EXPLORING THE CHAINE OPERATOIRE OF CERAMICS THROUGH X-RADIOGRAPHY

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Abstract: X-radiography is shown to be a suitable technique to enhance our understanding of the chaîne opératoire of ceramics, in particular in relation to assessing the fabric, identifying forming techniques, as well as visualising attachments and breaks. Its advantages are that it is non-destructive, able to assess the complete artefact, comparatively quick to produce and good value for money. A case study from Bronze Age Crete demonstrates its potential and offers new interpretation for our understanding of the emergence and use of the potter's wheel.

Keywords: chaîne opératoire, X-radiography, ceramics, forming techniques, Bronze Age Crete

Introduction

One could argue that it is the diversity embedded within the *chaîne opératoire* approach that appeals so greatly to us and allows us to explore a wide variety of avenues within the overall paradigm. With the emphasis on the *chaîne*, the 'sequence', we acknowledge that the sum of all component parts is greater and more meaningful than each individual aspect. Nevertheless, it is the particular strength of the *chaîne opératoire* approach to first explore each stage of the sequence on its own terms, consider the meaning of the choices made in relation to the variety of choices available in principle prior to offering an overarching interpretation.

While the concept of the *chaîne opératoire* is often perceived in terms of the technological sequence, it actually encompasses three interlinked aspects:

1) The technological 'operational sequence' of the making of an object from the acquisition of raw materials to its final discard. Influenced – but not constrained or pre-determined – by environmental and technical factors as well as knowledge, skill, experience, etc.
2) The cultural processes, cultural choices and belief systems that find themselves embedded within each step, and the overall sequence.
3) The sensual aspects interwoven in the interaction between material, object, maker and user.

Many techniques have been used successfully to investigate individual stages of the operational sequence. Among the less well-known techniques is X-radiography. It is thus the aim of this paper to present the potential of X-radiography for our understanding of the *chaîne opératoire* of ceramics. A brief introduction to the technique is followed by a detailed discussion of its potential. A case study from Bronze Age Crete will serve as illustration.

X-radiography and the *chaîne opératoire*

To put it simply, X-radiography is a type of electromagnetic radiation that penetrates objects in proportion to the atomic density of the materials and thickness of the object. The outgoing radiation is captured as a greyscale image on a photographic film or monitor. Since the discovery of X-rays in 1895 by Röntgen, X-radiography has been successfully used to understand a wide range of archaeological materials, including paintings, metals, ceramics, textiles, stone and paper objects as well as soils, sediments and bones (for an excellent summary see Lang and Middleton 2005). While X-radiography of metals possibly represents the most common application in modern archaeology, investigations into ceramics have become more popular (Berg 2009; Berg and Ambers, forthcoming; Carmichael 1990, 1998; Glanzman and Fleming1986; Johnston and Betancourt 1984; Laneri 2009; Levi 1999; Magrill and Middleton 2001, 2004; Maniatis *et al.* 1984; Nenk and Walker 1991; Vandiver 1987). The first X-rays of clay objects date back to the first half of the 20th century (Titterington 1935; Digby 1948; van Beek 1969) and since those pioneering days, characterisation of clay fabrics through inclusion or tempers and identification of manufacturing techniques have remained the two main topics of investigation (Berg 2008; Carr 1990; Ellingson *et al*. 1988; Middleton 2005; Rye 1977, 1981).

The advantages inherent in radiography make it a very effective complementary technique to macroscopic investigations, microscopy and conventional destructive provenance analyses: 1) it is a non-destructive technique; 2) it permits investigation of fragments *and* complete objects; 3) it can be done comparatively rapidly and cheaply; and 4) suitable medical or industrial facilities are available in many places. In almost all cases, the attention has focused on clay vessels. However, the underlying technological principles make it a suitable investigatory technique for almost any kind of clay object.

In relation to the technological aspects of the *chaîne opératoire* approach, X-radiography can help with the following aspects:

1) Characterisation of clay fabrics to determine composition and provenance
2) Identification of primary forming techniques, their combinations and minute specifics
3) Attachment of spouts, handles, etc.
4) Identification of repairs and breaks

X-radiography cannot help with:

5) Identification of secondary forming techniques and surface treatments

Characterising clay fabrics

If inclusions or tempering materials are of a different atomic density from the clay matrix and larger than 0.5mm in size, then they can potentially be identified on an X-ray (Figure 1; for details see Berg 2008).

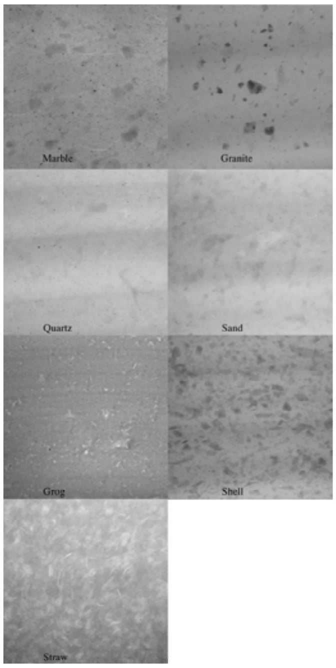

Figure 1: Visibility of different tempering materials. Enhanced radiographic images.

In some circumstances, size, morphology, number and angle of crystal faces might give clues as to the specific type of inclusions, though similar radiodensities and morphologies for chert, quartz, and pure sandstone, for example, make a specific attribution unlikely (Carr and Komorowski 1991). However, broad categorisation of mineral inclusions, such as felsic, mafic and opaque, is possible. Organic inclusions, on the other hand, including straw, wood, sponge, insects, seeds and shell, are readily recognisable; so is grog when it is made of a clay of different atomic density (Foster 1985).

Thus, under the right conditions, X-rays can help us understand the composition and nature of clay selection and preparation. Characterisation of the inclusions/temper can support provenancing of individual vessels or assemblages, can help in defining fabric groups or can be used to determine whether fragments belong to the same vessel (Adan-Bayewitz and Wieder 1992; Berg 2008; Blakely *et al.* 1989; Blakely *et al.* 1992; Braun 1982; Carr 1990, 1993; Foster 1985; Maniatis *et al.* 1984; Rye 1977). Likewise, unusual tempering practices or combinations of different clays on the same vessel will be visible on an X-ray, such as the use of two different clays (one fine, one coarse) on Cretan Kamares Ware bases (Day *et al.* 2006: fig. 10-13)[1]. However, given the outlined caveats, radiography is best considered as a suitable complementary tool rather than as a replacement of petrography and chemical analyses.

Identifying forming techniques

X-radiography is an important tool in understanding primary forming techniques. This is because X-rays detect the internal structure and orientation of inclusions as laid down during the primary forming. Visual inspection by specialists, on the other hand, will focus on those features visible on the surface and often represent secondary forming and surface treatments which may have obliterated traces of the original shaping procedures. The criteria for identifying pinching, coil- and ring-building, slab-building, drawing, moulding and wheel-throwing were established by Rye (1977; 1981; see also Berg 2008 and 2009 for a detailed discussion of coil-building, wheel-throwing and wheel-coiling features) and are based on the orientation of voids and elongated temper particles (Figure 2). However, be it as a result of the skill of the potter, vessel thickness or the nature of the inclusions, not all vessels can be successfully identified. A success rate of between 60 and 80 per cent of all X-rayed vessels can normally be expected.

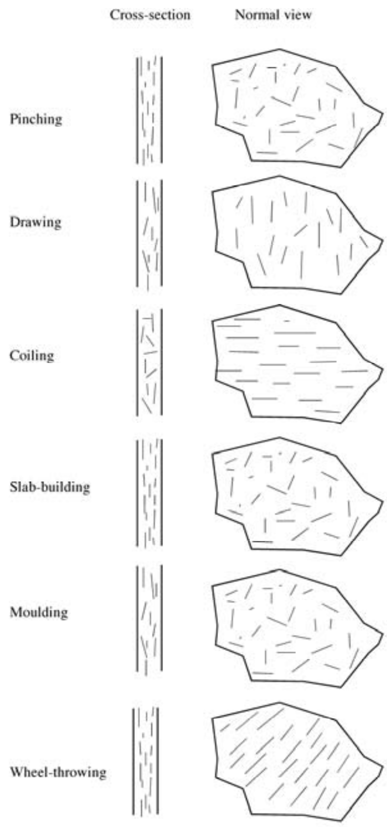

Figure 2: Characteristic features of the main pottery forming techniques (after Carr 1990: fig. 1; Rye 1981).

Thus, under normal circumstances, X-radiography is able to identify all primary forming techniques that were used in the making of a particular vessel. While many vessels are made using one single technique, there are examples of the use of multiple techniques. For example, a Cretan Bronze Age amphora was made using three distinct techniques (Figure 3): the bottom third was wheel-thrown, the middle section was coiled and then drawn, while the top third was coiled (Berg and Ambers, forthcoming). As X-radiography investigates the complete vessel, it is able to provide a more comprehensive and nuanced understanding of every stage of the manufacturing process than would otherwise be possible. In addition, X-radiography can offer information on minute details, such as coil heights and hidden drying or firing cracks.

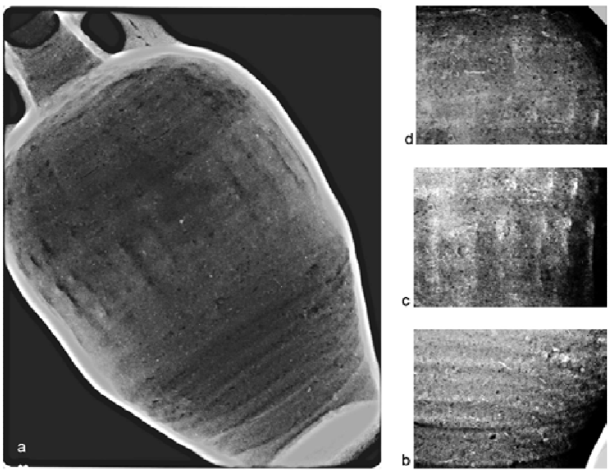

Figure 3: Enhanced radiographs of British Museum reg. no. 1906,1112.90. A) Whole vessel. B) Detail of lower body showing diagonal voids characteristic of wheel-throwing. C) Detail of central zone showing parallel joins characteristic of coil forming and evidence of secondary working. D) Detail of upper body showing evidence of coil forming. Image copyright Trustees of the British Museum.

Applications are, of course, not limited to clay vessels. X-radiography of clay figurines from the Cretan peak sanctuary of Philioremos has proven very effective in understanding how each figurine was formed (Berg, forthcoming; Foster 1983). In this case, two techniques can be identified: a) simple squeezing and forming of the whole figurine from a single lump of clay (Figure 4 left) and b) joining separately-made sections together (Figure 4 centre and right). The latter type was made by making a coil and bending it in the middle to create the lower half of the figurine. The torso was made separately with the lower part pulled downwards to create the loincloth (Berg, forthcoming).

Attachment of spouts, handles, joining of sections, and addition of internal mechanisms

Because air is likely to be trapped in between the two areas that are being joined, such joints are often detectable in an X-ray. Also, when a handle, for example, is not merely pressed onto the external surface, but actually pushed through, this is clearly visible. A very good illustration of the potential is demonstrated by an investigation into Mycenaean Bronze Age stirrup jars which could be shown to have been made in three distinct ways: a) with a hollow false spout thrown in one with the body, b) a solid false spout placed on top of a closed body and c) a solid false spout placed on top of a body with a gap for the spout (Leonard *et al.* 1993). An unusual discovery was made when specialists X-rayed a Peruvian water jug and revealed the internally hidden mechanism (Digby 1948).

Returning to the clay figurines from the peak sanctuary (Figure 4 centre and right), they clearly indicate that two of the figures were made of two parts which were joined together in a way that left no apparent visible traces, but which the X-ray reveals to be just an ingenuous cover up (literally in this case, with the loincloth hiding the actual joint) (Berg, forthcoming).

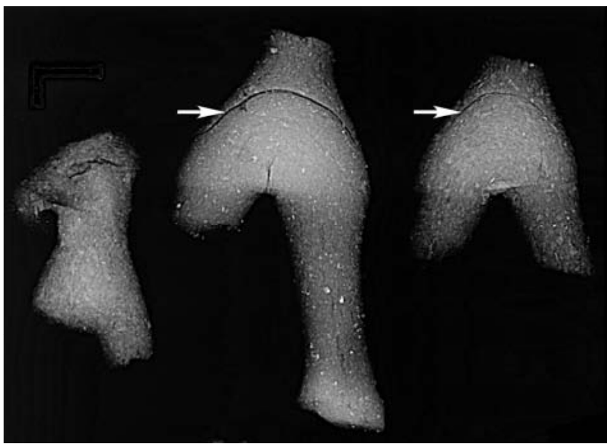

Figure 4: Enhanced radiograph. Left: human figurine (ID 204101); Centre: male figurine (ID 406144); Right: male figurine (ID 307106). Arrows mark the joint between upper and lower sections.

Identification of repairs and breaks

Repairs are often clearly visible macroscopically, but where confirmation is required, X-radiography will be able to detect them easily as they are normally undertaken with materials of a different atomic density, such as metals. In one example, a metal pin was inserted into the fake spout of a Mycenaean stirrup jar (Middleton 2005: fig. 3.1). Naturally, all cracks and breaks (firing cracks, temperature cracks, stress breakages, etc.) will be clearly visible in an X-ray. However, the technique is also able to detect breaks in the clay that might not be visible to the naked eye, but might have impacted on the usability of a vessel or indeed precipitated its discard.

Secondary forming techniques, surface treatments, decoration

Secondary forming techniques (such as scraping, trimming, and turning) and surface treatments are almost impossible to verify radiographically, because they do not generally involve severe modification of the clay that would be reflected in an X-radiograph (Berg 2008). They are therefore best identified by visual observation (Figure 5). The exception is the paddle and anvil technique which applies such considerable pressure to the original shape that it can obliterate all radiographically-visible attributes of the primary forming technique, but is itself recognisable by its characteristic pattern of inclusions (Rye 1981).

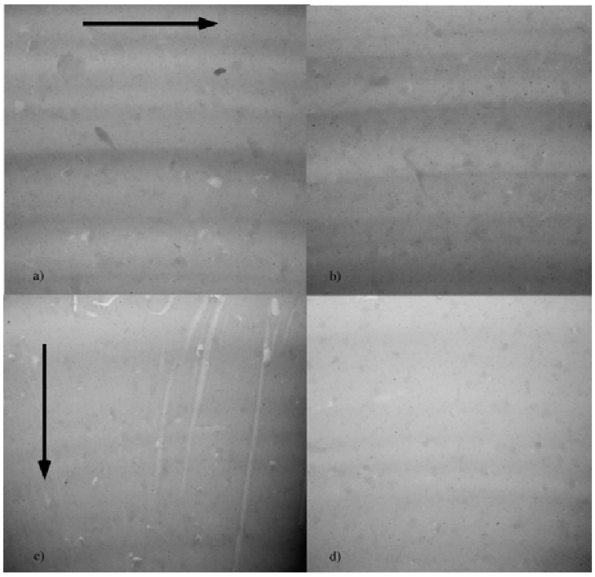

Figure 5: Radiographic features of secondary forming techniques and their lack of impact on primary forming: a) horizontal scraping with a wooden tool can create air pockets, b) no air spaces are visible on the untreated pot; c) vertical knife trimming can leave obvious indentations and air pockets, d) the untreated vessel half. The arrows indicate the direction of the scraping/knife-trimming motion. Enhanced radiographic images.

A case study from Bronze Age Crete

On Crete, the potter's wheel makes it first appearance in the Middle Minoan IB period (*c.* 1900 BC). Conventionally, the appearance of the potter's wheel is associated with the emergence of the Cretan palaces and their supposed links to craft specialisation. It is argued that these palaces, in order to legitimise the existence of their elites and gain political capital, introduced a host of new arts and crafts made by resident full-time craftsmen with superior and faster techniques, such as elaborately decorated Kamares Ware, figurative frescoes, writing, stone working and metal working. In this context, wheel-thrown pottery is seen as an elite technology that was introduced fully developed and replaced handmade production very quickly.

However, a large-scale X-ray study of a ceramic assemblage from Knossos was able to correct several of the traditional assumptions (for a detailed summary of the case study, see Berg *in preparation*). First, it showed that experimentation with a wheel device occurred already in the preceding Early Minoan III/Middle Minoan IA period and merely accelerated in Middle Minoan IB. While wheel-thrown production became more popular over time, handmade techniques continue to exist side-by-side until the Late Minoan II period (*c.* 1500 BC). This pattern might signal that the advantages of the potter's wheel were not necessarily fully apparent to all potters using it. Alternatively, socio-cultural factors or workshop organisation might have interfered with a complete and successful adoption.

Second, X-ray study conclusively proved the existence of two co-existing techniques that utilised the potter's wheel to different degrees, but whose end-products can look almost identical: wheel-throwing and wheel-coiling (Berg 2008). The former denotes a technique that uses a potter's wheel at speeds sufficiently high to pull up and shape the clay. The latter is a technique whereby the potter builds a vessel with coils and subsequently evens out its walls on a slowly revolving turning device (Figure 6). Up to now scholars have encountered limitations in their ability to detect this technique (Berg 2009).

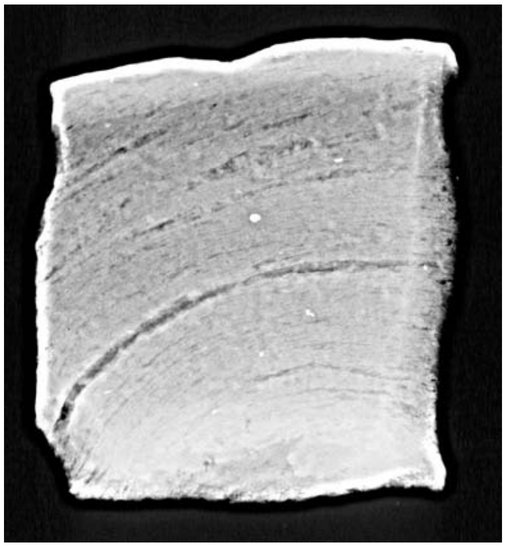

Figure 6: Enhanced radiograph of a Late Minoan saucer fragment from Knossos. Catalogue no 92, Berg 2009. This saucer is wheel-coiled, i.e. it was made of coils which were subsequently shaped on the wheel. The coil seams are clearly visible in the X-ray.

Third, handmade production covered the full range of vessel sizes from small cups through to large storage jars. On the other hand, wheel-thrown production was limited to small and medium-sized vessels below 12cm of height (Figure 7), indicating either that potters were not expert users able to throw medium and large-size vessels and/or that the abilities of the existing potter's wheel limited the vessel production due to the inability of the wheel to maintain the revolving momentum for a sustained period of time. Wheel-coiling, as can be expected of a technique that utilises both hand- and wheel techniques, falls in-between the ranges, though wheel-coiled vessels are generally closer in height to wheel-thrown vessels.

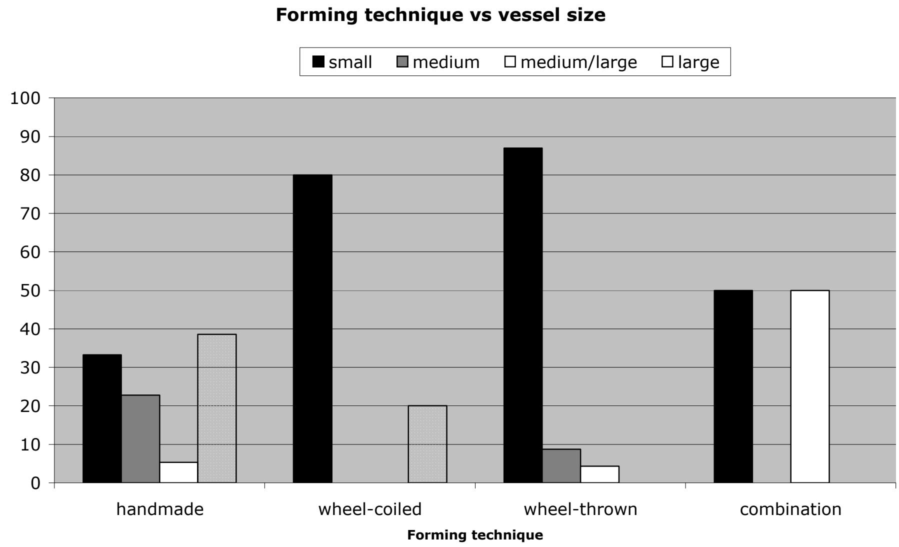

Figure 7: Comparison of vessel size by forming techniques.

Four, elite production is often linked to elaborate decorative designs. Surprisingly, the analysis demonstrated that decoration is more often found on handmade vessels rather than wheelmade ones. Two scenarios can be proposed: on the one hand, handmade vessels could be the more logical choice for adding elaborate decorative designs as they are generally larger and would thus provide a more extensive surface for displaying the decoration. On the other hand, potters might have left the wheel-thrown vessels undecorated *in order* to show off the new technique.

Originally seen as strongly correlated, the above analysis questions the connection between the emergence of palatial elites and the introduction/use of the potter's wheel by attached specialists. Indeed, research over the last decade has begun to emphasise the great importance of specialist pottery production centres in Crete already in the Early Minoan period, several hundred years prior to the introduction of the wheel (Day *et al.* 1997; Whitelaw *et al.* 1997). More importantly, it is now accepted that pottery specialists were producing high-quality wares (e.g. Kamares Ware) in non-palatial locales during the Middle Minoan period (Day and Wilson 1998; 2002; Day *et al.* 2006). It is in these contexts that the wheel made its appearance. Hence, it is proposed that we should envisage the emergence of the potter's wheel on Crete not as a result of palatial involvement, but rather in the context of innovation initiated by local specialist potting centres.

Circumstantial support for this interpretation is also provided by a re-assessment of the emergence of the palaces themselves, their administrative organisation, and architectural elite features (Wilson 1994; Schoep 1999, 2002, 2004). Having originally been assumed to be contemporary, evidence now suggests that different local/regional trajectories were at play, leading to the appearance of palaces in different regions over a considerable time span. Middle Minoan IB no longer is the watershed it was once assumed. Instead, a multitude of evidence points at a more fluid and dynamic process that stretches from the Early into the Middle Minoan period and emphasises the importance of communication and competition between local or regional elite groups in order to explain the emergence of the palaces.

Conclusion

X-radiography is a valuable and versatile technique for our understanding of the *chaîne opératoire* of ceramics and, together with a variety of other techniques, offers a useful starting point for explorations of the socio-cultural context of ceramic production, consumption and discard.

FOOTNOTES

[1] No such sherds have yet been X-rayed, but the principles of X-ray analysis make it highly likely that such manufacturing choices are detectable.

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