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EMPHASIS ON VISUAL AND TACTILE EXPERIENCES: MECHANICAL TREATMENTS OF BRONZES AND JADES IN ANCIENT CHINA

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Abstract

This article presents fresh evidence and arguments regarding the historical study of sensory experience through a focus on the mechanical treatments of bronzes and jades in ancient China. The techniques employed to polish and engrave hard bronze surfaces before the invention of iron tools that are harder than bronze remain a mystery. The article provides new insights into engraved/chiseled bronze inscriptions, which can be too easily dismissed by connoisseurs as fake. Through a focus on post-processing techniques for cast bronze objects made before 1 B.C.E. in China and exchanges of techniques between bronze producers and jade workers, I argue that some of the traces found on bronze objects that may have been left by working with abrasives such as those used in lapidary industry demonstrate that lapidary techniques and post-processing of cast bronze objects were interrelated. Investigations as to how bronze and jade producers interacted show that they aimed to improve the visual and tactile experiences for their customers or patrons. Active and frequent exchanges of ideas and techniques took place between the bronze and jade production communities. Their emphasis on visual and tactile experiences demonstrates how such industrial powers developed in ancient China and how they were sustained throughout the last two millennia B.C.E.

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Introduction

The study of sensory experiences has expanded substantially in both science and the humanities.[1] The study of historical sensory experiences is difficult, but valuable. Such study can be valuable in providing new insights into how humans perceive the world through bodily experiences. Studies of the senses, established in Western thought since the time of Plato, were pitted against studies of the mind. Many eminent philosophers, notably René Descartes (1596–1650), criticized a reliance upon sensory experiences to understand the world.[2] However, as some scholars have come to realize that the experiences of human bodies are the direct outcomes of interaction between human beings and the physical world, more attention has returned to sensory experiences.[3] As these direct outcomes eventually shape mental perceptions, both physical and mental perceptions are therefore cornerstones in the creation and development of any given culture.

Psychologists, neuroscientists, linguists, historians, and scholars of other disciplines have conducted related research in this field of the study of sensory experience. However, the study of sensory experience is difficult for historians who purely rely on textual records, since historical texts rarely record bodily experiences and provide little evidence for the study of sensory experiences. Moreover, relying on information retrieved from texts or manuscripts is different from treating manuscripts as objects. Art historians, archaeologists, and historians of materials or objects may, on the contrary, play an important role in the field. Visual experiences offered by object producers throughout history are still largely accessible, because many visual records such as paintings have been well preserved and still

1. Dennis Tay, "Bodily Experience as Both Source and Target of Meaning Making: Implications from Metaphors in Psychotherapy for Posttraumatic Stress Disorder," *Cognitive Linguistic Studies* 1.1 (2014), 84–100; Josselin Baumard and François Oslurak, "Is Bodily Experience an Epiphenomenon of Multisensory Integration and Cognition," *Frontiers in Human Neuroscience* 13 (2019), 1–6; David Howes, ed., *The Varieties of Sensory Experience: A Sourcebook in the Anthropology of the Senses* (Toronto: University of Toronto, 1991); David Howes, ed., *Senses and Sensation: Critical and Primary Sources*, 4 vols. (London: Bloomsbury Academic, 2018); M. H. G. Kuijpers, "A Sensory Update to the *Chaîne Opératoire* in Order to Study Skill: Perceptive Categories for Copper-Compositions in Archaeometallurgy," *Journal of Archaeological Method and Theory* 25.3 (2018), 863–91; Mark Smith, *Sensing the Past: Seeing, Hearing, Smelling, Tasting, and Touching in History* (Berkeley: University of California Press, 2007); David Karmon, *Architecture and the Senses in the Italian Renaissance: The Varieties of Architectural Experience* (Cambridge: Cambridge University Press, 2021).

2. Anthony Synnott, "Puzzling over the Senses: From Plato to Marx," in *The Varieties of Sensory Experience*, ed. David Howes, 61–76.

3. For example, see Howes, ed., *The Varieties of Sensory Experience*; Mark Smith, *Sensing the Past*; David Karmon, *Architecture and the Senses in the Italian Renaissance*.

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reflect their original visual forms. In the case of tactile experiences, which even contemporary scholars find difficult to describe, their study in the context of the ancient world offers a further level of complexity.[4] While an understanding of the visual and tactile experiences of ancient people can help us gather more evidence and generate new insights into their cultures, there remains the question of how to undertake such studies.

This article argues that bronzes and jades from ancient China provide evidence that allows us to explore how ancient Chinese producers paid attention to generating desirable sensory experiences for the users of their products.[5] Investigating the emphasis they placed on generating such experiences entails examining how they interacted with their customers, patrons, or commissioners, and with producers from other industries. These interactions reflected not merely the producers' technological developments, but also continuing improvement and enrichment of the industrial powers. Through processes ranging from the acquisition of raw materials to the generation of the final products, controllers or managers in these industries expanded their power by increasing productivity and consolidating exchange networks. These expansions aided in increasing social complexity, hierarchy formation, and state-building. Thousands of years of growth in industrial power from the Neolithic to the early imperial period led, through expansion founded upon continuous improvements in industrial technologies, to a gigantic state/empire. Those improvements were founded upon the emphasis placed on desirable visual and tactile experiences. Studies of state-building and social organizations are made from the perspectives of groups of people, while studies of sensory experiences are made from the perspectives of individuals. However, these two perspectives are but two sides of the same coin. Taken together they constitute a larger scope within which the growth of states and industries can be explored.

The emphasis on visual and tactile experiences is reflected by examples of jade-working techniques and of cold mechanical treatments of bronzes, which include techniques for polishing bronze surfaces and chiseling inscriptions during the period before the invention and wide

4. See Jessica Rawson, *Chinese Jade: from Neolithic to the Qing* (London: British Museum Press, 2002), 13–109. Density of materials may affect tactile experiences, which may be a worthwhile and interesting topic for future research. See Liu Ruiliang and A. Mark Pollard, "Squeezing Mind Out of Metal: Combining Textual Evidence with Scientific Data for Metallurgy in Early Dynastic China," *Archaeological and Anthropological Science* 14 (2022), 10. See also Kuijpers, "A Sensory Update to the *Chaîne Opératoire* in Order to Study Skill," 870–72.

5. For the producers' own sensory experiences when they were interacting with their materials and tools, cf. Kuijpers, "A Sensory Update to the *Chaîne Opératoire* in Order to Study Skill."

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dissemination of iron tools. Many ancient Chinese bronze inscriptions were cast. Engraved/chiseled inscriptions did appear, but they are often judged to be forgeries by modern epigraphers because the inscriptions were added after the bronze was cast.[6] While the inscriptions on the Western Zhou bronze bell set of Jin Hou Su 晉侯穌 (Marquis Su of Jin, mid-ninth century B.C.E.) were originally dismissed as fake, later scholars realized that they were made soon after the bells had been cast.[7] The methods by which these ancient inscriptions were added after the bronze was cast constitute a major line of evidence in this article. The generic standpoint of previous scholars that engraving on bronze required the use of iron tools is a hasty conclusion that requires further investigation. By studying how the inscriptions were made we can also examine how producers cared for the visual and tactile experiences that their bronze products yielded to the audience and users.

Bronze producers could relate to jade workers, who developed and used new techniques, because they shared the similar aims of generating desirable visual and tactile experiences for the users. Previous scholarship has made a substantial contribution to the study of the exchanges of ideas and techniques between different production communities.[8] As this article demonstrates, there were active and frequent exchanges of ideas and techniques between the production communities of bronze and jade. Some of the traces of polishing, engraving, and chiseling on bronzes might have been left by working with abrasives as practiced in the lapidary industry, demonstrating that lapidary skills and the post-processing of cast bronze objects were interrelated. Exchanges could have taken various forms that were not necessarily through direct communication that was recorded in texts. For example, the shared use of abrasives reflects actual exchanges between the bronze and lapidary industries; it did not develop naturally, independent of the intentions of the workers, but was, rather, a deliberate choice of action. Producers of industries that show no signs of contact with each other might not

6. Ma Chengyuan 馬承源 et al., eds., *Zhongguo qingtongqi* 中國青銅器 (Shanghai: Shanghai guji, 1990), 542, 548.

7. Guan Xiaowu 關曉武 et al., "Jin Hou Su zhong keming chengyin shitan" 晉侯穌鐘刻銘成因試探, in *Jin Hou mudi chutu qingtongqi guoji xueshu yantaohui lunwenji* 晉侯墓地出土青銅器國際學術研討會論文集, ed. Shanghai bowuguan 上海博物館 (Shanghai: Shanghai shuhua, 2002), 332.

8. For a brief discussion of the close relationship between bronze and jade and white ceramics, see Mou Yongkang 牟永抗, "Shilun Changjiang liuyu shiqian shiqi de baise taoqi" 試論長江流域史前時期的白色陶器, in *Changjiang zhongyou shiqian wenhua ji dierjie Yazhou wenming xueshu taolunhui lunwenji* 長江中游史前文化暨第二屆亞洲文明學術討論會論文集, ed. Hunan sheng wenwu kaogu yanjiusuo 湖南省文物考古研究所 (Changsha: Yuelu shushe, 1996), 278–79.

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share the same concerns for sensory experiences. The tactile experience provided by a bronze surface is not the same as that of a textile surface; producers in the two industries did not, in this case, share the same concerns. It was not by simple, intuitive action that bronze producers and lapidary producers came to share the same concerns.

Cast bronze objects from ancient China (1800–1 B.C.E.) have received much scholarly attention over the past hundred years. Studies of metallurgy, clay models and molds for casting, functions, shapes and decorative patterns, and the inscriptions on these bronzes have constituted major research projects. Post-processing of the bronzes has, however, been an understudied field. This field generally does not fit into the above research orientations, and it lacks the evidential and intellectual frameworks to work on the limited available evidence. This article provides evidence to be used in solving some of these problems. Due to the preservation conditions of artifacts and the rarity of available evidence, it is necessary to roam through centuries and across a vast region to retrieve related information.

Review of Literature on Mechanical Treatments of Chinese Bronzes and Jades

There are many problems affecting the study of the post-processing techniques of ancient Chinese bronzes. The initial discussions demonstrating awareness of the field lack a comprehensive perspective to introduce readers to the corpus of post-processing techniques.[9] Detailed

9. John Rutherford Gettens, *The Freer Chinese Bronzes*, vol. 2, *Technical Studies* (Washington, DC: Freer Gallery of Art, 1969), 149–57; W. T. Chase, "Chinese Bronzes: Casting, Finishing, Patination, and Corrosion," in *Ancient and Historic Metals: Conservation and Scientific Research*, ed. David A. Scott, Jerry Podany, and Brian B. Considine (Los Angeles: The Getty Conservation Institute, 1994), 92; Ma Chengyuan, "Jin Hou Su bianzhong" 晉侯穌編鐘, in *Shanghai bowuguan jikan* 上海博物館集刊, vol. 7, ed. *Shanghai bowuguan jikan* bianji weiyuanhui 《上海博物館集刊》編輯委員會 (Shanghai: Shanghai shuhua, 1996), 1–17; Li Chaoyuan 李朝遠, "Jin Hou Su zhong mingwen de kezhi yu Xi-Zhou yongtie wenti" 晉侯穌鐘銘文的刻製與西周用鐵問題, in *Xu Zhongshu xiansheng bainian danchen jinian wenji* 徐中舒先生百年誕辰紀念文集, ed. Sichuan lianhe daxue lishixi 四川聯合大學歷史系 (Chengdu: Ba Shu shushe, 1998), 116–21; Guan Xiaowu et al., "Jin Hou Su zhong keming chengyin shitan," 331–45; Donna Strahan and Mark Fenn, "A Transfer of Technology: Jade Abrasive Methods Used to Create Inscriptions in Ancient Chinese Bronzes," in *Scientific Research on the Sculptural Arts of Asia: Proceedings of the Third Forbes Symposium at the Freer Gallery of Art*, ed. Janet G. Douglas et al. (Washington, DC: Archetype Publications, 2007), 26–36; Hua Jueming 華覺明, "Shang Zhou qingtong liqi zhuhou jiagong de tantao" 商周青銅禮器鑄後加工的探討, *Ziran kexueshi yanjiu* 自然科學史研究 26.3 (2007), 401–6; Zhang Changping 張昌平, "Shang Zhou qingtongqi mingwen de ruogan zhizuo fangshi—yi Zengguo qingtongqi cailiao wei jichu" 商周青銅器銘文的若干製作方式——以曾國青銅器材料為基礎, *Wenwu* 8 (2010), 61–63; Xiuzhen Janice Li, Marcos Martinón-Torres, Nigel D. Meeks,

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investigations require observations of the traces of post-processing at a micro-level, usually relying on high-resolution photographs. In many cases the observers only noted that some parts of the bronzes, especially inscriptions, were engraved, without providing supporting photographic proof.[10] For some bronzes with engraved patterns, such as those excavated from the Warring States tomb at Jiangsu Huaiyin Gaozhuang 江蘇淮陰高莊,[11] no detailed observations of the traces of engraving have yet been provided.

Ancient Chinese bronze inscriptions were usually cast or engraved. Engraved inscriptions also provide important historical evidence. There has been concern about the authenticity of these engraved inscriptions, however, and epigraphers have deemed some engravings to be forgeries.[12] When the Western Zhou bronze bell set of Jin Hou Su first appeared in the antique market, epigraphers were concerned that their

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Yin Xia, Kun Zhao, "Inscriptions, Filing, Grinding and Polishing Marks on the Bronze Weapons from the Qin Terracotta Army in China," *Journal of Archaeological Science* 38 (2011), 492–501; Yue Zhanwei 岳占偉 et al., "Yinxu qingtongqi mingwen de zhizuo fangfa" 殷墟青銅器銘文的製作方法, *Zhongyuan wenwu* 中原文物 4 (2012), 66–68; Tian Jianhua 田建花 and Wang Jingyi 王靜藝, "Xian-Qin qingtongqi de zhuhou jiagong" 先秦青銅器的鑄後加工, *Zhuzao* 鑄造 67.10 (2018), 906–9; Zhai Shaodong 翟少冬 et al., "Qiantan Yinxu qingtongqi de zhuhou damo gongyi" 淺談殷墟青銅器的鑄後打磨工藝, *Jiang Han kaogu* 江漢考古 5 (2020), 98–109.

10. Yue Zhanwei and his colleagues cite a number of examples that they believe to be engraved inscriptions (Yue Zhanwei et al., "Yinxu qingtongqi mingwen de zhizuo fangfa," 66–68): the *Ge fu yi jue* 戈父乙爵 in Rong Geng's 容庚 catalog, *Shang Zhou yiqi tongkao* 商周彝器通考 (Shanghai: Shanghai renmin, 2008), 67, 70 (This is the version Yue and his colleagues cited. The version that is available to me is the 1941 version, *The Bronzes of Shang and Chou*, vol. II [Beijing: Harvard-Yenching Peiping Office, Yenching University, 1941], 225, item no. 425, accessed on March 25, 2022, https://taiwanebook.ncl.edu.tw/zh-tw/book/NCL-9900009898/reader); in Zhongguo shehui kexueyuan kaogu yanjiusuo 中國社會科學院考古研究所, "Henan Anyang Meiyuanzhuangxi de yizuo Yin mu" 河南安陽梅園莊西的一座殷墓, *Kaogu* 2 (1992), 187, Yue and his colleagues mention a *gui* 簋 with engraved inscription; for the source in Anyang shi wenwu gongzuodui 安陽市文物工作隊 and Anyang shi bowuguan 安陽市博物館, *Anyang Yinxu qingtongqi* 安陽殷墟青銅器 (Zhengzhou: Zhongzhou guji, 1993), 132–33, Yue and his colleagues mention that some bronzes were actually engraved and that the original report is inaccurate; for *Zhongguo qingtongqi quanji* bianji weiyuanhui 《中國青銅器全集》編輯委員會, ed., *Zhongguo qingtongqi quanji* 中國青銅器全集 (Beijing: Wenwu, 1998), vol. 4, 160–61, figs. 165–67, and captions on p. 45, they also mention an engraved *you* 卣. However, I have examined these sources and found that they provide no clear photographic proof. Neither do Yue and his colleagues provide clear photographs. Thus there are only textual descriptions for the sources, which cannot be further validated.

11. Huaiyin shi bowuguan 淮陰市博物館, "Huaiyin Gaozhuang Zhanguo mu" 淮陰高莊戰國墓, *Kaogu xuebao* 2 (1988), 195–211, 231; He Tangkun 何堂坤, "Kewen tongqi kexue fenxi" 刻紋銅器科學分析, *Kaogu* 5 (1993), 465–68.

12. Ma Chengyuan et al., eds., *Zhongguo qingtongqi*, 542, 548.

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engraved inscriptions might be forgeries.[13] They concluded, however, that the inscriptions were genuine, probably engraved with tools made of iron, of which meteoric iron was presented as one option.[14] It has become a widely held belief that inscriptions on bronzes made after the Warring States period were engraved by iron tools.[15] But this belief is in need of re-examination.

If not made by iron tools, engraved inscriptions were probably created using "jade abrasive methods."[16] Some astute scholars have observed traces of scratching, grinding, and polishing on hard bronze surfaces, which could have been caused by much harder materials than bronze, such as sand grits that were used as abrasives to work on jades.[17] They used simulation experiments to imitate these working processes and to postulate that the traces on the bronzes were made by jade abrasive methods.[18] In the absence of further comprehensive studies, which appear in the future, these approaches have been informative. It should nevertheless also be understood that a mix of different methods could have been used to produce the desired patterns and inscriptions. Cast inscriptions could have been further engraved and polished in order to be even more visually prominent. Traces of one method do not necessarily rule out the possibility of another method also having been employed.

This article investigates, through examining the aims and priorities of ancient Chinese bronze producers when they processed already-cast bronzes to create patterns (non-textual) and inscriptions (textual). I advocate a more open and holistic point of view when studying such post-processing marks. As the ephemeral actions and now-vanished tools for post-processing may have been intriguing and complex, perhaps only options with higher probabilities can be proposed, with no definitive conclusions able to be formed.

I present evidence of the close relationship between the arts of lapidary working and bronze post-processing, introducing a more

13. Guan Xiaowu et al., "Jin Hou Su zhong keming chengyin shitan," 332.

14. Ma Chengyuan, "Jin Hou Su bianzhong," 1–2; Li Chaoyuan, "Jin Hou Su zhong mingwen de kezhi yu Xi-Zhou yongtie wenti," 116–21; Guan Xiaowu et al., "Jin Hou Su zhong keming," 333–35.

15. Zhang Changping, "Shang Zhou qingtongqi mingwen de ruogan zhizuo fangshi," 62.

16. Gettens, *The Freer Chinese Bronzes*, 2:149–57; W. T. Chase, "Chinese Bronzes: Casting, Finishing, Patination, and Corrosion," 92; Donna Strahan and Mark Fenn, "A Transfer of Technology," 26–36; Zhang Changping, "Shang Zhou qingtongqi mingwen," 61–63.

17. For brief descriptions of actions and tools used on working on jades and bronzes, see Li et al., "Inscriptions, Filing, Grinding and Polishing Marks," 493–94.

18. Donna Strahan and Mark Fenn, "A Transfer of Technology," 26–36.

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comprehensive discussion of the simultaneously existing skill sets of lapidary working and bronze post-processing, and delineating a fuller picture of technical exchanges between related production communities. Bringing attention to post-processing techniques other than engraving inscriptions, such as the decoration and beautification of bronzes by a variety of cold mechanical methods,[19] shows that producers cared about both the visual beauty of their bronzes and the tactile experiences that their products could provide to people who looked at them and used them.

Abrasives and Techniques from the Art of Lapidary- and Bone-Working

Since most post-processing tools have been lost, and little textual evidence recording these processes has been preserved, scholars can only work to reconstruct the processes by observing their remaining traces on bronze surfaces. Until now, scholars have adopted the approach of comparing the different types of working traces left by various tools and attempting to rule out some of the options. The criterion used to evaluate these options has been the measurement of the hardness (scratch resistance level) of each material. The Mohs scale can be used to compare the relative degrees of hardness of materials from ancient China (Table 1).[20][21]

Table 1. Hardness (scratch resistance) of materials from ancient China[20]

Mohs scale	(Diamond: 10)
Silicon dioxide (SiO_2) /quartz/sand grits	7
Nephrite	6–6.5
Turquoise	5.5
Bone (certain types)	5
Iron and steel	4–5.5
Cast bronze	around 3 (copper: 3, tin: 1.5, lead: 1.5); fluctuates depending on the alloy composition[21]

19. Gettens, *The Freer Chinese Bronzes* 2:149–57; W. T. Chase, "Chinese Bronzes: Casting, Finishing, Patination, and Corrosion," 92.

20. Stephen Marshak, *Essentials of Geology* (New York: W. W. Norton Press, 2004), 94–96; Bruce M. Rothschild et al., "The Power of the Claw," *PLOS ONE*, 8.9 (2013), 1. John R. Rumble et al., eds., *CRC Handbook of Chemistry and Physics: A Ready-Reference Book of Chemical and Physical Data* (London: CRC Press, 2017), 4-127 to 4-133, 12.222 to 12.223.

21. This table reflects that cast bronze is softer than those materials with a higher hardness degree, but cast bronze may occupy a range of hardness depending on its

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Materials that are harder than bronze can be used to create patterns and inscriptions on bronze surfaces. Cast iron and steel, invented and popularized during the Eastern Zhou-Western Han period (fifth to first century B.C.E.), could therefore be used to work on bronze surfaces.[22] Scholars such as Li Chaoyuan 李朝遠, Guan Xiaowu 關曉武, and his colleagues believe that before the invention and popular use of cast iron and steel, meteoric iron would have been the material used to work on bronze.[23] However neither Li nor Guan and his colleagues considered the possibility of using abrasives, such as sand grit, which has been proposed by Donna Strahan and Mark Fenn.[24]

As far back as the Neolithic era, lapidary workers realized the power of abrasives. Sand grits, which are mainly composed of quartz and are in widespread existence, are harder than both bronze and many of the precious stones treasured by the ancient Chinese. These grits had been used effectively as abrasives on nephrite and turquoise for cutting, drilling, filing, wheel-cutting, and other procedures as required.[25] It would have been a convenient way for bronze producers to obtain information and inspiration in the uses of materials and techniques from those employed by lapidary workers. As well as working with smaller abrasive sand grits, larger stones were used as whetstones to scrape off protrusions and to grind and polish bronze surfaces. In a Shang period bronze foundry site at Xiaomintun 孝民屯, in Anyang, Henan, 246 stones are identified as whetstones, along with other objects recognized as bronze knives and needles, ceramic beaters, and bone awls.[26] They are believed to have been used to work on clay models and molds and on finished bronzes.

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alloy composition. This is the same for iron and steel. They show a relative range of hardness, but not a set of absolute values because there are many types of alloys.

22. Donald B. Wagner, "The Earliest Use of Iron in China," in *Metals in Antiquity*, ed. Suzanne Young et al. (Oxford: Archaeopress, 1999), 1–9; Ma Chengyuan, "Jin Hou Su bianzhong," 1–2; Guan Xiaowu et al., "Jin Hou Su zhong keming," 338–39.

23. Li Chaoyuan, "Jin Hou Su zhong mingwen," 116–21; Guan Xiaowu et al., "Jin Hou Su zhong keming," 333–35.

24. Donna Strahan and Mark Fenn, "A Transfer of Technology," 26–36.

25. Tang Chung 鄧聰 (Deng Cong) et al., "Yirou zhigang—shasheng jieyu kao" 以柔制剛—砂繩截玉考, *Gugong wenwu yuekan* 故宮文物月刊 265 (2005), 70–82; Tang Chung, "Dongya Xian-Qin yazhang zhu wenti" 東亞先秦牙璋諸問題, in *Yazhang yu guojia qiyuan: yazhang tulu ji lunji* 牙璋與國家起源：牙璋圖錄及論集, ed. Tang Chung et al. (Beijing: Kexue, 2018), 223–28 (originally published in *Zhongguo wenhua yanjiusuo xuebao* 中國文化研究所學報, 6 [1997], 325–32); Zhongguo shehui kexueyuan kaogu yanjiusuo, *Erlitou* 二里頭 (1999–2006), vol. 3 (Beijing: Wenwu, 2014), 1385–427.

26. Zhongguo shehui kexueyuan kaogu yanjiusuo Anyang gongzuodui 中國社會科學院考古研究所安陽工作隊, "2000–2001 nian Anyang Xiaomintun Dongnandi Yin-

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Further materials that should not be dismissed as work tools are bones and claws. The teeth, jawbones, and femurs of mature human beings, and certain animal bones and claws, can be as hard as steel (Table 1).[27] Although they may not be hard enough to work on jades, they would have sufficed to serve as abrasives to work on bronze. The use of abrasives on bronzes involved a number of calculated steps. The choice of appropriate types of abrasives (which types of sand grits), the method of attaching the abrasives to other certain materials, and the techniques for controlling the movement of the abrasives, were by no means natural choices to the bronze producers. Bone workshops have been located in various cities in ancient China; Erlitou 二里頭 in Yanshi 偃師, Henan (1800–1500 B.C.E.) and Anyang housed many.[28] Therefore, bronze producers would have found no difficulty in exchanging information and experiences of using work tools and techniques with bone workers. While there have been no simulation experiments conducted in the use of bone and claw as abrasives working on bronze, this possibility should not be ruled out at this stage.

To attempt to identify exactly which materials bronze producers employed could in any case be fruitless because of two reasons: first, traces on extant bronzes may not provide a full picture, as the traces left by different abrasives can appear very similar; second, bronze producers might not have restricted themselves to the use of one single type of material to accomplish their tasks. Iron and steel tools remained an option among others, Guan and his colleagues raised the possibility that high-tin bronze was employed,[29] and bone tools with sharp edges could

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dai zhutong yizhi fajue baogao" 2000–2001年安陽孝民屯東南地殷代鑄銅遺址發掘報告, *Kaogu xuebao*, 3 (2006), 375–76, and color pls. 15.3 to 16.5.

27. Rothschild et al., "The Power of the Claw," 1.

28. Ma Xiaolin 馬蕭林, "Jin shinian Zhongguo guqi yanjiu zongshu" 近十年中國骨器研究綜述, *Zhongyuan wenwu*, 2 (2018), 51–56; Chen Guoliang 陳國梁 and Li Zhipeng 李志鵬, "Erlitou yizhi zhigu yicun de kaocha" 二里頭遺址製骨遺存的考察, *Kaogu* 5 (2016), 59–70; Zhongguo shehui kexueyuan kaogu yanjiusuo Anyang gongzuodui, "2000–2001 nian Anyang Xiaomintun Dongnandi Yindai zhutong yizhi fajue baogao," 376; Zhongguo shehui kexueyuan kaogu yanjiusuo Anyang gongzuodui, "Henan Anyang shi Tiesanlu Yinxu wenhua shiqi zhigu zuofang yizhi" 河南安陽市鐵三路殷墟文化時期製骨作坊遺址, *Kaogu* 8 (2015), 37–62; Fu Zhongyang 付仲楊, "Fenghao yizhi de zhigu yicun yu zhigu shougongye" 豐鎬遺址的製骨遺存與製骨手工業, *Kaogu* 9 (2015), 92–100. Roderick B. Campbell et al., "Consumption, Exchange and Production at the Great Settlement Shang: Bone-working at Tiesanlu, Anyang," *Antiquity* 85 (2011), 1279–97.

29. Guan Xiaowu et al., "Jin Hou Su zhong keming," 335–38. However, Ma Chengyuan and Li Chaoyuan noted that the Shanghai Museum staff discounted this option after conducting related simulation experiments. See Ma Chengyuan, "Jin Hou Su bianzhong," 1.

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also have been used for bronze engraving. Taking all of this into consideration, the precise material bronze producers actually used may not be of prime importance, given that the concept of using abrasives and the necessity for harder tools had been known to them since the beginning of the Bronze Age. The present article suggests that sand grits, iron and steel, high-tin bronze (if possible), bones and claws, and probably other materials, all might potentially have served as useful abrasives and tools. While the exact materials used may not be reconstructed without hesitation, the aims of the engravers, carvers, or polishers can, however, be deduced.

The techniques and actions employed while using abrasives and tools were important to the appearance and the feel of the finished product. In order to create the desired shapes and patterns on precious stones, ancient Chinese lapidary workers had developed a corpus of sophisticated techniques in working with abrasives. Bone-working techniques were included in this corpus as the range of lapidary techniques was so diverse that it covered a rich variety of actions that a person could exercise upon an object. Slicing the desired sections out from the raw stones and cutting them into square, rectangular, oval, or round shapes was only the beginning of the process. The actions of denting, filing, wheel-cutting, riffling, and drilling created more technical challenges. Lapidary workers had to be able to control the movement of their abrasives to create the planned shapes and patterns. In order to generate a filing or sawing motion they would sometimes have used harder stone flakes, or wet strings soaked in sand grits. Wheel-cutting and drilling required more complicated sets of tools and platforms.[30] To create trenches/lines, grooves, or notches on the smooth surface was not easy. Lapidary workers would need to connect pre-set dented or drilled dots/areas in order to stabilize the cutting tools. Polishing with whetstones, leather products, cotton, bamboo, or other plants would constitute one of the final steps.[31] These techniques could be applied to processing the bronze surfaces and reflect what the producers' aims were.

30. Margaret Sax and Nigel D. Meeks, "The Introduction of Wheel Cutting as A Technique for Engraving Cylinder Seals: Its Distinction from Filing," *Iraq* 56 (1994), 153–66; Margaret Sax et al., "Methods of Engraving Mesopotamian Cylinder Seals: Experimental Confirmation," *Archaeometry* 40.1 (1998), 1–21; Tang Chung et al., "Yirou zhigang—shasheng jieyu kao," 70–82; Donna Strahan and Mark Fenn, "A Transfer of Technology," 26–36.

31. Gu Fang 古方 et al., *Zhongguo guyu tudian* 中國古玉圖典 (Beijing: Wenwu, 2007), 41–42. See also Zhongguo shehui kexueyuan kaogu yanjiusuo, *Erlitou*, vol. 3, 1404–6. Tang Chung, "Dongya Xian-Qin yazhang zhu wenti," 224.

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Traces on Bronzes

The traces remaining on bronzes can show us what types of actions were performed on them, and thus what aims the producers had in mind. Since the surface of a newly cast and cooled bronze was rough and coarse, and covered with small protrusions and dented areas, its visual beauty and tactile quality would not yet have been what was desired. It would have been a major and time-consuming task after casting for the producers to remove those undesired protrusions and to smooth the surface by scraping, abrading, grinding, and polishing.[32] If there were cast inscriptions, the inscribed areas would need to be scraped and polished for the characters and emblems to be clearly visible. Engraved decorative patterns and inscriptions would also be made at this stage. Polishing selected areas made them shinier and glossier, creating visual contrast between the polished and unpolished areas. The producers would undertake the post-cast decoration and inscription with these aims of beautification and clarity in mind.

Traces of Lapidary Tool-Use on Bronze Mirrors

We will first examine how bronze patterns were processed. The requirements for treating the patterns differed from those of treating the inscriptions. Producers of ancient Chinese bronze mirrors aimed to create beautiful decorative patterns, while also judging how glossy and smooth their patterns were and bearing in mind the visual contrast they would create against unprocessed areas.

Figure 1a shows the back, decorative side of a mirror excavated from Tomb 2 at Hunan Changsha Yuanjialing Datong xiaoxue 湖南長沙袁家嶺大同小學 (hereafter "Changsha-Xiaoxue mirror"), dating to approximately 300 B.C.E. in the Warring States period.[33] Produced from high-tin bronze, its color is silverish-white. The front, reflective side is highly glossy and smooth (Figure 1b), a finish achieved by many cycles of grinding and polishing that left almost no working traces. The back of the mirror is made up of two different finishes—heavily ground and polished areas, and less processed areas. In order

32. Hua Jueming, "Shang Zhou qingtong liqi zhuhou jiagong de tantao," 401–6. The musical properties of freshly cast bells would also be impacted by rough bronze walls. This will be a study of the auditory experience. See also Liu Yu 劉煜, *Yinxu chutu qingtong liqi zhuzao gongyi yanjiu* 殷墟出土青銅禮器鑄造工藝研究 (Guangzhou: Guangdong renmin, 2019), 158–62.

33. The accession number of this mirror in the Changsha Municipal Museum is *zongzhanghao* 總帳號 4817, *fenleihao* 分類號 1B313. See Changsha shi bowuguan 長沙市博物館, *Chufeng Hanyun: Changsha shi bowuguan cangjing* 楚風漢韻：長沙市博物館藏鏡 (Beijing: Wenwu, 2010), 10.

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Figure 1a. Bronze mirror from Hunan Changsha Yuanjialing Datong Xiaoxue M2. Diameter 11.4 cm. Changsha Municipal Museum, *zongzhanghao* 4817, *fenleihao* 1B313, c. 300 B.C.E. Photo by the author.

Figure 1b. Detail of the reflective side (front) of the Changsha-Xiaoxue mirror. Photo by the author.

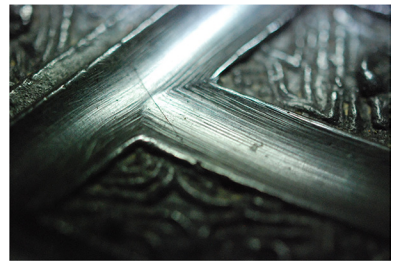

Figure 1c. Detail of one of the slanting-T main motifs on the decorative side (back) of the Changsha-Xiaoxue mirror. Photo by the author.

to remove any undesired protrusions and sharp points, newly cast bronzes needed to be abraded, ground, and polished to a certain level. The glossy areas seen in Figure 1a, especially the slanting-T main motifs, the central square knob seat, and the edges, were highly processed; the rest of the surface remains less processed or unprocessed. Figure 1c and Figure 1d show the details of the highly processed and glossy areas of the slanting-T motifs. Numerous striations can be seen inside the contours of the slanting-T motifs. The inner parts of the contours are dented or sunken, while the edges of the motifs seem to tilt outwards. The striations stop at the tips of the motifs (Figure 1d),

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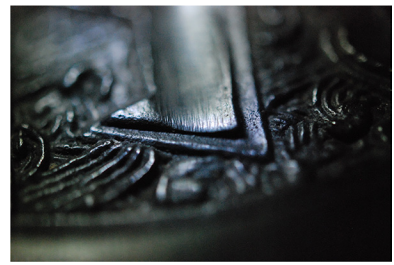

Figure 1d. Detail of the back of the Changsha-Xiaoxue mirror. Photo by the author.

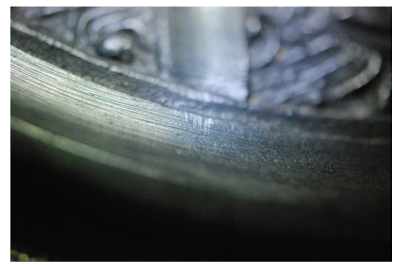

Figure 1e. Detail of the edge of the back of the Changsha-Xiaoxue mirror. Photo by the author.

creating a slope-like edge. The background patterns, unpolished and so with no gloss appearance, create a visual contrast against the main motifs of the slanting-Ts. The rough surface and uneven heights of the background patterns, compared to the highly processed motifs sharing a smooth surface with parallel striations, do not reflect light easily and thus appear duller even under light. Figure 1c shows that the smooth surface of the inner contours of one slanting-T reflects light well, creating the gloss effect.

The minute striations resulted from numerous cycles of abrasion, grinding and/or polishing, by small whetstones, or by abrasives stuck on wet bark, hemp-woven fabric, or other fabrics made of cheaper fibers. The abraded and polished areas, namely the reflective main motifs, would easily catch a person's attention. They also invite close handling and touch. Their smooth texture would give their users a distinct tactile experience compared to other parts of the mirror and other bronze objects. In my handling experience, the dented inner contour is just wide enough to house a finger pulp. A person holding the mirror could trace the contour of the main motifs by moving their finger along the smooth, glossy, and dented areas of the main motifs. Such beauty, gloss, and tactile experience were the qualities that the mirror producers were aiming to achieve.

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Minute striations are very often seen on precious stones. For example, turquoise beads from Henan Wuyang Jiahu 舞陽賈湖 dating to about 7000–5000 B.C.E. and turquoise flakes from Henan Yanshi Erlitou show such striations on their flat sides.[34] Tang Chung 鄧聰 and colleagues have discussed how these striations and the flat sides of the turquoises were created by being worked on whetstones.[35] Although some of the Jiahu beads and Erlitou flakes have lost their hue after years of corrosion by chemicals in the buried environment, and some Erlitou flakes had not yet been processed, the processed flakes of the Erlitou turquoise dragon preserve their hue and gloss. The Erlitou dragon lapidary workers had transformed small unprocessed pieces with irregular shapes into neat, smooth, rectangular flakes by abrading and grinding off protrusions using whetstones. The processed flakes were then tiled to form the dragon. Similarly, whetstones in a particular shape could have been used to work on the slanting-Ts on the Changsha-Xiaoxue mirror, creating not just the polished, gloss effect but also, by scraping the inner contours, the dented areas.

The possibility of attaching abrasives to wet bark or fabric is considered here owing to the use of abrasives in the lapidary industry in a different form. Wet strings coated with abrasives were very often used to slice jade, as demonstrated in simulations by Tang Chung and his colleagues.[36] Strings, however, could not have been applied on the flat surface of the Changsha-Xiaoxue mirror. Figure 2 shows the detail of another Warring States mirror unearthed from the site of Construction Bank (Jianshe yinhang) in Changsha.[37] Close attention to the connected areas between the adjacent main motifs on this mirror reveals that the striations do not stop at the edge but run across onto connected areas. The connected areas are slightly raised, while the inner contours are

34. Chen Xingcan 陳星燦, "Peiligang wenhua lüsongshi chutan—yi Jiahu wei zhongxin" 裴李崗文化綠松石初探—以賈湖為中心, in *Xinshiji de Zhongguo kaoguxue—Wang Zhongshu xiansheng bashi huadan jinian lunwenji* 新世紀的中國考古學—王仲殊先生八十華誕紀念論文集, ed. Zhongguo shehui kexueyuan kaogu yanjiusuo (Beijing: Kexue, 2005), 57–73; Tang Chung, Xu Hong 許宏, and Du Jinpeng 杜金鵬, "Erlitou wenhua yu gongyi xiangguan wenti shishi" 二里頭文化玉工藝相關問題試釋, in *Yazhang yu guojia qiyuan: yazhang tulu ji lunji*, 275–81 (originally published in *Keji kaogu* 科技考古, vol. 2, ed. Zhongguo shehui kexueyuan kaogu yanjiusuo kaogu keji zhongxin 中國社會科學院考古研究所考古科技中心 [Beijing: Kexue 2007], 120–32).

35. Tang Chung, Xu Hong, and Du Jinpeng, "Erlitou wenhua yu gongyi xiangguan wenti shishi," 279–81.

36. Tang Chung et al., "Yirou zhigang—shasheng jieyu kao," 70–82.

37. From Changsha Renminlu Jianshe Yinhang 人民路建設銀行 M1. *Zongzhanghao* 17142, *fenleihao* unknown. See Changsha shi bowuguan, *Chufeng Hanyun: Changsha shi bowuguan cangjing*, 19.

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Figure 2. Bronze mirror from Changsha Renminlu Jianshe yinhang M1. Diameter 10.5 cm. Changsha Municipal Museum, *zongzhanghao* 17142, *fenleihao* unknown, c. 300 B.C.E. Photos by the author.

dented. The background patterns have not been polished. If a whetstone had been used, it was likely to have stopped at the raised area. Fabric of an appropriate size, however, could easily have been used to access the dented and raised areas, and the connected areas between the adjacent main motifs. The abrasives were the hard matter that created the minute striations rather than their bark or hemp carrier. By soaking wet fabric in abrasives, the hard particles were attached within the fibers of the fabric. The polisher could then simply scrape with the fabric while adding water and abrasives.

The tools and polishers' movements described would have created striated, but not circular, traces. Figure 1e shows long, circular polishing traces on the edge of the Changsha-Xiaoxue mirror. The neighboring areas were, however, unpolished, which implies precise control of the abrasives having been exerted solely on particular areas. Figure 3 shows long, circular polishing traces on another Changsha mirror, also contained in the edge areas.[38]

To examine how these traces were created while polishing the circular edges requires reference to lapidary workers' round platforms and drilling techniques and tools. Figure 4 shows a cylindrical section partially drilled from raw jade. According to Gu Fang 古方, this jade belongs to the Qijia 齊家 culture dating to approximately 2200–1500 B.C.E.[39] A tube made of perishable material (probably bamboo or wood),[40] of the size in cross-section close to that of the Qijia jade, was pressed down on top of the raw jade. The jade worker would have been adding water and abrasives to the contact areas between the tube and the raw jade while

38. From Changsha Yuanjialing—Jing 袁家嶺—警 M3. *Zongzhanghao* 1645, *fenleihao* 1B213. Changsha shi bowuguan, *Chufeng Hanyun*, 39.

39. Gu Fang et al., *Zhongguo guyu tudian*, 29, figure 7.

40. Zhongguo shehui kexueyuan kaogu yanjiusuo, *Erlitou*, vol. 3, 1401.

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Figure 3. Bronze mirror from Changsha Yuanjialing—Jing M3. Diameter 11.3 cm. Changsha Municipal Museum, *zongzhanghao* 1645, *fenleihao* 1B213, c. 300 B.C.E. Photos by the author.

rotating the tube. The rotating tube drove the abrasives that eventually drilled out the cylindrical section, guaranteeing precise control of the extracted cylindrical shape. Similar drilling tools could have been used to polish the edges of a circular mirror. By using custom-sized tubes, the polisher could have ensured there was no contact with the areas that were to remain unpolished.

Figure 4. Cylindrical piece ready to be drilled out from raw jade. Qijia culture, c. 2200–1500 B.C.E. After Gu Fang et al., *Zhongguo guyu tudian*, 29, fig. 7.

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Post-Processing of Already-Cast Inscriptions

Bronze producers treated inscriptions in a careful manner; they not only attempted to render the inscriptions clearly and beautifully but also attended to the smoothness of the bronze surface carrying the inscriptions. We will focus solely on the inscriptions that are on the side conspicuous to the viewers, rather than those that are on the reverse of the lid or the bottom of the vessel. The shape, length, width, and depth of the strokes, the shape of each character, the general layout of the entire inscription, and the arrangement of the characters whether regular or scattered across the surface, all pertain to the visual qualities and visual experiences. Careful inscribers preferred that the chiseled marks not be visible to the viewer, and so attempted to remove the chiseled marks with tools and to render the strokes in a deep and flawless manner. Treating already-cast inscriptions required a particular approach. Where inscriptions were well cast and the sunken tracks of the character strokes were deep enough,[41] polishers needed simply to polish the surface in the standard fashion. If, however, the sunken inscriptions were too shallow, polishing the surface could probably have removed them, and in that case the clarity of the inscriptions would have been strengthened by engraving or chiseling deeper tracks of the strokes.

Cast inscriptions on a bronze weight excavated in the mausoleum complex of Qin Shihuang 秦始皇 (First Emperor of Qin, r. 246/221–210 B.C.E.) were ground and polished (Figure 5, hereafter the "Qin Shihuang weight").[42] While it was claimed that the inscriptions on numerous Qin-Han period bronzes were engraved (*ke* 刻), some of them were in fact cast. Detailed re-examination of most Qin-Han bronze inscriptions will be required in the future. Figure 5 shows the wide and deep tracks of the strokes of the cast character, *zhi* 之, in Qin Shihuang's edict about regulating measurement systems. As the weight is not greatly corroded, its surface retains its original condition at the time of the burial in the mausoleum complex. It can be seen that traces of grinding remain in the areas neighboring the strokes. The yellow parts (as indicated by arrows; in the black-and-white version of this article, the lighter areas) show the original color of the bronze.[43] With particular attention to the yellow

41. Grinding the inscriptions with raised strokes of characters was not necessary as it would remove the inscriptions. Thus we only focus in this article on sunken inscriptions.

42. Accession no. 2838, Qin Shihuang's Mausoleum Site Museum. See also Kin Sum (Sammy) Li, "To Rule by Manufacture: Measurement Regulation and Metal Weight Production in the Qin Empire," *T'oung Pao* 103.1–3 (2017), 1–32; Kin Sum (Sammy) Li, "The Design Origins of Qin Metal Weights," *Artibus Asiae* 77.1 (2017), 91–110.

43. For a recent discussion of the color of ancient bronzes, see Liu Ruiliang and A. Mark Pollard, "Squeezing Mind Out of Metal," 9–11; Kuijpers, "A Sensory Update to

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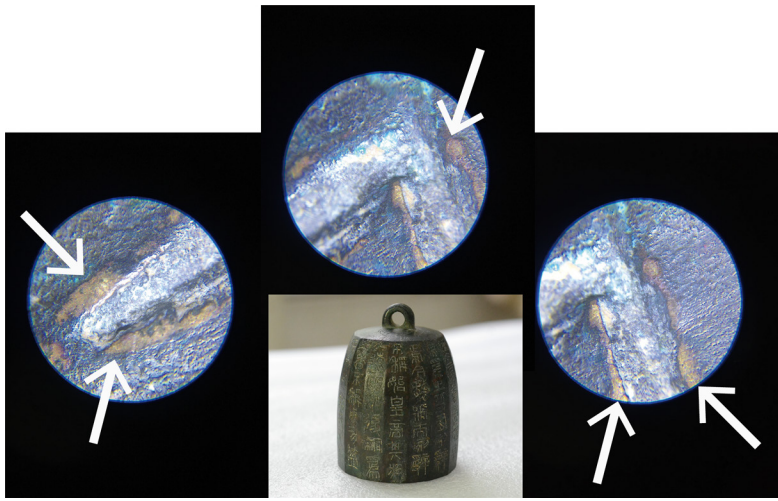

Figure 5. Bronze weight from the mausoleum complex of Qin Shihuang and magnified images of the character *zhi* 之 in the inscription of Qin Shihuang's edict about regulating the measurement systems. Height 7 cm, weight 256 g. Qin Shihuang's Mausoleum Site Museum, accession no. 2838. 209–207 B.C.E. Photos by the author.

areas, they seem to be slightly raised above the adjacent ground areas. When the producer prepared the inscription on the clay model of the weight, the clay had been squeezed out from the carved strokes. This clay being squeezed out became the raised edges of the strokes on the cast bronze. When the worker started grinding the inscriptions, they abraded parts of the raised edges. These abraded areas across the entire surface of the weight were not significantly oxidized, thus preserving the original bronze color while other oxidized areas darkened. The raised edges supposedly did not obstruct the display of the inscribed characters, but the edges were all abraded and smoothed, suggesting the inscriptions may have been intended to be touched.

Raised edges of cast inscriptions can be seen on many other bronzes, for example, on a bronze container in the collection of the Shanghai Museum. Its cast inscription includes Qin Shihuang's edict about regulating measurement systems and it is referred to hereafter as the "Qin Shihuang container." Figure 6 shows the character *nai* 乃 in detail. Its

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the *Chaîne Opératoire* in Order to Study Skill," 868. We should also note that color on the bronze would change constantly and the color we see today does not always afford grounds for sound aesthetic judgment. The color of the stones would also change because of the chemical interaction between the stones and their burying surroundings. As a result, the visual quality discussed in this article mainly refers to the beautiful shape and decorative patterns of the objects rather than their color.

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Figure 6. Bronze container bearing the inscription of Qin Shihuang's edict on regulating measurement systems and magnified images of the character *nai* 乃 in the edict cast on one side of the Qin Shihuang container. Length 19 cm, capacity 216 cm^3. Shanghai Museum, accession no. 46425, c. 221–207 B.C.E. Photos by the author.

wide, deeply sunk strokes, and smooth turns, show that this character was first carved on a clay model and eventually transferred to the cast bronze. The yellowish edges of the strokes, similar to those on the Qin Shihuang weight in Figure 5, were ground and polished. The rough, corroded areas adjacent to the cast strokes suggest that the edges had been polished before the container started to corrode.

In a well-known example, John Gettens, writing about the inscription under the handle of a Shang dynasty bronze *jue* 爵 in the collection of the Freer Gallery of Art (Figure 7), describes that "the raised edges of the characters … give them a 'pressed-in' look."[44] Robert Bagley surmises that the inscription was produced through the following process: the inscription maker first prepared a stamp in the shape of the character.[45] He then used the stamp to impress a piece of clay. An impression from the clay, with the character's strokes raised, was inserted into the mold so that the strokes of the character on cast bronze would be sunken. Bagley's theory around the making of the character in Figure 7 thus gives one explanation of how the clay was squeezed out. Another possibility is that carving into the clay squeezed out clay, and eventu-

44. Gettens, *The Freer Chinese Bronzes*, 2:143.

45. Robert Bagley, "Anyang Mold-making and the Decorated Model," *Artibus Asiae* 1 (2009), 85n55, and figure 34 on p. 73.

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Figure 7. Cast inscription under the handle of a bronze *jue*. Freer Gallery of Arts, accession no. 1956.19. Shang dynasty. After Gettens, *The Freer Chinese Bronzes*, 2:143, fig. 181.

ally that squeezed-out clay became the raised edges on the cast bronze. Figure 8 shows a similar phenomenon. Gettens describes the edges as being "raised as if the character originally was stamped in a plastic substance."[46] If the inscription had been ground and polished, it would appear as shown in Figure 5 and Figure 6.

Gettens provides a further example of two incomplete characters of a cast inscription (Figure 9).[47] He suggests that the missing strokes had been erased by an abrasive tool, based on his observation that there were

46. Gettens, *The Freer Chinese Bronzes*, 2:142.
47. Gettens, *The Freer Chinese Bronzes*, 2:151.

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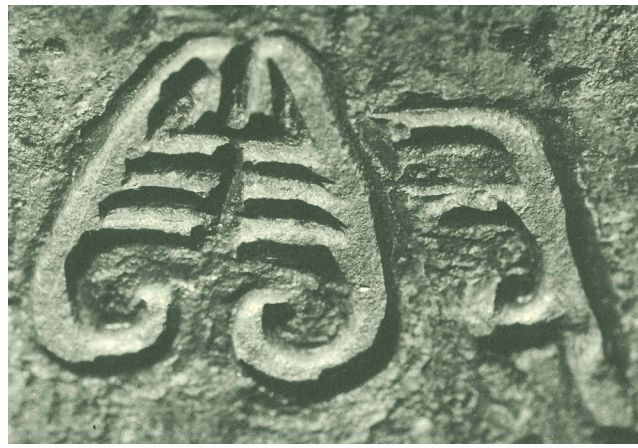

Figure 8. Cast inscription on a bronze *gu* 觚. Freer Gallery of Arts, accession no. 1940.3. Shang dynasty. After Gettens, *The Freer Chinese Bronzes*, 2:142, fig. 178.

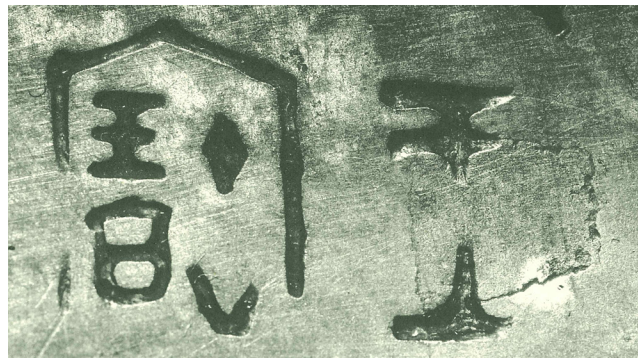

Figure 9. Cast inscription after grinding on a bronze *gui* 簋. Freer Gallery of Arts, accession no. 1911.38. Shang dynasty. After Gettens, *The Freer Chinese Bronzes*, 2:151, fig, 193.

grinding traces cutting across the inscriptions,[48] which also implies that the strokes were too shallow. There is another possibility; it may be that the missing strokes had not been cast well, causing damage to the raised lines on the mold, with the result that the lines intended to be sunken did not emerge on the bronze.

With reference to these theories, could the inscription on the Shang dynasty *zun* 尊 in the Avery Brundage collection at the Asian Art Museum of San Francisco, argued by Donna Strahan and Mark Fenn to be the evidence of one of the first engraved bronze inscriptions in

48. Gettens, *The Freer Chinese Bronzes*, 2:154.

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China,[49] be a mixed product of casting and engraving? Strahan and Fenn have demonstrated convincing arguments as to how the inscription was engraved by abrasive tools. The question can still be asked whether the engraver started working on a surface without any inscription or on a poorly cast one.[50] If the latter, engraving to strengthen the clarity of the inscription by widening and deepening the tracks of the strokes of the characters would also be a reasonable deduction. Due to insufficient evidence, in this case it is impossible to come to a final conclusion. As Strahan and Fenn argue,[51] there remains much to be re-examined. Gettens cautions that a variety of practices could have been adopted on the same object.[52] If producers prioritized achieving clarity and smoothness, rather than being bound by any particular method, casting and engraving techniques could well have been mixed to create better inscriptions.

Chiseled Inscriptions on Bronzes

Creating new inscriptions on cast bronze surfaces necessitated different priorities and practices. While many bronzes were originally cast without inscriptions, some of their owners later wanted to have inscriptions engraved on them. The owners might have acquired these bronzes by inheriting them from ancestors, looting, trading, or via other means. Some bronzes were probably engraved with inscriptions that were removed at a later stage. Some of the originally cast inscriptions might be removed and replaced with new inscriptions. Whatever their reasons, when the owners commissioned bronze producers to use mechanical means to create new inscriptions on cast bronzes, engraving and chiseling were the preferred methods.

Evidence of chiseled inscriptions can be seen on several bronzes, of which one of the best known examples is the Western Zhou bronze bell set belonging to Jin Hou Su. Figure 10 shows two engraved characters on one of the bells. Ma Chengyuan 馬承源 and others argue that this inscription was "engraved" (a more precise terminology is "chiseled") by a knife made of a material harder than bronze, probably iron (or high-tin bronze).[53] The strokes of each character appear blunt and narrow and, most importantly, there are traces of chiseling inside each stroke. It

49. Accession no. B60B958. Donna Strahan and Mark Fenn, "A Transfer of Technology," 27, 35.

50. There is another inscription, although incomplete, cast onto the interior of the *zun*. See Donna Strahan and Mark Fenn, "A Transfer of Technology," 28, figure 5, and p. 35.

51. Donna Strahan and Mark Fenn, "A Transfer of Technology," 35.

52. Gettens, *The Freer Chinese Bronzes*, 2:154.

53. Ma Chengyuan, "Jin Hou Su bianzhong," 1–2; see also Guan Xiaowu et al., "Jin Hou Su zhong keming," 331–45.

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Figure 10. Two characters on one of the Jin Hou Su bells. Shanghai Museum, c. 846 B.C.E. After Ma Chengyuan, "Jinhou Su bianzhong," 16, fig. 2.

can be seen that the chiseler had to cut into the bronze bit by bit, leaving repeated chiseling marks. These marks would not have been present had the inscriber worked on a soft clay model, which would have allowed easy carving of long, smooth lines. Detailed studies of the chiseled Jin Hou Su inscriptions have not yet been undertaken.

Zhang Changping 張昌平 provides a more detailed study of the chiseled inscription on one of the bronzes belonging to the marquises of Zeng 曾.[54] This bronze *pan* 盤, originally belonged to Zeng You Yu 曾侯與 (Marquis Yu of Zeng, late Spring and Autumn period), but was eventually owned by Zeng Hou Yi 曾侯乙 (early Warring States period, died in 433 B.C.E.) and interred in his tomb.[55] Some of the characters of the originally cast inscription were abraded and several new characters were chiseled in.

54. Zhang Changping, "Shang Zhou qingtongqi mingwen," 61–62, figures 1 and 2.

55. For the chronology of the Zeng marquises, see Fang Qin 方勤, "Zengguo lishi de kaoguxue guancha" 曾國歷史的考古學觀察, *Jiang Han kaogu* 4 (2014), 111, table 1.

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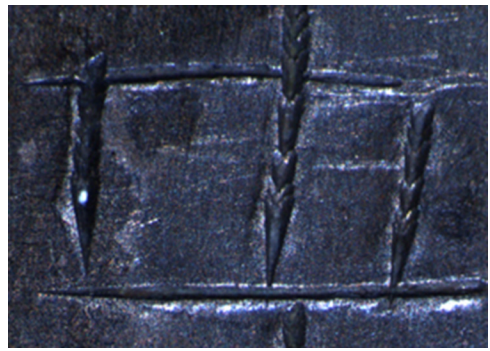

Figure 11. Chiseled strokes of the characters, *sigong* 寺工, of the inscription on the No. 860 bronze lance from the mausoleum complex of Qin Shihuang. Qin Shihuang's Mausoleum Site Museum, c. 259–210 B.C.E. After Li et al., "Inscriptions, Filing, Grinding and Polishing Marks," 495, fig. 5.

Xiuzhen Janice Li and her colleagues have closely investigated the methods used to make the inscriptions on bronze weapons unearthed from the pits of the Qin terracotta warriors and horses.[56] They suggest that traces of filing, grinding, and polishing, and especially evidence of using rotary wheels, can be found on the weapons.[57] One of their distinct discoveries is of the chiseling marks forming the characters *sigong* 寺工 (Figure 11).[58]

The Qin weapon producer chiseled a chain of marks to form one stroke of a character. Figure 11 shows that the pointed tips of newer marks break into the flatter bottoms of older marks, the strokes thus formed by a series of chevrons. The Jin and Zeng producers are known to have engraved longer marks to form a stroke, which do not form the chevrons. The Qin producer demonstrated a different technique by working up a stroke little by little.

A question could be posed as to why the producers did not engrave one long line to make a stroke. This can be answered by the technical challenge that this method presented. An engraver could make one stroke by engraving one long line, but this was not easy and it would not always provide a clear stroke. I conducted an experiment, working on a bronze plate with a modern iron knife (Figure 12).[59] Although I am inexperienced in engraving, the shortcomings of using this method to

56. Li et al., "Inscriptions, Filing, Grinding and Polishing Marks," 492.
57. Li et al., "Inscriptions, Filing, Grinding and Polishing Marks," 501.
58. Li et al., "Inscriptions, Filing, Grinding and Polishing Marks," 495, figure 5.
59. The copper content of this bronze plate is around 85 percent, but the content of tin and lead is unknown. The iron knife is virtually the same as modern steel, being much harder than ancient iron. For the scratch resistance levels of these materials, please refer to Table 1.

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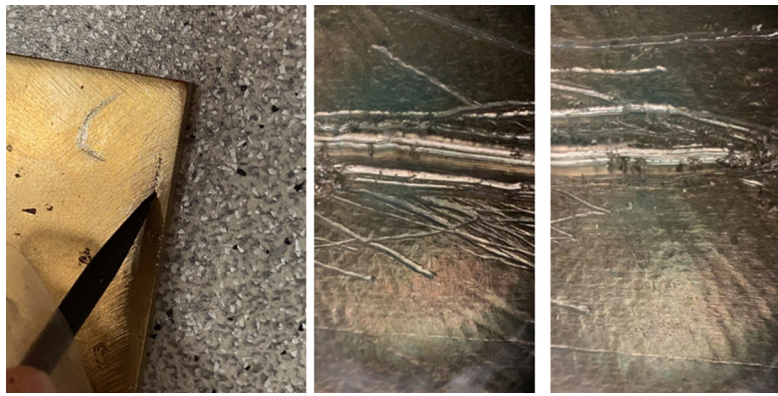

Figure 12. The author's simulation experiment of using an iron knife to engrave on a bronze plate (85 percent copper) and magnified images of the engraved lines. Photos by the author.

engrave a bronze plate were readily apparent. First, even when using an engraving tool harder than bronze, it is difficult to engrave a clear, straight line. The initially engraved line appears too shallow and narrow and had to be repeatedly engraved back and forth in order to produce a deeper line (Figure 12). Second, it is difficult to control the force of the tool. Third, this results in producing unnecessary trenches, which may ruin neighboring strokes and characters and the adjacent areas intended to be untouched. Fourth, any damage is irremediable unless a grinder abraded the entire surface again, which will also make the engraved lines less visible. Finally, the curves of the strokes are definitely not smooth. They appear blunt and rough because engraving is more suited to producing straight rather than curved lines.

It is very likely that as the Jin, Zeng, and Qin producers realized these shortcomings of the method of merely engraving long lines to form straight strokes. Instead, as described above, the Jin and Zeng producers engraved several shorter marks to form a stroke, and the Qin producers broke a stroke into a series of chevrons. All of the producers attempted to avoid excessive creation of curved strokes because the turns could not appear smooth. Working within these technically challenging parameters, currently available evidence shows that there are very few unnecessary engraved lines near the characters and almost none damaging the strokes, demonstrating the skill and care employed by the producers in question.[60]

60. Even if there had been any, however, they would have been removed by careful grinding and polishing.

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Denting and chiseling with abrasives

A further question can be posed as to what strategies the inscription makers could have employed when they desired to create smoother curves of strokes, with the beauty and clarity of the inscription as the priority in this case. When they ground the surface bearing the inscriptions, it is likely they had also intended people to touch the inscriptions. Thus the tactile experience might also have been incorporated into their working strategy. Realizing the shortcomings of the methods of engraving and chiseling, they would have been able to obtain inspiration from other industries to help implement their plans.

The object known as the "Shang Yang" 商鞅 container in the collection of the Shanghai Museum comes to our attention (Figures 13–17).[61] It resembles the Qin Shihuang container in shape, size, and volume. Different sides of the container were inscribed with different inscriptions. The most eye-catching inscription—Qin Shihuang's edict about regulating the measurement systems—is on its base. While previous scholars held that the edict had been engraved onto the container, it was actually cast. Figure 13 displays more images of the cast strokes of the character *yi* 壹 in the edict. These strokes can be compared with those of the character *nai* in Figure 6 on the Qin Shihuang container and with other cast inscriptions shown in Figures 7–9. There is no trace of engraving or chiseling within the strokes of the character *yi* in Figure 13. Its strokes appear wide, deep, and smooth. Some edges are tilted up, indicating that the strokes were first carved on a clay model. This suggests that the "Shang Yang" container was cast during or after Qin Shihuang's imperial reign, in or after 221 B.C.E.

In another inscription on one side of the "Shang Yang" container (Figures 14–17), the characters for Shang Yang's name, after whom the container was originally titled, appear.[62] Detailed images of the charac-

61. Accession no. 44331. For the inscription on the "Shang Yang" container, see Guojia jiliang zongju 國家計量總局 et al., *Zhongguo gudai duliangheng tuji* 中國古代度量衡圖集 (Beijing: Wenwu, 1984), 44–45, no. 81; Qiu Guangming 邱光明 et al., *Zhongguo kexue jishushi: duliangheng juan* 中國科學技術史：度量衡卷 (Beijing: Kexue, 2001), 166–68; Chen Peifen 陳佩芬, *Xia Shang Zhou qingtongqi yanjiu* 夏商周青銅器研究 (Shanghai: Shanghai guji, 2004), 6:470–73, no. 641; Kin Sum (Sammy) Li, "Attaining Accuracy and Precision of Measuring Containers during the Qin Dynasty," *Journal of Chinese History* 6.1 (2022), 1–22.

62. Shang Yang (c. 390–338 B.C.E.) has several names, such as Gongsun Yang 公孫鞅 (his original name), Wei Yang 衛鞅 (Yang from the Wei state), and Shang Yang 商鞅 (Yang, the Lord of Shang [Shang Jun 商君]). Shang Yang's deed of regulating measurement systems in the pre-imperial Qin state was probably still highly esteemed in the imperial period. Thus an inscription about him was created on an already-cast container. Adding old inscriptions with cold mechanical methods onto different sides of

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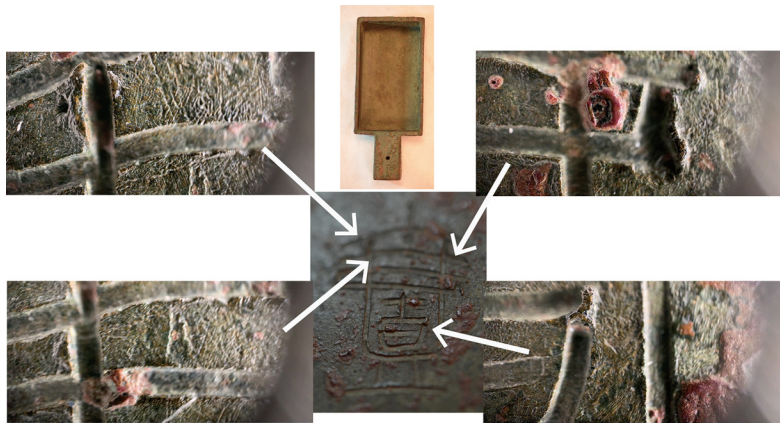

Figure 13. The "Shang Yang" bronze container and magnified images of the character *yi* 壹 in the inscription of Qin Shihuang's edict cast on the base of the container. Length 19 cm, capacity 202 cm^3. Shanghai Museum, accession no. 44331, c. 221–207 B.C.E. Photos by the author.

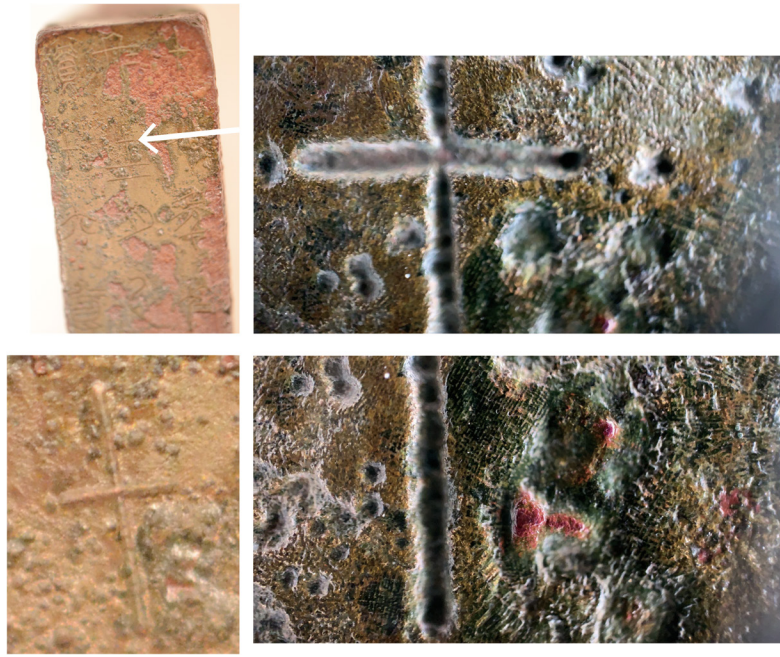

Figure 14. Magnified images of the character *shi* 十 in the chiseled inscription about Shang Yang on one side of the "Shang Yang" container. Photos by the author.

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Figure 15. Magnified images of the character *er* 二 in the chiseled inscription about Shang Yang on one side of the "Shang Yang" container. Photos by the author.

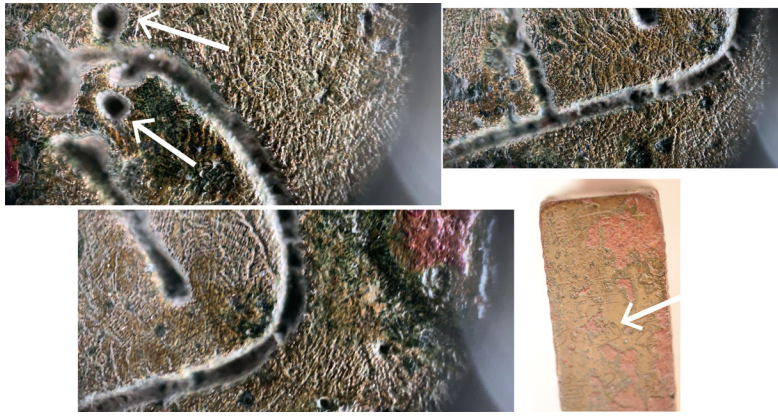

Figure 16. Detail of the character *yue* 月 in the chiseled inscription about Shang Yang on one side of the "Shang Yang" container. Photos by the author.

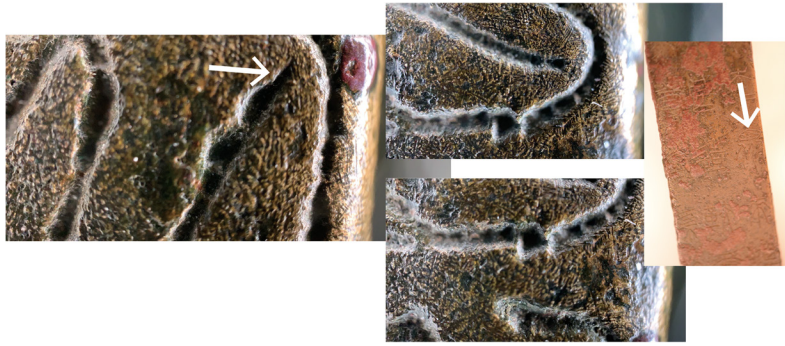

Figure 17. Detail of the character *zhong* 眾 in the chiseled inscription about Shang Yang on one side of the "Shang Yang" container. Photos by the author.

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ters *shi* 十, *er* 二, *yue* 月, and *zhong* 眾 in the inscription on this side show that they were created by cold mechanical methods on the cast bronze. How, then, were these parts of the inscription executed?

The strokes of these characters suggest that they were punched or drilled, chiseled, and/or engraved little by little.[63] Since the hardness of the tools, whether they were high-tin bronze, iron, or steel, was merely a little higher than the bronze being carved, it was not as easy as carving on a talc or clay. It therefore remained very difficult to control the orientation of the movement of the chiseling tool when working on the bronze surface. The producer of the "Shang Yang" container started by punching or drilling, which left various dented marks on the surface. Punching was done by hammering on a pointed tool, while drilling is undertaken by rotating a small tube stabilized on the surface, driving the wet abrasives to leave dented marks. Both techniques were done at an angle vertical to the bronze surface. The images available to me do not provide enough information to identify whether the marks were dented by punching or drilling; both options therefore remain as possibilities at this stage. The many marks in Figures 14, 15, and 16, which are not connected as strokes of the characters and are adjacent to the strokes, are evidence of punching. Traces of punching are more conspicuous in Figure 17. Some of the marks might be holes left by previous metallic crystal debris of corrosion having come off the bronze surface. However, there is almost no trace of grinding on the surface, so these holes should be few. More significantly, Figure 15, showing several consecutive dotted marks lined up above the horizontal stroke, and Figure 16, displaying two dots next to the beginning stroke of the character *yue* in the left sub-images, constitute strong evidence. With regard to Figure 15, the producer seemingly intended to use the consecutive dots to form a horizontal stroke, but for unknown reasons finally abandoned them. Regarding the left sub-images in Figure 16, the producer appeared to have been hesitant as to which dot to start at for the beginning curved stroke of the character *yue*. These dots were not caused by naturally occurring corrosive crystals having come off the surface, but by intentional punching. For some reason their maker abandoned them unused. In the top right sub-image of Figure 14, there are two dots that are not connected with the horizontal stroke of the character, *shi*; in the left

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the same container was, simultaneously, for public promotion of new policies and for commemorating history. See Yuri Pines, *The Book of Lord Shang: Apologetics of State Power in Early China* (New York: Columbia University Press, 2017), 7–24.

63. Ma Chengyuan argues that it was engraved ("Jin Hou Su bianzhong," 2, and figs. 2 to 4). Current evidence suggests, however, that this statement needs re-examination. See also Zhang Changping, "Shang Zhou qingtongqi mingwen," 62.

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sub-image of Figure 15, there is one dot to the right end of the stroke, which is also not connected to the stroke. These are also traces suggesting the producer abandoned them or forgot to connect them. The trapezoid dented mark in the two center sub-images in Figure 17, bridging two curved lines and forming one stroke of the character *zhong*, was clearly punched. It seems the producer was not confident of linking up the two originally separate tracks of the curved stroke of the character *zhong*, as shown in the two center sub-images of Figure 17, and so then decided to punch in a new trapezoid mark to finish the curved stroke.

The producer then connected all punched or drilled dented marks by chiseling. Chiseling could be done by hammering a tool with a sharp point, but in this case it was executed with an oblique angle to the surface. It almost seems as if the producer then played "join-the-dots." Earlier, strokes had been pre-planned and executed as individual marks; now the producer needed to connect the marks to form the tracks of the strokes. In this way, it was easier to stabilize the start and end positions of the tool and to control its movement than it would have been if starting from scratch on the hard, smooth surface. The producer needed only to settle their chisel on one punched mark, slightly hammer on the chisel and it would cut through to the next mark and stop there. Continuing this process, they could chisel out all the strokes with relative ease. Being apparently dissatisfied with the positions of some pre-planned marks, they decided to start from other positions. Therefore, the marks in Figures 14, 15, and 16 were left unused.

Simply connecting the marks produced shallow, narrow, and faint tracks of the strokes. These tracks then needed to be engraved several more times in order to make them appear deeper and clearer. This is seen more obviously on some strokes shown in Figure 14 and Figure 16. Traces of punching and chiseling can still be seen, but much more weakly, as the tracks of the strokes became deeper and smoother. In the left sub-image of Figure 17, the white arrow points to the trace of engraving that goes past the last punched mark. However, some tracks of strokes still appear much smoother than others, leaving few working traces. How did the producer manage to do this?

The Western Han Yangpingjia 陽平家 bronze lamp support in the Shanghai Museum collection provides some clues (Figures 18–21).[64]

64. Xu Weiren 徐渭仁 (1788–1855), *Han Jianzhao yanzudeng kao* 漢建昭雁足鐙考, 2 *juan* 卷, 1837, collection of the Chinese-Japanese Library, Harvard-Yenching Institute at Harvard University, 1.1–1.21; Xu Zhengkao 徐正考, "Fulu er, Handai tongqi mingwen huiji" 附錄二，漢代銅器銘文滙集, *Handai tongqi mingwen yanjiu*, 漢代銅器銘文研究 (Changchun: Jilin jiaoyu, 1999), 273; Wu Xiaoping 吳小平, "Cong mingwen kan liang Han tongqimin de shengchan jingying fangshi ji qi bianhua" 從銘文看兩漢銅器

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Figure 18. Chiseled inscription on the upper part of the Yangpingjia bronze lamp support. Shanghai Museum, accession no. 48298, 38–34 B.C.E. Photo by the author.

First, the characters in Figure 18 show that the inscription on the lamp support was made beautifully and clearly. The curved strokes are very smooth and all strokes have been executed deeply into the bronze. Figure 19 reveals traces of punched marks, all connected in the deep and wide tracks of the strokes. Figure 20 demonstrates that the tracks of strokes were smoothed by repeated engraving, as the traces of engraving occasionally come out of the tracks. There are very faint engraving traces next to the tracks of strokes in the bottom sub-image in Figure 20, suggesting that these might have been made in error by the producer. Overall, the types and sequence of cold mechanical methods of creating the inscription on the Yangpingjia lamp support were similar to those used on the "Shang Yang" container. However, the smooth interior bases of the chiseled tracks suggest that they were probably engraved with abrasives. When the producer was repeatedly engraving the connected tracks of the strokes, they might have added water and abrasives into the tracks, using the engraving tool to drive the abrasives. Abrasives would have smoothed the bases of the tracks and removed the traces of punching and chiseling. The yellow sand grits inside the tracks of strokes might have been the abrasives used by the producer. Yellow grits are found in the tracks of strokes of many characters (especially Figure 21), although it cannot be ascertained whether those grits were indeed the abrasives used. However, if the producer of the Qin

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皿的生產經營方式及其變化, *Gugong bowuyuan yuankan* 故宮博物院院刊 4 (2007), 103. See also similar lamp supports from Shandong Linzi 山東臨淄, recorded in *Zhongguo qingtongqi quanji* bianji weiyuanhui, ed., *Zhongguo qingtongqi quanji*, 12:108, no. 106, and description on p. 34, and from Shaanxi Baoji 陝西寶雞, cited in Li Zhongcao 李仲操, "Han Jianzhao yanzudeng kao" 漢建昭雁足燈考, *Kaogu yu wenwu* 2 (1988), 88–89.

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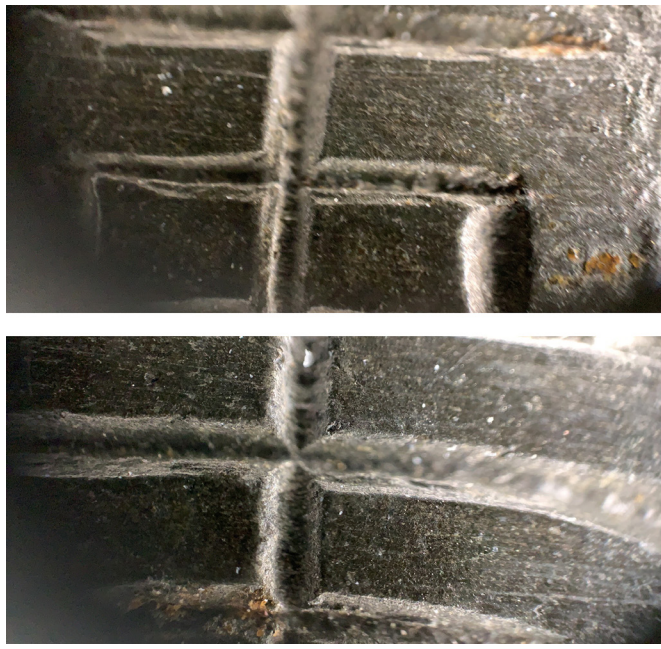

Figure 19. Detail of the character *hua* 畫 in the chiseled inscription on the Yangpingjia lamp support. Photos by the author.

weapons (Figure 11) had used the chiseling method with abrasives, the series of chevrons would have been removed to leave the deep and wide tracks of the strokes. This warrants a reassessment as to whether some tracks on the "Shang Yang" container might also have been created in this way.

The sequence of the techniques used on the "Shang Yang" container and Yangpingjia lamp support is as follows:

1. Make dented marks on the bronze surface by punching or drilling, defining the tracks of the strokes of the characters to be inscribed;
2. Roughly connect the dented marks by chiseling, similar to playing "join-the-dots." This also prevented the chisel from slipping out of the tracks of strokes;
3. Chisel deeper and wider tracks with abrasives;
4. Slightly grind and polish the inscribed areas made at the initial stage. Those deeply executed inscriptions were not easily removed.

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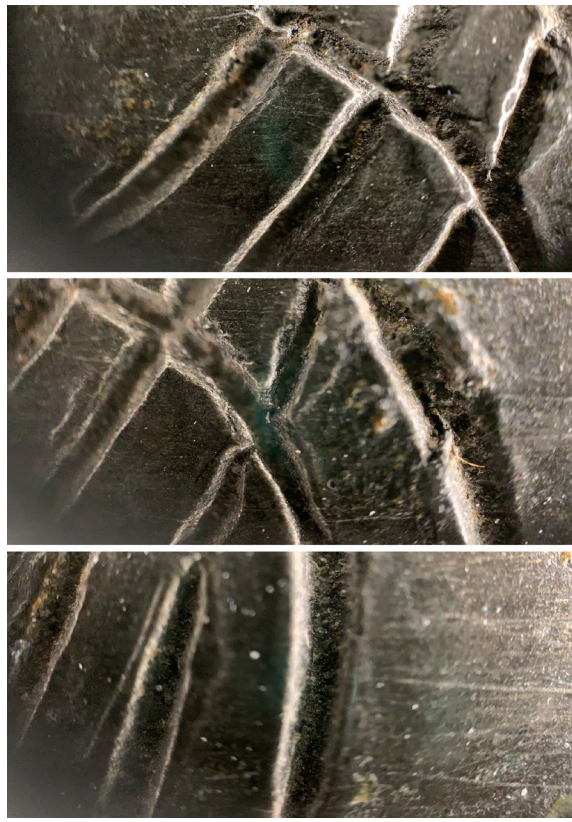

Figure 20. Detail of the characters *jia* 家 (upper two sub-images) and *yang* 陽 (bottom sub-image) in the chiseled inscription on the Yangpingjia lamp support. Photos by the author.

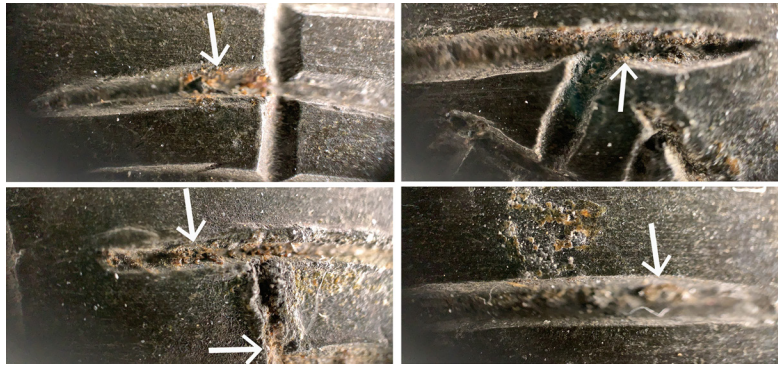

Figure 21. Sand grit inside the tracks of strokes of different characters in the chiseled inscription on the Yangpingjia lamp support. Photos by the author.

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Figure 22. Unfinished jade. Hongshan culture, c. 3300–2000 B.C.E. After Gu Fang et al., *Zhongguo guyu tudian*, 29, fig. 9.

The advantages of adopting such mixed methods are evident. First, the inscriptions would be clearly and beautifully displayed and the strokes of inscribed characters would be deep and smooth. This remedied the disadvantages of simply engraving and chiseling, and occasionally created the visual effect that the inscriptions were seemingly cast (Figure 18). Second, controlling the movement of the chisels and/or engraving knives was easier, so that damaging other strokes and characters with sudden excessive force could be avoided. Third, it was easier to stop when mistakes were spotted. Small punched marks that were to be abandoned were not obvious to the viewers. The producer could start with some newly placed punched marks to remedy mistakes.

These mixed methods had also been employed in the lapidary industry.[65] A piece of unfinished jade from the Hongshan 紅山 culture, dating to about 3300–2000 B.C.E., displays a series of drilled marks to be connected (Figure 22).[66] Punching would not have worked on jade, but drilling with abrasives could have made the marks. Connecting these marks by filing, probably with abrasives, would have produced the required trench. The unfinished trench on the left side of the jade in Figure 22 was likely intended to be elongated using mixed methods.

Two other Hongshan jades reveal additional clues. The first is a jade comb excavated from Liaoning Chaoyang Niuheliang 遼寧朝陽牛河梁 (Figure 23).[67] A pair of curved lines on top of the comb probably represented eyebrows on a face. The white arrows point to the start or end holes of the curved lines. The curved lines have been cut by sawing

65. Wang Yi 王毅 et al., eds., *Jinsha yugong I: Jinsha yizhi chutu yushizhang yanjiu* 金沙玉工I：金沙遺址出土玉石璋研究 (Chengdu: Sichuan renmin, 2017), 132.

66. Gu Fang et al., *Zhongguo guyu tudian*, 29. Usually the unfinished products show the working traces clearly; working traces on finished products have often been removed. The rougher the treatment, the more working traces we find.

67. Gu Fang et al., eds., *Zhongguo chutu yuqi quanji* 中國出土玉器全集 (Beijing: Kexue, 2005), 2:133.

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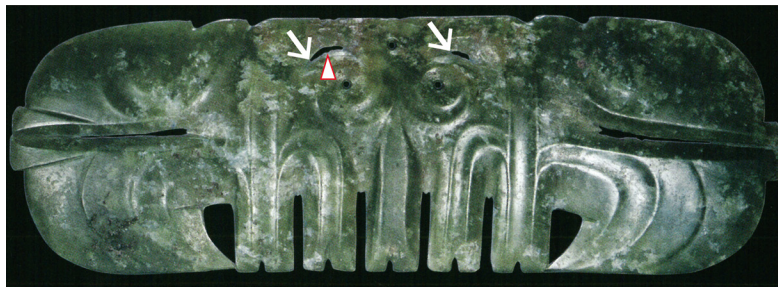

Figure 23. Jade comb from M27 of Burial Mound No. 1 at the second location at the Liaoning Chaoyang Niuheliang site. Length 28.6 cm, thickest point 0.6 cm. Housed in the Liaoning Provincial Institute of Cultural Relics and Archaeology. Hongshan culture, c. 3300–2000 B.C.E. After Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, vol. 2, 133.

with abrasives with the start and end positions at the holes. The sawing tools would have been wet strings coated with abrasives. There might originally have been other holes drilled but subsequently removed by the sawing that connected the holes (one possibility indicated by the triangle in Figure 23). The second, a jade pendant, also unearthed from Niuheliang, shows the connection between drilled holes with a much longer and smoother line (Figure 24).[68] Figure 24 shows the front and back sides of the pendant, the white arrows pointing to the start and end holes. Combining clues as shown in Figure 23, the curved connecting line might have been cut through by linking many holes. It would otherwise have been hard to stabilize the sawing string and to control the subsequent movement of the string. Without the consecutive holes drilled in advance, the lines, trenches, or areas to be cut may not have appeared as planned.

For these reasons stabilizing marks would have needed to be placed before sawing. Figures 25–27 show three pieces of jade or stone with stabilizing marks, which were or needed to be sliced or sawed. Figure 25 shows an unfinished jade tube from Xinglonggou 興隆溝 in Inner Mongolia, dating to approximately 6000 B.C.E.[69] Its stabilizing mark had already been dented for sawing along the dented trench. Another piece is a Hongshan culture jade coiled dragon claimed to have been found at Balinyouqi Yangchangxiang E'ergenwusu 巴林右旗羊場鄉額爾根勿蘇 in Inner Mongolia (Figure 26).[70] The mouth of the dragon was almost

68. Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, 2:131.

69. Yang Hu 楊虎 et al., eds., *Yuqi qiyuan tansuo: Xinglongwa wenhua yuqi yanjiu ji tulu* 玉器起源探索：興隆窪文化玉器研究及圖錄 (Hong Kong: Centre for Chinese Archaeology and Art, The Chinese University of Hong Kong, 2007), 124.

70. Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, 2:22.

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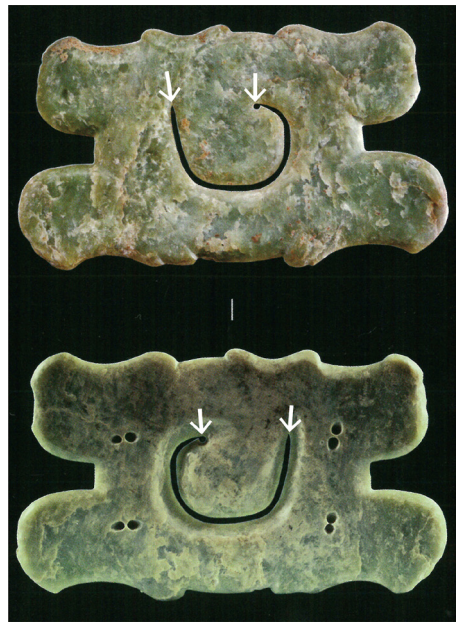

Figure 24. Jade pendant from M1 of Burial Mound No. 1 at the fifth location at the Liaoning Chaoyang Niuheliang site. Length 20.9 cm, thickness 0.9 cm. Housed in the Liaoning Provincial Institute of Cultural Relics and Archaeology. Hongshan culture, c. 3300–2000 B.C.E. After Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, vol. 2, 131.

Figure 25. Unfinished tube-shaped jade slit ring from House 22, Xinglonggou, Inner Mongolia, c. 6000 B.C.E. After Yang Hu et al., eds., *Yuqi qiyuan tansuo: Xinglongwa wenhua yuqi yanjiu ji tulu*, 124.

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Figure 26. Jade coiled dragon from Balinyouqi Yangchangxiang E'ergenwusu, Inner Mongolia. Height 16.3 cm, width 11.5 cm, diameter of the large hole 3–3.4 cm. Housed in the Balinyouqi Museum. Hongshan culture, c. 3300–2000 B.C.E. After Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, vol. 2, 22.

Figure 27. Stone disc from Wengniuteqi Danangou, Inner Mongolia. Diameter 12.1 cm. Housed in the Chifeng 赤峰 Museum. Xiaoheyan culture, c. 3000 B.C.E. After Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, vol. 2, 57.

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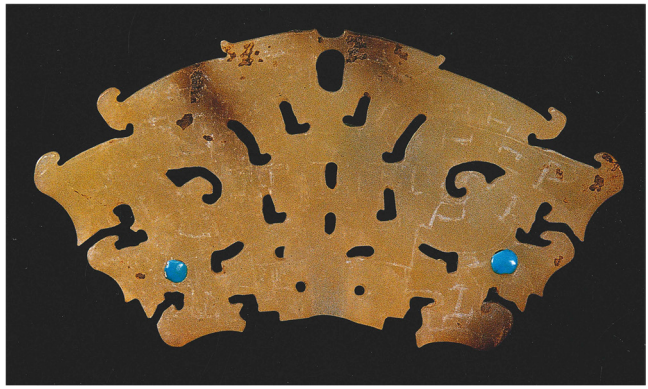

Figure 28. Jade hairpin finial, inlaid with turquoise, from M202 at Shandong Linxu Xizhufeng. Length 9 cm, thickness 0.45 cm. Housed in the Institute of Archaeology, CASS. Longshan culture, c. 2500–2000 B.C.E. After Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, vol. 4, 19.

finished, with only the final step of joining the dragon's mouth with the large hole remaining to complete it. The stabilizing and start mark was one of the striated marks on the dragon's mouth. From there the worker would have continued sawing with the string until joining the large hole. The third piece is a stone disc from Wengniuteqi Danangou 翁牛特旗大南溝, Inner Mongolia, belonging to the Xiaoheyan 小河沿 culture and dating to about 3000 B.C.E. (Figure 27).[71] Four lines had been made on the stone to provide stabilizing and start marks to transform the disc into a slit ring, although why four lines were needed is unknown. The jade hairpin finial excavated from M202 at Shandong Linqu Xizhufeng 山東臨朐西朱封, dating to 2500–2000 B.C.E. and belonging to the Longshan 龍山 culture, shows many marks created using such mixed methods (Figure 28).[72] Two well-polished turquoise beads had been inlaid on the drilled holes of the hairpin finial. Traces connecting the other drilled holes by sawing with abrasives can be seen on many parts of the hairpin finial.[73] Working on the hard, smooth surfaces of both bronze and jade required the producers to first settle and stabilize their tools on initial dented marks. Among the jades and bronzes investigated in this article, this new, firmer evidence demonstrates that bronze producers

71. Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, 2:57.

72. Gu Fang et al., eds., *Zhongguo chutu yuqi quanji*, 4:19–20.

73. A Shang dynasty jade pendant that resembles the Xizhufeng hairpin finial, despite lacking clear provenance, can be found in *Beijing wenwu jingcui daxi* bianweihui 《北京文物精粹大系》編委會 and Beijing shi wenwuju 北京市文物局, ed., *Beijing wenwu jingcui daxi—yuqi juan* 北京文物精粹大系・玉器卷 (Beijing: Beijing, 2002), 49, no. 17.

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might have obtained inspiration in terms of tools and techniques from lapidary workers.

Technical exchanges and production aims

Producers working on post-processing bronzes would have had many aims and approaches. They would have had to judge whether to adopt traditional methods or to devise novel ones to tackle new demands and materials. The changes of technologies and tools, with existing knowledge gained from long-term experience, would also have been part of their considerations. With regard to the bronzes featured in this article and the issues outlined above, producers would have given high priority to beauty and visual contrast, inscription clarity, and tactile experiences. When traditional tools and techniques from bronze working did not suffice to produce these qualities, they would have borrowed sharper tools and more efficient techniques from other industries. When they were working with their own tools and materials, the sensory experiences they obtained during the working process would also inspire them as they made subsequent decisions.

A number of the techniques and approaches explored in this article testify to the close relationship between the bronze and lapidary working (and probably bone working) industries: 1. Grinding and polishing main motifs on bronze mirrors; 2. Techniques of circular grinding and polishing mirror edges, on round platforms probably used in lapidary working; 3. Emphasis on creating smooth tactile experiences by polishing might have been a priority shared among bronze and lapidary producers; 4. Polishing cast inscriptions; 5. Drilling or punching onto the bronze to leave dented marks to stabilize cutting tools; 6. Connecting dented marks by chiseling with abrasives to work out deeper, wider, and smoother tracks for character strokes. These examples could be seen as exchanges of techniques between the two production communities.

The post-processing of patterns on mirrors took place with the aims of creating beauty, gloss, and tactile qualities. Mirror producers were not satisfied with merely scraping off undesired protrusions and simple polishing; they needed to do more to entice their commissioners or customers. The mirror front had to be reflective enough to function, and the main motifs on the decorated side glossy enough to create visual contrast with the background patterns. The producers also paid attention to the users' tactile experiences and so made the main motifs and edges smooth enough to invite people to closely interact with the mirrors. This was similar to the way in which workers of jades, turquoises, and other precious stones invested great effort to create patterns, and to enhance their gloss and smooth texture. Besides using lapidary tools and techniques, bronze producers likely followed lapidary workers in focusing

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on visual and tactile qualities. The use of whetstones and abrasives to grind and polish the decorative patterns and inscriptions was a shared practice between the two production communities. Another related example is the grinding of raised edges of cast inscriptions. The raised edges did not obstruct the display of inscribed characters, but the edges were all abraded and smoothed on Qin Shihuang's measures (Figures 5–6). The *gui* producer even ground the cast characters where some of the strokes were missing (shown in Figure 9). Some of these inscriptions may well have been intended to be touched, otherwise the producers' efforts in smoothing them became meaningless.

Merely demonstrating the use of the same tools would not have been enough to prove active exchanges between the working communities. The shared working approaches, priorities, techniques, and practices are also essential proof of such exchanges. The hard, smooth surfaces of bronze, jade, and turquoise presented similar challenges to those working on them. Therefore, the two communities of producers shared effective methods including both punching or drilling to leave dented marks to stabilize the chiseling tools and control the movement of those tools, as well as connecting marks by chiseling enhanced with abrasives. They shared similar aims of beauty, clarity, and pleasing tactile qualities, and the manner in which they fulfilled those aims, adopting similar techniques and practices, using similar tools, is demonstrated by the working traces remaining on the objects.

Many more bronzes that were treated by these cold mechanical methods remain unexamined. For objects whose wall thickness was of the utmost importance, for instance weapons, casting inscriptions was not a preferred option because dented or sunken inscriptions might weaken their strength, although rare exceptions do exist.[74] Engraved or chiseled inscriptions, then, were preferred. The sequence of grinding and polishing was also important, since excessive grinding might remove inscriptions. Inscribing after grinding might have become a preferred option, but light grinding after inscribing would also have been practiced because of the need to consider people touching chiseled inscriptions. In this case, the lapidary practices of polishing and smoothing surfaces were again brought into play. These interchanging and interlocking aims, priorities, techniques, and practices reflected how the two production communities substantially interacted.

74. Most of the bronze weapons from the Qin mausoleum complex were engraved and/or chiseled, see Zhang Tian'en 張天恩 et al., eds., *Shaanxi jinwen jicheng* 陝西金文集成, vol. 13 (Xi'an: Shaanxi xinhua; San-Qin), 20–65; for one exception, a cast inscription, see p. 28.

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Conclusion

It is hard to articulate a single universal pattern to account for all production practices, as different producers in various regions have had their own practices and preferences throughout history. Even among producers working on the same object, a variety of practices could be adopted, as cast and chiseled inscriptions appearing on the same bronze container have shown. As researchers, it is necessary to be specific as to which group of objects are being discussed, to try our best to make our observations as publicly accessible as possible, and to invite re-examination, challenges, and criticism. In particular, if those objects cited as evidence in an argument are not publicly accessible, they remain only the writer's private playthings rather than public proof.

A focus on single industries without a comprehensive evaluation of design and technical exchanges between production communities generates insufficient understanding of ancient Chinese art and archaeology. Although many material records from ancient China, such as perishable textiles and lacquerwares, have vanished, the remaining permanent materials such as bronze, ceramic, lapidary, glass, and bone objects could yield exciting evidence attesting to active exchanges between industries and, thus, illustrating a different picture of ancient China.

Developing research into sensory experiences in the art historical and archaeological study of ancient China is of critical importance. The examples cited in this article demonstrate the need for a more comprehensive study of ancient Chinese producers' aims to provide sensory experiences for their commissioners and users. Creating a smooth surface was a significant priority shared between producers of jades, turquoises, and bronzes. Making the inscriptions clearer was another key priority, achieved through the use of a mixture of methods. Such enduring emphasis on visual and tactile experiences prompted bronze and jade producers to continually improve their technologies. This sustained process of technological improvement required continuous investment in labor and material resources to enable producers to keep on experimenting with their materials.

Such ongoing investments eventually became efforts to expand the producers' powers. The Yangpingjia bronze lamp support, which was the culmination of thousands of years of technological developments in integrating the highest forms of bronze-casting, post-processing, and lapidary techniques, reflected the long-term technical and artistic challenges and achievements of the producers in the bronze and lapidary industries. The producers and their customers, patrons, and supporters, had formed ever-expanding industrial power groups to pursue even greater visual

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and tactile experiences. In the expansion process, every production step, ranging from the acquisition of raw materials, through the design aims of beauty and smoothness, to product finishing and post-processing, was imbued with political and social significance. As sociopolitical organizations became more developed, these industries became more powerful, and were able to place greater emphasis on visual and tactile experiences for users of their products. Individual users experienced the visual clarity and the tactile qualities of the inscriptions and patterns, and these individual users, along with the producers and the industrial power groups behind them, were driving forces of political and social developments in ancient China. Through studies of individuals' sensory experiences, combined with those of developments in sociopolitical organizations, new light can be shed on the ancient world.

視覺與觸感：古代中國青銅與玉石的機械處理

李建深

提要

本文為古代中國青銅與玉石的機械處理的歷史與感官經驗研究提供新證據與論述。鐵工具比青銅硬，但在鐵工具發明之前，如何在青銅表面刻劃與打磨是一個謎。本文也為刻劃或者鑿刻而成的青銅銘文的製造提供新思考，畢竟這些銘文太容易被鑑定專家認為是偽造的，因此這類問題還需要進一步探討。透過研究在公元紀年前中國青銅器的鑄後處理技術，以及青銅與玉石工匠的技法交流，本文論述玉石行業中使用的解玉砂可能也應用在青銅表面的刻鑿過程中，顯示玉石的處理手法與青銅的鑄後處理有緊密關係。青銅與玉石工匠的緊密聯繫反映了他們皆關心其產品提供給使用者的視覺與觸覺體驗。青銅與玉石生產行業有着頻繁又活躍的思想與技藝交流。他們對產品視覺與觸覺的關心與體現揭示了公元前兩千紀內中國產業的發展史。

Keywords: bronze, jade, chisel, China, abrasive
青銅, 玉石, 鑿刻, 中國, 解玉砂

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