were 2–10 cm-sized slags and 5–20 cm-sized broken furnace bricks with colours in red, orange and grey.

5) **11PSXH4 (H4)** was located in the northeast of 11PSXTG2, and sealed by layer ②. Half-elliptical in plan, it was slightly U-shaped, with a straight wall and flat bottom. The pit was 7–17 cm in depth and 22–24 cm from the surface. The deposit consisted of dark red clay with a loose structure. The inclusions were porcelain sherds, 2–4 cm-sized slags and 2–4 cm-sized broken furnace bricks.

*Trenches:*

1) **11PSXG1 (G1)** was located in the east of 11PSXT1 and sealed by layer ②. It was rectangular in plan, with a curved wall and bottom. The trench was 12–21 cm in depth and 10–22 cm from the surface. The deposit had two layers: the first was reddish brown clay with a small amount of charcoal debris, and the second was grey sandy soil with no inclusions.

2) **11PSXG2 (G2)** was located in the west of 11PSXT1 and sealed by layer ②. This pit was rectangular in plan, with a straight wall and curved bottom. The trench was 60–82 cm in depth and 7–17 cm from the surface. The deposit had two layers: the first was reddish brown clay with a tight structure, and the second was yellowish brown clay with a loose structure. Neither layer had any inclusions.

*Post hole:*

**11PSXD1 (D1)** was located in the northwest of 11PSXT (G2) and northwest to 11PSXH3, and was sealed by layer ③. This pit was circular in plan with a diameter of 13 cm, straight walls, and a curved bottom 8 cm in depth. The deposit of the trench consisted of reddish brown and yellow clay with a loose structure and no inclusions.
**Furnaces:**

1) **11PSXL1 (L1)** was located in the south of 11PSXT (G2) and sealed by layer ③. This furnace was circular in plan with a diameter of 100–105 cm. The furnace wall was approx. 5–9 cm thick and constructed with clay bricks. The colours of the furnace wall from outside to inside were dark grey, orange, and red. The surrounding area of the furnace wall had an orange layer of 5–7 cm. The interior furnace wall was fully covered by a slag layer, which was magnetic and thicker in the north part. There were two rectangular gaps about 10–15 cm wide on the northern furnace wall. Limestone bars about 2.7 cm long and 0.9 cm wide, and small nodules of 0.9 cm diameter, were discovered distributed around the left gap (located to the west). The remaining depth of the furnace was 56 cm (Figure 6). The furnace fill was reddish brown sandy clay with inclusions of slags, iron ores, and furnace bricks made of rocks and limestone.

2) **11PSXL2 (L2)** was located in the east of 11PSXT (G2) and sealed by layer ③ (Figure 7). The overall structure of furnace L2 was the same as L1 and had a diameter of 90–92 cm. There were also two rectangular gaps about 10–15 cm wide on the northern furnace wall. The remaining depth of the furnace was 35 cm. The furnace fill was a reddish brown sandy soil with inclusions of slags 2–10 cm in

*Figure 6.* Photos of furnace L1 showing, top left: the top view; top right: two gaps found on the northern furnace wall; bottom left: the northern interior surface with adhering slags; bottom right: details of the southern furnace wall.
size, and also furnace bricks made of red clay 2–10 cm in size, as well as limestone fragments.

3) **11PSXL3 (L3)** was located in the southwest of 11PSXT (G2) between furnace L2 and L4, and was sealed by layer ③ (Figure 7). The overall structure of L3 was the same as L1 and L2, with a smaller remaining diameter of 59–61 cm and 24 cm in remaining depth. No gap like L1 and L2 was discovered on furnace L3. The furnace fill was a reddish brown sandy soil with inclusions of slags 3–5 cm in size, broken furnace bricks made of red clay 2–10 cm in size, and small limestone fragments. Most of the fragments were small, with a size of five cm, but one was cylindrical in shape with adhering slags of a length of twenty cm and diameter of ten cm.

4) **11PSXL4 (L4)** was located in the southwest of 11PSXT (G2) and sealed by layer ③. The overall structure of L4 was the same as the other three, with a diameter of 90 cm. The remaining depth was twenty-eight centimeters. The furnace fill was a reddish brown sandy soil with inclusions of slags 3–8 cm in size, and also broken furnace bricks made of red clay 3–10 cm in size.

**Finds**

A small amount of pottery and porcelain sherds, as well as a large amount of refractory material, slag, iron ore, and flux were excavated.

*Pottery and porcelain*

Some object types can be identified from the pottery and porcelain sherds...
excavated. The types include urn, vat, jar, bowl, jug, basin, and vase, all of which are commonly used domestic objects (Figure 8).

**Tuyeres**

Three broken tuyeres were excavated from Xuxiebian in 2011 and one was collected from the site's surface in 2007. The tuyeres excavated in 2011 are all ceramic, and the one collected in 2007 is lithic. 11PSXTG1③:5, 11PSXTG1⑤:8, and 11PSXTG1④:10 are ceramic tuyeres with a reddish brown colour. The remaining length of 11PSXTG1④:5 is 22 cm, 17.8 cm wide, and 3.2–6 cm thick (Figure 9:3). 07PSXC:9 is made from greyish white sandstone. The tuyere is 17 cm long, 11.5 cm
wide, and 9 cm thick. There is some black vitrified slag adhering to one of the ends, which is possibly the side that fitted into the furnace (Figure 9:1).

Refractory Material
A total of sixty-nine furnace bricks and two furnace linings were collected and recorded from the Xuxiebian site. The furnace bricks excavated from Xuxiebian are made of three types: clay (48%), sandstone (27%), and limestone (25%).

Clay Bricks
There are thirty-two excavated clay bricks. Generally, these bricks are made of clays with inclusions of small stones and organic fibres (Figure 10:1, 2). They are neatly made with a regular rectangular shape. The colours usually vary from red and orange to grey and dark grey, depending on which part of the furnace they were from. One of the clay bricks is nearly intact (T1H2:6) and is made with inclusions of small stones and organic fibres. It has a fine fabric, high density, and grey colour, with dimensions of 18x11x4.5 cm. Of the excavated clay bricks with intact thickness, 79% have thicknesses between 3.5 and 4.5 cm, and the others are between 8 and 13 cm.

Limestone Bricks
The limestone bricks discovered are usually thicker, covered with a thin layer of slag, and badly eroded by the slag layer (Figure 10:3, 4). For example, T2H1③:FB1, is all covered with a thin layer of slag except for a section where the slag is black and coarse with inclusions of charcoal and small stones, and the thickest part of the slag erosion was about one centimeter. The remaining dimensions are 17x16x9.5 cm, with a white colour in the section. TG1②:FB7 is completely covered with a slag layer, and the remaining dimensions are 25x18x10.5 cm (with slag) and 19.5x14.5x9 cm (without slag). The surface of the brick is eroded by the slag layer for about two millimeters, one of the sides is eroded badly, and the brick is broken into two pieces at the middle. The colour inside is greyish white. On the other hand, there are some small limestone fragments (6–10 cm long and 2–3 cm wide) that were excavated, which might be broken pieces from the brick, or they may have been applied as a flux in the smelting.

Sandstone Bricks
There were nineteen sandstone bricks (seven are fragmented) excavated from the site. The bricks are of two types. The first type is covered with a thin layer of slightly vitrified slag on its surface, and the original thickness was predicted to be around ten centimeters (Figure 10:5, 6). Seven pieces of the second type were discovered, and have a high density with a U-shaped section. For example, T2H1③:FB2 has a burned red colour, high density, U-shaped section, and some tool marks on the flat surface. There is a triangular-shaped slag adhering to the curved surface, black in colour and non-magnetic. The colours in the section—red, dark red, greyish white, and yellow—are in different layers. The shape of the brick was likely made on purpose so it could be used to block the tapping hole,
and the adhering slag side is close to the inner side of the furnace. TG1:FB1, is similar to T2H1③:FB2 and is yellow in colour and U-shaped in section; one half of the brick is covered with a very thin layer of black and highly vitrified slag (glassy), while the other side is clean.

**Furnace Linings**

There were two furnace linings excavated from the site. T2H1③:FL1 is a burned clay with inclusions of small amounts of charcoal debris. It has a very dense structure with a dark red colour in the section. It is possibly a specially made refractory lining for the furnace. T2H1③:FL2 is a burned clay, with a high density, yellow in colour with red in some areas, very dense structure, and with some tamping marks. It is possibly part of the ground that was strengthened before building the furnace.

**Ore**

There were nineteen iron ore samples collected from the Xuxiebian site, most of which have a grey and somewhat metallic colour with a melted surface and an average size of 4.2 cm. Samples excavated from 11PGSTG2② are grey and somewhat metallic in colour with a half-melted surface, of moderate porosity with sizes 1–2 mm, and are strongly magnetic.

**Slag**

There were large amounts of smelting waste distributed in the layers excavated from 11PSXTG1. A total of 123 slags were collected and analyzed. The slags are divided into four different types (Figure 11), and the details of the macro-observation are shown in Table 2. Ten slag samples were prepared and analysed for microstructural and elemental analyses. From their microstructures and compositional analyses, type B and D slags formed at a temperature of 1,500–1,600°C, and type C slags formed at around 1,200°C (authors, manuscript in preparation). According to Crew (1996), type C slags are very possibly hearth slags from either fining or smithing. In addition, the type C slags were usually excavated inside the bowl-shaped furnaces; therefore, we believe that the type C slags are most probably fining slags.
Table 2. Typology and descriptions of slag samples collected at Xuxiebian

| Type | count & (%) | avg. dimensions | descriptions |
|------|-------------|-----------------|--------------|
| A    | 68 (55%)    | 8.2x6.0x4.1 cm  | grey colour, low to moderate density (20–30% porosity and pores are 2–10mm and spherical), smooth or rough surface texture, moderate viscosity, and low or non-magnetic. |
| B    | 46 (38%)    | 8.4x6.1x4.2 cm  | black colour, low density (more and larger spherical pores than type A), moderately magnetic, with a large amount of charcoal impressions on their surface. |
| C    | 8 (7%)      | 11.0x9.3x5.5 cm | grey colour, slightly larger than types A and B, much higher density, low proportion of porosity, shiny and smooth section, and usually strongly magnetic. |
| D    | 1 (<1%)     | 11.5x10.4x3.2 cm| grey and brown colours, rough surface, high density, small pores (1–2mm, mostly spherical), strongly magnetic in some areas. |

Discussion
Firstly, the iron ores used in the smelting at Xuxiebian were crushed into small pieces of 4–6 cm and were possibly roasted before charging into the furnace. A flux of limestone bars was possibly applied in the smelting, and the slags and other wastes from the smelting were discarded together on the lower side of the site.
Secondly, the type C slags excavated from furnaces L1, L2, and L3 suggest...
that the four bowl-shaped furnaces excavated at Xuxiebian are most probably fining furnaces. To build a fining furnace, the first step was to dig a bowl-shaped pit in the ground, and the earthen walls were then tamped hard. The second step was to use a mixture of clay, river sand, and straw (or other organic fibres) to strengthen the interior surface. The third step was to build a circular or rectangular shaped furnace wall above the ground with clay or stone bricks and set up the bellows on one side and connect the tuyeres to the centre of the furnace. The final step was to cover more than half of the furnace top with clay or stone slabs. There were two gaps (10–15 cm) on the northern furnace wall of both furnaces L1 and L2, which suggests that these possible fining furnaces were probably bellows-driven from the top. In addition, the two furnace bricks with a U-shaped section excavated from furnace L1 (TG2L1, file 93), may provide evidence of where the metalworkers set up the bellows, or, alternatively, these special shaped bricks could have been used to block the tapping hole of the blast furnace.

The structure of these fining furnaces at Xuxiebian is similar to a modern-type fining furnace which was popular for a long time in Shanxi Province (Yang 1982) (Figure 12:a). However, this modern type has a contracted furnace mouth (C-shaped rather than U-shaped in section), while all of the Xuxiebian type furnaces have a U-shaped section. The contracted mouth is an advanced structure which directs the hot blast from the furnace upwards rather than directly against the metalworkers. Otherwise, it is necessary to build another wall against the furnace mouth (no evidence of which was found near the furnaces at Xuxiebian) or the workers must stop pumping the bellows when the materials in the furnace needed to be stirred, which reduces operating efficiency.

One fining furnace of the mid-late Western Han dynasty (ca. 150 BC–AD 50) has been excavated from Tieshenggou 铁生沟, Gongxian 巩县, Henan Province. Furnace L17 is elliptical in plan, with its upper part destroyed, and with a remaining diameter of 28–37 cm and remaining height of 15 cm (Figure 12:b). When the Tieshenggou iron smelting site was excavated in 1958, the excavator predicted that the fining furnace was possibly like the low temperature bellows-driven fining furnaces widely applied in Henan and Shanxi Provinces in the 1950s. The excavator also believed that the furnace would have had a contracted mouth (C-shaped) originally, although the furnace was badly damaged and it was not clear whether this was the case or not in the published low-resolution diagram. However, if this is true, then the furnace structure of the Central Plains is somewhat more advanced than what we have found at Xuxiebian. There are some other examples of fining furnaces of the Han dynasty, one found at Wafangzhuang 瓦房庄 (Li 1991, 82, fig. 63), and six found at Zhaohecun, both from Henan Province (Zhao et al. 1962, 11). Unfortunately, none of them could provide more information about the upper structure of the furnaces.

Thirdly, according to the discoveries from each of the four pits excavated in 2011, pits 11PSXH2 and H4 were possibly dug for discarding the waste materials from the smelting, and pits H1 and H3 were likely the pre-smithing area (where the fined iron was hammered into bars or plates for later use). The fined iron from the fining furnace would need to be hammered immediately while hot to consolidate
the metal and expel the trapped slags. The pre-smithing was often carried out at the smelting site and near the fining furnaces. A reconstruction of the fining process based on the excavation of the Han dynasty iron smelting site at Wafangzhuang, Henan Province was made by Li Jinghua (Figure 12:c).

The surface of pit 11PSXH1 is black in colour with large amounts of slags and charcoal debris. There is a small rectangular area about 30x80 cm in the middle of the pit, which according to Li’s reconstruction might be where the anvil was set up. On the other hand, in Europe, the repeated heating that was required in the pre-smithing process could take place in a separate hearth, sometimes known as the “chafery,” which was introduced to speed up the refining process as early as the fifteenth century (Awty 2007, 784). The rectangular-shaped foundation on the east of pit 11PSXH1 was probably a separate hearth that collapsed eastward when

**Figure 12.** a) Diagram of a modern-type fining furnace popular in Shanxi Province (source: Yang Kuan 2004, 238); b) Fining furnace L17 excavated from Tieshenggou, Henan Province (source: Zhao 1962, 13, fig. 10); and c) A reconstruction of the Han dynasty fining process (source: Li Jinghua 1991, 82)
abandoned (Figure 13). The post-hole (11PSXD1) indicates that this pre-smithing area was possibly sheltered.

Fourthly, although no blast furnace or blast furnace foundation was discovered at Xuxiebian, as evidenced by the high temperature-type B and D slags, we believe that blast furnaces and pig iron smelting were undertaken at Xuxiebian. In addition, based on the amount of furnace bricks and the volume of smelting waste deposits discovered at the site, there was likely more than one blast furnace here operating at the same time. The furnaces were possibly located on the south side of the site (Figure 14).

Finally, with regard to dating we can say that the pottery sherds excavated in 2007 were dated to AD 220–420 (Zhou et al. 2008, 25). According to the local pottery assemblage and pottery and porcelain sherds excavated in 2011, the sherds excavated from layer ④ of 11PSXTG2 are dated to the Eastern Han dynasty (AD 25–220), and the porcelain sherds excavated from layer ③ of 11PSXTG2 belong to the Tang dynasty (AD 618–907), but not the Northern and Southern dynasties (AD 420–589). The fining process was known at the latest about the first century BC in the mid-late Western Han dynasty (Yang 1982, 311). The Xuxiebian site was probably later than the Western Han dynasty, but was reasonably active from the mid-late Eastern Han dynasty (ca. AD 150–200) onward.
Conclusion

In conclusion, we believe that Xuxiebian was an iron smelting and fining site operated probably from the late Eastern Han dynasty (ca. AD 150–200) to sometime before AD 420. There were no moulds of any kind discovered at Xuxiebian or any other iron smelting site in Southwest China. This might reflect the policy of the central government with regard to the iron industry of Southwest China during the Han dynasty (202 BC–AD 220). Any opportunity for making contact with iron weapons and implements would have been strictly prevented for security reasons. The risk of transporting primary material from an area distant from political and social stability is clearly much lower than transporting iron weapons and implements. The only function of the Xuxiebian iron smelting site was to turn iron ore into pig iron ingots and to convert the pig iron to wrought iron. The resulting ingots would have then been transported to areas under stronger control by the central government in the Central Plains, where they were then cast into different objects.

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