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The Implications of Variation in Ceramic Technology: The Forming of Neolithic Storage Vessels in China and the Near East

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ABSTRACT Examination of the macrostructures and microstructures of ceramic vessels and sherds from two Neolithic sites—Hajji Firuz, a sixth millennium farming village in the Zagros region of Southwest Asia, and Banshan, a fourth millennium grave site in Gansu province, China—was undertaken in order to reconstruct forming technologies. As would be expected, the two wares are dissimilar stylistically, so further study was conducted to see if there was a corresponding technological difference. The structure-property-processing relationships were determined to show the ecological and cultural factors important in manufacture, and the degree of similarity and variation in these two Neolithic ceramic technologies. Inferences are made about the methods and sequences of manufacture, and the pattern of motor movements. Ceramic-forming technology is reconstructed, and some of the problems faced by potters deduced. The results of the examination indicate that these two ceramic technologies, although different from each other, are more conservative than previously thought. It is clear that the available raw materials and the environment in which they occur are factors which interact with culturally determined ways of making pottery to create the final product.

INTRODUCTION

Differences in the technology of metals production in China and the Near East have often been described (Franklin 1985: 279–296; C. S. Smith 1981: 123–173, 191–206, 258–271; Gettens 1967: 205–212; Steinberg 1968: 9–15; 1977: 53–86; Lechtman and Steinberg 1968: 5–37), but little attention has been given to comparative ceramic production in these two regions. This neglect is surprising because ceramics, being durable although brittle, are present in great quantities at ancient sites; a conservative estimate of the ratio of metal artifacts to whole ceramic vessels at Near Eastern sites in the fourth and third millennia B.C. is one to ten thousand (Vandiver, unpublished study). The disparity can be explained by the relative rarity of metal objects in antiquity, the reuse of metals, and the corrosion of metals to their more stable form as oxides. Only a few ceramic artifacts were, however, recycled. If they attained rocklike hardness during firing, when broken they could have had only limited uses, for example, as covers, jar lids, roofing material, scrapers, or temper. If fired at a low temperature and buried in a moist environment, they reverted to clay.

Concentration on technical studies of metals rather than ceramics may be explained historically, in that in many cultures, including our own, great value has been attributed to metals. Their rarity among archaeological finds compared with lithic and ceramic artifacts is compelling, but we have also projected our view of metals as precious onto prehistoric occurrences, so that they have become desirable objects of study. Cyril Smith (1981: 112–113) in questioning this retrospective valuation hypothesized that early experimentation with metals in the Near East produced decorative objects. In China, on the other hand, early bronze technology was devoted primarily to the production of agricultural implements (Rawson, in press). Research on China and the Near East has shown differences not only in the purposes for which various metals are employed but also in the value placed on the metals themselves (Franklin 1985).

The nature of analytical techniques has also influenced studies of metals and ceramics. The structure and composition of metals have been amenable to a range of analytical techniques for a hundred years, because they have a larger grain size and greater chemical homogeneity than ceramic artifacts (C. S. Smith 1960: 129–245; 1981: 68–111). During the past sixty years ceramics have been investigated using three different approaches: visual examination, technical evaluation of date and composition, and technological reconstruction based on ethnographic data or theoretical considerations. Visual examination based on macrostructure (that is, structural and textural differences on a scale greater than 0.1 mm., which is just resolvable with the unaided eye) has enabled archaeologists and art historians to compare shape, rim profile, design motifs, and texture and color of fabric, slip and/or paint, in order to classify sherds or whole vessels (for example, Petrie 1921 and 1956; Delougaz 1952; Hole 1977: 24–37; Hole et al. 1969: 106–169; W. Y. Adams 1986). Problems related to sampling have usually prevented classification of the entire excavated sherd assemblage. The basis of sampling—the criteria by which diagnostic sherds are defined—is rarely explicitly stated (R. McC. Adams 1981: 40, 43–50, 301–322). Frequently, one or only a few sherds which are comparable stylistically to those from another site are singled out as evidence of contact or of cultural interaction without analytical standards established for each site or region. Recently, however, visually derived classifications of ware types have been studied in relation to methods of manufacture (Bourriau 1981: 8–56; 1985: 27–42; Henrickson 1986: 87–132; Van der Leeuw 1976; Franken 1974; Franken and Kalsbeek 1975), firing temperatures (Matson 1971: 65–79; 1974: 34–47; Kingery 1975: 204–207; Tite and Maniatis 1975: 122–123; Tite et al. 1982: 109–120), or identification of aplastic mineral inclusions (Shepard 1954: 156–167; Betancourt 1984; Rice 1981: 219–240; Rice and Cordell 1986: 273–296).

A second traditional method—studies of provenience by characterization of chemical composition (usually considered with dating as the basis of archaeometry)—has four general components: determination of bulk composition (Jones 1986; Pollard and Moorey 1982: 45–50; Freestone 1982: 99–116), trace element composition (Sayre 1957: 35–41; Perlman and Asaro 1969: 182–195; Harbottle 1982: 67–78; Hancock 1984: 199–209), isotopic ratios (Brill and Wampler 1965: 155–166), and mineral inclusions (Farnsworth 1964: 221–228; 1978: 1–20; Shepard 1954: 156–167; 1971: 55–64; Peacock 1977; Kamilli and Lamberg-Karlovsky 1979: 47–60). These studies are done to see if visually similar classes can be further subdivided and if dissimilar types can be regrouped. A connection is not usually made with the geological source materials (although there are exceptions, Abascal-M et al. 1974: 81–99; Bishop 1986: 47–66; Blackman 1985) and even more rarely with production technology (Betancourt 1984: 54–167).

Third, forming technology is usually not employed to provide additional discriminating factors in stylistic studies; if it were, hypotheses about workshops and craft organization could be developed (deAtley 1986: 297–330; Wright 1986a, b: 1–20; Henrickson 1986: 87–132). Macrostructural criteria have been applied to a small sample of different ware types to determine "the" methods of manufacture, decoration, and heat treatment; occasionally ethnographic material is related (Wu 1938: 4–5, 37; Zhang 1986; Betancourt 1984: 130–163; J.-F. Jarrige in Jarrige and Meadow, forthcoming). The analysis is often not detailed enough to determine the sequence of manufacture and the technological range of variation, so that technological criteria could serve as the basis of a typology. Reconstruction of the technology is necessary in order to understand how ancient people were making pottery. Occasionally, replication studies are done (Noble 1965; Richter 1923; Hodges 1983; Matson 1971), but more often interpretations are based on modern perspectives or contemporary ethnographic data. Standards for the critical processes, properties, and constraints of raw materials must be established.

Without knowing the total available sample and its bias, without understanding the technological range of processing, and without modeling the critical properties, students of technology have not gained the insights into cultural behavior which they could. In addition, existing technological studies do not go beyond the details of the technology to place it in economic or social context (Smith and Reber 1986: 1–18). Most ancient ceramic technology has no historical context (with the rare exceptions of the source of cobalt blue, Watt 1979: 63–85; and the introduction of Korean potters into Japan, Cort 1986: 331–362). Even when modern economic (Cort 1979) or ethnographic (Kramer 1982) evidence can be related to ancient practice, caution should be exercised because evaluating an ancient developmental situation in the light of a well-established or degenerate modern technology is questionable. The reliability of historic and ethnographic data, and models of socio-economic and technological transfer and innovation, must be determined before theoretical considerations can be synthesized with technical and analytical studies. As Lynn White has remarked (e.g., 1962: 486–500), we are just beginning to assemble the bare facts needed to build a history of a technology, and cultural interpretation seems far away. Perhaps establishing the context of technology should be the goal of current work, rather than elucidating details (Smith and Reber 1986: 1–18).

The techniques of modern materials science which have proved successful in studying electronics, metals, polymers, and high-tech ceramics are rarely applied to ancient ceramics (Kingery and Vandiver 1986: 3–5, 51–208). The paradigm of modern materials science is that the processing of raw materials in specified ways produces particular macrostructures and microstructures which in turn result in specific properties (Fig. 1). The information from both macrostructure and microstructure is integrated to discover relationships among structures, properties, and processes (Cohen 1978: 17–26, 41–49). The only part of ancient ceramics left to study is the structure. We do not know the processes used in manufacture or the properties which were desired in the final products, but we can determine, on increasingly finer levels of scale, the compositions and phases which make up each part of the structure. Only

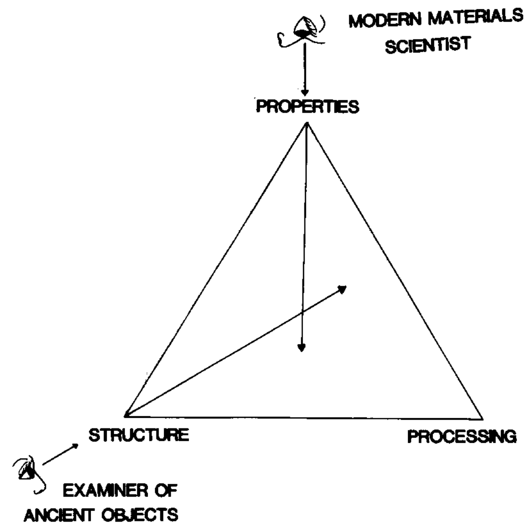


Fig. 1. The relationship between processing, properties, and structure

through the structure can the range of potential properties and processes be explored. Once this range is understood, the methods and sequences of manufacture can be established; suggestions can be made about selection and use of raw materials; and the resulting properties can be evaluated. Properties relate to function. Processes are not only the choice of raw materials or of method of manufacture—they are the way people work using technology.

A corollary to this method of analysis, discussed in *Archeomaterials* by Cyril Smith (1986–87: 3–11) and David Kingery (1986–87: 91–99), is the study of the continuum of structures, from macrostructure to microstructure to atomic structure, with each level of scale permitting new insights. Heterogeneities at each level of structure must be identified physically and chemically to understand the technology (Pye 1968: 4–34, 39, 54, 70, and plates; Smith 1981: 54; Morrison 1978: 54–70; Morrison et al. 1982: 1–17). A working knowledge of particular materials, their range of processing, both theoretical and reconstructed, and the resultant properties can show how things were made. As early as 1911, Louis Franchet recommended that a technological typology be established (*Céramique Primitive: Introduction à l'Etude de la Technologie*).

RELATIVE POROSITY PRODUCED BY DIFFERENT FORMING METHODS

MODELING, HAND FORMING ≃ TURNTABLE (SLOW WHEEL OR TOURNETTE) ≥ POTTER'S WHEEL (OR FAST WHEEL), JIGGERING OR JOLLYING OF OPEN FORMS > SLIP CASTING OF CLOSED FORMS > ISOSTATIC OR HOT PRESSING

Fig. 2. A scale of the differences in relative porosity produced by different forming methods. Lower forming pressures result in greater porosity.

VARIATION IN FORMING TECHNOLOGY: A TALE OF TWO POTS

This study began because little work has been done on the earliest pottery, coarsewares, which should yield more information about production techniques than the later more elaborately decorated finewares (Matson 1983). This emphasis requires the consideration of several issues. First, pottery should not be seen only as a chronological or economic indicator, but also as a technological one. Anna Shepard has noted that pottery typologies based on visual attributes tend to hide technological variables (1954: 181–182). Second, the process of manufacturing pottery leaves a record of individual motor movements, and the repetition of these same patterns in making other artifacts can be determined using a combination of scientific methods. Third, studying the principles of construction and the organization or sequence of building pottery allows culturally transmitted patterns of behavior to be elucidated. Fourth, an understanding of raw materials, processing, and properties shows which technical problems were central concerns and how they were avoided or solved.

Porosity as a Clue to Understanding Pottery Forming

Porosity is caused by the voids or air spaces left in a clay body when it is mixed with water. Large voids or bubbles may result from poor mixing, and small voids may occur where the water has not completely wetted the interstices between the agglomerated clay particles, aplastic inclusions, and tempering materials. Porosity also may be introduced during handling and forming. The amount of porosity decreases with increased forming pressure,

$$\text{Porosity} = \propto \frac{1}{(\text{Forming Pressure})^{x}}$$

where x depends on the forming process. The amount of porosity in a ceramic object depends on the method of forming (Fig. 2). Modeling and handforming, even on a turntable, require less forming pressure than wheel throwing or industrial rotation processes like the jiggering or jollying of open forms. (Jiggering involves ribbing the upper surface of a preformed clay disc as the lower surface, the interior of the form, is pressed onto a male mold; jollying is the opposite process using a female lower mold.) Throwing (that is, the process in which a wall is raised by centrifugal force) produces less porosity than does modeling or handforming, especially along joints. Slip casting of closed forms results in greater forming pressure and less resultant porosity than throwing. Pressing operations apply the greatest forming pressure and produce the least porosity. A secondary forming process, such as beating or paddle and anvil techniques, further compresses and aligns the pores and clay particles.

The shaping process affects not only the total amount of porosity but also the alignment of pores, which is indicative of the type of forming and of the details of the forming process (Fig. 3). Evenly spaced horizontal rows of horizontally elongated pores parallel to the wall of the pot indicate coiling; a fairly even distribution of pores elongated in a consistent diagonal direction, throwing; and pores with a random orientation distributed around discrete blocks of clay material, slab building (Rye 1981: 58–94). Observations critical in identifying construction processes can be made by examining vertical and horizontal fractured cross sections for the direction and

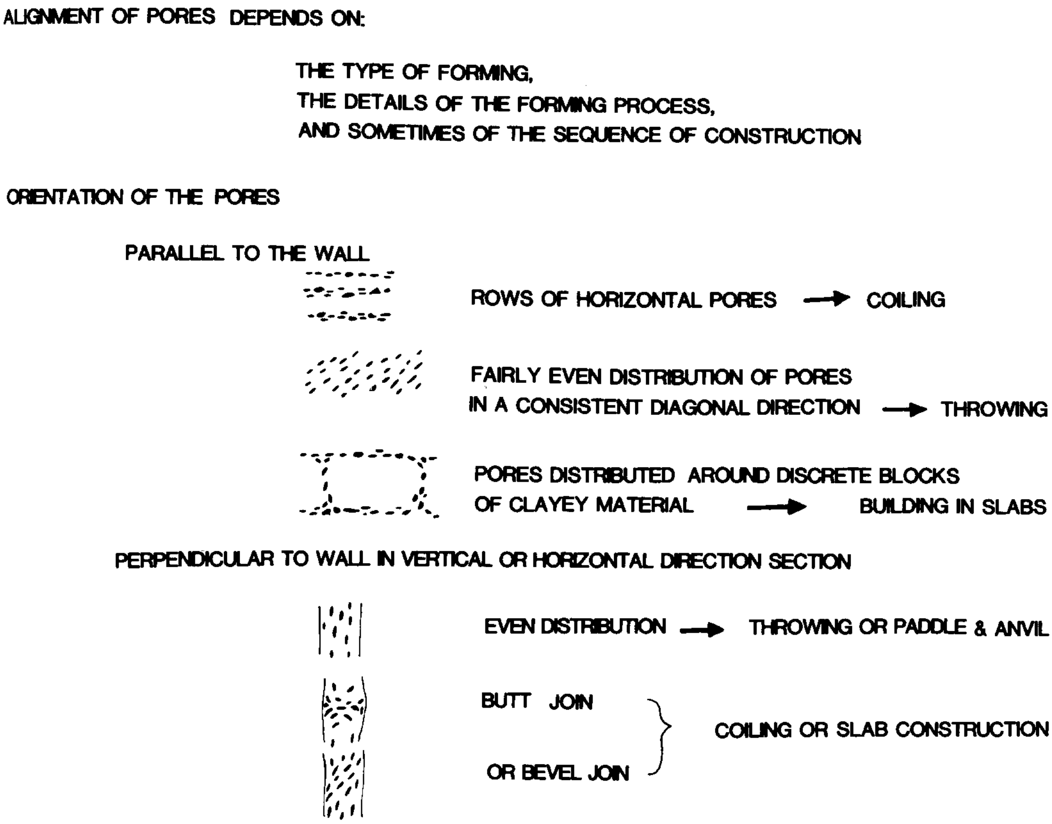


Fig. 3. The interpretation of the distribution and orientation of pores

degree of pore elongation, the distribution of pores (that is, whether even or grouped), and butt, bevel, or more complex joins. Joints are more apparent in a vertical than in a horizontal section, because the lower part in a vertical section tends to be drier than the upper part; this disparity, if considerable, leads to differential shrinkage during the drying of the clay body. In a horizontal section, the clay tends to have the same degree of wetness during the joining. Considerable differences in the wetness of the clay body lead to differential shrinkage during the drying, which can cause pores and cracks to develop. In a fine particled clay, such as a montmorillonite in which clay particles often measure one-tenth micron, this effect is amplified because there are more water films per unit length. The linear drying shrinkage can amount to more than 15 percent in a montmorillonite, but is usually about 5 percent in a coarse particled, tempered clay body (Singer and Singer 1963: 69; Grimshaw 1980: 546).

The placement, regularity, and morphology of porosity must be known to determine the method of manufacture. Examination of the surface texture (Pye 1968: 45–58; Shepard 1954: 181–213) and of the edge fracture of sherds in a raking light reveals joins in the walls of preformed elements used in the construction of the pot (Fig. 4). Where joints were formed, the wall may thicken, particularly if wet clay and somewhat dry clay were joined, or the wall may thin slightly if the join has been worked or the preformed elements thinned at the edges. Often a crack or even a large void occurs at a join. Sometimes the crack continues on the external surface along the join, because the area tends to be more porous and sometimes is thinner in cross section, and thus is more likely to fracture. Other features which are indicative of joints are

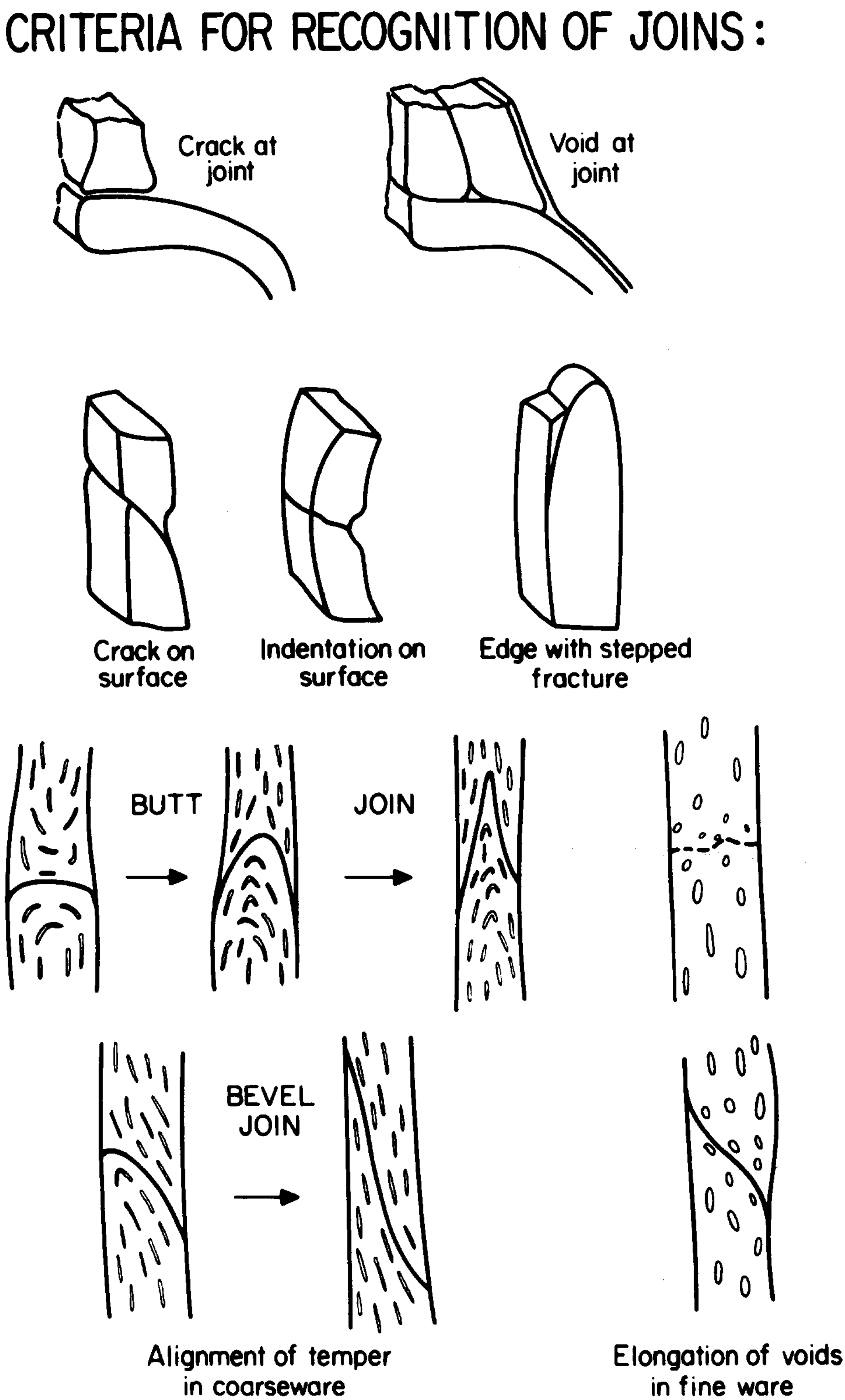


Fig. 4. Identification of joins

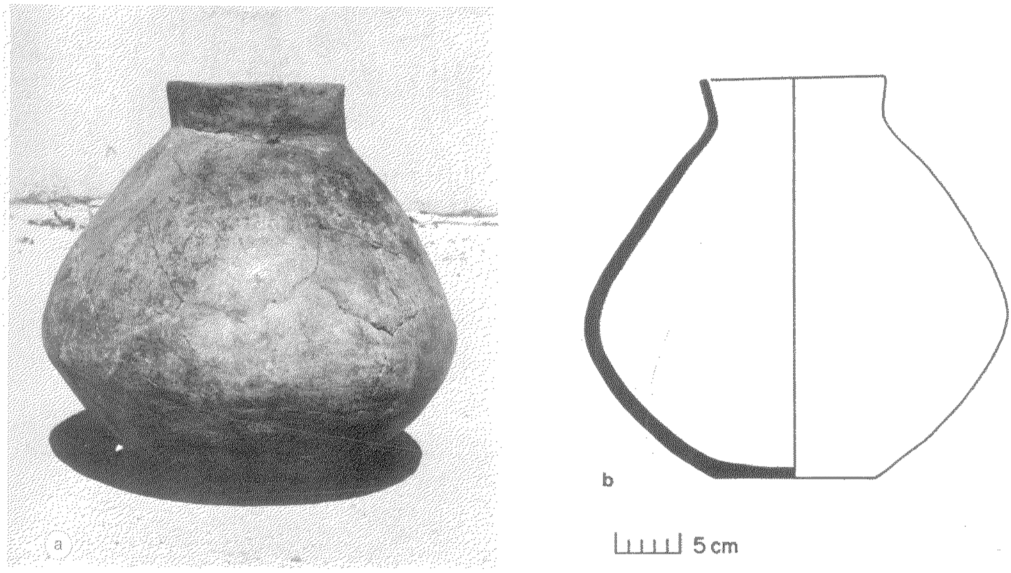


Fig. 5a–b. Hajji Firuz coarseware jar, view and profile. (Drawing from Voigt 1983: fig. 96C)

step fractures and the alignment of burned out vegetal material or chaff, or voids caused by pores in the clay body which occur at joins (Fig. 4 below). The distance between joins in edge fractures can be measured to determine the size of preformed elements in different parts of a pot, and these intervals can often be correlated with the surface texture. In addition, the spatial distribution of slabs or coils can be determined using xeroradiography to look into the wall of the pot (Alexander and Johnston 1982: 145–154; Glanzman 1983: 163–169; Glanzman and Fleming 1985: 114–121; Vandiver 1985: 75–86, 143–233). Xeroradiography—the exposure of an electrostatically charged selenium plate so that charge dispersal is dependent on density gradients—has the advantage over traditional film radiography of image enhancement at edges and density gradients which allow recognition of placement, alignment, and amount of porosity, and by extrapolation, understanding of the method of manufacture.

A pot which is light in weight and easy to handle requires a thin wall of fairly even thickness. During the building process, a plastic clay wall will support only a given amount of added material before it slumps, thickens, and eventually buckles and cracks. Thus, most large or handbuilt pottery is constructed in sections, with each section left to dry partially before the next addition is made. Recognition of section joins is important in the analysis of the sequence of manufacture. The larger the pot, the more immediate is the problem of keeping the base thin, and the higher the probability that it was built in sections. In general, utilitarian wares, such as those used for storage and cooking, tend to reveal direct evidence of manufacture more readily than ceramics made in imitation of stone or metal forms.

A Near Eastern Storage Vessel of the Sixth Millennium

Pottery was made and used by Neolithic farmers in Southwest Asia starting about 6400 B.C., as shown by the appearance of large quantities of sherds (Mellaart 1970; Watson 1965: 82–83) and the method of manufacture—sequential slab construction—is the same over a large region and span of time (Vandiver 1985: 143–281). It was practiced at Hajji Firuz, settled just after 6000 B.C., in the Solduz Valley of northwestern Iran, an area where a great diversity of resources permitted sedentism (Voigt 1983: 1–10, 295 f., 311 f., 249 f.). Subsistence was based on the cultivation of wheat (probably bread wheat), barley, and lentils, supplemented by collecting wild

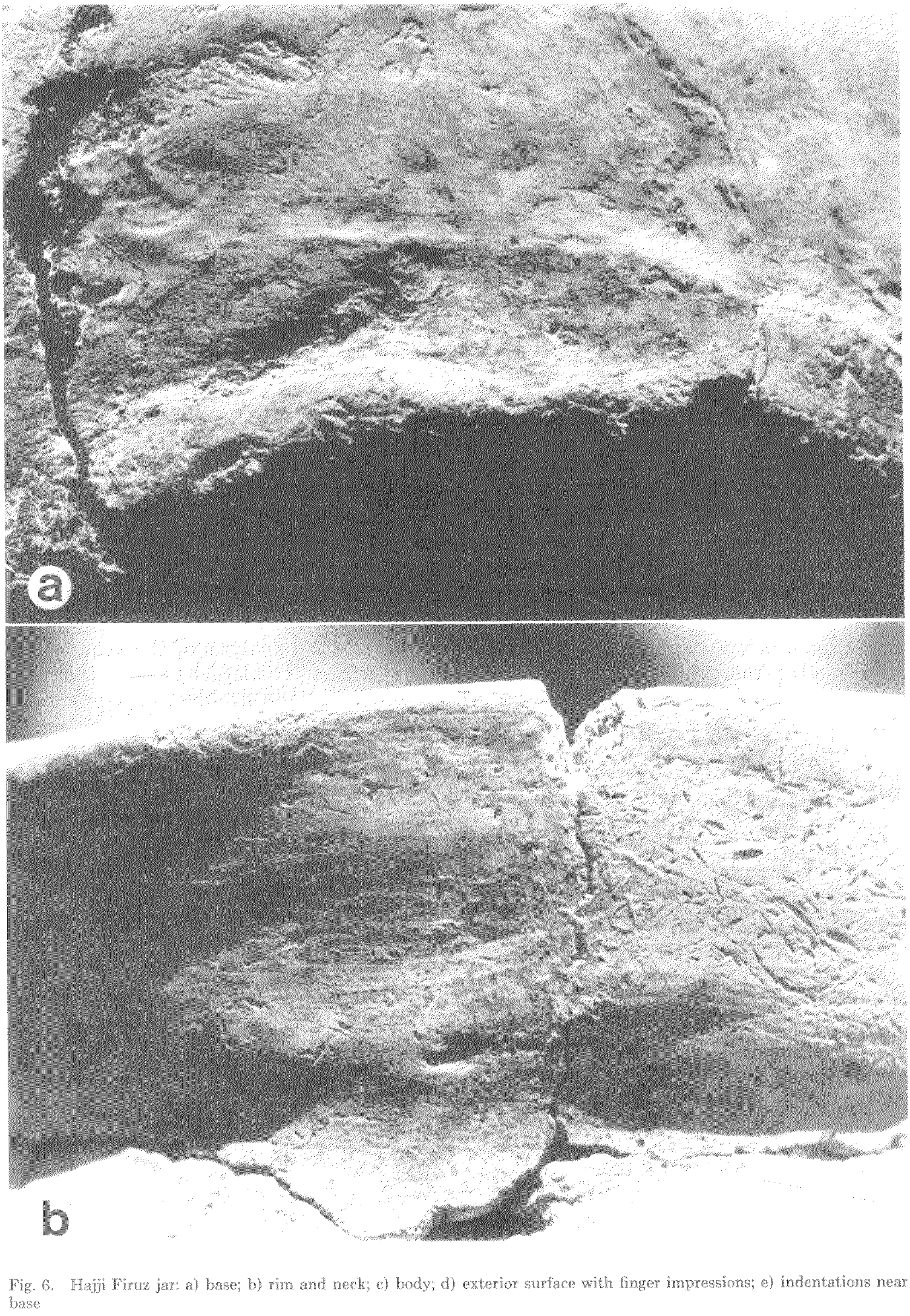


Fig. 6. Hajji Firuz jar: a) base; b) rim and neck; c) body; d) exterior surface with finger impressions; e) indentations near base

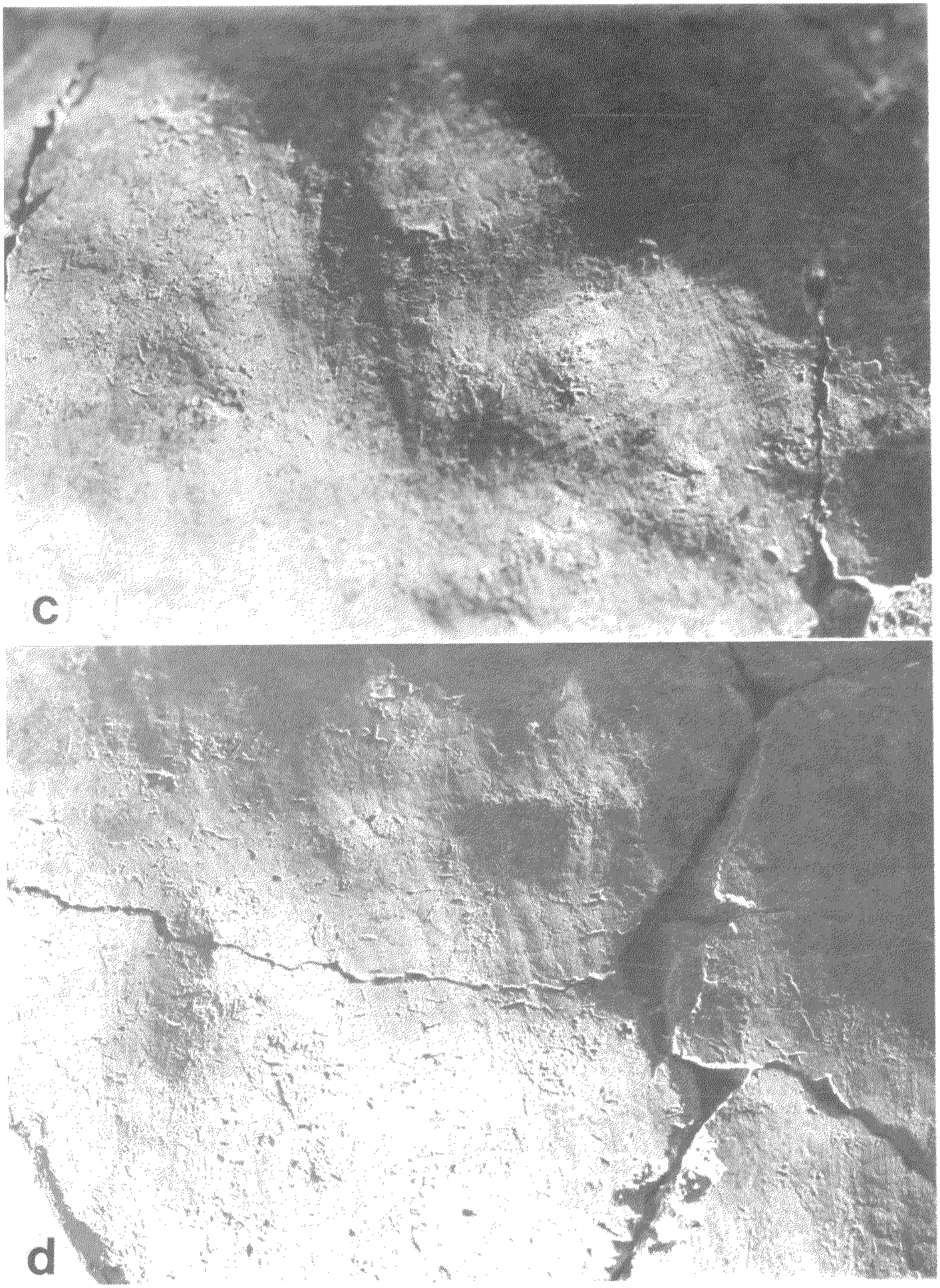


Fig. 6. Continued

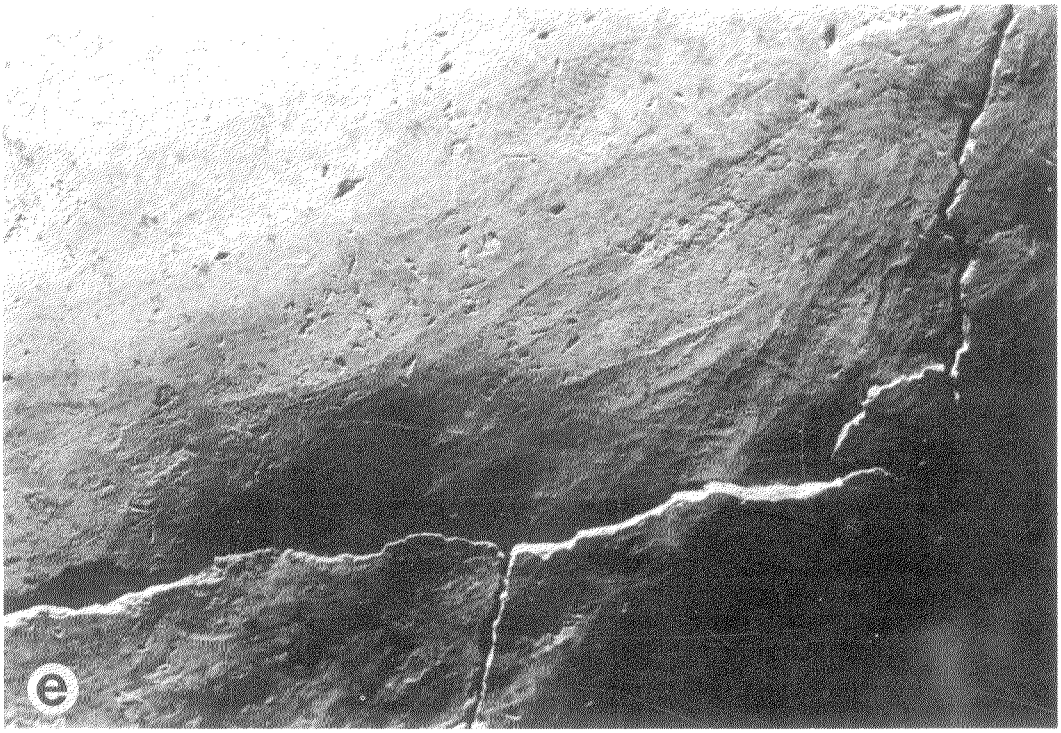
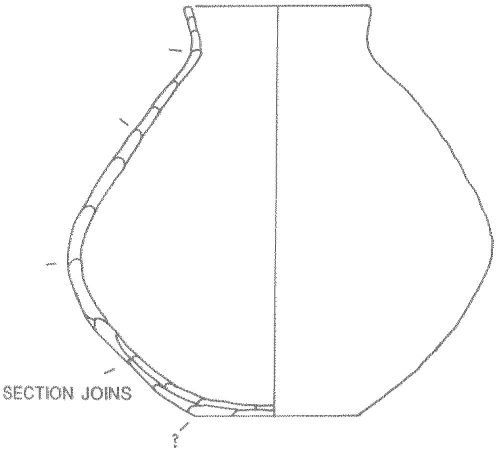


Fig. 6. Continued

plants, hunting, and herding sheep, goats, and pigs. Houses three to six meters square were constructed in packed mud (*tof*) or mudbrick. Fired clay vessels were used for storage, cooking, and serving, and rushes were made into baskets. Artifact types (and implied economic and social function and organization) resemble Hassuna-type assemblages, even though the site of Hajji Firuz is about 500 years later in time; Voigt suggests that settlers at Hajji Firuz migrated from the west.

The large collared jar shown in Figure 5a (University Museum No. 69-12-15, field no. HF68-205 from Phase A_3, Structure V_I, Room 2, F10(4C) (3A) (20); H. 31.2 cm.; rim D. 14 cm.) had been broken and employed as the base for a hearth (Voigt 1983: 132–133, fig. 86b). The vessel was probably originally used as a dry storage vessel, judging from its large size, closed shape (into which a hand can nonetheless be easily placed), and relative permeability. The reassembled vessel is asymmetrical; the body is bulbous with a low maximum diameter in line with the center of gravity and below the center of mass, so the pot is very stable (Fig. 5b). The rounded lower body makes the pot easy to rotate, move, and carry. The base is flat with a thickening of the wall where it joins the lower body (Fig. 6a). The rim and neck are constricted in a shallow ring, and the edge of the rim changes from rounded to squared off. There is an undulation in the surface and profile of the neck which is difficult to show in the profile drawing but which can be seen in a raking light (compare Figs. 6b and 5b). In addition, there is a larger undulation in the body (Fig. 6c, the profile in a raking light). The exterior surface, although now worn, has patches of the original burnish (Fig. 6d) and also fine rectangular and ovoid depressions caused by burned out vegetal temper (Figs. 6b and 6d), such as chaff, grass, or straw. There are finger impressions from pressing slabs together (Fig. 6d), and also four indentations of about 5 cm. in diam-



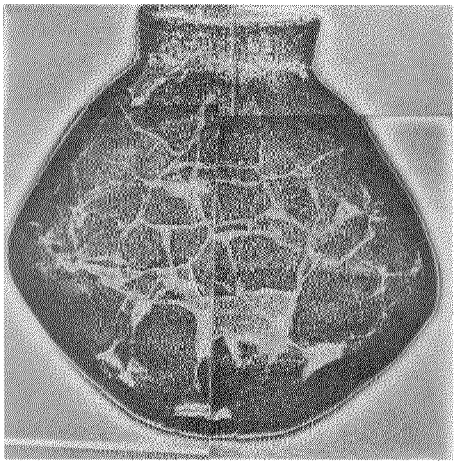
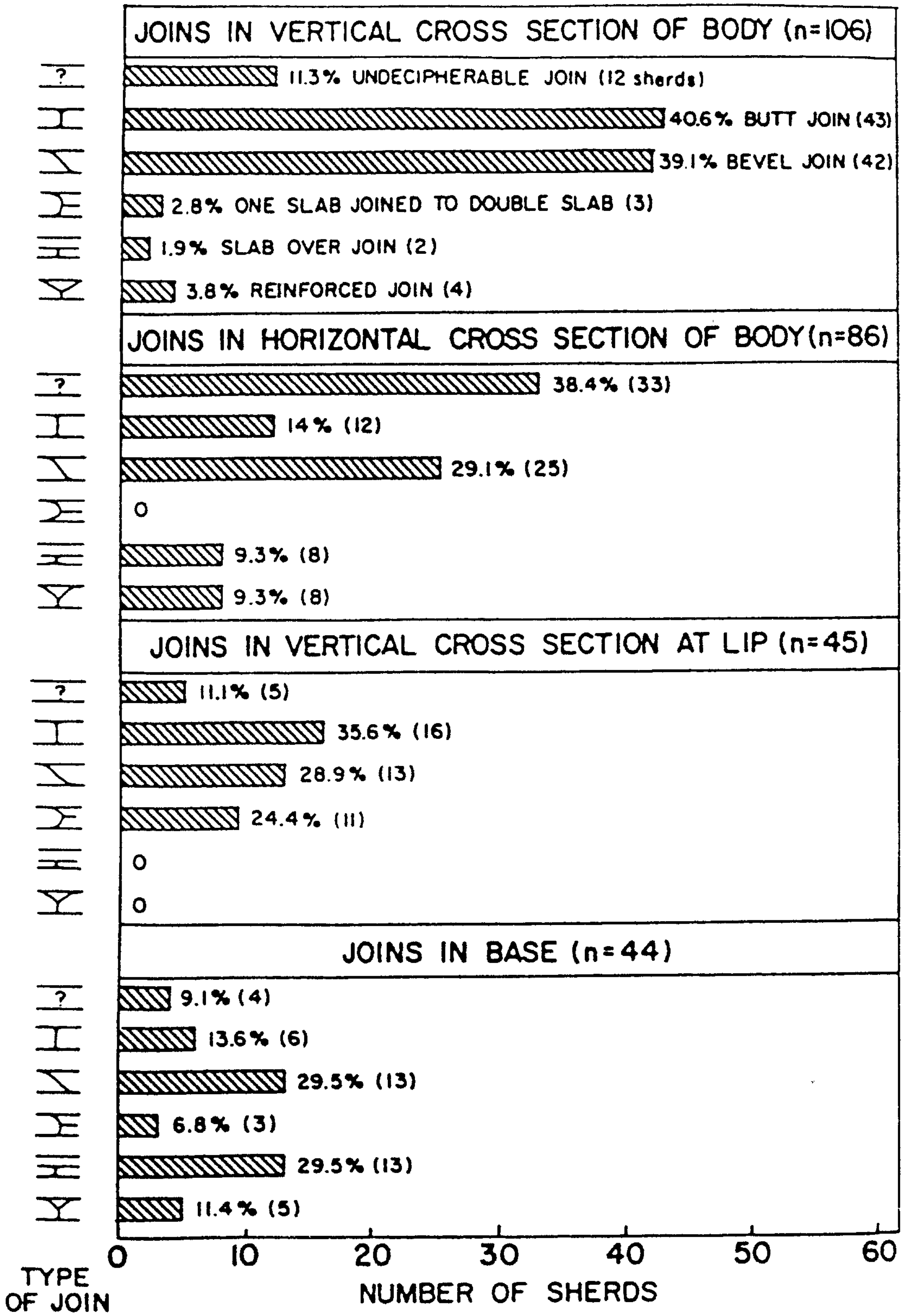


Fig. 7. Hajji Firuz jar, drawing of joins and xeroradiograph

eter near the base, one of them double (in the center of Fig. 6e), probably from handling of the pot while it was partially dry. The interior is matte and worn from use. The body fabric is gray in the middle with buff layers near the outer and inner surfaces. The wiped and burnished exterior finish has a slightly lighter color.

The gray core and oxidized surfaces indicate a rapid low-temperature firing, with the chaff burning slowly in reduction in the initial stages of firing, followed by oxidation at the peak of firing and during cooling which resulted in the reddish-buff oxidized color of the surface layers. The chaff temper consists of linear elements about 1–20 mm. in length by 0.1–3 mm. in width, with ends cut diagonally or perpendicularly; it was chopped intentionally. Vegetal temper, added in a volume of about 15 percent to the clay body, is fairly evenly distributed across the wall thickness. Dung additions would have left impressions of vegetal material split at the ends, with the fibers divided by chewing (Vandiver 1985: 125–131). The surface has been wet-smoothed, as evidenced by submillimeter parallel wipe marks between some burnish marks and in indentations. Either a viscous slip made from the same clay was wiped over the outer surface or a clay-containing wash was added. The surface layer, not distinguished by composition or particle size from the base clay, was probably wiped to produce a fine, smooth texture in preparation for burnishing. Its thickness varies from 0.5–4 mm. in the interior corner.

Examination of the edges of sherds through the cracks in the mended vessel showed that there are step fractures, voids, and indentations which indicate the existence of joints (cf. Fig. 4). In addition, the pores left by burned out vegetal temper are aligned parallel to the wall except at joints. When the information gained from examination of sherds is taken with the pattern of undulations in the surface, the preformed elements used to construct the pot become obvious (Fig. 7). Examination of one group of 195 ultrasonically cleaned sherds from Hajji Firuz showed similar join patterns. Both butt and bevel joins were used, and the bases had more complex joins with a double or triple thickness in the wall (Fig. 8). Evidence that the pottery was built in sections over a period of time is found in the periodic horizontal section joins which give a discontinuous surface texture, wall thickness, and porosity. It is more difficult to identify joins in the horizontal cross section than in the vertical one due to differential shrinkage. Measurement of the length and thickness of preformed elements shows that smaller ones were used for the necks and rims than for the body and the bases, with smaller slabs at the top of each section. In Figure 9 the ratio of length to thickness is plotted against the number of preformed


JOINS IN VERTICAL CROSS SECTION OF BODY (n=106)
11.3% UNDECIPHERABLE JOIN (12 sherds)
40.6% BUTT JOIN (43)
39.1% BEVEL JOIN (42)
2.8% ONE SLAB JOINED TO DOUBLE SLAB (3)
1.9% SLAB OVER JOIN (2)
3.8% REINFORCED JOIN (4)
JOINS IN HORIZONTAL CROSS SECTION OF BODY (n=86)
38.4% (33)
14% (12)
29.1% (25)
0
9.3% (8)
9.3% (8)
JOINS IN VERTICAL CROSS SECTION AT LIP (n=45)
11.1% (5)
35.6% (16)
28.9% (13)
24.4% (11)
0
0
JOINS IN BASE (n=44)
9.1% (4)
13.6% (6)
29.5% (13)
6.8% (3)
29.5% (13)
11.4% (5)
0
10
20
30
40
50
60
TYPE OF JOIN
NUMBER OF SHERDS

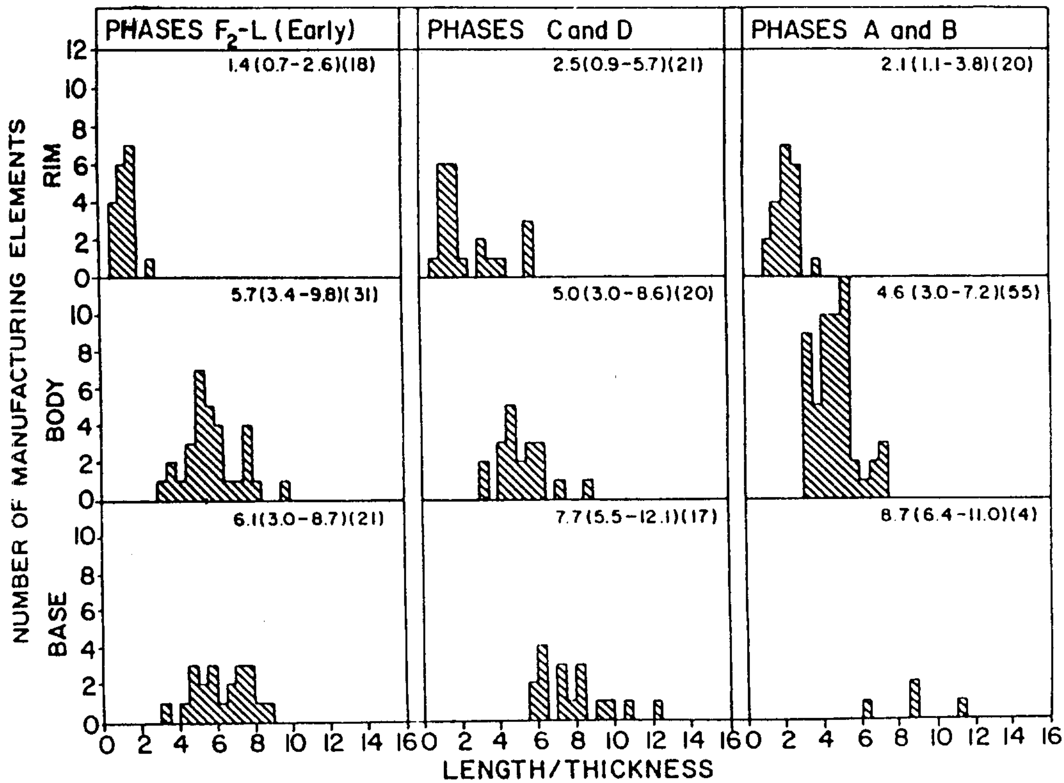


Fig. 9. Measurement of Hajji Firuz coarseware slabs showing the relative sizes of manufacturing elements used in base, body, and rim. In the upper right of each section, the mean, range, and number of elements are reported for plain buff coarseware and a few samples with fugitive red paint.

manufacturing elements in order to compare different sizes of vessels.

This almost random or organic method of construction using handfuls, bits, and lumps to build up a section, which is allowed to dry partially before the next section is added, is apparent in the xeroradiographic image (Fig. 10 above) (drawing after Voigt 1983: fig. 96c). The dotted circles at the section joins indicate finger impressions which are superimposed on the interior surface and are more prominent in the xeroradiograph than the joins. This sherd was sliced like bread to produce a set of cross sections; each slice was also xeroradiographed. Individual slabs can be seen to begin, grow, and end in the drawing shown at the bottom of Figure 10a. The section join is shown at the indentation on the interior of the sherd as a horizontal white line of low density in the xeroradiograph and as a join between slabs a and a′, and k, b, and c in the drawing of the cross sections (Fig. 10 below). Replication of this method of construction was undertaken with similar clays, and the product was analyzed with xeroradiography and optical microscopy (Vandiver 1985: 132–137). The results are comparable, thus proving that sequential slab construction was in fact practiced.

A composite of four xeroradiographs of the Hajji Firuz storage jar is shown in Figure 7b. Ignoring all the mended crack lines, one sees four concentrations of porosity in

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Fig. 8. Plot of Hajji Firuz coarseware pottery showing how the frequency and type of joins in 195 sherds vary from one part of the pot to another (all over 500 mm. long, from Operation V [1961], Phases F_2-L [early phases])

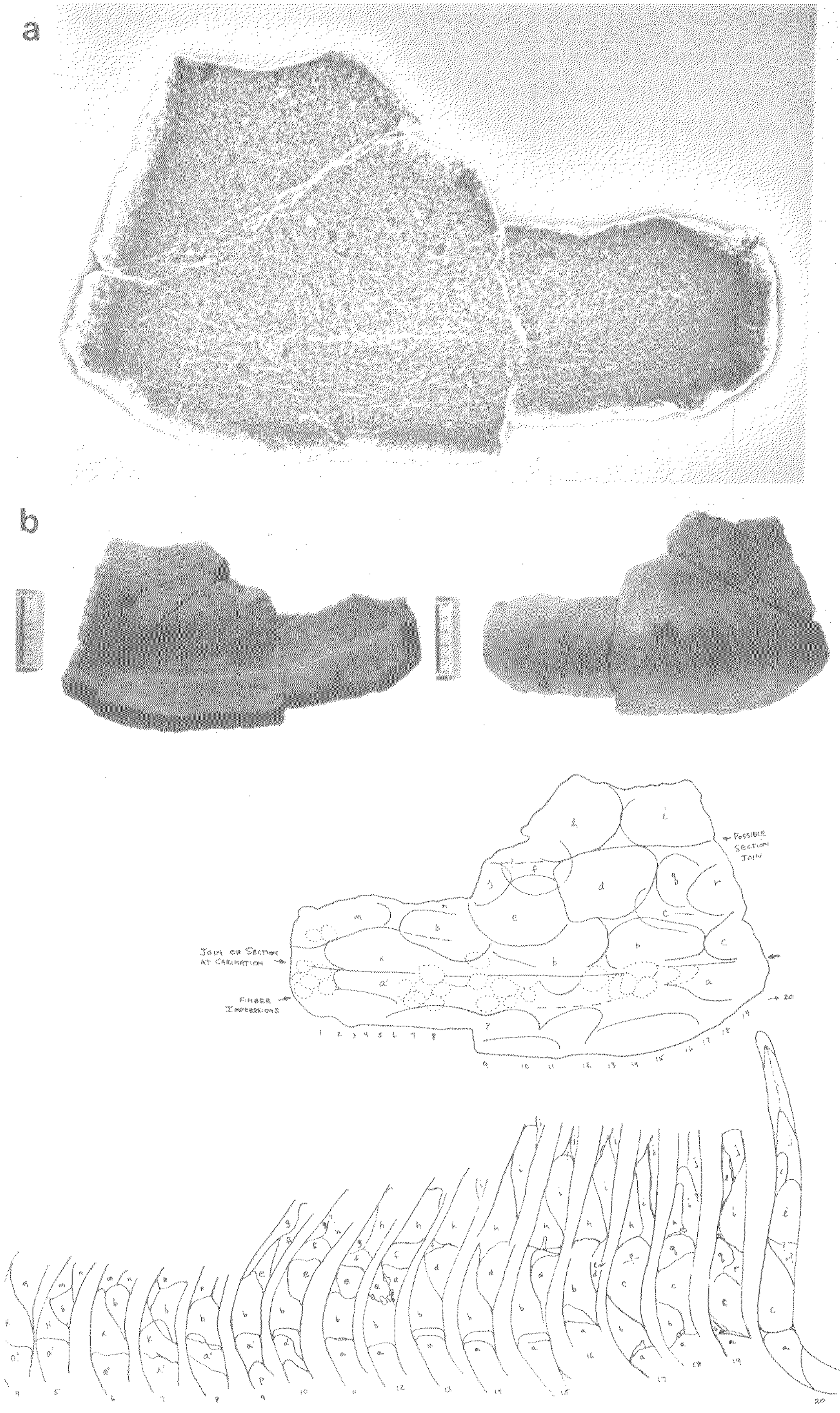

Fig. 10. Hajji Firuz jar sherd, xeroradiograph and drawings showing joins

lines across the lower body, the widest part, and about one-half to two-thirds of the way up toward the neck, as well as one at the join of the neck and body; the pot was clearly built in five sections (Fig. 7a–b). However, because we are looking through two thicknesses of the pot, the situation is more difficult to interpret than in the cross sections. The placement of individual slabs or lumps is consistent with a construction technique of larger, multiple-layered slabs at the base, small flattened handfuls of clay in the body, and even smaller bits in the neck and at the rim.

There is also some evidence for the use of a mold. The base was made with two layers, the inner one of which can be seen through a fracture in the base. Some sherds from Hajji Firuz have a negative basketry impression on this inner layer, with a less well-defined positive one on the exterior layer. These facts, as well as the knowledge that it is difficult to construct a wall on a 45° cantilever, led Voigt to conjecture that this pot was initially formed in an open face female mold, perhaps a hollowed-out bit of ground rather than a basket. The pot was turned over when the lower sections could support their own weight and slabs were added to form the base and heel, before the upper wall was constructed.

In order to differentiate the method of manufacture from the modern conception of pottery production as limited to slab or coil building in which the element size is constant, or to throwing—descriptions which are uncritically applied to ancient ceramic technology—Kingery and I have called it sequential slab construction (Vandiver 1985). Coils have a fairly constant thickness, with a height to thickness ratio of 1:1 to 3:1, and are arranged in the same way on successive vertical cross sections: there is often a texture of horizontal furrows and ridges on the interior surface, but rarely on the exterior, caused by the finishing operations. A preformed coil set in place shows little deformation at the joint, but a coil which is thicker than the final wall, and therefore must be thinned after being put in place, has a join which disrupts the undulating surface texture, deforms the alignment of temper, and disturbs the structural integrity of the preformed shape. Pots made with strip-shaped slabs do not have these characteristics.

Evidence for sequential slab construction, with multiple-layered walls in the base built of rounded handfuls of clay and section construction in which the elements decrease in size with the elevation, is found in about 40,000 sherds from sites in the Zagros area, including Dalma and Pisdeli in Azerbaijan, Sarab, Ganj Dareh, and Seh Gabi in the central Zagros, Chagha Sefid in the south, and Tepe Yahya on the central Iranian plateau (Vandiver 1985: 143–235; Lamberg-Karlovsky and Beale 1985: 91–100). Sequential slab construction was also used to make Neolithic pottery from Hassuna, Samarra-type wares found at Hassuna, Halafian ware from Halaf and Chagar Bazar, and a variety of wares from Jericho, as well as ceramics from Mostagedda and Merimde in Egypt and Mersin in Turkey (Vandiver 1988; Vandiver and Lacovara 1985–86). A variant exists at Mehrgarh in Pakistan in which the elements were usually made in strips, the sizes of elements in each part of the pot are more regular, and butt joins predominate. In the Egyptian examples, many of the joins have been extensively worked to form bevels, and the shapes of the elements are more irregular and less like oval or rectangular slabs, often having a complex outline. Some sherds from Mersin contain grit with only minor vegetal temper. Sequential slab construction is a long-lived and conservative technology, being used for fineware manufacture in the Zagros region and Iranian plateau until about 3000 B.C. (Vandiver 1985: 236–276), with later examples from Seh Gabi in the second millennium (Henrickson 1986: 66–74). The technique is also attested in the ethnographic record in the Near East, in southwestern Turkey (Voigt, personal communication; Vandiver 1985: 138–142) and in a village near Mehrgahr (K. Jarrige, forthcoming).

A Northern Chinese Yangshao Storage Vessel

The basis for analyzing the ceramic forming technology of Neolithic China is different from that for the Near East, because

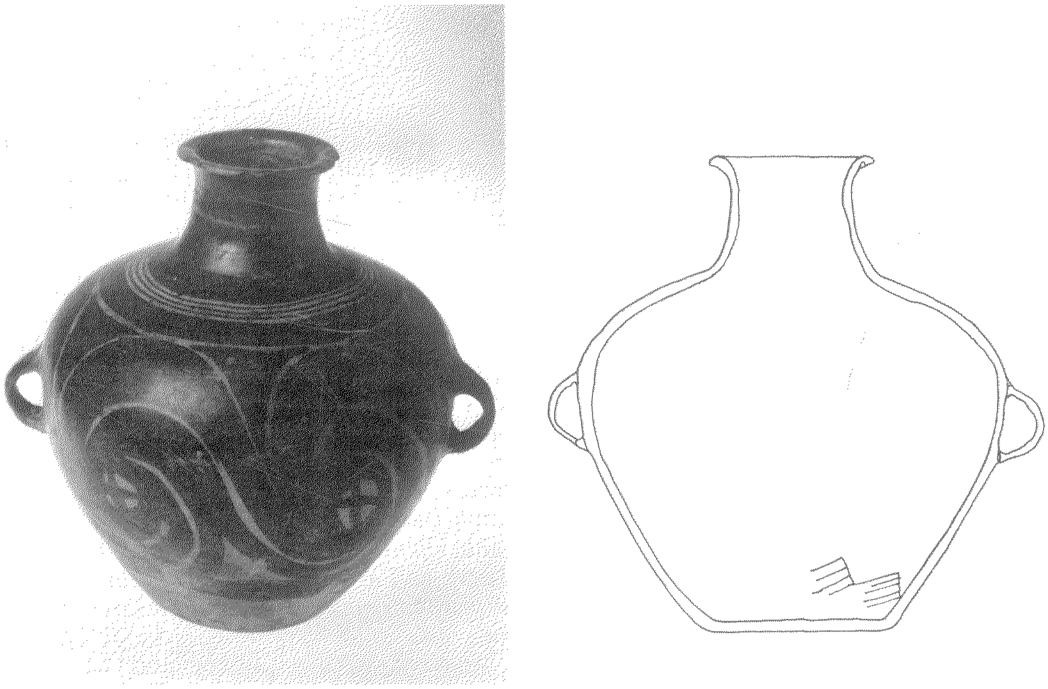

Fig. 11. Banshan vessel, Peabody Museum No. D2661, view and profile (D. 30 cm., H. 29 cm.)

Western collections of Chinese pottery contain only selected, unprovenanced examples of whole vessels and rare sherds which were usually acquired a long time ago. Five pots and about 100 sherds were studied intensively; one of the pots is discussed below. These vessels along with seven others are believed to be from Banshan (Pan-shan) in eastern Gansu (Kansu) province, probably from mortuary contexts. They were collected by J. Gunnar Andersson in 1924–1926, probably in Beijing, and sold to Langdon Warner with 23 others for the Peabody Museum, Harvard University. One has been dated by thermoluminescence to 3900–3600 B.C. (Huber 1981: 7–9).

K. C. Chang, in synthesizing results of excavations at several hundred Yangshao sites, noted a general cultural unity with no marked changes in typology over time (Chang 1986: 97). Farmers cultivated foxtail millet, and perhaps vegetables, using the slash-and-burn technique of swidden or semi-sedentary agriculture; dogs and pigs were the chief domesticates. Houses were semi-subterranean or at ground level with wattle-and-daub foundations (completely subterranean houses are much later). Cemeteries and pottery making areas were separated from the residential zones, and animal pens and storage pits were placed in the centers of villages, which indicates spatial planning and segmentation of work. There is evidence for fishing, hunting, and weaving of hemp and perhaps silk. The difference between the early and later Yangshao subphases relates to the nature of spatial organization, perhaps affected by population pressure. The Banshan pottery dates to the later subphase. According to Wu (1938: 87), the pottery comes in plain, painted, and relief decorated styles. The storage vessel discussed here (Peabody Museum No. 50.1961, D2661; Fig. 11) was probably a mortuary offering, although sherds from similar painted pots were found in living areas.

The body of the vessel is bulbous with

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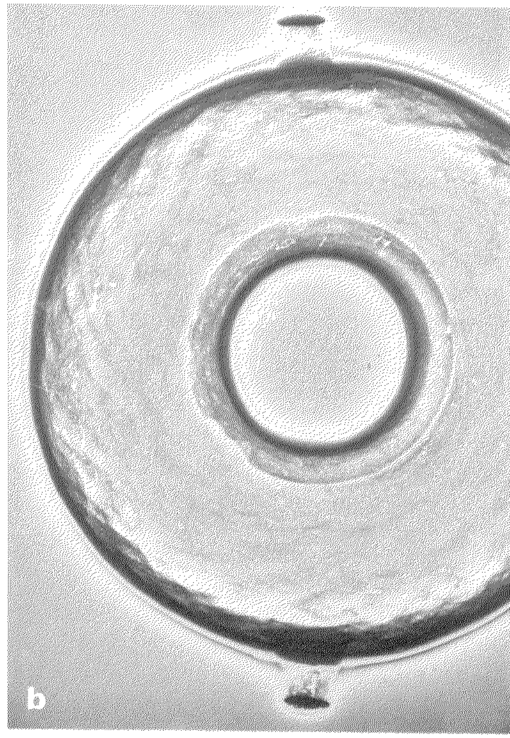
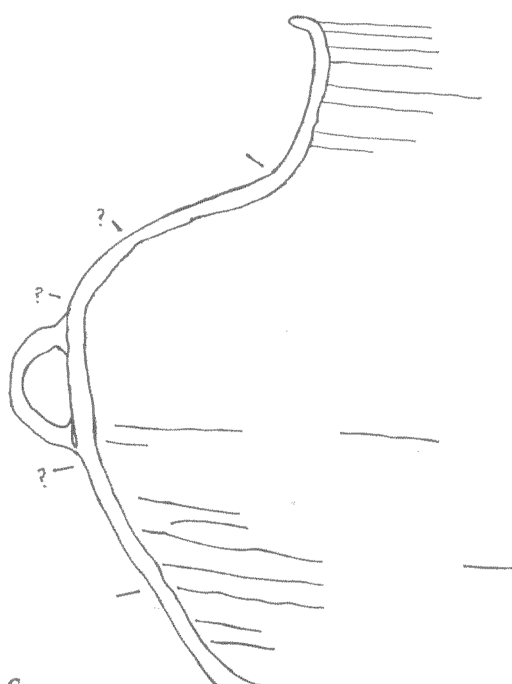


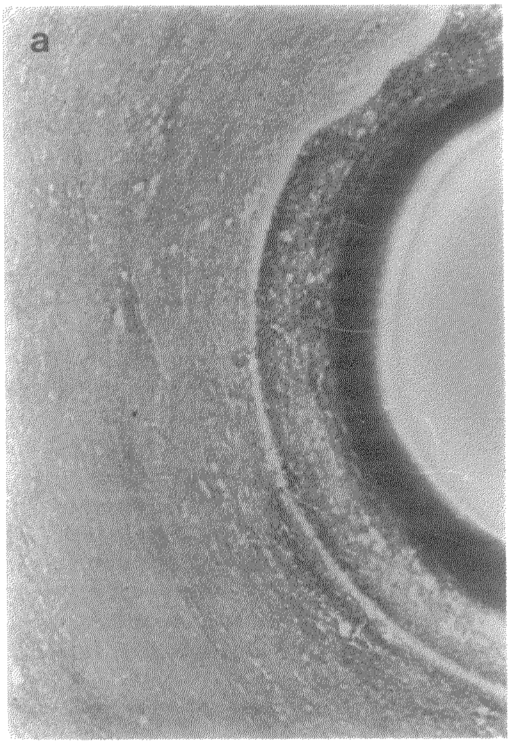
b

maximum curvature high on the shoulder, a slightly rounded bottom, and a collared neck with flaring or everted rim. Vertical loop handles are attached at and below the point of greatest diameter. The pot is about 30 cm. wide including the handles and 29 cm. tall, so it is smaller than the jar from Hajji Firuz. The body is somewhat asymmetrical (Fig. 11b). In a raking light, an undulation is visible on the interior of the neck in which swelling and narrowing occur in horizontal rings 6 to 7 mm. apart, a distance equivalent to the average wall thickness. The presence of preformed elements which are square in cross section and repetitive is indicative of coiling. The clay body has gritty inclusions, quartz and feldspar, and a very few small (2 mm.) voids from burned out vegetal temper occur at the surface. The voids are not numerous enough to affect the properties and are probably accidental. Some of them have linear grasslike shapes which are about 2–3 mm. long and 0.5–1 mm. wide. Random occurrence of pores left by the burning out



c

Fig. 12. Banshan vessel, D2661, xeroradiographs and drawing of joins



of vegetal temper suggests that its properties were known but not exploited.

To establish the method and sequence of manufacture, macroscopic examination was combined with xeroradiography. The exterior of the base is uneven, with indentations about 7–8 mm. across, probably caused by placement on an irregular surface (Palmgren 1934: pl. 33, examples of mat-impressed bases). The base has no scrape marks from finishing, but it is somewhat worn. Xeroradiography shows low porosity and a lack of joins in the base; the base was probably formed by beating a lump of clay into a flat pancake-like slab. There is no evidence for the use of a mold in making the base, and the lower wall is not sufficiently cantilevered to have been unstable during construction. The interior of the base is very smooth and has a wiped surface texture. The xeroradiograph (Fig. 12) shows that the pot was built with coils about 7–8 mm. high, as is clear in the base and at the neck. On the interior an indented ring in the surface corresponds to the lower band

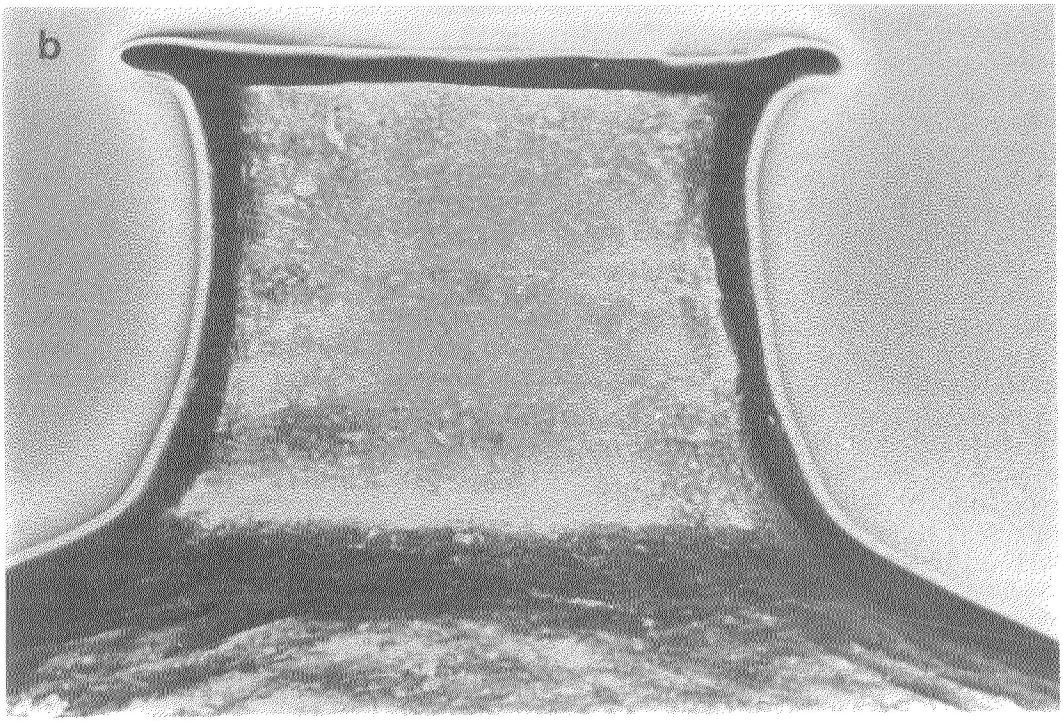


Fig. 13. Banshan vessel, D2661, xeroradiographs of neck

of painted decoration, indicating that the pot was coiled in sections.

Following construction, the body was subjected to a high forming pressure with a paddle and anvil, as shown by the individual paddle marks on the body (Fig. 12a–b). The surfaces have no facets which relate to paddle and anvil marks, and no indentations which indicate that this technique was used. The density variations are within the wall. This high pressure forming process decreased the porosity and increased the strength of the joins so that it is very difficult to find the coil joins in the bulbous part of the body, except in regions of horizontally aligned pores (Fig. 12c). The paddling started about 8 cm. above the base, indicating that the potter thought that the basal joints were strong enough without it. Moreover, in order to support the body the base would have to have been drier than the body and would thus have cracked had it been paddled. The smooth, carefully reworked surface bears no sign of the beating to which the pot was subjected. The interior of the wide part of the body has diagonal forming marks running from lower left to upper right as seen from the exterior, indicating that further shaping took place after paddling, probably in order to remove traces of facets and to round out the shape fully.

The handles as well as the neck and rim would have been added after the final shaping of the body, and a section join line can be seen at the neck (Fig. 13a–b). Each handle was formed of two or more coils and added to the pot after it had partially dried, as the cracks between the handles and body show (Fig. 12b). These internal cracks are particularly pronounced at the base of the handles where the body would have been driest. An extra coil of clay was put around the top of the handle, and three finger impressions appear at the base. Small bits of clay were added on the interior of the handle joints for reinforcement.

The careful joining and working of the surface are further indicated by facets made by a tool used on the surface and joints. The top view of the pot (Fig. 13a) shows a section line between body and neck about 1.5 cm. below the join, but the detail is insufficient to determine whether the upper section was added already built or coiled in place. Some horizontal striations on the interior just below the join of neck and body would suggest separate construction, but the fact that the ring coils in the neck do not deviate from the horizontal argues for individual attachment of coils. Wipe marks, shallow parallel circumferential striations on the interior of the neck, and a circumferential indentation about half way down the neck (Fig. 14a) indicate that the upper neck and rim were finished while being rotated on a turntable. There is no sign that a template or mold was held against the neck, as suggested by Palmgren and shown not to be the case by Wu (1938: 89–93).

Following construction and shaping, the surface was carefully reworked in several ways. First, when the body was dry or almost dry, the lower part was scraped in a diagonal direction with a flat riblike or gougelike tool about 2.5 cm. across (Figs. 14b and c). The marks produced are nearly horizontal in the body (Fig. 14d) and vertical in the neck (Fig. 14e). An indication that the upper body and neck were wetter than the base is provided by the character of the scrape marks. On the lower body, these marks are grooves, in which coarse grit was scraped along, but on the upper body and neck they are flat facets from which material was shaved such that coarse grit was not moved. Second, the surface was wiped, smoothed in some areas (such as handles; Fig. 14f) with a tool, and then slipped and partially painted. There is no slip on the interior, but a drip of slip runs from the rim down the interior of the neck. The slip appears to have been wiped on horizontally at the rim, and this decorative technique, rather than the processes of smoothing or forming, may indicate the use of a turntable or rotatable support. The black slip paint was applied in strokes about 2–4 cm. wide (Fig. 14a shows short lines painted on top of the rim). The bands were painted as continuous lines while the pot was on a turntable. The black paint was an iron-manganese mixture with clay and perhaps a little lime, whereas at Hajji Firuz

Fig. 14. Banshan vessel, D2661, details of shaping and finishing

the impermanent, fugitive red paints consisted of bright red, fully oxidized iron oxide (Vandiver 1985: 240).

Thus, the method of construction is very different from that practiced at Hajji Firuz. It involved the joining of preformed coils into what was essentially a weak structure because of the large number of joints, followed by consolidation and reduction of porosity through a paddle and anvil process, then by reworking to shape the surface, and finally by wet-smoothing, slipping, and painting of the surface. The jar was extensively reworked in several labor-intensive steps to obtain particular qualities of shape and finish, which obscure the preceding processing. Construction, consolidation, and final shaping are separate processes, and thus show the motor movements which produced the pot: a) building up with similar small linear elements made by a rolling action between the hands; b) hammering one hand against the other; c) rocking to smooth, scrap, and apply the slip.

This pattern of construction with some variation is documented in three other Banshan jars. A large jar (Peabody Museum No. D7162) was paddled at a later state of drying with the result that the coils are more prominent in the xeroradiograph (Fig. 15) than are the signs from the compressive paddle and anvil step. A small narrow-necked jar (Peabody Museum No. D2663) shows variation in raw materials—vegetal material was added or allowed to accumulate in the raw materials, so unaligned spherical pores (Fig. 17) remained after the seeds or other organic temper burned out. The wide-mouthed vessel with vertical handles, which would have been suitable as a cooking vessel (Peabody Museum No. D2669), is made in the same way as the other Banshan vessels (Fig. 16), although there are indications of the constraints imposed by the raw materials. An internal radial crack, widest where the pot has been paddled, resulted from using the paddle and anvil technique on the lower part of the vessel when it was too dry, an instance of potter error.

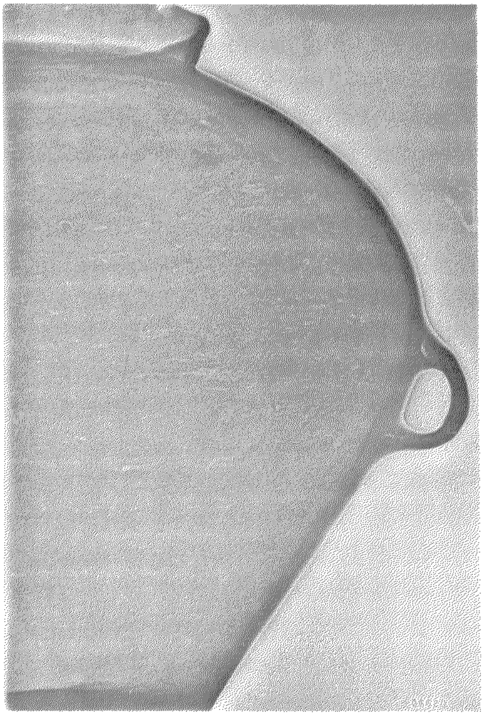


Fig. 15. Banshan jar, Peabody Museum No. D7162, xeroradiograph

The detailed evidence derived from these vessels is consistent with what is known about other Yangshao vessels, particularly those in the collection of the Museum of Far Eastern Antiquities, Stockholm (Palmgren 1934: 1–164). However, there is no evidence for the use of molds in the 23 vessels at Harvard. G. D. Wu (1938), in a study which included ethnographic as well as archaeological data on pottery manufacture in China between 1927 and 1935, reached similar conclusions. I have, however, emphasized the sequence of manufacture and used a more powerful tool for analyzing the resultant structure of the pottery, but the size of the sample is limited, and only a few sherds and no plain wares were examined.

My work, as well as that of Palmgren and Wu, deals with the later Yangshao subphase. To discern whether the same mental template for the manufacture of pottery in Gansu also existed in the early Yangshao phase requires study of the sherds and whole vessels from a type site such as Banpo. Zhuo Zhenxi (1985: 72–73), on the basis of her investigation of the Yangshao pottery of Banpo-type from Xianmeng village, Shaanxi province, has proposed that a rotating disk which could turn slowly and only for a short time was used to shape and decorate pottery. The pottery was built in sections, some of which were preformed. Coiling and paddle and anvil techniques were similar to those utilized in the contemporary Dai culture in the south (Zhuo Zhenxi, November 1985, personal communication). My examination of sherds at Banpo showed the characteristic circumferential alignment of pores in the horizontal section; the pores were grouped periodically in the vertical section as close together as the sherds were thick—with a length to thickness ratio of 1. The same periodic pattern of porosity was found in the two vertical cross sections of sherds, but it differed from the continuous circumferential alignment of the top and bottom horizontal cross sections. The majority of the joins were butt joins which showed evidence of extensive working: the

Fig. 16. Banshan jar, Peabody Museum No. D2669, xeroradiograph

pattern of porosity across the join was convoluted rather than straight, providing circumstantial evidence for the use of paddle and anvil. Thus, from a small sample we can state that similar methods were used in the early subphase of Yangshao. We fall short of being able to demonstrate a long-lived ceramic tradition, but two further lines of analysis support it. Chang (1977: 97–119) recognized an integrated cultural configuration and similarity of artifact types in the Yangshao culture. Rawson concluded (1980: 19), on the basis of a review of excavations at Banpo, that "... the special attention given to kilns and to ceramic manufacture at Banpo underlines the central role of ceramic techniques in early Chinese society." Because of the unity of Yangshao culture and the importance of its ceramic technology, we argue that, in the north, a well-developed, continuous, and conservative technology was based on a labor-intensive process of multiple reworkings of pottery vessels to promote strength and to refine shape and surface.

Variation in the Nature and Distribution of Raw Materials Causes Variation in Forming and Firing Technology

It is not generally recognized that the differences between the properties of the sandy illitic clays found in the loess deposits of northern China and the calcareous montmorillonite clays of Southwest Asia are as great as those between, for instance, bronze and iron. The northern Chinese loess consists of poorly weathered, wind-driven deposits laid down in arid conditions. These deposits are mostly unstratified, sometimes measuring 60 meters thick, the thickest being up to about 500 meters in Gansu province (Barbour 1925). Loess deposits are quite homogeneous in composition and physical properties along much of the Yangtze River and its tributaries (Huang 1985; Barbour 1925; Yang 1986). These clays are refractory, having a high melting temperature. Montmorillonite clays from Southwest Asia, on the other hand, occur as ancient seabed sediments. Because of the nature of deposition, they tend to be impure, stratified, extensively weathered, and heterogeneous in both composition and physical properties. They contain limestone, salts, and other impurities which lower their melting temperature. Thus, each clay type presents different problems to people trying to form and fire pottery.

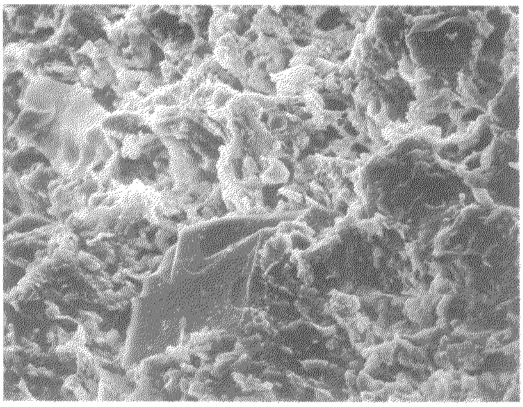
Both illites and montmorillonites have a three-layer crystal structure, whereas kaolinite has a two-layer structure (Kingery et al. 1976: 73–80). Both have finer particle sizes than kaolinite. Strains in the three-layer lattices preclude stability of the large 5–10 micron size commonly found in the platey stacks of kaolinite particles. Illites have a platey appearance and measure in the 1–5 micron size range, whereas montmorillonites are generally submicron, about 0.1–1.0 microns, and are poorly crystallized with edges that appear wispy like the edges of windblown clouds (Kingery and Vandiver 1986: 38, 232–236). Because of their finer particle size, montmorillonite clays are less porous and more plastic, but they shrink much more during drying. In addition, naturally occurring clays contain impurities in the clay structure and are mixed with coarse particles which are incompletely weathered from the source rock or which have been picked up during transport. Northern Chinese loess has a gritty feel and consists of a yellow-gray, porous mixture of coarse angular grains of quartz, biotite mica, feldspars, and a small amount of other mineral inclusions mixed with what is mostly illitic clay; although other clay types may be present, they do not exceed 10 percent of the total clay fraction (Huang 1985; Yang 1986; Barbour 1925). Occasional bits of granite are also present, which show almost no sign of weathering. There is a fairly continuous range of particle sizes: about 20 wt. percent in the clay range of 0–5 microns, 50 percent in the silt range of 5–50 microns, 28 percent in the very fine sand range of 50–100 microns, and about 2 percent over 100 microns (Barbour 1925; Zhang and Fu 1983: 1470).

The aplastic inclusions in the Southwest Asiatic montmorillonites, such as quartz, feldspar, and limestone, are often rounded, and micas are broken into fine particles.

Fig. 17. Banshan jar, Peabody Museum No. D2663, xeroradiograph

The particle size tends to have a bimodal distribution with the clay fraction below 5 microns, averaging below 1 micron, and the coarse fraction between 40 and 100 microns but rarely larger.

We can compare the characteristics of these clay sources with the microstructures of the two different pots (Fig. 18). Partially melted particles of quartz and feldspar in the Yangshao pot combine with high porosity and a relatively small fraction of sintered clay matrix to show the heterogeneous nature of loess soils (Figs. 18 and 20). The clay particles and inclusions are aligned parallel to the wall of the pot (Fig. 18a), an indication of extensive working of the clay body. The Hajji Firuz storage vessel contains imprints left by burned out organic material with a fine particled, relatively poorly sintered clay body (Figs. 18d and e). Rounding at the edges of clay particles is visible only at higher magnification (Fig. 18g). The higher-fired Yangshao pot has more rounded pores and more extensive sintering (compare Figs. 18 b and f). There is more silica in the pot from Banshan, an indication that more quartz is present, whereas, more alumina is present in the



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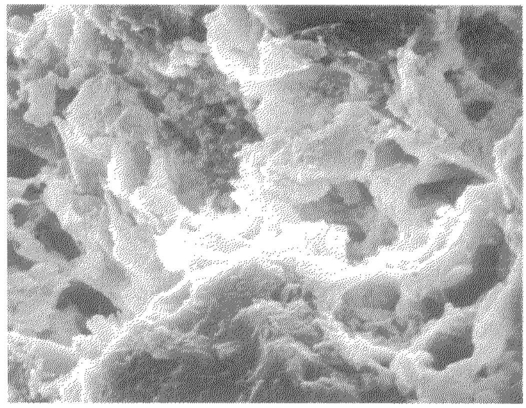

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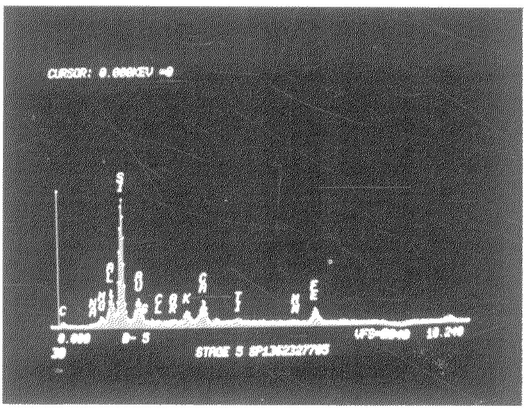

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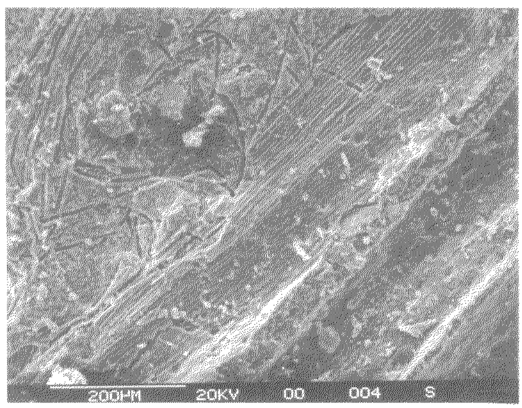

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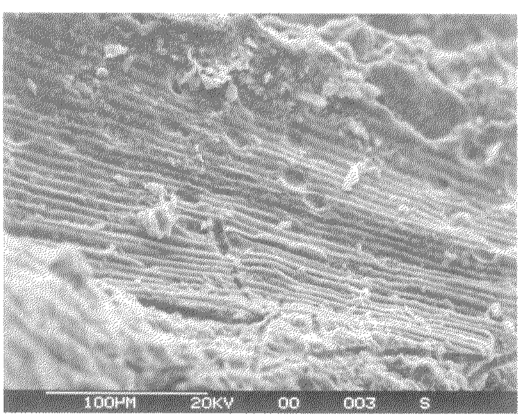

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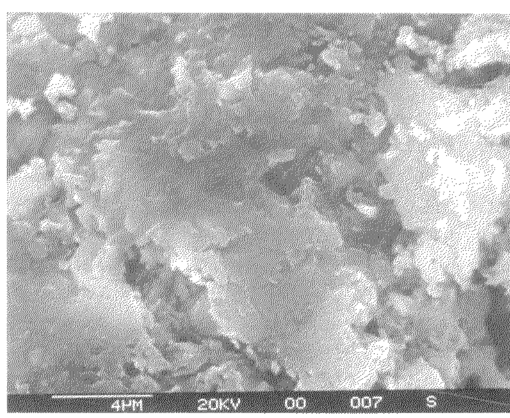
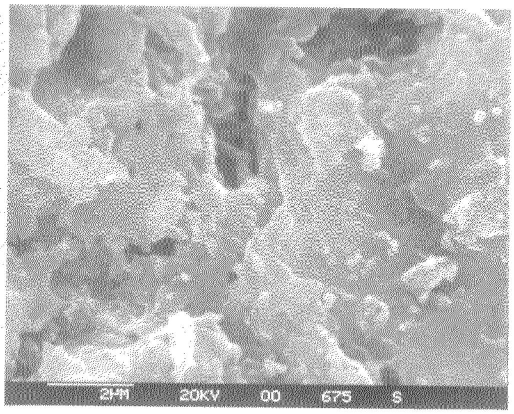


f

Fig. 18a–c. Banshan jar, D2661, scanning electron micrographs: a) ×900; b) ×2700; c) energy dispersive X-ray spectrum (E. D. S.); Fig. 18d–h. Hajji Firuz jar, scanning electron micrographs: d) ×135; e) ×300; f) ×5000; g) ×10,000; h) E. D. S. spectrum



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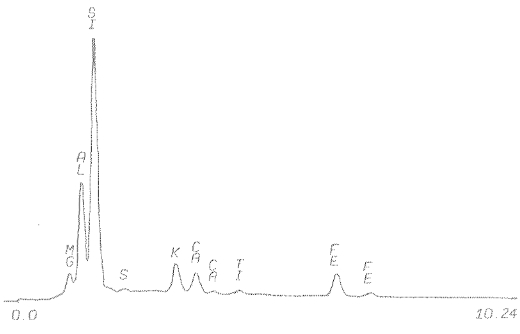

h

Fig. 18. Continued

Hajji Firuz example, an indication that relatively more clay fraction is present (compare Figs. 18c and h). The elemental compositions show silica, alumina, potassia, iron, calcia, magnesia, titania, and sulfur in the Hajji Firuz body, and silica, alumina, calcia, iron, potassia, magnesia, and titania in the Banshan body. Although the two compositions seem similar, they are not. Since illitic clay represents only a minor weight percent of the total loess, it is apparent that the potential fluxes, potassia, calcia, magnesia, and iron, are bound in refractory grit materials, like mica and feldspar. In the Hajji Firuz body, montmorillonite is the major constituent and the fluxes are found as exchangeable bases within the clay, highly fusible salts and limestone. Tables 1, 2, and 3 compare the composition of clay bodies used for Yangshao pottery with possible Yangtze and Fen River loess clay sources showing fairly good agreement. The compositions of Near Eastern clay sources and pottery are likewise related (Vandiver 1985: 109–121). The low lime content of the pottery compared with the range of available clayey soils shows that low lime clays were selected. There is insufficient knowledge of the Chinese clay sources to associate excavated pottery with the clay deposit used; that is, whether alluvial sources were utilized (for another opinion, see Freestone 1988; Zhang in 1987 also expressed differing views [personal communication]). Based on comparisons of composition, microstructure, phase, and thermal behavior, we conclude that illitic loess provided the raw material for Banshan pottery, and that calcareous montmorillonite clays with intentional additions of chopped vegetal fibers were used for Neolithic pottery at Hajji Firuz and other sites in Southwest Asia.

Figure 19 summarizes the available data

TABLE 1. Energy dispersive microprobe analyses of polished sections of Yangshao pottery and loess reported as average and range of 5 analyses

	Vessel 4192	Vessel D 2663	Vessel D 2669	Loess, Xian 5
SiO_2	58.5 (54.6–61.7)	61.6 (55.4–66.8)	56.7 (52.1–60.7)	64.6 (62.9–66.4)
Al_2O_3	20.0 (18.6–21.6)	16.1 (15.3–17.1)	20.5 (18.9–22.1)	17.6 (16.5–18.4)
CaO	5.9 (5.1–6.9)	8.4 (6.9–11.2)	5.2 (3.5–8.8)	4.4 (4.1–4.9)
MgO	3.5 (3.2–3.8)	3.1 (2.2–4.2)	4.3 (4.0–4.6)	2.4 (1.9–2.9)
TiO_2	0.6 (0.5–0.9)	0.4 (0.4–0.7)	0.6 (0.4–0.8)	0.7 (0.5–0.9)
P_2O_5	0.5 (0.0–1.2)	0.2 (0.00–0.9)	0.1 (0.01–0.2)	0.1 (0.0–0.6)
FeO	5.1 (4.1–6.0)	4.9 (3.7–6.1)	6.5 (5.9–6.9)	5.2 (4.9–5.7)
Na_2O	2.4 (1.6–3.0)	2.5 (1.4–3.5)	1.9 (1.6–2.3)	2.3 (2.2–2.7)
K_2O	3.5 (3.0–3.9)	2.9 (2.5–3.2)	4.0 (3.1–5.5)	2.6 (2.2–2.9)
Total	100.0	100.1	99.8	99.9

TABLE 2A. Wavelength dispensive electron beam microprobe analyses given as mean with standard deviation in parentheses of fused clays from the Yangtze River Valley, travelling from west to east. Note the homogeneity of the analyses with the greatest variation being in the phosphorus and calcium oxides****

	1 Fine, brown plastic clay Xian, near Ching Lung Ts'e temple	2 Fine, brown plastic clay, near Xian Shensi	3 Loess clay,** sandy brown, Won Chuan Hsien, Fen River Valley, Southwest Shansi	4 Fine, light brown loess clay from alluvium of neolithic village, Fen River Valley**	5 Fine, brown plastic loess clay from Luoyang, Henan, Royal Ontario Museum	6 Fine light brown loess probably from Henan, taken from Shang bronze in Royal Ontario Museum	7 Brown clay probably from Anyang, Henan, taken from surface of Shang T'sun (Freer 51.19)****
No. of Analyses	(45 analyses)	(30)	(30)	(30)	(30)	(90)	(90)
SiO_2	64.86 (5.5)	63.23 (8.1)	63.96 (7.6)	65.40 (7.7)	62.45 (6.7)	67.32 (5.1)	63.48 (4.4)
Al_2O_3	16.16 (1.8)	17.00 (3.4)	16.93 (3.5)	17.94 (3.4)	18.53 (3.1)	18.00 (2.0)	18.77 (1.8)
FeO	4.63 (0.4)	6.23 (1.0)	5.32 (1.0)	5.16 (1.1)	6.13 (1.2)	4.85 (0.6)	5.23 (0.5)
MgO	2.20 (0.3)	2.49 (0.6)	2.34 (0.6)	2.29 (0.5)	2.44 (0.5)	1.95 (0.2)	2.15 (0.3)
CaO	7.14 (0.9)	5.43 (1.3)	5.99 (1.5)	3.23 (0.7)	5.20 (1.0)	3.20 (0.3)	4.88 (0.8)
K_2O	2.37 (0.2)	2.82 (0.4)	2.91 (0.2)	3.07 (0.3)	2.80 (0.3)	2.31 (0.2)	2.51 (0.2)
Na_2O	1.53 (0.1)	1.68 (0.2)	1.57 (0.2)	1.52 (0.2)	1.32 (0.2)	1.33 (0.1)	1.72 (0.2)
TiO_2	0.92 (0.2)	0.95 (0.3)	0.83 (0.3)	0.95 (0.4)	0.88 (0.2)	0.94 (0.3)	1.07 (0.4)
P_2O_5	0.20 (0.05)	0.17 (0.07)	0.16 (0.07)	0.45 (0.1)	0.26 (0.1)	0.11 (0.07)	0.19 (0.07)
Total:	100.01	100.00	100.01	100.01	100.01	100.01	100.01

* These samples, given by W. T. Chase from the Freer Technical Laboratory study collection, were found suitable for pottery manufacture by coil and paddle and anvil methods. They all had low linear drying shrinkages of less than 5% and at 800° C fired hard, orange to red depending on iron content. By differential thermal analysis and SEM-EDS, each contained illite, quartz and other mineral inclusions. WDS was carried out on samples fused to promote homogeneity in the Mineral Sciences Probe Lab of the Museum of National History, Smithsonian Institution, under the direction of Gene Jarosevich with help from John Neelon and James Collins. Appropriate geological standards were used, and the beam current was continuously monitored. The beam was defocused to 16 microns. Working standards were analyzed before and after the analysis of the clay samples. Totals amounted to 96–98% and have been normalized to 100% for comparison. The low totals were caused by inclusion of tungsten and perhaps carbon during fusion. The 200–600 mg. samples were ground to 200-mesh and fused in an arc at about 1300° C. Samples 6 and 7 were each fused two times to check for homogeneity.
** Collected by Bishop from the Neolithic site, Won Chuan Hsien. Sample 3, earth containing charred millet is reported in *Archaeological Research in China*: Plate 49, Fig. 2 and text p. 381.
*** Six other samples were tested and found to contain too much sand (3), too much ash (1), too much lime (2) to be fired as pottery.
**** Published in J. A. Pope, An Analysis of Shang White Pottery, *F.E.C.B* (June 1949): 49–54.

on the distinction in working properties between naturally occurring clays and clay bodies suitable for pottery. The range of water content from cracking (the plastic limit) to flowing (the liquid limit) is greater in montmorillonites than in illites and kaolinites. The range in naturally occurring clays tends to be greater than in suitable pottery clays in which the mix of particle sizes has been found or adjusted to limit the range of added water. This is done so that the clay body can be worked and support its own weight without extensive shrinkage during drying and without critical control of water content. Montmorillonites are plastic over a wider range of water content, 20–40 percent, than are gritty illitic loess clays which have low plasticity (a plastic limit of 14 percent is reported by Zhang and Fu 1983).

When water is added to each of these different clay bodies, the capillary forces which cause the clay particles to cohere vary. The surface tension of montmorillonite is greater, but considerably more force is required to deform the heavily gritted illite. Because larger particles must be dislodged in illites than in montmorillonites, and because the surface tension is greater, the plastic region of montmorillonites is considerably greater than for loess, another important distinction between these clays. Coarse particled bodies are critically dependent on water content, and only a small variation causes grit tempered clay bodies to slump, a characteristic referred to as short by potters, so they must be formed quickly without adding much water. The best way to form illitic loess clay bodies is to work with small elements such as coils so that

*TABLE 2B. Loess soil analyses****

	Loess, Henan*	Loess, Wei-ning, Gansu*	Alluvium, mouth of Yangtze River, Nanjing Channel (75% illite)**	Alluvium, Yangtze Estuary (less illite, more chlorite)**
SiO_2	64.22 (69.86)	59.30	68.71	48.64
Al_2O_3	18.1–Fe_2O_3 (19.69)	11.45	16.14	21.86
CaO	6.31 (6.86)	14.90	0.29	1.39
MgO	2.09 (2.27)	4.58	1.14	3.41
TiO_2	—	0.60	2.29	0.84
P_2O_5	—	0.20	—	—
Fe_2O_3	18.1–Al_2O_3	3.87	1.27	9.61
Na_2O	0.22 (0.24)	1.80	0.60	0.44
K_2O	0.99 (1.08)	2.17	4.08	3.50
MnO	tr	—	0.01	0.08
L.O.I.	—	0.96	4.73	9.46
H_2O	—	0.96	3.66	8.06
Total	91.93 (100.0)	100.79	99.26	99.23

* Barbour 1925: 459, 519.
** Huang 1985: 64.
*** Only total Al_2O_3 and Fe_2O_3 were analyzed. For comparative purposes these can be normalized without L.O.I. and H_2O, as has been done in parenthetical numbers.

the water content can be easily controlled. Because of the coarse particle size of loess, tamping or paddle and anvil techniques have a greater influence on particle alignment and packing in decreasing porosity, than on the finer, less porous montmorillonite clays. (In contrast, the clays of southern China are derived from fine lateritic soils, and have working and drying properties similar to montmorillonites. In the south, in addition, pottery was tempered with organic materials, including rice leaves, husks, and finely ground charcoal in Hemudu pottery [Hemudu Archaeological Team 1980: 1, 11; Wu 1982: 61].)

The behavior of Near Eastern montmorillonites is not particularly dependent on variations in water content. However, the addition of linear vegetal materials, such as chaff, increases the deformation stress so that a larger section can support its own weight and not deform or buckle. Aligning the chaff temper in the composite clay body adds strength to the wall. If, however, too much extension of the clay occurs, the clay will delaminate from the linear chaff or vegetal elements and crack. Thus, coiling with chaff tempered Near Eastern clays is impossible, but slab building with a composite fiber-reinforced material provides a sufficient increase in strength so that the clay body is about equal to the northern Chinese clay bodies. An increase in strength but decrease in extension can be achieved by decreasing the amount and extent of wetting. By not allowing the montmorillonite clays to become wet completely (that is, to use the clay shortly after mixing with water), a doughy consistency can be maintained. This body, however, readily cracks during forming unless linear vegetal matter is added to form a composite material. This technique was also used in Near Eastern building for bricks and "tof" or "chineh" construction where horizontal sections of wall were built using lumps of straw tempered mud.

The particle size of the clays is also important to the drying shrinkage. The fine particle size of montmorillonite results in a wetted clay with a large number of water films per unit length, so that the linear drying shrinkage amounts to 10–15 percent and often more (Fig. 19). Chaff temper additions keep this drying shrinkage to under 5 percent, thus limiting the possibility of cracking. Gritty limestone frequently mixed in Near Eastern clays produced the same effect on working properties and drying shrinkage, but caused problems in firing. It decomposes at or above 840° C to quicklime, which expands on rehydrating and recarbonating. For montmorillonite clays which are not wet through by being aged, and are thus not fully plastic, the drying shrinkage amounts to about 5–10 percent. The addition of chaff temper limits the drying shrinkage and is better than grit additions because it encourages the pasty clay body

TABLE 3. Other analyses of Yangshao Neolithic pottery

	YSh 1–3* painted	YSh 2–54A*	YSh 3–YS*	YSh 4–44*	YSh 5–IR*	YSh 6–2R*	YSh 7–K	YSh 9–TO 63:5* red ware
SiO_2	67.08–68.51	66.5–67.53	67.00–68.30	60.22–64.72	61.90	63.42	57.8–59.22	67.21–67.95
Al_2O_3	16.07–16.41	16.65–16.82	14.80–15.09	17.07–18.35	19.13	17.73	14.50–14.85	16.64–16.82
CaO	1.67–1.71	2.28–2.31	1.60–1.63	1.02–1.10	2.61	3.17	9.20–9.43	1.09–1.10
MgO	1.75–1.79	2.28–2.31	1.30–1.33	2.57–2.76	3.10	2.03	2.90–2.97	2.00–2.02
P_2O_5	—	—	—	—	—	—	—	0.17
TiO_2	0.8–0.81	0.88–0.89	0.80–0.82	0.79–0.85	0.99	1.19	0.70–0.72	0.97–0.98
Fe_2O_3	6.4–6.54	6.24–6.34	8.80–8.97	6.99–7.51	8.37	6.91	8.1–8.3	5.97–6.04
Na_2O	1.04–1.06	0.69–0.70	1.00–1.02	1.14–1.23	0.57	1.86	1.00–1.02	1.18–1.19
K_2O	3.00–3.06	2.98–3.02	2.80–2.85	3.21–3.45	3.21	3.48	3.40–3.48	3.50–3.54
MnO	0.09	0.06	—	0.03	0.11	0.15	—	0.18
L.O.I.	1.47	1.43	1.8	6.72	—	—	2.4	1.17
Total	99.37–99.38	99.90–99.98	99.9–100.01	99.76–99.97	99.99	99.95	99.99–100.00	99.99–100.08

* Li Jiazhi et al. 1986: 3, 24. Wet chemical analyses.
** Zhang Fukang 1986: 24. Wet chemical analyses.
*** Ian Freestone et al. 1988. Normalized energy dispersive analyses with standards calibrated by atomic absorption.

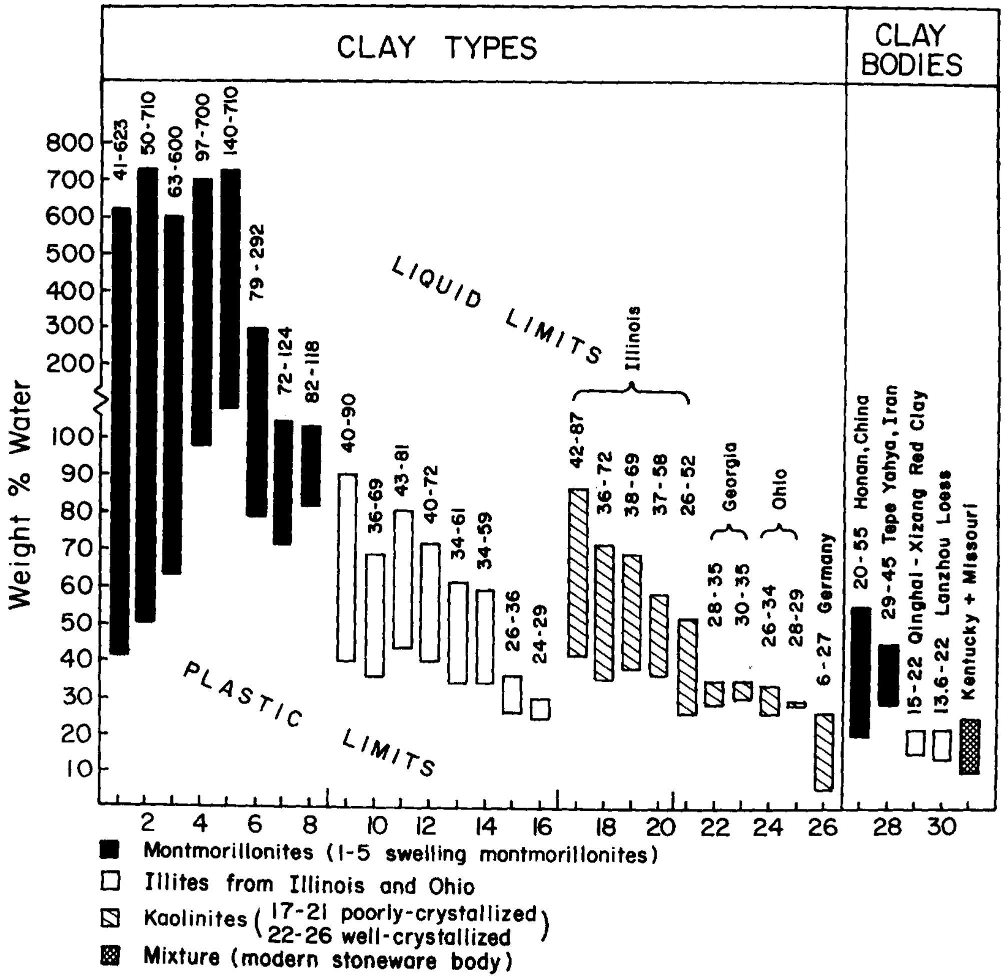

Fig. 19. Distinction in working properties between naturally occurring clays and clay bodies

TABLE 3. Extended

Mal–56B* Majiayao	Banpo painted** pottery		Yang-shao red** pot-tery	Loyang beak-er**	Gansu yellow** pottery		Gansu*** Neolithic pottery vessel	Gansu*** Neolithic pottery vessel	Banpo-type*** Neolithic sherd	Banpo-type*** Neolithic sherd
54.92–57.04	64.66	67.08	66.50	60.22	75.27	51.0	56.4	58.4	70.2	67.7
17.47–18.14	17.35	16.07	16.56	17.7	12.81	14.9	19.8	18.7	15.3	15.9
9.28–9.64	2.39	1.67	2.28	1.02	1.84	15.1	6.5	4.7	0.9	2.6
3.18–3.30	3.35	1.75	2.28	2.57	0.41	4.0	3.8	3.3	2.3	2.4
0.75–0.78	0.77	0.80	0.88	0.79	0.14	1.1	0.8	1.1	0.8	0.8
—	—	—	—	—	—	—	<0.3	<0.3	<0.3	<0.3
6.17–6.41	6.52	6.40	6.24	6.99	1.35	8.8	(FeO) 7.2	8.4	5.3	5.7
0.69–0.72	1.26	1.04	0.69	1.14	3.37	1.5	1.6	1.0	2.0	1.8
3.59–3.73	3.35	3.00	2.98	3.21	3.88	2.0	3.9	4.4	3.2	3.0
0.23–0.24	0.09	0.09	0.06	0.03	0.04	—	—	—		
3.39	—	1.47	1.43	6.72	0.77	1.4	—	—	—	—
99.65–100.01	99.96	100.25	99.90	99.76	99.91	99.8	<100.3	<100.3	<100.3	<100.3

to cohere and thus a good range of working properties develops. Grit tempered illites, large particled in comparison, tend to have drying shrinkages below 5 percent. Thus, the use of chaff temper is the best way to circumvent the limitations of montmorillonite clays since it increases the strength and decreases the shrinkage, but it does not improve the properties of loess bodies. However, the addition of chaff temper restricts the ways in which a clay body can be worked, making coils impractical and slabs optimal.

Variation in the occurrence of raw materials and in the nature of clay deposits also has an influence on firing. In the Near East clay deposits tend to be lenses several feet to kilometers across, with highly variable lime and salt contents. Firing one sample of soil may sometimes result in plaster

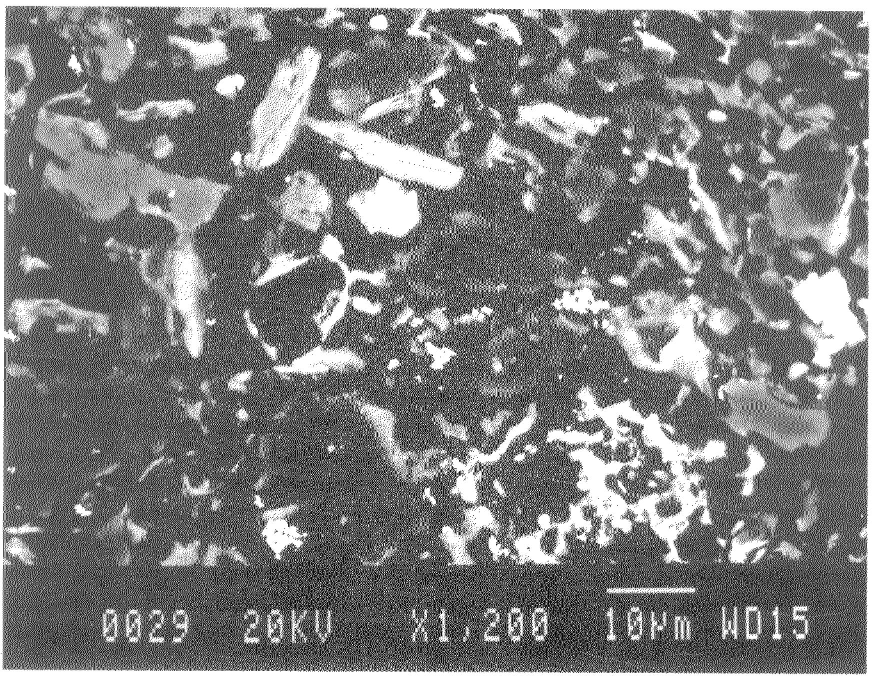

Fig. 20. Banshan jar, scanning electron micrograph, ×1200

or in a fired clay product, with many useless chemical combinations possible between these two extremes. In northern China the clay deposits are continuous loess layers 3–100 meters deep, which tend to be of the same refractory nature everywhere. This means that potters prospecting in a new region in north China had less variability to contend with and a more stable resource. Because of the consistency in resource distribution, digging into the earth and tamping a kiln chamber were more likely in China than choosing particular earths and constructing a kiln on top of the ground. The earliest kilns at Banpo were dug into the ground; thus, well-insulated, refractory chambers were used from earliest times. The firing temperatures of the Banshan pottery were 900–1000° C, with variability, more often toward increased temperatures up to 1100° C. Chinese scholars report 800–1000° C as the firing temperature range for Yangshao pottery (Li et al. 1986). At Hajji Firuz, the firing temperatures were lower, 700–850° C, with some as low as 650° C. Although no kilns were found at Hajji Firuz, the earliest kilns at nearby Yarim Tepe, dated about 5000 B.C., are above ground with a separate firing chamber placed at ground level below the ware chamber (Oates and Oates 1976: 42–43). Other kilns in the Near East are of similar design (Majidzadeh 1976: 207–221). These kilns were not so well insulated or capable of achieving such high temperatures as those of northern China. The type and distribution of raw materials may have influenced kiln construction and promoted earlier development of higher firing temperatures in China than in the Near East. Such basic technological differences as those among kiln structures, temperatures, and firing practices continued to characterize the variation between Chinese and Western ceramics in later times.

The two clay bodies are very different in their firing behaviors. The amount of impurities in montmorillonites promotes sintering at a fairly low temperature of about 600° C, and the small capillaries between clay particles provide a driving force for the densification of the body. Thus, when these clays start to flow at about 1000–1100° C, they slump and bloat within a narrow range of temperature with some resistance from large voids. Illitic clays, in which there are many and highly refractory impurities, behave very differently. Fusion begins at about 800° C. As more glass is formed to sinter and melt the clay particles together and to transform the clay to mullite, the dissolution of more refractory materials actually produces a more refractory and more viscous glass composition. Thus, the grit tempered illitic clays are more forgiving over a wider range of firing temperatures, which could have been the impetus for the firing of Chinese earthenwares to higher temperatures. The properties of the pottery would improve, becoming for example less permeable; the kiln structures, being more fully vitrified, thus would be more stable and long-lived. Exactly the opposite would happen to Near Eastern kilns pushed to higher firing temperatures. They would begin to flow with repeated use and fail, and greater control in firing over a narrow range of temperatures would be necessary to produce impermeable wares. In fact, we know this problem existed because some kilns are lined with multiple layers of sandy clay and contain interior supports (Majidzadeh 1976; Jarrige, forthcoming; Oates and Oates 1976). Thus, autocatalytic forces gradually caused the ceramic technology of China to develop the way it did, toward high temperature porcelains, and account for why such a development was so late in coming to the West.

The structures and properties of Near Eastern and northern Chinese clays are sufficiently different that the ways in which they can best be processed are also different. This implies variation in the experience of working with each type so that two separate patterns of working would have resulted in particular mental sets of what is required to make pottery. The variations in the nature and distribution of raw materials, as well as the differences in the forming, drying, and firing practices of Neolithic potters, make it unlikely that any transfer of technology took place between the Near East and northern China. Instead, two independent traditions persisted over the years between 6400 and 3000 B.C., in which locally available resources were treated in the best ways for the making and firing of pottery.

THE CONSERVATIVE NATURE OF TECHNOLOGICAL DEVELOPMENT

The detailed examination of two different ceramic traditions has shown that the nature of technological change is conservative. Formal aspects of decoration and shape, on the other hand, changed relatively rapidly during the Neolithic period, and local cultural groups have been classified by ceramic ware types. The slow rate of technological change resulted from the effectiveness of the exploitation of resources and of the technological decisions which yielded the desired properties. Once successful means of fabrication are found, particularly if the product is difficult to make or highly desirable, people are reluctant to change. The technology becomes accepted as "traditional" practice because it works—it has become part of the motor vocabulary and the reasons for making the original choices are forgotten. Culturally patterned choices continue to be preserved in a tradition and only minor changes are introduced by analogical reasoning with what has gone before. This is as true for contemporary developments in high-tech ceramics as for ancient ones. For instance, in the 1970s menhadden fish oil was found to be a particularly successful binder in the forming of substrates for computer chips. Ten years later, this fish oil was still being added, although other binders were by that time also included in the composition. No one could remember why menhadden oil had been so successful, but no one wanted to drop it. Each company in which substrates were made adapted the composition to suit its needs, adding something else to improve the binder.

Technology can be transferred by people, by objects, or by documents. In order to preserve a complex and resource-specific tradition, the technology is transferred by people teaching skills to others. Even today, despite the fact that new technologies can be learned from written documents, the critical elements of a craft are transferred by an apprentice process (Sahal 1981: 42, 200, 202). The transfer of early industrial technologies from Europe to America and within Europe took place in this way (M. R. Smith 1977; Stapleton 1987; Kingery 1987).

The distribution and properties of the raw materials affect the processes of manufacture, but a cultural bias also influences the nature of the decisions that are made. The pattern by which things are done is based on thought and action, which explains structural similarities in various activities practiced within a group of people. For instance, dwellings, kilns, and pottery vessels are all chamberlike "containers." In the Near East the same raw materials (calcareous clays with vegetal temper) with the same composite working properties and the same methods of slab building are used for all three structures (Vandiver 1985: 254–265). In northern China the building of a chamber, whether kiln, pot, or dwelling, also entailed the use of similar materials and processes. The semi-subterranean houses at Banpo were made by compacting the loess soil, and constructing tamped layers above ground or filling in tied wooden frames. The kilns are subterranean, and their construction involved excavation and compaction. The pottery was made by compacting the base, followed by the building up of small individual elements and then by more compaction of the surfaces. These similarities are significant examples of the way different patterns of thought are reflected in materials handling, so that formal and technological styles are culturally distinct, appropriate entities.

PROCESSUAL DETERMINISM

Processual determinism may provide the background for, although not a full explanation of, why technology is so conservative and how this conservatism relates to transmission processes. The way people interacted with their surroundings and derived knowledge from earlier experiences determined how pottery was made and how the different styles of technology acquired distinctive traits. Previous choices limit present possibilities.

The precursors of pottery are materials and objects from the early Neolithic period, impermanent and for the most part unknown to us. One exception is plaster which was extensively used in the Prepottery Neolithic Near East. These plasters were worked in the same way as the clay in early pottery. As soon as permanent artifacts, such as pottery, kilns, or architecture, appear in the archaeological record, Chinese and Near Eastern technologies are already markedly different.

Examination of a technology and its changes provides insights into many levels of culture. Reconstruction of the manufacture of an individual pot shows how the sequence of patterned motor movements was based on personal experience. On another level, the complex of behavior involved in making pottery is indicative of the constraints imposed by materials on manufacturing processes, as well as of the technological decisions which patterned how things were made. The qualities of materials in an area stay the same; their properties are measurable and reproducible, and the technology and formal style demonstrate the problems that were considered important enough to be solved. The identification of specific pottery-making traditions permits recognition of cultural change as cultures interact and adopt aspects of technology from other groups. Finally, ceramic technology as a whole can be used to determine functional categories; not those convenient devices for classifying artifacts from an excavation or in a museum, but categories based on the original purposes for which the ceramics were employed—food preparation and serving, furniture, architecture, storage pits, kilns, basins, hearths, and ovens (Vandiver and Kingery 1986).

General expectations regarding behavior can be derived from the significant features of these two traditional ceramic technologies. In both, the structure-processing-property relationship was exploited to produce functional pottery. Both were based on elements derived from other commonly practiced technologies. Both underwent a gradual process of innovation in which only a few minor features were changed at one time. This technological evolution was conservative compared with other cultural indicators, as for example the decoration of pottery which changed rapidly enough to allow cross-dating, seriation, and stratigraphic differentiation. An indication of the success of the two technologies was their preservation and transmission as tacit knowledge, without articulating or reformulating technical choices, for several thousand years.

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ADDENDUM

In the year since this article was written, there has been great interest in the interpretation of material culture in relation to styles of technology, variations in perception, and patterns of thought (D. N. Keightley, "Archaeology and Mentality: The Making of China," *Representations* [1987] 18: 91–128; H. N. Lechtman, "Book Review: Red Gold of Africa," *Technology and Culture* [1988] 29.1: 130–133). Based on these and other contributions cited in this text, the time has come to propose expanding the Whorf-Sapir hypothesis that "people who speak different languages live in different realities" to material culture, in that people who practice different styles of technology also live in different realities. However, generalizations about technology must be made from the most careful and intensive studies that are possible and the interpretation must not overstate the reality, or we will return to Bergson's ideal of *élan vital* as the characterization of cultural identity.