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XERORADIOGRAPHY: A KEY TO THE NATURE OF TECHNOLOGICAL CHANGE IN ANCIENT CERAMIC PRODUCTION

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Over the last two decades Industry and Medicine have developed and fully exploited various X-ray techniques, especially xeroradiography. It is only recently, however, that the latter has found significant use in museum-related disciplines, the appeal being that it is nondestructive in its usual mode of application. Though the production of xeroradiographic images has been largely constrained to situations where the X-ray beam incidence is normal to the object's surface – we will illustrate that information recovery is not optimized in that configuration – some valuable data has been gleaned about certain characteristic features of ceramic structure. For example, the frequency, grain structure and gross aspects of rock and mineral inclusions are often radiographically distinct, when their effective atomic number is significantly different from the surrounding clay matrix. (Haematite, muscovite and calcite show up particularly clearly.) Similarly, remnants of organic matter, such as any rice or straw temper that the potter may have added, produce quite distinct images. We have now adapted routine xeroradiographic methods to accurately reconstruct the method of manufacture of individual pottery vessel types from a wide range of past cultural horizons. Adjustments in X-ray exposure settings and angles of incidence, coupled to an internal study of certain vessel forms (using a "thick section" technique that we will describe in detail), has allowed us to identify subtle changes with time in ancient pottery production methods, and has prompted much reassessment of current ideas about technological innovation within several cultures, including those of Bronze Age Jordan and prehistoric Thailand. This paper will summarize the technical aspects of these changes, and consider the past social conditions which may have stimulated them.

1. Introduction

There is an extensive literature available today that covers the contemporary potting traditions of various cultures around the world (e.g., Rye and Evans [1], Bandler and Bandler [2], Reina and Hill [3], Sweezy [4], among others). It is extremely important ethnographic material because so many of these traditions are being gradually overwhelmed by the mass production concepts of the industrialized western world. Such studies, however, may serve as a measure of past potting traditions only to a quite limited extent, and reflect the development of ideas just a few centuries old. In fact it would be naive to think otherwise, when we can look at so many other crafts (notably, metallurgy and weaving) and document the dynamic nature of their technological change with time. To understand the ancient potter's methods (and perhaps, by inference, the prevailing organizational structure of his craft) we have to reconstruct in a step-by-step way, how the characteristic vessels of his times were fabricated. If by virtue of a clearly defined site stratigraphy, we can allocate those vessels to quite brief time phases, then we can build a picture of when new fabrication methods emerged, whether certain methods were linked to the creation of specific vessel forms, etc.

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2. Macroscopic features

There are only three discrete stages in pottery making, but many different techniques that can be employed within each stage before the vessel is turned into a durable product by firing: (a) formation by such methods as coil-building, wheel-throwing, etc.; (b) shaping, in some instances by direct hand manipulation, in others through application of a tool; and (c) surface finishing (e.g., patching, burnishing, etc.). Each of these treatments of the clay leaves a set of characteristic features which become "fossilized" in the vessel's structure.

Some of these features are quite visible. For example, one vessel from a third millennium burial at the site of Ban Chiang, in Thailand, displays coil-joins that have only been partially obscured by a smoothing of its interior surface. On its exterior, most of those joins are obliterated by a striated patterning produced by a cord-covered paddle (fig. 1). Another Thai vessel of similar date has on its inside numerous tightly-packed, elliptical depressions, all about 19 mm in length and running in a horizontal band. These markings resulted from a convex-headed anvil being held against the interior wall while the exterior was beaten rhythmically with a cord-covered paddle. In this case, except near the

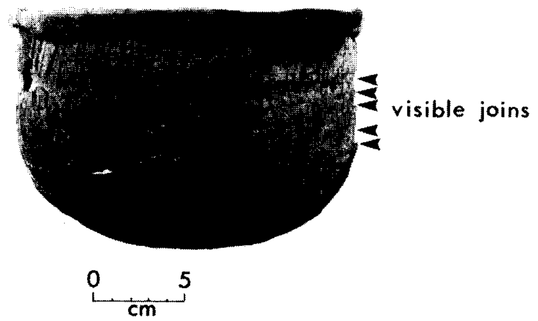

Fig. 1. Side-wall view of a simple globular vessel (MASCA inv. BC-44) from a second millennium B.C. burial at the prehistoric site of Ban Chiang, in northeast Thailand. The marks of cord-paddling obscure all but a few of the remnants of the 13 coil-joins involved in the fabrication of this vessel.

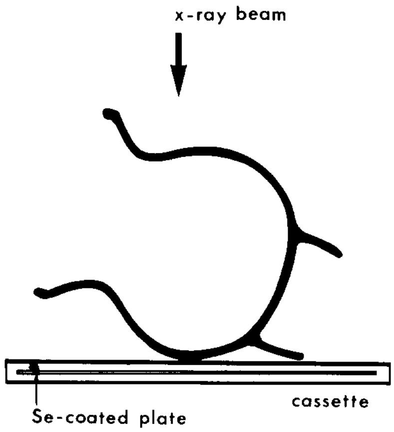

Fig. 2. Schematic of a complete (or restored) vessel undergoing xeroradiography. Both the side of the vessel adjacent to the cassette and that closest to the X-ray source will contribute an image on the semiconductor plate, thus creating significant problems in data interpretation (see text). X-ray voltage settings are usually in the range of 50 to 65 kV, dependent upon the thickness of the vessel's fabric.

vessel's base, all the exterior striations produced by the paddling were subsequently smoothed by an intensive burnishing treatment.

In general, however, the macroscopic observations that we can make are dominated by those features that document the shaping and surface finishing stages of pottery making; the signs of the formation stage are invariably overwhelmed by later treatments. This introduces appreciable hazards into data interpretation. For example, one bowl from a Late Bronze Age (circa 1500 B.C.) burial cave in the Baq'ah Valley of Jordan exhibits a series of fine striations on its surfaces that spiral upwards in a tightly-wound manner that might suggest that it was formed by wheel-throwing. Yet it also has patches on the interior and exterior of the basal region that would serve no obvious purpose within the practicalities of that formation method, and there is no patch where we would have expected it, at the join between the main body and the pedestal foot added to it. How was this vessel really made? Following xeroradiographic studies of the kind summarized below, we conclude that a coil-building method of fabrication was used in what we term as the "upside-down" mode of clay manipulation (see below), and that the "wheel-marks" are only an artifact of the shaping stage.

3. Xeroradiography: measurement parameters

All our xeroradiographic images were obtained at the Outpatient Radiology Unit of the Hospital of the University of Pennsylvania. The Picker GX 850 X-ray source and exposure regulator were used in conjunction with the standard Xerox medical imager cassettes and processing equipment. The theoretical principles underlying xeroradiography are covered by Jacobi and Hagen [5] and Brown [6], and its mechanics by Oliphant [7], Bickmore et al. [8] and Boag [9]. The past usage of X-rays in general, and xeroradiography in particular, to ancient pottery has been reviewed by Glanzman [10].

Our research material comes in all shapes and sizes. Some vessels are large and globular, others are small and squat; rims and bases vary from non-existent to exaggerated and/or massive. If a vessel is near-complete or fully restored since excavation, our xeroradiographic images are often overlays of two portions of the pottery structure, with image density and resolution much influenced by vessel contour (see fig. 2). The correct setting of the angle of incidence of the X-ray beam relative to the surface of the walls or base of a vessel then becomes a crucial step. The orientation within the pottery structure of many of the features associated with the formation stage is often dependent upon the specific techniques used by the potter. Experiments using test tiles exposed to X-rays normal to their surface indicate that surface smoothing not only masks macroscopic features of the construction method but also can obscure the xeroradiographic image (figs. 3 and 4). Nonetheless, by altering exposure settings and the angles of incidence of the X-ray beam, we have been able to discriminate between three different construction methods used in antiquity.

4. Practical observations

As used in prehistoric Thailand, the *coil-and-slab* construction method was achieved by first forming a slab base and then adding coils onto it while the entire

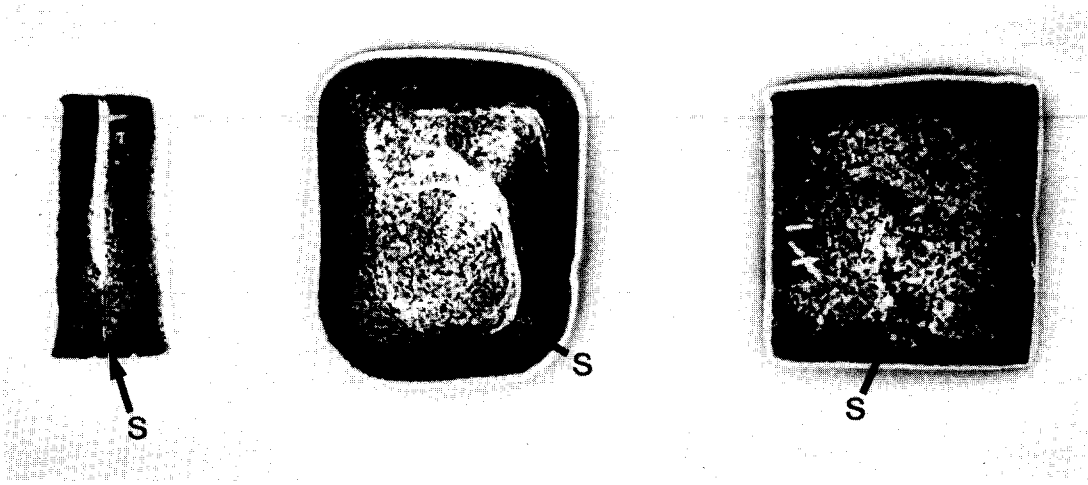

Fig. 3. Xeroradiograph of three test tiles which were constructed in the way shown in fig. 4. Each image was taken normal to the surface. The remnants of the coil and slab seams (s) are almost obliterated, suggesting that other angles of X-ray incidence might be required to resolve the seams more clearly. Measurement conditions: 100 mas., 1.00 s, 44 kV and 0.91 m focal distance.

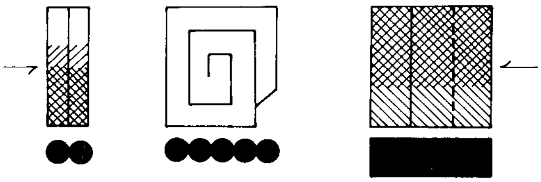

Fig. 4. Schematic construction drawing of three fired clay test-tiles made either by coiling (left) or by slab building (right). Surface smoothing on their bottom surfaces (///) and their top surfaces (\\\) illustrates the masking effect that those actions have on the macroscopic traces of vessel construction, as well as their influence on surface-normal xeroradiographs (see fig. 3). Similar effects have been noted by Van Beek [11].

unit was kept in an "upright mode" (fig. 5). In the xeroradiographic image of the vessel's wall, the joins between the coils appear as laminar air voids (fig. 6); that of the basal region lacks any such voids, and denser inclusions (feldspars, etc.) that appear radiopaque in the image are randomly oriented in the fabric.

In contrast, in ancient Jordan, the building up of the coils was the first step in vessel formation, and the final forming of the base was carried out with the entire unit in an "upside-down mode" (fig. 7). We call this a *coil-on-coil* construction method, though clearly it could also be regarded as a variant on the coil-and-slab method if the original platform for the work was a clay slab that could subsequently be fashioned into the vessel's base (see Glanzman 1983). In its xeroradiographic image, taken at an oblique aspect of the vessel's wall, the joins between the coils appear as elliptical air voids (fig. 8). The coils themselves have been completely obliterated on the surface by subsequent vessel shaping on a tournette.

A distinctive macroscopic feature of the Jordanian coil-on-coil method is the addition of a thick patch on

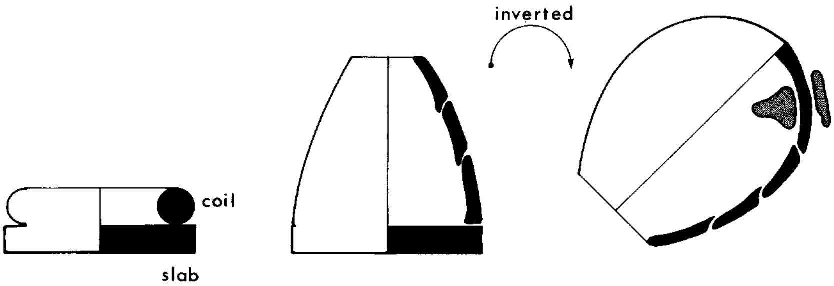

Fig. 5. The coil-and-slab construction method, as used by ancient Thai potters. The vessel shaping stage was performed using the paddle-and-anvil technique. (Artwork by Helen Schenck.)

Fig. 6. Xeroradiograph of the Thai vessel illustrated in fig. 1. The coil joins are arrowed. Measurement conditions: 400 mas., 0.20 s, 50 kV and 1.02 m focal distance. (Image taken acute to normal incidence.)

the inside of the vessel's base. The purpose of this is apparent in the appropriate xeroradiograph obtained by the "thick section" imaging technique discussed below (fig. 9), to seal off the fine spiral-shaped gap which was created as the potter applied a final twist to the clay to seal the base.

A third construction method we have been able to isolate is the *lump-and-slab*, again among Thai pottery (fig. 10). The macroscopic evidence for its usage is twofold: (a) the presence of rhythmically aligned anvil markings, and (b) an added clay seam that was pressed onto the inside of the vessel along the angle of its carination. In the xeroradiographic image of the vessel's wall the only join we can detect occurs at this carination. There is a complete absence of any void lines (i.e., no coil joins) anywhere in the body above that point (fig. 11). The air voids and the inclusion alignments that are just discernable are a response to later paddle-and-anvil working.

Both sets of evidence indicate that the top part of the vessel was modelled from a lump of clay which was first hollowed out, then ruptured open so that its upper edge could be smoothed down to join onto the slab base. The addition of an inner clay seam was obviously intended to strengthen the vessel at its weakest point, where the original lump and slab abutted together.

A striking ethnographic parallel for the creation of this shape has been documented by Rye and Evans (1976) amongst modern Pakistani potters. However, they achieved it using the coil-and-slab method. No parallels for either this shape, or the lump-and-slab method has been published for modern Thai potters, indicating the temporal dynamism of their craft.

5. "Thick section" studies

The great advantage of surface imaging of the kind illustrated in figs. 6, 8 and 11 is that it is nondestructive. This is much welcomed by museum curators, but it has drawbacks, not least that each investigation is made time-consuming by a need for multiple X-ray exposures

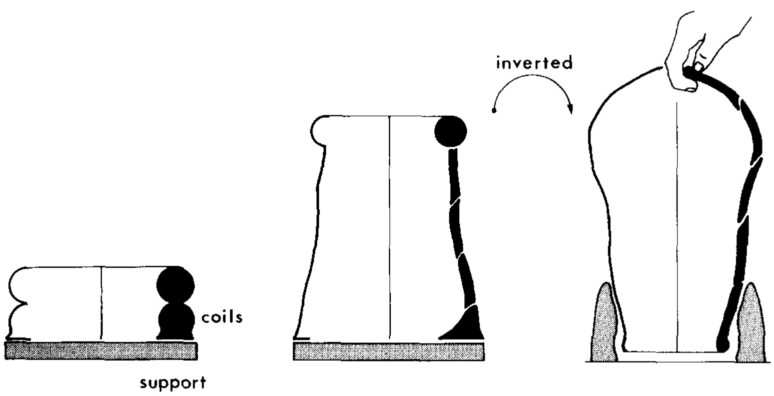

Fig. 7. The coil-on-coil construction method, as used by ancient Jordanian potters. The vessel shaping stage was performed by rotation on a tournette. (Artwork by Helen Schenck.)

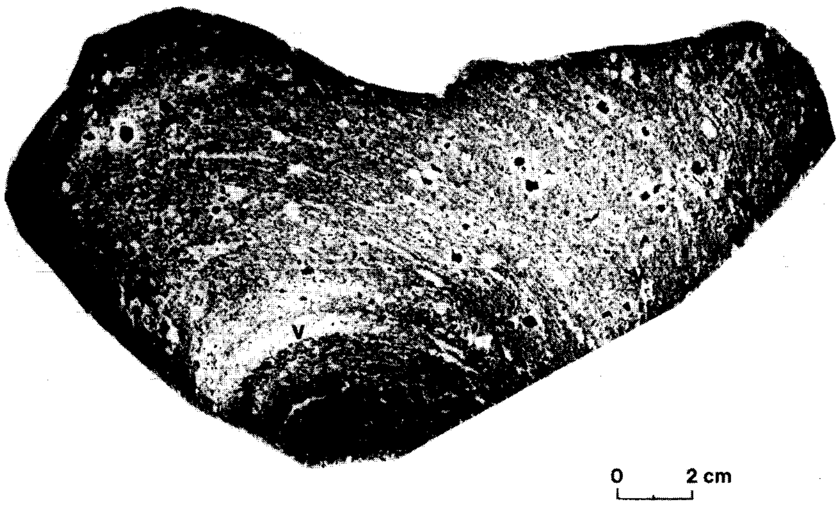

Fig. 8. Xeroradiograph of the base of a jar (MASCA inv. B3. 154) from a Late Bronze Age (circa 1400–1200 B.C.) burial cave in the Baq'ah Valley of Jordan. The elongated, elliptical voids (v) occur where air was trapped along coil-joins that underwent shaping by the tournette. Measurement conditions: 150 mas., 1.00 s, 60 kV and 1.02 m focal distance. (Image taken oblique to normal incidence).

at different angles of incidence. We have recently both simplified the demands on xeroradiographic interpretation and much increased the level of detail in the data gathered by employing what we term a "thick section" imaging technique.

A thin diamond-impregnated wafering blade is used to cut a strip of pottery from along the vessel's vertical axis, the slice being ideally as wide as the vessel's average thickness. One of the cut surfaces is laid upon the imaging cassette, so that the xeroradiograph pro-

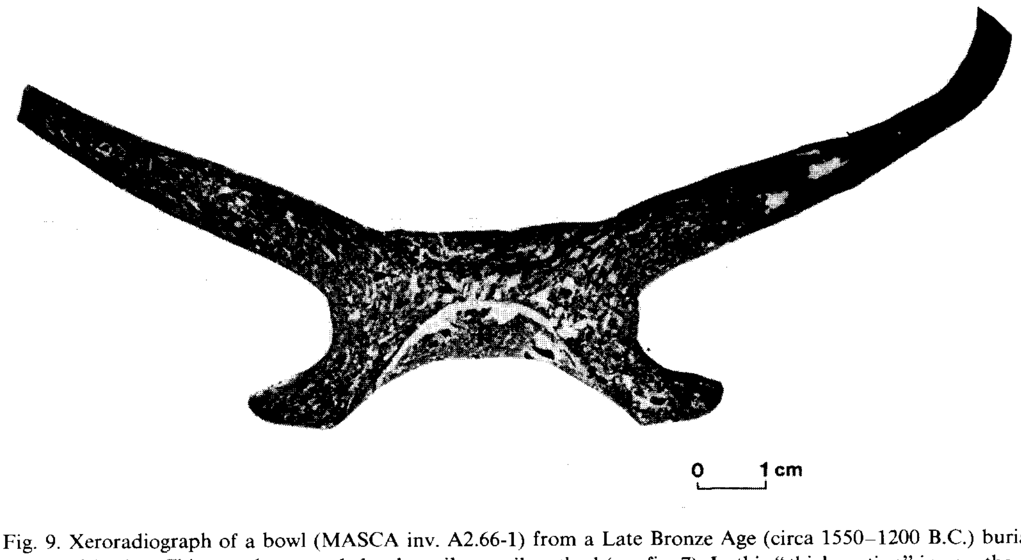

Fig. 9. Xeroradiograph of a bowl (MASCA inv. A2.66-1) from a Late Bronze Age (circa 1550–1200 B.C.) burial cave in the Baq'ah Valley of Jordan. This vessel was made by the coil-on-coil method (see fig. 7). In this "thick section" image, the air voids (v) flow in a continuous pattern from the pedestal foot into the lower body, where they become squeezed into an elliptical pattern near the break. At this point a coil was added to form the rim (now lost). Note the contrast in air void patterning between the patches (p) and the fabric of the vessel. Measurement conditions: 150 mas., 1.00 s, 60 kV and 1.02 m focal distance.

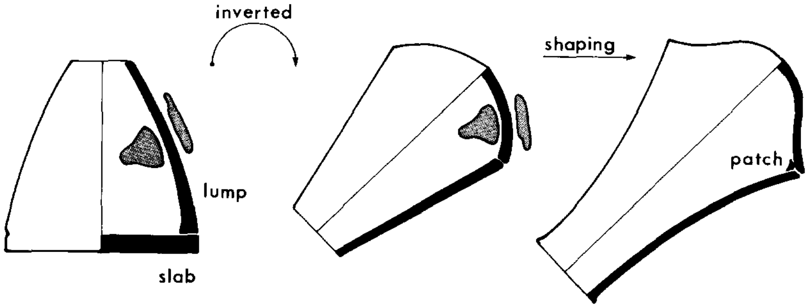

Fig. 10. The lump-and-slab construction method, as used by ancient Thai potters to create a dinstinctive carinated form. Again, the vessel shaping stage was performed using the paddle-and-anvil technique. Note the interior carination patch which is so characteristic of this potting method. (Artwork by Helen Schenck.)

Fig. 11. Xeroradiograph of the upper body and base of a disassembled carinated vessel (MASCA inv. BC-7) from a first millennium B.C. burial at the prehistoric site of Ban Chiang, in northeast Thailand. This vessel was made by the lump-and-slab method (see fig. 10). The only laminar void pattern in evidence is at the carination (s), where the upper body joins the basal slab. Measurement conditions: 400 mas., 0.20 s, 50 kV and 1.02 m focal distance.

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vides an in-depth cross-sectional view of the patterns in air voids and inclusion orientations that resulted from the forces applied during the formation stage of the vessel's manufacture. All joined surfaces can be identified with very little ambiguity.

"Thick section" imaging has shown that an S-shaped stress crack in the vessel's base is a common feature of the "upright mode" of wheel or tournette use (c.f., fig. 7 for the "upside-down mode"). Additionally this method of imaging has proven the only way to isolate a criterion for distinguishing between wheel-thrown and coil-built pottery. The former is characterized by a completely parallel-to-surface alignment of air voids, the latter by air void discontinuities and varying alignment (fig. 12). The only times we have found "thick section" imaging difficult to apply is when large amounts of organic temper – e.g., rice in Thai pottery, dung in Jordanian pottery – were added to the clay stock.

Fig. 12. Xeroradiograph, as a "thick section" image of a jar (MASCA inv. A2.66-2) from a Late Bronze Age (circa 1550–1200 B.C.) burial cave in the Baq'ah Valley of Jordan. This vessel was made by the coil-on-coil method (see fig. 7). Note the complete rounding off of the voids at the vessel top and below the coil join (s), that reveals the remnants of the coils themselves (r). Measurement conditions: 150 mas., 1.00 s, 60 kV and 1.02 m focal distance.

6. Conclusions

Xeroradiographic data gathered in the way described above has enabled us to make a chronological study of the evolution of pottery making at the site of Ban Chiang in Thailand during the third and second millennium B.C. (Glanzman and Fleming [12]), and in the Baq'ah Valley of Jordan during the second millennium B.C. (Glanzman and Fleming [13]). There are innumerable situations in both Old and New World archaeology where a similar methodology could be applied, since pottery is usually the most prevalent artifact in excavation. These studies underscore the fact that modern technologies, with minor modifications, can be powerful tools in the examination of the dynamics of technical (and hence cultural) change in the distant past.

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