A cast-iron bridge pier dated 96 BCE found in Sichuan, China

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Translated by Donald B Wagner

ABSTRACT: A cast-iron bridge pier weighing 1.38 tons and dated 96 BCE was discovered in 2007 near Chengdu, Sichuan, China. Nearby were found fragments of the mould in which it was cast. The article describes the metallography of the artefact and reconstructs the process by which it was cast.

Introduction

In February 2007 an iron bridge pier of the Han period (Fig 1) was discovered in a hardpan layer in a sandbank 420m from the bridge of the Sichuan-Shaanxi Highway over the Shi'ting River (Fig 2). Preliminary excavations were undertaken here by the Deyang Municipal Institute of Cultural Relics and Archaeology and the Guanghan Municipal Cultural Heritage Administration (Liu Zhangze *et al* 2015). Several fragments of a ceramic casting mould were found, together with potsherds ranging in date from the Shang to the Han period (*c*16th century BCE to 3rd century CE). This is the largest Han-period iron casting ever discovered in China. Not only is it perfectly preserved, but it has a precise and reliable date, providing important material for research on large-scale iron-foundry technology in the Han period as well as bridge construction and transportation.

Description

The drawing of the bridge pier (Fig 3) shows it is roughly cylindrical, 1.1m high, with a diameter of 510mm at the top, 535mm at midpoint and 551mm at the base. Running across the top is a slot, 170mm wide and 510mm deep. On either side of the recess are two symmetrically placed square holes, 100×100mm (K1, K2). A layer of hardpan, 60mm thick, adheres to the bottom of the recess. Under the recess is a rectangular hole, 140×100mm (K3, K4), filled with hardpan that runs all the way through the casting. Near the base is another rectangular hole, 170×100mm (K5, K6), that also runs all the way through the casting. On the top surface is a small rectangular lug, 60×20×10mm, cast in one with the body of the artefact (Fig 1e).

On the sides of the artefact is a relief inscription in seal script (Fig 4) which reads:
廣漢郡雒江橋敦重卌五石太始元年造
and can be translated as 'Guanghan Commandery, Luo River bridge pier, weight 45 *shi*, made in the first year of the Taishi period' (96 BCE).

The reign-period name Taishi (Grand Beginning) was used by four rulers in Chinese history, but of these only one, Emperor Wu (156–87 BCE) of the Western Han dynasty, had control over the Chengdu Plain. His Taishi period was 96–93 BCE. The Luo River of the Han

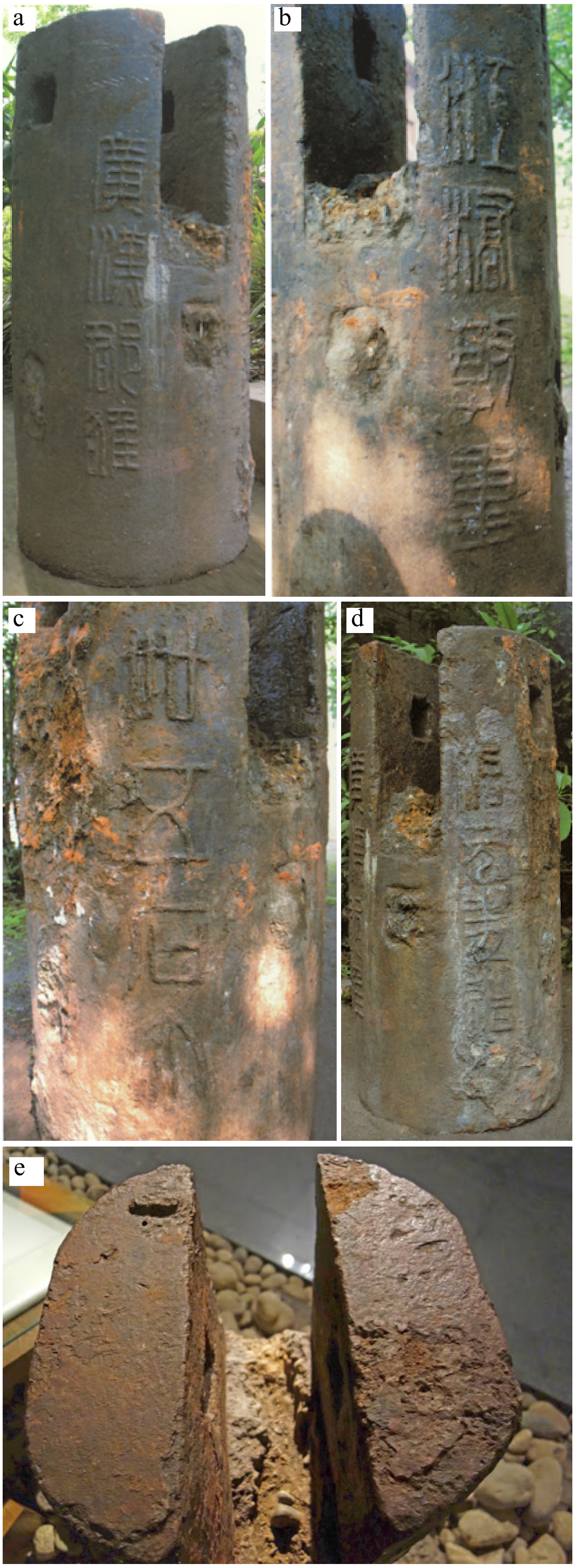


Figure 1: a-d, the four sides of the bridge pier, height 1.1m (after Liu Zhangze and Liu Jun 2015); e, oblique view of the top (by Zhang Mengyi).

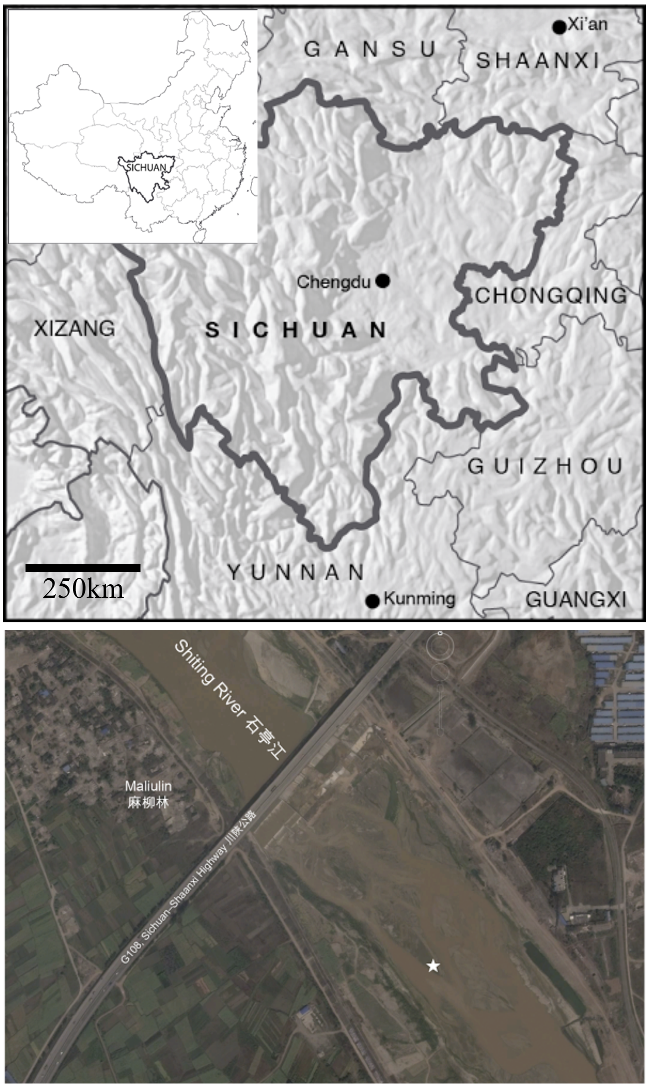


Figure 2: Map showing where the bridge pier was found, about 45km NE of Chengdu, close to where the G108 Sichuan-Shaanxi highway crosses the Shi'ting River. The star on the aerial photo indicates the findspot.

period is the modern Shi'ting River, where the bridge pier was found (Fig 2). In the Western Han period the unit of weight *shi* was equal to 30.7kg, so 45 *shi* was approximately 1.38 tons which corresponds well to the actual measured weight of the bridge pier.

Metallurgical characteristics

The Luo River Bridge Pier is the earliest large-scale iron casting so far found in China. In order to obtain an overall understanding of its metallurgical characteristics and casting technology, a sample was taken and subjected to metallographic and chemical analysis.

Metallography

A sample, approximately 20×20×20mm, was taken from the side of the recess near the top of the bridge pier (Fig 5). From this a sub-sample was cut using a

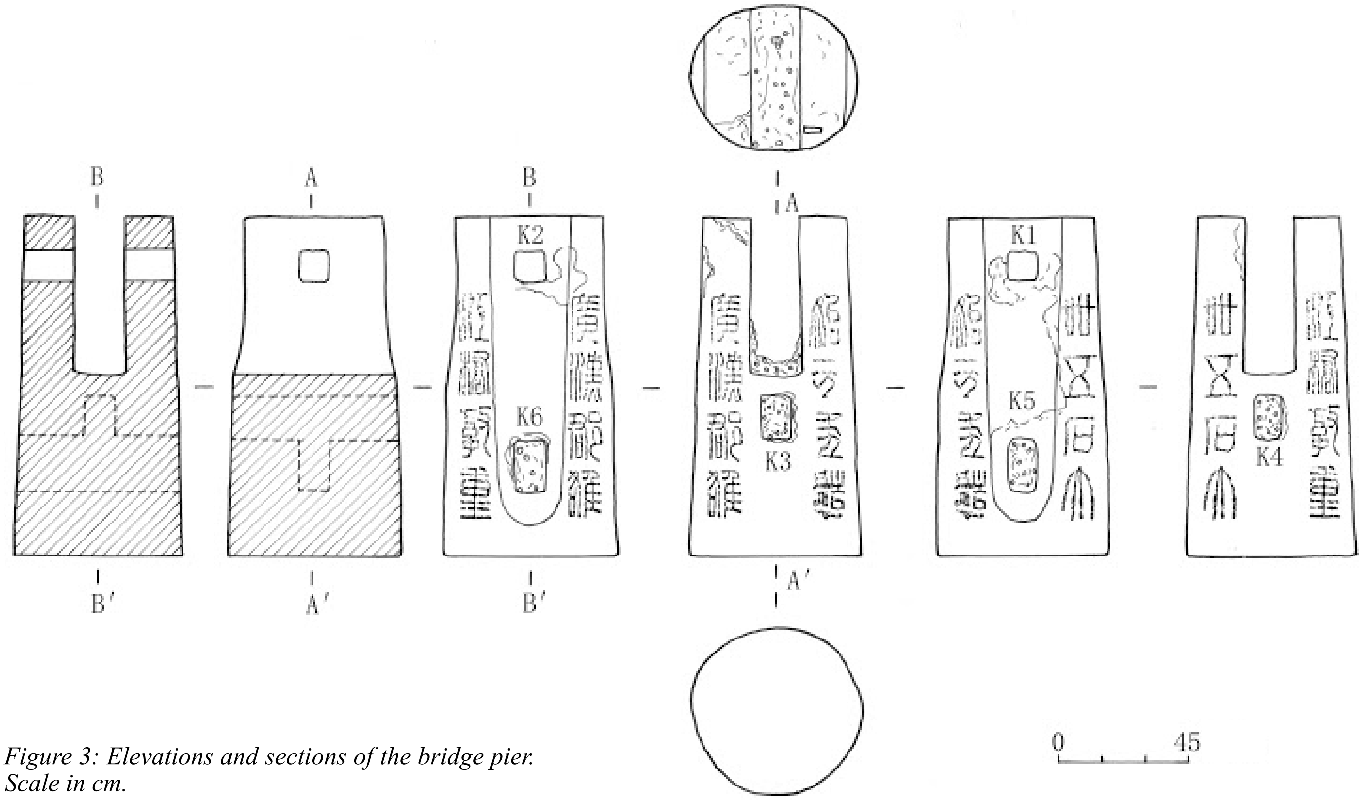


Figure 3: Elevations and sections of the bridge pier. Scale in cm.

Figure 4: Rubbing of the inscription.

Figure 5: Location of the sample taken for metallographic examination.

Buehler AbrasiMatic 300 abrasive cutter and mounted with black bakelite powder to make a cylindrical mount with diameter 30mm and height 25mm. This was ground and polished using a Buehler automatic polisher, then etched with 4% nital. The sample was examined using a Zeiss Axio Imager A1m metallographic microscope.

Flake graphite in a metallic matrix could be seen in the unetched sample (Fig 6). Etching revealed a structure of flake graphite with pearlite (Fig 7). At high magnification some ferrite could be seen (Fig 8). The microhardness was $HV_{0.5}$ =184.5.

Chemical composition

The metallic parts of the sample were examined and analysed using the JEOL JSM-7500F scanning electron microscope at the Analytical and Testing Centre of Sichuan University. Conditions for chemical analysis were: accelerator voltage 20kV, backscatter detection employed. Conditions for energy-dispersive spectrometry were: working distance 10mm, analysis voltage 20kV, counts per second ≥200,000. Conducting

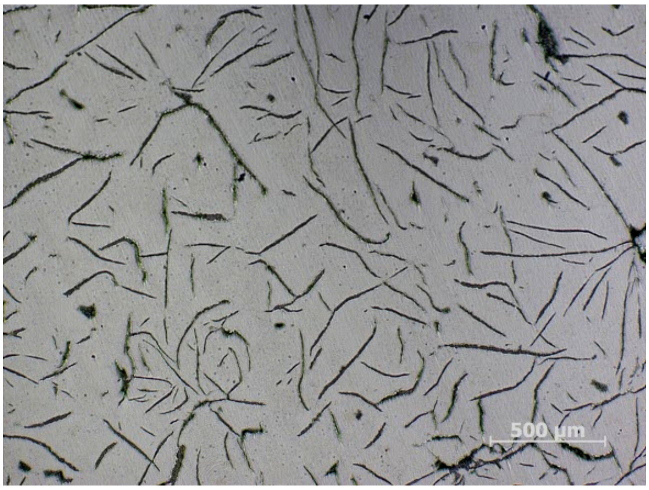


Figure 6: Flake graphite (dark) in metallic matrix. Unetched. Scale bar 500μm.

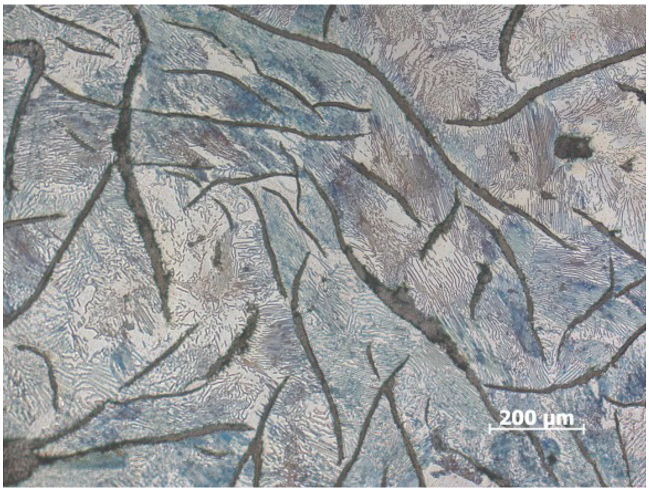


Figure 7. Flake graphite (dark) in pearlite matrix. Etched with nital. Scale bar 200μm.

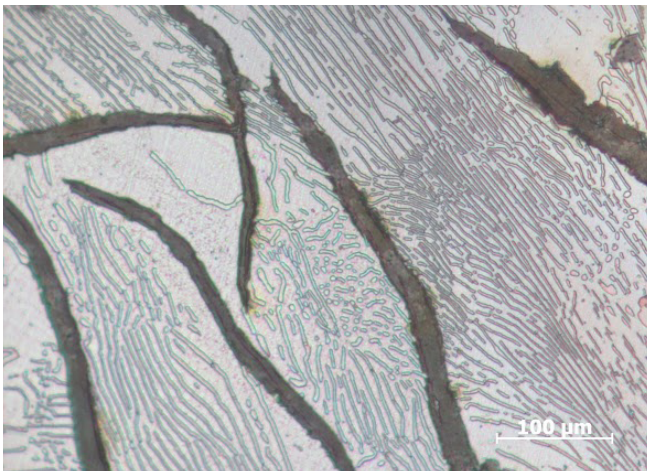


Figure 8. Flake graphite (dark) in matrix of laminar graphite and ferrite. Etched with nital. Scale bar 100μm

glue was used to connect the sample to the base. A representative area of the sample about 1mm across was chosen for chemical analysis which showed it contained only iron, carbon and oxygen; other elements were not detected [though Figure 9 appears to show a small peak for silicon at 1.8keV].

Metallurgical conclusions

The data reported above indicate that the Luo River Bridge Pier is pearlitic grey cast iron. Examination of the microstructure shows flake graphite with fine long flakes, evenly distributed. The pearlite structure is uniform and distributed in layers.

Foundry technique

Two further investigations at the site by the Guanghan Municipal Cultural Heritage Administration in March and May of 2007 produced 29 fragments of ceramic casting moulds. Detailed investigation of the fragments, together with consideration of the physical characteristics of the bridge pier, has contributed to the reconstruction of the process by which it was cast.

The mould

The mould fragments are described in detail and illustrated in the Appendix. They are composed of coarse sand and silt, with the silt serving as adhesive. The surface is fragmentary. The cross-section is slightly curved. The colours of the inner and outer surfaces are different: dark red on the outside, greyish brown on the inside, which was in contact with the molten iron. Iron corrosion products adhere to the inner surfaces. Some of the fragments are dark red on the inner surface and show clear signs of 'honeycombing'. The specific locations of the fragments within the mould can be determined for 14 of them (see Appendix).

The casting technique of the bridge pier

Ancient Chinese casting technology developed in waves. As early as the Shang period there were extremely large bronze castings, for example the Simu Wu *ding* and the Four Rams square *zun* [for details of the large bronze castings of this period see *eg* Fong Wen 1980], but very few large castings have been found from the Han period. In the following Nanbeichao period (386–581 CE) large Buddhist iron statuary began to be cast, and in the Tang and Song periods (618–1279 CE) the techniques of monumental iron castings matured. Examples are the iron oxen, men, and mountains of the Pujin bridge anchor (Fan Wanglin and Li Maolin 1991); the Heavenly Axis erected by the Empress Wu Zetian (r 690–705) to celebrate her accomplishments; the iron column of Midu County, Yunnan, dated 872; and the Iron Lion of Cangzhou [see also Wagner 2000 on Chinese monumental castings]. These exceed by far the scale of the iron castings of the Nanbeichao period in dimensions and weight. The Heavenly Axis (*Da Zhou Song De Tianshu*) is not extant, but is described in the 12th-century text *Xin Tang shu* (1975, 76: 3483); it was

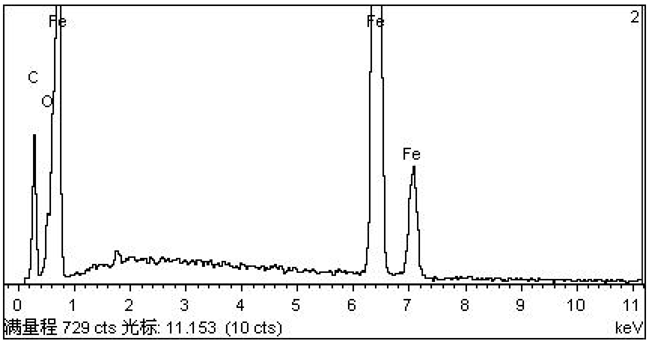


Figure 9: EDS spectrum showing the main elements present are iron, carbon and oxygen.

an octangular shaft, said to be *c*30m high and 1.5m on each of the eight sides (*Tianshu* is the Chinese name of the star Dubhe (α *Ursa Major*), the first star of the Big Dipper). The Midu iron column can still be seen some 5km north of Midu city; it is a cylinder, *c*3.3m high and 1m in diameter.

The iron castings of the Han period are generally fairly small, mostly implements, weapons, household utensils and carriage parts cast in ceramic or cast-iron moulds. [For details of these see *eg* Wagner (2008, 150–161 and throughout ch 4–5)]. The Guanghan County Luo River Bridge Pier is very large, and its casting technique is very different from that of the smaller objects. Before this discovery it was believed that iron cauldrons of a few hundred kilograms were the largest Han-period iron artefacts. A Han-period iron pot found in 1999 in Pujiang County, Chengdu, Sichuan has a diameter of 1m, height 570mm and thickness 35mm; it weighs more than 200kg (Long Teng and Xia Hui 2002). Another Han-period iron pot is preserved in the Dongtai County Museum in Yancheng Municipality, Jiangsu. It has a diameter of 1.58m and height 900mm (Cao Aisheng 2009). Besides archaeological finds there are also descriptions of Han-period iron cauldrons in Song-period writings. Huang Tingjian (1045–1105) and Lu You (1125–1210) both described a *laopen* salt-boiling vessel inscribed ‘seventh year of Yongping’ (64 CE) from Wu Shan (*Li shi • Li xu* 1986, ch 3). Hong Kuo (1117–1184) described two *laopen* with inscriptions (Huang Lixin and Liu Yunzhi 2004).

Traces of moulds for large iron cauldrons were found at an ironworks site excavated at Wafangzhuang in Nanyang, Henan (Li Jinghua 1991, 9–10). These include traces of inner and outer moulds and circular marks on the ground where the casting was made. The faces of most of the moulds were more than 2.5m in diameter; among these the largest, D8, showed marks of casting 1.68–1.78m in diameter. From the form and structure of these features it can be concluded that the casting of a cauldron in the Han period involved four phases: preparing and firing the ground surface to make a floor; preparing the inner and outer moulds; melting and pouring the iron; and trimming the casting.

Laopen, iron salt-boiling cauldrons, were first cast in the reign of Emperor Wu (141–87 BCE) (*Shi ji* 1962, 30: 1429; translation Wagner 2008, 177). The *laopen* and the Luo River bridge pier, both cast in this period, are large iron castings, and their casting processes were presumably similar. However, they differ in size, function, and form, so there would also have been differences in the process.

Detailed examination of the bridge-pier mould fragments indicates that the outer mould and the cores are integral, and that there is no sign of joins between parts of the mould. In particular, on the surface of the casting itself there is no sign of flash marks (impressions of joins between mould pieces) or of cold shuts, caused by multiple pourings. We infer that the bridge pier was cast in an open ‘mould-pit’ in a vertical, inverted position, and that the casting was made in a single pour. It is possible that multiple melting furnaces were used in order to assure continuity in the pour.

On the basis of the form and characteristics of the casting and the mould fragments, we reconstruct the casting process as follows:

1. Preparing the site: On a sandbank by the river a suitable area is levelled.
2. Excavating the pit: Following a plan determined beforehand, a round pit is dug with diameter 0.5–0.6m and depth 1.1–1.2m. The pit is funnel-shaped, with the bottom smaller than the mouth. It has roughly the form of the intended casting, with the top facing downward. The sand in this river is mixed with gravel and large pebbles, and is not suitable for the casting surface of a mould, so the mould is finished with a layer of fine silt.
3. Preparing the inscription: The inscription may have been prepared in either of two ways. Stamps with the characters in relief may have been impressed in the wet surface of the mould, or the inscription may have been written on the surface, inverted and mirror-imaged, and then carved.
4. Installing the cores: Judging from traces of the cores still adhering to the casting, the cores were essentially of the same structure and material as the mould pit, formed of the gravelly sand available at the site. The core for the recess at the top of the casting was built up from the floor of the pit, with the cores for the holes K1 and K2. Then the cores for the holes

K3–K4 and K5–K6 that run right through the casting were added, and the mould was complete. The top of the mould was not covered, so that the bridge pier was 'open cast'.

5. Firing the mould: A mould must be totally free of water when the molten iron is poured. Traces of charcoal adhere to the mould-fragments, so it is clear that the walls and cores of the mould-pit were baked at a low temperature using charcoal. After firing, the mould would have been both dry and hard, so that the molten iron would not cause cracking.
6. Pouring the iron: The molten iron appears to have been poured directly along the surface K1–K5. On this surface the rust layer is severely spalled, unlike the other three sides, which are complete and smooth (Fig 1c). The mould fragments corresponding to this side of the casting show clear traces of 'honeycombing', and have the general characteristics of an iron casting surface. When the pour was complete, near the mouth of the mould, the iron cooled naturally, forming a smooth surface, the bottom of the bridge pier.
7. Cleaning the casting: After casting, the bridge pier was dug out of the sandbank, the mould was knocked off, and the cores dug out.

It is clear that the bridge pier was cast at the site of its use. In the Han period, large iron castings were sometimes cast at the ironworks for use elsewhere, sometimes directly where they were to be used. At the Wafangzhuang ironworks site, which was an official iron office under the state monopoly of the iron industry (Li Jinghua 2003; see also Wagner 2008, 239, 203–204), remains of moulds for *laopen* cauldrons for salt-boiling were found, indicating that the manufacture of this product was concentrated at the ironworks. On the other hand, at the Pujiang salt production site, semi-finished iron pieces were found, indicating that *laopen* cauldrons were manufactured on the spot (Long Teng and Xia Hui 2002). Monumental iron castings were often cast on the spot to avoid transportation difficulties, especially in the Tang period and after. Examples are the statues of men, oxen, and mountains, dated 724 CE, used as anchors for a floating bridge at Pujin in Yongji County, Shanxi, and the Lion of Cangzhou, dated 953 CE, in Cangzhou, Hebei [Wagner 2000; 2008, 289–292].

The 'Luojiang Bridge Pier' and the 'Golden Ox Road'

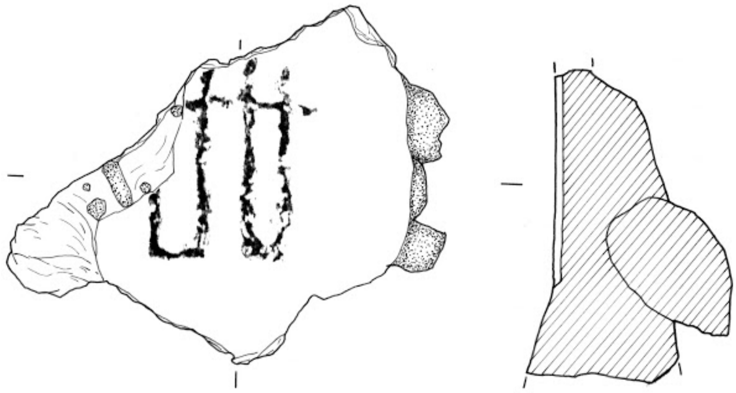
[The following is a summary of a detailed discussion in the original article]. Until the 1950s there was a base of an ancient bridge near where the bridge pier was found, and on the opposite bank are the remains of a flagstoned approach road. The locations of the bridge pier and these features indicate that the Shi'ting River in ancient times was c200m wide, so that the building of this bridge in the Han period was a major engineering and economic challenge. The bridge was part of the famous Golden Ox Road (Jinniu Dao). The road was originally built in about the 4th century BCE and continued to be the established route between Chengdu and Xi'an throughout Chinese history [see Needham 1971, 24]. The modern highway G108 largely follows the same route (see https://goo.gl/maps/AaZWi).

Acknowledgements

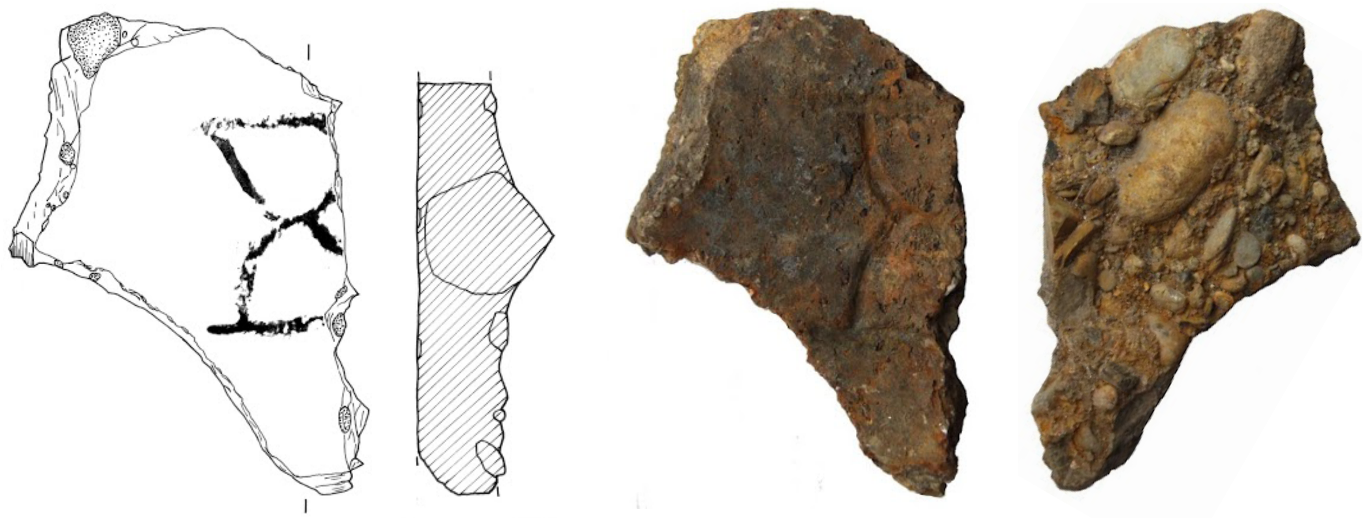
This article is one result of a major project of Sichuan University Advanced Interdisciplinary Research (skqy201202) and the National Social Science Fund of China (12BKG010). Valuable support was given by Qiu Dengcheng of the Guanghan Sanxingdui Museum and Liu Jun of the Guanghan Municipal Cultural Heritage Administration. Bai Yunxiang gave valuable advice on a previous draft. Many thanks to all! The paper was originally published in Chinese as: 'Sichuan Guanghan Shi'tingjiang Handai tie qiaodun de faxian ji xiangguan wenti yanjiu' in *Kaogu* [Archaeology], 2015, No 8. Figures 1 and 2 were supplied by the translator, who thanks the authors for valuable advice and for permission to publish the translation. Figure 2 includes material from Digital Wisdom and Google Earth.

Appendix: Catalogue of selected mould fragments

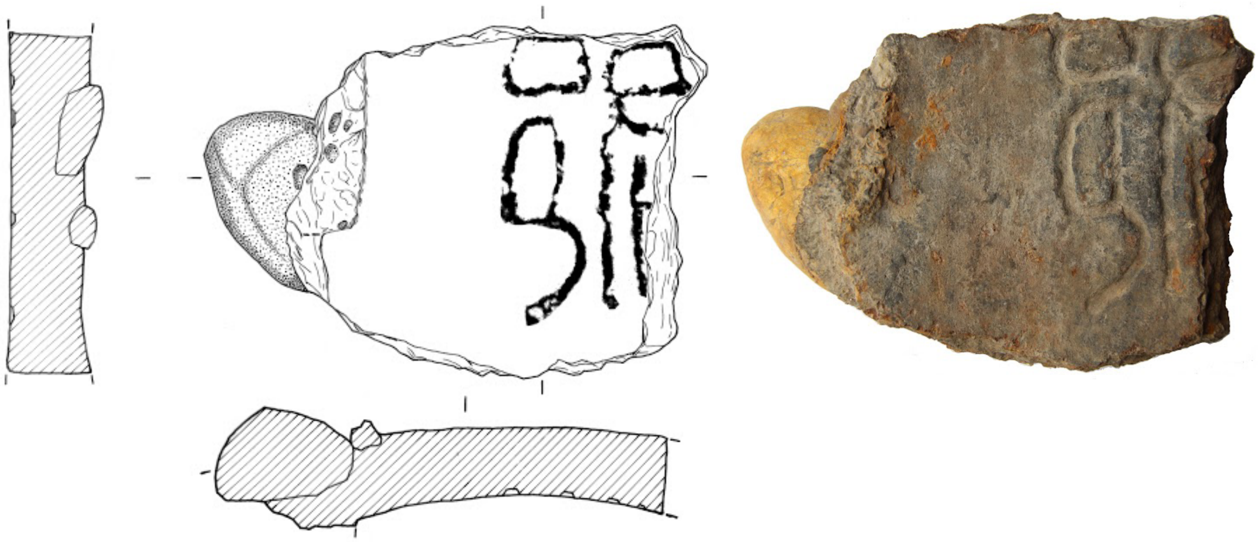
The mould fragments catalogued below all retain their inner surface, and some can be positioned relative to the casting as they have traces of the inscription surviving. They are relatively small so it is not surprising that none join. All are shown at the same scale (approximately 1:4).



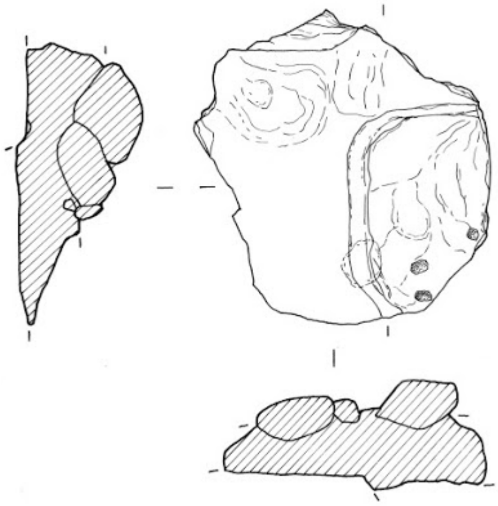
GST-cai-1: The outer surface is composed of a mixture of coarse sand and silt, with pebbles of various sizes adhering to it. The inner surface consists of uniform silt. On the inner surface is a fragment of the character 卌 with the same form and size as the corresponding character on the bridge pier. On the inner surface can be seen some honeycombing. Dimensions 243×188mm, 40–90mm thick.



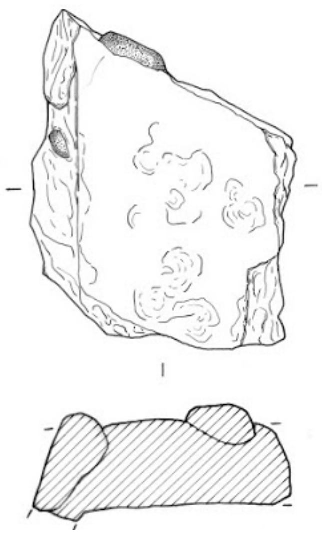
GST-cai-2: The outer surface is composed of a mixture of coarse sand and silt, with pebbles of various sizes embedded. The inner surface is composed of uniform silt mixed with charcoal. On the inner surface is a fragment of the character 五 with the same form and size as the corresponding character on the bridge pier. On the inner side can be seen some honeycombing. To the left of the character is a protuberance, 30×5×5mm, corresponding to the recess at the top of the bridge pier. Dimensions 255×188mm, 40–70mm thick.



GST-cai-3: The outer surface is composed of coarse gravel mixed with silt. The inner surface is primarily silt. On the inner surface is a fragment of the character 郡 with the same form and size as the corresponding character on the bridge pier. To the right of the character is a roughly rectangular protuberance, 90×40×5mm, corresponding to the penetrating hole K3 (Figure 3). Dimensions 260×180mm, thickness 40–70mm.



GST-cai-4: The inner surface is dark red, with clear honeycombing marks which match marks on the outer surface at K1 and K5 (Figure 3). At one side of the inner surface is an approximately rectangular protuberance, 106×73mm, 5mm thick. Judging from the honeycombing and the position of the protuberance we conclude that this mould fragment corresponds to the right side of K1. Dimensions 153×160mm, thickness 60mm.



GST-cai-5: The inner surface is dark red, with clear honeycombing marks which match marks at K1 and K5. At one side of the inner surface is a long narrow protuberance, 160mm long and 5mm thick. Judging from the honeycombing and the position of the protuberance we conclude that this mould fragment is from the corner of the mould adjoining the holes K1, K5, and K3. Dimensions 160×133mm, thickness 40–53mm.

GST-cai-6: On the inner surface is a fragment of the character 江 with the same form and size as the corresponding character on the bridge pier. To the left of the character is an approximately rectangular protuberance, 60×40mm, 20mm thick. Judging from the position of the fragment in the mould, the protuberance joins with the core for the recess at the upper part of the casting. Dimensions 260×180mm, thickness 40–70mm.

GST-cai-7: On the inner surface is the complete character 廣 with the same form and size as the corresponding character on the bridge pier. Dimensions 177×154mm, thickness 50mm.

GST-cai-8: The inner surface is dark red, with clear honeycombing marks. On the inner surface is a fragment of the character 太 with the same form and size as the corresponding character on the bridge pier. Dimensions 263×245mm, thickness 40–60mm.

GST-cai-9: The inner surface is greyish brown. On one side of the inner surface is a corner. We believe that this fragment corresponds to the top of the casting. Dimensions 173×133mm, thickness 45–60mm.

GST-cai-10: On the inner surface is a fragment of the character 年 with the same form and size as the corresponding character on the bridge pier. Dimensions 130×100mm, thickness 90mm.

GST-cai-11: Greyish brown. On the inner surface is a rectangular corner. We believe that this fragment corresponds to the top of the casting. Dimensions 213×140mm, thickness 60–100mm.

GST-cai-12: The inner surface is dark red, with clear honeycombing marks. The fragment corresponds to the area of the casting near K1 and K5. Dimensions 283×158mm, thickness 50mm.

GST-cai-13: The inner surface has part of a character which is too fragmentary to identify. Dimensions 122×83mm, thickness 44–100mm.

GST-cai-14: The inner surface has clear honeycombing marks and a fragment of the character 石 with the same form and size as the corresponding character on the bridge pier. Dimensions 145×90mm, thickness 80mm.

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