Crossbows and imperial craft organisation: the bronze triggers of China's Terracotta Army

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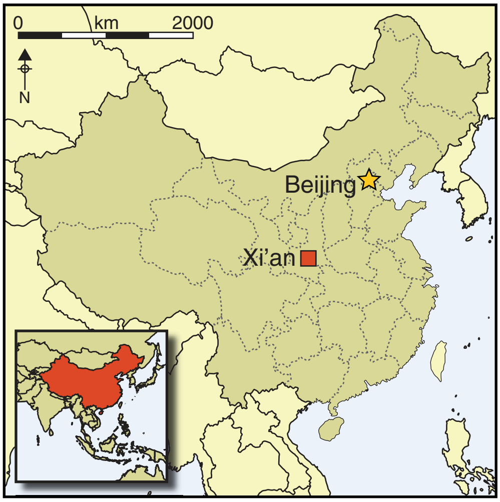

The Terracotta Army that protected the tomb of the Chinese emperor Qin Shihuang offers an evocative image of the power and organisation of the Qin armies who unified China through conquest in the third century BC. It also provides evidence for the craft production and administrative control that underpinned the Qin state. Bronze trigger mechanisms are all that remain of crossbows that once equipped certain kinds of warrior in the Terracotta Army. A metrical and spatial analysis of these triggers reveals that they were produced in batches and that these separate batches were thereafter possibly stored in an arsenal, but eventually were transported to the mausoleum to equip groups of terracotta crossbowmen in individual sectors of Pit 1. The trigger evidence for large-scale and highly organised production parallels that also documented for the manufacture of the bronze-tipped arrows and proposed for the terracotta figures themselves.

Keywords: China, Xi'an, third century BC, Qin period, Terracotta Army, standardisation, logistics, technology, spatial analysis

Introduction

Since their rediscovery by Chinese archaeologists in the 1970s, the tomb complex containing the Qin terracotta warriors of Xi'an has become one of the world's most impressive archaeological sites. An army many thousand strong, the ceramic warriors were originally equipped with fully functional bronze weapons and were stationed at the eastern end of the mausoleum of China's first emperor, Qin Shihuangdi (Figure 1) (259–210 BC) (SIAATQ 1988; Yuan 1990, 2002; Wang 1994; Ledderose 2000; Portal 2007; Duan 2011). To date,

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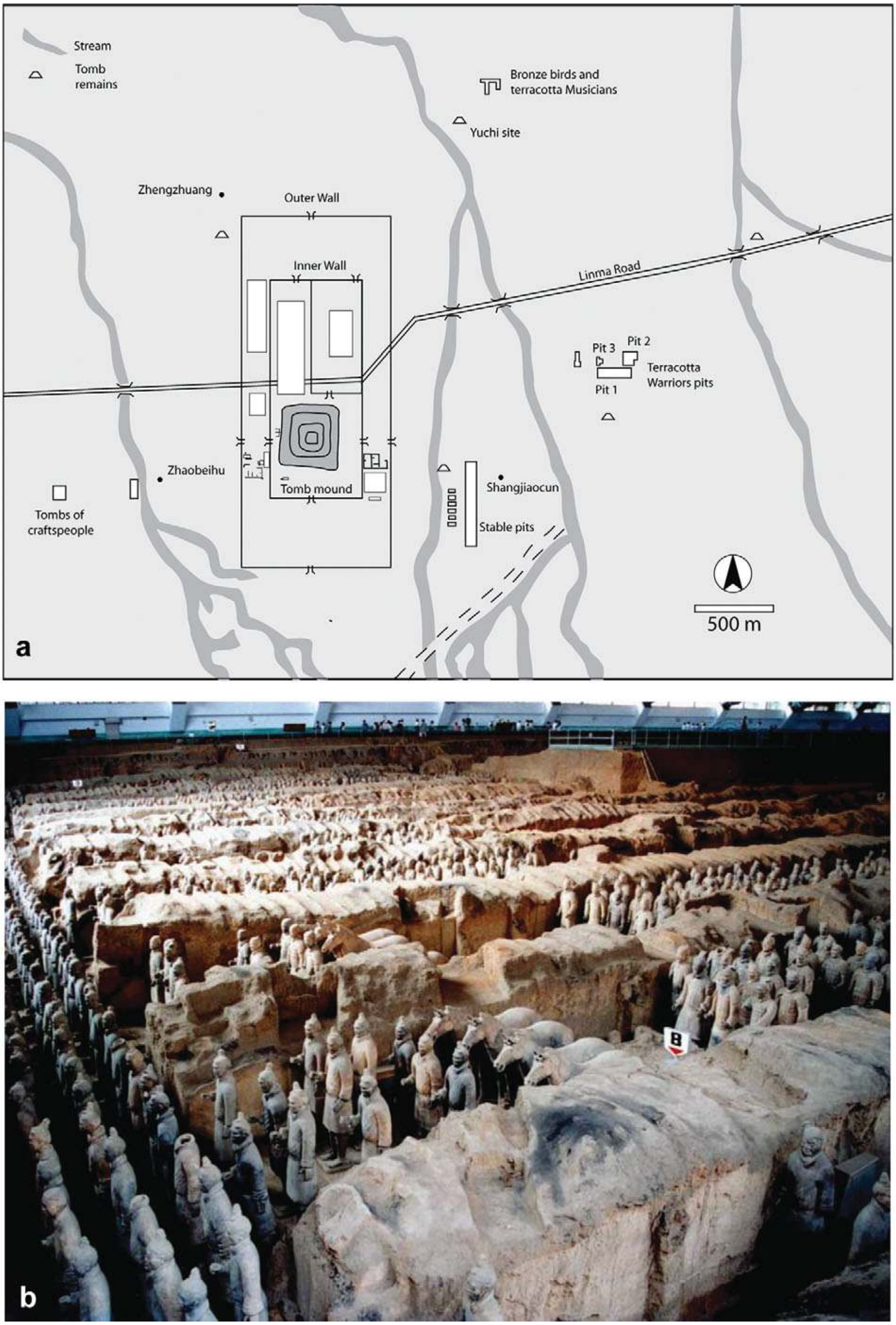

Figure 1. a) Plan of the mausoleum complex, with the imperial tomb towards the centre and the Terracotta Army pits (including Pit 1) to the east; b) view looking south over warriors in Pit 1 (image courtesy of Xia Juxian).

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more than 40 000 arrowheads and several hundred other bronze weapons have been found associated with the warriors in three different pits within the tomb complex. Only parts of these weapons have survived to the present day, but this remarkable assemblage includes crossbow triggers, sword blades, lance tips, spearheads, dagger-axe blades and halberds, as well as a few ceremonial weapons (Qin & Zhang 1983; Yuan 1984; Liu 1986; SIAATQ 1988; Huang 1990; MEQSTA 2008). The arrangement of the weapons in the pits reflects prevailing Qin battle formations and military strategies, and these have been widely discussed in the existing literature, both in Chinese and English (Yuan & Qin 1975; Wang 1980, 1983, 1990; Yuan 1990, 2002; Yates 2007). Far less has been said about what the bronze weapons might tell us about craft standardisation, workshop organisation or the logistics of this monumental funerary project (Yuan *et al.* 1981). One particular challenge our research faces is that no production remains have been found, and hence our reconstruction of production organisation has to be based on the reverse engineering of finished items in their depositional contexts. The present study focuses on the most extensively explored of the Terracotta Army pits (Pit 1) and on one particularly intriguing component: the multi-part triggers that were key devices behind China's early development of crossbow technology. Detailed typological and metrical characterisation of these artefacts combined with spatial analysis allows us to reconstruct possible workshop practices, storage behaviours and the logistical feat that placed these artefacts in their final positions beside the warriors.

If historical records from later periods are to be believed, the construction of the First Emperor's mausoleum was commissioned as soon as he became ruler of the Qin state in 246 BC. Construction took about 40 years and involved 700 000 labourers, who were conscripted to the Qin capital. It is likely that many of the items in the pit were produced specifically for the mausoleum: not only the terracotta warriors themselves, but the ceramic acrobats, officials, musicians and horse keepers, the bronze chariots and birds, as well as the stone armour (SIAMEQSTA 1998, 2000, 2006, 2007; Yuan 2002).

For the bronze weapons, several options should be considered: a) they could have been commissioned specifically for the Terracotta Army; b) they could have been made in one or more weapon-making facilities following ordinary practice for the supply of real armies; or c) they could have been removed from circulation in order to be deposited in the tomb, perhaps after a period of use. In any of these cases, the weapons may or may not have spent some time in storage prior to being transported to the tomb complex and being placed alongside the warriors.

The style of the triggers and other weapons is different from contemporary examples found in other parts of China, but comparable to those at other Qin sites (Yang 1980: 206–17). In addition, the 'regnal years' inscribed on a small handful of the weapons predate the ascent of Qin Shihuangdi to the imperial throne (Yuan 1984; SIAATQ 1988: 251; Li *et al.* 2011). However, most of the weapons, including the triggers, are not dated, and they could conceivably have been made later (see below). Our study of filing and other tool marks on the trigger surfaces showed no obvious wear marks (Li *et al.* 2011, 2012). The inscriptions on some of the triggers included the character *gong* (工), probably related to *sigong* (寺工) or 'government workshop' (Yuan 1984; Huang 1990; Jiang & Liu 2011: 248). Many others are uninscribed. We must also bear in mind the weapons' post-depositional life, given the evidence that the warrior pits were partially damaged by later human activities

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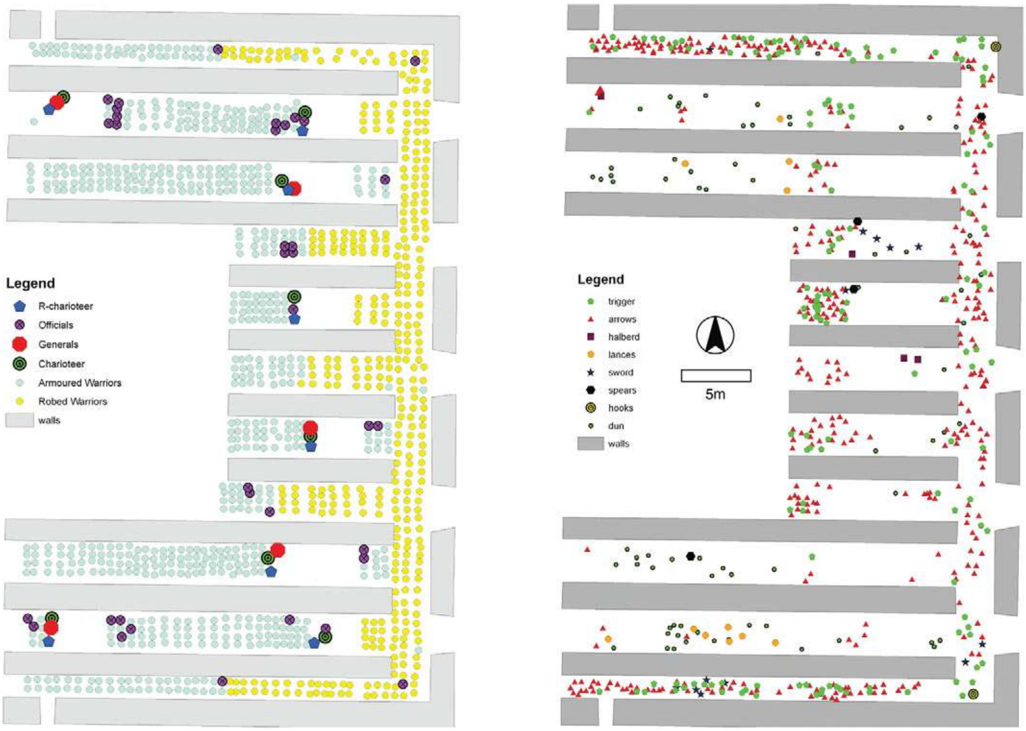

Figure 2. Plan of Pit 1 showing the spatial distribution of: left) warriors; and right) weapon types (including crossbow triggers).

such as burials, looting and agriculture. The challenge in the present study is to extract information about the structure, tempo and geography of some of these slowly unfolding activities, with a particular emphasis on craft standardisation, workshop organisation and the logistics of tomb construction.

Bronze crossbow triggers and the Qin Terracotta Army

Crossbows were complex technical artefacts, closely linked with the military advances of the emerging Qin Empire. The introduction of trigger-fired crossbows during the Warring States period (476–221 BC) revolutionised military warfare, as they required less skill and strength than a composite bow. Crossbows would have enabled soldiers to fire heavier arrows (i.e. bolts or quarrels) more accurately, with greater force and penetrating power, and over a longer distance (Yuan 1990: 256; Yates 2007: 42). In the pits of the Terracotta Army, the wooden and bamboo parts of the crossbows have perished after 2000 years, but fortunately the bronze triggers have largely survived in good condition (SIAATQ 1988: 280–96). The vast majority of these come from the extensive excavations in the easternmost area of Pit 1 (SIAATQ 1988: 10) (Figure 2). Some 216 triggers, considered in this paper, were discovered here, most lying with numerous arrows next to their crossbowmen in the front corridor or along the two side corridors. During the Qin period, armies consisted of chariots, cavalry, infantry and crossbowmen. As the above arrangement of crossbow triggers implies, the latter were normally placed in front or on the flanks of the force to enable them to fire the arrows over a long distance before the enemy could come close (Yuan 1990: 260; Yates 2007: 43). In addition, a few specialised crossbowmen were placed in the middle corridors, especially behind chariots.

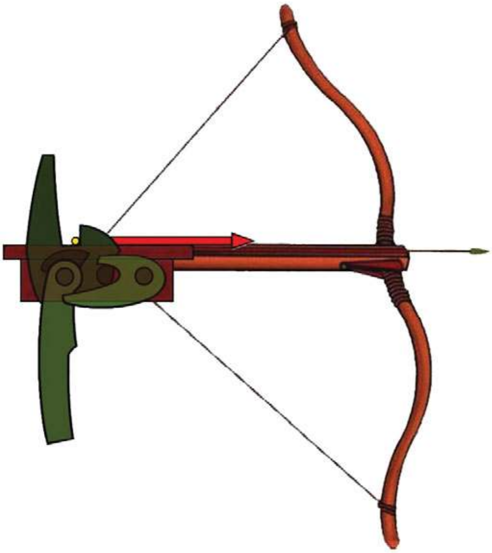

Figure 3. Diagram illustrating operation of the bronze trigger mechanism of a Qin crossbow (image courtesy of Zhao Zhen).

As complex devices made of several components, the bronze crossbow triggers should be particularly informative about the processes of standardisation and mass production employed in the making of Qin bronze weapons (Figure 3). A trigger was formed of three parts, held together by two bolts. They were designed and assembled in such a way that the string could be held in place and released effectively without the need for a spring. We shall refer to these parts as A, B, C, D and E. Part A, the trigger proper, is a handle. Part B, the tumbler, involves two functional elements: one end is used to catch the string of the crossbow, while the other extends upward as a 'regulator' or sighting pin. Part C, the rocking lever, was used to link parts A and B so that they could be manipulated effectively. Parts D and E are the bolts or transverse screws used to strengthen the crossbow stock and trigger. The trigger was made by casting each part separately in a mould, then filing the resulting parts down to remove unwanted rough edges, before finally assembling them as a trigger and inserting them into the wooden body of the crossbow (Williams 2008). Standardised morphology and dimensions were essential to allow the crossbow to work properly, and we should expect this concern to be reflected in the way workshops were organised.

Typology and measurements

One cased trigger (ID 5525), possibly dated to the Han Dynasty (206 BC–AD 220), was excluded from the study; its presence in Pit 1 remains to be explained (Yang 1980: 218). The rest of the triggers showed only minor differences in their shapes and styles, as was obvious from the outset, and from previous discussion (SIAATQ 1988: 293). Our first objective was therefore to combine macroscopic identification of these differences (where they were obvious) with precise measurements of three selected dimensions across each trigger part (to discover less obvious variability) and thereby classify the overall trigger assemblage into a series of sub-groups (Figure 4). Various multivariate methods were used to explore these typological and metrical observations, including hierarchical cluster analysis and principal components analysis (PCA). These different approaches all suggested very similar

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sub-groups, and so for clarity we only present the PCA plots below. The respective members of the sub-groups are identified by coloured data points in the PCA graphs; even if these groups are not always statistically clear-cut, their archaeological significance is supported by the correlations among specific sub-groups of the various parts assembled together, discussed later in this paper. The following sections discuss variability in parts A, B and C in turn, before considering how these parts were assembled.

Figure 4. Parts A–E of a crossbow trigger indicating the position of the measurements taken.

The metrical data for part A allow three main groups (Ag1–3) to be identified fairly easily both on a PCA plot (Figure 5a) and by eye in terms of the degree to which the part tapers along its length (Figure 5b).

Part B can be macroscopically divided into two types depending on whether or not they have a clearly defined notch (Figure 6b). The notch protrudes on the side that holds the string. Its function remains unexplained, but may be to do with different strategies for holding or releasing the string efficiently. Figure 6a plots the first two principal components of the metrical data, showing a further rough division into two groups, Bg1 and Bg2. Since these metrical groups do not match the macroscopic distinction between notched and un-notched parts, there is further subdivision into Bg1n, Bg1u, Bg2n and Bg2u, where n and u stand for notched and un-notched respectively.

Typology indicates that part C can be divided into curved and bevelled versions (Figure 7b). Thereafter, the first two principal components suggest three possible groups, one with a subset containing the bevelled examples (Figure 7a). This gives a total of four metrical groups: Cg1, Cg2, Cg3c and Cg3b, where c and b stand for the curved and bevelled versions respectively.

Understanding trigger-part groupings

Our overall interpretation of these results is that each trigger-part sub-group was made: (a) in the same casting mould, and/or (b) in nearly identical casting moulds based on the same parent model (e.g. the same prototype), and/or (c) from very similar moulds with a more complicated but linked workshop history. Even if a single parent model was used as a standard for producing several moulds for the trigger parts, the shrinkage of mould materials and the subsequent pouring of bronze and filing of the trigger parts by

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individual craftspeople would affect the degree of standardisation in the final product. To assess this within-group variability, a coefficient of variation (CV) was calculated for each set of individual measurements (Table 1). The results for trigger parts A, B and C all fall within the 0.6–6.3 per cent range, which indicates relatively high standardisation when compared to what we might expect cross-culturally and theoretically (i.e. with reference to the Weber fraction; see Eerkens & Bettinger 2001; Eerkens & Lipo 2005). It should be noted that the above analyses identify the minimum number of sub-groups in the assemblage; it is quite possible that more moulds existed but cannot be discerned metrically, given their similarities. For example, the lengths for group Ag2 range from 76 to 83mm, and it is quite likely that more than one mould is represented here. Furthermore, although we have assumed discrete groups for the purposes of this study, the triggers may exhibit a continuum of variation as a result of gradual drift in their parent models and moulds.

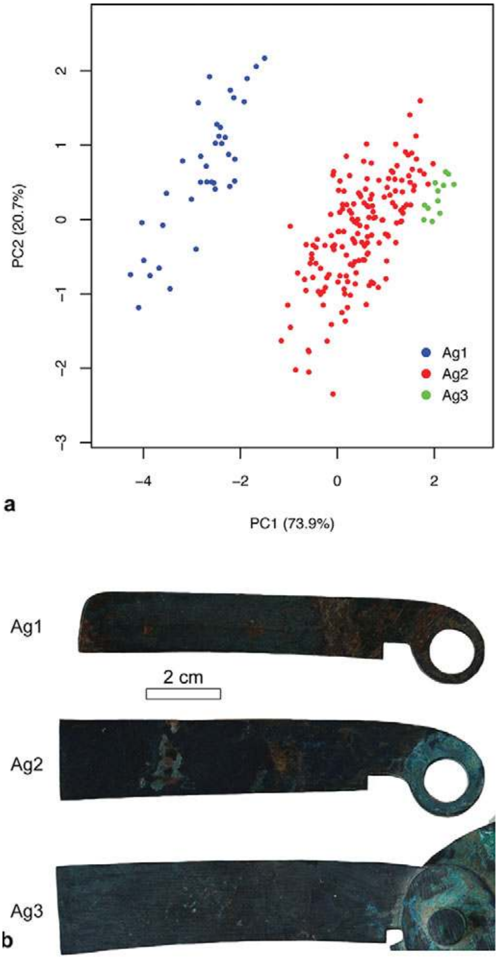

Figure 5. a) Plot of the first two principal components of all parts A from Pit 1 revealing three groups: Ag1, Ag2 and Ag3; b) typological variation of trigger part A.

It is difficult to know what the typical turnover was in models and moulds. The trigger groups from the same models and moulds should, however, be linked with single production events (at intervals that cannot be established) or manufacturing units in the workshop. From the information presently available, changes in model and mould could also relate to different phases of production. The production dates inscribed on lances and halberds from the pits make it clear that they were made between 244 BC and 228 BC, after the future Emperor Qin Shihuang became ruler of the Qin state in 246 BC, but before he unified China in 221 BC (SIAATQ 1988: 265; Yuan 1990, 2002; Li *et al.* 2011). Emperor Qin Shihuang died in 210 BC and the bulk of the extensive construction of his tomb complex has been argued to have been carried out within 10 years of the unification (Yuan 2002: 12; Duan 2011: 56–58). It is not clear whether the triggers were produced at the same time as the halberds and lances or somewhat later, but their production may likewise have extended over several years, given the numbers and variability involved.

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Trigger assembly and labour organisation

How were parts A, B and C assembled into a working trigger? If production was organised in a flow-line model (i.e. a large production unit with strong division of labour around a single assembly line; Groover 2010), we might expect each part to be cast in large batches by separate units of craftspeople. The parts would be assembled at a later stage of the flow line, perhaps by another set of workers. In this case, trigger parts cast in different batches would be mixed together in the final trigger assembly. Conversely, in a batch or cellular production model (Bagley 1995; Li 2006; Groover 2010) a single set of craftspeople would both cast and assemble all the required parts, possibly including the non-metallic components of the crossbow. Thus a single production unit could cast a relatively small number of parts A, B and C, and assemble them before moving on to produce the next batch. Such a production model would result in more homogenous and concentrated patterns in assembled trigger part groups.

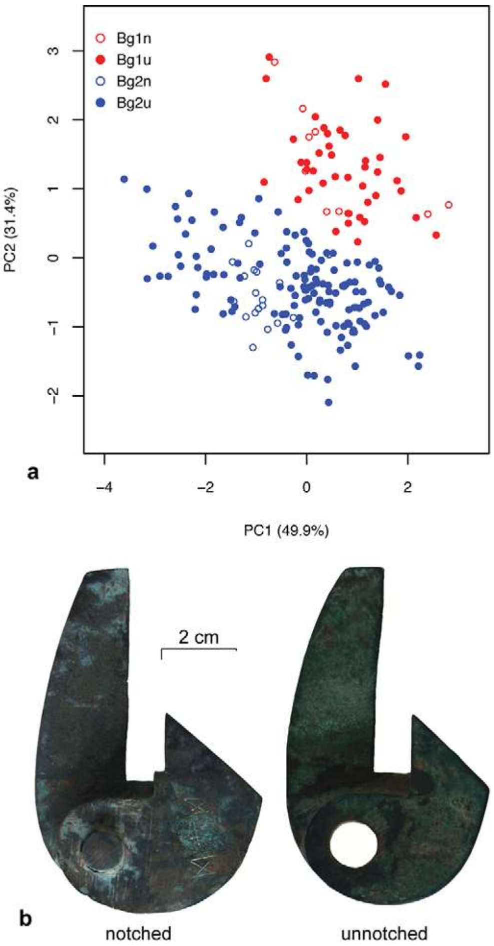

Figure 6. a) Plot of the first two principal components of all parts B from Pit 1. The green dots show the notched and the blue dots the un-notched examples; b) typological variation of trigger part B.

Our search for associations between trigger parts A, B and C belonging to the different sub-groups identified above revealed a surprisingly limited range of combinations (Table 1). Out of 48 possible combinations (3 × 4 × 4 sub-groups of each part), only eight appear consistently repeated (assembly groups 1–8), plus a few mixed-batch groups each represented by only one or two triggers (assembly groups 9–14).

The limited degree of part mixing outside those eight combinations is strongly indicative of a batch or cellular production model, whereby a production unit or cell would cast and assemble a small number of all the required parts before proceeding to manufacture and assemble the next batch. It has been proposed that the trigger parts were cast in so-called 'stack moulds', i.e. multi-layered moulds containing several impressions of the same part (Williams 2008). If so, it is possible that, after casting a 'stack' of each of the required parts, weapon makers would proceed immediately to assemble them. The morphological differences between the sub-groups of trigger parts would relate to the different production units or

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cells, each relatively autonomous albeit working under shared standards and supervisory structures.

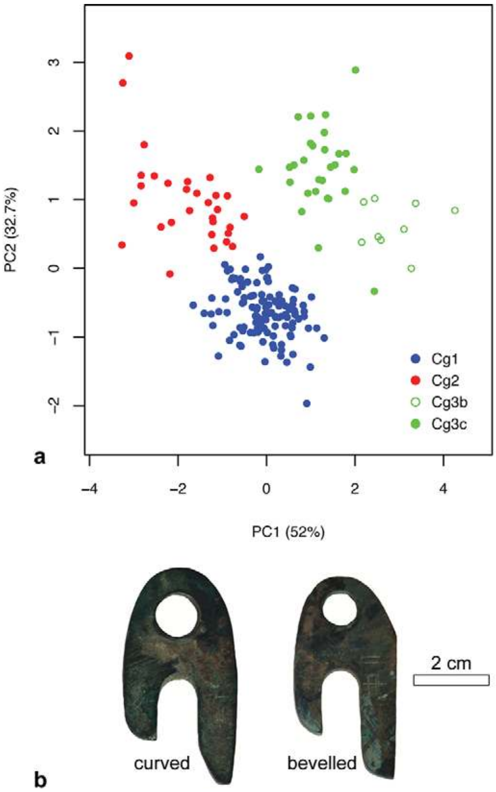

Figure 7. a) Plot of the first two principal components of measurements from trigger part C, revealing three groups; b) typological variation of trigger part C.

It is difficult to know whether all the various parts were totally interchangeable regardless of sub-group, e.g. whether a specific Ag3 sub-type of part A could be fitted to any sub-type of part B without compromising performance. The meticulous filing of excess metal on the various parts (Li *et al.* 2011), together with the symbols often inscribed in several parts of the same assembled trigger (Li & Gao 2010), perhaps to guide assembly, indicate that this was probably not the case. Working in small, carefully controlled batches and assembling the weapons in the same production unit before producing the next batch would minimise the risk of mismatches.

Although their diversity and complexity warrants further attention, an initial exploration of the marks inscribed on 70 per cent of the triggers (n = 160) corroborates these morphological groupings. Occasional traces of ink suggest that more inscriptions may originally have been present. Engraved marks include a wide range of individual symbols, characters and numbers which are probably related to assembly (and possibly quality control), as they are often repeated on more than one component of the same trigger (Li *et al.* 2011). In some cases there is a broad correspondence between the assembly groups and the types of inscriptions: for example, assembly groups 1 and 2 show no inscriptions; three stem-branch characters (酉丙卯) are found only on parts B of assembly group 4; the character *gong* (工) appears predominantly in group 6 (15 cases), with only two exceptions appearing in assembly group 3 (which is very similar in its component parts). As noted earlier, the character *gong* is of special interest as it may denote the involvement of a government workshop or *sigong*, but we lack direct evidence to clarify the organisational or chronological relationships between this and other potential workshops producing the other triggers.

Previous research suggests that similar workshop cells were also responsible for the production of the terracotta warriors themselves, which we can assume beyond reasonable doubt were produced specifically for the mausoleum (Yuan 1990: 352–65; Ledderose 2000: 50–73; Yuan & Liu 2009: 6–24). Names of at least 92 different potters were found

Table 1. Averages (in mm) and coefficients of variation (CV, in %) for the several dimensions in each sub-group of trigger parts A, B and C.

		A1		A2		A3	
Part A group	n =	Mean	CV	Mean	CV	Mean	CV
Ag1	37	78.5	2.3	15.6	3.5	15.8	2.7
Ag2	167	79.9	1.8	20.9	2.5	18.9	4.4
Ag3	12	81.9	0.6	22.5	1.0	20.2	0.9
		B1		B2		B3	
Part B group	n =	Mean	CV	Mean	CV	Mean	CV
Bg1n	9	82.8	2.7	50.9	3.1	16.0	5.0
Bg1u	43	82.8	2.1	50.3	3.4	16.0	6.3
Bg2n	19	82.2	1.4	53.4	1.8	19.3	3.5
Bg2u	145	82.4	2.3	51.2	5.0	19.1	4.9
		C1		C2		C3	
Part C group	n =	Mean	CV	Mean	CV	Mean	CV
Cg1	132	58.7	2.1	29.2	4.9	25.8	3.0
Cg2	36	63.2	3.5	31.2	3.9	25.3	3.8
Cg3b	18	56.5	1.4	25.5	6.0	21.7	3.4
Cg3c	30	60.0	1.6	27.5	3.6	22.1	5.0

Table 2. Trigger assembly groups and their constituent parts.

Assembly group	Assembly	n =
1	Ag1-Bg1n-Cg2	7
2	Ag1-Bg1u-Cg2	23
3	Ag2-Bg1u-Cg1	4
4	Ag2-Bg1u-Cg3c	13
5	Ag2-Bg2n-Cg3b	18
6	Ag2-Bg2u-Cg1	126
7	Ag3-Bg2u-Cg3c	11
8	Ag2-Bg2u-Cg3c	6
9	Ag1-Bg1n-Cg3c	1
10	Ag1-Bg1u-Cg1	1
11	Ag1-Bg1n-Cg1	1
12	Ag1-Bg2u-Cg2	2
13	Ag2-Bg2u-Cg2	2
14	Ag1-Bg2n-Cg2	1

marked on the back of some 1000 terracotta warriors, and each of these individuals probably supervised several apprentices. It is possible to identify different styles and characteristics in the figures that were created by different artisans. Many of the more robust-looking figures, for example, bore the names of artisans from the Qin capital Xianyang, while others were slimmer in build and had different marks (Yuan & Liu 2009: 22).

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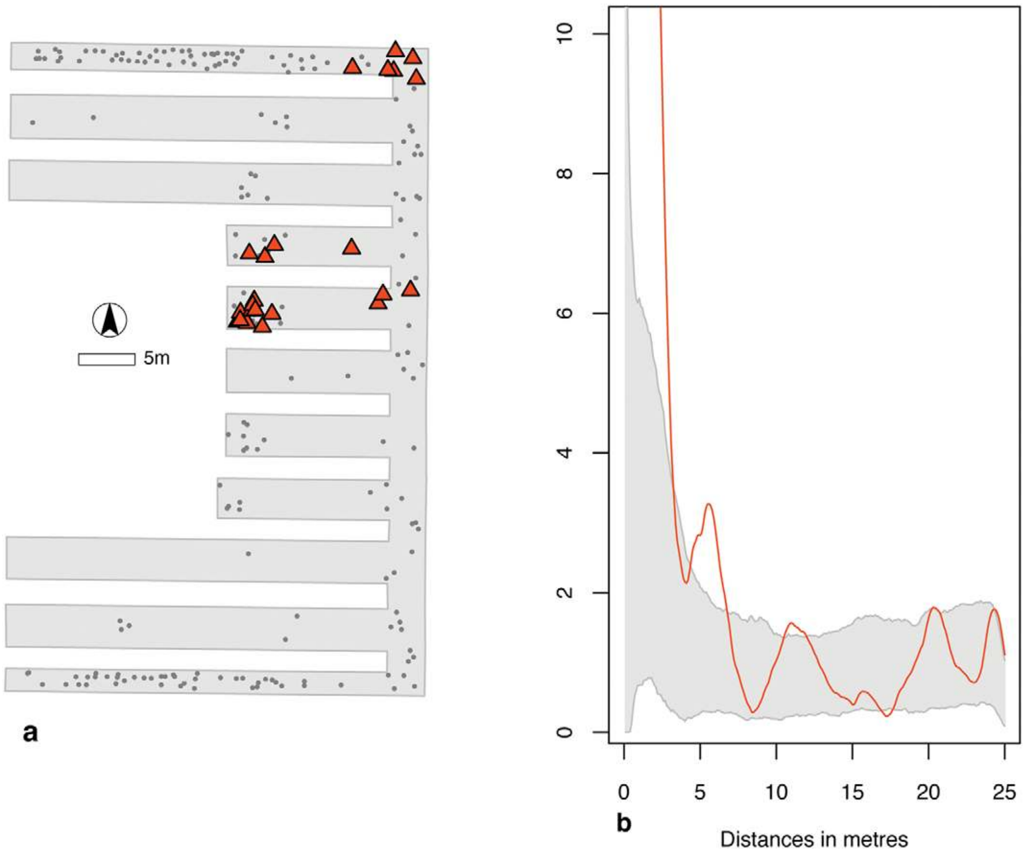

Figure 8. a) Spatial distribution of assembly group 2 triggers (combining parts Ag1-Bg1u-Cg2), shown as triangles, within the five easternmost trenches of Pit 1 in relation to all other triggers (grey dots); b) pairwise correlation of this group (red line) compared with a 95% critical envelope produced by random Monte Carlo simulations.

Cellular production is also suggested by study of the arrowheads from the Terracotta Army (Martinón-Torres *et al.* 2012). The extremely high degree of standardisation made it impossible to identify typological or metrical groups, but chemical analyses showed that the arrows in each of the 100-arrow bundles form a specific chemical group, most likely an individual batch deriving from a single crucible load (for chemical batches see also Freestone *et al.* 2009a & b, 2010). The low incidence of batch mixing between different bundles indicates that each unit would produce all of the components and assemble them as a finished bundle of arrows before moving on to produce the next.

The cellular production of weapons in batches leads us to ask whether the same cells would have had the versatility to produce the different categories of weapons present in the assemblage (for example, both triggers and arrows), and indeed whether they also manufactured the non-metallic components of these weapons (e.g. the crossbow frames or the arrow shafts). Logistical arguments and the available evidence (Martinón-Torres *et al.* 2012) suggest that both hypotheses are likely to be true. The spatial analyses presented below add weight to that possibility.

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Spatial analysis and logistical activities

We have established that well-defined batches of triggers were produced by different groups of craftspeople and/or at different times. After manufacture and assembly, each batch or group of triggers might have been stored in a specific place in a warehouse or dedicated arsenal. Alternatively, they could have been delivered directly to the Terracotta Army without any significant interim storage. The spatial distribution of triggers in Pit 1 is affected first and foremost by the position of crossbowmen in the battle order of the army. Above and beyond this pattern, however, the spatial distribution of a given trigger assembly group can inform about the organisational processes which governed the placement of the crossbows in the pit. For example, if this distribution proved to be regular (i.e. uniformly spaced) across those limited zones where triggers of any kind were found, then this might reflect a form of intentional arrangement by the workers. In contrast, if a given weapon assembly group proved to be spatially clustered in the pit, we might consider a number of possible causal factors, but the transportation and placement of a discrete production batch in one go into the pit is a likely explanation. In contrast, a random spatial distribution for a trigger assembly group can be treated as the statistical null hypothesis, indicating that no specific constraints dictated the particular location of each trigger in the pit. More precisely, it might suggest the mixing up of different batches of weapons in storage before they ended up in the pit.

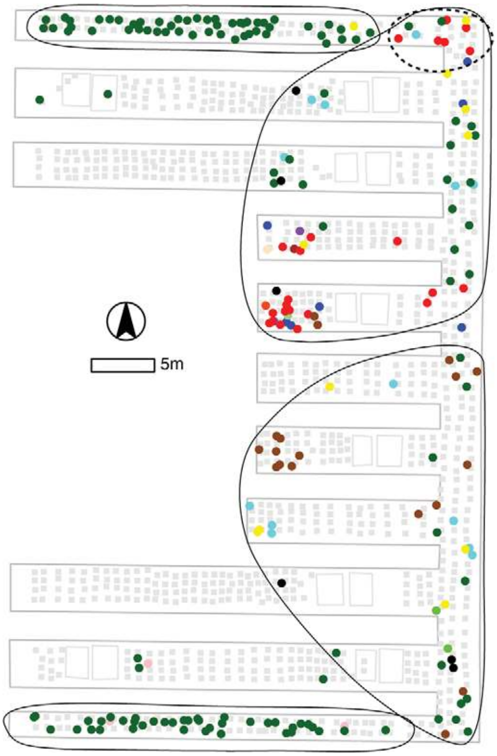

Figure 9. Spatial distribution of trigger assembly groups indicating both small-scale clusters of similar triggers (one example circled with a dotted line) and larger activity areas (circled in solid lines). The terracotta warriors are shown as light grey squares and chariots as grey-outlined boxes.

The spatial patterning was explored by a pair correlation function (PCF; Illian *et al.* 2008: 218–23; for archaeological examples, see Orton 2004; Bevan *et al.* 2013) which measures patterns of clustering or segregation over multiple distances and evaluates the significance of these patterns via Monte Carlo simulation (see Robert & Casella 2004). Figure 8 shows the application of this approach to the distribution of assembly group 2 (Ag1-Bg1u-Cg2), in the fully excavated section of Pit 1 (SIAATQ 1988: 10). The analysis reveals that assembly group 2 is strongly clustered at almost all separation distances up to about 7m and occasionally so thereafter. This suggests both very localised clustering of a few very similar triggers, and some wider grouping as well.

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Consideration of other trigger assembly groups using the same methods produces similar results. The localised clusters (Figure 9) probably result from some combination of workshop production and interim storage and transportation methods. Similar triggers may well have been cast using the same mould (or conceivably even in the same batch) by one group of craftspeople, attached to crossbow frames, and stored together in a Qin arsenal before being transported to the pit together. At a larger scale, the overall distribution of the various assembly groups across the pit also allows the identification of what may be broad 'activity areas' (Figure 9), revealing how the equipping of the warriors in the pit was organised both spatially and chronologically.

Interestingly, the easternmost activity areas show much more trigger group diversity than those in the northern and southernmost corridors. The latter two areas contain all of the '*gong*' inscriptions: this may imply that the artisans from that workshop had a greater output capacity, and we may recall that the '*gong*' inscriptions suggest production in a central government workshop. For the other activity areas, several cells may have had to work in unison to produce all the triggers required in a short time so that the construction of the army could proceed, resulting in a lower level of overall standardisation. Alternatively, these areas may reflect slightly different chronological phases in the laying out of the pit.

Conclusion

The model of imperial craft organisation we have inferred from the trigger data is consistent with that obtained from the analysis of the arrows and suggested for the terracotta warriors. Having several versatile cells, possibly functioning in parallel, to produce weapons and equip various sectors of the pit would require a multiplication of tools and skills, as well as a strong supervisory structure to ensure comparable standards—especially if a central government '*gong*' worked in parallel with other production cells. This model, however, would offer greater logistical adaptability and accommodate potential breakdowns or changes in any masterplan. Overall, it is fair to say that the organisation of production in Pit 1 offers a view in microcosm of wider patterns of close political and economic control in the Qin Empire.

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