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Identification of Wheel-fashioning Methods: Technological Analysis of 4th–3rd Millennium BC Oriental Ceramics

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In Oriental Asia, during the 4th–3rd millennium BC, clay vessels were not wheel-thrown but wheel-shaped. This technique, which combines coiling and wheel-shaping, can be achieved by four methods. These methods are not constrained by technical factors. They may represent cultural behaviour and their identification is potentially an aid towards understanding the historical reasons for the adoption of the wheel. An experimental study was designed to seek and define diagnostic surface features and microfibrils. Comparisons of the results obtained on the experimental materials with a selection of archaeological material have revealed that a variety of wheel-fashioning methods were practised in the past. Contrary to previous conclusions, the choice of these methods evidenced on ancient ceramics did not respond to techno-economic factors such as mass production. The debate concerning the adoption of the wheel in Asia during the 4th–3rd millennium BC must therefore be continued.

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Keywords: CERAMIC, TECHNOLOGY, WHEEL-SHAPING, SURFACE FEATURES, MICROFABRICS.

Introduction

In Oriental Asia (Mesopotamia, Iran and the Indus Valley), during the 4th–3rd millennium BC, two ceramic fashioning techniques were practised: coiling and wheel-shaping (Courty & Roux, 1995). Wheel-shaping can be achieved using different methods which represent possible choices in the course of the forming process. These methods are not strictly constrained by techno-economical factors. They may represent manifestations of cultural behaviour, given that the existence of strong linkages between technical facts and socio-economic systems is now well established (e.g. Pfaffenberg, 1992; Lemonnier, 1993; Dobres & Hoffmann, 1994; Gosselain, 1994). This paper intends to examine these methods from a technological point of view to understand, ultimately, the historical reasons for the general adoption of the potter's wheel in Oriental Asia by the second half of the third millennium BC.

The traditional hypotheses about emergence of the wheel are first reviewed. Then, the different wheel-fashioning methods, their techno-economical characteristics and the diagnostic criteria used to identify

them (surface features and microfibrils) are examined. Finally, the results obtained are applied to archaeological material in order to document the existence of different technological behaviour during the 4th–3rd millennium in Iran as well as in the Indus Valley.

Hypotheses about emergence of the wheel

The evolutionary sequence of ceramic techniques during the 4th–3rd millennium BC in Asia has long been restricted to a consideration of the development of rotative devices and to the socio-economical consequences brought about by the development of the wheel-throwing technique.

In 1959, G. M. Foster, following Franchet (1911) and Wu (1938, quoted in Foster, 1959: 100), proposed an evolutionary sequence from unpivoted to pivoted turntable, and from simple to double wheel. The simple wheel was concluded to have appeared in the course of the 4th millennium BC in Asia and was implicitly associated with adoption of the wheel-throwing technique. According to Foster (1959), the reduction in the time taken to produce a vessel may have been the driving force for adoption of the wheel. The wheel and

the associated wheel-throwing technique would have made possible production of the standardized mass-produced vessels often described in the late 4th-3rd millennium contexts of western Asia (Brew, 1956; Turney-High, 1949; Childe, 1954; Linton, 1955; Harisson, 1928; Laufer, 1917; quoted in Foster, 1959: 101).

This evolutionary sequence is still accepted and the invention of the wheel is considered by most anthropologists to be a continuous phenomenon (Edwards & Jacobs, 1987; Blackman, Stein & Vandiver, 1993; van der Leeuw, 1993, 1994; Mahias, 1993).

However, recent studies may have refuted most of these hypotheses (Courty & Roux, 1995; Roux & Courty, 1997). The 4th-3rd millennium BC oriental rotative devices used to fashion pots were not associated with wheel-throwing but with wheel-shaping. These wheels could have been used for shaping small and large pots. Evaluation of the concepts and complex skills involved in wheel fashioning (Roux & Corbetta, 1989) documents the evolutionary sequence as discontinuous with two major breakthroughs which are not linked to the type of wheel: the emergence of the wheel-fashioning technique, and the emergence of the wheel-throwing technique.

In the first case, the use of the energetic potential of the wheel to modify the morphology of clay walls requires the necessary development of new specific perceptual motor skills (Roux & Corbetta, 1989). These skills are radically different from the ones involved in coiling and are difficult to learn. They are comparable to those for wheel-throwing (Gelbert, 1997). In this regard, wheel-fashioning differs from preceding fashioning techniques. Use of the wheel for only shaping rims or for positioning the pot appears as an extension of the coiling technique because it does not imply change from the coiling practice, either in technique or in skill.

In the second case, the energetic potential of the wheel is not only used to shape wheel preforms, but also to form roughouts (for a definition of preform and roughout, see Appendix 1). The manufacturing process is entirely mechanized and the different operations are exerted in synergy through the use of rotative kinetic energy (RKE). A considerable gain of time follows. Such a synergy is unique among the ceramic production techniques which are usually a series of "independent" operations. In North West India, wheel throwing appeared during the first millennium BC (Roux, 1994); while in Mesopotamia, there is no evidence for its use during the 3rd millennium BC (Courty & Roux, 1995).

These results are in keeping with the general history of techniques which shows an evolution towards a synergy of the different elements that compose the technical object (Simondon, 1958). It would have been surprising that wheel-throwing would have cross-cut such an evolution and developed as soon as the rotative device was invented.

The Wheel-fashioning Methods (Figure 1)

A method is defined as the forming sequence, whereas a technique is defined by the physical processes by which a raw material is transformed (see Appendix 1). Our previous study (Courty & Roux, 1995), aimed at identifying the techniques practised during the 4th-3rd millennium BC, has defined a few diagnostic criteria with which to recognize the main steps of the forming sequence. However, observation of archaeological material from several periods (e.g. Shar-i-Sokhta, Period I to Period IV, Kalibangan, pre-Harappan and Harappan periods), has revealed a greater variety of surface features than identified in earlier studies. These are expressed by recurrent attributes such as the morphology of the walls, the rillings, the grooves and the striations as well as differences of work between internal and external faces. This variety can be tentatively interpreted to have been produced by different production methods. Therefore, the hypothesis that the two techniques, coiling and wheel-shaping, were combined in different ways leading to the formation of a wide range of surface features, has been proposed.

Description of the wheel-fashioning methods

Theoretically, the combination of coiling and wheel-shaping techniques depends solely on what stage RKE is used for shaping the clay. Four forming stages can be distinguished: forming the coils, joining them, thinning the walls and shaping them. They define only four methods (Table 1). In fact, the possibility of shaping the preform without RKE, in methods 2, 3 and 4, is not considered here because the experiment was designed to investigate ceramics that displayed clear evidence of wheel-shaping (parallel striations). In addition, the inability to mechanically decouple the different pre-shaping stages of methods 3 and 4 makes no other combination possible.

Method 1: Coils are built, joined and thinned by discontinuous pressures, without the help of RKE. Shaping the body is done with the help of RKE.

Method 2: Coils are built and joined by discontinuous pressures, without the help of RKE. Thinning and shaping the body is done with the help of RKE.

Method 3: Coils are built by discontinuous pressures, without the help of RKE. Joining the coils and thinning and shaping the body is done with the help of RKE.

Method 4: Forming and joining the coils as well as thinning and shaping the body is done with the help of RKE. In this method, the coil is set on the wheel and then thinned and shaped with the help of RKE. A symmetrical platform is fashioned, upon which is laid the next coil, once the wheel is stopped. Joining the two coils is done with the help of RKE.

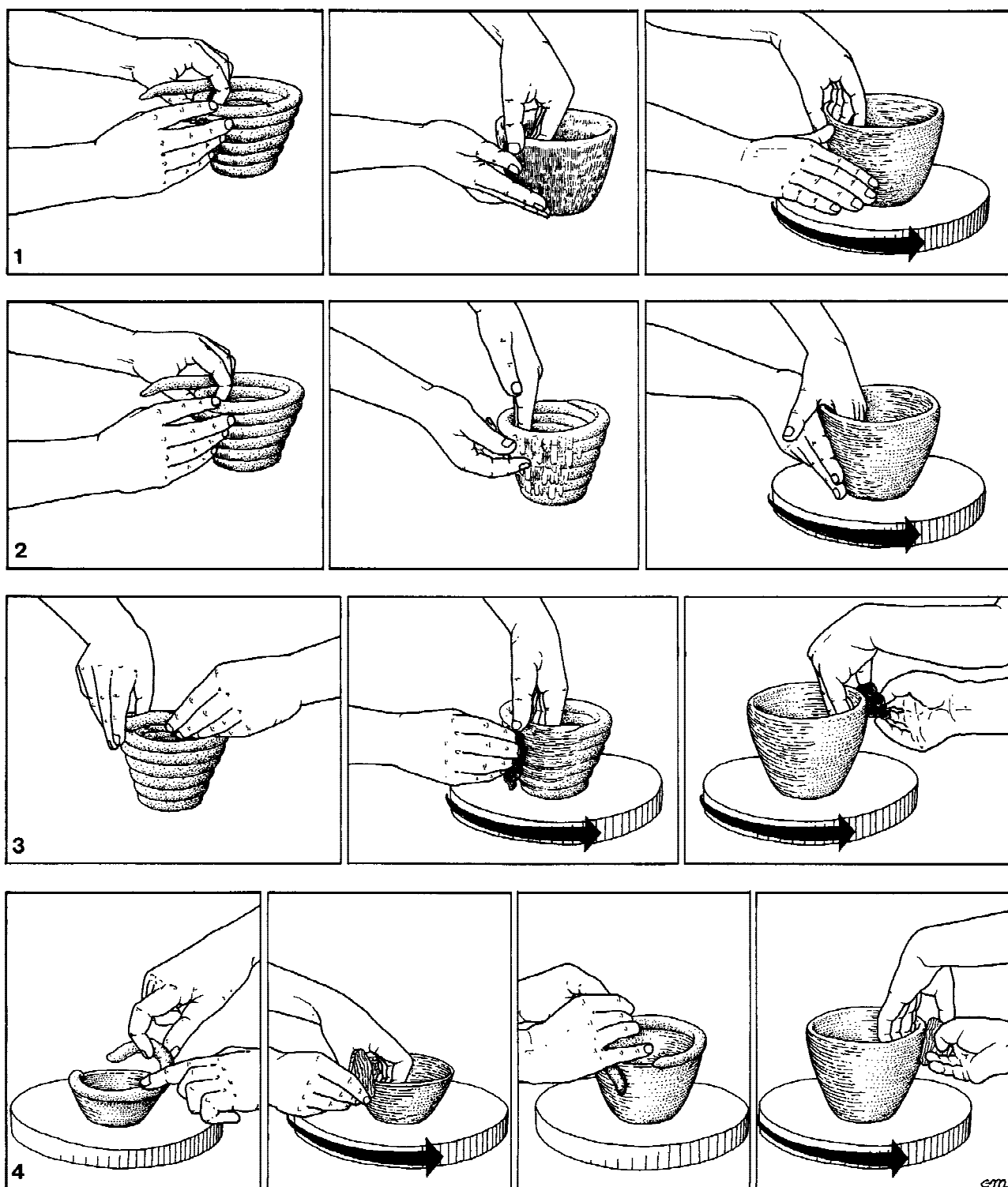


Figure 1. Manufacture of pots according to the four wheel-fashioning methods.

Technological characteristics of the wheel-fashioning methods. Comparatively, the four wheel-fashioning methods present the following technological characteristics:

Method. When considering the unfolding of the sequence, the four methods are very similar to each other. In all cases, pots are made of assembled elements which are joined, thinned and then shaped, and are

Table 1. Description of the four wheel-fashioning methods

	Forming the coils	Joining the coils	Thinning the coils	Shaping the roughout
Method 1	—	—	—	RKE
Method 2	—	—	RKE	RKE
Method 3		RKE*	RKE*	RKE
Method 4	RKE*	RKE*	RKE*	RKE

*RKE is used at the same time for different operations.

coiled from the base towards the neck. The use of RKE does not modify the unfolding of the sequence. The structure of the sequence is the same as the initial coiling sequence for which there is no use of RKE.

Technique. The different combinations of coiling and wheel-fashioning represent a progressive evolution towards a mechanization of the fashioning operations through the exploitation of the potential of RKE.

Concept. Concept is defined as the mental representation a potter has of both the physical and methodical modalities according to which a pot is made. Introducing RKE for fashioning assembled elements represents a major change of physical modalities and therefore a new concept. However, from a methodical viewpoint, combination of coiling and wheel-shaping does not differ from the coiling sequence.

Skills. The four different methods require the introduction of new skills radically different from those involved in coiling. They are considerably longer and more difficult to learn. These skills consist of a two-handed bilateral control, stability of the forearms, regularity and constancy of pressures, modulation of pressures according to clay plasticity, speed of the wheel and fashioning operation (Roux & Corbetta, 1989). Methods 1 and 2 are the easiest since RKE is applied on pots made of joined elements which, therefore, do not split apart when the centrifugal force is applied. Method 3, which requires intermittent pressures on each join of coil is the most difficult. This method is better adapted to big coils (equal to or greater than 1 cm diameter) and to coils of even thickness. Method 4 enables the potter to gradually centre each part of the pot and to join coils as and when placed. The problem of the application of centrifugal force to the assembled elements is therefore reduced to the joining of only two elements.

Tool. Variations of the speed of the rotative device according to fashioning operations differ between the four methods. The main factor involved in this variability is the behaviour of a heterogeneous body made of assembled elements when modified with the help of RKE. The effect of the centrifugal force that would split apart weakly-joined coils is avoided when the coils are assembled by intermittent pressures while the wheel

Table 2. Time manufacturing of 10 cm high restricted pots

Method	Operations without RKE	Operations with RKE	Total
Method 1	40 min	10 min	50 min
Method 2	30 min	10 min	40 min
Method 3		20 min*	20 min
Method 4		30 min	30 min

*Time manufacturing includes operations without and with RKE.

rotates slowly. The wheel speed is only increased once the body of the vessel has become a homogeneous solid. The linear speed of the wheel is then between 0.5 and 1 m/s (Pierret, 1995: 35).

Manufacturing time. When compared to the coiling technique, methods 1 and 2 present hardly any gain of time, taking into account the time required for building, joining and thinning coils by discontinuous pressures. Method 3 is the quickest. When comparing manufacturing time for 10 cm high, simple rim pots, the most time-consuming methods are, in decreasing order: methods 1, 2, 4 and 3. Time varies between 20 and 50 min (Table 2). It includes the time involved in coil forming. This time can be reduced considerably if an aid makes the coils.

Fashioning regularity. If the intention is to obtain regular walls that do not display marks of joins of coils, then the highest quality vessels are obtained by methods 1 and 4 which enable the potter to erase coiling patterns. On the other hand, methods 2 and 3 require the wall to be more strongly modified before joining patterns are erased. Similarly, a longer period of work at the surface would raise the problem of water saturation. Moreover, small restricted pots made according to methods 2 and 3 require, for the final shaping, a collaring operation. It consists of closing the mouth of the pot which had to remain large enough during the fashioning stages to enable the potter to put his hand inside the pot to work on the walls. The collaring operation is achieved through palm pressure on both sides of the external walls which easily induces a deformation of the clay and makes joins of coils again visible inside the pot.

Identification of wheel-fashioning methods

The analytical procedure presented here is based on the combined study of surface features and microfibrils following the methodology presented in Courty & Roux (1995). A controlled series of tests was designed to understand the mechanical behaviour of a specific clay material and to investigate surface features and microfibrils characteristic of the four different methods.

Variability of the pressures applied on the clay with the help of RKE helps to separate the four methods

Table 3. Summary of the main diagnostic surface features characteristic of the different wheel-fashioning methods

Method	Morphology of walls	Grooves	Rilling	Striations
1	Possible differential modification of external and internal faces Slight modification through RKE. Clay is not "stretched"	No trace of join of coils	Rare	Striations running around the internal and/or external face
2	Irregular microrelief: blisters with parallel pattern Possible differential modification of external and internal faces Slight modification through RKE. Clay is not "stretched"	Irregular wavy lines	Rare	Striations running around the internal and/or external face
3	Irregular microrelief: blisters with parallel pattern Strong modification of the two wall faces under the effect of RKE. Clay is "stretched"	Deep sub-parallel grooves Irregular way lines	Great variety of rilling Rilling in the form of a band crossed in the middle by a groove	Striations running around both faces
4	Strong modification of the two wall faces under the effect of RKE. Clay is "stretched"	Parallel grooves	Regular ridges out of adjustment	Striations running around both faces

clearly. In method 1, pressures with RKE slightly modify the morphology of the walls which have already been thinned by discontinuous pressures. In method 2, pressures with RKE strongly modify the wall surface in order to erase join patterns and thin the walls. In method 3, pressures with RKE strongly deform the coils and the wall surface in order to produce a homogeneous solid and erase join patterns. In method 4, pressures with RKE strongly deform the coils and the wall surface in order to produce a homogeneous solid and erase join patterns. The difference from method 3 lies in the binding of the coils.

Analytical procedure. The tests have been achieved with two professional potters who specialise in the coiling and wheel-throwing techniques*. For each method, the potters worked with the same illitic clay initially prepared for throwing pots on the wheel. The necessarily careful preparation is therefore consistent with the clay preparation observed on archaeological ceramics. The potters were asked to reproduce, as far as possible, the 3rd millennium ceramics with extremely regular wall surfaces showing parallel striations and, apparently, no marks of join between coils. For methods 1 and 2, coils were joined by vertical pressures in a downward direction on both sides of the wall, taking into account the type of binding observed on archaeological material.

Manufacturing time and water added during the different stages of fashioning were measured. A total of 63 pots were made using the different methods: 30 pots for methods 1 and 2, 16 pots for method 3, and 17 pots for method 4. Moreover, some pots were made by throwing or by coiling only, for a constant comparison of surface features between the different fashioning techniques. Pots were fired at *c.* 800°C temperature.

*The experimentation took place at the Historical-Archaeological Centre of Lejre, Denmark, during the summers 1994-1995.

The different parameters relating to the mechanical constraints that can act on surface features and microfabrics, were the following: shape of the pot: restricted and unrestricted; thickness of the coil: 1 cm for restricted pots, 5 mm for unrestricted pots. These thicknesses correspond to two broad categories met on the archaeological material (small vessels, big jars); placing of the coils: either straight above the lower coil, or against the inner side of the lower coil; platform upon which the coil is laid: this parameter appeared important for experimenting method 4; it can be symmetrical or asymmetrical; modification of the initial roughout walls when thinning: this modification can be either strong or weak; a weak modification hardly changes the coil thickness; a strong modification reduces coil thickness by 40%; pressure given with the help of RKE on the coils when thinning: it can be either intermittent or regular. This parameter is significant for the type of rilling formed; modification of the shape of the roughout at the shaping stage: this modification can be either strong or weak: a weak modification does not change the shape of the roughout, a strong modification changes the shape of the roughout; the unrestricted pots are given a carination, the restricted pots are compressed at the base and at the neck; care given to the different operations: this care is aimed at erasing joins of coils. It has been measured in manufacturing time.

Results. We present here a comparison of the diagnostic surface features and microfabrics obtained using each method.

Surface features (Table 3 and Figure 2). High quality finished products are necessarily obtained by a strong deformation of the coils and of the walls. Such a deformation enables the potter to obtain a homogeneous solid and to erase join patterns. As a consequence, all ceramics produced by the four methods

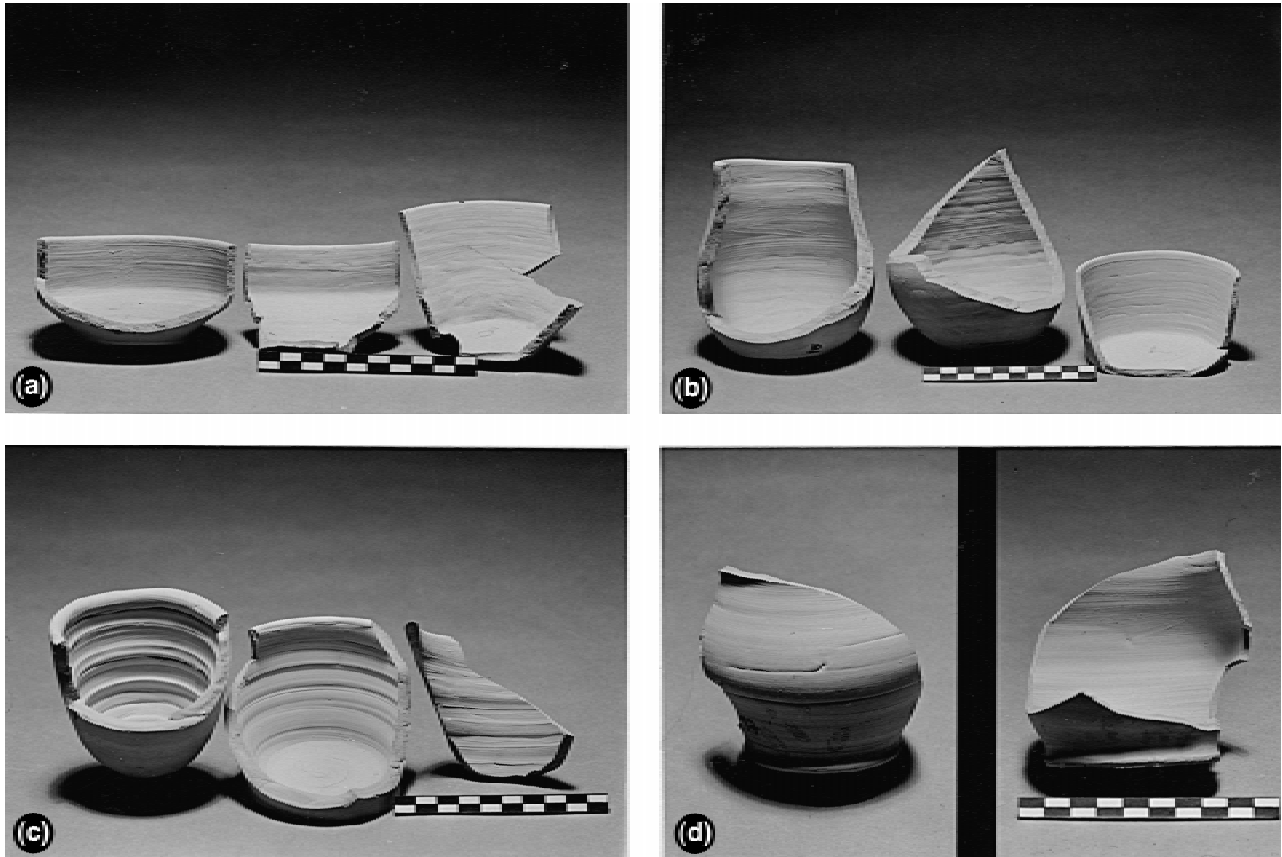


Figure 2. Surface features of experimental material. (a) Method 1, vessels display either regular walls or "non-stretched" walls. (b) Method 2, the vessels which have not been thinned enough under pressures combined with RKE display coil binding lines. (c) Method 3, pressures on joins of coils create bands crossed in the middle by a groove as well as a great variety of rillings. (d) Method 4, grooves displayed are parallel, located generally next to a compression zone (maximum diameter) and ridges are slightly out of adjustment.

display, at first glance, regular wall surfaces of similar aspect: presence of parallel striations and rilling running around the vessel walls, axial symmetry, and regularity of the wall thickness at a given height. However, careful examination of the surface features present on some significant pieces (pieces with flaws) reveals a large diversity of patterns which reflect the technical and mechanical constraints specific to each method.

Method 1 is characterized by walls, the morphology of which may have only changed superficially under the effect of RKE. The wall may be weakly "stretched". Occasional irregular microrelief can be present on the less worked parts of the walls (internal or external), and corresponds to the discontinuous pressures given in a downward direction to thin the roughout. The result is a wall that presents variations in thicknesses on limited spots ("blister"). These blisters can be found with a parallel pattern. In most cases, there is no trace of joins of coils. They have been erased at the roughout stage by discontinuous pressures. Rillings are rarely present since pressures are exerted on a formed homogeneous body.

Method 2 is characterized by occasional irregular wavy grooves on non-stretched clay walls (internal or

external) as well as by rare rillings. The wavy lines correspond to the binding lines of coils which, essentially, follow an irregular pattern. They can present different morphologies: it can be a fine single oblique feature, a broken line or a slightly furrowed wavy line. They have remained largely visible because of insufficient thinning and shaping of the clay with the help of RKE.

When fashioned using methods 1 and 2, clay walls can present faces (internal and external) with different morphologies (stretched, irregular). This difference reflects an asymmetry of pressures during thinning and shaping. Strongest pressures are given with the help of a tool.

Method 3 is characterized by a great diversity of rillings. One type of rilling is often found in the shape of a band which is crossed, in the middle, by a groove with an outline that is not rectilinear. It corresponds to the application of continuous pressures with the help of RKE on zone binding. The pressures create a band on both sides of the join of coil. The join is then located in the middle of the band. The variety of rilling is created by the intermittent differential pressures which press the clay at different intervals. This type of pressure is necessary with method 3: if not applied, the coils will

Table 4. Summary of the main diagnostic microfabric attributes characteristic of the different wheel-fashioning methods

Method	Structural pattern	Air voids	Particle orientation	Joins
1	Densely packed, subrounded, large clay domains Juxtaposition of (1) sub-parallel striated birefringence fabric and (2) random orientation with a speckled birefringence fabric	Rare, small, rounded Very rare, large, oblique	Random	Weakly expressed Rare oblique striations
2	Densely packed, elongated, large clay domains Dominantly cross-striated birefringence fabric (herring-bone pattern) merging to sub-parallel striated birefringence fabric at the edges	Rare, small, rounded Very rare, large, oblique	Random	Weakly expressed Rare oblique striations
3	Densely packed elongated large clay domains Inter-binding zones: sub-parallel striated birefringence fabric Binding zones: speckled birefringence fabric	Regular alternation of two types: V1 (inter-binding zone): sub-parallel, elongated; V2 (binding zones): large oblique vesicles	Rather random	Weakly to clearly expressed Oblique alignment of elongated vesicles
4	Dense packing of strongly compressed clay domains Periphery of the compressed clay domains: sub-parallel striated microfabrics Inner part of the clay domains: regular cross-striated birefringence fabric (herring-bone pattern)	Rare oblique vesicles Sub-parallel elongated when strong thinning	Expelled at the periphery of clay domains	Often weakly expressed; the sub-horizontal, thin discontinuities with strongly compressed clay domains

have a tendency to split apart under the combined effect of the centrifugal force and the continuous pressures. Pressures on the internal and external walls can be asymmetrical depending on the care given to both faces. If priority is given to the external face, then the less worked face, the internal one, can present deep sub-parallel grooves corresponding to the joins of coils which have not been properly bound. Another possibility is that joins of coils become distorted under strong pressures. They will be then visible in the form of irregular wavy lines.

Method 4 is characterized by regular ridges out of adjustment and parallel grooves on stretched clay walls, which correspond to a differential movement of the coils when placed above each other. In fact, perfect adjustment of one coil with the other requires great care and skill. This adjustment is especially delicate on restricted zones (base, mouth). Parallel grooves correspond to joins of coils. They are visible on zones of compression. Parallelism is a consequence of the fashioning of coils using RKE. It makes their section and their outline extremely regular even though, initially, this was not the case.

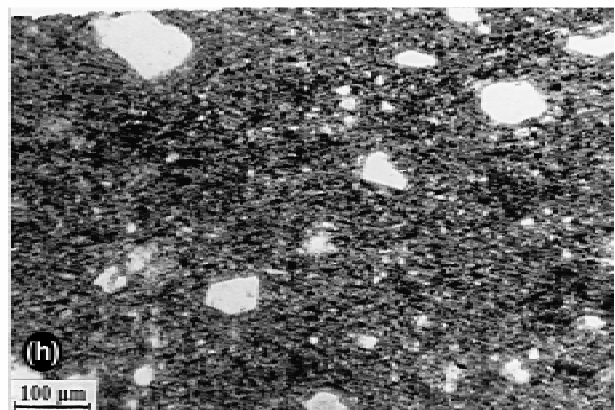
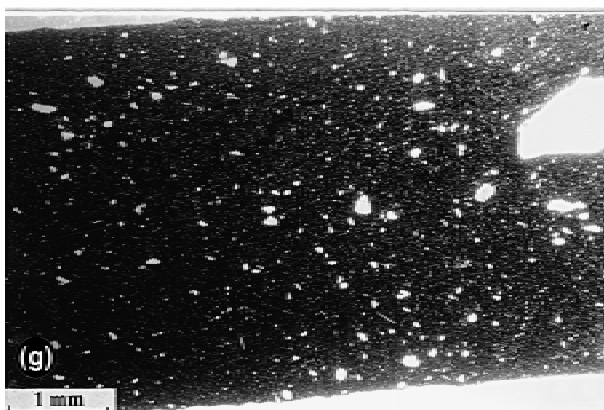
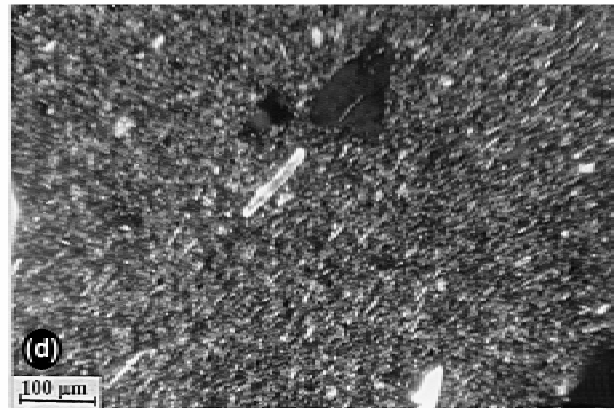
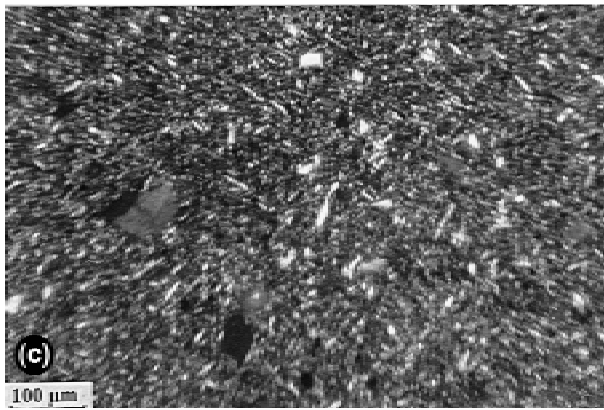
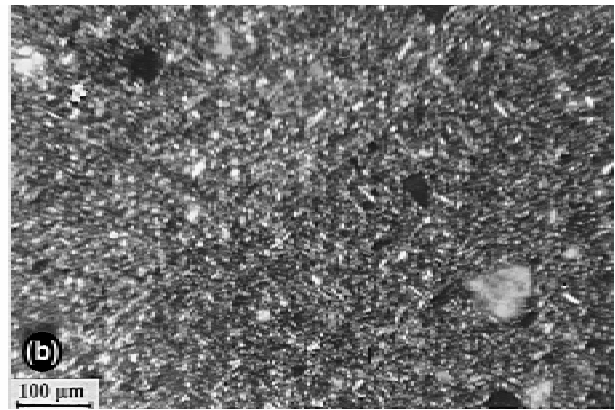
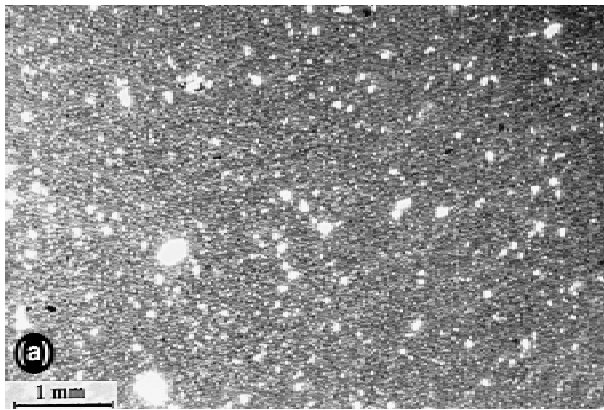
Microfabrics (Table 4 and Figure 3). Microscopic characteristics of cross-sections perpendicular to the wall surfaces, in the plane parallel to the vessel height, are described under the petrographic microscope by reference to the catalogue of microfabrics elaborated in Courty & Roux (1995). The various types of clay arrangements observed in experimental ceramics are correlated to the specific mechanical deformations of the clay induced by the different wheel-fashioning methods.

As previously demonstrated (Courty & Roux, 1995), a comprehensive characterization of ceramic microfabrics requires microscopic study, first at low magnification, of air void pattern, coarse particle distribution and general aspect of the fine mass, then, at higher magnification, morphology and arrangement of clay domains formed by the packing of clay-sized and fine silt-sized particles and their birefringence fabrics.

The experimental material is predominantly formed of micro-illitic clay domains mixed with a high content of fine silt-sized micaceous particles (c. 30%). It contains a minor proportion of silt-sized calcite particles (a few %) and subangular medium-sized quartzitic sands (5%). The resulting clay is characterized by its high rigidity and weak cohesion forces between clay domains and is therefore weakly sensitive to suffer plastic flow deformation under mechanical pressures at high water content (Courty & Roux, 1995). Although the vessels were fired at a temperature of c. 800°C, observation under polarized light (XPL) revealed that good preservation of the birefringence fabrics allows the recognition of the geometrical arrangement of clay domains at high magnification.

Observation at low magnification shows that all the experimental ceramics display a homogeneous, dense, fine mass which is formed of the close imbrication of a few hundred micron-sized, sub-rounded, clay domains with rare large voids and vesicles, with a random distribution and orientation of the coarse particles.

In general, whatever the method, joins of coils are not clearly visible at low magnification. They can only be recognized by minor imperfections, such as occurrence of oblique large vesicles, and weakly expressed



structural discontinuities. Evidences of joins of coils are no longer visible for most thinned ceramics due to the higher density and overall homogeneity of the fine mass.

Observation at higher magnification of the clay domain arrangement and of their birefringence fabrics allows identification of diagnostic properties that are relevant to characterize the energetic history specific to each forming method. Method 1 is characterized by the lower compression of clay domains expressed by a sub-orthogonal juxtaposition of two types of clay domain microfabrics: (1) sub-parallel striated birefringence fabric and (2) random orientation with a speckled birefringence fabric.

Reduction of the angle between the two types of birefringence fabrics for the ceramics produced by method 2 expresses the stronger continuous pressures applied during the wall thinning operation with RKE. This results in a regular arrangement of clay domains with a cross-striated birefringence fabric resembling a herring-bone pattern, very well expressed in this case due to the high rigidity of the illitic fine mass. The herring-bone pattern gradually merges to a predominant sub-parallel striated birefringence fabric at the two walls of the ceramic. Joins of coils appear to be marked by the development of longer sub-parallel striated birefringence fabric that is oblique to the wall faces, and often accompanied by a series of oblique small vesicles.

Ceramics produced by method 3 differ by the regularly spaced alternation of two types of birefringence fabrics that helps to recognize the successive joins of coils. The marked contrast between the central part of the coil (inter-binding zone) which displays a high structural reorganization (sub-parallel striated birefringence fabric) and the binding zone with low structural reorganization (speckled birefringence fabric) expresses the differential compressions when tensile forces are applied for forming the roughout with RKE. In addition to their specific clay domain pattern, joins between coils are often emphasized by large oblique vesicles left by trapped air in the weakly reorganized inter-binding zone, whereas vesicles are smaller and often elongated in the binding zone.

Ceramics produced by method 4 always display the highest degree of structural reorganization marked by a dense packing of strongly compressed clay domains resulting in an overall homogeneity of the clay micro-

fabrics. Sub-parallel striated microfabrics are generally observed at the periphery of the compressed clay domains while their inner part displays a regular cross-striated birefringence fabric with a herring-bone pattern. Furthermore, the strong pressures exerted when RKE is used for joining the coils produce differential displacement of the coarser grains which are expelled at the periphery of clay domains. Joins between coils are marked by sub-horizontal, thin discontinuities with strongly compressed clay domains that most probably correspond to the addition of wetted clay for binding the coils. A clear trend towards an elongated morphology of the clay domains is observed for the most thinned ceramics which have suffered important compressions (40% reduction of coil thickness, from 5 mm to 3 mm diameter). This specific microfabric is due to the formation of shear stress caused by important stretching with continuous addition of water when the coils are thinned with RKE. Absence of a sub-parallel micro-fissuration, however commonly observed in previous experiments, relates here to the illitic nature of the clay which minimizes effects of tensile stress and favours a homogeneous distribution of water (Courty & Roux, 1995).

In conclusion, the difficulty of distinguishing at low magnification between the different wheel-fashioning methods appears to be related, here, to the illitic nature of the clay and its very fine preparation. Examination of the cross-sections at higher magnification reveals distinct patterns in the clay microfabrics that are clearly characteristic of the four tested forming methods. However, diagnostic attributes are no longer visible on the most thinned ceramics which have suffered a 40% size reduction of wall thickness.

Archaeological Application

Ceramics of the two following sites have been examined. Shar-i-Sokhta, Hilmand, Eastern Iran. Occupation periods: from Period I to Period IV (end of the 4th millennium up to the end of the 3rd millennium, with a gap of occupation between Period III and Period IV) (Tosi, 1979). Kalibangan, Rajasthan, North West India. Occupation periods: pre-Harappan (first half of the 3rd millennium), Harappan (second half of the 3rd millennium) (Thapar, 1975).

Figure 3. Microfabrics of experimental ceramics. (a) Method 1. View at low magnification in plane polarized light showing the dense, homogeneous fabric, rare vesicles, random distribution of coarse inclusions and rare, fine vesicles. (b) Method 1. View at high magnification in crossed polarized light showing sub-orthogonal sharp contrast between a sub-parallel striated birefringence fabric on the left and one on the right with a random orientation and a speckled birefringence fabric. (c) Method 2. View at high magnification in crossed polarized light showing regular arrangement of clay domains with a cross-striated birefringence fabric (herring-bone pattern). (d) Method 3. View at high magnification in crossed polarized light of the inter-binding zone showing an oblique, sub-parallel striated birefringence fabric (high structural reorganization). (e) Method 3. View at high magnification in crossed polarized light of the binding-zone showing a speckled birefringence fabric (weak structural reorganization). (f) Method 4. View at high magnification in plane polarized light of the binding-zone showing horizontal alignment of vesicles and clay domains. (g) Method 4. View at low magnification in plane polarized light of a strongly thinned ceramic showing the very dense, homogeneous fabric. (h) Method 4. View at high magnification in plane polarized light of (g) showing the sub-parallel striated fabric caused by strong thinning.

The aim of the study was to test the value of our criteria for identifying wheel-fashioning methods. For this purpose, a limited number of sherds showing distinct surface features were selected. Results of a combined analysis of surface features and microfabrics were compared with the ones from the experiments.

The archaeological ceramics are not made from clay materials strictly comparable to the experimental one. The material from Shar-i-Sokhta is made from an illitic clay with a high proportion of silt-sized calcareous particles which modifies the clay behaviour under mechanical stresses. As previously demonstrated (Courty & Roux, 1995), an abundance of calcium carbonate reduces the differential displacement of illitic clay particles and, furthermore, makes the identification of clay domains microfabrics more difficult. In addition, the fine clay is mixed with a high amount of coarse, sand-sized particles increasing rigidity of the assemblage. The comparison is furthermore complicated by greater variability of the clay within the assemblage of each period, except for the Period III ceramics made of similar clay. The high degree of firing, responsible for a partial to total melting of the clay fine mass with resulting disappearance of the birefringence fabric has also made the study at high magnification difficult.

The material from Kalibangan is made of clay which contains in various proportion illite and smectite clay minerals, abundant fine silt-sized micaceous particles, in addition to a minor amount of coarse inclusions. A previous study has shown that the greater sensitivity to plastic deformation under shear stress may create specific microfabrics (Courty & Roux, 1995).

In spite of these difficulties, the comparison of the archaeological ceramics with the experimental assemblages has helped us to recognize a series of diagnostic attributes characteristic of the forming methods. The results given here are only examples which should, however, demonstrate the relevance of this new field of study.

Shar-i-Sokhta

Observation of Shar-i-Sokhta ceramics reveals four groups of surface features and microfabrics that match the four forming methods (Figures 4 and 5). At a first level of analysis, they are distributed according to the four chronological periods.

Asymmetry of wall faces. The external wall presents irregular microrelief as well as horizontal concentric striations. Transformation of the wall with RKE has not been strong enough to erase irregularities obtained while thinning the roughout by discontinuous pressures. No trace of joins of coils are visible. Rillings are absent. Internal face has been modified by pressures applied with RKE. The aspect is regular, "stretched"

with parallel striations. This combination of surface feature is similar to the one observed with method 1. It has mainly been observed on sherds belonging to Periods I and II.

Cross-sections display, at low magnification, a clearly expressed sub-parallel network of long, thin fissures and a high density of the fine mass. These two attributes result from both strong discontinuous hand pressures applied during the thinning operation and moderate stretching stress of the clay during the shaping operation with RKE. At high magnification, the common occurrence of clear structural discontinuities has allowed us to identify the joins of coils on most of the ceramics observed. They are generally marked by less compressed horizontal zones, with large sub-rounded vesicles. These characteristics are similar to the ones observed on experimental ceramics made using method 1.

Occasional irregular wavy grooves. This type of groove has been observed on the external wall of Pear Shaped Beakers (PSB) belonging to Period II. They are typical of a binding of coil by downward discontinuous pressures. Shaping on the wheel is shown by regular concentric striations and oblique wrinkles on the compression zones. These zones can also present strong deformations expressed by deep spirally orientated foldings: when forming small restricted pots, the mouth has to be left quite wide so that the potter, while thinning and shaping with RKE, can put his hand inside the pot. Once the overall pot is shaped, the mouth of the pot is then narrowed. The collaring operation implies that both hands apply pressures on the external walls. If the pressures are too strong or not progressive enough, or if the pot does not rotate fast enough, strong deformation of the clay is easily induced. Combination of occasional irregular wavy grooves and deformation of clay through RKE are easily produced by method 2.

Micro-analysis of PSB shows that they display a clearly expressed sub-parallel network of long, thin fissures, a high density of the fine mass and common occurrence of sub-horizontal discontinuities typical of joins between coils. The only significant difference with previous ceramics lies in a greater density of the clay domains which may relate to more important pressures applied with RKE for thinning, as observed for method 2.

Ridges out of adjustment. Most of the ceramics of Period III present a high quality of finishing which contrasts with previous periods. However, minor imperfections are visible in the form of undulated walls made of regular ridges out of adjustment and, in less proportion, rectilinear grooves. These surface features correspond to the ones observed on experimental material using method 4.

Microfabrics of ceramics from Period III totally differ from those of previous periods due to their great

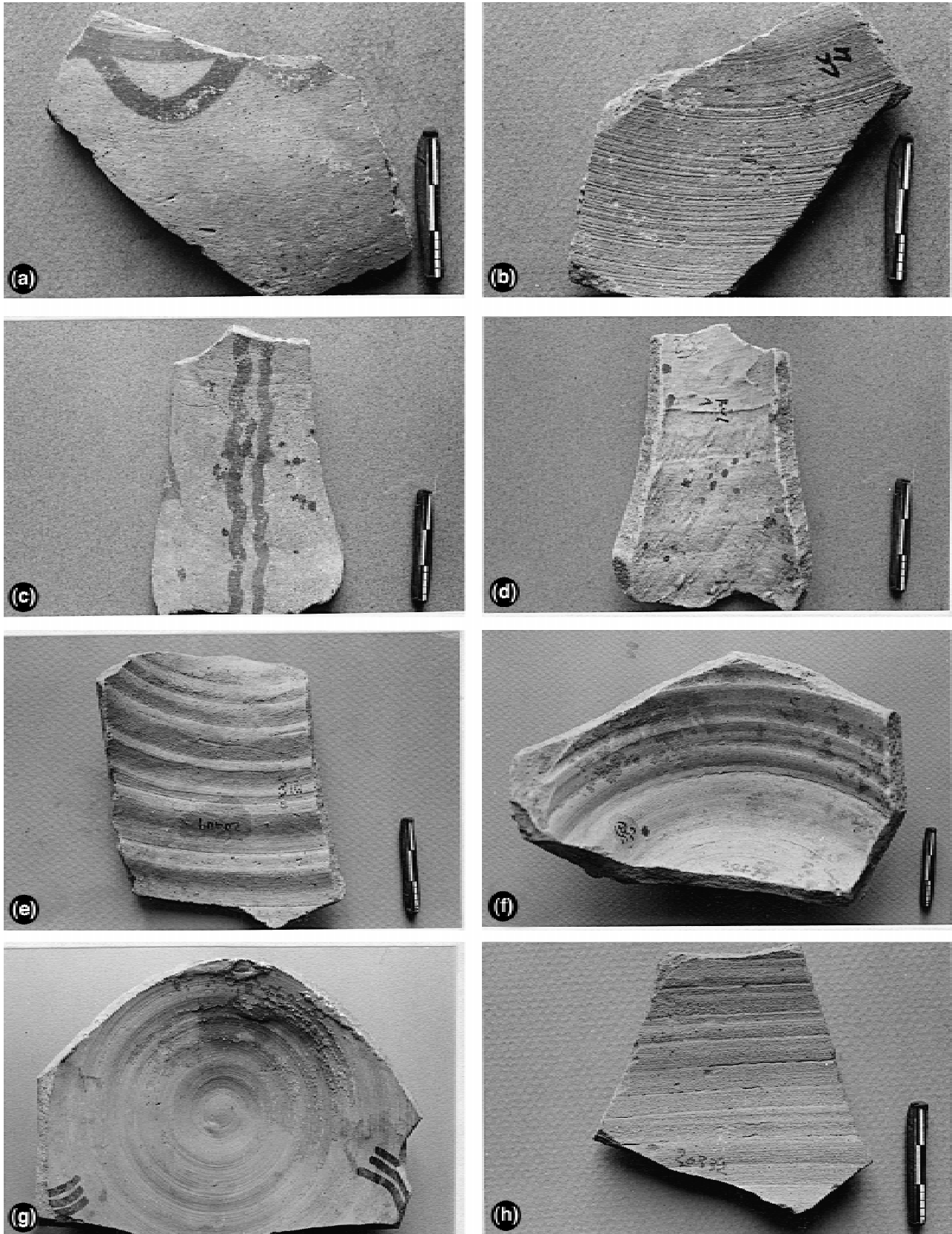


Figure 4. Diagnostic surface features observed on Shar-i-Sokhta ceramics. (a) and (b) Ceramic from Period I made according to method 1. (c) and (d) Ceramic (PSB) from Period II, made according to method 2. (g) and (h) Ceramics from Periods III and IV made according to method 4. (e) and (f) Ceramics from Period IV made according to method 3.

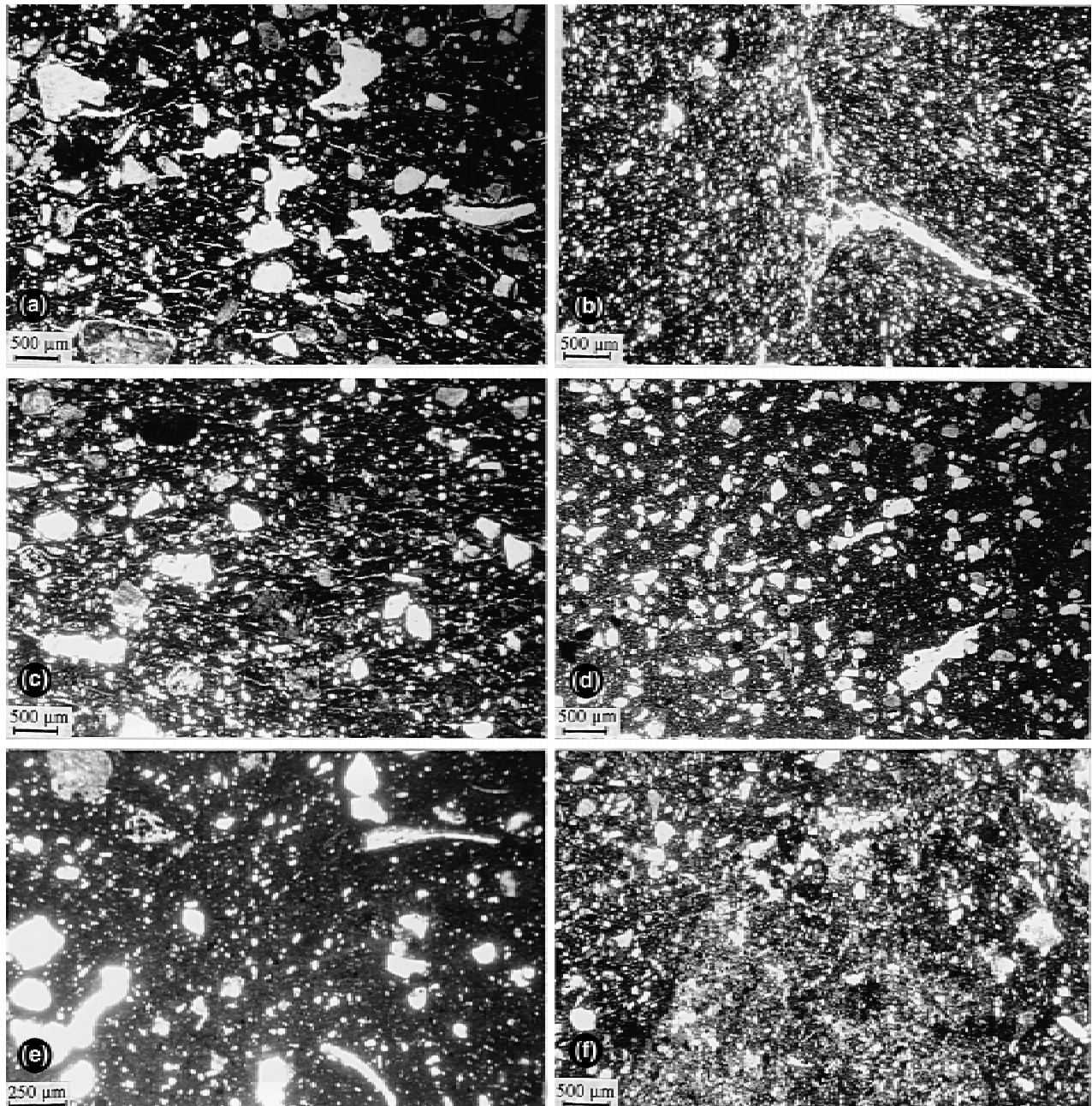


Figure 5. Microfabrics of archaeological ceramics, Shar-i-Sokhta. (a) View at low magnification in plane polarized light of a thinned Period I ceramic showing a sub-parallel fine fissuration and oblique vesicles at the contact between two coils. (b) View at low magnification in plane polarized light of a thick Period I ceramic showing distinct oblique vesicles at the contact between two coils. (c) View at low magnification in plane polarized light of a thinned Period II ceramic showing a regular, sub-parallel fine fissuration and lack of structural discontinuities due to careful erasement of coil joins. (d) View at low magnification in plane polarized light of a thinned Period III ceramic showing a very dense, homogeneous, microfabric, lack of fine fissuration and absence of structural discontinuities. (e) View at low magnification in plane polarized light of a thinned Period IV ceramic showing clear structural discontinuity at the contact between two coils expressed by the different morphology of the large voids. (f) View at low magnification in plane polarized light of a thinned Period IV ceramic showing clear structural discontinuity at the contact between two coils marked by a textural contrast.

homogeneity and absence of the sub-parallel network of fine fissures, except for the thinnest ceramics which display sub-parallel elongated vesicles. The rare occurrence of well marked sub-horizontal structural discontinuities is also a major difference. Only a few clear

ones have been observed either in the form of oblique to horizontal vesicles or as sub-horizontal striations. Occurrence of these rare imperfections and the great homogeneity of the fine mass suggest assigning Period III ceramics to method 4.

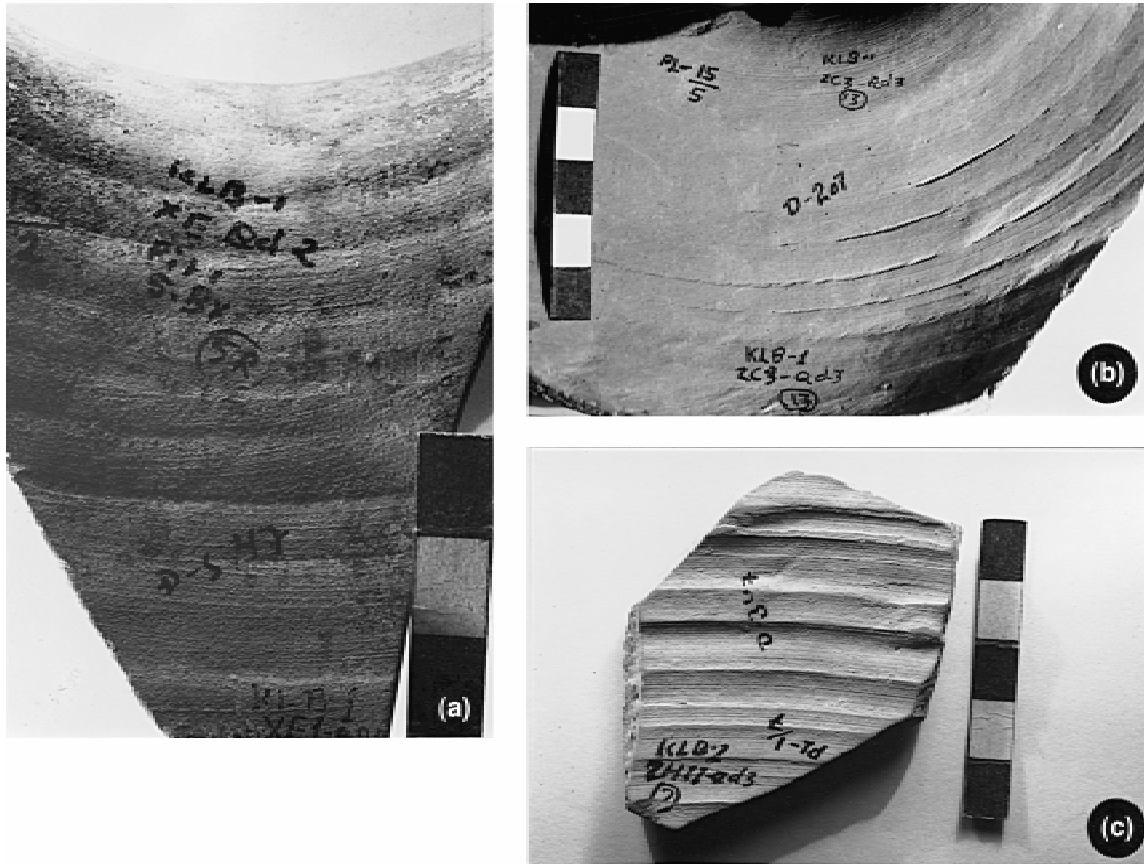


Figure 6. Diagnostic surface features observed on pre-Harappan ceramics. (a) Vessel with ridges out of adjustment, made according to method 4. (b) Vessel with parallel grooves on compression zones, made according to method 4. (c) Vessel with rilling in the form of a band, made according to method 3.

Variety of rillings. Pots belonging to Period IV present a great variety of rilling, such as the typical band crossed by a central groove described with method 3. As stated above, this band is obtained while applying pressures to joins of coils.

Ceramics from Period IV are, in most cases, characterized by the regular alternation of (1) thinner zones showing a very strong compaction and predominance of small, elongated vesicles and (2) less thinned zones which comprise oblique to sub-parallel, large vesicles in addition to small elongated vesicles. This double pattern has been shown to be typical of method 3.

Kalibangan

A great diversity of surface features is present on the pre-Harappan assemblage compared to the Harappan one (Figure 6). Examination of surface features and microfibrils has revealed that most of pre-Harappan ceramics were made without any use of RKE (classified as Fabric A by Indian archaeologists). Therefore, they are not specifically described here. On the contrary, most other Fabrics (B, C, D) and the Harappan ceramics do present the specific attributes of wheel-shaping, such as parallel striations and undulating

ridges and grooves running around the vessel walls, and regular networks of clay domains. The quality of their manufacture makes identification of the forming process difficult.

However, on a few pieces, significant surface features and microfibrils were highlighted (Figures 7 and 8).

Asymmetry of wall faces. Only the external wall shows stretching with RKE whereas the internal wall shows no traces of RKE. This asymmetry of surface aspects can only be found with forming method 1 or 2. They have been mainly observed on Harappan jar stands.

Ridges out of adjustment and parallel grooves. The ridges, often located in a compression zone (maximum diameter or mouth), can be outlined by parallel grooves. These surface features are typical of ceramics made according to method 4. They have been observed on a few pre-Harappan ceramics (classified as Fabric A) as well as on Harappan vessels.

Variety of rillings, rilling in the form of band. Rillings are varied. Some of them are present in the form of bands. They may also present deep sub-parallel grooves on the internal face. These surface features are



Figure 7. Diagnostic surface features observed on Harappan ceramics. (a) and (b) Jar stand made according to method 1 or 2. (c) Vessel made according to method 4. (d) and (e) Vessels made according to method 3.

typical of method 3. They have been observed on some pre-Harappan ceramics (belonging to so-called Fabric C) as well as on Harappan assemblage.

Microfabrics of pre-Harappan ceramics (wheel-shaped Fabric A and B) (Figure 8) are characterized by a very strong, homogeneous compaction of the

clay domains resulting in a predominance of the sub-parallel striated birefringence fabric. Elongated fine vesicles are common, in addition to large ones which may appear regularly spaced. Oblique orientated structural discontinuities marked by alignment of large vesicles and elongated coarse particles are often observed. They resemble the ones observed on experimental ceramics made using method 4, although the structural discontinuities are curvilinear and long in comparison to the ones of the experimental materials. This suggests a conical shaping of the platform before the assembling phase. In this case, occurrence of parallel striated birefringence fabric using method 4 reflects the greater sensitivity of the smectite rich illitic clay to shear stress (Courty & Roux, 1995). Some of the Fabric C ceramics are characterized by a dense network of strongly compressed clay domains with a very well expressed herring-bone pattern, rare for elongated vesicles and common rounded vesicles that are randomly distributed. Large vessels of Fabric C often display the juxtaposition of two microfabrics: (1) herring-bone pattern with a trend to sub-parallel striation and elongated fine vesicles; and (2) irregular packing of strongly compressed clay domains with randomly distributed rounded vesicles. This juxtaposition resembles the one observed for experimental ceramics made using method 3.

The Harappan bowls and plates are characterized by a similar pattern to those of the Kalibangan Fabric C, although they differ by the common occurrence of elongated fine to large vesicles (Figure 8). The large Harappan jars are predominantly formed of clay domains with a regular sub-parallel orientation, that are occasionally juxtaposed to zones with randomly orientated clay domains and large vughs. The latter can be assigned to relict traces of the initial fabric of the coils that have suffered less structural reorganization in comparison to the edges. The clear development of the sub-parallel microfabric is similar to the one obtained by method 4 for strongly thinned ceramics.

Conclusions

This paper has tentatively demonstrated that different wheel-fashioning methods were practised during the 4th–3rd millennium BC in Asia. They correspond to different technological as well as cultural behaviours.

Their identification should enable us, in the future, to understand better the historical reasons for adoption of the potter's wheel.

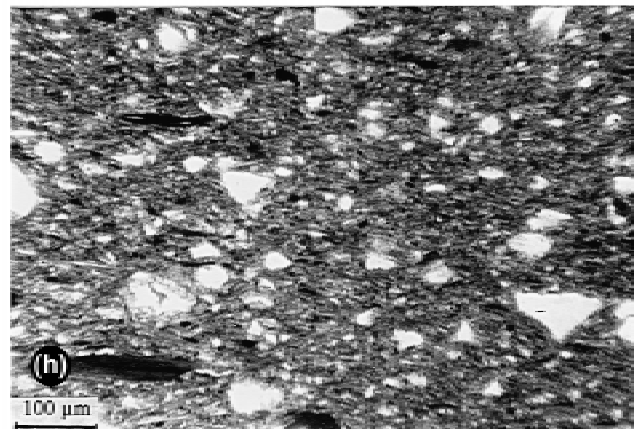
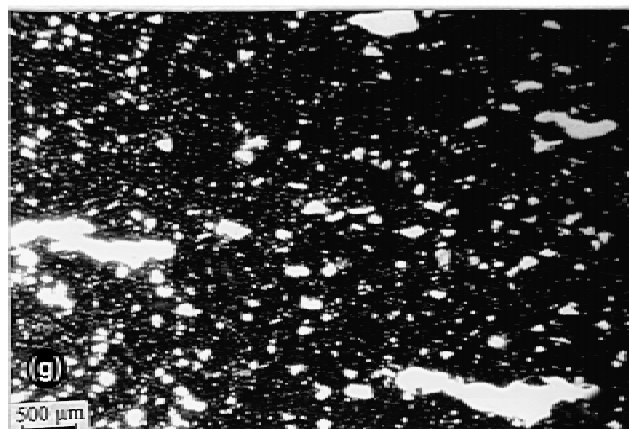
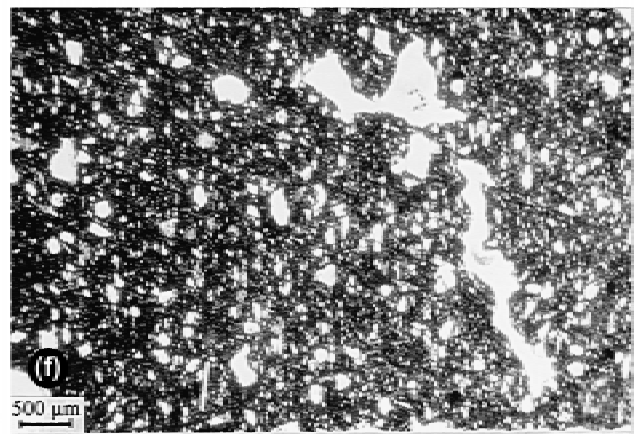
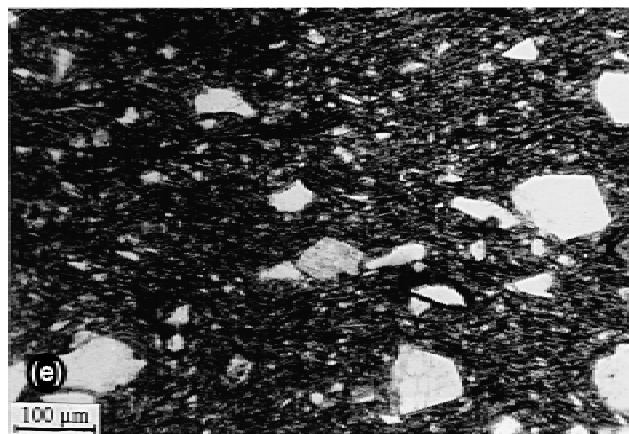
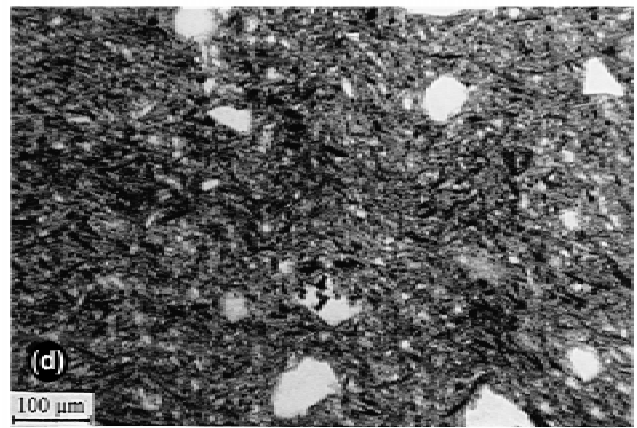
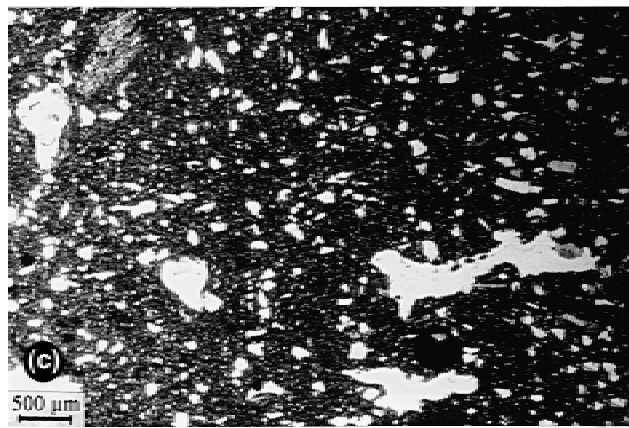
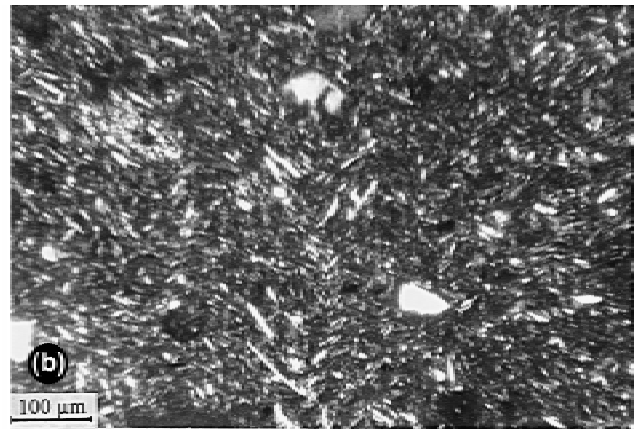
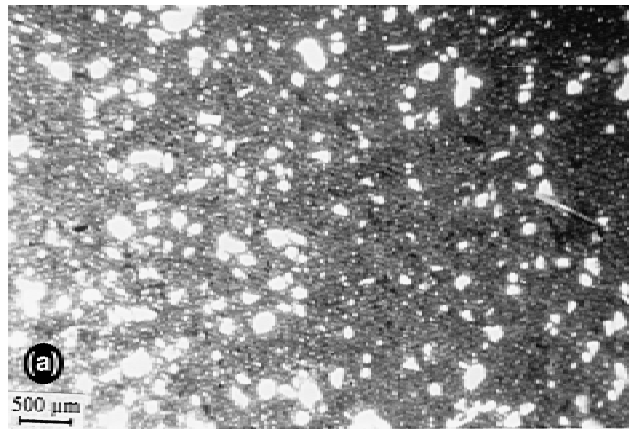
These experimental studies have enabled us to identify wheel-fashioning methods on the basis of surface features and microfabrics, both of which provide complementary evidence of the complex sequences involved in the ceramic forming processes. Surface features have been demonstrated to be dependent only upon forming methods. This has helped to discriminate effects induced by the type of clay preparation and nature of the clay on the variability of the microfabrics specific to each forming method. It follows that diagnostic attributes deduced from our study of one type of clay can be legitimately applied to ceramic assemblages made from a great diversity of clays.

A preliminary archaeological analysis has been performed on two ceramic assemblages: Shar-i-Sokhta in East Iran and Kalibangan in North-West India. The selection of ceramics, collected from main categories of surface features, has allowed us to identify different wheel-fashioning methods. Based on this preliminary application, a systematic inventory of ceramic assemblages should help, in the future, to highlight the history of the different methods and their significance with respect to socio-economic factors. However, it already appears that different methods simultaneously practised might not have been used for the same type of pot, and also that the different sites might have witnessed various developments of the wheel forming processes. A preliminary analysis (Roux, 1995) suggests that wheel-fashioning methods may have developed in relationship with the emergence of urban powers in Asia. The driving force was not reduction in manufacturing time or mass production, but a social representation of wheel-shaped ceramics and wheel-fashioning methods that would have acted as symbols of urban identity.

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Figure 8. Microfabrics of archaeological ceramics. Kalibangan. (a) View at low magnification in plane polarized light of a fabric C pre-Harappan, small-sized ceramic made of fine textured illitic clay. The fine preparation is indicated by lack of coarse porosity, random orientation of grains and fine voids. (b) View at high magnification in crossed polarized light showing very regular arrangement of clay domains with a cross-striated birefringence fabric (herring-bone pattern). Assigned to method 2. (c) View at low magnification in plane polarized light of a Harappan, strongly thinned jar. The photo is taken at a weakly expressed structural discontinuity typical of a coil join: note the sharp contact between the oblique vesicles on the left and the elongated ones on the right. Assigned to method 3. (d) View at high magnification in plane polarized light of (c) showing the inter-binding zone with a cross-striated birefringence fabric (herring-bone pattern). (e) View at high magnification in plane polarized light of (c) showing the binding zone with a sub-parallel fabric due to strong compression. (f) View at low magnification in plane polarized light of a Harappan, large-sized jar showing a clear structural discontinuity between two coils marked by oblique vesicles. (g) View at low magnification in plane polarized light of a Harappan, strongly thinned plate showing elongated vesicles and lack of structural discontinuities (erased by strong compression). (h) View at high magnification in plane polarized light of (g) showing a sub-parallel fabric due to strong compression.



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Appendix 1. Definitions of Preform and Roughout

Method: complex sequence of forming which involves phases, stages and operations, each of which can be achieved through different techniques. Three main forming phases should be considered: fashioning of the body (lower part, upper part), of the orifice (neck and rim) and of the base. The fashioning of the body can be divided into two stages; the forming of the roughout and of the preform.

Roughout: hollow volume which does not present the final geometrical characteristics of the pot. A roughout is usually obtained by thinning operations.

Preform: a pot with its final geometrical characteristics but where the surface has not been (or will not be) subjected to finishing techniques. A preform is obtained by shaping a roughout.

Each of the different phases and stages can comprise different operations.

Technique: physical modalities according to which clay is fashioned. These modalities can be described on the basis of the following parameters:

- the source of energy (pressure of the fingers/hands versus pressure of the fingers/hands combined with rotative kinetic energy).
- the type of pressure (discontinuous versus continuous).
- the clay mass onto which the pressures are exerted (mass of clay versus assembled elements).