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Identifying forming techniques in Knossian Bronze Age pottery: the potential of X-radiography*

In 2006, a collaborative project was initiated by the two authors to investigate the manufacturing technique of several Bronze Age vessels from Knossos, Crete, held in the British Museum collection by means of X-radiographic analysis. The purpose of this project was two-fold: firstly, to establish whether Cretan fabrics were in principal suitable for X-radiographic analysis and, secondly, to provide comparative data to existing macroscopic and thin-section results about forming techniques.

Radiography

Put simply, X-radiography uses X-rays to ‘look through’ objects. X-rays are a type of electromagnetic radiation which can penetrate objects in inverse proportion to the atomic density and thickness of...
the materials of which they are made. The outgoing radiation is then captured as a greyscale image either in hard copy (usually on photographic film) or digitally on a suitable monitor. Results can be modified by adjusting a wide range of variables, including type of film, strength of the current, tube voltage, exposure time, and positioning of the object as well as the addition of filters or screens. Once produced, the resultant image can then be scrutinized under a strong light and archived. If not captured directly in digital format, rapid digitisation and subsequent archival storage of radiographs is possible through a variety of methods, with bespoke radiographic scanners being the ideal. Once digitised, advanced filters and edge detection kernels available for imaging software programmes can be applied to make even small details clearly visible.

The application of radiography to cultural materials
Following Wilhelm Röntgen’s discovery of X-rays in 1895, a whole new way for people to ‘look through things’ (Röntgen 1896) opened up. While the first published images demonstrated the technique’s potential for medical uses, X-rays of Peruvian and Egyptian mummies soon established its potential also for archaeological applications. However, it was only in the 1930s that archaeologists began to employ X-radiography for artifacts other than human or animal remains. Since then, the technique has become a tried and tested tool for the investigation of paintings, metals, ceramics, textiles, stone and paper objects as well as geoarchaeological applications to soils and sediments (see Lang – Middleton 2005 for a useful summary). Among the most common uses of X-radiography of cultural materials are the identification of: 1) the object and its condition; 2) manufacturing method(s); 3) joins, faults, breaks, repairs and reuse; and 4) finishing methods and decoration. In conjunction with supplementary information, it can also provide information about materials and forgeries. Given its range of applications, X-radiography has become a particularly valued tool among museum and gallery conservators (Gilardoni 1994; Graham – Eddie 1985; Lang – Middleton 2005).
Other radiological techniques, such as neutron radiography, stereoradiography, computer-assisted tomography (CAT) and microfocus radiography are now also in regular use in the study of cultural heritage (Halmshaw 1995; Vandiver et al. 1991; Lang et al. 2005) and more advanced equipment such as the highly focused ionizing radiation beams produced by synchrotrons are being drawn in to use as they become available.

Ceramics and radiography
The earliest application of X-radiography to ceramics dates back to 1935 when Titterington published a radiograph of seven sherds from North American Indian burials in order to illustrate differential proportions of inclusions. A decade later, Digby employed the technique to investigate a defect in the construction of a Peruvian stirrup-handled pot (1948). However, it was only in 1977, with the publication of a seminal paper by Rye, that the potential of X-radiography for ceramics was fully appreciated (see also Rye 1981). However, the demise of xeroradiography in the late 1990 led to a noticeable interruption in research activity. It is only now, with a better appreciation of the power of imaging software programmes, that X-radiographic research into ceramics is gaining momentum again (Bowman – Ambers – Maclean 2002; O’Connor – Maher 2001; O’Connor – Maher – Janaway 2002). Characterisation of clay fabrics through inclusion or tempers and identification of manufacturing details continue to remain the two key research topics (Carr 1990).

For this collaborative project, it is X-radiography’s potential to identify the primary forming method — more specifically, pinching, drawing, coil-building, slab-building, moulding and wheelthrowing — that is of the greatest importance. It was Rye who first recognised that “the application of pressure to plastic clay causes mineral particles, voids and organic fragments to take up a preferred orientation” which will affect the whole clay body. The resulting alignment and distribution of inclusions, as well as shape and orientation of voids is characteristic of each forming method and will not normally
be obliterated by secondary forming or decoration procedures (Rye 1977: 206; Berg 2008).

Radiographic case studies applied to Greek Bronze Age ceramics
So far, radiographic techniques have not been widely employed in Aegean pottery studies. Analysis of East Cretan Dark-on-White Ware and LH III Mycenaean stirrup jars present the only published applications of this technique to Greek Bronze Age pottery known to the authors (Johnston – Betancourt 1984; Leonard et al. 1993). An historic case study of 5th century B.C. Punic amphorae from Corinth was undertaken by Maniatis and colleagues (1984). All three case studies are examples of highly informative interdisciplinary projects which employed xeroradiography in combination with physicochemical analyses, visual inspection, and replication studies to investigate the forming technique and fabric composition in relation to a distinct ceramic ware or vessel shape. For example, Johnston and Betancourt established that East Cretan White-on-Dark ware pots were built up from strips and that their clay preparation was irregular (1984). Leonard and his colleagues were able to document two different ways of making stirrup jars (1993), while Maniatis and his colleagues demonstrated xeroradiography’s ability to assign individual vessels to two different fabrics (1984).

Identifying forming techniques of Knossian vessels at the British Museum
For this project, twelve open and closed vessels with a firm Knossian provenance were chosen from the British Museum’s collection. They were radiographed, scanned and their visibility enhanced digitally. The radiographs were scanned using an Agfa RadView digitiser with a 50 micron pixel size and 12 bit resolution, in order to allow digital enhancement of the images. The figures shown have been subject to manipulation of greyscale levels and enhanced using an “unsharp mask” filter to emphasise edges and discontinuities. It must be emphasised that the resulting images merely reflect features detect-
able, if only faintly, on the unenhanced films. The forming technique could be unambiguously identified for eight vessels, the remaining vessels did not provide as many characteristic clues and identification of manufacturing processes is based on a combination of radiographic and visual features:

1. Reg. No: 1906,1112.88. Listed as A 461 in Forsdyke (1925). Figure 1a. Jug (Middle Minoan I): Most of spout restored. Long, horizontal voids indicate that this vessel was made by using the coiling technique. In fact, three coil seams are clearly visible in the shoulder area.

2. Reg. No: 1950,1106.16. Figure 1d. Bell-shaped handled cup (Middle Minoan I): The diagonally stretched voids indicate that rotative kinetic energy (RKE) was used in the making of this vessel. The handle was pulled and its bottom attachment only lightly pressed onto the body.

3. Reg. No: 1906,0115.27. Listed as A 589 in Forsdyke (1925). Figure 1e. Amphora (Middle Minoan III): Long, horizontal voids indicate that this vessel was made by using the coiling technique. In fact, three coil seams are clearly visible in the shoulder area and at least another five can be detected on the body. After coiling was completed, the paddle and anvil technique was applied with its characteristic localised patches of differential wall thickness especially around the area of the widest diameter.

4. Reg. No: 1906,1112.57. Listed as A 576 in Forsdyke (1925). Figure 1b. Straight-sided cup (Middle Minoan III): In the frontal view, diagonal voids indicate that this vessel was made using RKE. The base view reveals the typical spiral-shaped arrangement of voids and inclusions in the base.

5. Reg. No: 1906,1112.89. Listed as A 588 in Forsdyke (1925). Figure 4a. Amphora (Middle Minoan III): The rilling is very obvi-
ous visually, but there is no characteristic void or inclusion orientation that can be recognised radiographically to support this visual assessment.

6. Reg. No: 1906,1112.90. Listed as A 590 in Forsdyke (1925). Figure 3. Oval-mouthed amphora (Middle Minoan III): Three distinct sections can be identified on this image: the diagonally stretched voids around the lower body indicate that rotative kinetic energy was used in the making of this section (figure 3b). The middle section is characterised by parallel joins representative of coil-building, although these are partially concealed by secondary shaping visible in the differential thickness of the wall (figure 3c). This secondary working shows as elongated vertical lines on the radiograph, and probably represents drawing marks, although there is no evidence of preferential vertical orientation in the inclusions or voids to confirm this, and there is a slight chance that it is due to the use of a paddle and anvil technique, using a rod shaped paddle. The shoulder zone was also made using coils, but did not receive any secondary treatment, leaving the coil joins more recognisable (figure 3d).

7. Reg. No: 1906,1112.91. Listed as A 592 in Forsdyke (1925). Figure 1f. Two-handled jar (Middle Minoan III): Diagonal voids indicate that this vessel was made using RKE.

Figure 1 (left): Enhanced radiographs of vessels showing distinctive forming patterns. All radiographs were recorded on Kodak Industrex film in a cassette with 0.25 mm lead sheets on both sides of the film.

a) 1906,1112.88 (vessel 1 in article). 70 kV, 25 mA mins
b) 1906,1112.57 (vessel 4 in article). 60 kV, 24 mA mins
c) 1950,1107.1 (vessel 12 in article). 70 kV, 25 mA mins
d) 1950,1106.16 (vessel 2 in article). 60 kV, 20 mA mins
e) 1906,0115.27 (vessel 3 in article). 70 kV, 25 mA mins
f) 1906,1112.91 (vessel 7 in article). 80 kV, 25 mA mins
8. Reg. No: 1906,1112.92. Listed as A 591 in Forsdyke (1925). Figure 4c. Spouted jar (Middle Minoan III): The vessel is heavily restored on the upper body. Experimental work (Berg 2008) has confirmed that the presence of too many inclusions can obliterate characteristic features — this is what seems to have happened in this case. However, irregular unevenness in the wall thickness makes hand-building the more likely forming technique.

9. Reg. No: 1906,1112.93. Listed as A 587 in Forsdyke (1925). Figure 4b. Jug (Middle Minoan III): With the white painted horizontal lines visible on the X-ray, it is likely that the paint contained some lead although Raman spectrograph of a small sample indicated that the bulk of the pigment was gypsum. The vessel has been heavily mended and restored. Neither voids nor inclusions provide
Figure 3: Enhanced radiographs of 1906,1112.90 (vessel 6 in article). All radiographs were recorded on Kodak Industrex film in a cassette with 0.25 mm lead sheets on both sides of the film.

a) Whole side. 70 kV, 25mA mins
b) Detail of lower body showing diagonal voids characteristic of rotative kinetic energy
c) Detail of central zone showing parallel joins characteristic of coil forming and evidence of secondary working
d) Detail of upper body showing evidence of coil forming

a clear pattern, although the unevenness in wall thickness points to hand-building. Visual observation seems to indicate that the middle section was drawn up.

Figure 4d. Straight-sided cup (Middle Minoan III): there is no apparent orientation of voids or inclusions in this vessel, so that the forming technique cannot be clearly identified. However, the lack
of voids itself indicates comparative lack of water during the forming process and is circumstantial evidence for handmade production. This hypothesis is supported in the very straight, progressively thinning wall characteristic of hand-built vessels.

11. Reg. No: 1938,1119.03. Figure 2. Trefoil-mouthed jug (Middle Minoan): The diagonal voids are a clear indication of having been thrown on the fast wheel. However, the base area is more surprising. Hidden within the heavy base is what appears to be the outline of a small, footed cup (figure 2b). This feature remains a puzzle. It may be that the production of the jug actually involved two vessels, with a small, footed cup being made (and probably fired) first. The jug base would then be built and the cup pressed into it, leaving the now visible void. The remainder of the jug was then thrown on the wheel. Alternatively, and much more explicably, the feature may be related to wheel throwing technique, being formed by the hand of the potter while rotating the wheel, with the two elongated hollows representing the impressions of fingers and the remainder of the hollow the hand as seen in another vessel from Knossos (figure 2c). In both examples, the particular features appears to point at hasty and/or inexpert execution.

12. Reg. No: 1950,1107.1. Figure 1c. Amphora (Middle Minoan): Based on visual observation alone, the vessel displays rilling characteristic of wheel-thrown pottery. That the lower body was made with the use of RKE is also apparent radiographically in the clearly visible diagonal voids when seen frontally. This is supported by the spiral pattern in the inclusions’ orientation in the base itself. Further diagonal void orientation can be noticed in the shoulder region, but the remainder of the vessel (middle section and neck) appears to lack further identifying features. It therefore has to remain uncertain whether the vessel was thrown in one process, in several sections or indeed made of a combination of wheel-throwing and hand-building techniques.
Figure 4: Enhanced radiographs of vessels showing no distinctive forming patterns. All radiographs were recorded on Kodak Industrex film in a cassette with 0.25 mm lead sheets on both sides of the film.

a) 1906,1112.89 (vessel 5 in article). 70 kV, 25 mA mins
b) 1906,1112.93 (vessel 9 in article). 80 kV, 25 mA mins
c) 1906,1112.92 (vessel 8 in article). 70 kV, 25 mA mins
d) 1906,1112.102 (vessel 10 in article). 70 kV, 20 mA mins
Overall, the vessels analysed demonstrate the great variability in forming techniques employed by Minoan potters. While small, open vessels were made using the fast wheel, large, closed vessels were often handmade. More important, however, is the recognition that potters utilised the whole spectrum of forming techniques — sometimes combining several methods on the same vessel. An interesting ethnographic example of this is given in Nicholson and Wendrich (1994) looking at modern traditional potters in Middle Egypt, where the bodies of water jars are handformed by the women of the village, but the rims are wheelmade and luted on by the men.

Conclusion
This project has demonstrated that X-radiography can serve as an effective technique for identifying the forming techniques of Knossian pots made of coarse fabrics. In addition, a large-scale diachronic study of Knossian Bronze Age pottery initiated by one of the authors (IB) has been able to show X-radiography’s potential also for fine and semicoarse fabrics (Berg 2008). With an industrial X-ray unit now available through INSTAP, it is hoped that X-radiography, alongside macroscopic observations and scientific techniques, will become an accepted investigative tool for pottery specialists working on Crete.
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