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How Were Bronze Inscriptions Cast in Ancient China? New Answers to Old Questions

Abstract: After many decades of scholarly consensus on how bronze inscriptions were cast in Chinese antiquity, over the past twenty years, archaeological discoveries as well as research on inscriptions’ specific features have undermined the long-established interpretation. In contrast to the traditional stance – that inscription moulds were prepared by impressions from a master pattern – the new interpretation argues that inscriptions were modelled from additional clay directly on the moulds. This article offers an overview of the genesis and main advantages of the new interpretation together with a detailed reconstruction of the technical procedure.

1 Introduction

The last two decades have fundamentally changed our understanding of how ancient Chinese bronze inscriptions were produced. New material evidence yielded by archaeological excavations, together with scholarship focusing on the special features of cast inscriptions, have challenged the long-standing consensus on the main technique for producing ceramic moulds in which inscriptions were cast during the ‘golden age’ of Chinese bronze epigraphy, i.e. between the eleventh and fifth centuries BCE. This has further prompted reassessment of the techniques employed in even earlier times. While the traditional view has been reiterated in all literature on the subject since at least the 1960s, the advantages of the novel interpretation have hitherto not been comprehensively presented in a Western language.¹

There are manifold reasons why these details should interest a student of ancient Chinese bronzes and ancient Chinese history in general. The most apparent is the authentication of inscriptions on unprovenanced objects, as it is

¹ For a fairly comprehensive treatment in Chinese, see Zhang Changping 2010; Guan Shuqiang 2016; Shi Anrui 2020a; for a discussion in English, see Nickel 2006, 36–38; Zhang 2012; Škrabal 2019, 314–331.
commonplace that inscriptions were forged onto authentic bronzes. It goes
without saying that without a thorough knowledge of ancient inscription tech-
niques, it is almost impossible to assess the genuineness of unprovenanced
inscriptions reliably. Furthermore, such knowledge can aid textual scholarship
by elucidating how certain mistakes came into being during the production
process; this can provide information about the content and form of an inscrip-
tion’s master copy. From a palaeographic perspective, it can indicate how well
and how directly an inscription represents the handwriting of its time, and how
certain misspellings or variants may be products of casting infelicities rather
than of the scribal hand. Furthermore, it can make research on calligraphy more
complex by clarifying the technology by which the artistic features of inscrip-
tions were produced, the extent to which they were determined or limited by
inscription techniques and the relation between an epigraphic style and inscrip-
tion technique. Historians of technology will also be interested in the level of
achievement of early Chinese craftsmen, the variety of techniques they em-
ployed, the dynamics of the emergence of these techniques or their place in the
global context of the ancient world.

2 Preliminaries: Piece-mould technique, simple
inscriptions and the inscription block

Until the fourth century BCE, due to the late advent of iron carving tools, bronze
inscriptions were typically cast. Cast inscriptions could be produced in a variety
of ways. In particular, bronzes from the Late Shang period (thirteenth to elev-
enth century BCE), when bronze epigraphy was still in its infancy, indicate that
various simple techniques were used to produce short inscriptions several
graphs in length. As the bronzes were cast from ceramic moulds, a negative
version of an inscription had to be prepared in the mould to yield a positive

2 While the earliest inscriptions carved in bronze come from the first half of the eleventh
century BCE (Yue Zhanwei, Yue Hongbin and Liu Yu 2012, 66–67; Liu Yu 2019, 106–109; Yang
Huan and Yang Jian 2020), only from the ninth century BCE on was carving occasionally used to
produce longer inscriptions, typically on reused objects. From the fourth century BCE on, with
the emergence of iron tools, carved inscriptions gradually dominated the epigraphic landscape
of ancient China. For carved inscriptions from those times, see Zhang 2012, 267–268; for
chiseled inscriptions, see Li et al. 2011, 494–496. For iron metallurgy in ancient China, see
Wagner 1993.
3 For details, see Bagley 1990.
inscription upon casting. Thus, it is the ceramic stage of inscription-making that is of main interest here. Between the thirteenth and eighth century BCE, inscriptions were typically cast on the interior walls of objects, except for some liquor cups (jia斝, jue爵) and bells, which commonly featured inscriptions on the outside walls. This was also the case for weapons, tools, chariot fittings and decorative pieces. The former type of inscription was prepared on the core (inner mould), while the latter was prepared on the outer mould(s). However, the technique did not differ.

The easiest way to prepare an inscription was to engrave a mirror-reversed text directly into the leather-hard clay core (or mould). The intaglio lines of such an engraving became positive relievo graphs on the cast object. Relievo inscriptions are seen only occasionally in Late Shang and Early Western Zhou (late eleventh to early tenth centuries BCE) bronzes, mainly inside the foot of gu觚 beakers and inside alcohol containers. While relievo inscriptions were easy to produce, they were also more susceptible to mechanical damage during post-casting finishing and regular cleaning after the vessels were used in a sacrificial ritual.

It was also possible to engrave the mirror-reversed outlines of a graph into the core and to pare down the clay outside of this sketch. The sketched graph would thus rise above the surface of the core, and a positive intaglio inscription was produced after casting. To spare the efforts of scraping a layer of clay off the entire surface of the core, the graph could be sculpted on a separate clay slab (a so-called ‘inscription block’), which could then be embedded in a niche gouged out of the core for this purpose. Even with the use of the inscription block, this technique was too laborious to produce inscriptions with more than just a few graphs.

However, the edges of the inscription block are still discernible in many inscriptions, and it is generally believed that inscriptions were indeed commonly

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4 From the eighth century BCE on, inscriptions were placed on the outside walls of the vessels increasingly often. For more on this shift, see Huang Tingqi 2018, 46–62.
5 Zhang 2012: 268; for examples, see Barnard and Wan 1976, 50–53. By Zhang’s count, of the 792 gu觚 beakers recorded in Zhongguo shehui kexueyuan Kaogu yanjiusuo 2007, 98 have relievo inscriptions. My own count shows that, of the 825 you сос containers recorded in Wu Zhenfeng 2012, at least 24 have relievo inscription (some cases are difficult to determine). There are also cases in which the lid of a you сос has a relievo inscription and an intaglio inscription is cast in the bottom of the container (and vice versa).
6 For examples of inscriptions that are believed to have been produced by this technique, see Barnard and Cheung 1996, 226–239. Note that Guan Shuqiang 2017, 69–71, offered an alternative explanation of how some of them were produced.
prepared on such blocks but using a different technique than described above. Several scholars have nevertheless justly pointed out that some of the longest inscriptions cast on the hemispherical interiors of ding 鼎 cauldrons would be difficult to produce using a flat inscription block.\(^7\) There is, however, little reason to believe that a different inscription technique was used in those cases. Rather, the use of inscription blocks should be understood as a convenient technique that was applied where possible, such as on straight or slightly curved walls. When the complexity of the surface did not allow for the use of inscription blocks, the inscription had to be sculpted directly on the core,\(^8\) which was admittedly less convenient for craftsmen.

### 3 Special features of cast inscriptions in ancient China

Before looking in detail at the most consequential of inscription techniques, it might prove useful to summarise the features of a typical bronze inscription cast in ancient China. To prevent any confusion, I use the term ‘typical’ to refer to an inscription with more than three graphs in length that was cast during the Middle and Late Western Zhou periods (mid-tenth to early eighth centuries BCE), when most of the famous inscriptions were produced. These features include:

1. Intaglio (sunken) lines. For the reasons described above, intaglio inscriptions were largely preferred.\(^9\)

2. No mechanical reproduction. Mechanical reproduction was only introduced into inscription-making during the late eighth century BCE. This first involved repeated impressions of the master pattern block with the entire text.

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\(^7\) Chang 1974–1975, 472; Hayashi 1979, 12–13; for further problematical surfaces, see Li Feng 2015b: 144–146.

\(^8\) Consider, for example, the set of the twelve Qiu ding 逑鼎 cauldrons. Most of their inscriptions were prepared on inscription blocks (as confirmed by discernible boundaries of the blocks and in one case even by blocks inserted in wrong order). However, as Li Feng 2015b, 149 suggests, for several cauldrons of this set, the inscription was most likely prepared directly on the core.

\(^9\) The décor on the exterior of ritual bronzes was sometimes filled with a black or colourful substance to enhance the visual effect, see Gettens 1969, 197–204; Su Rongyu 2020. Sunken inscriptions allowed for the same treatment, but I am aware of only one such case; this is the Xiaochen Bu ding 小臣逋鼎 in the collection of the Tsinghua University Library 清華大學圖書館, Beijing.
of an inscription. From the seventh century BCE on, stamps with individual graphs were also used.

3. Undercut. The sidewalls of the grooves of intaglio graphs are typically inclined so that the grooves are somewhat wider at their bottom than at their opening (Fig. 1:3).

4. Wavy lines. Under magnification, the lines of individual strokes (i.e. the edges of the grooves) often show uneven width and their edge lines appear wavy, not straight (Fig. 1:3).

5. Thickened cross-strokes. The grooves are sometimes remarkably thicker at the intersections of two or more strokes (Fig. 1:4).

6. Raised-edge effect. Sometimes, the edges of the stroke grooves are slightly higher than the surrounding surface of the inscription.

7. Relievo grid lines. Some inscriptions are written into a regular relievo grid that allots one space for each graph (Fig. 1:2). More inscriptions show faint traces of grid lines that have been removed during the post-casting polishing procedure.

8. Intaglio graphs with partial relievo strokes. Occasionally, intaglio graphs occur with a part of their strokes in relievo (Fig. 1:7); in rare instances, the entire graph is registered in relievo. This situation can only be preserved in inscriptions to which abrasive polishing was not applied.

9. Missing strokes. Sometimes the intaglio graphs miss a part or the whole of a stroke (Fig. 1:5), and occasionally, the entire graph is not registered in the inscription. This feature is not uncommon and occurs in inscriptions that were polished.

10 Sakikawa 2017.
12 Chen Jieqi and Chen Jingdi 1919, 6; Pope et al. 1967, 96 and *passim*; Gettens 1969, 141–147; Tan Derui 1999, 243; Zhang Yuyao and Zhang Tian’en 2018, 66.
16 See Barnard and Wan, 1976 for examples.
18 Li Feng 2015b, 150; Zhou Ya 2017, 318; Shi Anrui 2020a, 153–155.
19 Zhang 2012, 273–276; Li Feng 2015b, 150.
10. Displaced strokes. At times, an intaglio stroke of a graph appears broken or displaced from its original position (Fig. 1:8).²⁰

11. Ghost characters. This is a rare feature where residues of a relievo graph are visible in the area immediately surrounding an intaglio graph (Fig. 1:6).²¹

Note that some of these features remained unnoticed until fairly recently (nos 8, 9, 11) while others were considered signs of forgery (especially nos 3, 4, 5).²² These suspicions were, however, dispelled over the last 50 years by abundant evidence from archaeologically recovered inscribed bronzes. A model of inscription-making in the Middle and Late Western Zhou periods should convincingly explain the presence of all 11 features.

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4 The traditional master pattern technique: a critique

To explain how inscriptions were made in ancient China, a variety of interpretations have been proposed during the last two centuries. One of the earliest interpretations – and surely the most influential – was formulated by Ruan Yuan 阮元 (1764–1849):

余所見鐘鼎文字，揣其制作之法，蓋有四焉。一則刻字于木范為陰文，以泥抑之成陽文，然後以銅鑄之成陰文矣。一則調細泥以筆書于土范之上，一次書之不高，則俟其燥而再加書之以成陽文，以銅鑄之成陰文矣。三則刻土范為陰文，以銅鑄之成陽文矣。四則鑄銅成後鑿為篆銘。漢時銅印有鑿刻者，用此法亦陰文也。

Regarding the inscriptions on bronze vessels and bells that I have seen, should I assess their production technique, they would be roughly of four kinds. One is carving the text into a wooden mould to produce an intaglio inscription; impressing clay on it will then produce a relief inscription; subsequently, casting a bronze in it will produce an intaglio inscription. Another [technique] is mixing a very fine clay and applying it with a brush on the surface of the clay mould. A single application would not produce a high enough [relief], so upon hardening, more layers were added to obtain a relief inscription; upon casting, this produced an intaglio inscription. The third [technique] is carving [a text] into the clay mould to produce an intaglio inscription, which, upon casting, produced an inscription in relief. The fourth [technique] is such that after the casting was completed, a carved-style inscription was chiselled [into the surface]; among the bronze seals of the Han period, there are [also] instances of carved [inscriptions]. This technique also produced an intaglio inscription.23

Ruan further asserted that the Late Western Zhou San Shi pan 散氏盤 inscription, which was executed in a style that is representative of this period, was cast from ceramic moulds prepared using the first technique: impression from a positive inscription carved into a wooden block. Writing around 1823, Ruan laid the grounds for a conventional interpretation that has been widely accepted for nearly 200 years with only minor touch-up: Scholars agreed that the inscription was not initially incised in a wooden board, but in a clay slab, of which an imprint was then taken to create an inscription block with mirror-reversed relievo text. Then, the block was fired and inserted into the core (or mould) of the piece-mould casting assembly, into which the object was cast, producing an intaglio

23 Ruan Yuan 1823, 17.
inscription. This is the traditional explanation, the so-called master pattern technique.

However, already in the 1940s Rong Geng 容庚 (1894–1983) highlighted a major problem with this interpretation: If the inscription block was produced by an impression from a master pattern, then it must have been possible to create several identical inscriptions through repeated impressions from one master pattern. Yet, as pointed out by Rong and corroborated by all the bronzes discovered since his work was published, even though the same text may be copied a dozen times on the vessels cast in a set, there is no evidence of mechanically reproduced inscriptions in the Western Zhou period.

Moreover, this interpretation fails to account for most of the remaining features listed above. Attempts at explaining the coexistence of the relievo grid lines and intaglio inscription illustrate the problems with the traditional model: To produce such inscriptions using this model, the relievo grid had to be sculpted on the master pattern block, which means additional time and material were required beyond the default procedure; note that this complication would be introduced only to cast a relievo grid that was, however, typically polished away after casting. This is counter-intuitive. Moreover, when considering the occasional relievo strokes or ghost characters, proponents of the traditional explanation have obvious difficulties: Barnard candidly admitted being baffled by this feature, while Li Feng 李峰 submitted a convoluted proposal that remains un-compelling due to the same fallacy – it enormously complicates the production scenario solely to explain the presence of ghost characters. The ghost characters were, however, undesired and only occasionally and only by chance did they fail to be polished away. Other features, such as the undercutting, wavy lines and thickened cross-strokes, also remain unexplained by the traditional model.

Due to some of the above shortcomings, scholars sought alternative explanations. Rong Geng himself proposed that the text was first written in ink on the surface of the inscription block and then the surrounding clay was pared down to produce a relievo inscription, a technique already mentioned above. Chang

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24 The loci classici are Chen Mengjia 1954, 41; Shi Zhangru 1955, 121; Barnard 1961, 157–161; Barnard and Cheung 1996, 239–248.
25 Rong Geng 1941, 158–159.
26 For such studies, see, for instance, Barnard and Wan 1976; note that Barnard here committed the same fallacy that he himself criticised later with regards to Hayashi’s proposal concerning the raised-edge effect, see Barnard and Cheung 1996, 220.
28 Li Feng 2015a; an English translation of it was published as Li Feng 2015b.
Kuang-yüan 張光遠 later elaborated on this, arguing that even the longest inscriptions, such as that of the Mao Gong ding 毛公鼎, were produced in this manner, but his proposition has been convincingly debunked. ^29 Hayashi Minao 林已奈夫, Matsumaru Michio 松丸道雄, Li Feng and Zhou Ya 周亞 also submitted imaginative proposals, each of which, however, suffered from serious shortcomings, mostly because they rendered the process much too complicated. ^30 As a result, for all its drawbacks, the general literature on ancient Chinese bronzes embraced and perpetuated the default master pattern model.

5 The modelling technique: a genesis

Of the many proposals in the prior literature, the only one that explains all eleven features listed above is the so-called ‘modelling technique’ (duisu fa 堆塑法). In essence, this technique is similar to Ruan’s second proposal. In fact, Chen Jieqi 陳介祺 (1813–1884), the most famous connoisseur and collector of ancient Chinese bronzes, who was renowned for not having a single forgery among the several thousand pieces in his collection, was convinced that the ancient inscriptions were produced by the modelling technique:

古人模範之精，今多不能思議。以土為範，範土以刀畫之成格，格上漆書字，字上再以土堆成陽字，鑄成即成陰款。 ^32

The ingenuity of the moulds [produced by] the ancients cannot, for the most part, be even imagined today. [They would] make a mould from clay, [and then] make incisions in the mould using a knife to create a grid. In the grid, they would [first] write the [desired] graphs using paint, and on these [painted] graphs, they would then model relief graphs from clay. Upon casting, this produced an intaglio inscription.

Among subsequent scholars, only Shang Chengzuo 商承祚 (1902–1991) ^33 endorsed Chen’s proposal, such that his suggestion remained neglected or even forgotten. It was not until the late 1990s that Chen Chusheng 陳初生, Shang’s
former student, inspired by the phenomenon of displaced strokes, revived Chen Jieqi’s idea with some modifications. Soon afterwards, in 1999, Tan Derui, the foremost expert on ancient Chinese bronze casting, published an important paper on the piece-mould casting technique. In this paper, he acknowledged the traditional explanation, but proposed that inscriptions with the undercut feature, such as the Liangqi zhong 梁其鐘 and Larger Ke ding 大克鼎, were produced by the modelling technique.

That very year, the Zhouyuan Archaeology Team launched a large-scale survey of the Zhouyuan site, which led to the discovery and excavation of an ancient bronze foundry site west of Lijia village, Fufeng, Shaanxi. Remains of ceramic moulds recovered from the site exhibited an interesting feature: the raised lines of the décor were modelled from clay and attached to the mould. Moreover, at places where the décor lines dropped from the mould, shallow intaglio sketch lines were exposed. These materials were analysed by Chen Yang, who suggested two ways in which the relief décor lines might have been produced: the clay lines were either modelled separately and inserted into grooves that were previously sketched on the surface of the mould, or they were directly squeezed into the grooves using the slip trailing method (also known as tube lining).

The sketched grooves served a double purpose: they constituted a guideline for the execution of décor lines, and they provided a base on which clay lines could be securely anchored on the surface of the mould.

News of this discovery began to circulate in academic circles soon after the excavations and had far-reaching influence. In 2006, Lukas Nickel authored a thorough study on ceramic moulds in which he traced the use of the modelling technique to the Late Shang period, arguing that inscriptions were also produced in this manner. In his view, the lines of both the décor and the inscriptions were produced by slip trailing, and he showed how this technique elegantly resolves the problem of undercutting. The same year, in his book on ancient Chinese bronze casting, Dong Yawei 董亞巍 argued that modelling was used already in the Middle Shang period (fourteenth to thirteenth century BCE) to create decorated moulds, and he maintained that the majority of Shang and Zhou inscriptions were produced with this technique. Apart from the undercutting, he

34 Chen Chusheng 1998.
35 Tan Derui 1999, 242–243. In his view, this was achieved either by the method proposed by Ruan Yuan, or by applying strips of clay of the size of an individual character or of the whole column and cutting them into shape of desired graphs.
36 Zhouyuan kaogudui 2004: 447.
37 Chen Yang 2005, 27.
38 Nickel 2006, 36–37; for a response defending the traditional view, see Bagley 2009.
identified the wavy lines as an accompanying feature of the modelling technique, and proposed that for some inscriptions, especially those from the Late Shang and Early Western Zhou periods, the clay lines applied on the inscription block were carefully trimmed, while for other inscriptions, they were left untrimmed, producing the wavy effect. The idea caught on, but it was not until 2010 that Zhang Changping 張昌平 provided a reconstruction of the entire procedure of inscribing bronzes using the modelling technique. Zhang’s paper marked a breakthrough, not only because he presented solid epigraphic evidence for his argument but also because he highlighted the importance of the sketching and polishing procedures that were disregarded by some earlier authors. In the last decade, other scholars have also subscribed to the modelling interpretation, offering further evidence of how this technique successfully explains puzzling features of Western Zhou inscriptions, including the presence of ghost characters.

At the same time, excavations of several bronze foundry sites have yielded hard evidence corroborating the use of the modelling technique. In 2006, excavations of the bronze foundry site at Kongtougou 孔頭溝, Qishan County, Shaanxi, brought to light a small shard of an inscription block 3.9 cm high, 4.1 cm wide, and about 3.8 cm thick (Figs 2–3). Dated roughly to the second half of the ninth century BCE, the shard bears shallow intaglio grid lines, intaglio sketches of two complete graphs and a part of one additional graph.

A decade later, several more inscription block shards were discovered during the excavations of another bronze foundry site at Guanzhuang 官莊, Xinyang County, Henan. Similar to the Kongtougou find, these shards, dating to the first half of the eighth century BCE, feature shallow intaglio sketches of individual graphs, but in some places, residue of clay lines modelled in the sketched grooves is preserved, either in full relief or partially broken.

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39 Dong Yawei 2006, 93–95; 110–113.
40 Zhang Changping 2010; for an English translation, see Zhang 2012.
41 See below for the individual arguments and references.
42 Guo Shijia, Chong Jianrong and Lei Xingshan 2020, 107–109. I am grateful to Guo Shijia 郭士嘉 and Lei Xingshan 雷興山 for providing photographs of the shard and for the permission to reproduce them here.
43 Hui Xiping 2017.
44 Observations made during a personal study, 29 October 2017. Zhengzhou daxue Lishi xueyuan et al. 2020 published only the décor moulds unearthed from this site; these were also decorated using the modelling technique and show the very same feature. I am indebted to Gao Xiangping 郭向平 for sharing this report while still in press. In fact, two similar shards were reported from the excavations of a bronze foundry site at the Beiyao 北窯 District in Luoyang,
6 The modelling technique: a reconstruction

While the archaeological evidence is compelling in its own right, it is still necessary to explain how the modelling technique can explain the long list of features presented above. This section offers a step-by-step reconstruction of the inscription process, with particular attention to how those features were produced.45

First, a leather-hard clay slab of the desired size was prepared (Fig. 4:1), and the grid was incised (Fig. 4:2). The uneven width and height of grid lines in cast...
inscriptions suggest that they were typically incised by a stylus rather than by impressions of a long, thin bamboo slat or a similar tool. However, it is possible that sometimes the incisions were not done freehand, but by using a straightedge. The analysis of the inscription block shard unearthed in Kongtougou bronze foundry site in 2006 suggests that the vertical lines were incised first.\footnote{Guo Shijia, Chong Jianrong and Lei Xingshan 2020, 107. The size of the grid cells on this shard is 2.3 cm in height and 1.4–1.5 cm in width; the depth and width of the incised grooves does not exceed one millimetre, see Fig. 3.}

In the next step, the text of the inscription was incised in the prepared grid (Fig. 4:3). Ideally, each graph would occupy one cell of the grid, but there are cases in which graphs overwrite the horizontal grid lines to crowd more (or evenly distribute less) characters into a column. The incised lines of the Kongtougou shard show a U-shaped cross-section in which the bottom of the grooves is narrower than their opening, and the middle parts of strokes are slightly deeper than their ends (Fig. 3).\footnote{Guo Shijia, Chong Jianrong and Lei Xingshan 2020, 107.} Note that the graphs were incised in mirror-reversed form, a practice that is still observable in much later bronze mirror workshops.\footnote{Note that if free rein was given to one’s hand and the sketch was prepared in positive, this would result in a mirror-reversed graph or inscription, an effect not uncommon in ancient Chinese bronze epigraphy. For this point, see Chen Chusheng 1998, 120; Nickel 2006, 37.}

![Fig. 3: Close-up of the Kongtougou shard (H48:6) with an intaglio graph and grid lines. © School of Archaeology and Museology, Peking University.](image-url)
The question that remains to be clarified is whether the manuscript from which the artisan transferred the text to the inscription block was already carried out in mirror writing to facilitate the transfer, or whether the conversion occurred during the transfer; the latter case would imply that the artisan was trained in mirror-writing or made use of a handy mirror.

Next, proofreading took place – though not always, as suggested by occasional mistakes in cast inscriptions. There were several ways of correcting a mistake discovered during proofreading. An omission of an individual graph could be remedied simply by supplementing the graph onto a blank space available in the laid-out inscription, or by levelling up the grooves of the graph sketched in the position where the omitted graph was originally planned and then reincising both graphs in a somewhat smaller size in this cell. More complex mistakes, such as inadvertent additions or omissions of larger chunks of text, required levelling up the flawed part of the sketch and new incision of the correct text. When the sketched grooves of unused graphs were not levelled up, they became faint relieve ghost characters in the cast inscription.

After proofreading came the most crucial stage of the modelling procedure. Thin lines were modelled from clay and their bottom portions were nested in the grooves sketched in the inscription block, so that relieve graphs were created (Fig. 4:4). How exactly the clay lines were modelled is a question that awaits more archaeological evidence. Both scenarios proposed by Chen Yang are feasible, but the ‘liquid’ appearance of graphs in some inscriptions (the wavy lines) seems to suggest that the ridges of relieve graphs were produced by slip trailing, a method in which thin lines of watered-down clay (slip) are squeezed from a dispenser onto the surface to create a relief line. Essentially, as Chen Yang put it, this is like decorating a cake using a piping bag. Upon drying, the ridges could be trimmed with a stylus to even the width of strokes. Such a procedure would arguably leave gouges or impressions of the stylus in the surface of the inscription block in the immediate vicinity of the modelled ridges, which, upon casting, would create the raised-edge effect. The slip trailing method seems more efficient than other techniques, for which the craftsmen would need to constantly divide their attention between ‘writing out’ the relieve lines of an inscription and modelling the clay into the desired shape in their hand. In any

49 For studies on such hypothetical manuscripts, see Škrabal 2019; Shi Anrui 2020b.
50 For both types of correction, see Škrabal 2019, 309–313.
51 Škrabal 2019, 318–326. Sometimes graphs were re-sketched only to improve their position, see Shi Anrui 2020a, 159–160.
52 Chen Yang 2005, 27.
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The cross-section of the relief ridges on both the décor and inscription moulds are wider at the top of the ridges than at the bottom, which explains the undercutting feature. Moreover, where two ridges join, the excessive clay would spread around the intersection, creating thickened cross-strokes.

After the relief inscription had been modelled and, optionally, proofread and trimmed, the inscription block would have been dried, fired and embedded in the core or outer mould (Figs 4: 5–6). The piece-mould assembly was then set up to receive the molten bronze. When the bronze solidified and the moulds cooled off, the assembly was dismantled, quite likely beginning by removing the core. This procedure (divesting) required several strokes of a mallet, and the laboriously produced moulds, core and the inscription block were thus turned into shards, such as those discovered at Kongtougou and Guanzhuang.

Divesting was followed by cleaning, which included removing the sprue, cleaning away the residue of moulds and core, deburring, polishing and perhaps even burnishing to achieve the desired effect. Note that, due to the undercutting, the ceramic strokes might have become wedged in the cast inscription; this would explain why some inscription block shards do not have relief ridges. Chipped-off fragments of ceramic strokes would then have to be removed from the inscription area.

Finally, the inscription area could be polished to remove any undesired protrusions (Fig. 4:8). These protrusions were by no means limited to the grid lines. When poured into the moulds, the weight of the molten bronze could cause some of the relief lines of the modelled inscription to shear off, and then the bronze would flow into the exposed grooves in which the lines were originally nested. When the casting was completed, this resulted in partial relief strokes in otherwise intaglio graphs (Fig. 4:7b). The degree to which graphs were flawed

53 For a photograph of such cross-section on a décor mould, see Chen Yang 2005, 28 figure 18:1, reproduced also in Shi Anrui 2020a, 145.
55 You Guoqing 2012, 349; Guan Shuqiang 2016, 185–186; Guan Shuqiang 2017, 72.
56 Liu Yu 2019: 158.
57 See Dong Yawei 2006, 42–45; Hua Jueming 2007; Liu Yu 2019, 158–162 for details. Fine-grained and coarse-grained sandstone were used for polishing, see Liu Yu 2019: 159–160. 246 sandstone whetstones were unearthed from the remains of the Late Shang bronze foundry in Xiaomintun, see Zhongguo shehui kexueyuan Kaogu yanjiusuo Anyang gongzuodui 2006, 375–376 and plates 15–16.
58 For inscriptions containing ceramic remains, see Zhang Yuyao and Zhang Tian’en 2018, 66. It is also possible that parts of the ridges were detached from the block later, during the discarding process.
in this way varied from a negligible portion of a stroke to a considerable part of
the whole graph, and occasionally, the relievo lines of the entire graph were
washed away and the graph registered in relievo upon casting.\textsuperscript{60} In some cases,
the detached relievo line was not washed away completely, dislocated from its
original position, producing the displaced stroke effect.\textsuperscript{61} Moreover, when proof-
reading and subsequent corrections left behind unused intaglio grooves in the
inscription block that were later not levelled up, the molten bronze flowed in
and turned these abandoned grooves into ghost characters in the cast inscrip-
tion. Polishing of the inscribed area would efface the relievo grid lines as well as
all relievo strokes produced by casting (Fig. 4:8b). While it was certainly desira-
ble to remove the unwanted ghost characters, polishing off the relievo strokes of
the intended graphs produced the missing stroke (or even missing graph) effect,
a toll paid for a smooth and shiny inscription area.\textsuperscript{62}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4}
\caption{Production of an inscription using the modelling technique.}
\end{figure}

\textsuperscript{60} Zhang 2012, 276 suggested that these cases might be due to negligence that led the intaglio
sketch of a graph to not be filled by relievo clay lines. While it is possible that sculpted strokes
broke off the inscription block also during manipulation prior to casting, the displaced strokes
testify that it was not uncommon for ridges to break off when pouring the molten bronze.
\textsuperscript{61} Chen Chusheng 1998; Shi Anrui 2020a, 160–161.
\textsuperscript{62} Škrabal 2019, 325–326; Shi Anrui 2020a, 157–159. Note that the 'missing graphs' are typically
simple graphs consisting of only few strokes; see Shi Anrui 2020a, 155 n. 1. As noted by
Hayashi 1979, 9 and 36, most of the 'raised edges' would also be polished away.
It follows that the grid lines, reliefo strokes and ghost characters can only be observed in inscriptions that were not polished or were polished incompletely (Fig. 4:7). In some vessels, polishing was not done due to limited accessibility of the inscribed area, such as inside the neck of hu 壺 containers. On the other hand, flat and open inscription areas on vessels such as gui 簋 tureens, xu 盪 containers or pan 盞 trays were nearly always polished.⁶³

7 The modelling technique and the inscriptions of earlier periods

While the above survey is based on evidence from the tenth to eighth centuries BCE, archaeological evidence seems to corroborate that modelling was in use already by the Late Shang period, though the exact procedure seems to have differed somewhat. Between 2000 and 2001, excavations of Late Shang bronze foundry remains in Xiaomintun 孝民屯 near Anyang, Henan, yielded a nearly complete inscription block 6.2 cm high, 4.4 cm wide and roughly 3 cm thick, inscribed with 11 graphs in three columns.⁶⁴ All graphs were first incised in the block, but unlike in later periods, the incisions are not limited to thin lines; rather, the incised strokes are written out in full width. Subsequently, reliefo graphs were modelled in these incisions.⁶⁵ The fact that most of the grooves preserve remains of the modelled ridges means that they were well nested in the grooves and would not break off as easily as in later periods.⁶⁶ Thus, it seems

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⁶³ There are, of course, cases in which easily accessible inscriptions were left unpolished. Of these, the Larger Ke ding inscription constitutes a special case in which the polishing procedure was not completed out of concerns for legibility; see Škrabal 2019, 324–325.
⁶⁴ Zhongguo shehui kexueyuan Kaogu yanjiusuo Anyang gongzuodui (2006), 374–376, plate 15.2. For an English summary, see Anyang Work Station, Institute of Archaeology, CASS 2007.
⁶⁵ See You Guoqing 2012, 349; Guan Shuqiang 2016, 184–185, Guo Shijia, Chong Jianrong and Lei Xingshan 2020, 112–113, pace Yue Zhanwei, Yue Hongbin and Liu Yu 2012, 63–64, who claim that the block was produced by an impression from a master pattern. However, in that case, the reliefo lines of individual graphs on the Xiaomintun block would not break away so cleanly and leave the surrounding surface undisturbed. Scholars made the same point with regards to the Lüshun core, see below. Note that the graphs on the Xiaomintun block are written in positive, which means that the inscription cast from it would appear mirror-reversed.
⁶⁶ However, both displaced strokes and intaglio graphs with partial reliefo strokes can be observed in Late Shang bronze inscriptions; for the former, see Hayashi 1979, 42–43; for the latter, see for example the inscription on the lid of the famous Min fanglei 皿方罍.
that the modelling technique evolved over time.\textsuperscript{67} The features of the Xiao-
mintun block match well those of an inscribed ceramic lid core of unknown
provenance, roughly from the mid-eleventh century BCE, which is now in the
collection of Lüshun Museum in Dalian, Liaoning. This is an unused
core,\textsuperscript{68} so the majority of its relievo graphs are preserved, but where parts of the
ridges broke off, the surrounding core surface is undisturbed, suggesting that
these graphs, too, were modelled directly on the core and not embossed from a
master pattern.\textsuperscript{69}

It is obvious that the modelling technique underwent new developments
during the tenth century BCE. Earlier, the grooves incised into the inscription
block were of the same width as the modelled ridges, or even slightly wider
(producing the raised edge effect upon casting). However, during this period,
the grooves were linearized, with significantly wider ridges modelled over them.
On the one hand, this solution expedited the production of longer inscriptions,
but on the other hand, the modelled ridges were not as firmly nested in the
grooves and were more susceptible to breakage. This explains not only the dif-
fERENCE in ductus between the Early and Middle Western Zhou periods (compare
Figs 1:1 and 1:2) but also the increasing presence of missing strokes and related
features from this time on.

\section*{8 Conclusion}

In so far as production technique is concerned, ancient Chinese cast inscrip-
tions are unique in the context of the ancient world. Their specific features have
long bemused scholars; some leading specialists even considered them to be
acid etched.\textsuperscript{70} In recent years, the study of inscription-making in ancient China
has entered a new stage in which scholarly interpretations are supported by

\textsuperscript{67} Guan Shuqiang 2017, for instance, suggested that at an earlier stage, strips of clay were
applied on the inscription block and carved into the desired shape (as proposed in Tan Derui
1999), and at a later stage, slip trailing was employed. The proposal advanced in Zhang Yuyao
and Zhang Tian’en 2018, 65–67 combines elements of the master pattern and modelling tech-
niques but remains unconvincing as it retains the weaknesses of the traditional explanation.
\textsuperscript{68} An observation by Matsumaru Michio as quoted in Hayashi 1979, 52, n. 30. For photographs,
see Hayashi 1979, 30–31; Barnard and Cheung 1996, 214; Lüshun bowuguan 2009, 28.
\textsuperscript{69} This point was made by the most unlikely person, Noel Barnard, who, however, concluded
that the core must be a twentieth century forgery, see Barnard and Cheung 1996, 215–219. The
Xiaomintun block refutes his conclusion.
\textsuperscript{70} Gettens 1969, 146–147.
archaeological evidence. The current question is not anymore what the main technique of inscribing bronze was in ancient China, but rather when the modelling technique began to be used, how exactly the relievo lines were modelled, at what stages the moulds were baked, and what factors led to its simplification during the tenth century BCE. The new interpretation has a direct bearing on understanding of various aspects of ancient Chinese bronze inscriptions, from authentication to comparative research. In fact, some of the past verdicts of spuriousness may warrant reassessment, while later uses of the modelling technique for both bronze and ceramic production deserve further attention. The confidence with which Chen Jieqi identified modelling as the ancient technique to inscribe bronzes suggests that it was probably known in ceramic workshops of his time; indeed, slip trailing remains a common technique used in ceramic workshops worldwide. Regarding Chinese bronze epigraphy, hard evidence confirms that modelling was used as late as the fifth century BCE and was likely that it was known in later centuries as well, perhaps even until the beginning of the Common Era. Soon afterwards, however, the proliferation of powerful carving tools seems to have brought to an end this remarkable chapter in the production of written artefacts.

**Acknowledgements**

The research for this article was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany’s Excellence Strategy – EXC 2176 ‘Understanding Written Artefacts: Material, Interaction and Transmission in Manuscript Cultures’, project no. 390893796. The research was conducted within the scope of the Centre for the Study of Manuscript Cultures (CSMC) at Universität Hamburg. I am grateful to Edward L. Shaughnessy and two anonymous reviewers for comments and suggestions that helped to improve this article.

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71 The inscription on the bottom side of the handle of a bronze measure dated to 9 CE, which is in the collection of the Xiangyang City Museum, shows some features of the modelling technique; see Zhang Tian’en 2016, 134–135. However, personal study with a magnifying glass is required to corroborate this observation.
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