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Making Weapons for the Terracotta Army

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The Terracotta Army of the First Emperor of China is one of the most emblematic archaeological sites in the world. Many questions remain about the logistics of technology, standardisation and labour organisation behind the creation of such a colossal construction in just a few decades over 2,000 years ago. An ongoing research project co-ordinated between the UCL Institute of Archaeology and the Emperor Qin Shihang's Terracotta Army Museum is beginning to address some of these questions. This paper outlines some results of the typological, metric, microscopic, chemical and spatial analyses of the 40,000 bronze weapons recovered with the Terracotta Warriors. Thanks to a holistic approach developed specifically for this project, it is possible to reveal remarkable aspects of the organisation of the Qin workforce in production cells, of the standardisation, efficiency and quality-control procedures employed, and of the sophisticated technical knowledge of the weapon-makers.

Qin Shihuang (259–210 BC) is one of the most famous and controversial figures in Chinese history. Widely known as 'the First Emperor', he forcibly unified China for the first time, prosecuted intellectuals and opponents, abolished feudalism, and standardised philosophy, script, coinage and law. The enormous mausoleum complex he commissioned for himself in Xian, Shaanxi, remains an unequalled material representation of his world, providing an almost inexhaustible source of information about the powerful political and symbolic system that was built up around his personality. Today, the complex is a UNESCO World Heritage Site and attracts over four million visitors a year, in addition to contributing to major travelling museum exhibitions across the globe.

The mausoleum complex covers an area of over 50 square kilometres. Alongside the colossal main pyramid structure underneath which the Emperor is said to be buried, archaeological research in the last four decades has unveiled a wealth of other installations that were built to provide an ideal environment for the ruler's afterlife. There are various pits with: life-sized servants, acrobats and musicians; water channels with delicate bronze birds; bronze carriages fitted with gold and silver implements and lavishly decorated with polychrome pigments – and surely, many more finds yet to be discovered (**Fig. 1**). The Terracotta Army, however, since its discovery in the 1970s, has become the very emblem of the site – an unarguable manifestation of the substantial military power, lavish wealth and artistic achievement of the Qin Empire. Stationed in three pits to the east of his tomb, the Terracotta Warriors are supposed to have been placed there to host and protect the Emperor from his many enemies in his afterlife. So far, c.2,000 individually crafted warriors have been recovered during archaeological excavations in three

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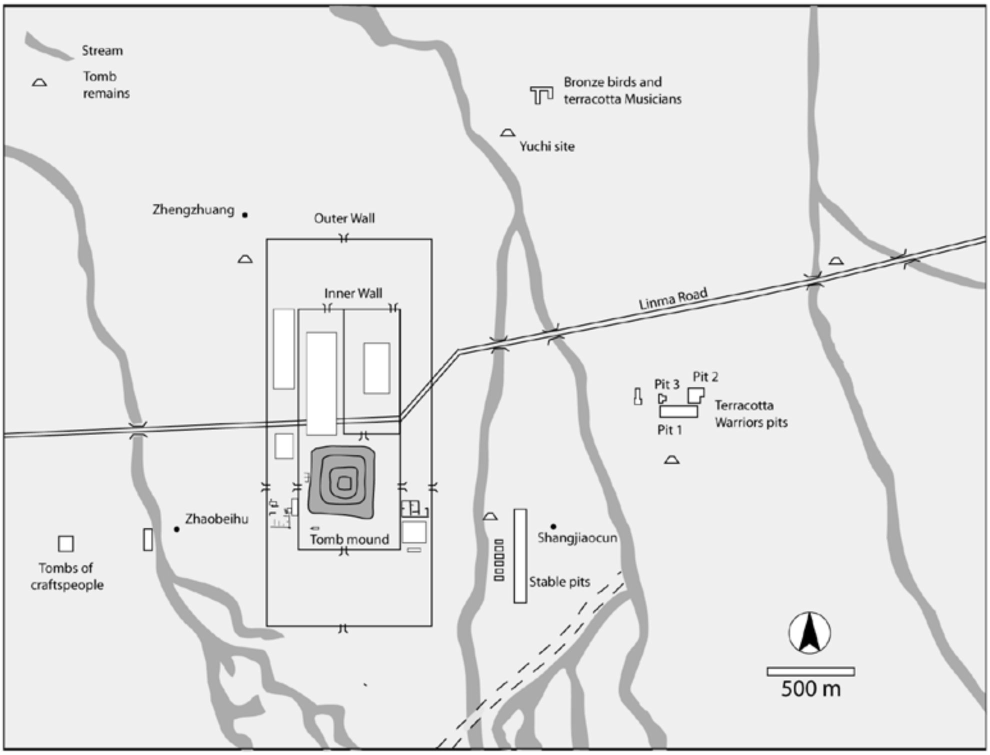

Fig. 1: Site plan of the First Emperor's Mausoleum, showing the location of the Emperor's Tomb towards the centre, the Terracotta Army to the east, and other elements of the complex.

pits, although it is estimated that their number may reach up to 8,000 (**Fig. 2**).[1]

The public eye is now used to the stunning image of the battle formation in Pit 1, besides detailed pictures of the individualised facial features and hairstyles of the warriors, or the well-preserved polychromy on some of the archers. Fewer people know, however, that the warriors were fully equipped with state-of-the art bronze weapons. The assemblage excavated so far includes over 40,000 arrowheads, as well as hundreds of crossbow triggers, swords, lances, spears, halberds, hooks, honour weapons (*Su*) and the ferrules that were fixed at the end of the wooden hafts of the longer weapons. Many of these pieces of military equipment are in such a pristine state of preservation that they would still be lethal today (**Fig. 3**).

The mausoleum appears even more impressive when one considers that everything was built in fewer than four decades at most (between Qin Shihuang's ascent to the throne in 246 BC and his death in 210 BC), and that nothing of its kind had been created in China before. The speed, quality, originality and scale of this work must have created important logistical and technological challenges that the Emperor's craftspeople met in a range of demonstrably successful ways. Since 2006, a collaborative agreement between the Emperor Qin Shihuang's Terracotta Army Museum and the UCL Institute of Archaeology has allowed the regular transfer of students, specialists and knowledge between Britain and China. In addition to developing long-lasting research skills and networks in both countries, the project has focused on investigating the logistics of technology and labour organisation behind the construction of the Terracotta Army. The first stage of the project has concentrated

Fig. 2: Overview of some warriors in Pit 1 of the Terracotta Army (photo: Xia Juxian).

on the bronze weapons from Pit 1, involving an exhaustive typological analysis, extensive archaeometric studies and careful spatial analysis.[2] This paper outlines some of our main results so far.

Battle formation and weapons' distribution

The Chinese archaeologists who excavated Pit 1 in the 1970s recorded the location of all the warriors and artefacts associated with them in a very thorough way.[3] We have been using their detailed excavation report as the basis for establishing an enhanced database that supports the full range of our typological, archaeometric and spatial research. The location of individual warriors and weapons, or minute variations in their style or technology, can be mapped and analysed statistically. **Figs 4** and **5** illustrate, respectively, the spatial distribution of warrior types and weapon types across the excavated area.

Fig. 3: A bronze halberd from the Terracotta Army; note the sharpness of the blades and good state of preservation.

These images provide a snapshot of the battle formation and, implicitly therefore, of the military strategies of the Qin army. For example, one can easily see how seemingly lower-status robed warriors were placed on the front line, followed by armoured warriors and the generally smaller numbers of offic-

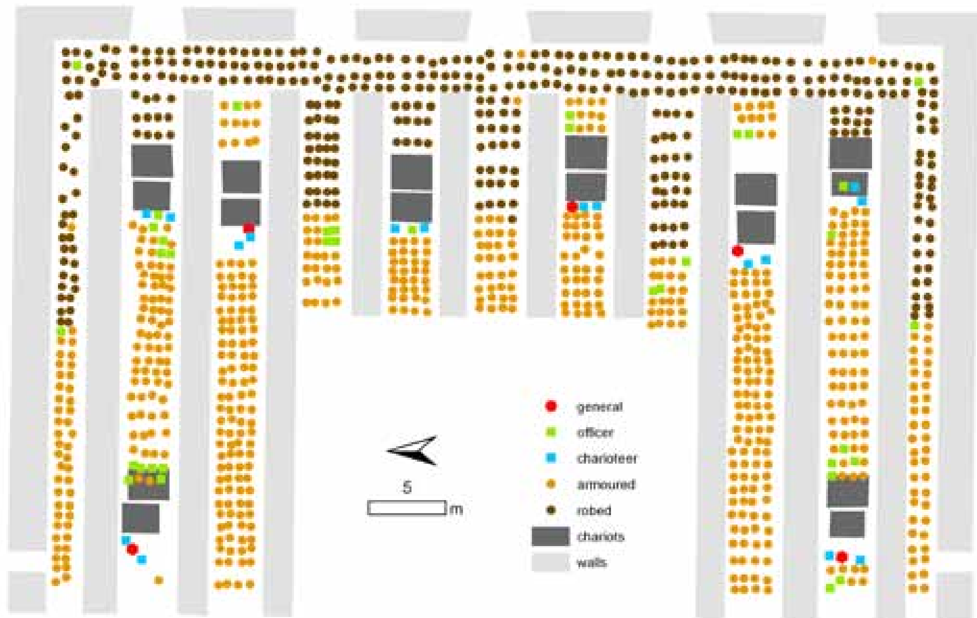

Fig. 4: Plan of the excavated area of Pit 1, showing the distribution of different warrior types.

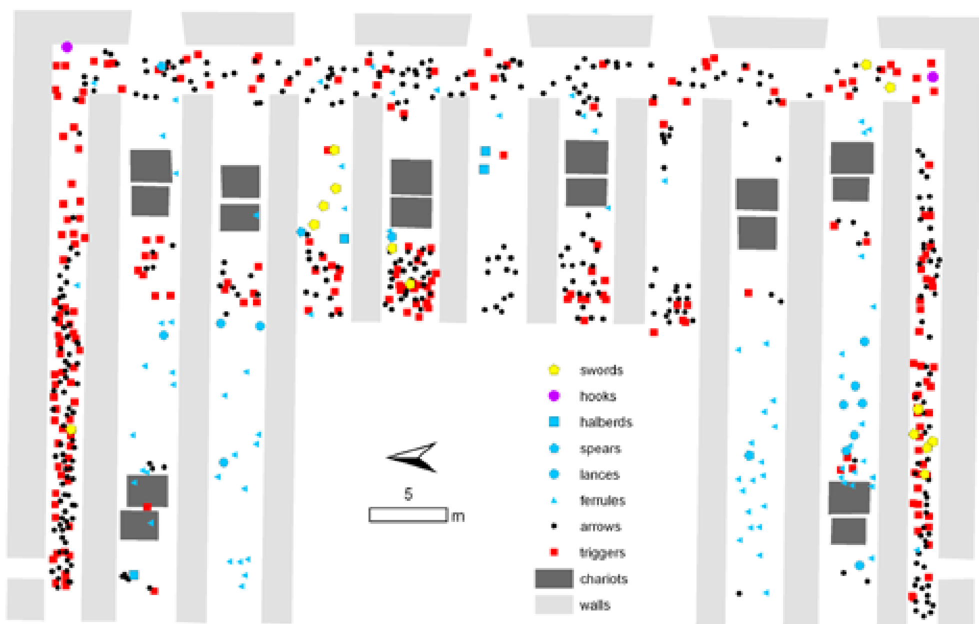

Fig. 5: Plan of the excavated area of Pit 1, showing the distribution of different weapon types.

ers or generals. Likewise, the distribution of arrowheads and crossbow triggers indicates that crossbowmen were placed primarily on the front, and along the flanks, of the battle formation, with chariots and warriors carrying other weapon types placed towards the core.

Our analysis, however, seeks to go beyond these superficial impressions and reveal less obvious patterns that may inform our understanding not just of battle formations, but also of how labour was organised to create such large numbers of weapons and to place them with the warriors in the pit. We will begin to illustrate our approach using the crossbow triggers as a case in point. Approximately 250 bronze triggers have been recovered so far – being the only non-perishable parts of the crossbows. Each of them is composed of three joining parts held together by two bolts (**Fig. 6**). From the outset, we expected to confirm a strong degree of control over production quality and standardisation so as to ensure that different trigger parts fitted together accurately and hence that the arrow release-mechanism functioned properly. Indeed, all the triggers appear visually to be very similar to each other. Under more detailed scrutiny, however, it is possible to distinguish subtly,

Fig. 6: A bronze crossbow trigger.

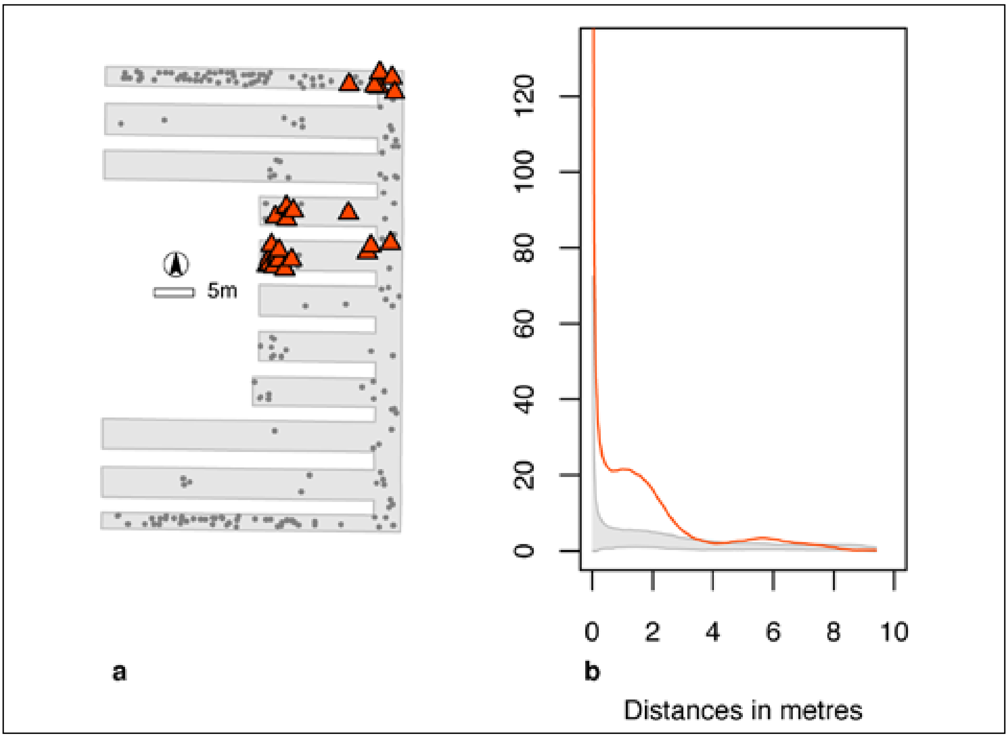

Fig. 7: Plots of (a) the spatial distribution of one of the subgroups of triggers, showing a clustering in the north-west of the pit, and (b) a statistical treatment of this evidence that formally confirms this pattern and the 4–6m radius zones over which it most obviously operates.

Fig. 8: A handful of the 40,000 bronze arrows so far recovered from the Terracotta Army.

Fig. 9: Analysis of bronze weapons using a portable XRF.

but undeniably different trigger subgroups. A careful metrical and typological analysis reveals small differences in either the shape or dimensions of different parts of the triggers which suggest the existence of different casting moulds, different metallurgical workshops and/or different organisational practices. If we select one of these trigger subgroups and examine its distribution on the site plan, it can immediately be seen that these artefacts cluster in the north-east corner of the pit (**Fig. 7a**). In this particular example, the clustered spatial pattern is fairly obvious without further testing, but other more subtle cases require more careful statistical treatment. In fact, consideration of the spatial patterns of minute variations in artefact style and technology, while controlling for the overall spatially non-random pattern of weapons in the pit, presents an analytical challenge that is rarely confronted as often as it should be in archaeology. Such a challenge allows us to deploy and further develop some innovative spatial analytical methods (e.g. **Fig. 7b**, based on 'multi-scalar' and 'inhomogeneous' point process modelling). The results, both in the intuitively obvious example shown in **Fig. 7a** and in trickier cases, confirm that these distributions of weapon subgroups are far from random and must reflect some real human behaviours. For example, the clustered patterns of trigger subgroups in the pit most likely reflect the combined outcome of different workshops producing marginally different crossbow triggers, the interim storage of weapons from these workshops (often in their original production groups) and, finally, the equipping in one event of certain zones of Pit 1 with these weapon batches. Taking this a step further, it is also possible that the clusters indicate that the pit was more formally divided into 'activity areas' which were assigned to different groups of workers, allowing them (and conceivably the different workshops or storage units that supplied them) to operate more or less independently and in parallel, while of course following an overall masterplan. Such a possibility is strengthened when we expand our coverage to other weapons and incorporate the results of chemical analyses.

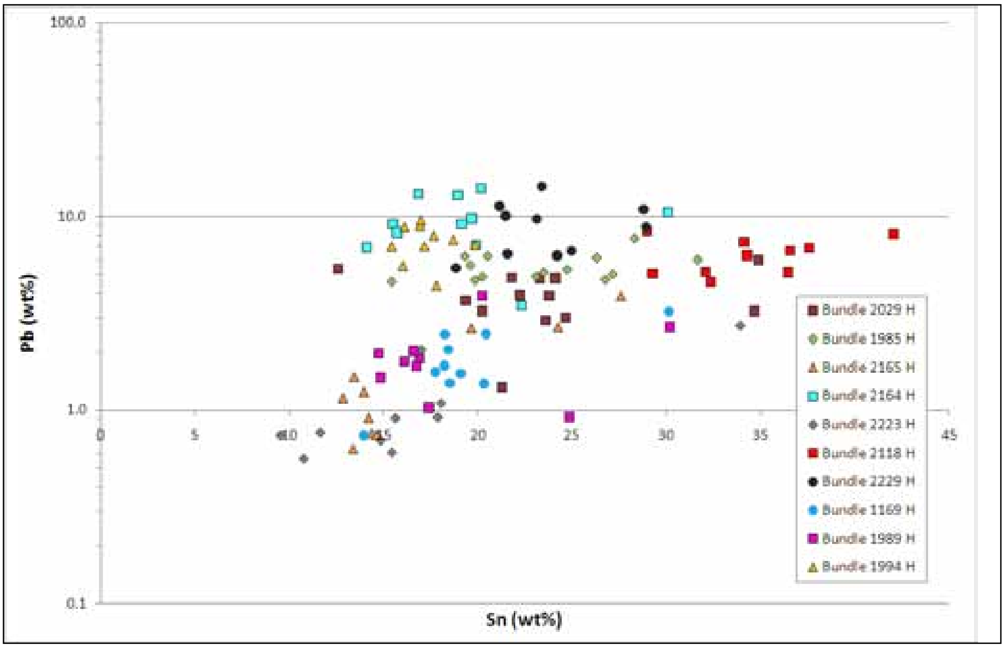

Fig. 10: Scatterplot of the composition of some arrowheads discriminated by bundle; note the clustering of each bundle denoting an individual metal batch.

Arrow bundles and chemical analyses

Arrowheads are by far the most abundant artefact type in the pit. They appear typically in bundles of 100 units which are thought to represent the contents of a single crossbowman's quiver. Each arrow was composed of (a) the triangular pyramid-shaped projectile point, and (b) a tang which assisted the point's snug insertion into (c) a bamboo or wood shaft, with a feather attached at the distal end. The metallic components of the arrow are the arrowhead proper and the tang, which are the parts invariably preserved (**Fig. 8**).

Such a large assemblage, produced over a short time span (and carefully recovered from a relatively closed archaeological context), provides an excellent opportunity for assessing issues of standardisation and craft organisation; however, our early efforts at identifying arrow subgroups through metric analyses proved frustrating. Approximately 1,600 individual arrowheads from across the site have been measured, and these demonstrate an extremely low coefficient of variation in the arrowheads' length and width (systematically lower than 4%). In other words, and assuming that our sample is representative, the arrowheads of the Terracotta Warriors are all almost visually identical to one another; subtle differences can only be revealed by using callipers – and these appear not to be systematic. The length of the tangs shows somewhat higher variability: two main modes were identified (one c.8cm, the other c.14cm), but these are not very tight and did not have a clear counterpart in the spatial distribution. The higher variability in tang length may be due to the fact that tangs would have been covered by the arrow shafts and, therefore, these differences would not have been noticeable in the end-product.

Considering the extreme standardisation of the arrowheads, it was necessary to resort to other means in order to identify subgroups that could inform us about production practices. In particular, we targeted a selection of arrow bundles and employed a portable X-ray Fluorescence Spectrometer, or 'XRF' (**Fig. 9**). This instrument allowed us to perform chemical analyses of a large number of artefacts, directly in the museum and without removing any samples (currently c.200 arrows and their respective tangs, measured separately). Given the analytical limitations of surface analyses of metal artefacts, the numerical results of such work can only be regarded as semi-quantitative, but they suffice to reveal interesting patterns, as discussed below.

The first interesting result of the chemical tests is clear evidence for alloy optimisation. Although the arrowheads and tangs are both made of bronze, the heads tend to have higher tin contents than the tangs, a pattern which can be explained as a result of a technical constraint. Bronzes with high-tin levels are hard and can produce very sharp blades – the ideal material property for an arrowhead; the downside is that high-tin alloys tend to be more brittle, and so the tangs, which were long and thin for insertion into a shaft, were made in a lower-tin (and hence tougher) bronze.

Of greater significance to our technological reconstructions were the clusters which were found when the chemical results were plotted discriminating the arrows by bundle; **Fig. 10** shows a plot of a representative selection of the dataset. All of the arrowheads are bronzes; however, it can be seen that (with some exceptions), the arrowheads in each bundle form a relatively tight cluster which is internally coherent and marginally different from the next. Our interpretation of this pattern is that each bundle represents an individual metal batch, probably cast from a single crucible. Similar pictures of the bundles' internal homogeneity are produced when the tang compositions are plotted. The fact that individual metal batches were preserved together – from the casting workshop to the army pit – is very meaningful in terms of the organisation of production. More precisely, we believe that this discovery indicates that the production of weapons for the pits was organised in semi-autonomous cells rather than as a single production-line.

Cellular production and quality control

In a typical production-line, one could envisage a specialised unit producing arrowheads more or less continuously, with another unit producing tang and another one producing bamboo shafts – and so on. These parts would then be joined in an assembly-unit, before being bundled, placed in a quiver and attached to a warrior. If this was the case, however, we should expect a mix-up of different metal batches as they went through the different stages of the production-line. In other words, we would not have the correspondence between arrow bundles and chemical clusters documented above. Conversely, the chemical clusters in the bundles indicate that, in all likelihood, the finished individual arrows and the 100-unit bundles were produced more or less immediately after the casting of a single batch. It is even possible that the same workshop was producing a complete quiver (if not a totally equipped warrior, although this is still a question for further research) and that several workshops were producing these in parallel.

As suggested above by the spatially-explicit study of the crossbow triggers, having different cells of workers functioning in parallel, and arranging the army in different 'activity areas', would allow for a much more efficient production: no overstock would be generated, breakdowns could be accommodated, and the multi-skilled, versatile work-units could be deployed on different tasks as the project developed. Such organisation of labour would require duplicating instrumental and skill resources, but it would be more adaptable to changes in the masterplan. It should not be forgotten that nothing comparable to the First Emperor's Mausoleum had ever been built in China before, and thus the need to ensure adaptability, while maintaining efficiency, must have been of the utmost concern. Alternatively, we can speculate that this arrangement of labour was not specifically designed for the Terracotta Army, but was normal for the production of weapons. In this case, cellular production would also

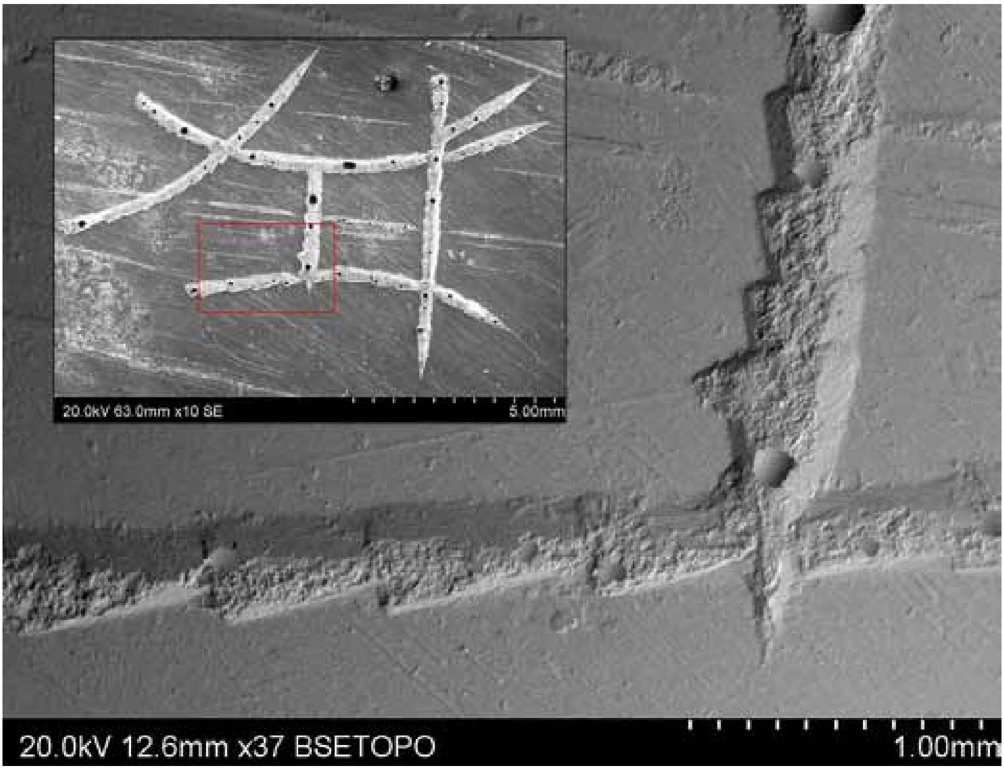

Fig. 11: SEM image showing of a detail of a character of an inscription on a weapon surface, showing the triangular chisel marks forming the lines, with (inset) SEM overview of the character; both images are from a silicone rubber impression so that they show a positive cast of the inscription, with protrusions representing depressions on the weapon itself.

be a useful solution, as the multi-skilled cells could more easily be moved with the real army to repair and produce arrows as needed.

If our suggestion of a cellular organisation of labour is correct, then those in charge of the operations must have faced another important challenge: how to make sure that standards were kept when there were various semi-autonomous units producing finished products at the same time? That they managed to keep those standards is obvious in the assemblage. How they managed is a different question, but one that can be approached by studying the inscriptions on many of the weapons belonging to the Terracotta Warriors.

Lances and halberds bear long sentence inscriptions, whereas swords, triggers, hooks and ferrules were only partially marked with numbers, a note of the workshop and/or other symbols. The long inscriptions on these weapons indicate the regnal year in which they were produced, the name of the person in charge of production, the official or workshop and the name of the specific worker who did the work. The shorter inscriptions, consisting of numbers and symbols, probably denote some form of quality control. In fact, up to four hierarchical levels of supervision can be reconstructed from the long inscriptions, ranging from the Prime Minister to a large number of individual workers.[4] Thus the combination of a de-centralised cellular production with a centralised supervision system, in charge of models, moulds and quality control, seems to be the main recipe – in terms of technology and human resources – behind the Emperor's mausoleum.

Further technical aspects

Whereas the major focus of our project concerns the standardisation and organisation of the labour force, our ongoing research efforts continue to reveal a myriad of technical details about the sophisticated technical knowledge of Qin metalworkers, as well as the skills of the individual workers. A particularly insightful aspect of our approach has involved the use of a dentist's toolkit to examine the surfaces of weapons.

As shown above, the inscriptions on the weapons can be read as texts that inform about workshop organisation, but the act of inscribing can also be studied from a technical perspective. In order to do this, we obtained precise moulds of the weapons' surfaces using vinyl polysiloxane impression material – the rubber employed by dentists to obtain crown, denture and bite registration impressions. Under the Scanning Electron Microscope (SEM), these rubber impressions clearly show how the different segments making up the characters are formed from the juxtaposition of overlapping marks, resulting in ragged edges. Each of these marks has an elongated triangular shape, indicating that the line was chiselled blow by blow, with a finely-pointed tool, ending on a wedge shaped like the letter 'V'. The overlapping of the marks indicates that the chisels were hammered into the bronze at an angle, starting from the bottom of the cone shape, i.e. the base of the triangle was the starting point of the cut, with the sharp end of the mark being the finishing point (**Fig. 11**). A comparison of these types of features, as recorded in various weapons, may lead to the identification of different tool types, and even of slight variations perhaps caused by different chiselling techniques – or craftspeople.

The same rubber impressions have allowed us to study in detail other aspects, such as the filing marks on the surfaces of the joining parts of the crossbow triggers. This careful filing was probably aimed at removing imperfections and excess metal from the surfaces in order to improve the functioning of the trigger; however, one of the most impressive technical discoveries made through the study of rubber impressions concerns the analysis of grinding and polishing marks. Not only bladed weapons, such as swords and lances, but also every single example of the arrowheads examined, have invariably displayed densely packed, extremely fine and perfectly parallel, grinding and polishing marks (**Fig. 12**). Such features are diagnostic of the use of rotary mechanical devices for the painstaking polishing that ensured the sheen and sharpness of the weapons. As such, this constitutes the earliest documentation of the systematic use of a rotary mechanical means for mass production. Besides the anecdotal value of this discovery, the polishing and sharpening demonstrates that these weapons were not funerary models, but lethal armaments, ready for use.

Fig. 12: A bronze lance from the Terracotta Army, with (inset) SEM image of a silicon rubber impression taken on a lance blade, showing the fine polishing marks; their density and parallel arrangement denote the use of a rotary mechanical device.

Conclusion

Ongoing collaborative work between staff and students at the UCL Institute of Archaeology and the Emperor Qin Shihuang's Terracotta Army Museum is revealing a wealth of information about the technical skill and the logistics of labour organisation behind the construction of the Terracotta Army. The results indicate that production was organised in multi-skilled cells that worked under centralised supervision, with well-defined models, moulds and quality-control procedures, which ensured extremely high degrees of efficiency and standardisation. The huge range of specialised skills and vast amounts of labour orchestrated to produce the bronze weapons cannot be overstated. Furthermore, one should not forget that these weapons are but relatively inconspicuous components of the Terracotta Army and, moreover, that the army itself is only a satellite construction within a much larger mausoleum complex.

The integration of fieldwork with artefact studies, which amalgamate typological, metric, material and spatial analyses, is proving challenging but also highly rewarding. While research on the weapons continues, the project is now expanding in several directions – and we are planning to expand our coverage to analyse the warriors themselves. We also hope to contextualise our work more widely within the archaeology both of the site and of the broader region, seeking to understand better the provision of raw materials and the management of both natural and artificial resources. It took fewer than four decades to construct the First Emperor's Mausoleum, but there is no doubt that this iconic site will continue to raise questions for generations to come.

Acknowledgements

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Notes and references

1 A good introduction in English to the First Emperor's Mausoleum can be found in J. Portal (ed.) (2007), *The First Emperor: China's Terracotta Army,* London: British Museum.

2 Many aspects of the metric and spatial analyses are reported in detail in Xiuzhen Janice Li's forthcoming PhD thesis, 'Standardisation and Labour Organisation in the Bronze Weapons of the Qin Terracotta Warriors, China', in progress at the UCL Institute of Archaeology.

3 Details of the excavation and the initial artefact studies are included in the *Excavation Report from Pit 1 of the Terracotta Warriors and Horses (1974-1984)* by the Shaanxi Institute of Archaeology and the Excavation Team of the Terracotta Army (Beijing: Culture Relic Press, 1988), as well as in subsequent reports by the same team. 陕西省考古研究 所始皇陵秦俑考古发掘队:"秦始皇陵兵马俑坑一号坑发掘报告(1974-1984)", 文物出版社, 1988版。

4 For further details on the study of the inscriptions, including the technical aspects discussed in the next section, see X.J. Li, M. Martinón-Torres, N.D. Meeks, Y. Xia and K. Zhao (2011), 'Inscriptions, filing, grinding and polishing marks on the bronze weapons from the Qin Terracotta Army in China', *Journal of Archaeological Science* 38, 492–501, DOI: http://dx.doi.org/10.1016/j.jas.2010.09.012.