Valentine Roux
In collaboration with Marie-Agnès Courty

Ceramics and Society

A Technological Approach to Archaeological Assemblages

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In memory of Jean-Claude Gardin, for his invaluable epistemological contribution, his visionary concept of human sciences, his concern for the cumulativity of knowledge and his taste for well-formed and well-founded scientific constructs.

To Jacques Tixier, for establishing the bases of technological analysis and promoting technological studies to their current rank in archaeology.

Acknowledgements

This handbook is a translation of the French manual “Des céramiques et des hommes. Décoder les assemblages archéologiques.” (2016, Presses Universitaires de Paris Ouest, Nanterre). It has benefitted from many encounters and experiences, beginning with my arrival in the “Prehistory & Technology” laboratory in 1990, marked by immediate and productive exchanges: lithic technology had made considerable advances and had become at that time an approach adopted by the majority of researchers. Those exchanges never ceased and were driven by a common preoccupation, an anthropological approach to material culture based on technology.

As a faithful disciple of the principles of empirical verification advocated by the logicism of Jean-Claude Gardin, one of my main concerns was to elaborate reference frameworks in order to enhance the interpretation of archaeological pottery. These references have been built up during constant interactions between archaeology, experimentation and ethnoarchaeology. The experimental section benefitted greatly from several stays in Denmark at the Archaeological and Experimental Centre and inestimable help from two remarkable potters, Lizbeth Tvede-Jensen and Inger Hildebrandt. Ethnoarchaeological research took place in the north of India, in Haryana, Uttar Pradesh and Rajasthan, where I met with many potters who provided the references proposed in this volume. Their contribution has also been invaluable, in the same way as the time we spent together and our countless exchanges on subjects extending beyond the scope of strict ethnographic investigations. The archaeological component took place in the Levant, thanks to successive invitations from Geneviève Dollfus, Pierre de Miroshedji and Jean-Paul Thalmann.[†] During repeated field trips to Israel, funded by the Ministry for Foreign Affairs, I received a warm reception at the CRFJ (Centre de Recherche Français in Jerusalem) and from many Israeli colleagues who made their collections available to me, enabling me to progressively build up a history of pottery techniques in the Levant.

Pottery is a complex field necessitating pluridisciplinary collaboration. Collaboration with Marie-Agnès Courty, researcher in soil sciences, is present throughout this volume. She has made a major contribution to the development of the methodology proposed here. I sincerely thank her, all the more so as I am aware that pottery is not her area of predilection. Our collaboration is above all, based on a long-term friendship.

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This volume came to fruition while I was teaching ceramic technology in Paris Nanterre and while I was directing several PhD theses on ethnoarchaeological or archaeological subjects relating to extremely diverse chrono-cultural periods. These theses presented the opportunity to test the solidity of the approach developed in this book. I wish to extend sincere thanks to the authors of these dissertations for trusting me when I suggested new methodologies or a new approach to their assemblages: Vincent Ard, Phaedra Bouvet, Claude Coutet, Laure Degoy, Agnès Gelbert, Aude Favereau, Sokhna Gueye,[†] Sébastien Manem, Freda Nkirote M'Mbogori, Marion Silvain, Hsiu-Chi Wu.

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Chapter 1
Introduction to Ceramic Technology

The aim of this book is to provide a cutting-edge theoretical and methodological framework, as well as a practical guide, for archaeologists, students, and researchers to study ceramic assemblages and their diachronic and synchronic variability. As opposed to the conventional typological approach, which focuses on vessel shape and assumed function with the main goal of establishing a chronological sequence, the proposed framework is based on a technological approach. Such an approach utilizes the concept of *chaîne opératoire*, which is geared to an anthropological interpretation of archaeological objects, that is, both a cultural and sociological interpretation. The first enables us to deal with the specific, particular characteristics of populations and their place in history and the second with institutions, social structures, and practices (Testart 2012).

The concept of the *chaîne opératoire* is now over 50 years old (for a recent history of the concept, see Delage 2017). It was first used by ethnologists observing the diversity of chains of object fabrication and their imbrication in the social and symbolic system of the societies they were studying. They brought to light the social and cultural dimension of these chains and, consequently, that of the technical fact in general (Mauss 1947; Maget 1953; Haudricourt 1964). This resulted in a genuine school of techniques in anthropology and archaeology under the guidance of researchers such as Creswell (1976), Balfet (1973), Leroi-Gourhan (1973), and Tixier (1967).

Many discussions focused on the definition of the *chaîne opératoire* (Balfet 1991) and the cultural value of its different structuring components. One of the earliest definitions is from Leroi-Gourhan: "Technique is both the skill and the tool, organized into a sequence by a genuine syntax that gives operational series both their rigidity and their flexibility"[1] (Leroi-Gourhan 1964, 1:164). The *chaîne opératoire* concept is currently used either to describe a general technical activity – when it is defined as "a series of operations that transform raw material into finished

[1] In French: "La technique est à la fois geste et outil, organisés en chaîne par une véritable syntaxe qui donne aux séries opératoires à la fois leur fixité et leur souplesse."

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product, whether it is a consumer object or a tool" (Creswell 1976, 13) – or to describe a portion of the technical activity that can then be divided into several *chaînes opératoires* (Lemonnier 1983).

In archaeology, the success of the *chaîne opératoire* concept came about when it was first applied to lithic industries and entailed widespread anthropological interpretation. *Chaînes opératoires* were much more than the identification of past ways of doing things, as they enabled researchers to bring "objects to life," to "humanize" them, to "find the people" who made these objects, and thus to raise a number of questions concerning their behavior, their characteristics, their interactions, their mobility, or their ideologies (Tixier 1967).

This anthropological interpretation was explicitly based on advances in anthropology which highlighted that techniques are the visible expression of cultural and social groups (Lemonnier 1993; Latour and Lemonnier 1994). This link between techniques and cultural or social groups was not an isolated observation but a real regularity, namely, a recurrent and timeless relationship between objects and attributes (Gallay 2011).

Amidst this scientific atmosphere characterized by significant interactions between ethnologists and prehistorians, ceramic technology was not forgotten, as shown by the publication of founding works (Balfet 1965; Balfet 1966; van der Leeuw 1977; Rye 1977; Franken 1978; Rye 1981; Balfet et al. 1983). These include descriptions of *chaînes opératoires* and the characterization of the attributes used to identify them in archaeological material. The stated objective was to recognize ancestral actions in order to characterize the assemblages, from both a cultural and a sociological point of view.

However, ceramic technology did not meet with the same success as lithic technology. Indeed, it is not easy to shake off old habits, and for a long time, forms and decorations remained favored markers (and still are at times) for classifying and making sense of archaeological assemblages. It is important to add that before the development of datations, ceramics were the main material used for establishing relative chronologies and tracing relationships between groups. It was not before the 1980s and the significant upswing in ethnoarchaeological studies that the social and cultural dimension of vessels was really reconsidered. These studies focused on presenting the important variations in the different stages of the *chaîne opératoire* from one population or group to another, irrespective of any physicochemical or economic determinism and regardless of their geographic origin, African, Asian, Eurasian, or American (e.g., Saraswati and Behura 1964; Rye and Evans 1976; Scheans 1977; Miller 1985; Longacre 1991; Mahias 1993; Dietler and Herbich 1994; Stark 1998; Bowser 2000; Gosselain 2000; David and Kramer 2001; Gosselain 2008).

In this way, the selection and preparation of clay materials, the first stages of the *chaîne opératoire*, underwent numerous investigations conducted in very different physical and cultural environments (see the bibliography cited in Stark 2003). These showed very wide variability in the selection and preparation of clay material among potter communities (e.g., in the Philippines (Longacre 1991; Longacre et al. 2000; Neupert 2000; Stark et al. 2000), Central and South America (Arnold

1985; Arnold et al. 1999; Arnold 2000), and Africa (Livingstone Smith 2000; Gosselain and Livingstone Smith 2005)). This variability can coexist with functional objectives, for which potters modify the composition of their materials in order to enhance ceramic resistance properties – for example, by adding tempers to reinforce resistance to thermal or mechanical shocks (Tite et al. 2001). This led to the general observation that the properties of clay materials influence technical choices but provide, at the same time, the possibility of variability, in terms of selection as well as preparation. Communities then act on this margin of maneuver to varying degrees, leading to distinct traditions issued from interplay between functional constraints and cultural factors (Fowler 2017).

The second stage of the *chaîne opératoire* is related to forming. Many ethnographic examples show that a recipient of the same size, of the same shape, and with the same function can be formed using different techniques and methods and that these differences vary from one group to another. There are many examples of this. In Africa, let us cite the research conducted by Gallay in Mali (Gallay 2012), Gosselain in Cameroon and Niger (Gosselain 2002; Gosselain 2008), and Gelbert in Senegal (Gelbert 2003), showing that the roughout techniques applied to the lower parts of vessels and the forming methods vary depending on the ethnic or ethnolinguistic groups. In India, these variations are linked to gender and sub-castes (Mahias 1993; Kramer 1997; Degoy 2008). In the Philippines, they follow the insular fragmentation of communities (Scheans 1977). But there are also examples where techniques, such as coiling or wheel throwing, can be practiced on a very wide scale with no differentiation between social groups. In such cases, variations must be sought out in methods, operating procedures, tools, or postures (e.g., Saraswati and Behura 1964; Kramer 1997; Degoy 2006).

Finishing operations and surface treatments modify the superficial layer of vessels. They also vary in relation both to cultural and/or functional factors. For functional factors, ethnoarchaeological studies have combined field observations with laboratory analyses. The results obtained concern the performance properties of vessels (Schiffer et al. 1994; Skibo 1994) and show that if the operations themselves can comply with functional constraints, their variability, on the other hand, is linked to cultural choices.

As for the variability of decoration operations carried out before or after firing, numerous studies (David and Kramer 2001, Chap. 7) have highlighted the absence of regularity between "stylistic provinces" and social groups necessitating contextual interpretation (Hegmon 1998). However, given that situations exist where stylistic complexes overlap with social boundaries, it seems that the variability of decoration is tied to even more complex mechanisms linked to production as well as consumption contexts. It is essential to distinguish between decoration and decorative techniques. The first is, above all, the expression of demand. The second is related to producers, and variability in decorative techniques is determined by social factors in the same way as the other stages of the *chaîne opératoire* (Gelbert 2003).

Lastly, the same observation applies to firing techniques. Whether in South America, Africa, or Asia, it is clear that they display marked variability, conveying above all cultural traditions, irrespective of physicochemical or economic determinism (see examples in Africa in Gosselain 1992a).

This brief overview of the ethnoarchaeological research conducted over the past decades thus shows that the technical traits describing the fabrication process of ceramic vessels derive from interplay between constraints linked to material and cultural factors, resulting in diverse ways of doing things among different social groups. This interplay is explained differently depending on the theoretical framework: for example, a compromise between cultural and functional factors, according to the behavioral approach (Schiffer and Skibo 1987; Schiffer and Skibo 1997; Skibo and Feinman 1999); adaptive advantage, according to the Darwinian approach (Boyd and Richerson 1985; Shennan 2002; Richerson and Boyd 2005); and social essence of technical facts, cultural choices, and identity factors, according to the culturalist approach (Latour and Lemonnier 1994).

Another approach to explaining the cultural dimension of techniques and, more specifically, the link between technical tradition and social group is to question not so much "why" this regularity exists (why do technical traditions distinguish between social groups?) but rather "how," meaning the process by which these different traditions develop. In this way, we are not dealing with explanatory factors that presumably vary from one situation to another but with the mechanisms underlying the formation of traditions, which, conversely, we can presume to be universal.

These mechanisms are related to the transmission process. They are studied within different theoretical frameworks and on the basis of different observable data (e.g., culturalist *versus* evolutionist, cognitivist *versus* ecologist) but lead to the same broad tendencies where the relationship between technical tradition and social group can be considered to be well-founded, as well as the evolution of technical traditions and their overlap with social groups can be considered to be reliant on transmission process (e.g., Stark et al. 2008).

Indeed, studies of transmission show that a technical practice necessarily results from a learning process based on the observation of actions in a social group (on this topic, see the communities of practice literature; Lave and Wenger 1991). From this point of view, a technical practice is always the emanation of a social group's way of doing things. It is part of a heritage that develops on an individual (learning) and collective level (transmission), according to biological and anthropological "rules."

On an individual level, psychology studies reveal that any learning involves a tutor and a model (Reed and Bril 1996; Bril 2002). If the individual explores himself/herself the task to accomplish, he/she does so through the observation of a model that represents the tutor's way of doing things. The role of the tutor is to educate the learner's attention and to direct his/her exploratory activities toward the development of a model to accomplish. Guidance not only facilitates the learning process but also directly participates in the reproduction of the task. It is the key to the cultural transmission of ways of doing things. At the end of the learning process, the skills learned are literally "incorporated." Not only does the learner build up motor and cognitive skills for making objects according to the model used in his/her culture, and only those; but he/she also uses this model for building up a representation of the technical act, a representation shared by all the members of his/her social group (e.g., Foster 1965; Nicklin 1971; Arnold 1985; Gosselain 1992b; Dobres 2000).

These skills and the associated representation then act as a fixative of the cultural model: it will be difficult for the individual to conceptualize and make objects in any other way than that practiced by the group, owing to "biological rules" imposing learning by copying a model and not by innovating (Bril 2002). The transmission process may induce modifications ("copying with error"), thereby introducing change into stable situations, leading to evolution through the selection of the trait introduced "by mistake" (Cavalli-Sforza et al. 1982). However, these mistakenly introduced traits are often minor and are not related to the skills themselves.

On a collective level, tutors are traditionally selected within the learner's social group. As a result, technological boundaries conform to social boundaries, namely, the social perimeter of the transmission of ways of doing things, and, hence, the boundaries beyond which other networks develop and transmit other ways of doing (e.g., Stark 1998; Ingold 2001; Knappett 2005; Degoy 2008; Roux et al. 2017). The "anthropological rules" governing skill transmission networks are here the same as those maintaining the cohesion of the group by ensuring its reproduction. The nature of the community in which the same way of doing is passed on is variable. It may correspond to a group, a clan, a tribe, a faction, a caste, a sub-caste, a lineage, a professional community, an ethnic community, an ethnolinguistic group, a population, or to gender (exclusive transmission of women's or men's ways of doing things), knowing that this nature can vary during history and that social boundaries can shift and change. In this way, a technique can be used at a given moment t by a socially limited group and at a different moment $t + 1$ by a socially enlarged group. In this case, the social boundary delimited by the transmission network has changed, and the technique has become the social expression of a different kind of group. Furthermore, a same community can comprise several transmission networks, depending on the objects made. Thus, in the ceramic domain, the production of culinary vessels can be controlled by the women in each household, whereas the large storage jars may be in the hands of several regionally specialized men. This leads to different historical dynamics and evolutionary modalities, creating what we refer to in archaeology as arrhythmia phenomena (Perlès 2013).

In sum, learning and transmission processes explain that technical traditions reflect social barriers; they are transmitted from one generation to another within social groups, thereby becoming the expression of these social groups. These processes also explain that in spite of contacts between social groups, in spite of the circulation of people and ideas, there is nonetheless a persistence of boundaries or, in other words, a resistance to sustainable homogenization of material culture (on this topic, see McElreath et al. 2003; Flache and Macy 2011; Flache 2018). These processes also enable us to reconsider the notion of identity and its relationship with techniques. They emphasize how this identity relationship develops and how it is linked to a shared practice as shown by the communities of practice literature (Lave and Wenger 1991). In archaeology, the analysis of the nature of the social group is necessarily contextual and often conjectural given the lacunar aspect of the archaeological data. From this point of view, it would be more accurate to say that techniques refer not to the notion of social identity but to the notion of "groupness" (Brubaker and Cooper 2000), where the group is defined through the practice of a same technical tradition, regardless of the links between the individuals forming the group. "This will enable us to distinguish instances of strongly binding, vehemently felt groupness from more loosely structured, weakly constraining forms of affinity and affiliation" (Brubaker and Cooper 2000, 21).

This has major implications for archaeology, outlined as follows:

- A tradition is an inherited way of doing things, intergenerational transmission ensuring the accumulation of knowledge and turning the history of the human species into a unique history.
- Any *chaîne opératoire* is indicative of a way of doing things inherited from one generation to another; it is a technical tradition.
- A technical tradition is the expression of a social group.
- The spatial distribution of technical traditions indicates the social perimeters within which they were learned and transmitted.
- The changes affecting technical traditions are the expression of the history of societies.
- Technical traditions can be powerful chrono-cultural markers, in particular in cases where the only stylistic expressions of the objects (forms and decoration) are of little significance (Roux et al. 2011; Ard 2013).
- The combined study of technical processes and objects (forms and decoration) is essential for the anthropological interpretation of archaeological assemblages; by only taking into account stylistic aspects, and leaving aside technical processes, we are depriving ourselves of related sociological and historical information. Thus, vessels of the same form and with the same decorative motifs can be made by different ethnolinguistic groups using different techniques. It is then neither the form nor the decoration that enables us to differentiate these groups but the *chaîne opératoire* only (as an example, vessels with the same shape and same decoration were made by the Halpulaaren and Soninke ethnolinguistic groups in the middle valley of the Senegal River; they could be distinguished solely on the basis of roughout techniques, the Halpulaaren using the modeling technique and the Soninke the molding technique; Gelbert 2003).

On the basis of these proposals, a research strategy to process archaeological assemblages using the *chaîne opératoire* concept had to be developed. The presentation of this strategy is central to this manual, which aims to provide archaeologists with the essential notions for applying the technological approach to their assemblages. This strategy represents the originality of the approach.

Founding works in the domain of ceramic technology emphasize the anthropological dimension of techniques and the relevant features to identify them (van der Leeuw 1977; Rye 1981; Balfet et al. 1983). In contrast, up until now, no methodology for classifying archaeological assemblages in a systematic order has been developed to enable their sociological interpretation. Yet this sociological interpretation is the necessary prerequisite for any cultural and anthropological interpretation.

The implementation of this methodology is at the heart of this book and governs the organization of the different chapters of this book. Their sequencing is ruled by the didactic need not only to explain how to study archaeological series but also why the study methods presented here are essential for approaching ambitious interpretations in a well-founded way.

First of all, this involves the identification of the different pottery *chaînes opératoires*. These cannot be identified without prior knowledge of the techniques and, more specifically, of the main forces at work in the deformation of clay materials. In this aim, Chap. 2 proposes to describe and classify ceramic techniques according to the physical principles governing the properties of clay materials and finished products. The properties of clay materials are analyzed in view of the qualities of the paste sought after by the potter, bearing in mind that the intention of the latter is to produce durable containers with good resistance to physical shocks. These analytical methods are innovative, given that physicochemical criteria are generally used to address mostly the question of provenances. Manufacturing techniques are also ordered using original classification directly inspired by the researches and terminology forged by lithic analysts (Tixier 1967). This terminology has largely proven its worth for the analysis of archaeological material in terms of the forces applied, successive sequences, tools, and gestures. From this viewpoint, this classification does not result in a simple catalogue of techniques but organizes them according to the forces involved. The understanding of these forces is essential for analyzing how pastes are deformed during the course of recipient manufacturing and how the diagnostic traits of the techniques are formed.

Chapter 3 follows on as a logical suite to Chap. 2 by explicating the diagnostic traits that allow for the identification of the *chaînes opératoires* with the practical aim of training archaeologists in their reading of the archaeological material. It presents the significant surface features and microfabrics highlighted during the course of experiments and ethnographic observations. Whether they are from the specialized literature or new experiments, the description of these traces is carried out using new analytical grids. These are based on a detailed understanding of the mechanisms underlying the transformation of clay materials exposed to different constraints. These grids were developed in collaboration with the field of geoscience, working closely with M.-A. Courty. At the end of this chapter, it becomes possible to analyze the ceramic material using different scales of observation and to identify the significant surface features and microstructures of the main techniques used. This approach paves the way for future experiments in order to improve our understanding of the singular traces present on any archaeological material.

After the mastery of the technological interpretation of sherds or vessels comes the classification stage of ceramic assemblages. The principles of ceramic assemblage technical classification are outlined in Chap. 4. These principles advocate a classification of all the sherds in a given assemblage according to technical processes and finished products successively. This is contrary to usual practices. The aim is to highlight traditions, that is to say, ways of doing a given functional range of containers. Once this classification is established, the challenge is to evaluate whether the variability of the *chaînes opératoires* is functional or sociological and whether sociological variability is simple or complex. The study of the function of vessels relies on shapes and physico-chemistry. The study of sociological variability leads to, first of all, an analysis of the sociological landscape and the function of the sites at a macro-regional level.

Chapter 5 complements the analysis of technical traditions by dealing with degrees of the potters' expertise and skills involved in manufacturing techniques and finished products. The characterization of expertise and skills is aimed at enriching interpretations of social groups (learners *versus* experts), the organization of production (domestic *versus* specialized), or the nature of change (continuous *versus* discontinuous). The necessary interdisciplinary dimension of skill-related studies is emphasized, and the methodology is exposed, with a view to validating hypotheses.

Chapter 6 summarizes the scope of the technological approach for interpreting the synchronic and diachronic variability of technical traditions and is a culmination of the analyses presented in the previous chapters. It shows how the *chaîne opératoire* concept is powerful for modeling techno- and socioeconomic systems and for analyzing cultural lineages and their evolution through the elementary and universal mechanism of transmission. In the same way, it shows how this concept is essential for appraising the history of techniques and the underlying evolutionary forces using theoretical frameworks combining the singularity of historical scenarios and anthropological regularities, Francophone and Anglophone approaches.

In order to demonstrate the technological approach to the study of pottery assemblages, both archaeological and ethnoarchaeological examples are given throughout this volume. Many of the archaeological case studies are from the milieu of the ancient Near East, a field directly related to the author's long-term research. Although currently there is only a limited number of wide-scale technological analyses of ceramic assemblages in sociological terms, and the technological approach is not yet widely practiced in Near Eastern archaeology, given their relevance, these selected examples illustrate universally applicable general principles, regardless of the chrono-cultural assemblage studied. These case studies serve as a model for researchers and students to guide them in formulating their own studies of archaeological pottery assemblages, using the technological methodology proposed in this book.

Finally, it is important to stress that the research strategy developed in this volume is also guided by the resolve to empirically verify the hypotheses issued from the anthropological interpretation of ceramic objects. For this purpose, the epistemological principles underlying the interpretative approach in archaeology, and involving the construction of actualist references in technology, that is, ethnographic and experimental references liable to explain past phenomena, are recalled in the inset below. As these actualist references are essential for interpreting archaeological material, they are alluded to throughout this volume.

Interpretative Procedure

The interpretation of archaeological objects inevitably calls upon references outside archaeology in order to make sense of a documentation, which is, by nature, incomplete (Gallay 2011). It always follows the principle of analogy (Gardin 1980; Wylie 1985). The interpretative approach consists in establishing an analogy between archaeological data and referential data and then transferring the attributes of the latter to the former.

In other words, on the one hand, we have an archaeological situation which raises questions as to the significance of our observations. On the other, we have a present-day situation where a recurrent link between observations and significance is known, and this link then considered as regularity. If archaeological and present-day observations are analogous, the regularity is transferred to the archaeological data. However, such a transfer can only be valid if the validity context of the regularity is defined, given that, in theory, all observations are polysemous and can thus have several meanings. For example (Fig. 1.1), after establishing links between macro-/micro-traces and forming techniques in an actualist setting (ethnographic or experimental), it is

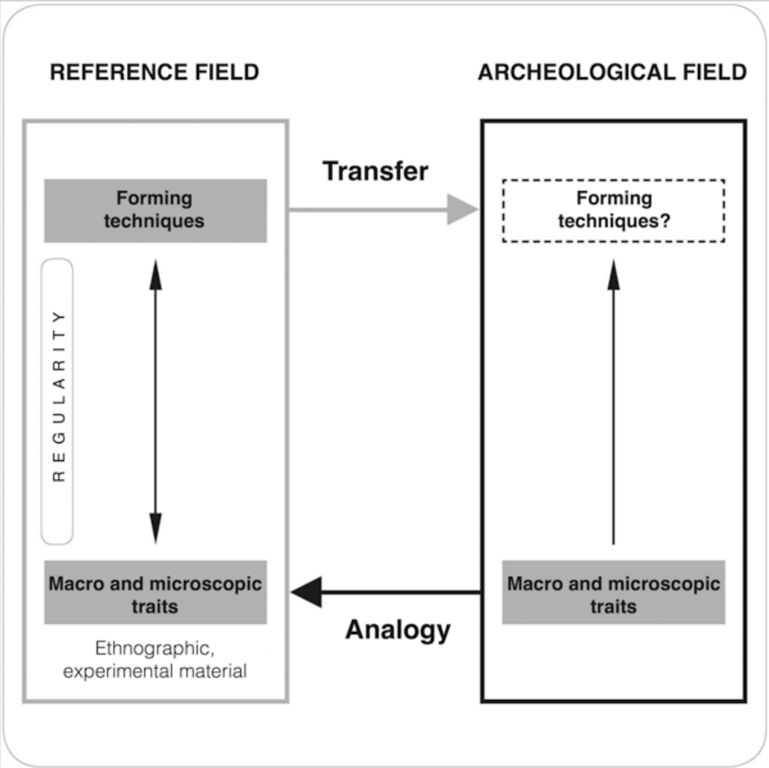

Fig. 1.1 Schematic chart of the interpretation process by analogy (after Gardin 1980)

imperative to define their scope of application on the basis of experiments conducted using protocols involving variations of one parameter at a time. This leads to the understanding of the formation of traces and thus of the mechanisms behind the consistent patterns (the regularities) linking traces and forming techniques. This then allows for not only the characterization of the context in which they can be used but also the interpretation of original traces in terms of techniques that do not necessarily have present-day parallels.

Another graphic representation of the interpretative archaeological procedure has been proposed by Gallay (2011) (Fig. 1.2). On the one hand, we have archaeological artifacts that can be interpreted on the basis of regularities brought to light in actualist settings; on the other, the explanatory mechanisms of these regularities allow for the definition of the context of their application, thereby enabling us to overcome the analogy dilemma. The axis linking mechanisms-regularities is based on actualist situations, whereas the axis linking regularities with archaeological data relates to the past. These mechanisms can never be used for the reconstruction of historical scenarios which must necessarily refer to regularities. The study of the mechanisms accounting for regularities is necessarily interdisciplinary (Roux 2017). Depending on the context, it calls into play material sciences, physical and chemical sciences, or anthropology, including ethnology, sociology, economic sciences, experimental psychology, or movement sciences.

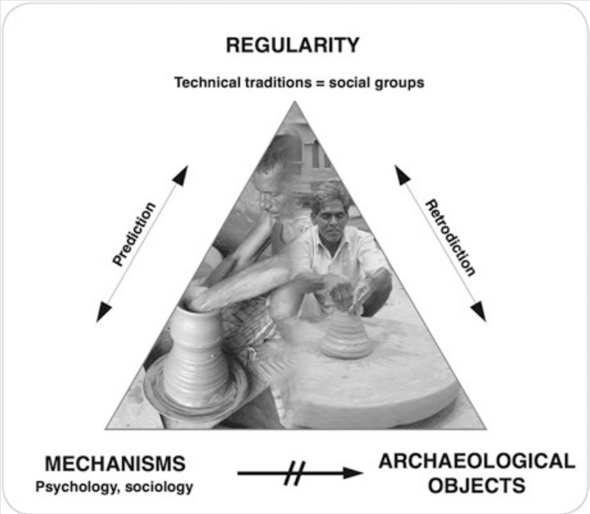

Fig. 1.2 Schematic chart of the archaeological reasoning (after Gallay 2011). The regularity linking technical tradition to social group can be explained under universal learning and transmission principles. Hence it can be used in archaeology whatever the cultural context

In technology, regularities pertain on the one hand to static phenomena – the diagnostic traits of *chaînes opératoires*, technical skills, the quantification of technical operations, and the social expression of technical traditions – and on the other to dynamic phenomena, the actualization conditions of change processes (Roux 2003, 2007). In this latter case, the hypothesis is that these conditions could correspond to evolutionary laws.

References

Ard, V. (2013). Ceramic traditions and cultural identities: West-Central France during the late Neolithic II period (c. 3400–2900 cal. BC). *Oxford Journal of Archaeology, 32*, 367–389.

Arnold, D. E. (1985). *Ceramic theory and cultural process*. Cambridge: Cambridge University Press.

Arnold, D. E. (2000). Does the standardization of ceramic pastes really mean specialization. *Journal of Archaeological Method and Theory, 7*(4), 333–376.

Arnold, D. E., Neff, H. A., Bishop, R. L., & Glascock, M. D. (1999). Testing interpretative assumptions of neutron activation analysis: Contemporary pottery in Yucatan, 1964–1994. In E. S. Chilton (Ed.), *Material meanings: Critical approaches to the interpretation of material culture* (pp. 61–84). Salt Lake City: University of Utah Press.

Balfet, H. (1965). Ethnographical observations in North Africa and archaeological interpretation: The pottery of the Maghreb. In F. R. Matson (Ed.), *Ceramics and man* (pp. 161–177). New York: Viking Fund Publication in Anthropology.

Balfet, H. (1966). La céramique comme document archéologique. *Bulletin de la Société Préhistorique Française, 63*, 279–310.

Balfet, H. (1973). A propos du tour de potier. L'outil et le geste technique. In Collectif (Ed.), *L'Homme, Hier et Aujourd'hui. Recueil d'études en hommage à André Leroi-Gourhan* (pp. 109–122). Paris: Editions Cujas.

Balfet, H. (1991). *Observer l'action technique: des chaînes opératoires, pour quoi faire?* Paris: Editions du CNRS.

Balfet, H., Fauvet-Berthelot, M.-F., & Monzon, S. (1983). *Pour la normalisation de la description des poteries*. Paris: Editions du CNRS.

Bowser, B. J. (2000). From pottery to politics: An ethnoarchaeological study of political factionalism, ethnicity, and domestic pottery style in the Ecuadorian Amazon. *Journal of Archaeological Method and Theory, 7*(3), 219–248.

Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. Chicago: University of Chicago Press.

Bril, B. (2002). L'apprentissage de gestes techniques: ordre de contraintes et variations culturelles. In B. Bril & V. Roux (Eds.), *Le geste technique. Réflexions méthodologiques et anthropologiques* (pp. 113–150). Technologies/ Idéologies/ Pratiques. Ramonville Saint-Agne: Editions érès.

Brubaker, R., & Cooper, F. (2000). Beyond "identity". *Theory and Society, 29*, 1–47.

Cavalli-Sforza, L. L., Feldman, M. W., Chen, K. H., & Dornbusch, S. M. (1982). Theory and observation in cultural transmission. *Science, 218*, 19–27.

Creswell, R. (1976). Techniques et culture, les bases d'un programme de travail. *Techniques & Culture, 1*, 7–59.

David, N., & Kramer, C. (2001). *Ethnoarchaeology in action*. Cambridge: Cambridge University Press.

Degoy, L. (2006). La variabilité céramique en Andhra Pradesh: regard sur des productions céramiques indiennes entre histoire, sociologie et transformations économiques. Nanterre: Université de Paris Nanterre. PhD.

Degoy, L. (2008). Technical traditions and cultural identity: An ethnoarchaeological study of Andhra Pradesh potters. In M. T. Stark, B. J. Bowser, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 199–222). Tucson: The University of Arizona Press.

Delage, C. (2017). Once upon a time… the (hi) story of the concept of the chaîne opératoire in French prehistory. *World Archaeology, 49*, 158–173.

Dietler, M., & Herbich, I. (1994). Ceramics and ethnic identity. Ethnoarchaeological observations on the distribution of pottery styles and the relationship between the social contexts of production and consumption. In J. Courtin & D. Binder (Eds.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (pp. 459–472). XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. Juan-les-Pins: Editions APDCA.

Dobres, M. A. (2000). *Technology and social agency*. Oxford: Blackwell Publishers.

Flache, A. (2018). Between monoculture and cultural polarization. Agent-based models of the interplay of social influence and cultural diversity. *Journal of Archaeological Method and Theory, 4,* 996-1023.

Flache, A., & Macy, M. W. (2011). Small worlds and cultural polarization. *The Journal of Mathematical Sociology, 35*, 146–176.

Foster, G. M. (1965). The sociology of pottery: Questions and hypotheses arising from contemporary Mexican work. In F. R. Matson (Ed.), *Ceramics and man* (pp. 43–61). New York: Viking Fund Publication in Anthropology.

Fowler, K. (2017). Ethnography. In A.M.W. Hunt (Ed.), *The Oxford handbook of archaeological ceramic analysis* (pp. 469-486). Oxford: Oxford University Press.

Franken, H. J. (1978). The analysis of ancient methods of potmaking. *Acta Praehistorica et Archaeologica Berlin*, *9-10*, 77–78.

Gallay, A. (2011). *Pour une ethnoarchéologie théorique*. Paris: Editions Errance.

Gallay, A. (2012). *Potières du Sahel: A la découverte des traditions céramiques de la boucle du Niger*. Gollion: Infolio.

Gardin, J.-C. (1980). *Archaeological constructs: An aspect of theoretical archaeology*. Cambridge: Cambridge University Press.

Gelbert, A. (2003). *Traditions céramiques et emprunts techniques dans la vallée du fleuve Sénégal. Ceramic traditions and technical borrowings in the Senegal River Valley*. Paris: Editions de la Maison des sciences de l'homme, Editions Epistèmes.

Gosselain, O. (1992a). Bonfire of the enquiries. Pottery firing temperatures in archaeology: What for? *Journal of Archaeological Science, 19*, 243–259.

Gosselain, O. (1992b). Technology and style: Potters and pottery among Bafia of Cameroon. *Man, 27*, 559–586.

Gosselain, O. (2000). Materializing identities: An African perspective. *Journal of Archaeological Method and Theory, 7*, 187–217.

Gosselain, O. (2002). *Poteries du Cameroun méridional styles techniques et rapports à l'identité.* Monographie du CRA 26. Paris: CNRS Editions.

Gosselain, O. (2008). Mother Bella was not a Bella. Inherited and transformed traditions in Southwestern Niger. In M. Stark, B. Bower, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 150–177). Tucson: Arizona University Press.

Gosselain, O., & Smith, A. L. (2005). The source clay selection and processing practices in sub-Saharan Africa. In A. Livingstone Smith, D. Bosquet, & R. Martineau (Eds.), *Pottery manufacturing processes: Reconstruction and interpretation* (pp. 33–48). BAR international Series 1349. Oxford: Archaeopress.

Haudricourt, A.-G. (1964). La technologie, science humaine. *La Pensée, 115*, 28–35.

Hegmon, M. (1998). Technology, style, and social practice: Archaeological approaches. In M. T. Stark (Ed.), *The archaeology of social boundaries* (pp. 264–279). Washington, DC: Smithsonian University Press.

Ingold, T. (2001). Beyond art and technology: The anthropology of skill. In M. B. Schiffer (Ed.), *Anthropological perspective on technology* (pp. 17–32). Albuquerque: University of New Mexico Press.

Knappett, C. (2005). *Thinking through material culture: An interdisciplinary perspective*. Philadelphia: University of Pennsylvania Press.
Kramer, C. (1997). *Pottery in Rajasthan. Ethnoarchaeology of two Indian cities*. Washington and London: Smithsonian Institution Press.
Latour, B., & Lemonnier, P. (1994). *De la préhistoire aux missiles balistiques. L'intelligence sociale des techniques*. Paris: Editions La découverte.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.
van der Leeuw, S. (1977). Towards a study of the economics of pottery making. In *Ex Horreo* (Vol. 4, pp. 68–76). Amsterdam: University of Amsterdam.
Lemonnier, P. (1983). L'étude des systèmes techniques, une urgence en technologie culturelle. *Techniques et Culture, 1*, 11–34.
Lemonnier, P. (1993). *Technological choices: Transformation in material cultures since the Neolithic*. London/New York: Routledge.
Leroi-Gourhan, A. (1964). *Le Geste et la Parole. Technique et Langage. Vol. 1*. Paris: Albin Michel.
Leroi-Gourhan, A. (1973). *Evolution et techniques. Milieu et techniques. Vol. 2*. Paris: Albin Michel.
Livingstone Smith, A. (2000). Processing clay for pottery in northern Cameroon: Social and technical requirements. *Archaeometry, 42*(1), 21–42.
Longacre, W. A. (1991). Sources of ceramic variability among the Kalinga of Northern Luzon. In W. A. Longacre (Ed.), *Ceramic Ethnoarchaeology* (pp. 95–110). Tucson: The University of Arizona press.
Longacre, W. A., Xia, J., & Yang, T. (2000). Ceramic materials, technology and the organization of production. *Journal of Archaeological Method and Theory, 7*(4), 273–294.
Maget, M. (1953). *Guide d'étude directe des comportements culturels*. Paris: Civilisations du Sud.
Mahias, M.-C. (1993). Pottery techniques in India: Technological variants and social choice. In P. Lemonnier (Ed.), *Technological choices: Transformation in material cultures since the Neolithic* (pp. 157–180). London/New York: Routledge.
Mauss, M. (1947). *Manuel d'ethnographie*. Paris: Payot.
McElreath, R., Boyd, R., & Richerson, P. J. (2003). Shared norms and the evolution of ethnic markers. *Current Anthropology, 44*, 122–130.
Miller, D. (1985). *Artefacts as categories. A study of ceramic variability in Central India*. Cambridge: Cambridge University Press.
Neupert, M. A. (2000). Clays of contention: An ethnoarchaeological study of factionalism and clay composition. *Journal of Archaeological Method and Theory, 7*(3), 249–272.
Nicklin, K. (1971). Stability and innovation in pottery manufacture. *World Archaeology, 3*, 13–48.
Perlès, C. (2013). Tempi of change: When soloists don't play together. Arrhythmia in 'continuous' change. *Journal of Archaeological Method and Theory, 20*, 281–299.
Reed, E. S., & Bril, B. (1996). The primacy of action in development. A commentary of N. Bernstein. In M. Latash (Ed.), *Dexterity and its development* (pp. 431–451). Hillsdale: Erlbaum Associates.
Richerson, P. J., & Boyd, R. (2005). *Not by genes alone. How culture transformed human evolution*. Chicago/London: The University of Chicago Press.
Roux, V. (2003). A dynamic systems framework for studying technological change: Application to the emergence of the potter's wheel in the southern Levant. *Journal of Archaeological Method and Theory, 10*, 1–30.
Roux, V., Courty, M.-A., Dollfus, G., & Lovell, J. (2011). A techno-petrographic approach for defining cultural phases and communities: Explaining the variability of Abu Hamid (Jordan Valley) early 5th millenium cal. BC ceramic assemblage. In Y. Rowan & J. Lovell (Eds.), *Culture, chronology and the chalcolithic: Theory and transition* (pp. 113–132). CBRL Levant supplementary monograph series. Oxford: Oxbow Books.
Roux, V. (2007). Ethnoarchaeology: A non historical science of reference necessary for interpreting the past. *Journal of Archaeological Method and Theory, 14*, 153–178.

Roux, V. (2017). Not to throw the baby out with the bathwater. A response to Gosselain's article. *Archaeological Dialogues, 24*, 225–229.

Roux, V., Bril, B., Cauliez, J., Goujon, A.-L., Lara, C., Manen, C., de Saulieu, G., & Zangato, E. (2017). Persisting technological boundaries: Social interactions, cognitive correlations and polarization. *Journal of Anthropological Archaeology, 48*, 320–335.

Rye, O. S. (1977). Pottery manufacturing techniques: X-ray studies. *Archaeometry, 19*, 205–211.

Rye, O. S. (1981). *Pottery Technology. Principles and Reconstruction. Manuals on archaeology 4*. Washington, DC: Taraxacum Press.

Rye, O. S., & Evans, C. (1976). *Traditional pottery techniques of Pakistan: Field and laboratory studies*. Washington, DC: Smithsonian Institution Press.

Saraswati, B., & Behura, N. K. (1964). *Pottery techniques in peasant India*. Calcutta: Anthropological Survey of India.

Scheans, D. J. (1977). *Filipino market potteries. Vol. 3*. Manila: National Museum of the Philippines.

Schiffer, M. B., & Skibo, J. M. (1987). Theory and experiment in the study of technological change. *Current Anthropology, 28*, 595–622.

Schiffer, M. B., & Skibo, J. M. (1997). The explanation of artifact variability. *American Antiquity, 62*(1), 27–50.

Schiffer, M. B., Skibo, J. M., Boelke, T. C., Neupert, M. A., & Aronson, M. (1994). New perspectives on experimental archaeology: Surface treatments and thermal response of the clay cooking pot. *American Antiquity, 59*, 197–217.

Shennan, S. J. (2002). *Genes, memes and human history: Darwinian archaeology and cultural evolution*. London: Thames & Hudson.

Skibo, J. M. (1994). The Kalinga cooking pot: An ethnoarchaeological and experimental study of technological change. In W. A. Longacre & J. M. Skibo (Eds.), *Kalinga ethnoarchaeology: Expanding archaeological method and theory* (pp. 113–126). Washington, DC: Smithsonian University Press.

Skibo, J. M., & Feinman, G. M. (1999). *Pottery and people: A dynamic interaction*. Salt Lake City: University of Utah Press.

Stark, M. T. (2003). Current issues in ceramic ethnoarchaeology. *Journal of Archaeological Research, 11*, 193–241.

Stark, M. T., Bishop, R. L., & Miska, E. (2000). Ceramic technology and social boundaries: Cultural practices in Kalinga clay selection and use. *Journal of Archaeological Method and Theory, 7*, 295–332.

Stark, M. T., Bowser, B. J., & Horne, L. (Eds.). (2008). *Cultural transmission and material culture. Breaking down boundaries*. Tucson: The University Arizona Press.

Stark, M. T. (Ed.). (1998). *The archaeology of social boundaries* (Smithsonian series in archaeological inquiry). Washington/London: Smithsonian Institution Press.

Testart, A. (2012). *Avant l'histoire: l'évolution des sociétés, de Lascaux à Carnac*. Paris: Editions Gallimard.

Tite, M. S., Kilikoglou, V., & Vekinis, V. (2001). Strength, toughness and thermal shock resistance of ancient ceramics, and their influence on technological choice. *Archaeometry, 43*, 301–324.

Tixier, J. (1967). Procédés d'analyse et questions de terminologie dans l'étude des ensembles industriels du Paléolithique récent et de l'épipaléolithique en Afrique du Nord-Ouest. In *Background to evolution in Africa* (pp. 771–820). Chicago/London: The University Press of Chicago.

Wylie, A. (1985). The reaction against analogy. *Advances in Archaeological Method and Theory, 8*, 63–111.

Chapter 2
Description of the *Chaînes Opératoires*

This chapter proposes a descriptive system of the ceramic *chaînes opératoires* in order to enhance the comparison and understanding of their synchronic and diachronic variability. The descriptive framework is based on widely accepted physical principles. These principles regulate the initial properties of the clay materials collected from natural sources and those of the finished products. The framework was constructed around the type of natural processes and technical operations that significantly changed the structure of the clay material and the surface condition of the clay pastes. Two levels of description are differentiated.

The first level describes the main actions that organize the progressive transformation of the clay material into a finished product. These are the collection and preparation of the clay materials, fashioning, finishing, surface treatments, decoration (which can take place before or after firing), and firing. Given the properties of the material and the intended final goal, the order of these actions is universal.

The second level describes the *chaînes opératoire*s involved in implementing each of these actions. Their diversity is to be considered as an anthropological implementation of practices conditioned by cultural and functional constraints.

The cultural constraints are expressed in the many reasons advanced to explain the different ways of doing that are still observable in the world. In effect, the *emic*[1] point of view of the potters contains abundant and diverse explanations on the fact that, for example, the same recipe is used for making a wide functional range of recipients or, conversely, that different recipes are used for making the same morpho-functional type of recipient. This *emic* point of view not only varies from one community to another but also within a same community, which can be made up of potters with no explanation about their practices (they do it like that because that is the way they were taught) or with explanations based on belief with no empirical foundation (they do it like that because it is better for such and such

[1] The *emic* viewpoint relates the potters' discourse. It is opposed to the *etic* viewpoint which refers to the scientific discourse.

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symbolic, technical, economic, or functional reason) or with grounded explanations. The latter cases are not very frequent. They generally concern experts with a technical understanding enabling them to go beyond the cultural representations acquired during apprenticeship (Roux 2011; Roux et al. 2018).

The functional constraints are linked to the properties of the material and the desired finished product. The diversity of the technical traditions is part of the room for manoeuver delimited by these constraints. They can be assessed by a knowledge of materials based on a characterization of their physical and physicochemical properties.

Consequently, in the first part of this chapter, we will consider the properties of the material in relation to the main purpose of the potters, i.e., making durable containers with good resistance to physical, mechanical, and/or thermal shocks, regardless of the function of the containers. The notions presented are based on basic principles shared by all geosciences relative to clay materials. Several references are given as guidelines to direct the reader toward more in-depth analyses in order to provide answers to more specific questions (*clay minerals*, Brown and Brindley 1980; Tessier 1990; Schulten and Leinweber 1999; Baldock and Skjemstad 2000; Chenu et al. 2000; Chenu and Stotzky 2001; Zhang and Horn 2001; Six et al. 2002; Kaiser and Guggenberger 2003; Blanco-Canqui and Lal 2004; Bergaya et al. 2006; Nalbantoglu 2006; Velde and Meunier 2008; Marchuk and Rengasamy 2011; Huang et al. 2012; Theng 2012); *paleosoils*, *paleogeography*, and *clay sources* (Hourani and Courty 1997; Murray 1999; Fedoroff and Courty 2005; Sedov et al. 2007; Fedoroff et al. 2010); *clay materials and ceramics*, Whitbread 2001, 2017; Hein et al. 2008; Reedy 2008; Tite 2008; Velde and Druc 2012; Quinn 2013; Hunt 2017). In order to remain on a general level, the references to the numerous case studies related to the study of clay sources in their paleogeographic context are not presented.

2.1 Collection and Transformation of Clay Materials

The *chaîne opératoire* linked to the preparation of the paste includes two main stages: the collection of clay sources (raw materials) and their transformation into a malleable and homogeneous paste that can dry without cracking and harden irreversibly and without accidents during firing.

These two stages are closely linked in the sense that the type of raw material used depends not only on the potter's environment but also on the intended finished products and the potter's cultural tradition.

Describing the *chaîne opératoire* linked to the collection and the transformation of clay materials and characterizing potters' cultural behavior thus involve:

- Finding the properties of the collected raw material in terms of its qualities for making the required finished products

- Understanding the choice of this raw material in terms of the potter's natural and cultural environment
- Reproducing the possible modifications made to the raw material in terms of its qualities for making the sought-after finished products but also in terms of the cultural tradition in which these modifications were made

In this aim, we will first of all specify the qualities that a clay paste should present in order to be fashioned, dried, and fired without accidents, so that the finished product will be resistant to physical shocks once it is fired. We will then characterize the properties of the clay raw materials in terms of the anticipated qualities of the paste when moist and fired, depending on the types of environment in which they are found. Then we will consider the modifications of the clay materials by potters to obtain the sought-after pastes.

Required Properties of the Clay Materials

The required properties of clay materials to transform them into ceramic pastes are malleability, ductility (or plasticity), tenacity, and the capacity to harden during drying.

Malleability

The malleability of clay materials corresponds to their capacity to be modified and fashioned, either by simple mechanical work while wet or by a change in the original composition by adding, removing, and/or transforming constituent compounds. This property is mainly linked to the abundance of small lamellar crystals or phytillous minerals, which define clay minerals strictly speaking. The clay denomination refers to all particles with a size inferior to 2 μm containing clay minerals and variable proportions of other mineral and organic components. In practice, raw clay materials from natural sources and those derived from different transformation operations are composite geomaterials made up of a high proportion of granulometric clays (at least 30%) which define the fine mass. This is mixed with silts (2–50 μm), or even sands (50 μm–2 mm), which form the coarse compounds. The malleability of the clay materials is closely dependent on the level of organization of the fine mass, the mineralogical nature of the fine and coarse components, and the links between the different types of constituents. The level of organization of the fine mass is determined by the assembly type of the constitutive compounds, which corresponds in general to a dense arrangement of the clay domains – arrangement of clay minerals and organo-clay complexes – with sizes ranging from several microns to several dozens of microns.

Ductility (or Plasticity)

Ductility corresponds to the capacity of clay materials to deform plastically without breaking while wet, due to the movement of the constitutive elements by dislocation. These movements include dislocations at the interface of elementary lamellae at the heart of the phytillous minerals and those resulting from sliding phyllite processes at the interface of clay domains. These levels of plastic behavior are expressed by a wide range of shear planes,[2] which are recognizable on thin sections by the birefringence microfacies observed at different magnifications with natural polarized light with a petrographic microscope. In presence of a defect (fissure, cavity, or discontinuity linked to a coarse element), plastic deformation becomes critical, and a zone of rupture spreads in general to the interface of clay domains, resulting in the formation of heterogeneities in their assemblage.

This mechanical dislocation behavior by shear fracturing directly results in the reticular structure of the clay minerals, which is a consequence of their crystalline sheet organization and their absorption capacity and defines their electrostatic properties. Unlike sands and silts which have no electric charge, in the presence of water, phytillous minerals display high reactivity which results in the formation of an ionic seal at the surface of the lamellar crystals. The formation of these negative surface charges causes cation exchanges in order to reestablish chemical neutrality. As it is impossible for the electrostatic charges to balance out totally, the clay mineral retains a clear negative charge or cation exchange capacity (CEC) which strongly conditions the stability of the clay domains. In this way, their cohesion is dependent on the type of clay minerals, especially on their specific surfaces, the cation charge of the environment (relationship between dispersive cations and flocculating cations), and the chemical nature of the organic compounds absorbed in the clay domains.

Ductility thus corresponds to complex mechanical behavior due to the concomitant implementation of different processes: physical or plastic deformations strictly speaking, chemical or cation exchanges, physicochemical or type of forces at the interface of clay sheets, and biochemical or clay/organic compound interactions. Consequently, the control of the plasticity of the clay materials by the potter from raw material collection to the production of the workable material should be assessed as a sequence of subtle operations based on an empirical knowledge of complex and concomitant processes. Some of these processes occur at instantaneous time scales, for example, plastic deformations, while others require longer reaction times (hours to weeks), in particular cation exchanges. For others, the duration of times can attain several years, for example, for the formation of lubricant polysaccharide gels[3] forming at the core of clay domains during the course of the slow maceration of clays rich in organic compounds. Without claiming to master the complexity of these interactions, it is nonetheless appropriate to understand the framework in order to discern the revealing traces of experienced potters' skills.

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[2] Fracture surface generally produced at the interface of clay domains in response to the application of tangential constraints.

[3] Organic composite macromolecules in long chains are playing a binding, fluidifying, or lubricant role due to their swelling property.

Tenacity and Capacity to Harden During Drying

Generally, regardless of the function of the ceramics, fired clay must be hard and enduring in order to resist mechanical and thermal shocks after firing. Tenacity is the capacity of a material to resist to crack propagation. Due to the composite nature of clay materials, this parameter is strongly influenced by the cohesion forces between the different constitutive elements, particularly at the interface between clay domains and contact zones between the coarse fraction and fine mass. In this way, the presence of fine films of water introduced during the preparation of the paste and during shaping can generate a fluidal state in places which causes the formation of fissures during drying. These localized losses of viscosity form zones of discontinuity in the fine mass, which are the main cause of the fragilization of the clay material during drying before firing. In the same way, incorporation of voids in the fine mass during preparation of the clay material can generate zones of rupture which lead to the propagation of cracks during drying.

The capacity of clay materials to harden during drying denotes the concomitant action of several factors. The respective roles of these factors are closely connected to the mineralogical nature of the clay materials, their degree of preparation, and their state of hydration. These parameters are controlled during the preparation and shaping of the paste in order to ensure the good cohesion of the assembly and minimum withdrawal during drying. The homogeneity of the worked clay material is unquestionably the key for regular drying with no density gradient, to avoid the formation of an impermeable outer crust. Like for porosity, the type of coarse fraction and its degree of incorporation – original components or tempers introduced during preparation – serve to control withdrawal in order to ensure better, fast, and homogeneous drying.

The first stage of hardening occurs at ambient temperature, by slow drying, preferentially with no direct exposure to UV rays. The main resulting modifications correspond to the partial evaporation of free water, retained at the interface of clay domains and in the porosity, as well as to mild and relatively slow (several dozen hours) chemical and mineralogical transformations, which can occur at temperatures of 20–30 °C. For the latter, there are in particular two types of reactions: (1) an evolution of the organo-clay complexes modified by the mechanical mixing of clay materials marked by a beginning of polymerization with the formation of relatively pasty gels; the presence of metallic or carbon catalysts in the fine mass, for example, graphite or carbon black, is likely to accelerate hardening at this stage; (2) a partial hardening after a hydration of components initially present in the fine mass or intentionally added for this purpose; these can, for example, be sulfates or finely divided calcium carbonates, or slaked lime in coarse particles or fine powder, or even aluminosilicates of calcium liable to play the same polymerizing and cementation role. Overall, these are reversible or partially reversible transformations. At this stage of drying, the clay material is still relatively plastic and can thus react to mechanical work without breaking, for example, percussion to thin the walls. Nonetheless, the rigidity of the assemblage is such that shear stress is limited or even impossible.

The definitive and irreversible stages of hardening occur progressively during the course of firing, in the continuity of the transformations initiated during air-drying. The main transformations are induced by water losses, first by the evaporation of free water between 100 and 130 °C; then between 130 and 400 °C, by the evaporation of the water trapped in the fine mass, for example, at the interface of the clay domains; and then between 400 and 700 °C, by the departure of the water forming an integral part of the clay crystallite. This represents an irreversible structural change which is generally accompanied by mineralogical modifications with neogenesis of new mineral phases, for example, of magnesium and calcic silicates, and/or transformations of mineral phases, or even their disappearance, particularly for salts and carbonates. In parallel, the organo-clay complexes undergo first of all (150–400 °C) irreversible polymerization and then partial decomposition, apart from thermoresistant carbon-clay complexes which can persist in the fine mass well beyond 700 °C. All of these mineralogical transformations and interactions of phases are essential for the clay paste to acquire a sufficient degree of cementation to become an inert to water, non-wettable material, with a physical reactivity adapted to the mechanical and thermal stress exerted during use. The degree of homogeneity of the clay material plays a key role in its reactivity during firing, particularly to prevent the formation of cracks.

Characteristics of Clay Materials

Source Materials and Deposition Contexts

In most traditional past or present ceramic production situations, the sources of clay materials are in surface or subsurface deposits. These are generally soils and fine sediments, with a clayey-silty texture, accumulated in depressions, for example, in abandoned river meanders, alluvial flats, interdunal depressions, endorheic basins, or sedimentary traps such as karstic cavities (Fig. 2.1). The parent materials result from inputs by waterborne and/or the aeolian transmission of fine sediments with abundant detrital clayey minerals, transformed by pedogenesis during the course of deposition. In the vast majority of cases, the physicochemical processes did not profoundly modify the mineralogical nature of the clays as deposition contexts were rapidly renewed. The in situ production of new-formed clayey minerals, derived from the weathering of aluminosilicate rocks, is part of a long-term geological evolution that can lead to the formation of primary clays at the scale of hundreds or even millions of years. The clay sediments in the surface or subsurface deposits are thus mostly made up of secondary clays of detrital origin, which are in turn derived from diverse primary and/or secondary sources. The clay materials used in these types of environments are thus intrinsically composite, as a result of multiple origins and in situ transformations by meteorological (water, UV) and biological (fauna and flora) agents and physical (shrinkage-swelling) and physicochemical actions (reactions to the interfaces of mineral elements). The combined effects of

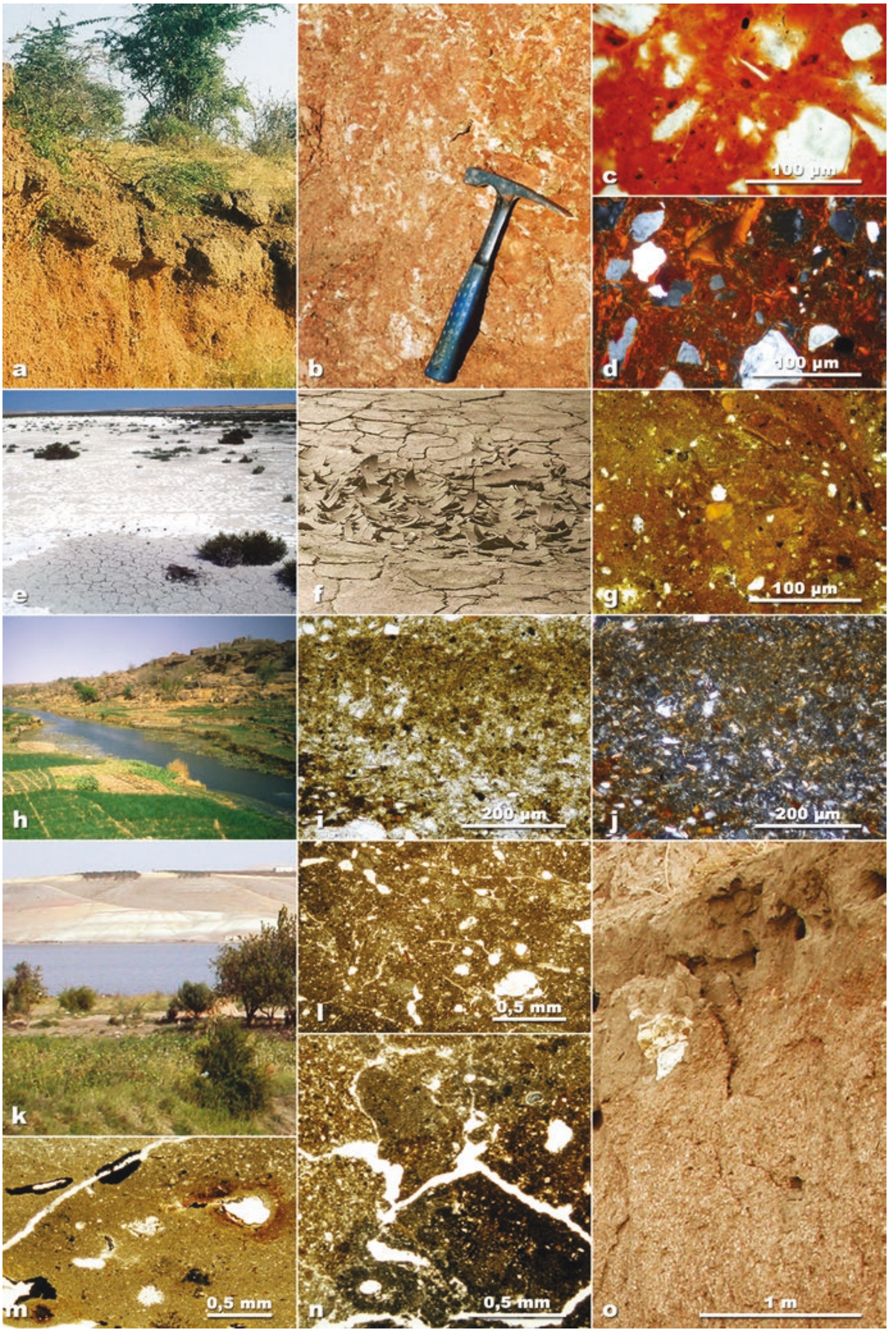

Fig. 2.1 Examples of clay sources and of the raw clay material characters: (**a**) subsurface pedogenized clay, Chennai region, South India; (**b**) soil profile showing the mottled deep horizon facies expressing an iron-leached pattern along fine fissures and the more homogeneous facies toward the

these pedological processes for hundreds, or thousands, of years led to the natural shaping of the fine mass, to variable degrees, depending on environmental conditions, giving these clay materials optimal properties for ceramic production. In this pre-preparatory stage carried out by natural processes, the quality of the exploited sources is closely dependent on three main parameters: structural maturation, which refers to the state of microaggregation of the fine mass; textural maturation, which takes account of the state of micro-division of the clay component by gravitational effects during deposition (decantation) and mechanical effects during in situ evolution (natural micro-crushing); and mineralogical maturation. The latter refers to all the interactions between clay minerals, strictly speaking, organic compounds, and the other fine elements of the clay domains. Textural, mineralogical, and structural maturity thus denote the complexity of the processes at work in the acquisition of the properties of clay materials and, in particular, those required by potters: malleability and ductility.

On account of the relatively long durations of time involved in these sedimentary processes (several hundred to several thousand years), the clay materials from each depositional context generally present homogeneous characteristics. Overall, the sources used thus offer rather similar properties. At a more detailed level of characterization, a source of clay materials can present some variability as regards its properties, often denoted by the heterogeneity of facies within the deposit, for example, lenticular deposits with attributes contrasting with the surrounding clay materials. These vertical and lateral facies variations generally convey the occurrence of modifications, during a relatively short lapse of time (several years to several dozen years) in depositional conditions, leading to the formation of significantly different clay materials (Fig. 2.1l–o). These can be, for example, episodes of aeolian

Fig. 2.1 (continued) surface; (**c**) upper horizon microfacies in plane analyzed light showing the dense packing of the clay domains mixed with angular quartz sands and rare micaceous flakes; (**d**) view of (**c**) in polarized analyzed light showing the juxtaposition of randomly organized, microdivided clay zones expressing an intense turbation by shrink-swell and oriented clay domains resulting from clay translocation along to soil development (illuviation); (**e**) endoreic basin with saline accumulation, semiarid Sebkha, Egypt; (**f**) surface view showing the clay deposit by natural settling; (**g**) microfacies of the upper horizon in plane analyzed light showing a compact silty-clay facies with angular fine quartz sands, with abundant silty-clay intercalations and papules (fragments of surface crusts) integrated by the natural mechanical turnover (shrink-swell cycles); (**h**) alluvial floodplain, Western Africa; (**i**) microfacies of subsurface deposits in plane analyzed light showing a bedded facies formed of silty and sandy silt with abundant micaceous silt; (**j**) view of (**i**) in polarized analyzed light; (**k**) floodplain of the Euphrates upper basin (Northern Syria) modified by a recent dam; (**l**) upper horizon, view in plane analyzed light showing an aggregated microfacies marked by the dense packing of biogenic aggregates issued from earthworm galleries; (**m**) profile bottom, view in plane analyzed light showing a homogeneous silty-clay microfacies marked by the juxtaposition of domains cemented by carbonates and organic matter and of carbonate-leached clay domains; (**n**) middle part of the profile, view in plane analyzed light showing a heterogeneous microfacies marked by the juxtaposition of domains cemented by carbonates and organic matter and of carbonate-leached clay domains; (**o**) profile showing a sequence of strongly pedogenized silty-clay materials sealed by a layer of archaeological construction deposits charged with fine aluminosilicate and carbon aerosols, corresponding to a marked increase in atmospheric dust synchronous with fires. A notable increase in fine precipitations concomitant to an atmospheric acidification following volcanic eruptions may also have temporarily caused a deflocculation of clays and an in situ separation by decantation, followed by a segregation of the fine and coarse components of clay materials in the soil. In soils in humid subtropical and Mediterranean regions, water table fluctuations, synchronous with climatic changes and/or geomorphological modifications, could have led to processes of transformation of iron oxides and hydroxides accumulated in the clay mass in the fine deposits filling the flats, generating marbled and stained aspects revealing spatial and vertical heterogeneity in the degree of clay cementation.

The meticulous management of these local heterogeneities at the scale of deposition contexts, related by many traditional potters from a wide diversity of cultural and geographic backgrounds, shows the finesse of the knowledge acquired and transmitted from generation to generation in the exploitation of clay sources. In the absence of historic data relating the detailed evolution of these practices through time, only the attributes of clay materials memorized by firing in ceramics enable us to track the ancestral knowledge of these practices. In order to identify and interpret these practices in terms of deposition contexts and formation conditions of source materials, we must be able to place the distribution of possible clay sources during the studied periods in a model of paleogeographic evolution for each region.

The elaboration of such a model is not one of the direct aims of a study of ceramic technology but involves the parallel implementation of an in-depth paleoenvironmental study, based on a high-resolution stratigraphic study of the superficial formations and associated pedological cover, for the study region and for the periods involved. The precision reached in the reconstruction of the evolution of the sedimentary formations rich in clay, in times and places, profoundly influences the identification level of potential sources on the basis of the attributes of the clay materials used for making ceramics.

Sources and Extraction of Clay Materials

Many ethnographic examples show that the clay sources used are either near the habitat (e.g., Arnold 1985, 2005; Kramer 1985; Gosselain and Livingstone Smith 2005), or several tens of kilometers away, when the means of transport allows (animal, fluvial, road transport), or near other task sites (Michelaki et al. 2015) (case of Jordanian potters carrying out their activities seasonally at the time of and on the site of harvesting), or places where the consumers are based (case of itinerant potters) (like in Peru or Crete: Voyatzoglou 1974; Ramón 2011), or on the routes taken by nomadic potters. The diversity of situations in archaeological contexts shows that clay materials were frequently transported over several tens of kilometers or even exceptionally over longer distances. These long-distance exploitations could have been associated with practices of mixing different sources to optimize the quality of the final clay material or for cultural reasons. The diversity of the possible scenarios reinforces the necessity of an exhaustive database of the potentially exploitable clay sources for the region considered and of robust analytical criteria for tracing the origin of the exploited clay materials.

Depending on the localization of the clay materials in the landscape, they are extracted using four main methods (Gosselain and Livingstone Smith 2005): from the surface, pit, gallery, and underwater. In the case of surface extraction, the material is collected without having to dig deeply, in very variable environments: floodplains, fields, undergrowth, banks, reservoirs, shallows, marshes, etc. (Fig. 2.2).

Fig. 2.2 Examples of selective exploitation of clay sources: (**a**) surface extraction of salted clay materials (Rohat, Rajasthan, India); (**b**) profile showing a mottled clay paleosoil sealed by layers formed of collapsed archaeological constructions, Niasangoni region, Burkina Faso; (**c**) gray kaolinitic clay from the deep horizons showing a compact structured facies – clay material predominantly used for the ceramic production; (**d**) composite clay from the upper profile formed of illite/kaolinite composite clay with iron oxide impregnation – materials used for the ceramic decoration by mixing with the gray kaolinitic clay

For pit extraction, the soil is dug out until the required layer is reached. Pits display very variable dimensions, in depth and width, depending on the environment and the production context. Gallery extraction involves first of all the construction of a vertical shaft until the required layer and then a horizontal extension by digging lateral galleries. The durability of pits and galleries is variable from site to site. Underwater extraction consists of taking clay from riverbeds when the water level is low (during the dry season or at dams).

A wide diversity of tools are used to extract clay materials, without using specialized techniques but most often by borrowing from other spheres of activities, such as pickaxes or shovels (fieldwork, construction work, etc.). The means of transport of clay materials are also varied (human, animal, fluvial, road transport).

Mineralogy, Texture, and Structural States of Natural Clay Materials

In view of the nature and the diversity of clay collecting contexts, the composite sources selected cover a very wide range of clay materials. This diversity is evident in the multitude of possible combinations of the three diagnostic parameters of the nature of the clay materials: mineralogy, texture, and structure. The identification of these combinations and their interpretation in terms of properties (malleability, ductility, aptitude to harden) and/or sources are thus an essential stage in the analysis of all ceramic assemblages. The importance of this interpretation is related to the need to differentiate the attributes of clay materials used for ceramic production derived from the deposition contexts – defined here as natural – and those acquired during the different preparation stages, which, by extrapolation, can be defined as anthropogenic. We will not go into detail here regarding the basic principles and concepts of clay materials, in particular notions of crystallography, which are described at length in numerous specialized volumes and articles. The priority here is to recall several essential points in order to master the identification of natural *versus* anthropogenic attributes.

Mineralogy

In terms of mineralogy, the clay materials are very small crystallized units (<micron) which can only be observed with a scanning electron microscope for the overall morphology and in transmission mode for the internal structure up to an atomic scale. The individual crystals are fine platelets, or flakes, an assembly of multiple sheets formed by recurrent sequences of a same atomic pattern. All the families of clay minerals only comprise two types of elementary atomic units: tetrahedral sheets of silica and octahedral sheets of alumina (Fig. 2.3). Only the octahedral sheet presents substitutions by different types of cations, and these variations define the dozen clay minerals identified up until now.

Kaolinites, referred to as type 1:1, are characterized by the recurrence of a tetrahedral sheet and an octahedral sheet. This elementary unit with a thickness of

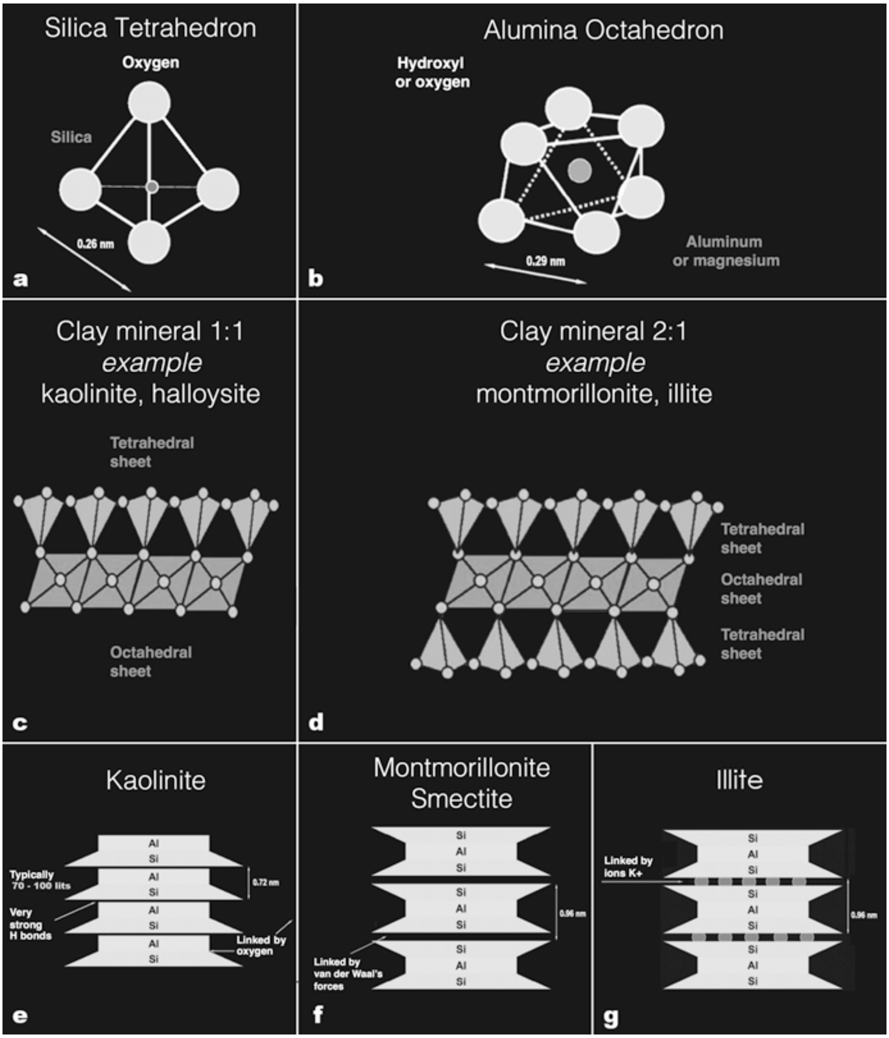

Fig. 2.3 Schematic representation of the atomic structure of clay minerals: (**a**) elementary unit, the silica tetrahedron; (**b**) elementary unit, the alumina octahedron; (**c**) bilayer unit of 1:1 clay minerals; (**d**) multilayer Si/Al assemblage of a kaolinite; (**e**) trilayer unit of a 2:1 clay mineral; (**f**) multilayer Si/Al/Si assemblage of a montmorillonite; (**g**) multilayer Si/Al/Si assemblage of an illite

0.72 nm can extend indefinitely in two directions, as the links between the double base unit are made by very strong hydrogen bonds. Consequently, the elementary kaolinite crystal is a rigid unit which can be made up of 70–100 elementary units.

Halloysites are also type 1:1 clay minerals and differ in that they present a tubular shape and the presence of hydrated levels between the elementary units.

Montmorillonites, called smectites, are type 2:1 clay minerals made up of an octahedral unit between two tetrahedral units. The elementary unit with a thickness of 0.96 nm can also extend indefinitely in two directions. Unlike the kaolinites, the bonds between the siliceous units are rather weak van der Waals forces.[4] The sheet formed by four negative planes presents a deficit of positive charges. This deficit of the octahedral units in positive charges is compensated by additional cations situated at the surface of the sheets and surrounded by water molecules. This results in an edifice of sheets organized side to front, weakly bonded between them, with the capacity to swell in the presence of water.

Illites are also type 2:1 clay minerals, characterized by a very high deficit in positive charges and systematically compensated by potassium cations, K^+, in close contact with the surface of the sheets in which they are inserted. This results in sheets organized face to face and which are consequently more bonded than smectites but less bonded than kaolinites. The bonds between elementary sheets are ensured by potassium atoms. This edifice does not swell in the presence of water and is thus more rigid.

Chlorites are made up of recurrent sheets of octahedral and tetrahedral units which alternate with a unit of gibbsite (Al) or brucite (Mg) to form type 2:2:1 edifices. This type of clay mineral provides considerable possibilities of isomorphic substitutions and swelling, on account of the capacity to integrate water between the sheets. However, it is less active than the montmorillonites.

These different elementary units can present hybrid combinations, defined as mixed units, for example, an interstratification of montmorillonite with chlorite and illite. Unlike these crystallized clay minerals, amorphous or allophane clays with no regular structure can also form in certain conditions, in particular in volcanic contexts.

Texture

As for the texture, grains of elementary particles of clay are rare in the natural environment and only occur in very diluted clay-water systems in conditions allowing for total dispersion (Fig. 2.4a, b). In practice, all clay materials are made up of assemblages of elementary clay particles which are units of organization with well-defined contours and mechanical behavior governed by specific cohesion forces (Fig. 2.5). They correspond to the clay domains defined for soils and to the pseudo-silts, or even pseudo-sands, defined in sedimentary formations. Cohesion is ensured by organic binding agents, organo-mineral complexes, or mineral cements.

[4] Phenomenon linked to the interaction of couples of electrical charges of weak intensity between atoms and molecules or between a molecule and a crystal.

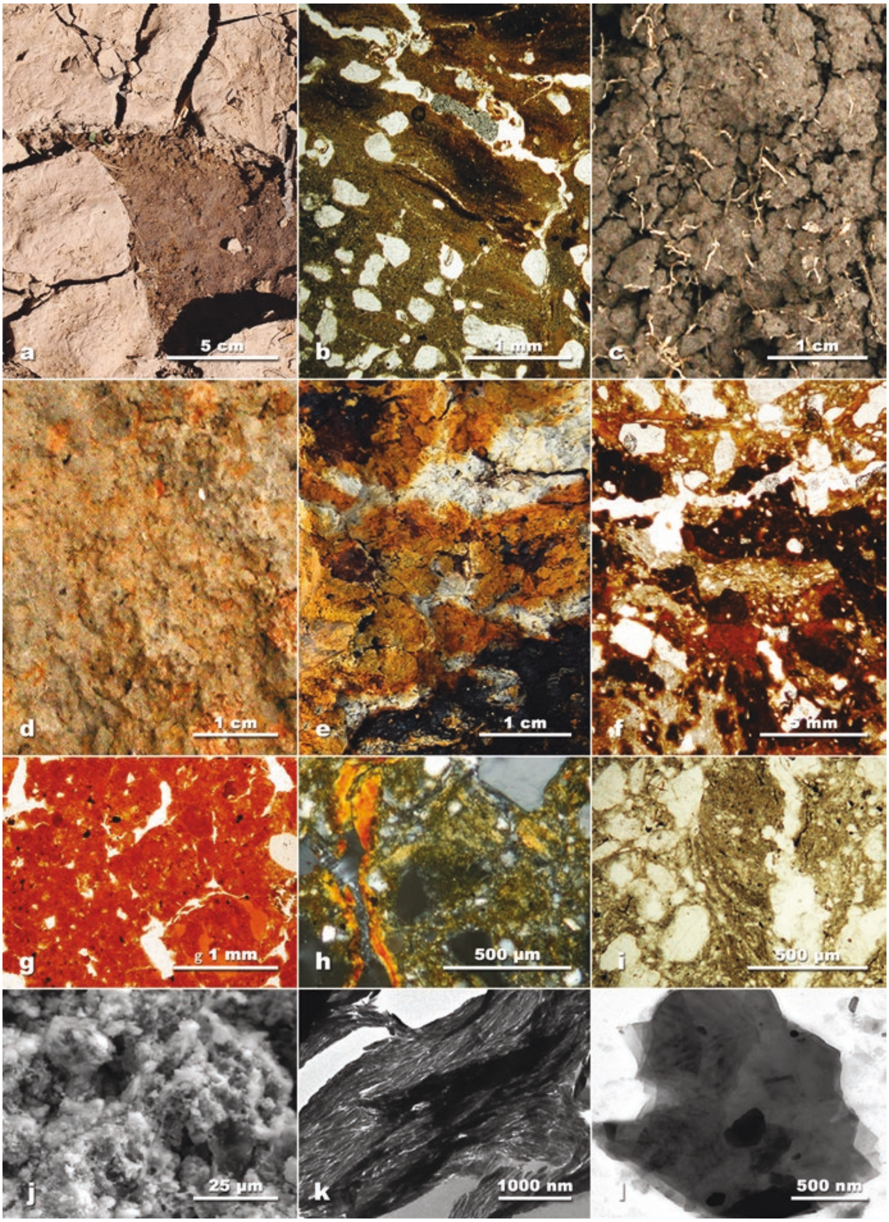

Fig. 2.4 Views at different scales of textural and structural states of raw clay materials: (**a**) gently settled clay; (**b**) view of settled clay with quartz sands (cf. Fig. 2.1a) in plane analyzed light showing the regular fine bedding and the diffuse organic impregnations – the lack of microaggregated structure is noticeable; (**c**) open granular, microaggregated structure formed by intense mechanical turbation of the soil fauna (earthworms) occurring in the subsurface soil horizon developed on silty-clay materials in a low-lying depression; (**d**) dense aggregated structure of a deep soil horizon with a mottled facies developed on composite clay materials; (**e**) detailed view of (**d**) showing the juxtaposition of dark brown, gray, and reddish-brown domains; (**f**) view of (**e**) in plane analyzed

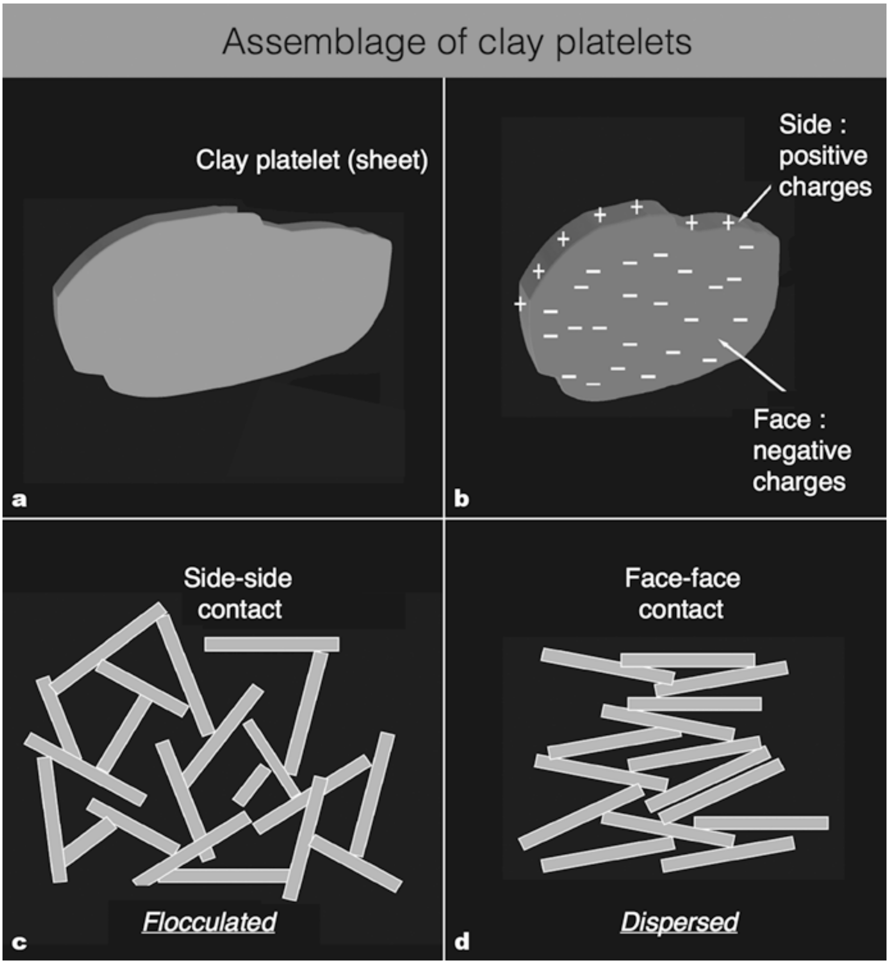

Fig. 2.5 Schematic representation of electric charges on sides and surfaces of clay platelets and assemblage modes of the clay platelets: (**a**) clay platelet; (**b**) positive and negative charges on clay platelet; (**c**) and (**d**) assemblage modes of the clay platelets

Fig. 2.4 (continued) light showing the fine imbrication of brownish-red sandy-clay domains, organo-clay domains with oxide and hydroxide impregnations and of reddish-brown fine clay domains; (**g**) view in plane analyzed light of a dense homogeneous microaggregated clay assemblage with iron oxides typical of an argillic horizon (accumulation by clay translocation) of a red Mediterranean soil developed on smectite/illite composite clay; (**h**) view in plane analyzed light of an argillic horizon microfacies typical of a brown soil developed on aeolian sandy-clay silt which developed under a temperate forest vegetation – the accumulation of translocated fine clays along the fissures and the voids which formed during development of the forested soil has to be noticed; (**i**) view in plane analyzed light of a homogeneous dense assemblage of iron-leached, sandy-clay domains; (**j**) view in scanning electron microscope (SEM) of a fine mass showing the dense imbrication of silty-clay domains; (**k**) view in transmission electron microscope (TEM) of a smectite tactoïde formed of finely imbricated clay platelets – note their deformation expressing their plasticity; (**l**) view in transmission electron microscope (TEM) of superimposed illite clay platelets

Structure

On a structural level, all clay materials are defined by the geometric arrangement of assemblages of particles and porosity in and between assemblages. The structural state includes a continuum of geometric arrangements on a macroscopic to nanoscopic scale, generally described as levels of specific aggregation assessed by different techniques of characterization (optical and electronic microscopy, physical measurements): macro-, meso-, and microaggregates, clay, and tactoid domains. In addition to the chemical charges at the interface of the domains and clay particles, cohesion between the structural entities at the different levels of organization is closely dependent on compounds intricately linked to the fine mass (Fig. 2.5). In this way, iron oxides and hydroxides settling on the surface of the clays profoundly change their properties, in particular, their reaction to ionic exchange and surface charges. Only appropriate chemical treatments can dissolve these clay/iron oxide associations which generally display strong cohesions. Consequently, these associations are practically unchanged by the preparation of pastes and shaping and thus present an original imprint of the sources of clay materials used. The presence of micrometric particles of calcium carbonate, closely linked with the fine mass of natural clay materials, also has an important influence on the different aggregation levels. On wet material, this component increases the overall rigidity of the assemblage and reduces the plastic deformation of the clay domains. During drying and firing, the transformations of carbonate-crystallization phases, thermal decomposition beyond 700 °C with formation of calcic silicates through interaction with the clays, result in profound modifications of the original materials and of their properties.

Preparation of the Paste: Modification of the Clay Materials

In most cases, the clay material is prepared in order to obtain a paste with properties suitable for fashioning, drying, and firing (Fig. 2.6). This preparation is modulated depending on the characteristics and properties of the original clay material and includes the following operations: fragmentation, granulometric sorting, hydration, removal of the coarse elements, addition of tempers, mixing of clay materials, and homogenization. The coarse elements are removed during fragmentation, granulometric sorting, or homogenization. Tempers are generally added during homogenization. The mixing of clay materials can take place before or during homogenization operations.

These operations lead to modifications of the raw material which affect more specifically: (1) the structural state, the aim being to obtain an homogeneous humectation and plasticity down to the level of the clay domains; (2) the textural composition, first of all by removing coarse elements to optimize the homogenization of the material and then by adding tempers at an advanced stage of preparation to rigidify the homogenized clay paste and/or increase its thermal and/or mechanical resistance; and (3) the mineralogical composition of the fine mass by mixing clay and/or fine particles in order to control and adjust the malleability of the clay material and/or its thermal and mechanical resistance.

Fig. 2.6 Preparation of the paste: (**a**) fragmentation of the clay material with a stick (Rajasthan, India); (**b**) granulometric sorting by sieving (Uttar Pradesh, India); (**c**) hydration of the coarse fraction by humectation (Uttar Pradesh, India); (**d**) hydration of the coarse fraction by humectation and hydration of the fine fraction by impregnation (Rajasthan, India); (**e**) hydration of the dry fine fraction by impregnation by mixing it with the moistened coarse fraction (Uttar Pradesh, India); (**f**) liquid sieving of a previously sieved clay material hydrated by immersion (Uttam Nagar, India)

Fragmentation of the Clay Material

The aim of the fragmentation of clay materials is to divide the raw material into granulometric categories of aggregates with the same hydration capacities. These categories correspond to groups of homogeneous structural entities that can also have specific mineralogical and textural characteristics. Fragmentation is carried out on previously dried clay material in order to facilitate the fragmentation along the major discontinuity planes which often correspond to concentrations of impermeable organic clay complexes, present as coatings or microfiber linings. The mechanical work will break up these impermeable facets in order to obtain homogeneous humectation.

The fragmentation of lumps of clay is carried out using different techniques with varied tools: direct percussion (with a beater, stick, pestle, hand) or percussion on anvil (with a grinder, chopper). Fragmentation is described as crushing, pounding, grinding, and chopping, depending on the tool used, although the technical operation is always the same. The lumps of clay can be splitted immediately after the extraction of the clay material at the extraction site, but in most cases, this operation takes place in the workshop, where the clay material is reduced to an advanced stage of homogeneous structural entities.

Granulometric Sorting

Once the clay material is crushed, it can be granulometrically sorted either by sieving the dry or liquid material or by decantation of the liquid material.

Sieving of the Dry or Liquid Material When the material is dry, it is sieved using perforated hide, perforated metal sheets, textiles, sieves in plant fibers or in metal, baskets, or calabash, which are shaken (referred to as winnowing). The holes in traditional sieves are rarely less than 1 mm, unless textiles are used (in India, there is an example of an iron sieve perforated with holes 2 cm long and 3 mm wide). When the material is liquid, it is sieved with a fine sieve in order to remove the undesirable elements that were not eliminated during the first dry sieving.

Decantation The aim is to obtain an optimal granulometric sorting in order to separate the finest aggregate component, the only component then used for the production of pastes. It is carried out for large quantities of clay materials in containers or basins, frequently made of stone or brick paving, and filled with water. The material is mixed and diluted in water and then left to sit. After evacuation of the water (with buckets or through channels or by evaporation), the fine component is removed and wedged. Unlike liquid sieving, which is widely used for all production contexts, decantation seems to be specifically associated with industrial production contexts.

Hydration

Clay materials can be hydrated using three main methods: by immersion, humectation, and impregnation.

Hydration by immersion consists in pouring the clay material into a container, a tank, or a basin, covering it with water for total absorption of the water by the clay material, followed possibly by an evaporation phase until the clay is of the required consistency for wedging/kneading.

Hydration by humectation consists in infiltrating water from a central well (same principle as for mixing flour and water to make pastry) or sprinkling water over the clay material.

Hydration by impregnation is only for the fine fraction of the clay material. Impregnation takes place by mixing the dry fine fraction with the wet coarse fraction. The mixture is then left to sit until homogeneous hydration of the fine fraction occurs by capillarity.

These different hydration methods can be combined in view of the differential absorption capacity of the different components of the clay material.

The empirical understanding of this phenomenon can be illustrated by the practices of Har Kishan, a potter in Uttam Nagar, New Delhi (India). This potter constantly endeavors to improve the quality of his pastes, and first of all carries out two successive dry sieving operations: the first sieving with an iron sieve to separate the coarse and fine fraction, then a second sieving of the fine fraction with a finer nylon sieve. After these two sieving stages, two piles are formed: a pile made up of the coarse fraction removed during the course of sieving, a pile comprising the fine fraction issued from the second sieving. The pile of coarse fraction is then immersed in a container. Once it is in liquid form, the clay material is sieved again in a fine nylon sieve above another container in order to definitively eliminate undesirable elements. After several hours, once the clay material has a wet consistency, it is wedged and mixed with the dry fine fraction obtained during the second sieving. The paste obtained is then left to sit in order to leave time for the fine fraction to moisten by impregnation.

A similar situation is described in Benin (Gosselain and Livingstone Smith 2005, 41): the potters from the Bariba de Tourou village crush the clay in a wooden mortar, then separate the fine fraction from the coarse fraction with a calabash shaken for this purpose. The coarse fraction is crushed a second time and immersed in a jar in the sun. Once it is liquefied, it is sieved and the coarsest elements are eliminated; then it is mixed with the dry fine fraction and left to sit.

Removing Coarse Elements

Removing coarse elements consists in removing the coarsest undesirable elements such as gravel, roots, and other large plant debris that can hinder the different stages of the *chaîne opératoire* – fashioning, drying, and firing.

Removal is carried out by hand or with a sieve for dry, wet, or liquid clay material.

Removal by hand (Fig. 2.7a, c) is the simplest technique. It is applied to dry clay materials, during the course of fragmentation, and on wet clay, during the kneading

Fig. 2.7 Removing coarse elements: (**a**) by hand during the course of fragmentation; (**b**) with a sieve on liquid clay; (**c**) by hand during kneading

of the paste and the dough pieces. The largest inclusions are visible to the eye or emerge in the hand during kneading and are easily removed.

Removal with a sieve (Fig. 2.7b), in a dry or liquid state, consists in removing the undesirable elements with a sieve that were not removed during fragmentation (if fragmentation took place). When the clay is dry, removal occurs during sieving separating the coarse fraction from the fine fraction (see below).

Adding Tempers

Tempers are made up of mineral material (quartz, flint, feldspar, limestone, basalt, etc.), organic matter (plants, bones, shells, etc.), siliceous or carbonated ash, even slaked lime, or fragmented ceramic material (grog). Temper is thus named in reference to its capacity to modify the properties of the clay material. Generally, the addition of temper does not exceed 20%, as a higher proportion can render the recipient fragile (Kilikoglou et al. 1998).

Non-plastic material is added during wedging/kneading when the clay material is still wet (Fig. 2.8a). The mineral, organo-mineral, or ceramic temper can be obtained by crushing (pounding and/or grinding). Granulometric sorting is carried out by hand or with a sieve. The temper can be added to the whole volume of the paste intended for making the recipient or just to part of this volume. In the latter case, the tempered part is intended to be used for making certain parts of the recipient only. Volumes of clay with tempers of different sizes can also be used for shaping the different parts of a same recipient.

Fig. 2.8 Adding tempers: (**a**) adding granite grains and sawdust to hydrated paste during kneading (Salawas, Rajasthan, India); (**b**) adding salt to the coarse fraction before hydration in order to get "hydroceramic" paste (Salawas, Rajasthan, India)

In Africa, there are examples of grog with different grain sizes used for the same pot. The base is made with coarse grog, the walls with medium grog and the neck with medium and small grog. (Virot 2005)

In India, culinary pots are wheel-made with lumps made up of a dough made from a non-tempered sandy material for the lower part and from a dough made from the same sandy material, but tempered with donkey dung or sawdust for the upper part. Both doughs are joined together by compression to form a lump which is then put on the wheel.

Depending on the case in hand, the addition of temper serves different purposes. It can improve the mechanical reaction of very plastic clay materials to fashioning by creating the effect of a flexible and deformable skeleton. It can favor homogeneous drying by inducing the formation of a fine network of regular cracks at coarse grain/fine mass interfaces. Depending on the mineralogical nature of the incorporated components, the temper can also increase resistance to thermal and mechanical shocks or favor thermal conduction.

Improving the Plasticity of the Paste for Shaping and Drying

Different categories of non-plastic compounds are used depending on the nature of the clay material in order to modulate the degree of plasticity and shrinkage during drying.

The addition of organic material such as chopped grass, moss, or animal feces results in better mechanical handling and improved plasticity, regardless of the type of mineral matrix, as shown by different experimental studies (London 1981; Skibo et al. 1989; Sestier 2005). Moss appears to be the most efficient material, and when added in small quantities (2–4%), it facilitates the handling of materials that are otherwise poorly plastic. Animal feces also favor plasticity as they contain a high proportion of organic fibrous components, considered to be polysaccharides of bacterial origin which act as a lubricant.

During drying, the volume of the paste decreases to different degrees, depending on the properties of the clay material. On average, shrinkage varies from 2% to 10% but can be higher for swelling clays, particularly those rich in smectites. Shrinkage is harder to control when the objects are voluminous. In this way, the bases of large objects frequently present an S-shaped crack. The addition of temper, which does not shrink, limits deformations by decreasing the retraction of the clay material and by slowing down the propagation of fissures. Among these tempers, plant tempers are good drying regulators and could be a solution for working diverse materials with undesirable effects (Sestier 2005).

Adding Material to Improve Resistance to Mechanical and Thermal Shocks

Studies on mechanical and thermal shocks are supported by the sciences of materials stating that the resistance of a material to shock depends on its hardness and tenacity (overview of thermal and mechanical properties in Müller et al. 2010;

Müller 2017). Hardness is the capacity of the material to resist to surface penetration, whereas tenacity is the characteristic determining the "total" mechanical resistance and which corresponds to the work (or energy) required to break or rupture the material by pressure, stress, or shearing. Tenacity contrasts with "fragility," which generally characterizes harder materials and which is determined by specific tests such as resistance to impact. If resistance is equal, the most tenacious material will resist better before breaking or fracturing.

Experiments on bricks in clayey calcareous and noncalcareous materials were conducted in order to evaluate to what extent the addition of tempers rendered the material more resistant to mechanical shocks and thermal stress (Steponaitis 1984; Kilikoglou et al. 1998; Tite et al. 2001). The relationship between the addition of tempers (type and quantities) and resistance to mechanical shocks was tested by measuring the tenacity, that is, the quantity of energy required to fracture the material (surface delimited by the constraint-deformation curve). The main result was to demonstrate that the tempered pastes were more tenacious than pastes without tempers. Thus, pastes tempered with more than 20% of quartz and fired at 800 °C are, for example, more tenacious than those tempered with less than 10% of quartz and fired at 950 °C. The latter are harder than the former but present a lesser deformation capacity and are more fragile. The relationship between the addition of tempers and resistance to thermal shocks was established by showing how a sudden difference in temperature between the inner and outer surfaces of the recipient produces fissures and how the tempered pastes were more resistant due to their better thermal conduction (see below) and their greater capacity not to fracture as soon as fissures formed (Kilikoglou et al. 1998).

Overall, regardless of the clayey material, limestone, eggshell, or grog tempers give the pastes a higher degree of hardness than quartz, on account of their lower dilatation coefficient and their reduced capacity to form voids once the pastes are fired (Tite et al. 2001). But flattened eggshells render pastes more resistant than quartz on account of their flattened shape which significantly increases resistance to the propagation of fissures (Steponaitis 1984).

Improving Thermal Conduction

Thermal conduction is a thermal transfer mode induced either by contact with a source of heat or by a difference in temperature between the contents of the recipient and the ambient atmosphere of the recipient.

Improving Heat Transfer

Good thermal conduction contributes significantly to resistance to thermal stress, which varies according to the difference in temperature between the outer and inner walls of the vase. This requires pastes that are not too porous and permeable, which may seem to be in contradiction with the production of tenacious pastes resistant to thermal shock. Tempers with a high dilation coefficient (dilation to heat and contraction to the cold), such as calcite, would be better choices for cooking pots as they favor heat conduction (when hot, the pastes are not porous) and resistance to mechanical shocks (when cold, the contraction of the tempers opens voids which represent zones of resistance to the propagation of fissures).

Improving the Conservation of Water Coolness

To improve the coolness of the water contained in the jars, ceramic pastes must allow for thermal exchanges by phase changing, defined as latent heat vaporization, in order to ensure continuous condensation on the outer wall. Continuous evaporation leads to a loss in energy of the liquid contained in the recipient and thus to cooling by evaporation. This effect is more marked when the ambient air is warm and dry and thus contains very little humidity. To achieve this, "hydroceramic" pastes are prepared, which "sweat" due to the condensation and evapotranspiration of the water. In contrast, these pastes are not favorable to heat conduction.

The preparation of hydroceramic pastes involves implementing recipes favoring porosity and permeability. Porosity corresponds to the relative volume of the pores present in the paste. Permeability measures the aptitude of a paste to let water through. The porosity of a ceramic paste can be empirically measured by determining the volume of water contained in the paste of a recipient. The recipient is weighed before and after a prolonged period in water. The difference measured in grams is converted into volume ($1 \text{ g} = 1 \text{ cm}^3$), and this volume represents the volume of the pores. Permeability can be empirically measured by calculating the time it takes for a volume of water to go through the recipient wall.

Several recipes are applied to make hydroceramic pastes with high absorption capacities by capillarity. Among them, the addition of organic tempers increases the porosity and the permeability of pastes as they are destroyed during firing. Pastes with such tempers are characterized by networks of entangled canals which give rise to pores opening on both sides of a wall, favoring water percolation. Hydroceramic pastes can also be obtained with granite-type mineral tempers.

Lastly, the nature of the clay itself can play a role in the porosity of pastes. This is the case for salted clay materials, as salt favors the flocculation of clay and thus produces more porous pastes (Fig. 2.8b).

Clay Mixing

Ethnographic situations show that different clay materials are frequently mixed to obtain the desired malleability, for example, by adding to sticky clay, rich in expansive clay minerals such as smectite, a component rich in rigid clays such as illites, or rigidified by iron oxide cements, or polymerized humic-clayey gems, or clays with a high sandy content.

For example, in the north of India, two clays are used, one of which is black and the other yellow. These two clays are situated near the villages. The black clay contains more or less rigidifying elements, depending on where it is extracted from. If it is considered to be too plastic, that is, if it does not contain enough sand according to the potters, then yellow clay is added (in 80%/20% proportions). When the stock of yellow clay is depleted, sand is added. On the other hand, if the black clay presents optimal plasticity, then nothing is added. The different clays are either mixed before the fragmentation operation, or afterwards, once the clays are sieved, during hydration.

Preparation of the Paste: Homogenization of the Paste

Wedging and Kneading

After the hydration of the clay material, it is wedged to obtain a homogeneous state of humectation, a regular distribution of the different non-plastic elements in the fine mass, and to reduce the pore volume by eliminating the maximal quantity of trapped air (Fig. 2.9). The homogenization of the hydric state, the incorporation of non-plastic elements, and the evacuation of pores are decisive operations for ensuring optimal malleability during shaping, to facilitate centering during wheel throwing and to guarantee regular drying.

Large quantities of clay are wedged (50–100 kg) in different ways, depending on the quantity: using the foot, the hand, or a pestle (examples in Scheans 1977; Rye 1981; Arnold 1991; Mahias 1993; Gosselain 2002). When wedging is carried out with the foot, pressure is exerted with the heel, and wedging follows a spiral movement from the center toward the periphery. It can involve a mass, or slices cut in the mass and then superposed to constitute a block to be wedged before being cut up again, as this division favors the pore volume reduction process and homogenization.

After wedging, the lumps of clay obtained are stored protected from air, wrapped in diverse materials (plants, textiles, plastic, etc.). They are then left to lie in hermetic conditions.

Just before shaping, the lumps of clay are worked again by kneading. Wedging and kneading are two successive and progressive stages serving the same purpose. They can be merged into a single operation immediately followed by the shaping of the recipient. This depends mainly on the quantities worked and thus on the production contexts: a context where the paste is stored *versus* a context where the pots are shaped as the paste is prepared. The kneaded quantities are smaller than for wedging. Kneading is often carried out with both hands which are used for compression movements. The introduction of non-plastic elements (tempers) can occur during the kneading stage, which ideally allows for uniform distribution in the paste.

Depending on the degree of kneading and the quantity of non-plastic elements contained in the paste (naturally present or added), the obtained pastes have fine to coarse textures. The fine pastes, often with a grain size inferior to 60 μm, have low porosity. Coarse pastes, with a continuum of inclusions with medium to coarse grain size often irregularly distributed in the fine mass, can have high porosity (Rice 1987; Blondel 2001).

Fig. 2.9 Wedging and kneading: (**a**) wedging using the foot (Uttar Pradesh, India); (**b**) wedging using a pestle (Leyte Island, Philippines); (**c**) kneading before wheel throwing (Rajasthan, India)

Maturing or Biodegradation

Maturing consists of storing a wet paste, in order to expose it to the action of time before using it for shaping. The duration of maturing is very variable and can range from several days or months to several years. The quantities of maturing clay are also variable. It is important to note that, in general, except in large pottery factories, clay stocks are never very large. In certain warm and dry seasons, like in Pakistan, stocks of clay paste are kept in wells where they are kept cool and sheltered from the rain. In Japan, master potters store pastes matured for many years, up to 100 years, in order to obtain pastes with exceptional plasticity.

Long maturing periods result in the development of organic clayey gels, or even pure organic gels rich in polymer filaments which act as lubricating substances during wedging, favoring the cohesion and movement by shearing of the clay domains.

2.2 Fashioning

The fashioning *chaîne opératoire* comprises a series of operations that transform the paste into a hollow volume. It can be described in terms of methods, techniques, gestures, operating procedures, and tools. These terms are defined below, followed by a general classification of techniques. The latter is based on elementary physical principles which should enable us to describe the very wide diversity of existing or past fashioning *chaînes opératoires*, ancient *chaînes opératoires* not having necessarily present time analogs.

Terminology

The terminology used is based on terms initially created by lithic specialists (Tixier 1967) in order to envisage unified technological studies favoring comparisons between technical systems (lithic, ceramic, bone, metallurgic).

Method

A method is defined as an ordered sequence of functional operations carried out by a set of elementary gestures for which different techniques can be used. A sequence comprises phases and stages.

Phase The phases describe the fashioning of the different parts of the recipient: the base (or bottom), the body (lower and upper part), and the opening (neck and rim). They are related to the concept of partonomy used by van der Leeuw (1993). The sequencing of the phases is variable. It is not constrained by the material, or by the shapes of the recipients, or by fashioning techniques. Succession of the phases is combined with assemblage operations. Only wheel throwing ensures synergy between the different fashioning phases.

Stage The shaping of a recipient comprises two successive stages intended to progressively obtain the desired form. These two stages are *roughing out* which produces a roughout and *shaping* which results in a preform. A single technique unites these two stages: molding.

A *roughout* is a hollow volume that does not present the final geometric characteristics of the recipient. It is obtained by thinning operations on homogeneous or heterogeneous volumes.

A *preform* is a hollow volume with the final geometric characteristics of the recipient without undergoing the finishing operations. It is obtained by shaping operations.

By definition, the thinning operations lead to a greater deformation of the elementary initial volume than the shaping operations.

The phases can be interrupted by the drying time which aims to consolidate part of the recipient before pursuing the operations in order to avoid sagging and to favor assemblage operations between elements and parts of the recipient. In the same way, the stages can be interrupted by drying times so that the paste attains a leather consistency and can undergo subsequent deformations by pressure or percussion. A paste with a leather consistency is a paste that has dried and reached a rather rigid consistency but is nonetheless sufficiently soft to be deformed.

Technique

A technique is defined by the physical modalities used to transform the raw material.

Five parameters describe these physical modalities: the source of energy, the elementary volume, the forces, the type of pressure, and the degree of hygrometry.

The Source of Energy

The shaping of recipients involves:

- Either muscular energy, i.e., active forces
- Or muscular energy combined with rotary kinetic energy (abbreviated RKE), a passive force transferring human force to the clay material (see inset on wheel throwing by Gandon et al.)

The Elementary Volume on Which the Forces Act

An elementary volume is homogeneous or heterogeneous. A homogeneous elementary volume consists of a lump of clay in which a hollow volume is made. A heterogeneous volume is formed of assembled elements.

The Forces

The active forces used in shaping consist of pressure and percussion. They are directly exerted by hand (interdigital, digital-palm, or inter-palm pressure or percussion) or indirectly with tools.

Pressure is internal or external depending on whether it is exerted on the exterior toward the interior or the interior toward the exterior of the pottery (in the first case, for narrowing the diameter; in the second case, for enlarging it). It is oriented in a horizontal, vertical, or oblique direction.

Percussion is exerted either on both sides of the walls, or on the outer walls with no internal support, or on the inner walls against an anvil support.

The Type of Pressure

The pressure exerted on the clay is discontinuous or continuous depending on whether it is applied with a discontinuous or continuous movement.

Discontinuous pressure is applied by successive movements on the clay paste. These movements are either translation movements (vertical or horizontal stretching) or pinching movements.

Continuous pressure is applied by a continuous rotating movement, either of the recipient or of the subject around the recipient.

The Hydric State of the Clay Paste

The drying of a clay paste is a continuous phenomenon. However, it is possible to distinguish between two main hydric states depending on the technical operations carried out during fashioning. These are a wet state and a leather-hard state. In *the wet state*, the clay material is plastic and has the qualities of a deformable semisolid. In the *leather-hard state*, the paste has undergone a first drying which gives it a sufficiently firm consistency to support its own weight while remaining soft, similar to leather, which gives it the qualities of a solid. It nonetheless retains a deformation capacity, and clay matter can thus be removed (shaving, trimming); clay body can be paddled, or elements can be assembled. Unlike the liquid state or the dry state, the leather-hard state comprises different degrees of hygrometry and slightly variable consistencies which the potter can adapt to by using different tools. The duration of drying to attain leather-hard consistency depends on the ambient heat. This consistency can be maintained by covering the recipient and leaving it sheltered from air. When dry, the clay material is no longer deformable. It becomes solid and hard and therefore fragile. No fashioning technique can be applied to a dry recipient.

Operating Procedures

Operating procedures are defined as an implementation strategy of the functional operations. They entail:

- The operating procedures for the elementary volume: fashioning of one or several recipients from a same lump and fashioning of one or two elements from a same lump
- The procedures for removing recipients when they are fashioned on wheels or turntables: removal by thread or force
- The operating procedures for assembly, that is, the joining and reinforcement procedures for the junctions between several elements: junction between the base and the body (inner or outer face), junction between the upper and lower parts (inner or outer face), or even the junction between each assembled element

(examples of reinforcement of coil junctions by adding extra-coils in Guyana among the Kali'na potters (Coutet 2009) or in Kenya among the Bantu potters (M'Mbogori 2015))

Gestures

The fashioning gestures are exerted using bilateral movements and can be described, in ethnographic contexts, in terms of their structural and functional organization (Roux and Corbetta 1989) (see Fig. 5.1).

The structural organization of the gestures describes the position of the arms in relation to the axis of the body. Two types of movement are observed; either symmetric movement in relation to the axis of the body, where the two forearms move on either site of the subject, or asymmetric movement in relation to the axis of the body. The two forearms act in one of the hemi-planes of the subject (right or left). The term hemi-plane refers to the spatial plane situated in front of the right or the left of the subject in which the manual actions are carried out.

The functional organization of the gestures describes:

- On one hand, the behavior of the hands: unimanual or bimanual. For unimanual behavior, only one hand works the clay paste, while the other operates a rotary device. For bimanual behavior, both hands are used to work the clay paste.
- On the other hand, the activity of the hands: combined or undifferentiated. In the case of a combined activity, either both hands are active or one hand is active and transforms the clay paste, while the other is passive and acts as a support; they can be alternately positioned on the inner or outer sides of the recipient. In the case of undifferentiated activities, both hands are used for the same gesture.

Tools

The tools used in the ceramic fashioning *chaîne opératoire* include active tools, passive tools, and rotary instruments. The use of tools is not essential, as shown by many ethnographic examples. Similarly, the range of tools used by potters is variable and can be very limited or, on the contrary, very wide, including manufactured tools or natural materials found in the immediate vicinity (mineral or organic elements: stones, pebbles, shells, seeds, fruit, wood, etc.).

Active Tools

They are handheld by the artisan. We can distinguish between pressure tools and percussion tools (Fig. 2.10). In both cases, they can be used on wet or leather-hard paste. The terminology adopted below takes account of the mode of action on the material (pressure *versus* percussion) and the technical goals (variable depending on the shaping stage).

Fig. 2.10 Examples of active tools: (**a**) wooden scraper (Experimental Centre of Lejre, Denmark); (**b**) wooden forming tool (Experimental Center of Lejre); (**c**) iron shaving tool (Michoacan, Mexico); (**d**) stone pusher (Experimental Centre of Lejre, Denmark); (**e**) ceramic tenon hammer (Uttar Pradeh, India); (**f**) wooden paddles and ceramic tenon anvils (Uttar Pradesh, India)

Pressure Tools

- Scrapers. They are used on wet clay. They give the intended profile of the recipient and thin and regularize the surfaces during the course of shaping and/or finishing operations (scraping and smoothing); they can be made up of very diverse materials (wood, flint, calabash, bone, pottery, metal, plastic, etc.) and present very variable forms. They can be rigid or flexible. They generally have an active profiled part, but this is not a rule. Scrapers used for scraping are called scrapers, and those used for smoothing are called smoothers. However, they can be used for both operations; the profiled part is used for scraping and the flat part for smoothing. Both terms, scrapers and smoothers, also describe the set of expedient tools used for these two operations (textiles, corn cobs, leaves, seeds, etc.).

- Forming tools. These are spatula type (wooden or bone) tools used, as their name suggests, to shape the roughout. They are used on wet clay to join or attach assembled elements on the walls of the recipients (e.g., coils, prehensile elements).
- Awls. They are rigid rods (in metal, stone, plant, bone). They are used to trim the upper edge of recipients, either when it is irregular or when height needs to be reduced. They are also used to incise the clay paste so that the different elements adhere to each other. They can be used on wet or leather-hard clay.
- Brushing, shaving, or trimming tools. They are used on leather-hard paste. These tools come in diverse forms and materials. Brushing tools are used in rubbing motions and are characterized by a rough surface. Shaving or trimming tools present a tapered cutting edge designed to remove clay chips in order to thin walls or round out the bases of the recipients.
- Pushers. These are shaping tools intended to profile the roughout when it reaches leather-hard consistency. They are used to press against the walls of the recipient. They are in ceramic or stone. The active part is rounded.

Percussion Tools

- Hammers. They are used as percussion tools to thin a mass of wet clay or to thin walls with a leather consistency. They can be in stone, in ceramic, or any other sufficiently heavy material to effectively hammer the clay volume. Their dimensions and weight depend on the mass to thin. The active surface is slightly to very convex. They may present a means of prehension, in which case they are called tenon hammers.
- Paddles and counter-paddles (also called anvils). They are used as percussion tools in association with beating/paddling actions; the paddles are often in wood (but can be in ceramic like in Ecuador) with a flat or slightly concave active surface, whereas the latter are in ceramic, stone, or any other hard material against which pressure is exerted. The active surface is slightly to very convex. The dimensions and weight of paddles and counter-paddles depend on the size of the recipients. Paddles are used on wet clay during the roughout stage and on leather-hard clay during the shaping stage. The use of the paddle does not systematically involve the use of a counter-paddle. On one hand, the hand can play the role of a counter-paddle. On the other hand, when the paddle is used as a profiling tool on wet clay, it does not necessarily require an internal support. The paddles used for profiling the edges are smaller than those used for the walls.
- Rollers. They are placed on wet clay and rolled to thin clay slabs. They are generally in wood.

Passive Tools

They include work plans, supports, and molds (Fig. 2.11). These three types of passive tools can be made or adapted from varied materials: plant material, wood, ceramic, fired or unfired clay, and stone.

- Work plans. They can be removable or not and can be covered with textiles or basketry. They have two functions. When they are used as anvils on which the clay paste is hammered, they generally correspond to "natural" surfaces and are

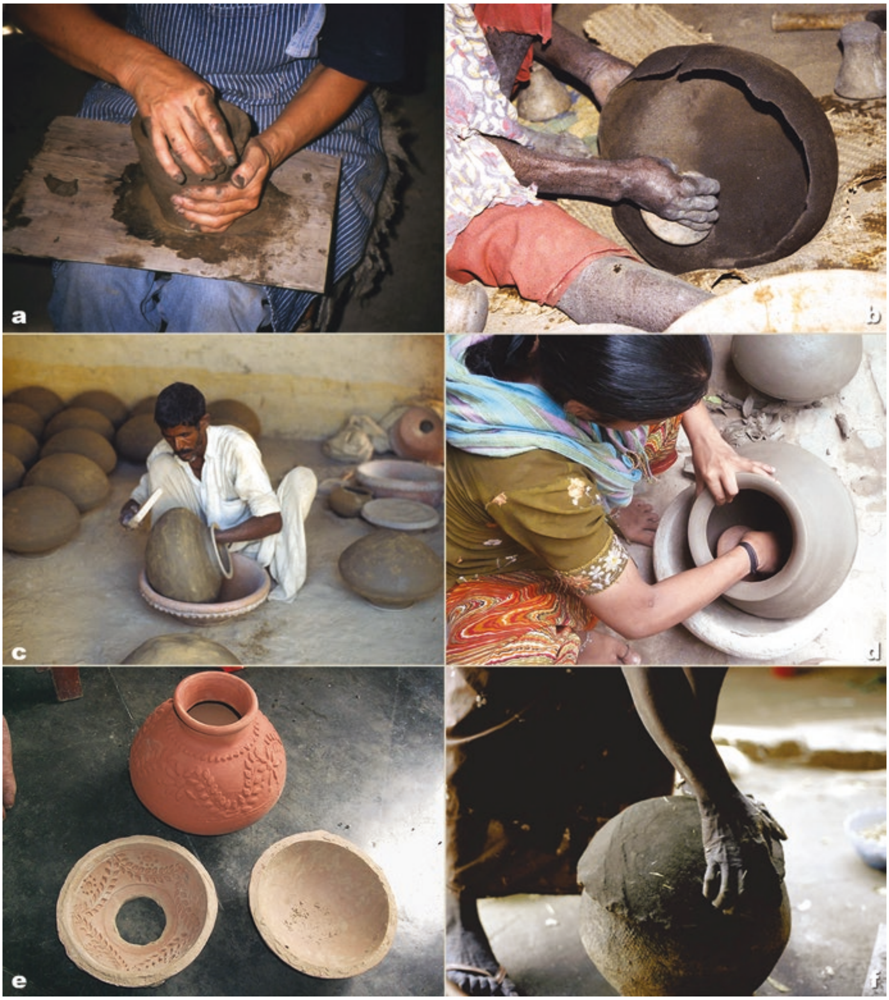

Fig. 2.11 Examples of passive tools: (**a**) removable wooden work plan (Experimental Center of Lejre, Denmark); (**b**) concave working plan covered with a mat (Mali, ©A. Gallay); (**c**) ceramic forming support (Uttar Pradesh, India); (**d**) ceramic anvil support (Uttar Pradesh, India); (**e**) ceramic concave molds (Uttar Pradesh, India); (**f**) reuse of a jar base as a convex mold (Senegal, ©A. Gelbert)

horizontal or concave, depending on how the ground is prepared. When they are work plans on which the forming or the anvil support is placed, they are characterized by a plane surface. Removable work plans can be simple stone slabs, planks, or blocks of wood.

- Forming supports. These are generally manufactured removable objects on which recipients are formed (roughing out or shaping). They can have different morphologies. When they have a disc shape, they are called bat. They can be in different materials (wood, unfired or fired clay). They are either intentionally made or are reused objects (e.g., the bases of jars for placing the recipient during beating/paddling or for pivoting the recipient during forming). They are placed on the ground or on work plans.
- Anvil supports. These are removable and play the role of an anvil against which the clay mass or the leather-hard walls are hammered. They can be in diverse materials (wood, unfired or fired clay). They have to be hard enough to resist percussion blows and thus have thick walls if they are in ceramic.
- Molds. They play a shaping role, giving the recipient its final shape, whether the elementary volume placed in the mold is a lump or is made up of several elements (coils). Molds can be concave or convex, horizontal or vertical, or mobile or set. They can be made for this purpose in diverse materials, they can correspond to used objects (example of the reuse of jar bases), or they can be dug out in the soil.

Rotary Instruments

There are three categories of rotary instruments: rotary devices, turntables, and the wheel (Fig. 2.12). These three instruments are differentiated by the quantity of rotary kinetic energy (RKE) supplied by the rotation movement initiated by the potter. This quantity depends on the momentum of inertia of the instruments (evaluated by their resistance to rotation), which depends on their weight, dimensions, and morphology. Depending on this quantity, the active forces applied to clay materials by the potter slow down the rotation movement of the rotary instruments more or less quickly. This deceleration speed is used to classify them in the following decreasing order: rotary device, turntable, and the wheel. Only the wheel supplies sufficient RKE for wheel throwing, that is, to say for the slowing down of centering pressures not to stop the rotary movement.

The rotary device is a device that is not mounted on an axis and which allows the potter to rotate the recipient continuously.

> In Africa, there are many examples of rotary devices. In this way, Mayor (2010) describes a ceramic recipient weighted by earth or sand lying on the compact ground lubricated with oil or butter. The potter places a ceramic forming support in the centre of this device on which she shapes a pot. When the device is activated quickly (operating the weighted recipient), the rotary movement is sufficiently fast for the potter to work with both hands.
>
> In Central America, there are also examples of rotary devices, one of which is made up of two convex jug bases; the first is placed on the second turned upside down on the ground. The other example is a wooden disc with a diameter of about 10 centimetres, with a thickness of 6 to 10 cm; the outer side is rubbed with wax to reduce friction with the ground (the *kabal* in Yucatan). (Foster 1959)

Fig. 2.12 Examples of rotary instruments: (**a**) rotary device (Mali, ©A. Gallay); (**b**) turntable fixed on a wooden plank (Leyte Island, Philippines); (**c**) simple wheel launched with a stick (Uttar Pradesh, India); (**d**) double wheel (Uttar Pradesh, India)

The turntable (also called tournette) is a rotary instrument mounted on an axis for which rotary kinetic energy is not sufficient to throw lumps of clay with a weight exceeding 1–2 kg. In other words, the wheel does not produce enough rotary kinetic energy to resist the friction of the pressure required for centering, hollowing, and thinning a mass of clay. Experiments indicate a maximum speed ranging from 80 to 120 rotations/min depending on the type of turntable (Roux and de Miroschedji 2009). This speed is insufficient for wheel throwing but sufficient for wheel coiling, whatever the form and dimensions of the recipients. Turntables can be made in diverse materials and present variable morphologies. Their mode of action also varies: some turntables are activated by the potter himself, by hand or with the foot, whereas help is required for others. When turntables have a low momentum of inertia and they are activated by hand, the shaping gestures are necessarily unimanual, with one hand shaping, while the other activates the turntable. When they have a higher momentum of inertia or when they are activated by the foot or with help, the potter can shape the recipient with bimanual gestures. Among the turntables used to work large-sized jars, we can cite those of Laos activated by the toes and those of Crete activated with help.

Palestinian and Mesopotamian turntables are two examples of archaeological turntables. The Palestinian turntable (fifth-third millennium B.C.) is in basalt (Fig. 2.13). It is made up of two elements: a) an upper wheel with a diameter of 23 to 37 cm, with a socket on the lower face, namely a cavity shaped like a cone, and b) a lower wheel of 10 to 18 cm with a biconical perforation. Experiments showed that a wooden axis stuck into the ground, went through the lower wheel and was set into the socket of the upper wheel, allowing it to rotate. In addition, the rotation of the upper wheel was facilitated by spreading clay slurry onto the lower wheel, which acted as a lubricant. These turntables could reach a maximum speed of 80 rotations/min when they were activated with help (Roux and de Miroschedji 2009). The Palestinian turntable was found on Early Bronze Age (abbreviated EB) sites (EBI, II and III). Chalcolithic specimens found at Halif and Wadi Ghazzeh suggest that these turntables were already in use by the second half of the fifth millennium B.C. They disappeared with the collapse of the first urbanization (EBIII).

The Mesopotamian turntable (third-first millennium B.C.) is composed of three elements: a) a large upper wheel in clay lying on b) an upper stone in basalt with a tenon slotting into and pivoting on c) a lower stone with a socket also in basalt (Amiran and Shenhav 1984; Powell 1995) (Fig. 2.13). The experiments conducted by Powell (1995) have shown that these turntables could reach an average speed of 100 rotations/min. They are thus faster than Palestinian turntables. However, their speed and momentum of inertia are not sufficient to resist the pressures applied to large lumps of clay during the wheel throwing centring stage. According to Roobaert and Trokay (1990) and Trokay (1989), who listed all the tenon turntables found in the South and North Levant, as well as in Mesopotamia, the oldest basalt tenon turntables were found in Northern Syria, in settlements in the Middle Euphrates. The authors also signal a discovery at Tell Kannâs in the sector of the southern temple dated to the Uruk period (second half of the fourth millennium B.C.). However, this discovery is the only one of its kind. These authors also indicate a tenon turntable at Tell Abed dating from 2500–2000 B.C. At Tell Banat, a tenon turntable was exhumed from levels dating from period IV (2600–2400 B.C.) (Porter and McClellan 1998, 6, fig. 20). At Mari, an upper wheel with a tenon was found on the floor of a dwelling from area F, belonging to the Shakkanakku period, dating from between the 23rd and the 20th century (Margueron 2004, 396, fig. 385). In the North Levant, at Hama (Fugmann 1958, 74, fig. 93), a wheel was found in a backfill in level J3, dating from about 2000 B.C., and at Tell Arqa, a tenon turntable was found in Byzantine backfill but could be attributed to the potter's workshop from level 14, dated to the Middle Bronze Age (Thalmann 2006, plate 135: 1). The oldest tenon turntables would thus date from the second half of the third millennium and would be from Northern Syria. These same turntables were then diffused throughout the central and Southern Levant during the second millennium B.C. (turntables found at Hazor [Yadin et al. 1958, 1960], Meggido [Guy 1938], Lachish [Magrill and Middleton 1997]) and in Egypt [Powell 1995; Doherty 2015]).

The wheel produces sufficient kinetic energy for the rotary movement to resist the necessary friction and pressure to center, hollow out, and thin a mass of clay, whatever its weight. There are two main wheel categories: simple potter's wheels and double wheels. The maximum speed of both these wheels is comparable and is about 220–230 rounds/min. The advantage of a double wheel compared to a simple wheel is that it provides the possibility to ensure a continuous rotation without

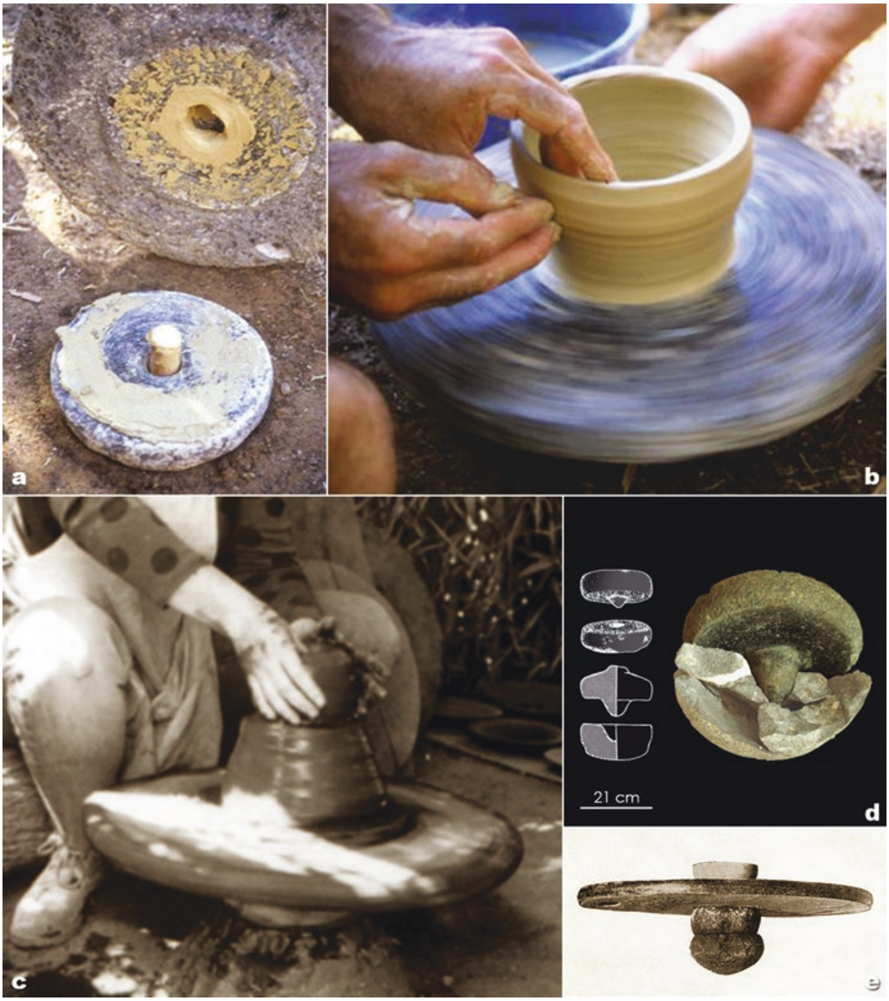

Fig. 2.13 Examples of archaeological turntables: (**a**) and (**b**) Palestinian basalt turntable made of two wheels whose rotation is facilitated by the slurry spread on the lower wheel; the maximum speed is of 80 rounds per minute when activated with help (experiment with an EBIII turntable found at Tel Yarmouth; Roux and de Miroschedji 2009); (**c**) Mesopotamian basalt tenon turntable (experiment by Powell 1995, 325, Fig. 10); (**d**) Middle Bronze Age basalt tenon turntable from Jericho (Rockfeller museum, Jerusalem); (**e**) Reconstruction of a Mesopotamian tenon turntable (with the upper wheel in wood) by Amiran and Shenhav (1984, 111, Fig. 3)

interruption when relaunching the wheel and to modulate the speed precisely depending on the different forming operations.

Simple Wheels. Different types of simple wheels exist, which are either indirectly launched with a stick or directly with muscular force. For wheels launched with a stick, the potter works sitting, kneeling, or standing in front of the wheel. The wheel is activated with a stick over 1 m long, with variable dimensions depending on the potter's posture. It is placed in a hole situated on the periphery of the wheel. The stick is driven by a circular movement and activates the wheel which is regularly relaunched when its speed decreases.

Stick wheels existed in Europe until the 18th century (Löbert 1984). We currently find them in many Asian countries east of the Indus. In India, the diameter of the wheel is between 70 and 100 cm and the thicknees, between 7.6 and 10 cm. It is solid or with spokes and is in stone, clay, or more recently, in cement. There is a socket or a wooden pivot (5–10 cm) in the centre of the inner face which is respectively set into a wooden pivot or a stone socket fixed to the ground. The centrifugal force gives the wheel its horizontal position, which is why it is called also a fly wheel. On account of their hollow structure, spoke wheels have a momentum of inertia twice as long as solid wheels, which means that they can be launched with less effort.

There are present-day examples of wheels driven by muscular force in Turkey. The potter sits over a horizontal wheel imbedded in the ground at the same level as his feet. Both feet are used alternately to activate it. A stand is set in the centre of the wheel, which attains the waist of the potter and on which a clay ball is placed, so that the potter can work without stooping. The Chinese wheel is another example of a wheel driven by muscular force. It is represented in 19th century engravings where the potter is depicted on a bench in front of a wheel which can be activated either by the foot of a helper who is kept in balance by grasping a rope hanging from the ceiling, or by hand by an assistant sitting at the same height as the wheel, or by a rope wrapped around the wheel and operated by an assistant (Brongniart 1977, vol. 2, plate XLIII) (Fig. 2.14)

The manufacture of traditional fly wheels in India is described by Saraswati and Behura (Saraswati and Behura 1964, 10–12):

"The clay used in this wheel (the fly wheel) is well tempered with chopped grass, human hair, molasses and cotton. The tempering materials are thoroughly mixed with the clay and left about a fortnight or so till the potter is sure that the clay has attained its binding quality. Once again, the clay is thoroughly kneaded. The prepared clay is then spread out on the ground in the form of a thin circular disk. This is then beaten with a wooden mallet, and thereafter with an anvil, so that it may attain perfect cohesion. To make the disk a complete geometrical circle an indigenous wooden compass called *farma* is used. It is a wooden stick with a short pointed wooden nail attached to one end of it. During operation, the other end of the compass is placed at the centre of the disk and pressed with the thumb of the operator. When the instrument is rotated, the pointed and projected end cuts the circular disk. The clay disk thus well cut and prepared is fitted with a stone socket at its centre. The disk is left for drying for two or three weeks after which it is ready for turning. The pivot is made of tamarind wood and shaped into a rough cone. The base of the cone is firmly buried in the ground. The length of the visible portion of the pivot is only 5 cm to 10 cm. It is on this pivot that the wheel rests and rotates".

Double wheels are also called foot wheels. They are made up of two wheels connected by a vertical axis (Fig. 2.12d). The upper wheel is small and can be in wood or metal. It is driven by the lower wheel, which is larger, generally in wood, and activated by foot. The potter sits at the height of the upper wheel, on which he works his clay balls. Double wheels are either partly buried in the ground, with the upper wheel emerging several centimeters above the ground, or installed above the ground. In the first case, the diameter of the pit is about 70–75 cm. Double wheels are found from the Mediterranean to the Indus. In India, a plank of wood goes through the wheel axis below the upper wheel and rests on either side of the pit. The potter works sitting on this plank. One leg activates the lower wheel, while the other leg is bent.

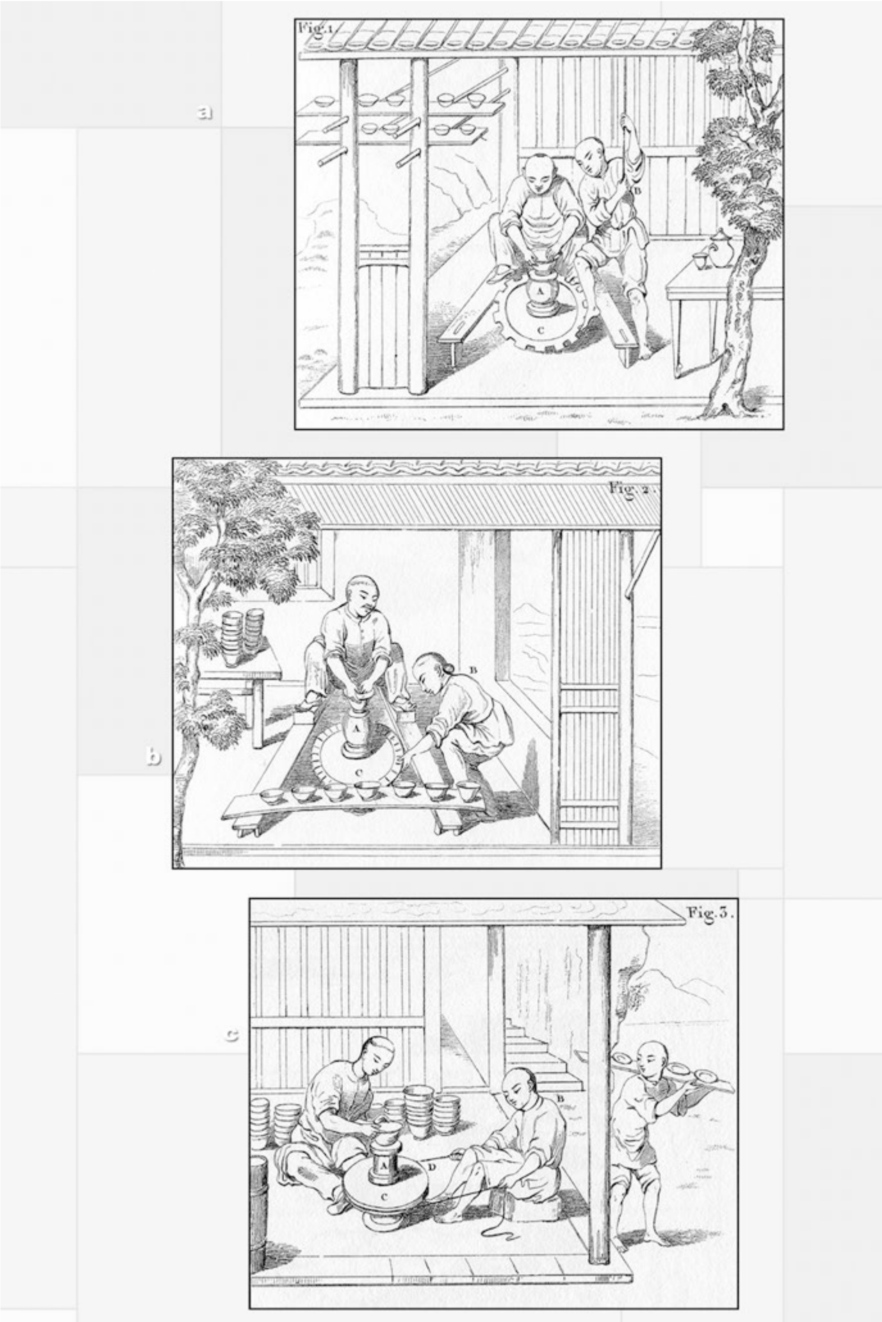

Fig. 2.14 Different ways to rotate the wheel in China: (**a**) with assistant's foot; (**b**) with assistant's hand; (**c**) with a rope wrapped around the wheel and operated by the assistant in a reciprocating movement (Brongniart 1977 (1877), PL. XLIII)

Fashioning Techniques

Two main fashioning techniques can be differentiated depending on the source of energy used: techniques without rotary kinetic energy (abbreviated RKE) and techniques with RKE. We will see that like the techniques used to transform other materials (flint, metallurgy, bone material), there are a limited number of pottery fashioning techniques.

Roughing-Out Techniques Without RKE

There are eight roughing-out techniques without RKE. They separate fashioning from assembled elements and fashioning from the clay mass; these two families are further divided depending on whether pressure or percussion is used.

Roughing Out Without RKE from Assembled Elements

There are four roughing-out techniques with assembled elements (Fig. 2.15):

- The coiling technique, a pressure technique which includes coiling techniques by pinching, spreading, and drawing
- The slab technique, a technique involving percussion for the fashioning of the slabs

The Coiling Technique

The coiling technique consists in roughing-out recipients or parts of recipients using coils. The coil is a roll of paste obtained either by rolling an elementary volume of paste between the palms or on a flat surface with both palms or by modeling exerting interdigital pressure. The coils can be of relatively regular morphology: some are perfectly cylindrical rolls with circular sections, others are coarse coils, and others are rolls that are then flattened with the hand or a hammer or a roller. They have variable lengths and diameters.

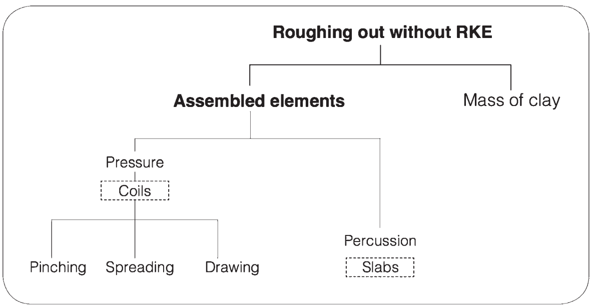

Fig. 2.15 Classification chart of roughout techniques without RKE from assembled elements

The coiling technique can be used to form the different morphological parts of recipients: the base, body, and neck. The body and the neck are obtained by overlaying the coils on each other in a vertical plane. The base is obtained by adding coils against each other in a horizontal plane.

The modalities of placing and thinning the coils distinguish the coiling techniques by pinching, spreading, and drawing (Fig. 2.16).

The coiling technique by pinching – also called *coiling by superimposition* – consists in placing the coil on the edge of the previous one, or astride of it, and then joining them by exerting discontinuous pressure with the thumb and fingers on either side of the coil. During this pressure, the thinning of the coil is slight.

The coiling technique by spreading – also called *coiling by internal/external apposition* – consists in placing the coil against the previous one and flattening it by discontinuous pressure following a movement of horizontal translation, on the interior or exterior wall while the other hand supports the exterior or interior wall. During this pressure, the thinning of the coil is average.

The coiling technique by drawing consists in stretching one or several large coils following a vertical translation movement with discontinuous symmetric pressure. This technique is also called *drawing of a ring* or *drawing of superimposed rings*, depending on whether the roughout is made up of one or several coils (Gosselain 2000). In relation to the initial state of the coil, the deformation of the coil is strong.

Depending on the forming sequences, the coils are joined as and coils are placed or once all the coils have been superimposed.

For large recipients, there can be several drying phases intended to reinforce the lower parts and thus prevent the recipient from collapsing under its own weight. In this case, after drying, the edge of the lower coil is incised and then coated with *clay slurry* – a clayey material with the viscosity of "thick cream" – in order to favor adhesion to the upper coil and avoid detachment during drying due to differences in hygrometry.

Active tools: Hands sometimes form tools; they are used to join the coils with horizontal or vertical pressure.

Passive tools: Coiled roughouts are formed on work plans or forming supports, sometimes with concave molds. In the latter case, the coils are pressed against the mold and then thinned with a rigid tool (Sall 2005).

Instruments: Rotary devices can be used to facilitate the pivoting of the recipient and the placing of the coils.

Coil Forming Procedures

Coils can be used following several procedures, which are referred to here as spiral, ring, segment, and spiralled patchwork procedures (Fig. 2.17):

- Spiral procedure. A long coil is shaped and rolled around itself into a vertical spiral if it is to be used for forming walls and a horizontal spiral for the base. For small recipients, a single coil can be used for the base and walls.

Fig. 2.16 Coiling techniques: (**a**) and (**b**) forming coils by rolling an elementary volume of paste on a flat surface (Uttam Nagar, northern India); (**c**) coiling by pinching (Uttam Nagar, northern India); (**d**) coiling by drawing (Uttam Nagar, northern India); (**e**) and (**f**) coiling by spreading (Mali, ©A. Gallay)

Fig. 2.17 Coil forming procedures: (**a**) spiral procedure; (**b**) ring procedure; (**c**) segment procedure (Ajlun region, Jordan)

- Ring procedure. Each row is formed with a single ring. Both ends are joined after being placed in a coil, unless the coil is preformed into a ring before being placed (example in Africa).
- Segment procedure. Several coils are stuck to each other to form a row.
- Spiralled patchwork procedure. This procedure has been identified recently at Neolithic Mediterranean sites (Gomart et al. 2017). It consists in constructing vessels by juxtaposing circular patches, each formed by a spiral coil, probably fused and flattened before their use as patch.

Coil Joining Procedures

The coiling techniques give rise to different joining procedures:

- Rectilinear joining is used with the pinching coiling technique. Let us recall that the coil is placed on the side of the lower coil with the right (or left) hand, while

the thumb and the index finger of the left (or right) hand exert symmetric horizontal pressures on either side of the coil. The circular coil section becomes rectangular, and the edge on which the following coil is placed is thus horizontal.
- Bevel joining is used with the coiling technique by pinching and spreading. In the first case, the coil is placed on the edge of the previous one and undergoes asymmetric vertical joining pressures with the thumb or the index finger on one of the faces. The asymmetric pressures from top to bottom result in the displacement of the paste and create a bevel (also called oblique) joint. Regardless of whether pinching or spreading techniques are used, the pressures can be external, internal, or alternating, creating joints with external, internal, or alternating bevels (alternating external and internal bevel joints). The alternate placing procedure presents advantages for the stability of the walls and the regularity of the profiles (Pétrequin et al. 2009).
- Semicircular joining (U-shaped) is used with the pinching coiling technique. The coil is placed and joined with point pressures from the thumb and the index finger on the upper part of the coil. This pressure creates a rounded edge. When a new coil is placed, it takes the form of the edge of the previous coil, i.e., a U-shaped.

The Slab Technique

The slab technique consists in roughing-out recipients or parts of recipients with parallelepiped slabs of variable dimensions made out of large coils or lumps (Fig. 2.18) which are flattened:

- Either by alternate percussion with a hammer or with the hands or feet
- Or by percussion with a roller type tool or the palm of the hand which flattens the coils or the lumps of clay on a work plan

Forming a slab wall consists in mounting the slabs on their sides and then joining the ends together. The slab technique can be used for manufacturing large and small recipients. Indeed, there is no link between this technique and the size of the recipients, even if it is currently preferentially used for large jars.

The slabs are either thinned to varying degrees, depending on their thickness (strongly thinned when thinning by drawing), or only undergo shaping operations.

The slabs used for making the bases are circular shaped. They are obtained from a flattened clay ball and are generally called discs. In many cultures, the same gestures are used for making pitta bread and forming a circular disc. Potters begin with a clay ball which is then progressively thinned by crossed and alternate tapping with both hands, in order to form a circular plaque, like for a pitta bread.

Active tools: Hands, hammers, rollers.
Passive tools: Work plans (ground, block of wood), forming supports.
Instruments: Like for the coiling technique, rotary devices can be used to facilitate the pivoting of the recipient and the placing of the slabs.

Fig. 2.18 Slab technique: (**a**) and (**b**) rectangular slab placed on its side, vertically, on a wooden block and joined as to form a cylinder; the neck and the rim are thinned and shaped by continuous pressures, while the body and the bottom will be paddled once the clay paste will reach a leather-hard state (Nagaland, India); (**c**), (**d**), and (**e**) manufacture of a *tandur*; a rectangular slab fashioned by alternate tapping is placed vertically on its side as to form a cylinder; it is then thinned by vertical pressures, bottom to top; the rest of the body will be fashioned from big drawn coils (Uttam Nagar, India); (**f**) fashioning of a disc by alternate tapping with feet (Vietnam, ©A. Favereau)

Slab Forming Procedures

Recipients of all sizes can be formed with a single slab or several rows of slabs. In the first case, the slab is used to shape the lower or the upper part of the recipient, whereas coils are used to shape the upper or lower part. When the recipient is formed of several slabs, the forming procedures are comparable to those used for coil forming (rings or segments), i.e., the rows are made of one or several slabs.

Slab Joining Procedures

The slab joining procedures are identical to those described for coils: horizontal, beveled, or U-shaped.

Roughing Out a Clay Mass Without RKE

Modeling is the generic term used to describe all the roughout techniques without RKE on clay masses. There are four roughing-out techniques by modeling (Fig. 2.19). They can be divided into:

- Pressure techniques, which include modeling techniques by pinching and drawing
- Percussion techniques, which include hammering and molding techniques

Modeling by Pinching

Modeling by pinching consists in transforming a spherical or flattened clay mass into a hollow volume with discontinuous point interdigital pressures. This technique is often used for shaping small recipients, but ethnographic examples describe this technique for making recipients up to 30 cm high.

Tools: The modeling of a clay mass by pinching is generally carried out by hand, without tools.

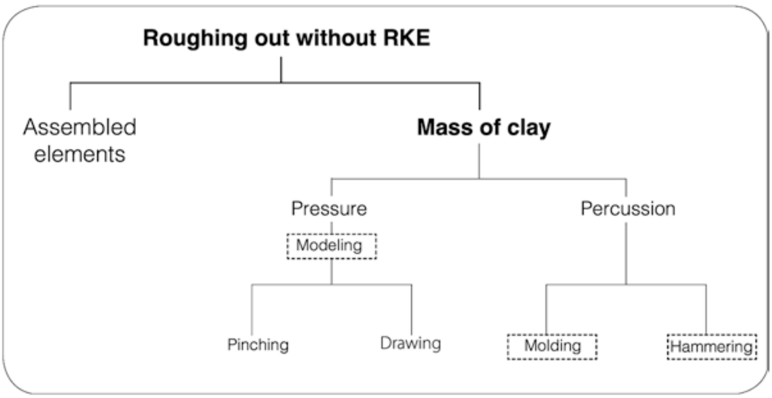

Fig. 2.19 Classification chart of roughout techniques without RKE on clay mass

Modeling by Drawing

Modeling by drawing consists in forming the walls of a recipient by thinning a lump of clay by discontinuous interdigital or inter-palm pressure, vertically from the bottom to the top (Fig. 2.20d, e). It is also called *drawing from a lump of clay*, *hollowing from a lump of clay*. It comprises a first hollowing phase where the mass is hollowed by interdigital pressure.

Tools: The modeling of a clay mass by drawing is generally carried out by hand, without tools.

Hammering Wet Paste

The hammering technique consists of roughing out a hollow volume from a clay mass by percussion, without using a mold (Fig. 2.20a–c). The clay mass is placed on a work plan, on an anvil, or in the palm of the hand. If required, during thinning operations, the hand opposite the hand thinning by percussion pivots the recipient on the work plan or on the anvil support on which the recipient is placed. There are two sorts of hammering: convergent and divergent (Gosselain 2010, 673). Convergent hammering consists in hammering a clay mass from the periphery toward the center, and conversely, divergent hammering consists in hammering from the center toward the periphery.

Active tools: Hammering can be carried out with the fist, fingers folded, or with the fingers clamped and straight, or with a hammer.
Passive tools: Hammering takes place on work plans which can be covered with a cloth or a mat or on anvil supports.

Molding

Molding consists in roughing-out and preforming recipients by spreading a clay mass onto a convex or concave mold (Figs. 2.20f and 2.21). The clay mass is progressively thinned by percussion, either directly on the mold or on the work plan or between the hands in order to obtain a clay slab which is then stamped (placed and pressed) into the mold. When it is directly thinned on the mold, the clay is spread by percussion which contributes to progressively thinning the clay mass and increasing its size until the slab reaches the maximum diameter of the mold. If necessary, the edges of the slab, spread out in or on the mold, are then regularized by cutting with a sharp tool. Anti-adhesive matter is sprinkled over the mold (e.g., sand, ashes) so that the clay slab does not stick to the mold.

In the case of a horizontal mold, only the lower part or both the lower and upper parts of the recipient are molded. When only the lower part is molded, the upper part is generally formed by coiling. When both parts are molded, the mold of the upper part presents an orifice which is used to cut the opening. The upper mold is placed on the lower mold once the paste reaches leather consistency. After demolding, the neck and rim are shaped from a coil which is placed around the orifice of the upper part and thinned by discontinuous or continuous pressure. Continuous pressure can

Fig. 2.20 Examples of roughout techniques without RKE on clay mass: (**a**) hammering with the fist; the palm of the passive hand is used as a forming support (Cebu island, Philippines); (**b**) hammering with the fist a clay mass placed in a concave forming support (Mali, ©A. Gallay); (**c**) hammering with a hammer a clay mass placed in a concave work plan covered with a matt (Mali, ©A. Gallay); (**d**) modeling by drawing a clay mass placed on a concave forming support (Senegal, ©A. Gelbert); (**e**) modeling by drawing a clay mass placed on the flat bottom of a jar (Vietnam, ©A. Favereau); (**f**) molding on a convex mold (Mali, ©A. Gallay)

Fig. 2.21 Concave molding in northern India (Uttar Pradesh): (**a**) a clay disc is fashioned by alternate tapping; (**b**) the disc is pressed in a ceramic concave mold and smoothed with a wet cloth; (**c**) a coil is placed on the edge of the lower part along a convergent orientation in order to stretch it later by discontinuous pressures on the upper part; (**d**) once the clay is leather-hard, the two parts are assembled; (**e**) the upper part is demolded; (**f**) the neck is formed from a coil and shaped by continuous pressures

be exerted with or without a rotary instrument. There are molds of lower parts with no bases. In this latter case, this is formed during a second phase, by adding paste or by thinning the lower walls which were intentionally left thick.

For vertical molds, the upper (including the neck and rim) and lower parts are made from a single piece (example in Mexico, van der Leeuw 1994).

> Example of molding on overturned pottery in Senegal. Gelbert wrote the following description (description in the cederom attached to Gelbert 2003): "the mold is covered with grog powder. The potter shapes a disc by hammering a lump of clay on the ground with a flat stone. She puts it on top of the mold then thins it and shapes it by hammering, until she obtains a regular wall. After humidification, the potter scrapes the surface with a calabash scraper, then smooths it with the palm of the hand. After partial drying, the potter demolds the base and shaves the inner wall with the calabash tool."

Active tools: Hands, hammers, rollers
Passive tools: Convex or concave, horizontal or vertical, mobile or set molds, with or without handle (the case for certain Mexican molds)

Molding and Joining Procedures

Different procedures exist for joining two molded parts. Either the edges of the lower part are incised and then coated with clay slurry to ensure that both parts stick together or a paste surplus is created in order to join both parts together. This surplus consists either of clay from pinching the edges or from placing a coil on the edge of the lower part along a convergent orientation in order to stretch it by discontinuous pressure on the upper part. In addition, a coil can be placed on the exterior joint in order to reinforce it. It is regularized by discontinuous or continuous horizontal pressure.

Preforming Techniques Without RKE

Preforming techniques are intended to give the recipient its final form. Different techniques are applied to wet paste and leather-hard paste, and each of these groups is divided into pressure and percussion techniques (Fig. 2.22). In total, seven preforming techniques without RKE have been identified.

Preforming Wet Paste Without RKE

Preforming wet paste without RKE is carried out either by pressure or percussion.

Preforming by Pressure

Preforming by pressure comprises:

- Scraping (Fig. 2.23) which consists in shaping the walls by discontinuous pressures by pushing them and profiling them with a rigid tool. Pressures are applied to the inner and/or outer faces of the recipients according to various directions and

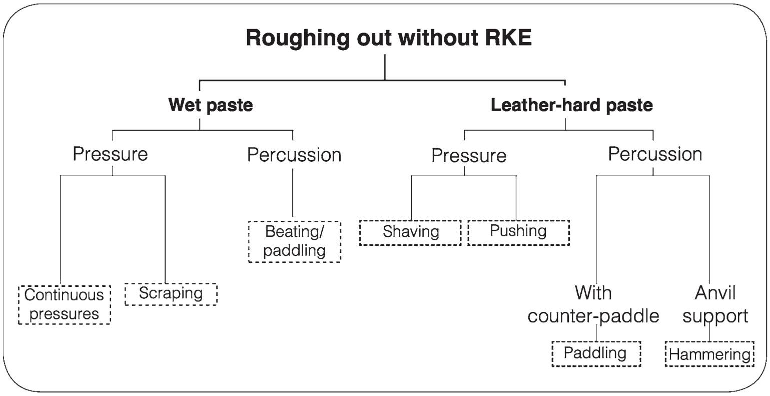

Fig. 2.22 Classification chart of preforming techniques without RKE

Fig. 2.23 Examples of shaping wet paste by pressure: (**a**) shaping and regularizing the topography by scraping (Mali, ©A. Gallay); (**b**) profiling the upper part of the jar by scraping (Mali, ©A. Gallay)

directly contribute to shaping the profile. During scraping, the paste is moved, creating irregular topographies which can then be levelled out during smoothing.

- Shaping by continuous pressures (Fig. 2.24a); pressures are applied to shape the edge of the recipients by placing it between the thumb and the index finger, with a moist soft tool (e.g., textile) placed across the edge. The continuous movement is obtained by turning the hand, turning around the recipient, or pivoting the recipient. In the latter case, the hand holding the recipient makes it pivot directly, or the passive hand makes it pivot with a lubricant (e.g., clay slurry) spread over the work plan or with a rotary instrument.

Active tools: Hands, scrapers, cloth, natural tools (shell, calabash, corn cob, etc.)
Instruments: Rotary devices, turntables

Preforming by Percussion

Preforming wet paste by percussion consists in beating the outer surface of recipients with a paddle (Fig. 2.24b). The aim is to profile the walls, the base, or the edges or to shape and level out a closed base externally, while the recipient is placed with the neck to the ground. The use of a counter-paddle is not necessary when the beating movements are of low amplitude. When a counter-paddle is used, it is placed at

Fig. 2.24 Examples of preforming wet paste by pressure and percussion: (**a**) shaping a neck with continuous pressures (Experimental Center of Lejre, Denmark); (**b**) shaping by percussion (Uttam Nagar, India)

the same height as the paddle, on the inner surface. It is used to receive movements of greater amplitude.

Active tools: Paddles, counter-paddles
Instruments: Rotary devices, turntables

Preforming Leather-Hard Paste Without RKE

Leather-hard paste can be shaped without RKE by pressure, consisting of pushing and shaving, or by percussion, consisting of beating/paddling and hammering.

Pushing

Pushing consists in applying a pusher against the inner wall with a vertical movement in order to thin and curve it progressively (Fig. 2.25a). The exterior hand is used as a support. The pressures are exerted, from bottom to top, along the walls.

Fig. 2.25 Examples of preforming leather-hard paste by pressure: (**a**) pushing walls with a pebble (Experimental Center of Lejre, Denmark); (**b**) shaving outer walls with a knife (Rudakali, Jodhpur dist., India)

This shaping technique was used until the beginning of the twentieth century in Jutland (Denmark). The pushers were pebbles. Very diverse shapes were obtained on a wide range of utilitarian ware including cooking pots.

Active tools: Pushers
Passive tools: Forming supports (not necessary)

Shaving

Shaving consists in removing chips of leather-hard paste with a cutting tool (Fig. 2.25b). The aim is to thin the walls and give the recipient its definitive form. It generally concerns the lower parts of recipients. During this operation, the outer surface of the base can be regularized, the body/lower body junction can be modified and highlighted by the creation of a carination, and the base profile can be rounded.

Active tools: Shaving tools
Passive tools: Trimming supports

Beating/Paddling Leather-Hard Paste

Beating leather-hard paste is also called paddling. It consists in beating recipient walls with a beating tool placed on the outer face of the recipients (Fig. 2.26). The aim is either simple profiling or the transformation of the thickness and shape of recipients, which can require several successive beatings depending on the initial volume and size of recipients. Depending on the amplitude of the blows, an anvil may or may not be used. If it is used, it is placed at the same height as the beating tool on the inner face of the recipient. The beating technique with a paddle and counter-paddle can lead to the production of large recipients with very thin walls and rounded bases, recipients with geometric properties that are difficult to obtain at the roughing-out stage for mechanical reasons (collapse of the recipient under its own weight). For this reason, wheel-thrown roughouts are systematically paddled in India. Roughouts have thick walls (about 3 cm thick on average for a recipient of average dimensions). Beating allows them to be thinned and gives the base a rounded form. Large recipients undergo two successive beatings interrupted by a short drying phase. Paddles are made of wood and counter-paddles are in terracotta or stone.

Beating can only be applied to part of the recipient, such as the base, in order to transform a flat bottom into a rounded bottom or to fashion a missing base by thinning the lower parts of recipients that were deliberately left thick. The percussion blows are progressive and convergent.

The paddled recipients are placed either on fixed or rotary forming supports, or held on the artisan's thighs, which can be covered with cloth, with the legs straight or folded. During beating, the recipient is turned by the hand holding the anvil or with the help of a rotary instrument.

Fig. 2.26 Examples of shaping by percussion leather-hard paste: (**a**) beating with a wooden paddle and a stone anvil; the recipient is placed on potter's thighs covered with a jute cloth bag (Banar, Jodhpur dist., India); (**b**) beating of recipients placed on a jute cloth bag kept pulled by a rope attached to a pole; the legs are folded and the knees rest on ceramic pots (Mokalsar, Barmer dist., India); (**c**) closing the bottom of the recipient by beating with a wooden paddle and a stone anvil (Manipur, India); (**d**) paddling without counter-paddle (Mali, ©A. Gallay)

The inner and outer walls of the recipients are regularly sprinkled with anti-adhesives (e.g., sand, ashes) so that the paddle and the counter-paddle do not stick to the recipient walls.

Active tools: Hands, beating tools (paddles), anvils (counter-paddles). The dimensions of the tools vary depending on the size of the recipients.
Passive tools: Forming supports (not necessary).

Hammering Leather-Hard Paste

Hammering leather-hard paste consists in hammering the inner walls or the bases of recipients with a hammer on an anvil support or on a work plan (Figs. 2.27 and 2.28). Unlike beating, no counter-paddle is used for hammering. The aim is to thin the lower walls and the base of the recipient. When the base is missing, it is created by the progressive thinning of the lower walls. Hammering is convergent. The outer base obtained by hammering is rounded or flat depending on whether it is made on a concave anvil support or a horizontal work plan.

Fig. 2.27 Hammering in a concave terracota support: (**a–c**) creating the missing base by the progressive thinning of the lower walls; (**d–f**) hammering with a terracota tenon anvil. Hammering on a concave anvil makes the bottom round (Uttar Pradesh, India)

Fig. 2.28 Hammering on a horizontal work plan: (**a**) wheel-thrown roughout without bottom; (**b**) placing the roughout on the work plan and removal of the clay surplus around the orifice; (**c**) sprinkling anti-adhesives (ashes) on the work plan; (**d**) humidification of the lower inner walls; (**e**) hammering with a terracota tenon anvil; (**f**) shaving with an iron tool. Hammering on a horizontal work plan makes the bottom flat (Uttar Pradesh, India)

Like for beaten recipients, the inner and outer walls of the hammered recipients and the walls of the anvil supports are regularly sprinkled with anti-adhesives (e.g., sand, ashes) so that the anvil does not stick to the recipient walls and the recipient walls do not stick to the anvil support.

Active tools: Hammers (anvils). The dimensions of the tools vary depending on the size of the recipients.
Passive tools: Anvil supports.

Roughing-Out Technique with RKE

Only one roughing-out technique is used with RKE: wheel throwing.

Roughing Out a Clay Mass with RKE: Wheel Throwing

Wheel throwing consists in using RKE to rough out and form an elementary volume of homogeneous paste. It is the only forming technique that generates synergies between all of the functional operations. This results in considerable time-saving: wheel throwing a small recipient only lasts for several seconds! From this point of view, wheel throwing represents a rupture in the history of techniques and the culmination of the evolution of pottery techniques using muscular force. The role of centrifugal force and RKE in wheel throwing is discussed below by Gandon, Casanova, and Bootsma (see inset).

Wheel throwing comprises the following main operations: centering, hollowing, thinning, and shaping (Fig. 2.29). These different operations are preceded by the kneading of the lumps of clay with RKE, once it is placed at the center of the wheel. This proceeds by alternating horizontal internal pressures resulting in the forming of a pin and vertical pressures from the top toward the bottom, giving rise to the descent of the pin by compression. This kneading by RKE is intended to eliminate the last air bubbles and to homogenize the clay mass as well as possible, which is a necessary prerequisite for successful centering, roughing out, and shaping. The latter operations are carried out with gestures and pressures using variable force and with variable sequences depending on the form of recipients and wheel throwers' methods (Colbeck 1981).

Centering is carried out by simultaneously applying two types of pressure to the rotary lump of clay: horizontal palm pressures pushing the lump of clay with one hand toward the center of the wheel and vertical pressures toward the bottom with the exterior edge of the palm of the other hand. The aim of centering is to make the clay turn in the middle of the wheel so that when the object is hollowed, the walls have a horizontal section with a constant thickness and are of equal height. Successful centering is essential for the rest of the operations: a lump of clay that has not been centered cannot be shaped, as the centrifugal force deforms the periphery of the recipients until they collapse.

Fig. 2.29 The different stages of wheel throwing: (**a**) centering; (**b**) hollowing; (**c**) and (**d**) thinning; (**e**) and (**f**) shaping (foot wheel, Uttar Pradesh, India)

Once the lump of clay is centered, it is hollowed. Hollowing is carried out by first of all inserting the thumbs in the center of the clay and then by a radial movement of the fingers from the center toward the exterior until the required width is obtained. The aims of the hollowing operation are to determine the interior shape, the thickness, and the width of the base. This operation comprises two essential points: (1) determining when to stop hollowing the base; the latter must be sufficiently thick so that the thread used to remove the final object does not go through it and sufficiently thin so that it does not have to undergo a long trimming operation; (2) evaluating the thickness of the walls in relation to the size of the pot to wheel throw.

Thinning is the operation by which the walls of a previously centered and hollowed mass of clay are pressed between the fingers uniformly, while both hands are raised together and at the same speed. It consists in thinning the initial wall formed by hollowing in order to form the roughout. The number of thinning operations does not only depend on the weight of clay but also on the form of the recipient, closed or open. Thinning involves simultaneous, progressive, and regular pressures on either side of the wall, which do not slow down the rotation of the clay, in order to avoid spiral deformations. The walls are raised during thinning.

Shaping is carried out following the same principles as for thinning, although the walls are thinner, softer, and thus more subject to deformation.

The different wheel throwing operations are carried out at variable speeds. Centering requires maximum speed, which nonetheless varies depending on the weight of the clay. The heavier the mass of clay, the stronger the pressures and the more they slow down the rotation of the wheel which must therefore turn faster. Conversely, during thinning, and especially during shaping, the wheel must be slowed down in order to minimize collapsing risks due to the centrifugal force that can act as a deformation constraint on the periphery of recipients.

All of the wheel throwing operations take place on clay materials and with hands which are constantly remoistened, as rubbing the hands against the paste has a drying effect which acts as a brake; re-humidification consists in applying a film of water between the hands and the paste. This film lets the hands deform the paste without slowing down rotation. But there must not be too much water on the surface or the bottom of the recipient as water can also be a factor in cracking and collapse when wheel throwing goes on for an excessive period of time. From this point of view, the artisan must know how to measure the required and sufficient quantities of water throughout wheel throwing operations.

Generally, the rotation speed exerted during wheel throwing and the quantity of water used also depend on the clay material and the wheel thrower.

Lastly, it is important to note that a recipient can be thrown in one or several stages: the whole object can be thrown at once or the lower and upper part can be thrown separately (this is the case for wheel throwing large containers) and assembled when the paste is leather-hard. These two ways correspond to two distinct wheel-thrown methods.

Active tools: Scrapers, awls, and thread for removing the recipient from the wheel or from the lump of clay, sponges, and cloth. Wheel throwing can take place without tools, with few or many tools. The use of scrapers for thinning circumvents adding water to the walls and thus avoids the accumulation of too much clay slurry. The scrapers used for shaping profile the walls when applied to the outer surfaces; the use of shaping scrapers also circumvents adding water and thus cuts out excessive surface water and clay slurry.

Rotary instruments: Simple or double wheels.

Wheel Throwing Procedures

Wheel throwing comprises two forming procedures. Either the lump of clay centered on the wheel is used to fashion a single recipient or part of a recipient or it is used to fashion several recipients. In this latter case, we refer to wheel throwing off

Fig. 2.30 Wheel throwing off the hump (fly wheel, Uttar Pradesh, India)

the hump (Fig. 2.30). This procedure is frequently employed for making small recipients (but it can be used for middle size recipients). It presents the advantage of being able to make series of recipients without having to center the clay between each recipient.

Wheel Throwing and Removing the Recipients

Wheel-thrown recipients are removed from the wheel, or from the lump of clay when they are thrown off the hump, with a soft or hard tool, such as a thread or a metal wire, or by force. When a soft or rigid tool is used, it is placed between the wheel and the immobile or rotary recipient. The recipient is then lifted off the wheel. When they are removed by force, the recipients are placed on a plate, a circular piece of wood, plaster, pottery, or unfired clay, attached to the wheel with clay rolls. There are two options: either the plate is removed from the wheel by force, which allows the recipient to dry and then to be removed from its support without deformation, or the recipient is removed from the plate by force. This is often the case with unfired clay plates. An anti-adhesive layer (sand) between the plate and the recipient facilitates the removal of the recipient.

Wheel Throwing and Centrifugal Force (Inset)

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The veritable role of centrifugal force in wheel throwing pottery has not been extensively explored, even though it is widely cited by many authors (e.g., Rye 1977; Balfet 1984; Rice 1987; Vandiver et al. 1991; Jeffra 2011), some of whom consider it as an "active agent in the forming and shaping of the vessel" (Orton et al. 1993). In the face of this conventional wisdom, the works of Pierret (2001) have shown that wheel throwing only consists in combining manual pressures with RKE and that centrifugal force does not play an *active role*. In other words, wheel fashioned clay is only deformed by the effect of manual pressures combined with the rotation of the wheel. However, the modeling proposed by Pierret was based on a simple element considered to be a small mass; it did not take into account the overall geometry of the object. The influence of centrifugal force in wheel throwing could not thus be precisely evaluated. This influence is measured here with the modeling method of finite element. This method is widely used for calculating the mechanical stresses of structures such as bridges, buildings, or boats and thus for anticipating possible risks of collapse. The advantage of the modeling of finite element is that it takes account of the overall geometry of the object. This approach is a continuation of the work by Gandon et al. (2011).

Reminder of the Forces Involved in Wheel Throwing

When the potter sets the wheel in motion, he applies a driving force that accelerates the rotation speed of the *wheel* + *clay* system and supplies RKE. By exerting manual pressures to the clay, the potter applies forces with vertical and radial components that deform the clay and a tangential component that slows down the rotation movement. By controlling the rotation speed throughout throwing, the potter compensates the resistant forces (i.e., the tangential component of the pressure applied) by the driving forces so that the deformation forces (i.e., the vertical and radial components of the pressures) continuously fashion the clay. In addition to the forces applied by the potter $\vec{F}_M$, two other forces (Fig. 2.37) are applied to the clay during wheel throwing, the weight of the lump of clay $\vec{P}$ ($\vec{P} = -mg\vec{z}$), and the centrifugal force generated by the rotation of the system $\vec{F}_C$ ($\vec{F}_C = m\omega^2 r\vec{u}_R$).

Weight is exerted in a vertical orientation $\vec{z}$ and toward the bottom; its intensity is equal to the product of the mass m and gravity g. Centrifugal force is exerted along $\vec{u}_R$, the radial orientation to the movement of wheel rotation and toward the outside; its intensity varies with the mass m, rotation speed ω squared, and the distance r to the rotation axis. If no pressure is applied to the clay, these

(continued)

two forces do not produce any deformation. On the other hand, if manual forces are applied, weight and centrifugal force are components of the sum of forces applied to the system. In other words, weight and the centrifugal force are added to the manual forces. The orientation of the weight does not allow this force to contribute to rising the clay; on the contrary, it counters it. The orientation of the centrifugal force does not allow it to contribute to rising the clay either. On the other hand, the centrifugal force can contribute to the deformations of the clay in a radial orientation, in the opposite direction to the rotation axis (Fig. 2.31).

Centrifugal Force and Clay Deformation: Corpus and Method of Analysis

To evaluate the influence of centrifugal force, we used the modeling method of finite element in order to take account not only of the orientation and the intensity of this force but also of the geometry of the object to which this force is applied. The corpus is made up of four different forms, each of which is produced with two different clay masses (Table 2.1).

These models were reproduced by 11 French expert potters working on an electric wheel with a sandstone-type clay. Tables 2.2 and 2.3 present the average dimensions and thickness of the reproductions.

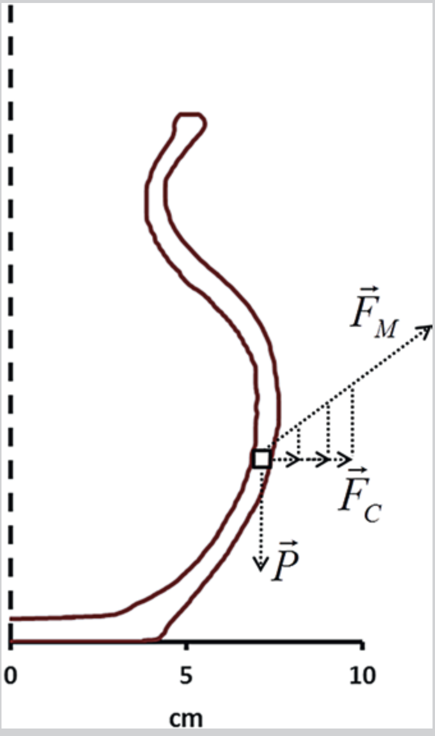


Fig. 2.31 Representation of the forces applied to the lump of clay during wheel throwing: the manual forces ($\vec{F}_M$), the weight of the lump of clay ($\vec{P}$), and the centrifugal force ($\vec{F}_C$). When the potter fashions the clay toward the outside and the top, the centrifugal force is added to the radial component of the manual forces. Depending on the rotation speed, the centrifugal force contributes more or less to the forces of deformation

(continued)

Table 2.1 The eight experimental conditions: four different forms (cylinder, bowl, sphere, and vase) with two clay masses (0.75 and 2.25 kg)

	Cylinder		Bowl		Sphere		Vase	
Form								
Clay mass (kg)	0.75	2.25	0.75	2.25	0.75	2.25	0.75	2.25

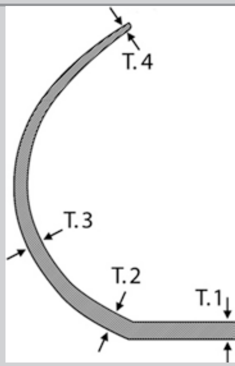
Table 2.2 Average dimensions of the experimental vessels (four forms and two clay masses)

Form	Mass (kg)	H (cm)	B (cm)	O (cm)	MD (cm)	HMD (cm)
Cylinder	0.75	17.7	10.1	10.5		
	2.25	28.6	14.2	14.4		
Bowl	0.75	9.2	8.6	21.4		
	2.25	13.8	12.8	33.0		
Sphere	0.75	12.1	9.7	8.6	15.9	5.9
	2.25	18.7	14.2	11.7	23.4	9.1
Vase	0.75	9.9	11.3	6.9	16.5	3.7
	2.25	15.1	16.9	8.9	24.3	5.2

H height, *B* base, *O* orifice, *MD* maximum diameter, *HMD* height of the maximum diameter

Table 2.3 Average thicknesses of the experimental vessels (four forms and two clay masses)

Form	Mass (kg)	T.1 (mm)	T.2 (mm)	T.3 (mm)	T.4 (mm)
Cylinder	0.75	7.3	10.5	6.5	5.2
	2.25	9.7	14.7	8.9	6.4
Bowl	0.75	9.7	18.2	8.5	6.4
	2.25	12.3	27.3	11.7	7.8
Sphere	0.75	6.4	15.4	6.5	6.8
	2.25	9.1	21.8	8.0	8.9
Vase	0.75	6.6	14.2	9.0	6.9
	2.25	8.9	20.5	11.1	8.8



Thickness has been measured at four levels: middle of the base (T.1), bottom of the wall (T.2), middle of the wall (T.3), and top of the wall (T.4)

(continued)

The eight average reproductions (4 forms × 2 masses) were modeled when they were freshly thrown, that is, when the clay was still wet. On the basis of (a) the geometry of the reproduced pots (profile and thickness), (b) the clay density (volume mass), and (c) a law of mechanical behavior (Young's modulus and Poisson's ratio), the average reproductions were modeled in 3D axisymmetric and discretized 3D and in a set of volumes called *elements*. For each element, the stresses of traction-compression and the stresses of shearing were calculated. We used the Von Mises mathematic norm – classically used for the mechanical studies of clay – to synthesize all of the mechanical stresses present on the walls of the pot. In addition, using the local calculation of the mechanical stresses of the pot, this modeling allows us to analyze the distribution of the mechanical stresses of different intensities inside the walls (Fig. 2.32).

To measure the mechanical stresses induced by centrifugal force, we modeled the mechanical stresses of these reproductions at different rotation speeds, ranging from 0 rotation/min (static situation) to 200 rotations/min in stages of 10

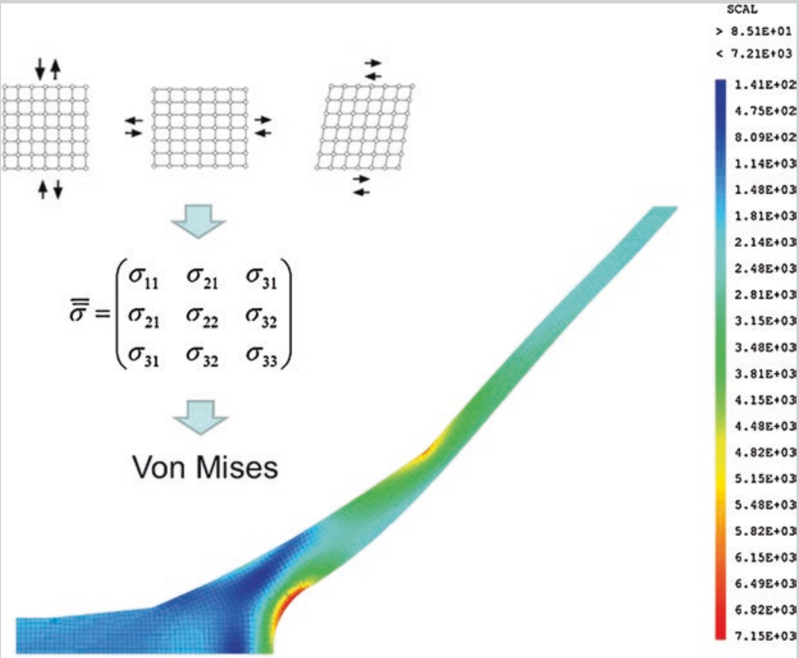


Fig. 2.32 Cross-sectional 2D profile of a 2.25 kg bowl mechanical modeling. The Von Mises norm synthesizes the matrix of mechanical stresses ($\bar{\bar{\sigma}}$), and the maximum value of this norm is an overall index of the mechanical state of the pot. This bowl reaches a Von Mises maximum value of 7.13 kPa. The color scale (from dark blue to dark red) represents the increasing values of mechanical stresses. The color mapping shows the distribution of the mechanical stresses inside the walls

(continued)

rotations/min. This range of rotation speed was chosen based on the literature (Rye 1981; Pierret 2001). When the wheel is stopped (i.e., zero rotation speed), the mechanical stresses to which the pottery is subject only come from the weight of the pottery. From the moment the wheel begins to turn, centrifugal force is added to the weight of the pottery. Given that the effect of the weight of the pot is constant, the increase in the measured mechanical stresses only corresponds to the increase in the centrifugal force induced by the rotation of the wheel.

Centrifugal Force and Clay Deformation: Results

Figure 2.33 presents the level of mechanical stresses, captured by the maximum Von Mises values of the eight pottery replicas in relation to the rotation speed of the wheel, varying from 0 to 200 rotations/min. The threshold of collapse determined by Gandon et al. (2011), i.e., the level of stresses resulting in plastic deformation (i.e., nonreversible), is also represented by a dotted horizontal line. As expected, the level of mechanical stresses increases with the rotation speed of the wheel for all these conditions. Nonetheless, we observe that this increase is variable depending on clay shapes and sizes. From zero speed to the maximum speed, the small cylinder displays the lowest increase (1.16 kPa), whereas the large bowl shows the highest increase (15.88 kPa), above the threshold of collapse.

During the start of rotation, we not only observe an increase in the maximum Von Mises stresses but also a modification of the most constrained zones of the wall (Fig. 2.34). Without rotation, the most fragile zone of the large bowl is at the exterior of the junction between the base and the wall. When rotation speed increases, the most constrained zone becomes the most offset zone of the rotation axis.

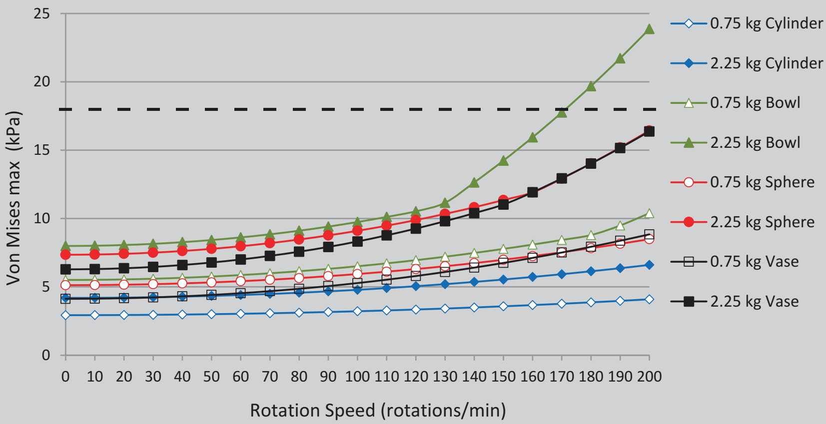


Fig. 2.33 The Von Mises maximum values for the eight reproductions depending on the rotation speed ranging from 0 to 200 rotations/min. The threshold of collapse (18 ± 2.7 kPa) is showed by a dotted line

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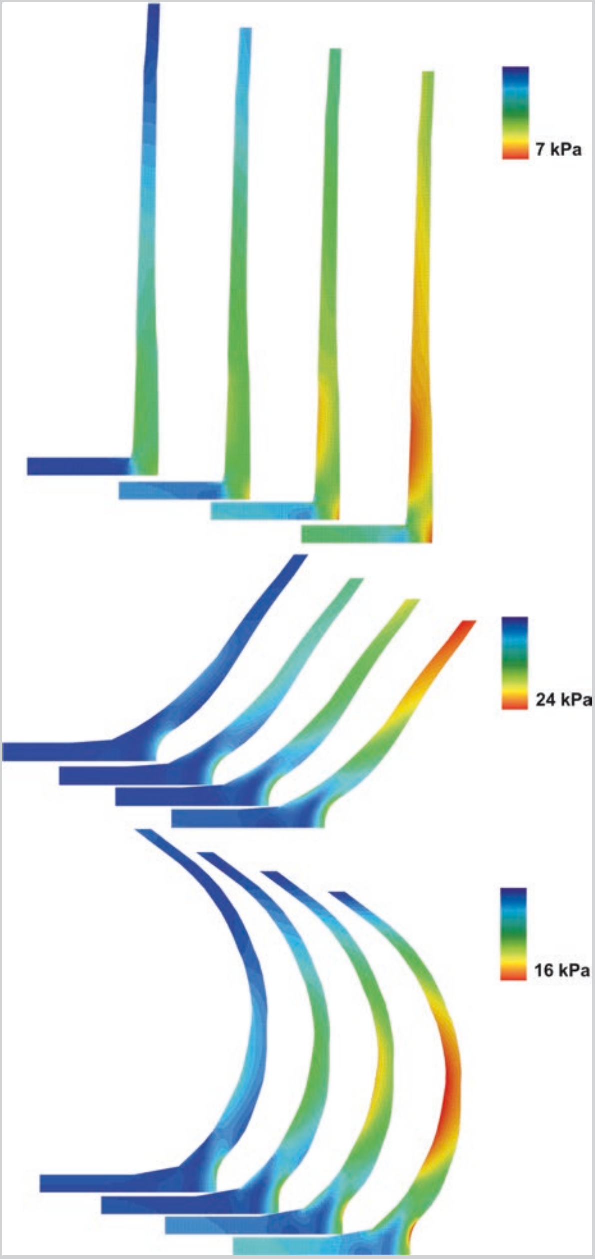

Fig. 2.34 Repartition of the mechanical stresses inside the walls of the cylinder, bowl, and sphere, for the 2.25 kg pots. From left to right, the rotation speed is 0, 120, 160, and 200 rotations/min. The change in stresses distribution observed here (on the 2.25 kg pots) is qualitatively similar to that of the 0.75 kg pots. The geometry of the vase being very close to that of the sphere, we have not presented it here

(continued)

Furthermore, as we can see in Fig. 2.33, even at a rotation speed of 200 rotations/min, for most of the pots thrown in the experiment by Gandon et al. (2011), the mechanical stresses remain below the threshold of collapse. Indeed, only the large bowl does not resist beyond 175 rotations/min. Thus, as already observed by Pierret (2001), centrifugal force alone does not give rise to a plastic deformation of clay for the rotation speeds used in wheel throwing.

In reality, potters regulate rotation speed so that the mechanical stresses induced by the centrifugal force are much lower than the threshold of collapse. Indeed, in a complementary experiment, we recorded an average rotation speed of 152 rotations/min for the pots of 0.75 kg and an average rotation speed of 125 rotations/min for those of 2.25 kg; this observed reduction in speed for the mass of 2.25 kg, compared to the mass of 0.75 kg turned out to be statistically significant (F (1.4) = 23.66, $p < 0.01$). When we consider these speeds, we observe that the increase in mechanical stresses induced by the centrifugal force (from zero speed to the recorded speed) attains between 0.66 kPa for the small cylinder and 3.20 kPa for the large vessel (Fig. 2.35). These values represent 3.7% and 17.8% of the threshold of collapse (18 ± 2.7 kPa).

In this way, as presented in Fig. 2.31, the centrifugal force is a passive force in the environment that can be used by the potter. When the potter fashions the clay with a component in radial direction toward the exterior, the centrifugal force helps with deformation; conversely, when the potter fashions the clay in a radial direction toward the interior, the centrifugal force counters deformation. Depending on the type of production, for a given rotation speed, the potter can use this passive force to varying degrees, with its intensity varying

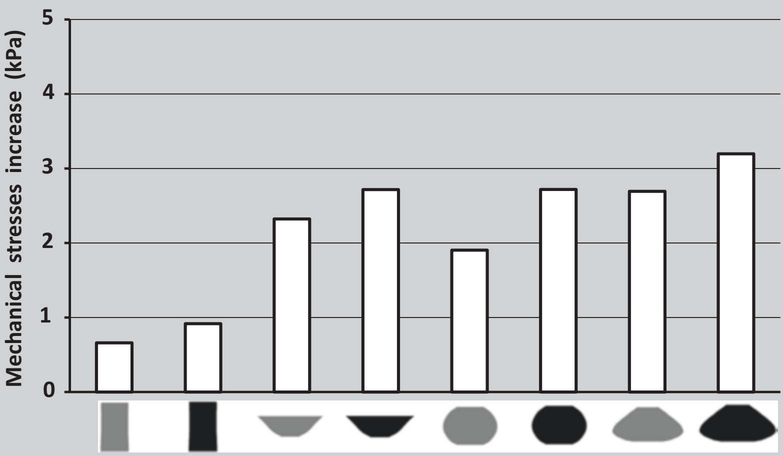

Fig. 2.35 Increase of the maximum Von Mises values, for the eight reproductions, from the static situation (zero speed) to the situation where the wheel is activated at 152 rotations/min (for the 0.75 kg pots) and 125 rotations/min (for the 2.25 kg pots). The four forms (cylinder, bowl, sphere, and vase) are represented on the *x*-axis; the pots of 0.75 kg are in gray and those of 2.25 kg in black

(continued)

with the diameter of the vessels. In the same way, for a vessel of a given form, the potter can use the centrifugal force to varying degrees depending on the radius of the wall being formed.

Conclusions

The results of the modeling presented here clearly show that in real wheel throwing conditions, the centrifugal force is not an *active agent* in the sense that it is not a force deforming the clay by itself. Even if an increase in rotation speed during wheel throwing allows the centrifugal force to fulfil this role at a given moment, it is important to realize that this does not result in the collapse of the vessel. Indeed, if rotation speed alone was sufficient to deform the clay, this deformation would first of all occur at the most fragile point of the vessel, which is situated at the most offset point. The deformation of the pot at this point would bring it further outward, which would reinforce deformation until the collapse of the pot.

Other authors have suggested that the centrifugal force would influence the *receptivity* of the clay to manual forces. For example, Jeffra suggests that "relative to the rotation of the wheel device, the clay is more responsive to inertial forces and is thus more readily drawn outward and upward through manipulation by the potter" (Jeffra 2011, 45).

As we have seen, the centrifugal force resulting from the rotation of the wheel produces stresses inside the walls, a comparable phenomenon to the stresses produced by the weight under the influence of gravity. For each of these forces, centrifugal force and weight, as well as for their combined effects, the stresses do not modify the structure of the clay, which conserves its elastic character until it goes over the plastic deformation threshold. When constrained in this way, the clay does not become more *receptive* or easier to form.

In order to understand the role of centrifugal force in wheel throwing, it is important to differentiate between the forces produced by the potter (i.e., active forces) and the other forces, which can be described as environmental or passive. Fine motor skills consist in taking account of the sum of all the forces at work (Bernstein 1967). In this way, the potter must produce active forces (i.e., muscular forces), which vary depending on the operating passive forces. In order to deform the clay during forming, the potter must ensure that the sum of the forces at work exceeds the plastic deformation threshold of clay. In some cases, the operating passive forces help the potter, who can use them (e.g., with other activities, see Holt et al. 1990; Goldfield et al. 1993; Sevrez et al. 2012). This is the case for weight, when the potter brings the clay downward, and centrifugal force, when the potter forms the clay toward the exterior. In other cases, the operating passive forces resist the action of the potter. This is the case for weight, when the potter shapes the clay upward, and centrifugal force, when the potter forms the clay in an inward direction. Passive forces can thus help or counter the shaping of the clay intended by the potter, but in all cases, the latter must take account of these forces when producing active forces.

Preforming Techniques with RKE

Shaping with RKE is used on wet or leather-hard pastes.

For shaping wet pastes, the roughouts are made with or without RKE. In the first case, the roughout is wheel-thrown, and shaping consists in giving the recipient its definitive shape with less hard but firm and constant pressures. In the second case, shaping techniques with RKE are applied to coiled or molded roughouts. We distinguish between wheel coiling and wheel molding.

For shaping leather-hard paste, the recipient is trimmed, that is, shaved using RKE.

Shaping Wet Paste with RKE

Wheel Coiling

Wheel coiling consists in shaping coiled roughouts with RKE (Fig. 2.36). RKE can be used during the positioning of the coils or once all the coils are positioned, joined, and/or thinned. There are four methods, depending on when RKE is used for shaping (Fig. 2.37):

- *Method 1*: the coils are positioned, joined, and thinned without RKE and then shaped with RKE.
- *Method 2*: the coils are positioned and joined without RKE, then thinned and shaped with RKE.
- *Method 3*: the coils are positioned without RKE, then joined, thinned, and shaped with RKE.
- *Method 4*: the coils are positioned, joined, thinned, and shaped with RKE.

Each method can be distinguished in terms of manufacture time and shaping quality. Method 3 is the fastest but less effective for transforming a heterogeneous mass into a homogeneous mass. Methods 1 and 2 are longer but ensure the transformation of the recipient into a homogeneous volume given the prior joining of coils with discontinuous pressures. Lastly, method 4 is the most remarkable in that it ensures very good cohesion between joints, remarkable wall regularity, and a higher manufacture speed than for variants 1 and 2 (Roux and Courty 1998).

Wheel coiling can also be used to shape only the neck or the foot of previously shaped recipients with or without RKE (e.g., wheel-thrown or molded). The recipient is left to dry until it reaches leather-hard consistency and is then positioned on the wheel. To make a foot, the base frame is incised and coated with clay slurry to favor adhesion to the coil. The coil is then placed, thinned, and shaped with RKE to make a foot. In the same way, to make a neck, the opening is incised and coated with clay slurry. A coil is then positioned, thinned, and shaped with RKE.

Wheel coiling is still a widely-used technique today. It is used in Crete at Thrapsano for making large jars (Voyatzoglou 1973), in Spain for manufacturing *cazuelas* (Gelbert 1994), in Pakistan (Rye and Evans 1976), in Laos or on Leyte Island in the Philippines for the

Fig. 2.36 Examples of wheel coiling: (**a**) and (**b**) wheel coiling on electric wheel (New Delhi, India); (**c**) and (**d**) wheel coiling on a turntable activated by the helper's foot (Vietnam, ©A. Favereau)

manufacture of different types of recipients (Scheans 1977). This technique was also prevalent in the Near East between the fifth and first millennia B.C. (Roux and Courty 1998; Roux 2009).

More generally, recent research on Oriental and Mediterranean ceramic assemblages from the third and second millennia B.C. tend to show that wheel coiling rather than wheel throwing was the technique in use (Roux 2009; Dupont-Delaleuf 2011; Jeffra 2011; Gauss et al. 2016). In this respect, some Greek authors, including Diodorus Siculus or Posidonius (D'Anna et al. 2011, 18), indicate the invention of the wheel, improvements to the wheel or even the name of the inventor of the wheel; this latter would be Talus, nephew of Daedalus, who would have invented the potter's wheel towards 1200 years B.C. (Brongniart 1977, 2:573). However, turntables existed in the Near East since the fifth millennium B.C. and their performance developed considerably during the course of the second half of the third millennium B.C. with the appearance of tenon turntables in northern Syria with speeds reaching 150 rotations/min. As wheel throwing is a late invention in all cases, we can wonder if the invention signalled in Greek texts is not in fact related to the invention of wheel throwing which would thus be a Greek invention *sui generis*.

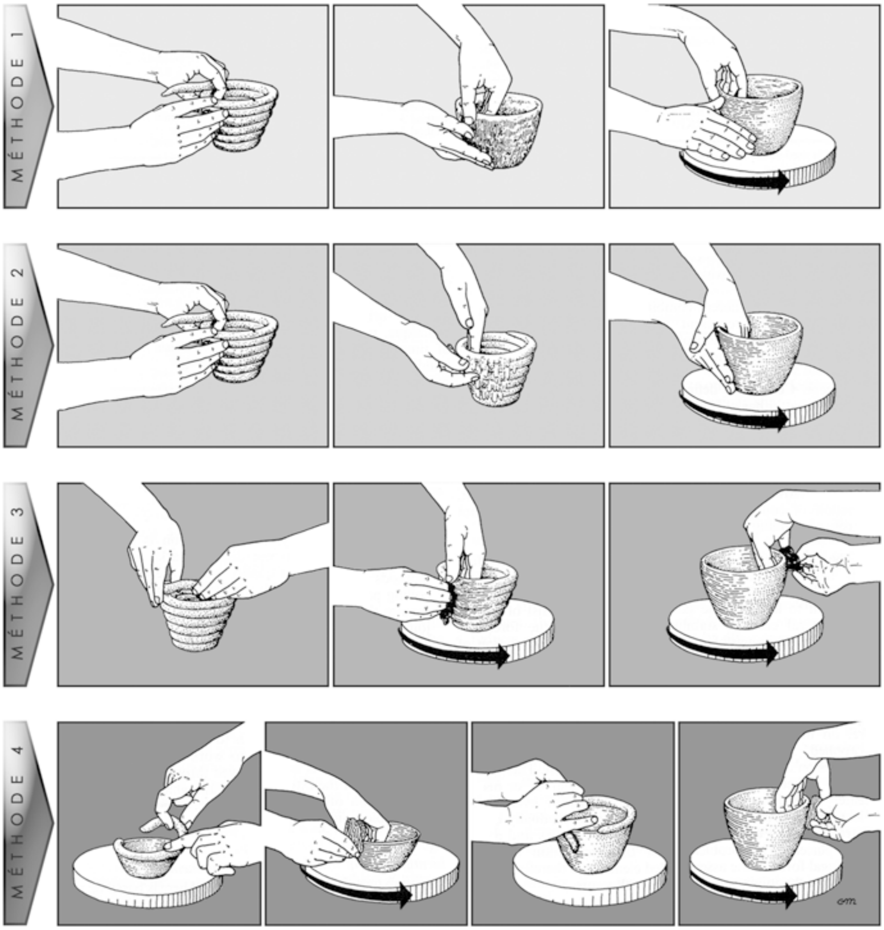

Fig. 2.37 Illustration of the four wheel coiling methods. (After Roux and Courty 1998)

Fig. 2.38 Egyptian potter workshop, Beni Hassan, tomb of Amenemhet, XII dynasty (end of the reign of Senwosret I) (Arnold and Bourriau 1993, 48)

Egyptian representations from the second millennium B.C. show potters working on tenon turntables and removing with string small bowls thrown off the hump, while others work larger pots unimanually, with one hand working the recipient walls, and the other hand activating the turntable (see Fig. 2.38, as well as the representations in the work of Arnold and Bourriau 1993). These depictions, as well as a recent study of Egyptian pottery (Doherty 2015), could reflect the existence of two distinct practices in Egypt during the second millennium B.C.: throwing off the hump for small recipients and wheel coiling for larger-sized recipients. Throwing off the hump only requires centring the top of the lump of clay and exerting simple pressures with the thumb and the index finger to hollow and thin the recipient. This technique is feasible with the tenon turntable. It may have been only applied to the manufacture of small bowls and not generalized to the rest of the production.

Active tools: Hand, scrapers. The application of a rigid scraper with RKE to the outer walls of coiled roughouts facilitates the homogenization and regularization of the walls.

Instruments: Turntables, wheels. Turntables with rotation speeds of less than 80 rotations are sufficient for wheel coiling. Nowadays, when wheels are used for wheel coiling, they are used for the wheel coiling of large-sized objects and for throwing objects of small and medium dimensions.

Wheel Coiling and Joining Procedures

The coil joining procedures are the same as those used for the coiling technique.

Wheel Molding

The wheel molding technique consists in thinning molded roughouts with RKE. The principle is the following: a mold is placed on the wheel, and a slab is placed inside the mold and is then thinned and regularized with RKE.

Wheel molding can be used for shaping only the lower part of the recipient or for the lower and upper parts. In the first case, the upper part is then formed with coils. In the second case, both parts are successively worked with RKE and then assembled.

An example of wheel molding is given in the work of Rye and Evans (1976). It is similar to the fashioning *chaîne opératoire* used for sigillata pottery (Fig. 2.39). A cloth ring is placed on the upper wheel of a foot wheel and a concave terracotta mold of the upper part decorated with hollow decoration is placed on this ring, with its opening against the ring. A disc is made by the alternate tapping of both palms on a previously sanded wooden plateau. The disc is then placed inside the mold, with the sanded surface against the mold. The wheel is set in motion and the disc is thinned by continuous pressures combined with RKE. Any surplus clay from above the mold is removed. The central hole corresponding to the opening is cut with a knife. The inner face is smoothed by continuous pressures using an anvil. The mold is then removed from the wheel and left to dry. During this time, the lower part of the recipient is made following the same process, apart from the fact that the clay surplus from above the thinned walls is not removed. When the upper part reaches leather-hard consistency, the upper mold is turned onto the lower mold which is positioned on the wheel and both parts are joined by applying continuous pressures with RKE on the clay surplus on the inner face of the recipient. The recipient made up of both parts of the mold is then turned upside down, with the opening of the neck against the wheel, and the lower part is demolded. It is then left to dry on the ground, with the upper molded part against the ground. Once the lower part is leather-hard, it is repositioned in the lower mold and the upper decorated part, which is midway between leather-hard and dry, is carefully demolded so that the relief decoration is not damaged. The lower mold and the recipient are then placed on the wheel and centred. A coil is placed on the opening, then thinned and shaped with RKE. The fashioning of the recipient is finished. The recipient is removed from the mold and left on the ground to dry.

Active tools: Hand, anvils (the anvil allows for smoothing without adding water and taking off the clay slurry).

Passive tools: Molds.

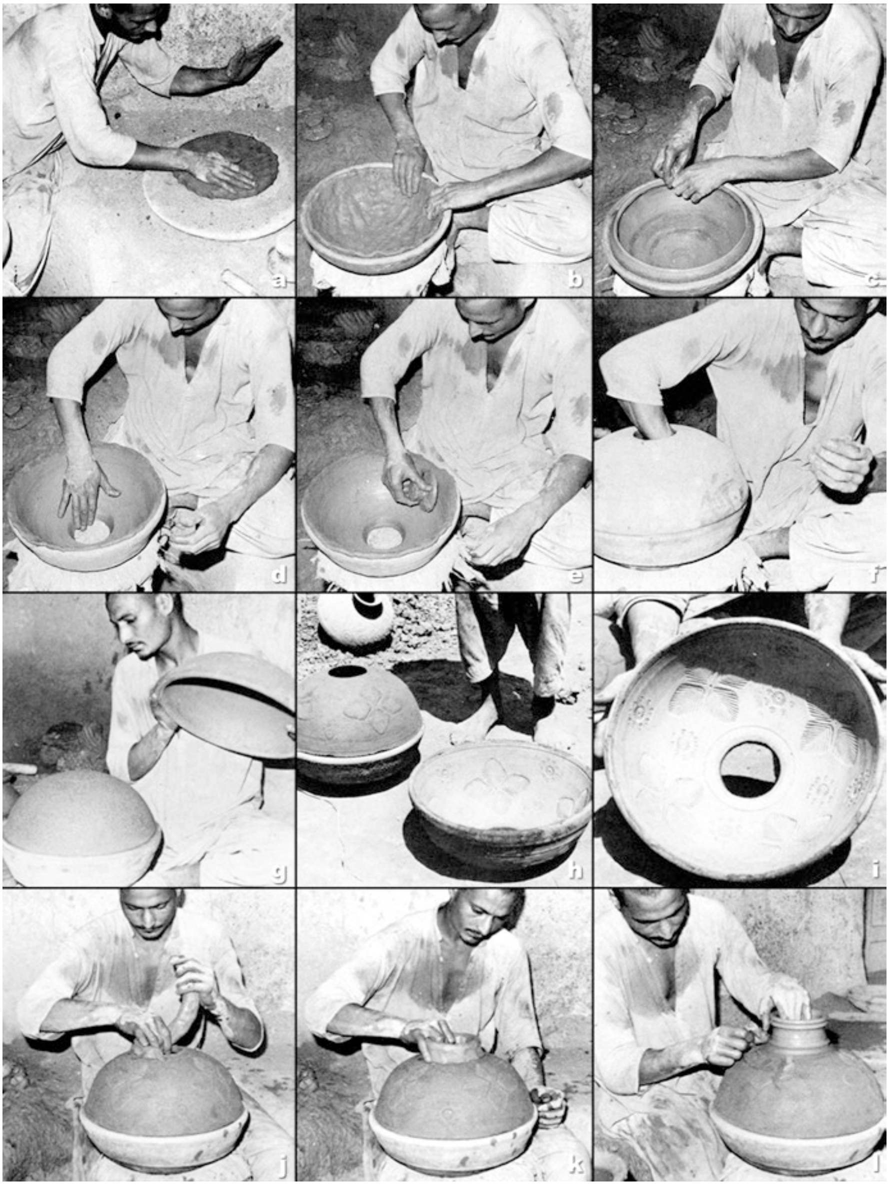

Fig. 2.39 Wheel molding of the lower and upper parts of a water jar (Pakistan, after Rye and Evans 1976, 222–223): (**a**) making a clay disc; (**b**) placing the disc inside the mold of the lower part of the recipient; (**c**) thinning the walls with RKE and leaving clay surplus from above the thinned walls; (**d**) and (**e**) thinning with RKE the walls of the upper part of the recipient whose opening has been cut; (**f**) turning the upper mold onto the lower mold and joining both parts with RKE; (**g**) demolding the lower mold; (**h**) and (**i**) demolding the upper mold; (**j**), (**k**) and (**l**) shaping with RKE the neck of the recipient placed on the wheel in the lower mold

Instruments: Turntable, wheel. In the Pakistani example, potters use the wheel molding technique with a foot wheel. However, the quantity of RKE for thinning a clay slab is much lower than the quantity required for wheel throwing and can also be produced with turntables.

Shaping Leather-Hard Paste with RKE

Trimming

Trimming consists in removing clay chips from leather-hard paste with a cutting tool (Fig. 2.40). This is carried out with RKE, at a fast speed, with the trimming tool held firmly by perfectly immobile hands. This gives the final shape to the recipient. During this operation, the outer surface of the base is regularized; the base, lower body junction is modified; the lower body is thinned; and the base profile is rounded.

Fig. 2.40 Examples of trimming: (**a**) trimming the rim of a large open recipient (New Delhi, India); (**b**) trimming the base of a water pipe (Uttar Pradesh, India)

Trimming involves first of all recentering the recipient dried to leather consistency on the rotary instrument. This centering must be precise or else the trimming hollows the walls on one side more than the other. If the upper part of the recipient is to be worked, it is positioned with the opening toward the top and secured to the wheel with clay pins. If the lower part is to be worked, it is positioned with the opening against the wheel. If the recipient has a narrow neck, it is secured on a trimming support (chuck), a hollow piece on which the narrow part of the recipient is placed, while the base and the lower outer part are worked. The trimming support is made according to the size and shape of the recipients. It can be in unfired clay. It is covered with a cloth once it has dried sufficiently. It can also be in fired clay (or nowadays in plaster) so that it can be used several times. The recipient is secured to the trimming support by clay pins, in the same way as the trimming support is secured onto the rotary instrument.

Active tools: Trimming tool; nowadays, these tools are in metal. Their profile varies depending on the degree of hygrometry of the paste.
Passive tools: Trimming supports (chucks).

Fashioning of Separate Elements: Handles, Spouts, and Feet

The separate elements are fashioned and then affixed on the recipient when it is wet or leather-hard (Fig. 2.41). On wet paste, the handles can be affixed directly onto the body or inserted in the body after hollowing or perforation. On leather-hard paste, the adhesion of the assembled elements is ensured either by incising the receiving part, which is then covered with clay slurry, or by adding small coils around the elements to be affixed, which are then spread out so that the elements can be joined to the body of the recipient.

The handles are obtained by discontinuous pressures. Depending on the shapes, they are obtained by modeling, rolling, or stretching. Handles modeled on wet paste are fashioned from a clay mass and can present very variable dimensions and forms; rolled handles are obtained by rolling a coil. Then, they are applied to the body of the recipient by discontinuous pressures. Stretched handles are obtained from a very wet pear-shaped clay mass. It is held in one hand and progressively stretched with the other by pressures exerted by the thumb and the index finger disposed in a ring. The mass is stretched to obtain a handle with a circular or rectangular section with an enlarged end which then becomes progressively narrower. Once the handle conforms to the required dimensions, it is cut with a rigid rod to separate it from the lump and then applied to the body of the recipient.

Spouts can be obtained by wheel throwing or modeling; once they reach leather-hard consistency, they are cut out depending on their form and the profile of the recipient wall.

Feet can be obtained by modeling or with RKE, either from a coil affixed on the recipient base or as an individual element.

Fig. 2.41 Fixing a handle: (**a**) double perforation of the wet body with the finger; (**b**) and (**c**) inserting the handle in the perforations; (**d**) application of two small coils for affixing the handle to the body (Michoacán, Mexico)

Fashioning Chaînes Opératoires

Altogether, 9 roughing-out techniques and 11 shaping techniques characterize ceramic fashioning techniques (Fig. 2.42). The latter are implemented with different methods, procedures, gestures, and tools and descriptions of these should reflect the diversity of fashioning *chaînes opératoires*. These are the result of a theoretically infinite number of combinations, for the fashioning phases and stages. Indeed, the different parts of a same recipient can be roughed out and preformed using several techniques and variable sequences which can begin by the base, the orifice, the upper, or the lower body. Examples of combinations are the roughing out and shaping of recipients with slabs and coils, molding and coiling, modeling by drawing and coiling, wheel throwing and beating, wheel throwing and hammering, molding and wheel coiling, wheel coiling and beating, etc. In addition, when a recipient includes assembled elements (spouts, handles, feet), the fashioning *chaînes opératoires* become longer, as they not only comprise the fashioning of the different constitutive elements of a recipient but also drying and assembling operations.

We find many examples of ceramic fashioning *chaînes opératoires* in accounts of African, Oriental, Asian, or American pottery traditions (e.g., Rye and Evans 1976;

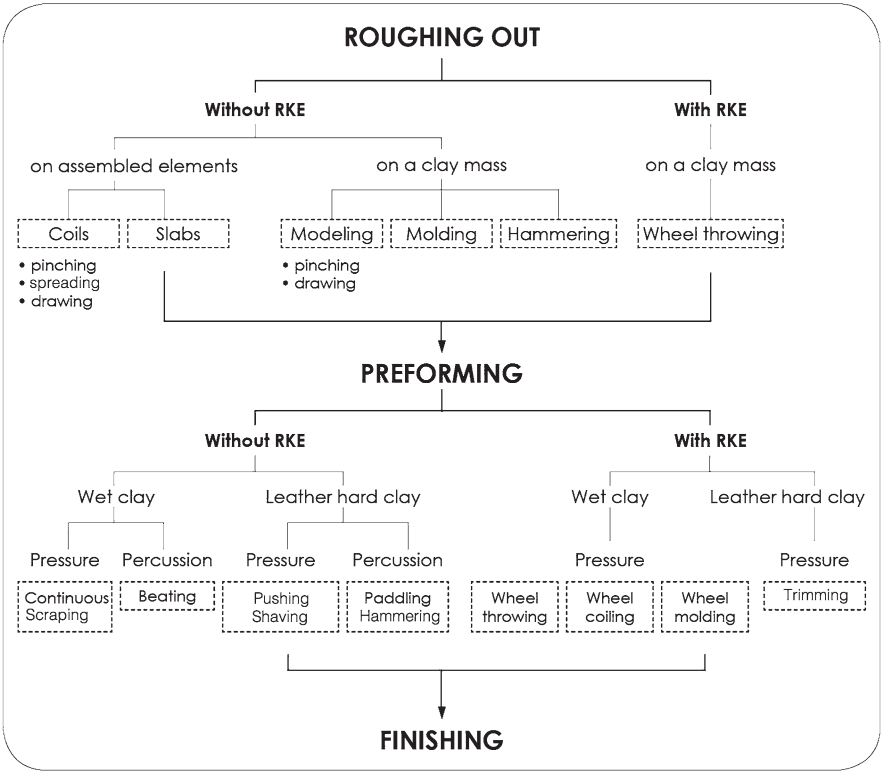

Fig. 2.42 Classification chart of the roughing-out and shaping techniques. Their possible combinations reflect the diversity of the *chaînes opératoires* observed nowadays in the world

Rostain 1991; Gosselain 2002; Gallay 2012; M'Mbogori 2015). Some of these *chaînes opératoires* have a name, showing that they were identified elements of cultural traditions. One such example is the *Tataki* tradition of Korean origin, which is characterized by the sequencing of the following techniques: wheel throwing the roughout, beating wet paste with a paddle and a stone anvil, shaping with RKE, drying to leather-hard consistency, paddling the preform still on the wheel (the wheel facilitates the pivoting of the recipient), drying, and finally, painting.

2.3 Finishing

Finishing operations are carried out after the shaping of the preform and before the surface treatments or decorative operations. They modify the superficial layer of the paste. Their main aim is to regularize the superficial layer of the walls.

Finishing techniques are classified according to two parameters (Fig. 2.43):

1. The degree of hygrometry of the clay material: either wet or leather-hard consistency. Three techniques can be differentiated on the basis of this parameter:
   - Smoothing wet paste
   - Smoothing leather-hard paste
   - Brushing leather-hard paste

     Once the clay is dry, no finishing operations can be carried out. Imperfections can be rectified by sanding with abrasives, but these episodic operations are not part of recurring sequences.
2. The type of pressure: discontinuous or continuous pressures depending on whether it is applied with or without a rotary movement.

The finishing of recipients can involve one or several techniques. In this latter case, either several techniques are used depending on which part of the recipient is worked or several finishing operations follow on from each other, each of which involves a different technique. In this way, the body of the recipient can be smoothed with a scraper, without a rotary movement, and the neck finished with a wet cloth and a rotary movement, or the inner body of the recipient can be smoothed while wet with a smoother and the outer body brushed when it reaches leather consistency and then smoothed with a wet cloth.

Finishing Wet Paste

Smoothing Wet Paste

Smoothing wet paste aims to regularize the superficial layer of recipient walls. It is carried out by rubbing the superficial layer of the paste with pressures applied by hand or with a tool. The plastic and non-plastic elements are aligned in the same direction as the movement of the tool.

Smoothing can be carried out with or without rotary movement (Fig. 2.44). In general, an active hand carries out the smoothing with internal or external pressures, while the other hand supports the inner or outer walls. In the case of molding, a single hand is active, and the inner or outer wall is supported by the mold.

Active tools: Smoothing tools can be soft or hard, manufactured or natural; we frequently observe the hand, cloth, and scrapers (smoothers).

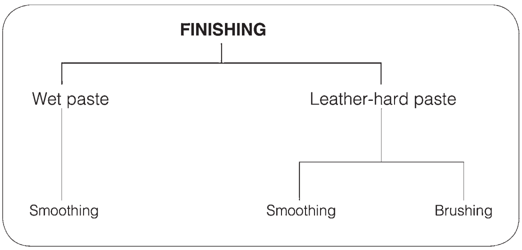

Fig. 2.43 Classification chart of the finishing techniques

Fig. 2.44 Examples of finishing wet paste: (**a**) smoothing with fingers (Experimental Center of Lejre); (**b**) smoothing the inner face of a recipient with continuous pressures; the rotation is provided by a hand-operated rotary device (Mali, ©A. Gallay)

Finishing Leather-Hard Paste

Brushing

Brushing consists in rubbing remoistened leather-hard paste with a rough tool (Fig. 2.45a). It is used on the outer faces of recipients in order to regularize them by moving clay paste and homogenizing thus the superficial layer covering the joints between assembled elements. Brushing pulls out tempers and brings them to the surface. It is followed by smoothing.

Active tools: Brushing tools; they can be natural expedient tools, for example, a cob of corn in Senegal (Gelbert 2003).

Fig. 2.45 Examples of finishing leather-hard paste: (**a**) brushing with a corn cob (Senegal, ©A. Gelbert); (**b**) smoothing shaved outer face with a wet piece of cloth (Uttar Pradesh, India)

Smoothing Leather-Hard Paste

Smoothing leather-hard paste consists in smoothing the remoistened paste with a soft tool (Fig. 2.45b). The smoothed surface may have been scraped, brushed, or shaved beforehand and is characterized by the pulling out of many surface grains and deep striations. The addition of external water makes the superficial layer viscous again. It is then spread out, by hand or with a soft water laden tool, over the whole surface of the recipient, so that it covers the striations or surface tempers in the case of prior shaving or brushing, with a fine layer of clay.

Smoothing leather-hard paste can be carried out with or without a rotary movement. In the latter case, the leather-hard recipient is repositioned and centered on the rotary instrument for smoothing with continuous pressures.

Active tools: Hand, soft tools (cloth, sponge, leather, etc.)

2.4 Surface Treatments

Surface treatments consist in transforming the inner and/or outer surface of recipients. They are applied to unfired leather-hard and dry pastes and to fired pastes. The transformation occurs by friction or coating. The aim can be utilitarian or both utilitarian and decorative (Rice 1996). Generally, surface treatments affect the permeability of the inner and/or outer surfaces of recipients (Schiffer 1988) and their resistance to abrasion. Their efficiency in ascending order is smudging, softening/burnishing/polishing, slip, texturing, organic, and siliceous coatings (Skibo et al. 1997). On cooking pots, they are conducive to a more progressive increase in temperature and a better resistance to thermal shocks (Schiffer 1990).

Surface Treatments by Friction

Surface treatments by friction are carried out on pastes with a degree of hygrometry on a continuum between "leather-hard" and "dry." The main effect of these treatments is to compact the superficial layer. Three main friction techniques can be differentiated: softening, burnishing, and shining. Softening corresponds to a friction action on leather-hard paste with a rigid tool and a continuous water input. Unlike the two other friction techniques, softening does not make the paste shine. Burnishing corresponds to a friction action on leather-hard to dry clay with a rigid tool and without water. Shining is comparable to burnishing but is carried out with a soft tool.

Softening

Softening consists in rubbing a leather-hard paste kept moist during the operation, with a hard tool (in stone or wood) (Fig. 2.46b). The aim is to spread the superficial layer, which has become viscous again, in order to fill in all the hollows, including the deep striations obtained during shaving or trimming operations, and thus to obtain a smooth and compact surface, silky to touch. The paste can be remoistened using wet hands or a wet soft tool or with a softening tool regularly immersed in water. The softened surfaces can be left natural – their aspect is compact and silky – or can then be burnished or coated.

Burnishing

Burnishing consists in repeatedly rubbing a hard tool against a slipped or non-slipped paste with dry or leather-hard to dry hygrometry (Fig. 2.46a, c). The aim is to make it shiny and compact. It results in compaction and an orientation of the clay

Fig. 2.46 Examples of surface treatments: (**a**) and (**c**) burnishing with a pebble (Manipur, India; Experimental Center of Lejre, Denmark); (**b**) softening with a piece of wood (Udaipur, Gujarat, India)

particles promoting light reflection, creating a shiny effect (e.g., Balfet et al. 1983; Rice 1987; Orton et al. 1993). The degree of gloss depends on a number of factors, including the degree of drying and the mineralogical composition of the clay (Shepard 1965). Before the paste is burnished, it can be remoistened and softened in order to obtain a perfectly smooth surface which then favors gloss. Re-humidification can also be used to obtain the required degree of hygrometry.

The terms burnishing and polishing have been the subject of much debate. Depending on the authors, burnishing and polishing describe on one hand different degrees of drying of the paste, leather-hard *versus* dry, leading to variable degrees of shine, and on the other hand, different degrees of intensity, with burnishing indicating a partial sheen characterized by shiny bands alternating with matt bands and polishing a uniform and covering shine (e.g., Rye 1981; Rice 1987; Arnal 1989).

It is important to recall here that the different degrees of drying of a paste are on a continuum. Depending on the ambient atmosphere, the same potter can work recipients with pastes of different consistencies in the same day without necessarily intentionally varying them. In addition, the degree of hygrometry is not the only factor determining the sheen. Depending on the paste, for the same hygrometry, friction can lead to more or less pronounced sheen. The correlation between burnishing *versus* polishing and degrees of hygrometry do not correspond to two different techniques from this point of view: the physical modalities of transformation of the state of the surface are the same.

As for the difference between burnishing and polishing, depending on whether the gloss is partial or total, these two operations reflect different intentions and time investments. Recipients can be burnished on the inner surface with rather sloppy gestures in order to render the paste compact and less permeable, which is a very different intention from a burnishing action over the whole surface with an aesthetic aim. But partial burnishing can also correspond to the desire to add a shiny decoration to a matt background.

It follows that we recommend the term “burnishing” for any rubbing operation aimed at making the paste shiny. “Polishing” implies that the sheen was obtained by adding a “polish,” in the same way as for a varnish (e.g., applying a glossy product such as oil to dry pastes or wax on fired clay).

The extension of burnishing (partial or total), its degree of sheen, and its position will be described in order to differentiate utilitarian burnishing from aesthetic burnishing.

Very different tools can be used for burnishing, but they are always rigid in order to compact the paste. The harder the tool is, the more micro-abrasion occurs, thereby increasing the shine.

Burnishing can be carried out with or without RKE. Burnishing with RKE involves centering the recipient beforehand on the rotary instrument.

Active tools: Burnishers (mineral or vegetal objects, hard plastic, etc.)

Shining

Shining is obtained by repeatedly rubbing a soft tool against a slipped or non-slipped dry or leather-hard to dry paste. The aim is to make the clay paste shine. This treatment has been referred to by different names depending on the tool used. As an example, the so-called patina treatment corresponds to shining with fleece (Lepère 2014).

Surface Treatment by Coating

The walls of recipients can be coated with clay materials, organic materials, graphite, siliceous materials, or carbon particles (smudging) (Fig. 2.47).

Fig. 2.47 Example of surface treatments: (**a**) slipping by soaking (Uttar Pradesh, India); (**b**) coating with organic material before firing (Senegal, ©A. Gelbert); (**c**) coating with clay slurry by wiping it on (Mali, ©A. Gallay); (**d**) coating with glaze on dry slipped and painted cooking pots, before firing (Uttar Pradesh, India)

Coating with Clay Materials

Coating with clay materials consists in coating the outer/inner face of a recipient with a layer of clay material. It includes clay coating, clay slurry, and slip.

Clay coating is a surface treatment aimed at covering wall surfaces. It is made of a thick grainy slip obtained by adding water to the clay paste. Clay coating can be applied to pastes with different degrees of hygrometry, from wet to leather-hard, but not too dry in order to avoid the risks of coating detachment during drying or firing; there are ethnographic examples of clay coating applied after firing (Heidke and Elson 1988). Clay coating is smeared on with soft or hard tools. This is applied in order to regularize and homogenize the surface by hiding any traces left by the roughing-out and/or the shaping operations (Roux 2017). It is also applied to create a grainy surface (adding in this case a non-plastic material such as sand). This latter case is referred to as stuccoing. The aim can be to diminish thermal spalling and cracking by protecting and/or reinforcing an outer surface intended to be exposed to thermal or mechanical shocks (e.g., cooking pots) (Schiffer et al. 1994, 208).

Clay coating differs from clay slurry which is a clayey material obtained from finely sieved clay material with the viscosity of "thick cream" and used for favoring the adhesion between coils.

When clay material is finely sieved and more water is added, it is called slip. It has a "liquid cream" viscosity. When it is mixed with oxides, it is colored. It is applied to the pottery in a fine layer. It is applied by soaking, pouring, or wiping it on with cloth or paintbrush to recipients with a degree of hygrometry varying from leather-hard to dry. The clay material must not be too dry to avoid problems of differential drying, including cracking during drying or detachment after firing. The slip gives a smooth and colored aspect to the pottery. It can then be burnished. The slip is an impermeabilizing coating which waterproofs porous pastes.

Most slips produce matt surfaces. However, there are slips that contain flux resulting in vitrification at low temperatures (around 900 °C). These vitrified slips waterproof the vessels and bring a certain hardness. The best-known example is the sigillata ware, as its composition has been extensively studied (Tite et al. 1982; Giorgetti et al. 2004; Gliozzo et al. 2004). Recently, vitrified slip was identified on ceramics from Southeast Asia dating from 400 to 200 B.C. (Bouvet 2012). The metal vitrified slip presents metallic shimmers produced by firing under a reduced atmosphere.

Active tools: Hand, soft and hard tools; application of clay slurry and slip by hand, with a cloth, by a paintbrush, or by soaking or pouring

Coating with Organic Materials

Coating with organic products takes place either before firing or after firing when the pots are still hot, in order to impregnate the paste as much as possible. These products can have an impermeabilizing or hardening effect and/or give a glossy aspect to the recipient. They are made from decoctions, macerations, or infusions of resin, bark, and leaves. They can also be made from food substances, like in Ethiopia where milk is applied to burning hot recipients to impermeabilize the surfaces or like in Guatemala where, for the same reason, the recipients are sprinkled with the water in which corn has soaked.

Several examples of coating with organic materials: in Senegal, Gelbert indicates that after the pot dries and before firing, the potter applies an organic coating on the inner wall of the pot to reduce the porosity of the walls. The coating is made up of dried, crushed, sieved and water-soaked baobab leaves (Gelbert 2003). In Cameroun, Livingstone-Smith gives the example of a decoction of bark mixed with clay and applied by hot sprinkling (after firing) in order to reinforce the recipients, according to the artisans (Livingstone Smith 2001a). In Amazonia, Rostain indicates the use of a thick layer of gum or of bark macerated in cold water to protect them from the corrosive effect of the drinks they contained (Rostain 1991). He also mentions the application of vegetal varnish (resin from trees) on still hot pottery intended to impermeabilize the walls of the recipients. The resin is rubbed against the hot walls and melts upon contact. (Coutet 2009)

Active tools: Application by hand or with tools in diverse materials.

Coating with Graphite

Coating with graphite consists in applying a graphite coating (variety of carbon) to the paste before firing, either as a powder diluted in water or in solid form (by friction). After burnishing, the gray-black surface color takes on a sparkling shining aspect.

Active tools: Hand, soft tools

Coating with Silica: Glaze

Glaze is a vitrified coating intended to render a porous paste impermeable and/or to be used as decoration. It is applied by pouring, soaking or with a brush, onto perfectly dry recipients (in the case of recipients fired at temperatures inferior to 1000 °C) or onto recipients fired once and which are called biscuits (in the case of clay fired at high temperatures).

Glaze is mainly made up of silica and flux used to lower the melting point and thus to favor the adhesion of glaze on recipient walls and the formation of the vitreous network. There are three main families of flux: lead oxide, alkaline flux (potassium carbonate and sodium), and boron oxide. Traditionally, lead glaze is applied to clay pastes, particularly in the Mediterranean region, whereas alkaline glaze is generally used for siliceous clays (frit clays), which are specific to the Near and Middle East (Porter and Castinel 2011).

The color of the glaze depends on the coloring oxides and flux. For example, in an alkaline glaze, copper gives a turquoise color, while the same copper in a lead glaze gives a green color. The glaze can be opacified, using, in particular, tin white (also called tin ceruse), which results in tin glaze.

The first glazes appear during the third millennium B.C. in Mesopotamia (Bouquillon et al. 2007).

Smudging

Smudging is a process consisting of surrounding the recipients with smoke (Rice 1987). The aim is to cover and impregnate the clay surface with carbon particles in order to obtain a black or gray, sometimes iridescent color, and/or to impermeabilize them (Schiffer et al. 1994). Smudging is practiced, either at the end of, or upon completion of a first firing, or in a decorative perspective (to obtain decoration in reserve), during a second firing. Propitious temperatures for smudging range between 400 and 700 °C.

Different processes exist:

- In open firing: the pottery is taken from the hearth while incandescent and placed on the combustible material (e.g., straw, pine needles), which is set on fire and gives off smoke in contact with the pottery; or else the combustible material is added at the end of firing to create smoke and blacken the pots (Gallay 2012).
- In the kiln: smoke materials are introduced at the end of firing, the openings are plugged, and sometimes the embers are removed.

2.5 Decoration

Decorative techniques are divided into surface decorations and impressed or relief decorations. These different decorations can be combined on a same vase.

As their name indicates, decorative techniques are intended to decorate recipients. However, they can also play a functional role. Determining this involves taking into consideration the technique and the position of the decoration on the recipient. For example, incised decorations on the inner bases of recipients can have a grating function (example in South America, Europe, and Asia). Relief decoration on outer walls can correspond to reinforcement or prehensile elements.

Surface Decorative Techniques

Painting

Painting is the main surface decoration technique. It can be made from a mixture of fine clay, oxides, and pigments, using the same recipe as slips or by directly diluting oxides and pigments in water. The paints are applied in continuous or discontinuous movements before or after firing using tools (e.g., brushes) (Fig. 2.48). When they are applied before firing, they are applied to previously dried slipped or non-slipped surfaces. Once dry, they can then be burnished.

Decoration referred to as "reserve decoration" or "negative decoration" consists in preserving the motifs or the background from the penetration of coloring (paint or carbon by smudging) (Fig. 2.51d). This can be carried out following different procedures: either the motifs are outlined when the paint is applied (with or without a pattern), or the motifs are outlined by scraping a removable material applied to all or part of the recipient from the dry clay (e.g., slip), or a removable material is applied on the motifs which are then preserved from the application of coloring. In the first two cases, if firing is oxidizing, the motifs are the same color as the natural surface or slip applied beforehand. In the third case, if only one firing was carried out in an oxidizing atmosphere, the motifs are preserved from the oxidizing process and are dark; if there are two firings, the removable material is placed on the motifs after the first firing, which is followed by smudging during the second firing (see example below); the motifs are thus protected from smudging and are pale.

Example of reserve decoration in Michoacán (Mexico, 2013). The recipients are fired in updraft kilns. They undergo a first firing in an oxidising atmosphere. Then the motifs are drawn with paintbrushes impregnated with removable materials (clay mixed with wax). The recipients are fired a second time, for a much shorter duration. The aim is to reach about 500°C to set the smudging (about 3 hours); at the end of firing, the embers are removed and replaced by firebrands in order to surround the recipients with smoke. Once the recipients smudged, the removable material is scraped with a wooden tool. The motifs appear in a pale color, contrasting with the dark aspect of the background.

When, conversely, the intention is to obtain dark motifs, the removable material is coated on the background to be preserved from smudging. After smudging, the motifs are dark in color on a pale background.

Fig. 2.48 Examples of surface decoration: (**a**) and (**b**) painting applied in continuous movement with a horsehair paintbrush (Uttar Pradesh, India)

The pigments used in the paints are coloring substances in the form of powder before being mixed with a liquid. They are of mineral or organic origin. Mineral colorings include iron oxides, which produce colors ranging from yellow (greenish to orangey) to different shades of red-brown, manganese oxides for black, metamorphic rocks such as lapis lazuli for blue, or rocks such as kaolinite for white. Organic pigments are extremely diverse and vary depending on the region.

For example, pigments of organic origin can include crushed bones for a white color, like in Senegal where the paint is applied after the firing of the pot (Gelbert 2003); or diverse vegetal ingredients for different colors, like among the Kali'na potters in Guyana. These include seeds, bark, the leaves from a liana shrub mixed with euphorbia leaves, sweet potatoes, manioc. Paint is applied, after firing, using a paintbrush made with a stick and long feathers from the Agami heron. (Coutet 2009)

The oxides or pigments can come from very far away. Arnold signals cases where distances can be as high as 800 km (out of 36 cases, 11 cases involve distances of more than 50 km) (Arnold 1985).

Active tools: Paintbrushes made from hair, fur, feathers, and plant fibers; fingers

Decorative Hollow and Relief Techniques

Decorative hollow and relief techniques are classified according to the physical methods used to obtain the decorations. These methods include the principle of the application of forces, gestures, the degree of hygrometry of the clay material, and the tools used to implement them, as their geometric properties directly affect the decorative effect.

The Principle of the Application of Forces This principle differentiates five main families of decorative techniques: hollow techniques including decoration by impression, incision, and excision and relief techniques including decoration by the application of separate elements and surface modeling.

Gestures The gestures are described based on the movements exerted to apply forces to the clay material. These movements depend on the way the tool is set in motion:

- Either the movements are exerted discontinuously, by successive movements.
- Or the movements are exerted continuously, without or with the rotation of the recipient.

Degree of Hygrometry Decoration can be implemented during the different stages of drying and transformation of the clay material: when it is wet to dry and all the intermediary states including leather-hard.

Tools The tools used to implement the decorative hollow and relief techniques mainly comprise active tools in extremely diversified materials (wood, metal, bone, ceramic, stone, basketry, etc.) and with very varied shapes. They include, for example, manufactured cylinders, roulettes, cords, spatulas, combs, awls, rods, sculpted paddles, blades, or natural objects found in the mineral or vegetal world (shells, plants, seeds, etc.).

The main passive tools are the molds used for stamped impression. In theory, passive tools could also have existed for other types of impression. As an example, rolled impression can be obtained by rolling the recipient on a support (and not by rolling the tool on the recipient).

Decorative Techniques by Impression

Impression consists in obtaining a decoration by pressing a hard object against the clay paste or by pressing the clay paste against a hard object. According to the classification proposed on the CerAfIm site (Gallin 2013) – a site aiming to promote the standardization of the description of decorative techniques –, it can be implemented with different movements. We distinguish five impression techniques, the first four of which are applied to wet paste, while the last is applied to leather-hard paste (Fig. 2.49).

Fig. 2.49 Examples of decor by impression: (**a**) tilted impression (Uttar Pradesh, India); (**b**) simple impression (Uttar Pradesh, India); (**c**) rolled impression (Mali, ©A. Gallay); (**d**) stamped impression (Uttar Pradesh, India); (**e**) paddled impression (Myanmar, ©A. Favereau)

Simple Impression

This consists in applying a tool to the paste without moving it. It can be perpendicular or oblique depending on the tilt angle of the tool. According to CerAfIm, simple impression can be repeated to produce spot patterns (arrangement of more or less organized elements on a restrained surface) or line patterns (linear, arc, or sinusoidal elements) or can cover larger surfaces.

Tilted Impression

This consists in tilting the tool on the paste from one end to the other. Simple or complex patterns can be obtained with this technique depending on how the tool is tilted.

Rolled Impression

This consists in printing a decoration by rolling a cylindrical shaped matrix on the surface to decorate. The impressions can be extremely variable depending on the roulettes used and the organization of gestures. There are many examples of these impressions in Africa (e.g., Virot 2005; Haour et al. 2010; Gallin 2011; Gallay 2012).

Stamped Impression

This consists in pressing the wet paste against a support decorated with patterns, which can be a mat or a mold decorated with hollowed patterns. In the first case, the decoration obtained is linked to a shaping operation. For example, if roughing out consists in hammering on a woven mat and if shaping does not affect the lower part or even the body of the recipient, this can present a base and body with decoration obtained by stamped impression, which may then be deliberately conserved or not (Gallay 2012).

Paddled Impression

This consists in beating the outer surfaces of leather-hard preforms with paddles sculpted in wood or around which cords are wrapped. The repeated movement of the paddle on the body produces impressions that can develop on the whole body of the recipient. The layering of impressions is also possible. There are many examples of paddled impression in Southeast Asia and Oceania (e.g., Frimigacci 1981; Wu 2012).

Decorative Techniques by Incision

Incision is the action of drawing patterns with linear movements. If we consider the state of the paste on which the incisions are made and the movements applied to make the incisions, we distinguish four incision techniques, the first three on unfired clay and the fourth on fired clay (CerAfIm website).

The incision of patterns on unfired clay can take place before or after slipping and/or painting. In the first case, the incisions can serve to delimit the zones to be filled with coloring. When the incisions are made on leather-hard to dry paste, the surplus is removed with a soft tool (e.g., cloth). In the case of burnishing of the recipient, the incisions made beforehand are generally redrawn, as burnishing tends to make the incisions close in.

Simple Incision

This consists in making an incision on wet/leather-hard/dry paste following a continuous or discontinuous linear movement (Figs. 2.50a and 2.51a).

A series of parallel concentric incisions made with a continuous linear movement gives a "combed" or "grooved" surface.

Pivoting Incision

This consists in making an incision on wet/leather-hard/dry paste following a discontinuous pivoting movement, with an instrument with at least two teeth: one end serves as a pivot, whereas the second incises the clay paste in a circular arc, like a caliper (website CerAfIm).

Incision on Dry Clay or Scraping

This consists in scraping the dry clay paste with a cutting tool or an abrasive with discontinuous linear movements, in order to obtain a coarse grainy surface. The partial scraping of previously slipped, burnished, or painted pottery can be used for a decorative effect.

Incision on Fired Clay or Engraving

This consists in engraving the decoration on fired pottery, with discontinuous linear movements. The engraving of previously slipped, burnished, or painted pottery can be used for a decorative effect.

Fig. 2.50 Examples of decor by incision, excision, and the application of separate elements: (**a**) simple incision (Mali, ©A. Gallay); (**b**) excision and incrustation with chalk (Mali, ©A. Gallay); (**c**) application of a clay band (Mali, ©A. Gallay); (**d**) openwork pottery (Mali, ©A. Gallay)

Decorative Techniques by Excision

Decoration by excision consists in shaping hollowed or relief decorations by removing material from leather-hard paste (Fig. 2.51b). The hollows obtained by excision are left as they are or filled in with plastic (different clay materials) or non-plastic (metal, wood, bark, shell, glass) elements (Fig. 2.50b). In this case, we refer to decoration by incrustation and incrusted pottery.

When the thickness of the wall is completely hollowed, the pottery is said to be with openwork design or openwork pottery (Figs. 2.50d and 2.51c).

Fig. 2.51 Surface treatments and decoration (Michoacán, Mexico): (**a**) incising a flower design on a red slip area; (**b**) shaping relief flower design by excision; (**c**) painting an openwork pottery; (**d**) reserve decoration obtained by both application of pastilles made out of clay and wax and smudging; once removed, the circular motifs appear in a pale color, contrasting with the dark aspect of the background

Decorative Techniques by the Application of Separate Elements

Decoration by the application of separate elements is carried out on wet paste or paste subject to a first drying (Fig. 2.50c). The elements are applied to the surface of recipients by digital pressure or with spatulas. These elements can be very diversified: cordon, pastille, knob, mamelon, and complex floral decoration. According to the definitions of Cauliez (2011), the knob is defined as a more or less circular protuberance, the cord as a relief band of clay, the mamelon as a small relief element with an oval shaped base, and the pastille as a small protuberance with a circular, oval, or flattened rectangular base. Pastillage is the action of applying series of generally circular elements of small dimensions (Balfet et al. 1983, 125).

Decorative Techniques by Modeling

Decoration by modeling consists in pinching the wet paste from the outer surface or pushing it from the inner surface to create different forms of relief, such as a pastille (in which case we refer to embossed pastillage). It also includes deliberate deformations, such as repeated depressions, to create a relief surface.

2.6 Drying

Drying is an integral part of the manufacturing process. It must be progressive in order to avoid tensions, deformations, and cracks. It is particularly difficult for thick objects which tend to dry differentially and rapidly on the surface and slowly deeper down, which causes cracks to form generally on the base where they are S-shaped. In order to ensure progressive drying, the recipients are manipulated throughout the process, with a first phase in the shade, when retraction is highest, and a possible second phase in the sun, for the complete evaporation of water. Large objects can be turned upside down several times to optimize the drying of the base. Recipients with separate elements such as handles can, in addition, be covered for some time to favor progressive drying, thereby enabling the separate element to remain joined in spite of a difference in hygrometry with the body of the object.

The duration of drying depends on the size and the thickness of the walls of the object, the temperature, air humidity (hygrometry), and ventilation. It can take several days. Good drying is a necessary prerequisite for successful firing.

2.7 Firing

Firing is an essential stage in the manufacturing process as the recipients acquire their irreversible physicochemical properties and characteristics during this stage: the paste loses its plasticity, and acquires new cohesion, and its definitive porosity, hardness, and color. The properties acquired during firing do not only depend on the type of clay but also on the thermal characteristics of a firing (its thermal profile): the firing temperatures, the heating rate, the time of exposure to temperatures (the soaking time), and the firing atmosphere. These different parameters are presented below. Then the two main firing techniques are described, firings where the objects to be fired are in direct contact with the fuel and firings where the objects are separated from the fuel.

Firing Parameters

Temperatures

Generally, the paste is irreversibly transformed into fired clay at temperatures of more than 400 °C, and firing is complete at temperatures of 650–700 °C. We refer to low temperatures when firing temperatures are lower than 900 °C and high temperatures when they are above 900 °C.

Heating Rate and Soaking Time

The result of firing not only depends on the temperatures but also on the heating rate and the soaking time. The rise in temperature corresponds to the combustion stage during which the fire is fuel fed. The soaking time corresponds to the period during which the temperature is at its highest before falling.

Firing Atmospheres

During firing, reducing and then oxidizing atmospheres follow on from each other. Combustion corresponds to the reducing atmosphere, which consumes a lot (but not all) of the oxygen present in the hearth and which is rich in carbon monoxide, whereas the oxidizing atmosphere corresponds to the post-combustion phase during which the atmosphere is rich in oxygen again and thus becomes oxidizing.

For pottery firing, we refer to oxidizing or reducing firing (e.g., Picon 1973; Echallier 1984; Rice 1987; D'Anna et al. 2011).

Oxidizing firing is firing where, in spite of the reduction phase during the rise in temperature when the combustible requires a lot of oxygen, the free post-combustion oxygen favors the oxidization of the paste, particularly of the organic and ferrous materials. Pottery fired in an oxidizing atmosphere is pale in color, due to deoxidizing and decarburization by post-combustion supplies of oxygen, with the iron oxides preserved as ferric oxides.

Reducing firing is firing "with a reduction phase" that is partially deprived of oxygen, not only during the rise in temperature but also during the post-combustion period. A reducing atmosphere can be created during post-combustion by reducing the supply of oxygen, for example, by blocking the air supply in the firing chamber or by adding combustible in order to generate a lot of smoke and surplus carbon due to insufficient oxygen. Reducing firing can also be obtained by placing the recipients in closed containers. Pottery fired in a reducing atmosphere is dark in color, gray to black, with the iron oxides transformed into ferrous oxides.

Oxidizing and reducing firing can be obtained by open and kiln firing. In addition, the same recipient can undergo oxidizing and reducing firing. This is the case for recipients piled on top of each other, with the opening against the base; the interior is deprived of oxygen and is thus black, whereas the exterior is red.

Firing Techniques

Two main families of firing techniques are distinguished: firing where the recipients are in contact with the fuel and firings where the recipients are not in contact with the fuel. The former are often associated with low maximum temperatures, fast heating rates, and short soaking times and the second with high maximum temperatures, slow heating rates, and long soaking times, leading to a better firing of the pastes. For these reasons, the latter were considered for a long time to represent progress in the control of fire. However, these positions have been nuanced by ethnoarchaeological investigations (Gosselain 1992; Livingstone Smith 2001b).

Firings with Contact Between Recipients and the Fuel

These firings comprise open firings and enclosed firings. In all cases, the general principle is the same. The recipients are in direct contact with the fuel on which they are either directly or indirectly placed. In the latter case, they can be placed on small supports, such as sherds. A layer of fuel partially or completely covers them. For this reason, the manufacture of glazed pots with this type of firing is very rare.[5]

Open Firing

Open firing is still widely used today (America, Africa, Asia), which facilitates the description of the main variants. This type of firing is used for very small productions (one pot), as well as for very large productions (several thousand pots).

The temperatures attained with open firing generally range between 600 and 900 °C. In some cases, temperatures reach about 1000 °C.

Open firing includes firing on fuel structures (e.g., bamboo wattle), on heaps (on horizontal ground), in depressions, and in pits (Figs. 2.52, 2.53 and 2.54). There are many variants depending on the fuel used; how the ceramics are arranged; the presence of insulation for maintaining the heat; the type of materials used for the insulation (sherds, clay materials, metal sheet, etc.); the oxidizing or reducing firing atmosphere; the methods of lighting the fire, which can involve one or several hearths before or after the layout of the firing structure;[6] the methods of air flow which are determined by the arrangement of the recipients (central, radial circulation, etc.); or the methods of fuel supply (continuous supply or not). Depending on these variants and the size of the structure, the fire spreads quickly or slowly, and combustion lasts for several minutes to several hours. According to ethnographic data collected in Africa, for the same fuel and structure size, the duration of firing without insulation is shorter (from 20 to 40 min) than for firing with insulation (from 60 to 114 min), and the duration of firing in a heap (from 20 to 60 min) is shorter than for pit firing (from 40 to 114 min) (Gosselain 1992). As for the fuel, all things being equal, straw-fed firing is much faster than cow dung-fed firing (D'Anna et al. 2011), as the latter also presents the advantage of keeping its original volume at the ember stage, thereby protecting the fired objects from sudden cooling.

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[5] An exception has been observed in Guatemala: Reina and Hill (1978, 86) cited in Rice (1987, 55).

[6] Lighting the fire before the arrangement of the structure consists in organizing a bed of embers on which the recipients or a bed of fuel are placed.

Fig. 2.52 Open firing in depression: (**a**) and (**b**) dung patties and wooden dust are laid down in a depression covered by a plastic sheet; (**c**) recipients are piled to form a chimney; (**d**) the recipients are covered with cow dung patties; (**e**) the fuel placed at the bottom of the chimney is lighted; (**f–h**) the open firing is covered successively with dung patties, straw, and wet clay (Dibai, Uttar Pradesh, India)

Fig. 2.53 Firing on bamboo wattle (Leyte island, Philippines). After their pre-firing (**b**), the potteries are laid on racks made of bamboo poles against which bamboo poles are placed vertically (**a**). The firing lasts less than 20 min. The potteries are removed from ashes with long bamboo poles (**c**)

Firing is followed by an equally variable cooling time, depending on whether the recipients are removed cold or red-hot. When they are removed cold, cooling time varies from between 12 and 24 h.

Note that for open firing, recipients can undergo pre-firing. The aim is to limit the heating accidents that can occur during the increase in temperature. Pre-firing consists in heating each recipient before firing by exposing them directly to a source of heat (e.g., a piece of burning wood placed in the recipient, for about 30 min). It is used for firing with combustibles that burn fast (Fig. 2.54). It is also used to accelerate the drying process before firing.

Fig. 2.54 Pre-heating and open firing: (**a**) pre-heating recipients placed on a layer of ashes; (**b**) after the recipients have been covered with cow dung patties, pine bark, and wood, the structure is covered with long dried herbs; (**c**) the firing is refueled after 7 min; (**d**) the pots are removed from the firing after 2 h (Michoacán, Mexico)

Description of open pit firing in the North of India (Fig. 2.52). Firing takes place in Dibai (district of Bulandshar, Uttar Pradesh, 2008). In order to ensure that the pottery lies on dry ground even after recent rains (the month of July is the monsoon period), plastic sheeting is first of all laid onto the ground and covered with straw. A first layer of dried cow dung patties mixed with straw is then laid out. Sawdust is sprinkled over the patties. In the centre, four previously fired potteries are laid out in a square. Pieces of the cow dung patties are placed in the centre of the square. Then unfired ceramics are piled onto the four fired ceramics to form a chimney. Cow dung patties are placed all around them, and a first row of ceramics is positioned on them, piled one on top of the other. Then a row of patties lying on their side is arranged, followed by another row of pottery. The firing pit is progressively filled from the centre towards the exterior, following this pattern, where rows of pottery alternate with rows of dung patties. The last exterior layer is made up of cow dung patties piled one on top of each other and not placed on their sides. At this stage, the upper part of the firing is sprinkled with sawdust; the fuel placed at the bottom of the chimney is lighted by placing pieces of incandescent cow dung there. The upper part is then covered with dung patties, and the whole pile is covered with straw. This is then coated with wet clay material for keeping the heat. In India, several thousand recipients can be fired in piles or pits. Firing lasts for about six hours (time to reach the maximum temperature), and the pottery is removed after 12h to 24h of cooling (example of firing beginning at about 10:00 in the morning, incandescent combustible at about 16:30 and removal of the pottery the following morning at about 9:30).

Enclosed Firing

Enclosed firing (also called furnace, Rice 1987; Gosselain 1992) differs from open firing by the presence of a built structure, which can block a slope or be closed (circular, rectangular) and surround a flat space or a shallow depression. The enclosure can be made of unfired bricks, stones, or bricks (Fig. 2.55). It has an opening or a series of openings at ground level for lighting the fire. The advantage of enclosed firing is to limit the effects of wind, which cause many firing accidents, and to reduce the surface of temporary insulation of the recipients.

Enclosed firing can be open or closed, that is, with or without permanent cover. Examples of enclosed firing with structures built of adobe and closed by a dome are observable at the present time in South America (example in Ecuador) and in Asia (examples in Thailand and Laos).

Variations in fuel, temporary insulation and firing time are the same as those described for open firing.

The capacity of enclosed firing can vary considerably, from 20 up to 1000 recipients (case in India).

Firing Without Contact Between Recipients and the Combustible

This category of firing combines all the kilns with a combustion chamber (also called firebox), an area for loading the combustible, and a firing chamber where the recipients are stacked. The different types of pottery kilns are subdivided on the basis of the distribution of heat. We distinguish between:

- Direct flame kilns: the flames go through the firing chamber; this is the case for vertical or horizontal updraft kilns.
- Indirect flame kilns: the flames are separated from the firing chamber by a mid-height partition; they are guided toward the firing chamber vault and are then turned down by a chimney which begins at the base of the firing chamber; the recipients are placed on floors that can be temporary ceramic bars leaning against the walls and piled on top of each other. As the flames do not go through the firing chamber, firing is more uniform than in direct flame kilns (Rye 1981, 104).
- Radiant heat kilns: direct contact with the flames is replaced by the circulation of heat in tubes built into the kiln, which ensure homogeneous heat distribution throughout the firing chamber.[7]

In this manual, we only describe present-day direct flame kilns, namely, vertical and horizontal updraft kilns, as this type of kiln corresponds to those known for the period preceding Antiquity. The temperatures reached in these types of kilns are

[7] Example of the tubular Roman kiln; Brongniart (1977).

Fig. 2.55 Enclosed firing: (**a**) a semicircular wall made of fired bricks block a slope; (**b**) the recipients are placed on a bed of straw and then covered successively with straw and branches; (**c**) the structure is coated with wet clay; (**d**) the firing starts from an opening made in the middle of the semicircular wall and is fueled with branches; it lasts around 5 h and the cooling lasts around 12 h (Andhra Pradesh, India); (**e**) enclosed firing with multiple openings (Pachpadra, Rajasthan, India)

between 850 and 1000 °C. Fire bricks that can resist temperatures of more than 1000 °C with no major modification of their physicochemical properties are used in these kilns.

Vertical Updraft Kiln

The vertical updraft kiln consists of a lower part, the combustion chamber, and an upper part, the firing chamber, where the pots are stacked (Fig. 2.56). These two chambers are separated by a perforated floor – with holes, spokes, etc. – made of diverse materials, such as earth, brick, or metal, which can rest upon one or two pillars or on lateral supports. The fuel is introduced into the combustion chamber through one or several openings. The heat rises vertically, from the combustion chamber toward the firing chamber.

The firing chamber presents many variants. It can be open or enclosed by a wall. In the first case, there is no wall. A floor separates the combustion chamber which is dug into the ground, whereas the recipients are stacked on the floor and possibly protected by a canopy. In the second case, the firing chamber is built above the firing box; it is circular, oval, square, or rectangular in shape. Firing chambers can be covered with temporary or permanent insulations. In the first case, the cover is formed most often by ceramic sherds, which may or may not be covered with organic material coated with wet earth, like for open firing. However, the cover can be formed by temporary brick domes. When it is permanent, it presents a removable loading window.

Pottery stacking methods in kilns are variable. Small pieces of fired or unfired ceramic paste of variable size and shape may be used to steady the vessels to be fired. For glazed ceramics, in order to prevent the pottery vessels from touching one another and sticking together on account of their meltable coating, pins are used as supports. These are generally triangular-shaped or tripod-shaped elements in fired clay.

Horizontal Updraft Kiln

Unlike the vertical updraft kiln, the horizontal updraft kiln is characterized by the horizontal direction of heat. The combustion chamber presents horizontal openings onto the firing chamber situated at the same level. The combustion chamber can be open or built. Like for vertical updraft kilns, insulation can also be temporary or permanent.

Fig. 2.56 (continued) situated at the bottom of the firebox (**e**). The number of pots fired at the same time depends on the dimensions of the structure. The firing time is 5 h, the cooling time, around 12–24 h. The maximum temperature is 850–900°. The life duration of a kiln is around 10 years

Fig. 2.56 Vertical updraft kiln (Rajasthan, India). The kilns are in fire bricks coated with clay material. They are circular in shape and consist of two chambers, the combustion and the firing chambers, separated by a floor made of metallic bars (**a**) or a perforated floor (**b**) resting on a central pillar. In the firing chamber, the bigger recipients are placed below and the smaller pieces above. The potter, helped by family's members, loads them from the opening of the firing chamber (**c**) and (**d**). The recipients are covered with shards (**e**). The fuel is loaded by an opening

Properties of Open Firings and Kilns

Ethnoarchaeological investigations, with several dozens of records of temperatures with thermocouples, as well as experiments, have shown that the thermal profiles of open firing and kiln firing overlap (Gosselain 1992; Livingstone Smith 2001b; Thér and Gregor 2011) (Table 2.4).

Indeed, based on these investigations, open firing can last for several dozen minutes to several hours and can reach temperatures ranging from 550 to 1000 °C, with heating rates ranging from several degrees per minute to 120 °C/min. Kiln firing can last between 1 and 6 h and can reach temperatures ranging between 650 and 1000 °C, with heating rate of less than 20 °C/min. The duration of soaking time at more than 700 °C is comparable in both cases and can last for about 20 min.

We can add that the hardness of the ceramics is comparable for open firing and kiln firing, as long as they are exposed to heat for a sufficiently long period of time.

The main technical differences between open firing (with or without walls) and kiln firing are illustrated by firing accidents: the risks are higher for open firing due to bad weather conditions (wind, rain), which can destroy whole loads at any time (Fig. 2.57).

Table 2.4 Comparative data on open firing and kilns

Firing structure	Duration to reach maximum temperature	Heating rate	Time of exposure	Duration of firing	Maximum temperature
Pit firing without insulation	40 min	Between several degrees per min and 120 °C/min	Above 700 °C, between 1 and 20 min	Between 20 min and several hours	Between 550 and 1000 °C
Pit firing with insulation	114 min				
Bonfire without insulation	20 min				
Bonfire with insulation	60 min				
Kiln	259 min	Less than 20 °C/min	Above 700 °C about 20 min	Between 1 and 6 h	Between 650 and 1000 °C

After Gosselain (1992) and Livingstone Smith (2001b)

Fig. 2.57 Open firing in depression and firing accident due to gusts of wind (Dibai, Uttar Pradesh, India)

References

Amiran, R., & Shenhav, D. (1984). Experiments with an ancient potter's wheel. In P. M. Rice (Ed.), *Pots and potters. Current approaches in ceramic archaeology* (pp. 107–112). Los Angeles: Institute of Archaeology, University of California.

Arnal, G.-B. (1989). *Céramique et céramologie du néolithique de la France méditerranéenne*. (Mémoire du Centre de recherche archéologique du Haut-Languedoc 5). Lodève: Centre de recherche archéologique du Haut-Languedoc.

Arnold, D. E. (1985). *Ceramic theory and cultural process*. Cambridge: Cambridge University Press.

Arnold, D. E. (2005). Linking society with the compositional analyses of pottery: A model from comparative ethnography. In A. Livingstone Smith, D. Bosquet, & R. Martineau (Eds.), *Pottery manufacturing processes: Reconstitution and interpretation* (pp. 15–22). BAR International Series 1349. Oxford: Archaeopress.

Arnold, D., & Bourriau, J. (1993). *An introduction to ancient Egyptian pottery* (Sonderschrift Deutschen Archäologischen Institutes. Abteilung Kairo 17). Mainz am Rhein: P. von Zabern.

Arnold, P. J., III. (1991). *Domestic ceramic production and spatial organization: A Mexican case study in ethnoarchaeology*. Cambridge: Cambridge University Press.

Baldock, J. A., & Skjemstad, J. O. (2000). Role of the soil matrix and minerals in protecting natural organic materials against biological attack. *Organic Geochemistry, 31*, 697–710.

Balfet, H. (1984). Methods of formation and the shape of pottery. In S. E. Van der Leeuw & A. C. Pritchard (Eds.), *The many dimensions of pottery. Ceramics in archaeology and anthropology* (pp. 171–201). Amsterdam: Universiteit van Amsterdam.

Balfet, H., Fauvet-Berthelot, M.-F., & Monzon, S. (1983). *Pour la normalisation de la description des poteries*. Paris: Editions du CNRS.

Bergaya, F., Theng, B. K. G., & Lagaly, G. (Eds.). (2006). *Handbook of clay science* (1st ed.). Oxford: Elsevier Science.

Bernstein, N. A. (1967). *The coordination and regulation of movements*. London: Pergamon.

Blanco-Canqui, H., & Lal, R. (2004). Mechanisms of carbon sequestration in soil aggregates. *Critical Reviews in Plant Sciences, 23*, 481–504.

Blondel, N. (2001). *Céramique: vocabulaire technique*. Paris: Monum Editions du Patrimoine.

Bouquillon, A., Caubet, A., Kaczmarczyk, A., & Matoïan, V. (2007). *Faïences et matières vitreuses de l'Orient ancien: étude physico-chimique et catalogue des oeuvres du département des antiquités orientales*. Paris – Gand: Musée du Louvre éditions – Snoeck.

Bouvet, P. (2012). *Interactions culturelles entre l'Asie du Sud-Est et l'Inde aux 4ème-2ème siècle avt J.-C.: étude technologique des céramiques de Khao Sam Kaeo (Thaïlande péninsulaire, province de Chumphon)*. Nanterre: Université de Paris Nanterre. PhD.

Brongniart, A. (1977). *Traité des arts céramiques ou des poteries considérées dans leur histoire,leur pratique et leur théorie* (Fac similé de l'édition de 1877) (Vol. 2). Paris: Dessain et Tolra.

Brown, G., & Brindley, G. W. I. (1980). *Crystal structures of clay minerals and their X-ray identification* (pp. 361–410). London: Mineralogical Society.

Cauliez, J. (2011). *2900–1900 av. n.-è. Une méthodologie et un référentiel pour un millénaire de produits céramiques dans le Sud-Est de la France* (Préhistoires méditerranéennes Supplément). Aix-en-Provence: APPAM.

Chenu, C., & Stotzky, G. (2001). Interactions between microorganisms and soil particles: An overview. In P. M. Huang, J. M. Bollag, & N. Senesi (Eds.), *Interactions between soil particles and microorganisms: Impact on the terrestrial ecosystem* (pp. 3–40). New York: Wiley.

Chenu, C., Le Bissonnais, Y., & Arrouays, D. (2000). Organic matter influence on clay wettability and soil aggregate stability. *Soil Science Society of America Journal, 64*, 1479–1486.

Colbeck, J. (1981). *La Poterie: Technique du Tournage*. Paris: Dessain et Tolra.

Coutet, C. (2009). *Archéologie du littoral de Guyane Française. Une approche ethnoarchéologique des techniques céramiques amérindiennes*. Paris: Université de Paris I, Panthéon-Sorbonne. PhD.

D'Anna, A., Desbat, A., Garcia, D., Schmitt, A., & Verhaeghe, F. (2011). *La céramique. La poterie, du Néolithique aux Temps modernes* (Nouvelle édition revue et augmentée. Archéologiques). Paris: Éd. Errance.

Doherty, S. K. (2015). *The origins and use of the potter's wheel in ancient Egypt* (Egyptology 7). Oxford: Archaeopress.

Dupont-Delaleuf, A. (2011). *Styles techniques des céramiques de la protohistoire en Asie Centrale: méthodologie et études de cas*. Nanterre: Université de Paris Nanterre. PhD.

Echallier, J.-C. (1984). *Eléments de technologie céramique et d'analyse des terres cuites archéologiques* (Documents d'archéologie méridionale. Numéro spécial, série méthodes et techniques 3). Lambesc: Association pour la Diffusion de l'Archéologie Méridionale.

Fedoroff, N., & Courty, M.-A. (2005). Les Paléosols et sols archéologiques: mémoire des climats et des hommes (Paleosols and archaeological soils: Memory of climate and mandkind). In M.-C. Girard, C. Walter, J. C. Remy, J. Berthelin, & J. L. Morel (Eds.), *Sols et environnement* (pp. 151–186). Paris: Dunod.

Fedoroff, N., Courty, M.-A., & Guo, Z. (2010). Palaeosoils and relict soils. In G. Stoops, V. Marcellino, & F. Meers (Eds.), *Interpretation of micromorphological features of soils and regoliths* (pp. 623–662). Amsterdam, The Netherlands: Elsevier.

Foster, G. M. (1959). The Coyotepec molde and some associated problems of the potter's wheel. *Southwestern Journal of Anthropology, 15*, 53–63.

Frimigacci, D. (1981). La poterie imprimée au battoir en Nouvelle-Calédonie. *Journal de la Société des Océanistes, 37*, 111–118.

Fugmann, E. (1958). *Hama : fouilles et recherches, 1931–1938. L'architecture des périodes pré-hellénistiques*. Copenhague: Nationalmuseet.

Gallay, A. (2012). *Potières du Sahel : A la découverte des traditions céramiques de la boucle du Niger*. Gollion, Suisse: Infolio.

Gallin, A. (2011). *Les styles céramiques de Kobadi : analyse comparative et implications chronoculturelles au Néolithique récent du Sahel Malien* (Reports in African archaeology 1). Frankfurt am Main: Africa Magna Verlag.

Gallin, A. (2013). CerAfIm. http://lampea.cnrs.fr/cerafim/ (accessed 14/12/2018).

Gandon, E., Casanova, R., Sainton, P., Coyle, T., Roux, V., Bril, B., & Bootsma, R. J. (2011). A proxy of potters' throwing skill: Ceramic vessels considered in terms of mechanical stress. *Journal of Archaeological Science, 38*, 1080–1089.

Gauss, W., Klebinder-Gauss, G., & von Rüden, C. (Eds.). (2016). *The transmission of technical knowledge in the production of ancient Mediterranean pottery* (Vol. Sonderschriften band 54). Wien: Österreichisches Archäologisches Institut.

Gelbert, A. (1994). Tour et tournette en Espagne : recherche de macrotraces significatives des différentes techniques et méthodes de façonnage. In J. Courtin & D. Binder (Eds.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes) (pp. 59–74). Juan-les-Pins: Editions APDCA.

Gelbert, A. (2003). *Traditions céramiques et emprunts techniques dans la vallée du fleuve Sénégal. Ceramic traditions and technical borrowings in the Senegal River Valley*. Paris: Editions de la Maison des sciences de l'homme and Editions Epistèmes, English/French extracts at http://www.thearkeotekjournal.org/tdm/Arkeotek/en/articles_reedites/Traditions.xml.

Giorgetti, G., Gliozzo, E., & Memmi, I. (2004). Tuscan black glosses a mineralogical characterization by high resolution techniques. *European Journal of Mineralogy, 16*, 493–503.

Gliozzo, E., Kirkman, I. W., Pantos, E., & Turbanti, I. M. (2004). Black gloss pottery: Production sites and technology in northern Etruria, part II: Gloss technology. *Archaeometry, 46*, 227–246.

Goldfield, E. C., Kay, B. A., & Warren, W. H., Jr. (1993). Infant bouncing: The assembly and tuning of action systems. *Child Development, 64*, 1128–1142.

Gomart, L., Weiner, A., Gabriele, M., Durrenmath, G., Sorin, S., Angeli, L., Colombo, M., et al. (2017). Spiralled patchwork in pottery manufacture and the introduction of farming to southern Europe. *Antiquity, 91*, 1501–1514.

Gosselain, O. (1992). Bonfire of the enquiries. Pottery firing temperatures in archaeology: What for? *Journal of Archaeological Science, 19*, 243–259.

Gosselain, O. (2000). Materializing identities: An African perspective. *Journal of Archaeological Method and Theory, 7*, 187–217.

Gosselain, O. (2002). *Poteries du Cameroun méridional styles techniques et rapports à l'identité* (Monographie du CRA 26). Paris: CNRS Editions.

Gosselain, O. (2010). Ethnographie comparée des trousses à outils de potiers au sud du Niger. *Bulletin de la Société préhistorique française, 107*, 667–690.

Gosselain, O., & Livingstone Smith, A. (2005). The source clay selection and processing practices in sub-Saharan Africa. In A. Livingstone Smith, D. Bosquet, & R. Martineau (Eds.), *Pottery manufacturing processes: Reconstruction and interpretation* (pp. 33–48). BAR International Series 1349. Oxford: Archaeopress.

Guy, P. L. O. (1938). *Megiddo tombs*. Chicago: Chicago University Press.

Haour, A., Manning, K., Arazi, N., Guèye, S., Keita, D., Livingstone-smith, A., MacDonald, K., Mayor, A., McIntosh, S., & Vernet, R. (Eds.). (2010). *African pottery roulettes past and present: Techniques, identification and distribution*. Oxford: Oxbow Books.

Heidke, J., & Elson, M. D. (1988). Tucson Basin stucco-coated plain ware: A technological assessment. *Kiva, 53*, 273–285.
Hein, A., Müller, N. S., Day, P. M., & Kilikoglou, V. (2008). Thermal conductivity of archaeological ceramics: The effect of inclusions, porosity and firing temperature. *Thermochimica Acta, 480*, 35–42.
Holt, K. G., Hamill, J., & Andres, R. O. (1990). The force-driven harmonic oscillator as a model for human locomotion. *Human Movement Science, 9*, 55–68.
Hourani, F., & Courty, M.-A. (1997). L'évolution morpho-climatique de 10 500 à 5 500 BP dans la vallée du Jourdain. *Paléorient, 23*, 95–105.
Huang, P. M., Li, Y., & Sumner, M. E. (Eds.). (2012). *Handbook of soil sciences: Resource management and environmental impacts*. Boca Raton: CRC Press, Taylor & Francis Group.
Hunt, A. M. W. (Ed.). (2017). *The Oxford handbook of archaeological ceramic analysis*. Oxford: Oxford University Press.
Jeffra, C. (2011). *The archaeological study of innovation: An experimental approach to the pottery wheel in Bronze Age Crete and Cyprus*. Exeter: University of Exeter. PhD.
Kaiser, K., & Guggenberger, G. (2003). Mineral surfaces and soil organic matter. *European Journal of Soil Science, 54*, 219–236.
Kilikoglou, V., Vekinis, G., Maniatis, Y., & Day, P. M. (1998). Mechanical performance of quartz-tempered ceramics: Part I, strength and toughness. *Archaeometry, 40*, 261–279.
Kramer, C. (1985). Ceramic ethnoarchaeology. *Annual Review of Anthropology, 14*, 77–102.
Lepère, C. (2014). Experimental and traceological approach for a technical interpretation of ceramic polished surfaces. *Journal of Archaeological Science, 46*, 144–155.
Livingstone Smith, A. (2001a). *Chaîne opératoire de la poterie : Références ethnographiques, analyses et reconstitution*. Bruxelles: Université Libre de Bruxelles. PhD.
Livingstone Smith, A. (2001b). Bonfire II: The return of pottery firing temperatures. *Journal of Archaeological Science, 28*, 991–1003.
Löbert, H. W. (1984). Types of potter's wheels and the spread of the spindle-wheel in germany. In S. E. van der Leeuw & A. C. Pritchard (Eds.), *The many dimensions of pottery. Ceramics in archaeology and anthropology* (pp. 203–226). Amsterdam: Universiteit van Amsterdam.
London, G. (1981). Dung-tempered clay. *Journal of Field Archaeology, 8*, 189–195.
M'Mbogori, F. N. (2015). *Population and ceramic traditions: revisiting the Tana Ware of Coastal Kenya (7th–14th century AD)*. BAR International Series 2717. Cambridge monographs in African archaeology 8. Oxford: Archaeopress.
Magrill, P., & Middleton, A. (1997). A Canaanite potter's workshop in Palestine. In I. Freestone & D. Gaimster (Eds.), *Pottery in the making: World ceramic traditions* (pp. 68–73). London: British Museum Press.
Mahias, M.-C. (1993). Pottery techniques in India: Technological variants and social choice. In P. Lemonnier (Ed.), *Technological choices: Transformation in material cultures since the Neolithic* (pp. 157–180). London and New York: Routledge.
Marchuk, A., & Rengasamy, P. (2011). Clay behaviour in suspension is related to the ionicity of clay–cation bonds. *Applied Clay Science, 53*, 754–759.
Margueron, J.-C. (2004). *Mari : métropole de l'Euphrate au IIIe et au début du IIe millénaire avant J.-C*. Paris: Picard, Editions Recherches Sur les Civilisations.
Mayor, A. (2010). Outils de potières au Mali: chaînes opératoires et traditions techniques. *Bulletin de la Société préhistorique française, 107*, 643–666.
Michelaki, K., Braun, G. V., & Hancock, R. G. V. (2015). Local clay sources as histories of human–landscape interactions: A ceramic taskscape perspective. *Journal of Archaeological Method and Theory, 22*, 783–827.
Müller, N. S. (2017). Mechanical and thermal properties. In A. Hunt (Ed.), *The Oxford handbook of archaeological ceramic analysis* (pp. 603-624). Oxford: Oxford University Press.
Müller, N. S., Kilikoglou, V., Day, P. M., & Vekinis, G. (2010). The influence of temper shape on the mechanical properties of archaeological ceramics. *Journal of the European Ceramic Society, 30*, 2457–2465.
Murray, H. H. (1999). Applied clay mineralogy today and tomorrow. *Clay Minerals, 34*, 39–39.

Nalbantoglu, Z. (2006). Lime stabilization of expansive clay. In A. A. Al-Rawas & M. F. A. Goosen (Eds.), *Expansive soils: Recent advances in characterization and treatment* (Vol. 1, pp. 341–348). London: Taylor & Francis Group.
Orton, C., Tyers, P., & Vince, A. (1993). *Pottery in archaeology*. Cambridge: Cambridge University Press.
Pétrequin, P., Martineau, R., Nowicki, P., Gauthier, E., & Schaal, C. (2009). La poterie Hoguette de Choisey (Jura), les Champins. Observations techniques et insertion régionale. *Bulletin de la Société préhistorique française, 106*, 491–515.
Picon, M. (1973). *Introduction à l'étude technique des céramiques sigillées de Lezoux*. Lyon: Centre de recherche sur les techniques gréco-romaines.
Pierret, A. (2001). *Analyse technologique des céramiques archéologiques : développements méthodologiques pour l'identification des techniques de façonnage. Un exemple d'application : le matériel du village des Arènes à Levroux (Indre)* (Thèse à La Carte). Villeneuve d'Ascq: Presses Universitaires du Septentrion.
Porter, Y., & Castinel, R. (2011). *Le prince, l'artiste et l'alchimiste: la céramique dans le monde iranien, Xe au XVIIe siècles*. Paris: Hermann.
Porter, A., & McClellan, T. (1998). The third millennium settlement complex at Tell Banat: Results of the 1994 excavations. *Damaszener Mitteilungen, 10*, 10–63.
Powell, C. (1995). The nature and use of ancient Egyptian potter's wheel. In *Amarna reports VI* (pp. 309–335). London: Egypt Exploration Society.
Quinn, P. S. (2013). *Ceramic petrography: The interpretation of archaeological pottery & related artefacts in thin section*. Oxford: Archaeopress.
Ramón, G. (2011). The swallow potters: seasonal migratory styles in the Andes. In S. Scarcella (Ed.), *Archaeological ceramics: A review of current research* (pp. 160–175). BAR International Series 2193. Oxford: Archaeopress.
Reedy, C. L. (2008). *Thin-section petrography of stone and ceramic cultural materials*. London: Archetype.
Reina, R. E., & Hill, R. M. (1978). *The traditional pottery of Guatemala*. Austin: University of Texas Press.
Rice, P. M. (1987). *Pottery analysis. A sourcebook*. Chicago and London: The University Chicago Press.
Rice, P. M. (1996). Recent ceramic analysis: I. Function, style and origins. *Journal of Archaeological Research, 4*, 133–163.
Roobaert, R., & Trokay, M. (1990). Surface finds. *Abr-Nahrain, 2*, 121–125.
Rostain, S. (1991). La céramique amérindienne de Guyane française. *Schweizerische Amerikanisten Gesellschaft, 55–56*, 93–127.
Roux, V. (2009). The potter's wheel in Midddle Bronze II in the southern Levant: Technological study of the Beth Shean ceramics. *The Arkeotek Journal* www.thearkeotekjournal.org.
Roux, V. (2011). Habiletés et inventions: Le comportement "intelligent", un facteur aléatoire dans l'évolution des techniques. In R. Treuil (Ed.), *Archéologie cognitive : Techniques, modes de communication, mentalités* (pp. 173–188). Paris: Maison des Sciences de l'Homme.
Roux, V. (2017). Smoothing and clay coating: Reference collections for interpreting southern Levant Chalcolithic finishing techniques and surface treatments. *The Arkeotek Journal* www.thearkeotekjournal.org.
Roux, V., & Corbetta, D. (1989). Wheel-throwing technique and craft specialization. In V. Roux (in coll. with D. Corbetta), *The potter's wheel. Craft specialization and technical competence* (pp. 1–91). New Delhi: Oxford and IBH Publishing.
Roux, V., & Courty, M.-A. (1998). Identification of wheel-fashioning methods: Technological analysis of 4th-3rd millennium BC oriental ceramics. *Journal of Archaeological Science, 25*, 747–763.
Roux, V., & de Miroschedji, P. (2009). Revisiting the history of the potter's wheel in the southern Levant. *Levant, 41*, 155–173.
Roux, V., Bril, B., & Karasik, A. (2018). Weak ties and expertise: Crossing technological boundaries. *Journal of Archaeological Method and Theory, 2*, 1–27.

Rye, O. S. (1977). Pottery manufacturing techniques: X-ray studies. *Archaeometry, 19*, 205–211.
Rye, O. S. (1981). *Pottery technology. Principles and reconstruction* (Manuals on Archaeology 4). Washington, DC: Taraxacum Press.
Rye, O. S., & Evans, C. (1976). *Traditional pottery techniques of Pakistan: Field and laboratory studies*. Washington, DC: Smithsonian Institution Press.
Sall, M. (2005). Cultural contacts and technical heritage in Senegambia. In A. Livingstone Smith, D. Bosquet, & R. Martineau (Eds.), *Pottery manufacturing processes: Reconstitution and interpretation* (pp. 57–66). BAR International Series 1349. Oxford: British Archaeological Reports Ltd.
Saraswati, B., & Behura, N. K. (1964). *Pottery techniques in peasant India*. Calcutta: Anthropological Survey of India.
Scheans, D. J. (1977). *Filipino market potteries* (Vol. 3). Manila: National Museum of the Philippines.
Schiffer, M. B. (1988). The effects of surface treatment on permeability and evaporative cooling effectiveness of pottery. In R. M. Farquhar, R. G. V. Hancock, & L. A. Pavlish (Eds.), *Proceedings of the 26th international archaeometry symposium* (pp. 23–29). Toronto: University of Toronto, Archaeometry Laboratory.
Schiffer, M. B. (1990). The influence of surface treatment on heating effectiveness of ceramic vessels. *Journal of Archaeological Science, 17*, 373–381.
Schiffer, M. B., Skibo, J. M., Boelke, T. C., Neupert, M. A., & Aronson, M. (1994). New perspectives on experimental archaeology: Surface treatments and thermal response of the clay cooking pot. *American Antiquity, 59*, 197–217.
Schulten, H.-R., & Leinweber, P. (1999). Thermal stability and composition of mineral-bound organic matter in density fractions of soil. *European Journal of Soil Science, 50*, 237–248.
Sedov, S., Solleiro-Rebolledo, E., Fedick, S. L., Gama-Castro, J., Palacios-Mayorga, S., & Vallejo Gómez, E. (2007). Soil genesis in relation to landscape evolution and ancient sustainable land use in the northeastern Yucatan Peninsula, Mexico. *Atti della Societa Toscana di Scienze Naturali Residente in Pisa, Memorie Serie A, 112*, 115–126.
Sestier, C. (2005). Utilisation du dégraissant végétal en contexte néolithique: hypothèses technologiques et expérimentation. In A. Livingstone Smith, D. Bosquet, & R. Martineau (Eds.), *Pottery manufacturing processes: Reconstruction and interpretation* (pp. 81–94). BAR International Series 1349. Oxford: Archaeopress.
Sevrez, V., Rao, G., Berton, E., & Bootsma, R. J. (2012). On the organizing role of nonmuscular forces during performance of a giant circle in gymnastics. *Journal of Applied Biomechanics, 28*, 57–62.
Shepard, A. O. (1965). *Ceramics for the archaeologist*. Washington, DC: Carnegie Institution of Washington.
Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil, 241*, 155–176.
Skibo, J. M., Schiffer, M. B., & Reid, K. C. (1989). Organic-tempered pottery: An experimental study. *American Antiquity, 54*, 122–146.
Skibo, J. M., Butts, T. C., & Schiffer, M. B. (1997). Ceramic surface treatment and abrasion resistance: An experimental study. *Journal of Archaeological Science, 24*, 311–317.
Steponaitis, V. P. (1984). Technological studies of prehistoric pottery from Alabama: Physical properties and vessel function. In S. E. van der Leeuw & A. Pritchard (Eds.), *Many dimensions of pottery: Ceramics in archaeology and anthropology* (pp. 79–122). Amsterdam: University of Amsterdam.
Tessier, D. (1990). Behaviour and microstructure of clay minerals. In M. F. De Boodt, M. H. Hayes, & A. Herbillon (Eds.), *Soil colloids and their associations in aggregates* (pp. 387–415). New York: Springer.
Thalmann, J.-P. (2006). *Tell Arqa, 1. Les niveaux de l'âge du Bronze* (Bibliothèque archéologique et historique 177). Beyrouth: Institut français du Proche-Orient.
Theng, B. K. G. (2012). *Formation and properties of clay-polymer complexes* (Developments in Clay Science 4) (2nd ed.). Amsterdam, The Netherlands: Elsevier.

Thér, R., & Gregor, M. (2011). Experimental reconstruction of the pottery firing process of late Bronze Age pottery from north-eastern Bohemia. In S. Scarcella (Ed.), *Archaeological ceramics: A review of current research* (pp. 128–142). BAR International Series 2193. Oxford: Archaeopress.

Tite, M. S. (2008). Ceramic production, provenance and use – a review. *Archaeometry, 50*, 216–231.

Tite, M. S., Bimson, M., & Freestone, I. C. (1982). An examination of the high gloss surface finishes on Greek Attic and Roman Samian wares. *Archaeometry, 24*, 117–126.

Tite, M. S., Kilikoglou, V., & Vekinis, V. (2001). Strength, toughness and thermal shock resistance of ancient ceramics, and their influence on technological choice. *Archaeometry, 43*, 301–324.

Tixier, J. (1967). Procédés d'analyse et questions de terminologie dans l'étude des ensembles industriels du Paléolithique récent et de l'épipaléolithique en Afrique du Nord-Ouest. In W.W. Bishop & J.D. Clark (Eds.), *Background to evolution in Africa* (pp. 771–820). Chicago and London: The University Press of Chicago.

Trokay, M. (1989). Les deux documents complémentaires en basalte du Tell Kannâs: base de tournette ou meule? In M. Lebeau & P. Talon (Eds.), *Reflets des deux fleuves. Volume de Mélanges offerts à André Finet* (pp. 169–175). Leuven: Publications of the Melbourne University, Expedition to Tell Ahmar.

van der Leeuw, S. E. (1993). Giving the potter a choice: Conceptual aspects of pottery techniques. In P. Lemonnier (Ed.), *Technological choices: Transformation in material cultures since the Neolithic* (pp. 238–288). London and New York: Routledge.

van der Leeuw, S. (1994). Innovation et tradition chez les potiers mexicains ou comment les gestes techniques traduisent les dynamiques d'une société. In B. Latour & P. Lemonnier (Eds.), *De la préhistoire aux missiles balistiques. L'intelligence sociale des techniques* (pp. 310–328). Paris: Editions La Découverte.

Vandiver, P., Ellingson, W., Robinson, T., Lobick, J. J., & Séguin, F. H. (1991). New applications of X-radiographic imaging technologies for archaeological ceramics. *Archeomaterials, 5*, 185–207.

Velde, B., & Druc, I. C. (2012). *Archaeological ceramic materials: Origin and utilization*. London: Springer Science & Business Media.

Velde, B., & Meunier, A. (2008). *The origin of clay minerals in soils and weathered rocks*. New York: Springer.

Virot, C. (2005). *La poterie africaine les techniques céramiques en Afrique noire* (Granit). Banon: Argile.

Voyatzoglou, M. (1973). The potters of Thrapsano. *Ceramic Review (London), 24*, 13–16.

Voyatzoglou, M. (1974). The jar makers of Thrapsano in Crete. *Expedition, 16*, 18–24.

Whitbread, I. K. (2001). Ceramic petrology, clay geochemistry and ceramic production. From technology to the mind of the potter. In D. R. Brothwell & A. M. Pollard (Eds.), *Handbook of archaeological sciences* (pp. 449–459). London: Wiley.

Whitbread, I. (2017). Fabric description of archaeological ceramics. In A. Hunt (Ed.), *The Oxford handbook of archaeological ceramic analysis* (pp. 200–224). Oxford: Oxford University Press.

Wu, H.-C. (2012). *Peuplement et dynamique culturelle à l'âge du Fer Ancien et Récent dans le Nord-Est et le Nord de Taïwan : approche technologique des assemblages céramiques du site de Chiwulan (Ilan, Nord-Est de Taïwan, 650–1850 EC)*. Nanterre: Université de Paris Nanterre. PhD.

Yadin, I., Aharoni, Y., & Amiran, R. (1958). *Hazor. I. An Account of the first season of excavations, 1955*. Jerusalem: Magnes Press, Hebrew University.

Yadin, I., Aharoni, Y., & Amiran, R. (1960). *Hazor. II. An Account of the second season of excavations, 1956*. Jerusalem: Magnes Press, Hebrew University.

Zhang, B., & Horn, R. (2001). Mechanisms of aggregate stabilization in Ultisols from subtropical China. *Geoderma, 99*, 123–145.

Chapter 3
Identification of the *Chaînes Opératoires*

Identifying ceramic *chaînes opératoires* is a difficult exercise for several reasons. The first is that each gesture produces traces that can obliterate the preceding traces. In this way, finishing operations tend to obliterate shaping operations, and a skilled and careful potter can make recipients with no visible signs to the naked eye likely to indicate the fabrication sequence. The second reason is the pluriform, polysemous nature of ceramic macro-traces: not only can a same trace be obtained by different techniques, but also a same technique can engender different traces. Thus, parallel striations can be obtained with or without RKE; a U-shaped horizontal break can be obtained on a coiled recipient or on a recipient that has successively been wheel-thrown and hammered; or again, fire marks on the body of a recipient can be produced during open firing or kiln firing. Finally, a last reason involves the taphonomic processes that can affect the conservation of ceramics.

The difficulty of the exercise explains why ceramic technology developed more slowly than lithic technology, even though the foundations of the discipline were laid down in the 1960s (Balfet 1966; Franken 1970; van der Leeuw 1977; Franken 1978). Since then, experimental and ethnoarchaeological research has shown that it is possible to identify technical gestures based on a detailed analysis of macroscopic and microscopic features. However, this research is still ongoing and is far from complete. In this chapter, we mainly present an overview of present knowledge and the approach to follow in order to enrich this knowledge in the future.

This chapter is divided into two main parts: the first part deals with the preparation of clay materials, and the second with fashioning, finishing, surface treatment, decoration, and firing. These two parts are distinct as they rely on two distinctive sets of references: on the one hand, on references based on geological and pedological knowledge and, on the other hand, on ethnographic knowledge and material sciences. Different descriptive grids are then presented, which, when combined, should make possible the reconstitution of the *chaînes opératoires*.

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3.1 Technological Interpretation of the Pastes

Investigating the technical operations on clay materials involves examining the collected raw materials and their transformations, which include, as we saw in the preceding chapter, fractioning, sieving, hydration, and lastly kneading and mixing operations, which modify the raw materials. These transformations define the specific deformation systems linked to the constraints of the materials and reveal locally developed traditions.

Methodology

The technological study of the pastes involves the identification of the final structural state of the clay material and the reconstruction of its initial state (raw material), in order to find the transformation sequence of the fabrics during the technical operations. This well-constructed structural interpretation calls on general reference sets of geological facies, as well as experimental reference sets based on the physics of materials (Fig. 3.1). It is intrinsically delicate, due to the mesoscale compactness of ceramic pastes inherent to the fabrication process and due to a relatively important obliteration of the structural states by firing. Nonetheless, markers subsist in the petrofabrics and in the petrofacies to at least partially reconstruct the technical sequence.

The *petrofabrics* describe the multi-scalar organization of the fine mass and the arrangement of the coarse components in the fine mass. They enable identification of the way clay material has been prepared.

The *petrofacies* correspond to all the petrographic, mineralogical, and granulometric characteristics of the coarse components and the mineralogical characteristics of the fine mass. They enable identification of the clay sources.

Let us note that the issue of identifying clay sources through chemical analysis is not addressed here because chemical analyses relate to crushed materials for statistically representative data. By contrast, our concern for the restitution of all the operations carried out for the preparation of the clay materials implies studying undisturbed materials, with intact links between the coarse and fine components. These are the links which are taken into account in the petrofacies analysis carried out under the petrographic microscope.

Descriptive Framework

The potential markers of the preparation of clay materials are not identifiable with the naked eye and are characterized on the basis of observations on fresh cross sections and on crushed sherds. The cross sections are studied under a

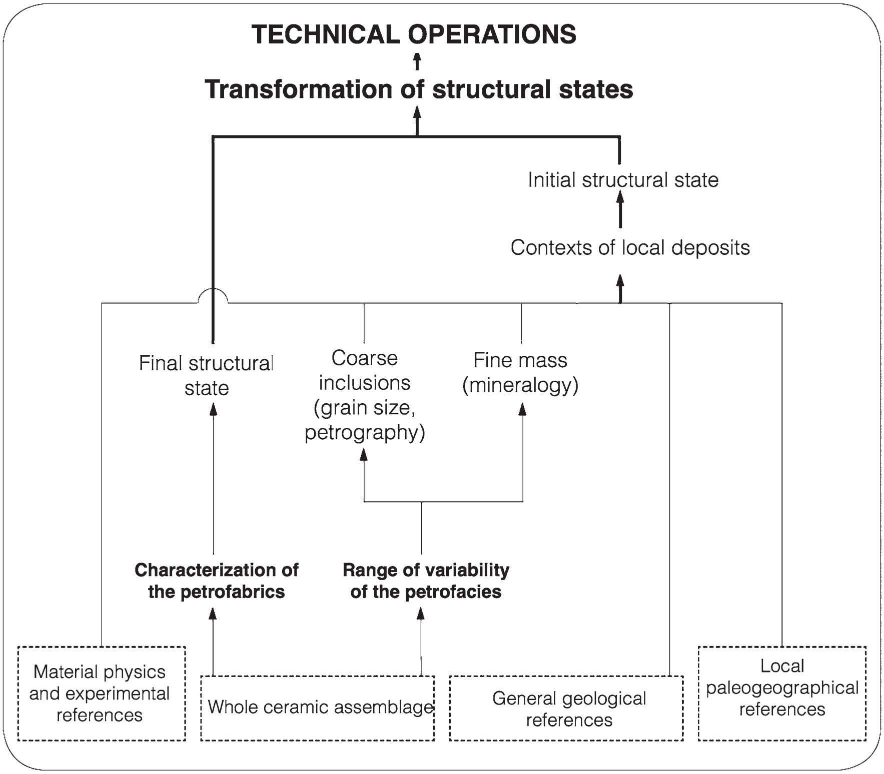

Fig. 3.1 Schematic illustration of the methodology used for the technological interpretation of the clay paste

stereomicroscope, a petrographic microscope, and a scanning electron microscope coupled with a microprobe. In parallel, crushed sherds are wet sieved, and the different sandy fractions are observed under the stereomicroscope and the scanning electron microscope. The crushing and the washing reveal components often dissimulated in the fine mass, in particular, carbon compounds.

The markers include the organic and mineral components of the fine mass and the coarse mass, as well as porosity (Fig. 3.2).

The Fine Mass

The components of the fine mass are less than 2 microns and include fine silts. A set of characteristics describe the fine mass:

– The color in reflected light (stereomicroscope) and transmitted light (under a petrographic microscope on thin sections with non-analyzed natural light)
– The chemical and mineralogical composition of the inclusions

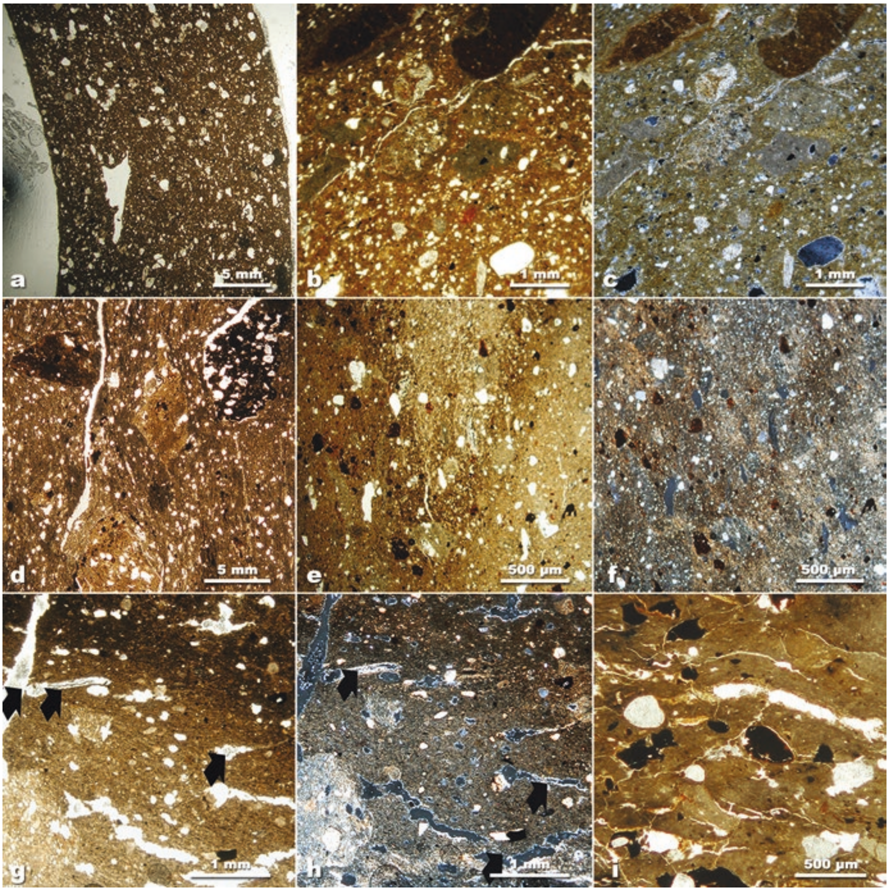

Fig. 3.2 Illustration of the criteria used for the technological study of the clay paste: (**a**) view at low magnification, fine color mass in plane analyzed light, morphology and abundance of large cavities and fine pores, abundance of the coarse fraction; (**b**) view in plane analyzed light, fissures and vesicles, bimodal coarse fraction (rounded calcareous coarse sands and subangular quartz fine sands), homogeneous dense fine fraction; (**c**) plane analyzed light, carbonate-rich fine fraction showing an asepic birefringence fabric; the clay domains are not clearly expressed due to firing transformation of the carbonates in the fine mass; (**d**) cracks and fissures, coarse fraction showing a strongly contrasted bimodal distribution with cm-sized sandstone inclusions and fine quartz sands, yellowish brown to grayish brown fine mass; (**e**) view at high magnification in polarized analyzed light showing the fine fissures and the elongated vesicles and the abundance of dark brown domains within the dense yellowish brown fine mass which are organic matter inclusions impregnated by iron oxides; (**f**) view in polarized analyzed light showing a well-expressed birefringence assemblage linked to a subparallel orientation of the clay domains along with the stretching direction; (**g**) view at low magnification in polarized analyzed light showing the cracks and the stretched fine cavities with plant residues, associated with a dense, homogeneous, yellowish brown fine mass; (**h**) view in polarized analyzed light showing the calcitic fine mass which were partly amorphized during firing and the ash-transformed plant residues in cracks and cavities; (**i**) view in plane analyzed light showing a porosity formed of fine fissures, stretched cavities and vesicles, a fine mass with stretched, compacted clay domains, and a well-sorted coarse fraction formed of dense carbonaceous grains (tar) and rounded quartz

– The birefringence assemblage of the fine mass (under a petrographic microscope on thin sections with analyzed polarized light)
– The mesoscale and microscopic structural state including the organization of the clay domains

Birefringence assemblage: orientation and geometric organization of the anisotropic clay domains and the coarse fraction.

The Coarse Fraction

The coarse fraction is made up of inclusions which are naturally present or added to the clay material. These inclusions can be:

– Simple mineral grains
– Composite grains (rock fragments, ceramic fragments [grog], bioclasts [fossil shells])
– Carbon compounds (siliceous plant residues [phytoliths], lignocellulosic debris [wood, stems, leaves], polymerized residues [fibers and filaments])

These inclusions can also be bone fragments. The nature of the mineral inclusions is identified on the basis of optical characteristics used in petrography. The nature of the carbon compounds is first of all identified with the stereomicroscope and then with the scanning electron microscope. For specific characterizations, other analytical methods can be used, such as infrared and Raman spectrometry.

Four variables describe the coarse fraction: the nature, quantity, granulometric spectrum, and the shape. The quantity can be evaluated using quantification charts (Fig. 3.3).

Porosity

Porosity (cracks, fissures, voids, cavities, and vesicles) is described on a meso- and microscopic scale, using soil micromorphology references (Bullock et al. 1985). Cracks and fissures are elongated voids. They are generally rectilinear, but they can also be large curved cracks. Vesicles are subcircular to elliptic voids, corresponding to subspherical volumes. Voids of organic origin present different shapes – circular, curled, rectangular, acicular, and vesicular – and correspond mainly in ceramics to imprints left by plant/organic fragments, which can be natural or added as tempers and burnt during firing (van Doosselaere 2011). Voids can also correspond to porosity left by air bubbles trapped in the fine mass during kneading.

The abundance of the different types of porosity can be estimated with the quantification charts generally used for inclusions (Fig. 3.3) or quantified with image analysis techniques using radiography, tomography (micro-CT), or thin sections.

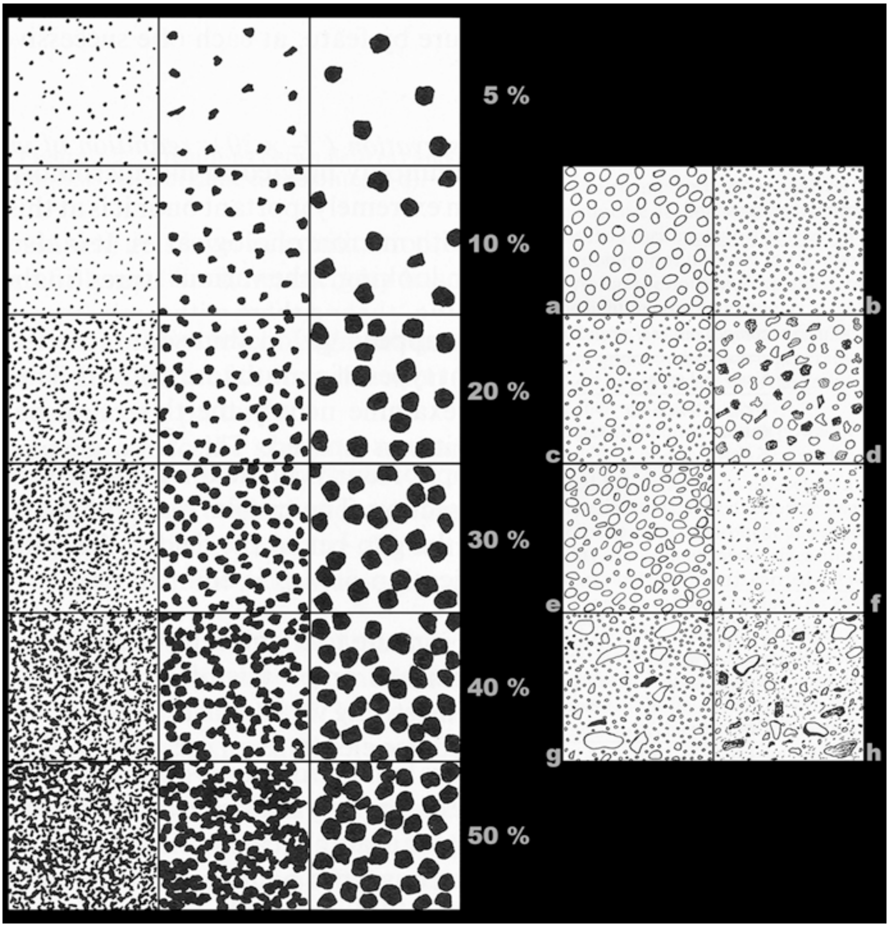

Fig. 3.3 Quantification charts (after Courty et al. 1989): (**a**) chart used to estimate the abundance of the coarse fraction in the fine mass; (**b**) chart used to estimate the degree of roundness of the coarse fraction in the fine mass

Characterization of the Petrofabrics

The final structural state of the sherd is defined mainly by the type of organization of the clay domains, as well as by the distribution of the coarse components in the clay domains and their interfaces.

The identification of the clay domains on a microscopic scale (from 50 to 200 μm) is based on the identification of contrasts in the micro-organization revealing a geometry of interfaces in the fine mass. The observation of regularity in this geometry at the scale of a sherd allows for the characterization of organization types in terms of porosity, size, and the compactness of the clay domains (arrangement of the microconstituents and microporosity).

It is important to recall that the identified clay domains correspond to the smallest structural entities issued from the fractioning of successive sieving operations during the preparation of the paste.

The visibility of the clay domains depends on their physical properties and on their transformation during kneading and mixing. This degree of transformation depends on the nature and the abundance of the organo-mineral micro-inclusions in the clay acting as a rigid deformable skeleton. For example, this degree is slight for a network of polymer filaments or calcitic inclusions closely associated with clays. Conversely, in the absence of this range of inclusions, plastic deformation leads to an important coalescence of the clay domains, and the geometry becomes difficult to identify (Fig. 3.4).

Identification of the Technical Operations

The characteristics to be identified correspond more specifically to the following technical operations:

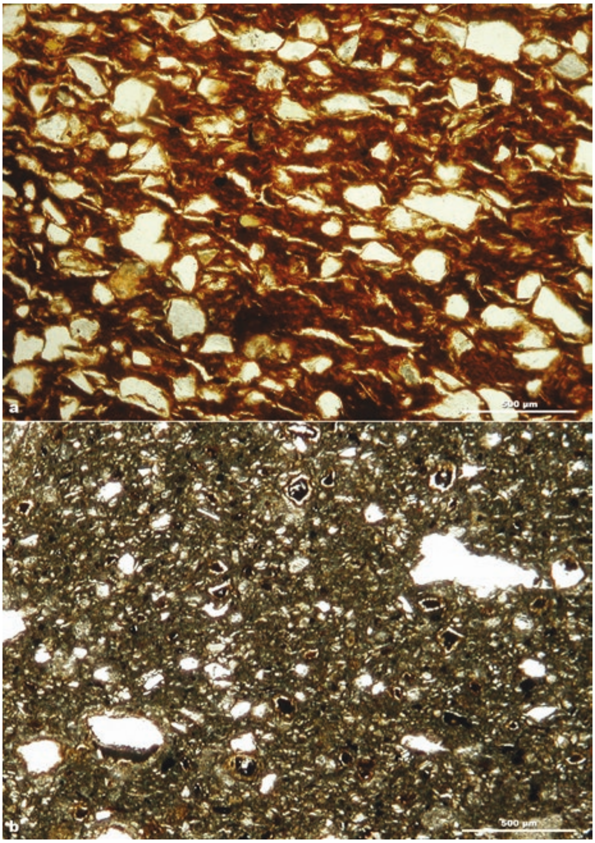

Fig. 3.4 Illustration of the different petrofabric types: (**a**) well-expressed organization of weakly transformed clay domains, clearly visible at this magnification; (**b**) dense fine mass with closed cavities showing an organization of strongly coalescent clay domains, weakly visible at this magnification

- Incorporation or not of plastic or non-plastic elements and/or mixing of clay materials modifying the initial petrofacies
- Fractioning and sieving participating in a process of raw material homogenization
- Wedging and kneading participating in a process of elimination of the air bubbles contained in the pastes, indispensable to prevent the appearance of structural defects (cracks, fissures)

These technical operations can be inferred from the comparison between the initial structural state and the final structural state. The identification of a granulometric and possibly a petrographic discontinuity between the population of coarse constituents and the inclusions in the clay mass is one of the most reliable diagnostic attributes for advancing the hypothesis of an intentional incorporation of

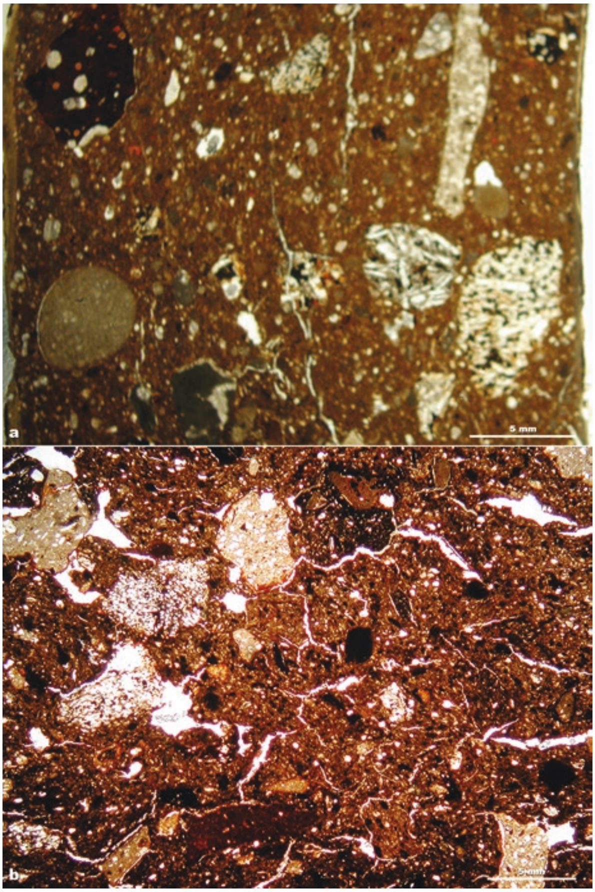

Fig. 3.5 Example of petrofacies classification: (**a**) distinct petrofacies showing coarse inclusions formed of crushed calcite within a homogeneous dense, brown, fine mass with abundant quartz fine sands; (**b**) example of a weakly differentiated petrofacies showing a size continuum from calcareous sands to quartz sands

tempers (Fig. 3.5). In contrast, the pastes showing a granulometric and possibly petrographic continuity, from the coarsest elements to the inclusions in the fine mass, present the characteristics of a non-modified to slightly modified raw material (Fig. 3.5). In fact, the use of geological reference sets shows a wide diversity of examples presenting such continuity in various deposit contexts: alluvial, eolian, or colluvial. Conversely, no ethnographic example shows the intentional incorporation of previously selected tempers presenting such continuity on account of the calibrations resulting from sieving. The most characteristic example of an intentional incorporation after careful preparation is that of pastes showing homogeneous coarse constituents from a petrographic and mineralogical perspective in a fine clay mass with no coarse inclusions (Fig. 3.5).

The interpretation of the continuity between coarse constituents and the fine mass can be confirmed by the identification of fabrics showing the integration of the constituents and coarse inclusions in clay domains. Such integration can only result from natural processes and not from an intentional incorporation of tempers, as the latter cannot create the same effect.

The identification of the structural transformations linked to fractioning/sieving, wedging/kneading operations is based on the interpretation of microfabrics using experimental reference sets. In this way, the degree of coalescence of the clay domains and the abundance of the porosity left by the air bubbles are the two most significant diagnostic attributes for assessing the quality of the mixing.

Characterization of the Petrofacies

The characterization of the petrofacies aims to establish their range of variability in a site. It must thus be based on the whole ceramic assemblage from the site.

The first stage consists in establishing a classification of the petrofacies based on stereomicroscopic observations of fresh cross sections of the sherds. This takes into account a set of diagnostic attributes of the fine mass and coarse inclusions, mainly their petrography, mineralogy, grain size, morphology, and abundance. Due to the limits of stereomicroscopic observation, in particular for the petrography and mineralogy of the fine and coarse fractions, it is essential to test the pertinence of the diagnostic attributes on thin sections.

For ceramic assemblages with either continuous variability for a well-defined type of petrofacies, or distinctive types of petrofacies, the verification of the diagnostic attributes used for the stereomicroscope classification with a petrographic microscope is straightforward. The task is more difficult for complex ceramic assemblages made up of a high number of petrofacies, which cannot be differentiated with the stereomicroscope due to the overlap of the diagnostic attributes. In practice, the most reliable procedure is to alternate stereomicroscopic and petrographic microscopic observations, until the pertinence of the classification established with the stereomicroscope is confirmed on thin sections (Fig. 3.6).

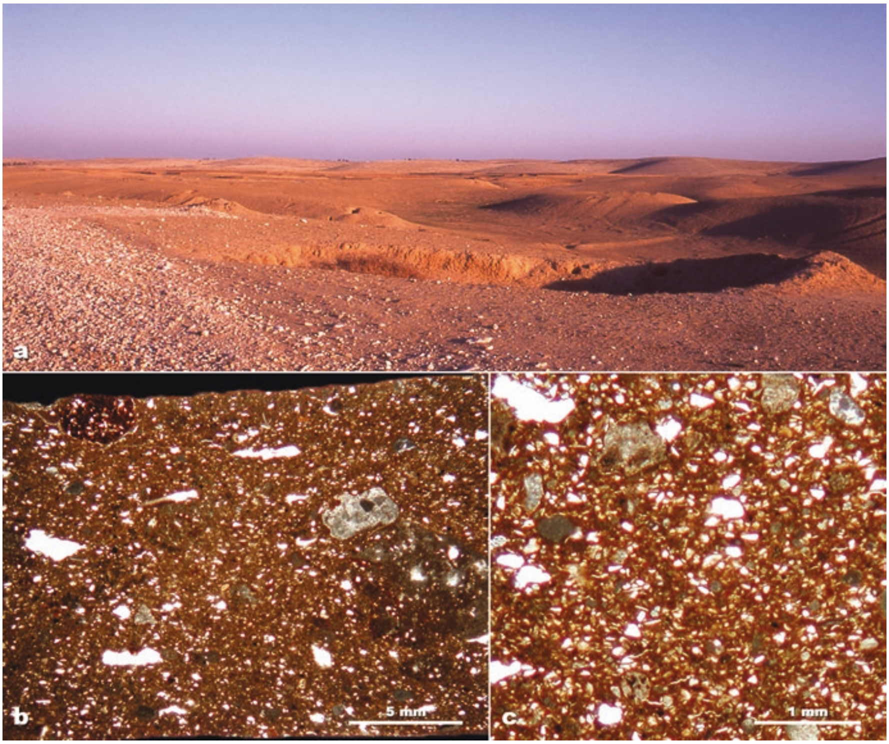

Fig. 3.6 Example of a correlation established between ceramic petrofacies and raw material provenance: (**a**) field view of loess deposit in the Upper Negev (Israel); (**b**) view at low magnification in plane analyzed light of a ceramic thin section (late Chalcolithic layer, Abu Hamid site, Jordan Valley) showing a dense reddish brown fine mass and bimodal coarse inclusions (rounded calcareous coarse sands and quartz fine sands); (**c**) detailed view in plane analyzed light showing a weakly pedogenized loessic petrofacies. The correlation established here implies a transport of the raw clay materials on more than 100 km from the Negev to the ceramic production center in the Jordan Valley

Petrofacies and Provenance

All of the classes of petrofacies identified for each site are then analyzed depending on the characteristics of the deposit contexts for the period under consideration, revealed by paleogeographic studies. The local and micro-regional sources used and their initial structural states can be inferred based on the similarities established between the petrofacies and the contexts of local deposits (Fig. 3.7).

The types of petrofacies that are not compatible with the local deposits are considered to be exogenous materials. A macro-regional knowledge of the geological provinces can provide sufficient information to identify the depositional contexts. In other cases, this identification can be more difficult, either because the depositional contexts underwent profound geomorphological transformations during the course of time or because the macro-regional landscape is relatively homogeneous, for example, in a loessic context.

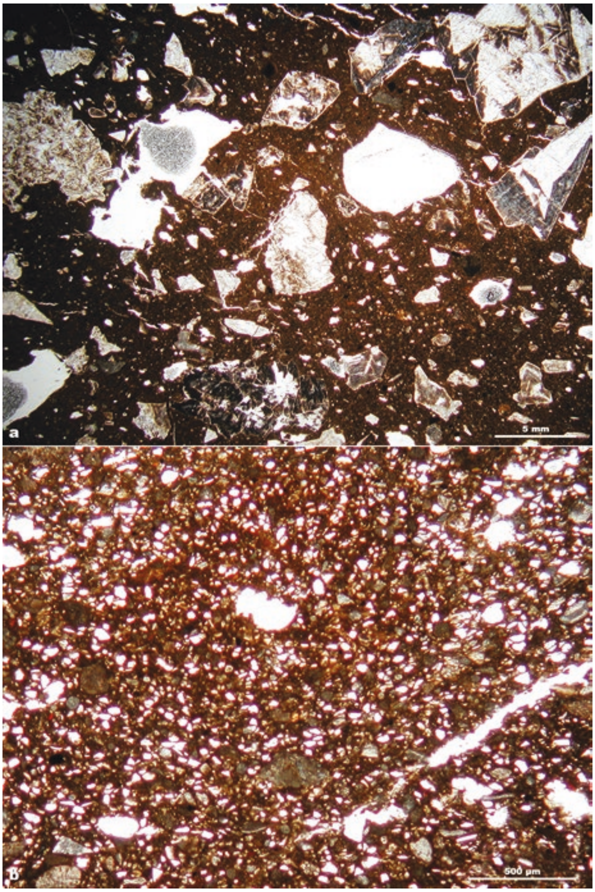

Fig. 3.7 Examples of particle-size continuity and discontinuity: (**a**) example of a sharp particle-size discontinuity revealing the intentional incorporation of temper formed of basalt, calcareous grains, and ferruginized sandstones in the form of rounded, coarse grains; the lack of a basaltic component in the fine mass indicates distinctive provenance of the coarse and fine components; (**b**) examples of particle-size and mineralogical continuities between the coarse and fine fraction revealing the identical source for the two component classes

In practice, the identification of clay sources is based on comparisons with a database made up of existing documents, observations of geological outcrops, superficial formations, and soils. Data from large-scale geological maps, at least 1:50,000, are the most pertinent although they must be used with caution as they give a biased idea of the spatial distribution and the geological nature of the superficial formations. Indeed, raw materials are generally extracted from superficial deposits in depositional contexts that react strongly to environmental changes, such as riverbanks and floodplain soils. Consequently, an adequate database of the available clay sources at a given time requires good knowledge of the paleogeographic state of the study region for the period in question. In addition, a detailed knowledge of the associated superficial formations and soils for past periods provides information on the variability of the source materials on a micro-regional scale. In this way, subtle differences in petrographic attributes can be used to subdivide a large group of clay materials, which correspond to the same regional type of geological formation, into distinctive entities from specific catchment areas within this geological formation.

3.2 From Fashioning to Firing

Methodology

The interpretation of ceramic recipients in terms of fabrication techniques relies on diagnostic features that provide information on the techniques, methods, procedures, tools, and/or gestures used.

One of the ways to bring these features to light is to carry out experiments. The principle is the following. We question the technical operations used for the production of certain traces. Hypotheses are made. We then design an experimental protocol where we vary one parameter at a time in order to bring to light, through comparison, the parameters playing a role in the formation of the traces in question. For example, when we focus on the tools used for surface treatment, we elaborate a protocol with varying tool types, clay materials, gestures, and degree of hygrometry of the paste. We compare the traces obtained. If some of them are specific to a single tool type, and if it is possible to explain their formation in terms of behavior of the materials, then we can consider that they are diagnostic, i.e., that they can be used as references to interpret equivalent archaeological traces.

The experimental approach is different from approaches aiming toward a formal reproduction. In this case, the resulting traces can only be considered to be diagnostic of the specific manufactured specimen. They must then necessarily be compared with diverse situations, in order to vary the parameters that may act on the formation of traces, and thereby assess to which extent they can be used as reference data.

Another approach is to conduct field experiments in an ethnographic context. This involves the construction of an experimental situation with familiar tasks and a familiar environment to the subject. The methodology should allow for a rigorous control of the parameters at stake, including the skills of the actors. In this way, in Senegal, Gelbert (Gelbert 2003a) asked 7 potters to make 72 water jars using the technique of molding and modeling by drawing, and modifying the dimensions of the pots, the temper, and the tool used, in order to bring to light the marks specific to each of these roughout techniques.

In experimental and ethnographic situations, the comprehension of the formation of the traces involves removing the recipients from the production process at different stages of the *chaîne opératoire* in order to evaluate the traces obtained for each stage.

In the domain of ceramic technology, diagnostic sets of attributes of the different techniques were brought to light after ethnographic observations and experiments in the laboratory and in the field. We refer to sets of diagnostic attributes as most often, it is the combination of attributes that is significant. Cases with one isolated unambiguous attribute are rare.

The attributes presented as diagnostic here were selected after the analysis of the mechanical deformation of the clay material. They correspond to results brought to light with experimental or ethnographic studies (e.g., Shepard 1965; van der Leeuw 1977; Rye 1981; Balfet et al. 1983; Rice 1987; Gelbert 1994; Huysecom 1994;

Courty and Roux 1995; Roux and Courty 1998; Martineau and Pétrequin 2000; Livingstone Smith 2001; Gelbert 2003b; Livingstone-Smith et al. 2005; Rosselló and Calvo Trias 2013; Lepère 2014). The features related to fashioning, and partly reported in the specialized literature, were tested on the one hand on ethnographic pottery produced according to different techniques and, on the other hand, on experimental series where the main parameters were varied, namely, the roughing-out and preform techniques, the clay material, the form of the recipient, and the care taken with the operations. The following techniques were systematically tested: roughing-out techniques without RKE on assembled elements (coils) and clay lumps (molding, modeling) and with RKE (wheel throwing) and preforming techniques without RKE (beating/ paddling) and with RKE (wheel coiling, wheel molding) (Gelbert 1994; Courty and Roux 1995; Roux and Courty 1998). The attributes related to finishing and surface treatments were also tested on ethnographic examples and on experimental series where the size of the temper, the degree of hygrometry of the paste (wet *versus* leather), the tools, and their water content were varied.[1] The following techniques were systematically tested: finishing on wet paste (smoothing) or leather paste (smoothing, brushing), with or without RKE, surface treatments by friction (softening, burnishing, shining), and coating (clay slurry, slip) (Roux 2017).

As for the diagnostic traits of decorative techniques and firing, they were mainly drawn from the existing literature.

For the attributes described in the literature, or those observed on experimental and ethnographic series, the descriptions have in all cases been reviewed with new descriptive approaches taking account of the forces applied, the tools and the gestures, as well as the different scales of observation.

Descriptive Grids

Two complementary and inseparable observation scales contribute to the identification of the different technical operations carried out during the fabrication process of a recipient: on the one hand, the macroscopic scale and, on the other hand, the microscopic scale. The first includes observation with the naked eye or at low magnifications with low-angled light. The second includes observation with the stereomicroscope (from 1 to x40) and the microscope. The reconstruction of the *chaînes opératoires* is more detailed and reliable when it is based on both of these observation scales.

This approach involves the use of distinctive analysis grids, which are based on the same principle: the parameters and variables used are in a position to record the deformations and transformations undergone by the paste when it is wet, leather-hard, and dry.

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[1] All of these experiments were conducted at the experimental center of Lejre (Denmark).

Macroscopic observation precedes the microscopic scale and the first examination of a sherd is carried out with the naked eye.

Macroscopic Scale

The descriptive grid for the macroscopic attributes applies to the internal and external surfaces of the recipients (Table 3.1). It includes attributes visible with the naked eye and others requiring observation with higher magnification.

– The first are likely to provide information on the forces applied to the paste, on the tools and gestures affecting the superficial layer of the recipient, and on firing and post-firing. These are the relief, type of fracture, the surface described in terms of shine and color, the decorative features, the color of the radial sections, and the degree of hardness.
– The second are related to the surface of the walls. They also undergo a set of deformations that depend on the forces applied, the water content, the type of clay material, the tools used, and the kinematics of the gestures.

Relief

The relief of a wall is directly influenced by the forces applied to the paste volume during roughing out and preforming. These forces affect the profile and topography of the walls.

The profiles are regular or irregular.

Table 3.1 Descriptive grid of the markers observable with the naked eye or with low magnification

Parameters	Variables	
Relief	Profile	
	Topography	Hollows Protrusions
Type of fracture	Orientation Profile	
Surface	Color	
	Shine	
	Granularity	
	Microtopography	
	Striation	Dimensions Layout Microrelief (edge, base)
Decorative traits	Morphology	Microrelief (edge, base)
Radial section	Color	
Hardness		

A regular profile presents either a progressively decreasing thickness or an equal thickness from the base to the top. On a whole or semi-whole recipient, the regularity of the profiles can be measured by an indicator based on the sum of the squares of the differences between the thickness on the right and on the left (in relation to the axis of symmetry of the recipient), where the number of thicknesses measured depends on the height of the recipient or the length of the profile.

Example: $(EpG1\text{-}EpD1)^2 + (EpG2\text{-}EpD2)^2 + (EpG3\text{-}EpD3)^2$

An irregular profile presents differences in thickness along the wall and between the right and left walls.

The topography of the walls is regular, discontinuous, or irregular (Fig. 3.8).

– A regular topography (inner and/or outer face) designates a uniform relief with a continuous plane.

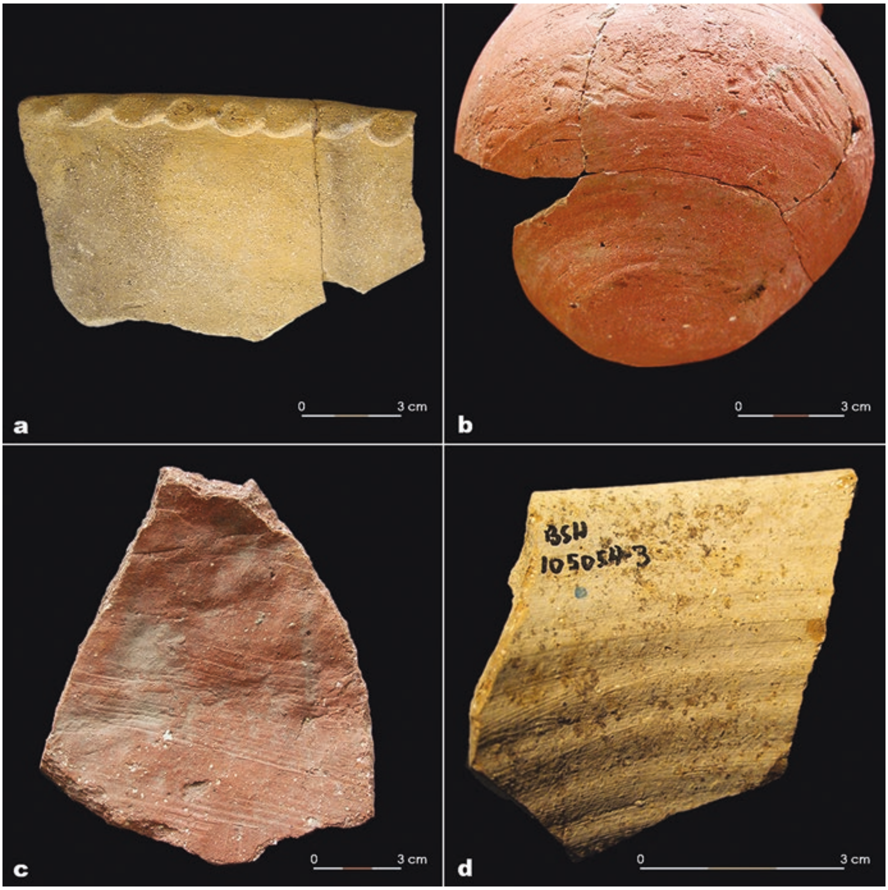

Fig. 3.8 Wall topography: (**a**) regular topography; (**b**) discontinuous topography; (**c**) irregular topography marked by protrusions and hollows; (**d**) irregular topography marked by concentric undulations

– A discontinuous topography (inner and/or outer face) designates a relief where the curve is not constant and presents secant planes. These planes are created during preforming (beating/ paddling, shaving, trimming).
– An irregular topography (inner and/or outer face) characterizes a relief with hollows and protrusions. The descriptive variables are the dimensions; morphology; the line, rectilinear and curvilinear (sinuous); orientation, vertical, horizontal, oblique, and concentric; and localization.

The *hollows* include depressions, fissures, crevices, cracks, and imprints (Figs. 3.9 and 3.10).

– *Depressions* are hollows with diffuse contours. When they are vertical and laid out in a rhythmic way, they correspond to finger prints on wet paste (Fig. 3.9a). Depressions with circular contours are called *concavities* or *cupules*, depending

Fig. 3.9 Examples of hollows: (**a**) vertical depressions; (**b**) crevices; (**c**) horizontal concentric fissure; (**d**) finger imprints left during thinning the bottom of the recipient

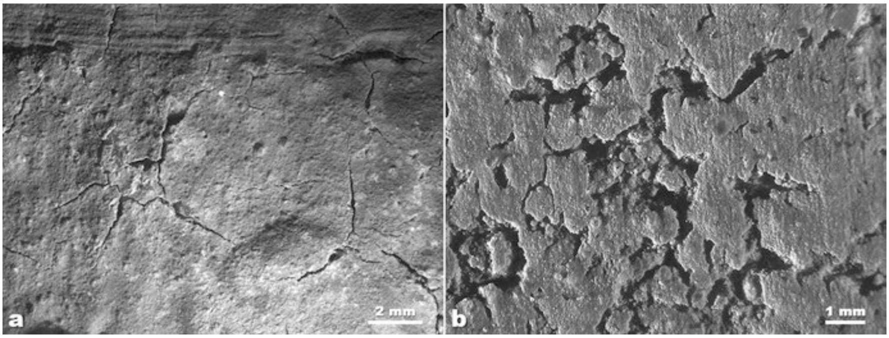

Fig. 3.10 Examples of cracks and crevices: (**a**) drying cracks; (**b**) crevices

on their size. They are created by hammer-type tools with a circular and convex active surface.
– *Fissures* are deep incisions situated at the limit of juxtaposed elements (Fig. 3.9c).
– *Crevices* are tears in the paste (Fig. 3.10b). They are either left by tools and formed after superficial pull-outs of a paste with too little hygrometry (leather consistency) or on the body of wheel-fashioned pastes stretched too fast (Fig. 3.9b). In the latter case, tears form as a result of the combined effect of shear stress and torsion. They appear easily on "meager" pastes, that is, pastes that do not have enough clay particles to compensate for the effects of shear creeping.
– *Cracks* are sinuous slits that appear during drying (Fig. 3.10a).
– *Imprints* are negatives left by artifacts or fingers during the course of the different fashioning and finishing operations (Fig. 3.9c).

Protrusions include concentric and intermittent protrusions. The former comprise undulations and bands, namely, undulations with a rectangular cross section. Intermittent protrusions include bumps, overthicknesses, crests, and compression folds (Figs. 3.11 and 3.12).

– *Bumps* are the expression of unequal pressures on the walls.
– *Overthicknesses* point to a movement of the clayey paste during joining (Fig. 3.11a), preforming, or finishing operations or to an application of clay coating (Fig. 3.12b). Regularly spaced internal concentric overthicknesses indicate an inner apposition of coils. Thin overthicknesses delimiting compact bands create *facets* obtained by the movement of the leather consistency paste (Fig. 3.12a).
– *Crests* are the result of an accumulation of clay slurry; they are present as filiform elevations (Fig. 3.12c).
– C*ompression folds* are obtained by the compression of the wall and are often located on narrowing zones (base and neck) (Fig. 3.11b).

A relief made up of bumps and hollows characterizes a bumpy surface, whereas a relief with regularly spaced concentric undulations characterizes an undulating surface.

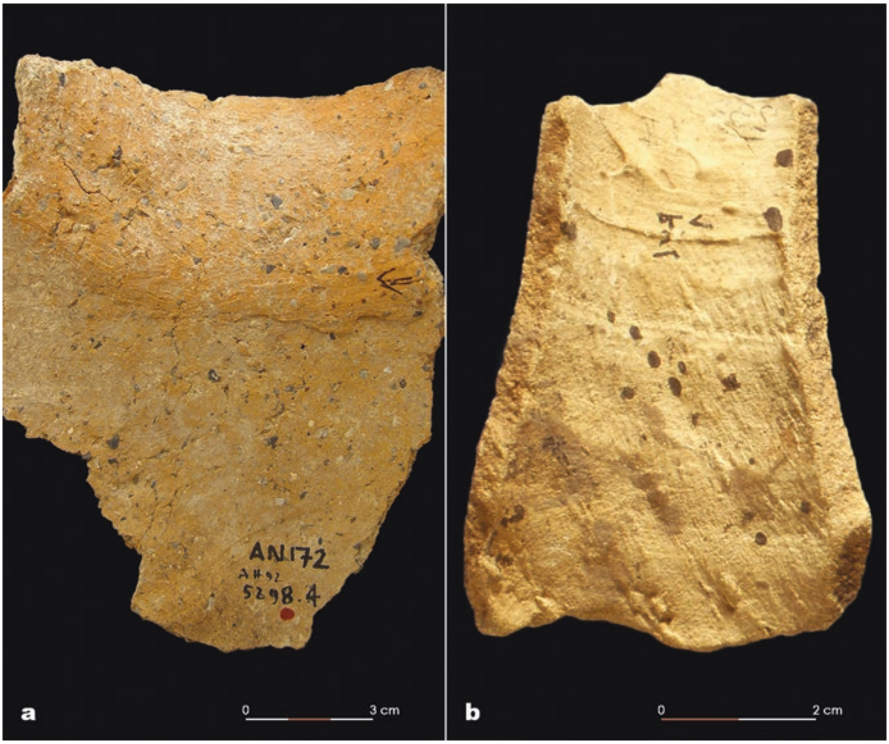

Fig. 3.11 Examples of overthicknesses: (**a**) overthickness created during joining of coils; (**b**) compression folds obtained with RKE

Type of Fracture

The types of fracture can provide information on the fashioning techniques and on the joining procedures between the assembled elements. The descriptive variables are the orientation and profile of the fracture from a longitudinal plane.

The orientation distinguishes fractures with a preferential or random orientation. The profile of the fracture differentiates straight fractures, arched fractures (U-shaped or rounded), or beveled fractures (internal or external [Fig. 3.13]).

The Surface

The descriptive parameters of the surface of a recipient are the color, shine, granularity, microtopography, and striation.

The *color* of a clayey surface can be classified into broad categories differentiating between an oxidizing atmosphere and a reduction atmosphere (pale color *versus* dark) and between a homogeneous and heterogeneous color (presence of more or less dark color stains linked to firing).

Fig. 3.12 Examples of overthicknesses obtained during surface treatments: (**a**) thin vertical parallel overthicknesses delimitating compact bands and creating facets; (**b**) overthickness due to clay coating; (**c**) crests due to an accumulation of clay slurry

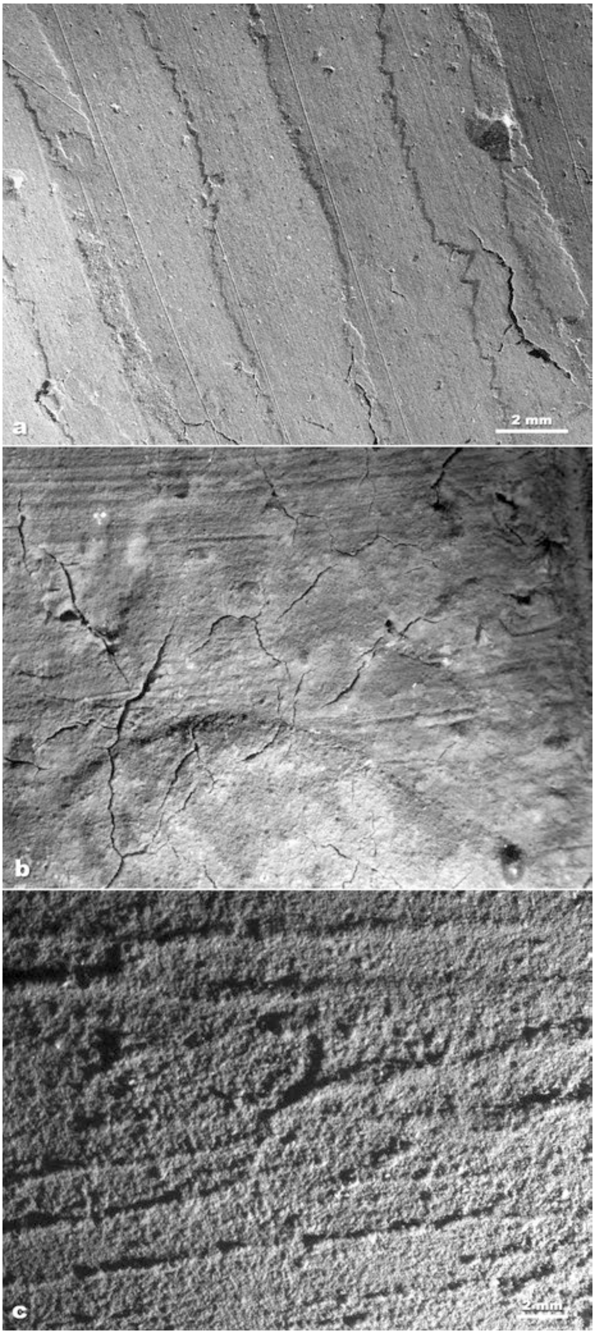

Fig. 3.13 Types of fracture: (**a**) U-shaped fracture; (**b**) rounded fracture; (**c**) beveled fracture

The *shine* defines a matt or shiny surface (Fig. 3.14). Shine can result from deposit conditions (deposits linked to use or burial) or technical operations (burnishing, shining, polishing). The distinction is made on a microscopic scale and is generally based on a meticulous examination of the context. When it results from technical operations, it is described in terms of the degree of shine and its extension on the recipient.

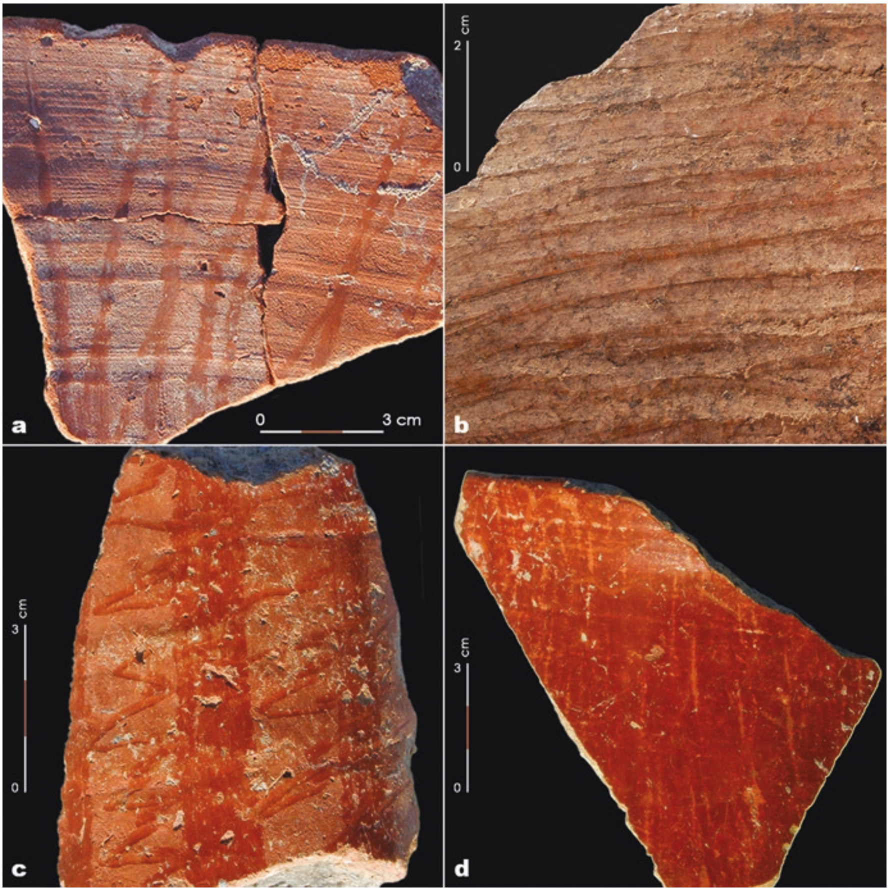

Fig. 3.14 Examples of shine: (**a**–**c**) shiny bands alternating with matt surface (**b**: ©S. Oboukoff); (**d**) covering shine

The *granularity* describes the irregularities that the coarse fraction grains form in relation to the fine mass. Five granularities have been observed which form five surface types (Fig. 3.15):

– *Protruding grains*: the coarse fraction grains stand out from the fine mass and form asperities; the grains are either *exposed or partially or totally covered* by a fine clay layer; in this latter case, the coarse fraction grains form elevations dispersed over the whole surface; this granularity forms on wet pastes with high shrinkage rates during drying or coated with clay material after fashioning. Surfaces with totally covered protruding grains are referred to as "lumpy."
– *Floating grains*: coarse fraction grains protrude on the surface; this granularity forms on pastes that have undergone coating operations.
– *Inserted grains*: coarse fraction grains are pushed into the clay paste and onto the same plane as the clay paste; this granularity is observed on pastes worked by percussion.

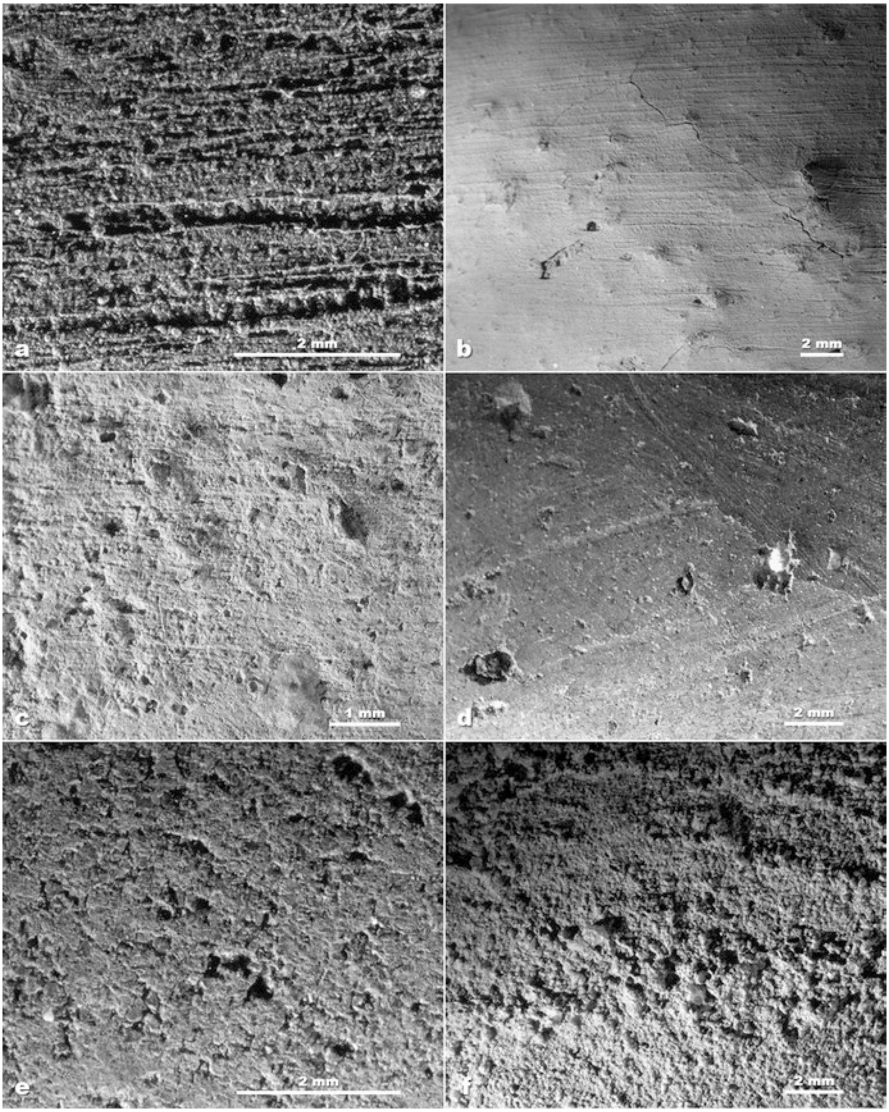

Fig. 3.15 Granularity: (**a**) protruding grains; (**b**) totally covered grains; (**c**) partially covered grains; (**d**) floating grains; (**e**) inserted grains; (**f**) micro-pull-outs

– With *micro-pull-outs*: coarse fraction grains are plucked out leaving negative micro-hollows; this surface is observed on pastes with leather-hard consistency after percussion blows.

The *microtopography* describes the state of the striated surface. It is smooth or irregular (Fig. 3.16):

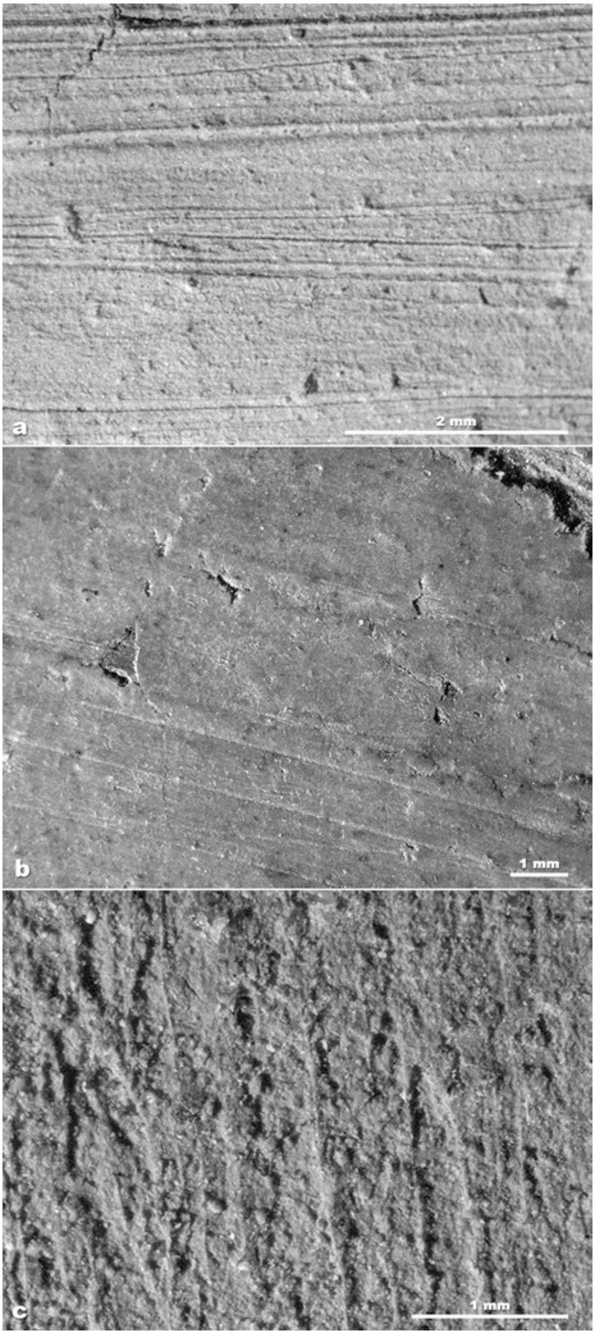

Fig. 3.16 Surface microtopography: (**a**) smooth, fluidified; (**b**) smooth, compact; (**c**) irregular

– *Smooth*: the state of the surface is fluidified or compact. In the first case, a fluidified film covers the surface; no pore is apparent (at low magnification), with nonetheless an emerging coarse fraction; this surface is observed on pastes

worked while wet with added water. In the second case, the pastes were worked by pressure while leather-hard or by percussion when wet or leather-hard.
– *Irregular:* this state is observed on pastes worked while wet with no added water.

The *striation* describes all of the linear marks running across the surface of the recipients. These marks result from a friction action against the clay paste with a tool (soft or hard), producing the movement or the plucking out of non-plastic grains. The striation can be described by three parameters: dimensions, layout, and microrelief.

– *Dimensions*: the striations are fine or coarse. In the literature, the term groove is sometimes used to describe wide and deep striations.
– *Layout*: this is regular or erratic. It can be described in terms of orientation (multidirectional, vertical, horizontal, oblique, concentric), organization (in parallel, subparallel, or intersecting bands), and development (continuous or discontinuous).
– *Microrelief*: the description relates to the bottoms and the edges (Figs. 3.17 and 3.18).

The bottoms present a fluidified or compact surface and indicate, respectively, a wet or leather-hard paste.

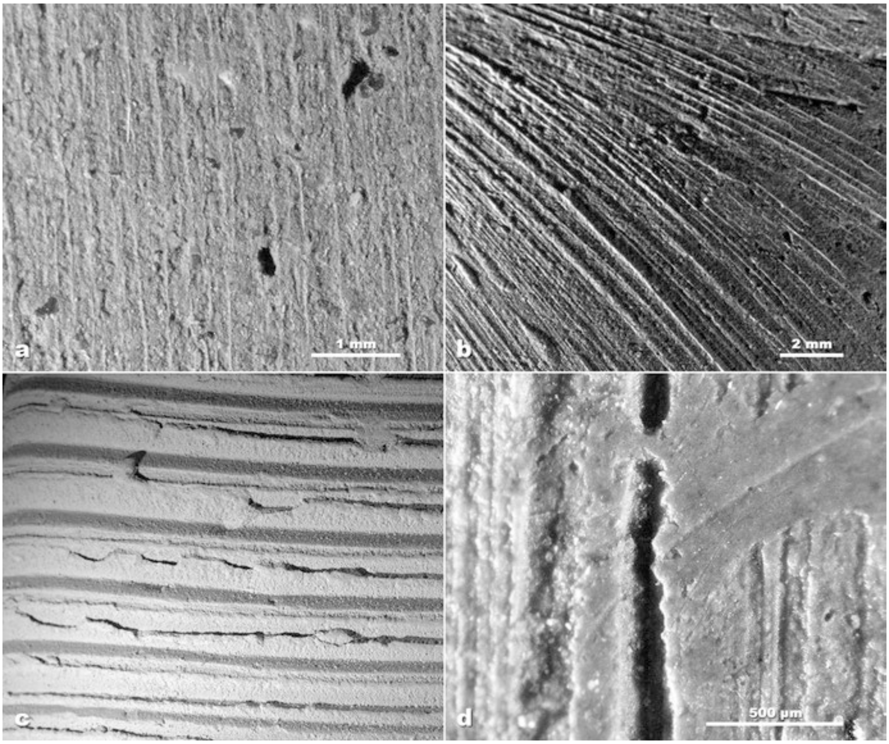

Fig. 3.17 Edges of striations: (**a**) threaded; (**b**) ribbed; (**c**) thickened; (**d**) scalloped

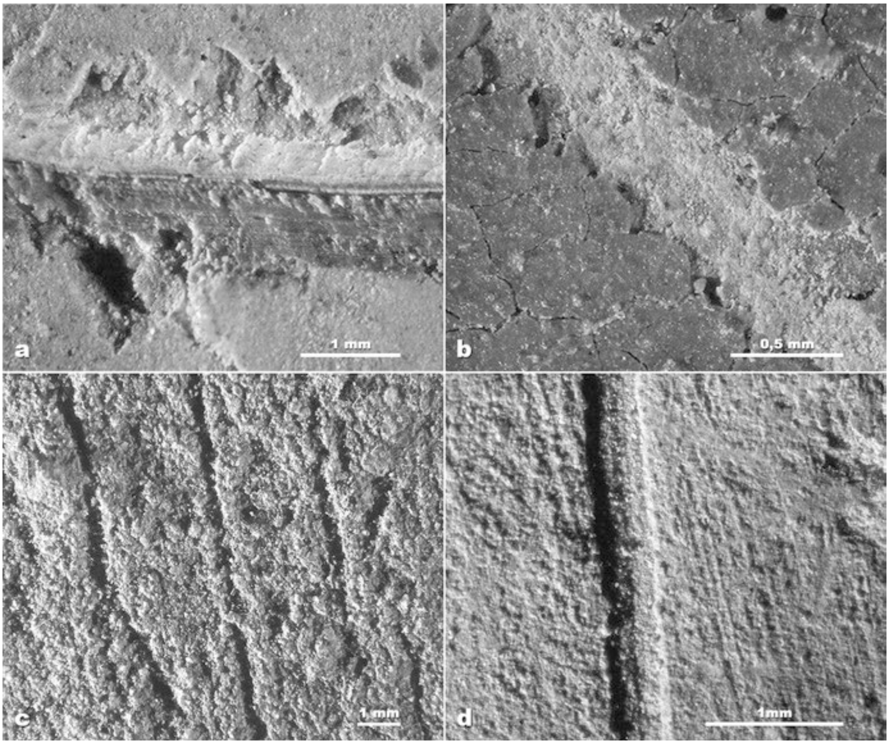

Fig. 3.18 Edges of striations: (**a**, **b**) scaled; (**c**) irregular; (**d**) regular

The edge morphology depends on the degree of hygrometry of the paste as well as the type of tool:

– *Threaded edges*: they are characterized by a trickle of clay slurry; they form on wet paste with no added water.
– *Ribbed edges*: they are characterized by a rib of clay slurry; they form on wet paste or leather-hard paste with added water.
– *Thickened edges*: they are characterized by varying degrees of thickening depending on the moisture content of the paste and the depth of the incision, and they appear as smears, crests, or bulges; they form on wet paste.
– *Scalloped edges*: they form a line of contiguous arcs and are obtained by the movement of leather-hard paste.
– *Scaled edges*: the edges present an angular cut and micro-removals produced by incision on dry or leather-hard paste.

Other types of edges exist, such as *irregular edges* (irregular with a tendency to close over the striation), *regular edges* (forming a sharp angle), or *diffuse* edges. However, they have been observed on wet and leather-hard pastes, with a hard and flexible tool, and are therefore difficult to interpret with current research methods.

Decorative Features

These include hollow or protruding surface features, for which the morphology is to be described, indicating the technique (impression, incision, excision), the tools, and movements used. In addition, like for the striation, the microrelief of the hollow features must be described (edges and bottoms) in order to determine in what hygrometric state the paste was worked and at which fashioning stage they were carried out.

Radial Section

The radial section of the walls can be described on the basis of the colors of the three zones structuring it: the outer margin, the core, and the inner margin.

Degree of Hardness

The degree of hardness of ceramics can be established with a durometer, or more approximately, based on their resistance to break. We can distinguish between clean or unclean breaks depending on whether they are clear or scaled. The former denotes a higher degree of hardness.

Meso- and Microscopic Scale

Deformation Regimes

The deformation undergone by the paste during the different production stages of a ceramic product is studied using a set of potential markers which are, like for the markers of paste preparation, porosity, the coarse fraction, and the fine mass. Generally, the organization acquired by the paste during roughing out and preforming is not significantly changed by later operations (finishing, surface treatment, decoration, drying, firing at less than 900 °C), and it is thus essential to characterize it for an accurate identification of the *chaîne opératoire*.

The pertinence of these markers for recording the deformations of a paste as a result of technical operations can be easily evaluated with the representation of an elementary volume of ceramic paste ready to be shaped, containing a fine fraction, pores, and coarse elements. The fine fraction and the pores are deformable, unlike the coarse grains. At the time of fashioning, the paste, in a specific hydric state (ratio of the volume of water to the volume of dry paste containing it), undergoes deformation as a result of the forces applied which are specific constraints (intensity, direction, direction of the applied forces). This results in a modification of its geometric properties. The degree of this modification varies depending on the observation plane and is particularly visible as voids, as well as translations and

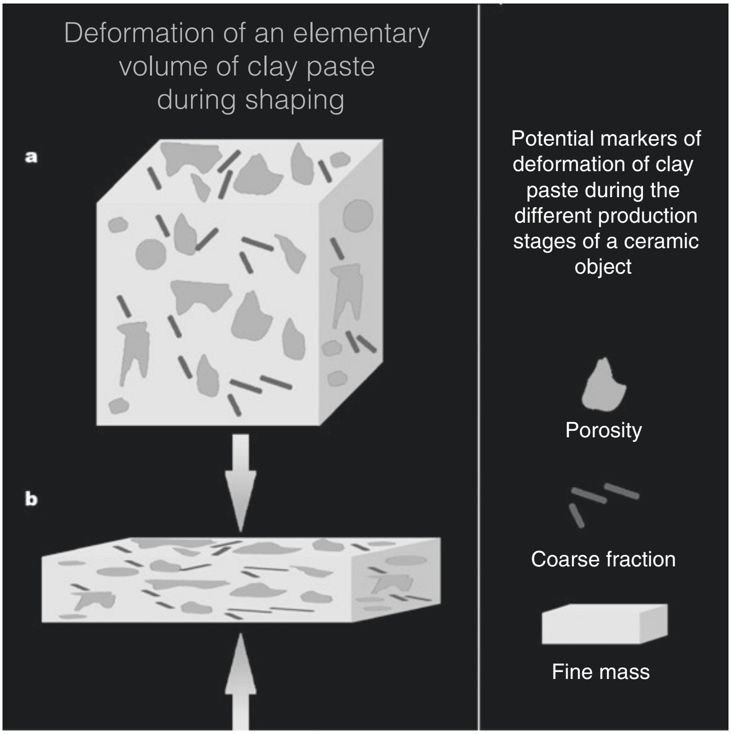

Fig. 3.19 Simplified view of the deformation of an elementary volume of clay paste (after Pierret 2001). This representation is at a mesoscale and does not take account of the deformations of the clay domains

rotations of the coarse asymmetric grains. At the scale of the fine mass and thus of the clay domains, the plastic deformation results in the movement or reorientation of the domains in relation to each other and in relation to the non-deformable coarse grains. This leads to the conclusion that the organization of the fine mass, the coarse asymmetric elements, and porosity are potential markers of the type of deformation that the paste undergoes during the different production stages of a ceramic object (Fig. 3.19).

Theoretically, the different types of deformation can be classified according to the constraints associated with each fashioning technique. Three theoretical situations can be distinguished (Pierret 2001): simple compression, compression combined with a revolving movement of the deformed mass, and shear stress (Fig. 3.20).

Simple compression is applied with percussive fashioning techniques: slab technique, hammering, molding, and beating. Deformation consists of the flattening of the pore systems and the clay domains along the plane perpendicular to the axis of maximal stress.

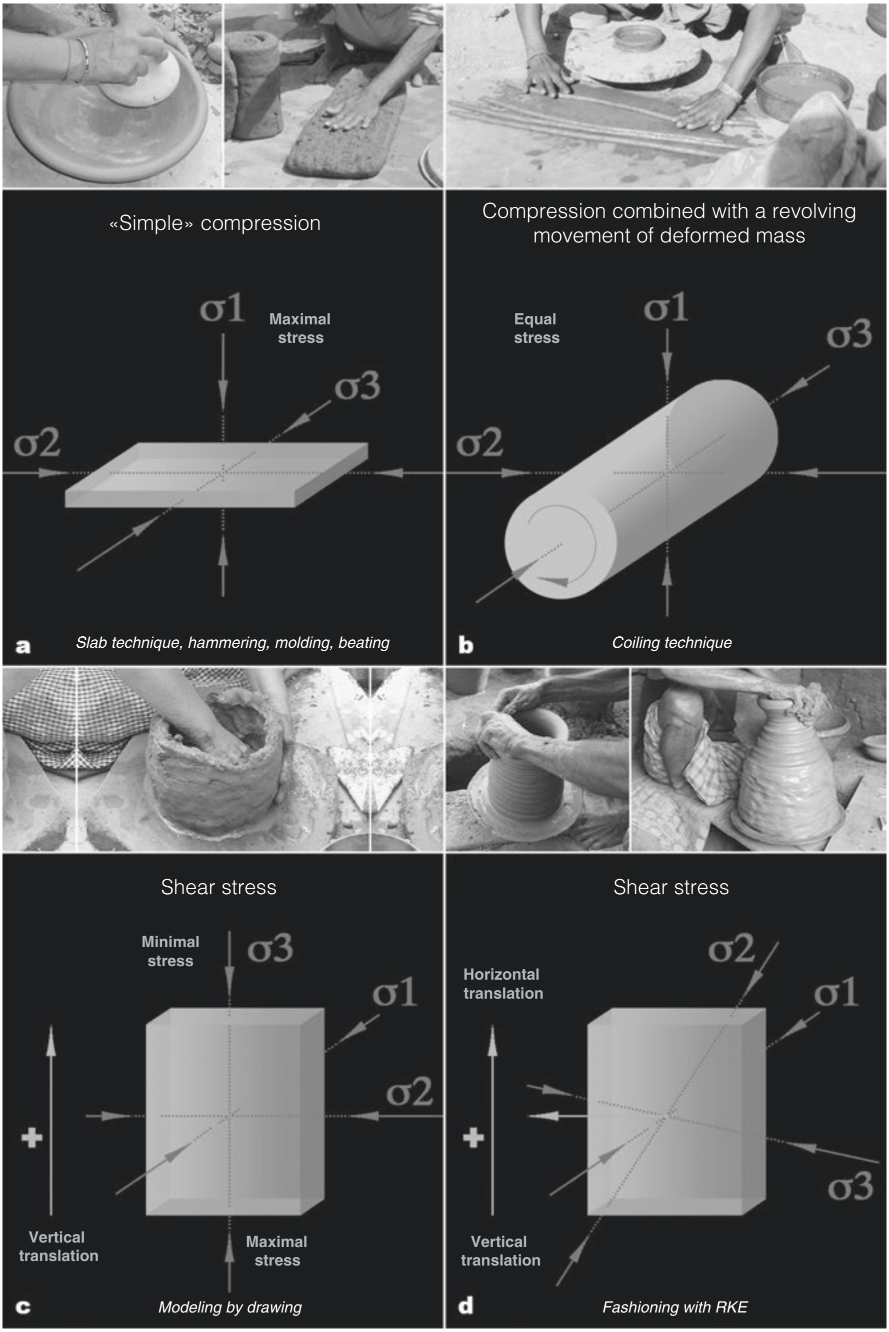

Fig. 3.20 Theoretical classification of the mechanical stresses associated with the different fashioning techniques (after Pierret 2001): (**a**) planar anisotropy (flattening along the plane perpendicular to the axis of maximal stress); (**b**) linear anisotropy (drawing along the axis of minimal stress); (**c**, **d**) plano-linear anisotropy (drawing along the axis of minimal stress and flattening along the plane perpendicular to the axis of maximal stress)

Compression combined with a revolving movement of the deformed mass is applied with the coiling technique. The deformation of the pore system and the clay domains consists of drawing with torsion expressing the revolving movement.

Shear stress is applied on the one hand by techniques using drawing during fashioning (coiling and modeling by drawing) and on the other hand by techniques using RKE during fashioning, i.e., wheel coiling and wheel throwing. In the first case, there is a vertical translation of the point of application of the main constraint. In the second case, there is a vertical translation of the point of application of the main constraint, along with a horizontal translation of the deformed mass. The deformation consists of drawing along the axis of minimal constraint, as well as flattening in the plane perpendicular to the axis of maximal constraint.

Descriptive Attributes of the Markers of Deformation

The markers of deformation – porosity, coarse fraction, and fine mass – are observed:

– On the ceramic assemblages over centimetric zones (of about 2 cm) in fresh radial section
– If necessary, on thin sections with a petrographic microscope and on fresh sections with a scanning electron microscope
– On the whole recipient using radiography (see the inset on radiography by Pierret)

Porosity includes the voids acquired during the preparation of the paste (air bubbles trapped in the paste), fashioning (air bubbles trapped between assembled elements), and drying and firing (structural discontinuities). It thus consists of a pore system defined by pore morphology and orientation which provides information on the type of constraints applied to the material during the course of mechanical deformations. The elementary types of pores include cracks, fissures, cavities, and vesicles (subcircular to elliptic voids) (Fig. 3.21). The pores left by the degassing of air bubbles present clear walls, unlike the voids resulting from the combustion of the organic residues included in the paste; the latter frequently show lignocellulosic or siliceous residues. The cracks and fissures are generally rectilinear and correspond to shrinkage cracks but can also be sinuous cracks at the limit of assembled elements. Poly-concave cavities can also appear, most often between two assembled elements. Fissures and cavities can reveal joining procedures: rectilinear, U-shaped, rounded, or internal or external (oblique) beveled joints. They can also reveal the successive layout of the assembled elements, in particular in the case of the junction between the base and the body.

The very fine microporosity of the clay domains, which is only visible at high magnification, is a characteristic of the raw material and does not vary with fashioning techniques. Therefore, it is not taken into consideration here.

The coarse fraction is described in terms of distribution, i.e., arrangement and orientation.

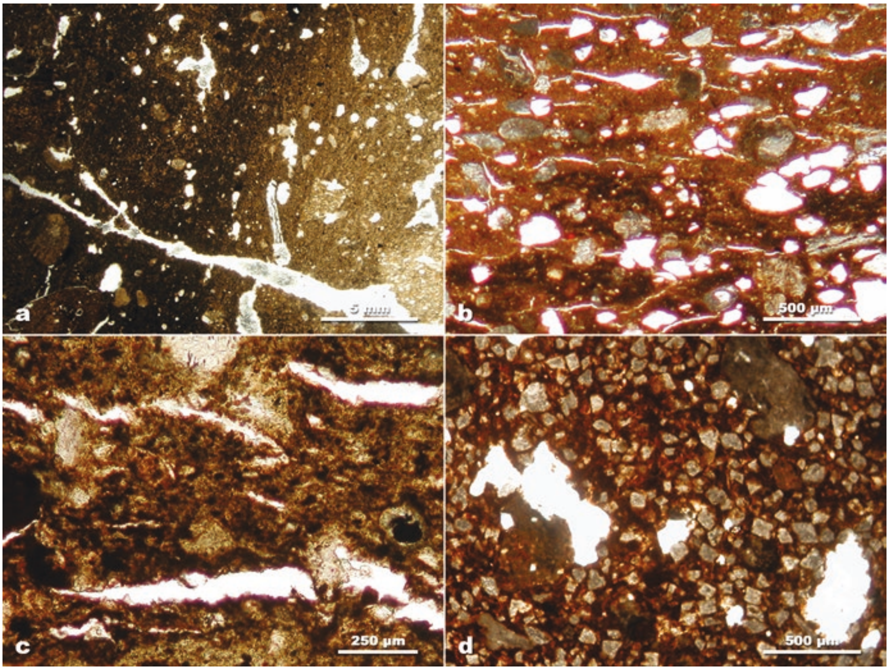

Fig. 3.21 Illustration of the types of pores often present in ceramic petrofabrics: (**a**) cracks and cavities; (**b**) fissures and cavities; (**c**) cavities and fine fissures; (**d**) vesicles

On fresh sherd sections, the fine mass is described in terms of compactness, morphology, and orientation of the structural elements (clay domains and coarse constituents) with a stereomicroscope.

The study of thin sections with a petrographic microscope combines observations carried out with natural light and polarized light in order to identify the arrangement of the clay domains through their contact surfaces and internal fabrics (birefringence assemblage). Birefringence assemblages are frequently obliterated, or even destroyed (amorphization) by firing, which impedes the identification of the arrangement of the clay domains (Fig. 3.22).

Diagnostic Features of Fashioning Techniques and Methods

The diagnostic features of fashioning techniques and methods result from mechanical stresses that define the deformation of the volume and superficial layer of the paste in a state of variable hygrometry.

Two main types of deformation distinguish the two main families of roughout techniques, that is, with and without rotary kinetic energy (abbreviated RKE). First of all, the aim is to identify them and then to identify the different operations carried out.

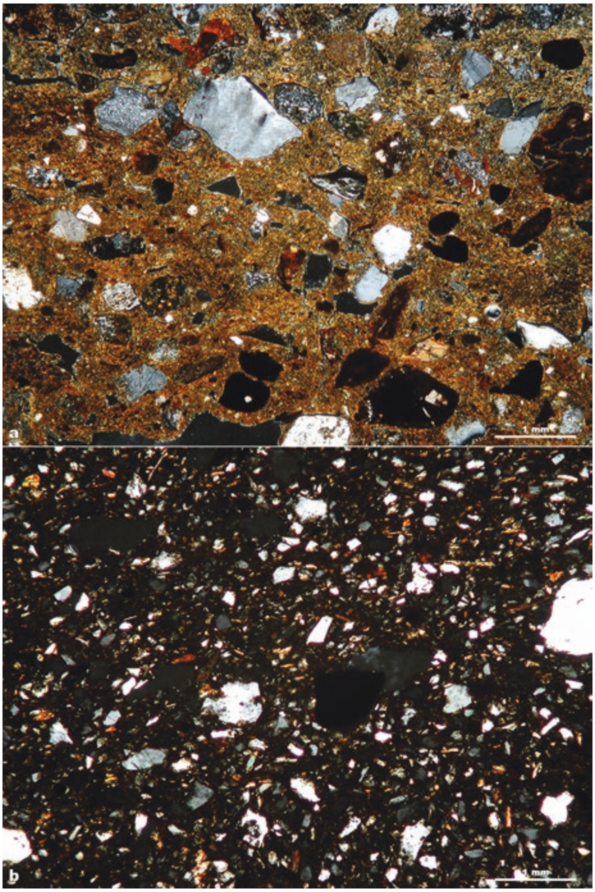

Fig. 3.22 Illustration of birefringence assemblages characteristic of ceramic petrofabrics: (**a**) birefringence assemblages non-obliterated by firing; the arrangement of the clay domains is visible; (**b**) birefringence assemblages obliterated by the firing of the clay mass given the transformation of iron oxides and the ensuing amorphization of the clay mass; the arrangement of the clay domains is not visible anymore

Roughing Out Without RKE

Roughing out without RKE is characterized by the absence of transformation of the walls with RKE. This absence of transformation is materialized by the following characteristics:

– Absence of concentric parallel striations covering the internal and/or external walls of the recipients
– Absence of walls with a regular profile characterized by regular decreasing thicknesses from the base to the top of the wall

The absence of a combination of these marks reveals roughing out without RKE. The sole presence of parallel concentric striations on the neck or on the walls can result from a simple rotational movement when the walls are smoothed.

Roughing out without RKE can either be carried out on assembled elements or on a clay mass using a combination of techniques for shaping the same recipient. The identification of these techniques is thus based on the different parts of the recipient.

The distinction between assembled elements and clay mass is a first level of identification based on the observation of a set of characteristics with the naked eye and at low magnification. An identification of the techniques used in these categories involves more detailed observation scales.

Roughing Out Without RKE Using Assembled Elements

As we saw in the previous chapter, there are two roughing-out techniques for assembled elements: coiling and slab forming, where the former corresponds to shaping by pressure and the latter to fashioning with direct percussion.

Coiling

The topography, the type of fracture, and the meso- and microstructures yield diagnostic features which must be combined, when possible.

Macroscopic Features

The main diagnostic feature is an irregular profile and a relief marked by rhythmic undulations that are perceptible by touch. These topographic features point to elements assembled by discontinuous pressures (Fig. 3.23a).

The other diagnostic feature is the presence of overthicknesses or rectilinear or curvilinear concentric fissures indicating coil joints that were not obliterated by subsequent scraping or smoothing operations. These overthicknesses or "coil seams" are due to the movement of the paste by discontinuous pressure for joining coils. When the overthicknesses and fissures are equidistant, they indicate the width of the coils (Fig. 3.23b, c).

Fissures in the form of a lying down Y correspond to the connection of the two ends of a ring-mounted coil. These traits are visible on rather careless productions or on the inner or outer faces of recipients, depending on whether they are closed or open, where finishing could have escaped the artisan's attention (Fig. 3.23d, e).

On the outer base of the recipients, the presence of a concentric fissure parallel to the outer edge indicates the addition of an external coil around a disc obtained from a mass of clay. The presence of several concentric fissures indicates a base made from juxtaposed or spiralled coils (Fig. 3.24).

The assemblage of elements creates fragile zones favoring the development of preferential horizontal fractures parallel to the direction of the coils. When the fracture covers almost the whole circumference of a large recipient, it points to a drying phase geared toward avoiding the collapse of the recipient under its own weight; this creates a difference in the hygrometry of the body of the recipient and the new coil (Fig. 3.25).

The profile of the breaks can indicate the different coiling techniques used (Fig. 3.13).

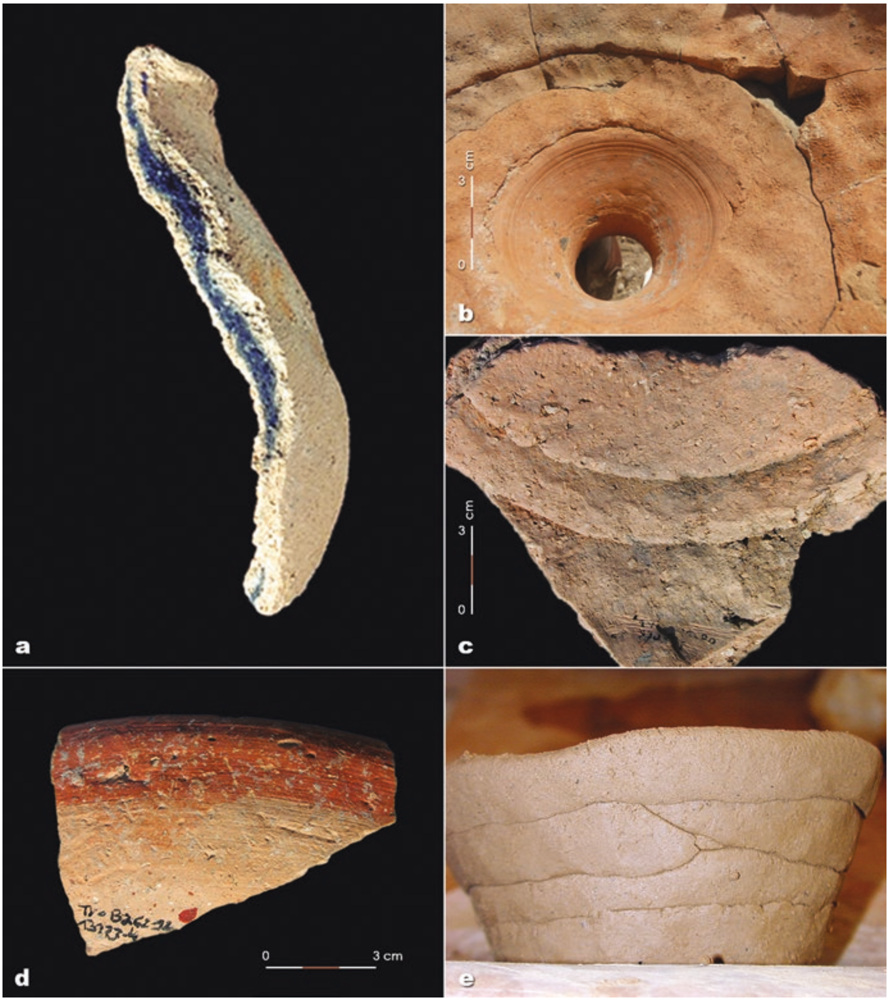

Fig. 3.23 Diagnostic features of the coiling technique: (**a**) irregular profile marked by rhythmic undulations; (**b**) concentric fissures; (**c**) concentric overthicknesses; (**d, e**) fissures in the form of a lying down Y

U-shaped and rounded breaks indicate coiling by pinching. The U-shaped breaks correspond to the hollow imprint of the edge of the upper coil, whereas the rounded breaks correspond to the lower edge of the upper coil. They indicate that the upper coil was placed on the edge of the lower coil without changing the general orientation of its profile. In the same way, straight breaks indicate that the coil was positioned without modifying the section of the preceding coil.

Beveled breaks indicate coiling by pinching or spreading (on the inner or outer face).

Alternating beveled breaks indicate the alternate placing of the coils (alternating external and internal bevel joints).

Fig. 3.24 Diagnostic features of coiled bases: (**a**) concentric parallel fissures; (**b**, **c**) concentric overthicknesses; (**d**) concentric fissure indicating the addition of an external coil around a clay disc

Fig. 3.25 Preferential horizontal fracture indicating a drying phase aimed at avoiding the collapse of the recipient under its own weight (©S. Manem)

Meso- and Microstructures

Porosity, the coarse fraction, and the fine mass are the different attributes for identifying coiling techniques and joining procedures, independently of subsequent preforming and finishing operations.

Macroporosity, observed on the radial plane of the walls, provides the diagnostic attributes for identifying coil joints and their layout. Coil joints are shown by long fissures or elongated vesicles. They can be rectilinear, semi-circular, or oblique and indicate the joining procedures (Fig. 3.27a, b). The distance between two joints is indicative of the size of the coils. The deformation of the coil during joining and preforming operations can play a role in the angle and the length of the fissure. The more the coil is deformed by discontinuous horizontal pressures (like with coiling by spreading), the more the joining fissure is elongated along an obtuse angle (Fig. 3.26b).

It is possible to observe U-shaped or rectilinear joints together on the same profile if the gestures are not very systematic, as a simple difference in pressure can produce either type of joint (Fig. 3.26a). In this way, in a given assemblage, if the recipients are mounted with U-shaped and rectilinear joints, they cannot be used as criteria of different ways of making ceramics, but rather as the expression of non-systematic gestures.

In the archaeological literature, sometime the S-shaped configuration is mentioned, which is said to correspond either to placing coils along a beveled joint, which are then thinned and stretched (Livingstone Smith 2001), or to placing coils along an alternating external/internal bevel, followed by thinning which increases size (Martineau 2000). When there are alternating external and internal oblique joints, accompanied by a subcircular or elongated pore system, this necessarily represents a case of alternate coiling by pinching or spreading (Fig. 3.26c). Oblique parallel joints correspond to either external or internal joining procedure.

In the specific case of the voids observable on the radial section of the bases, spiral coiling induces vertical parallel or divergent oblique voids on both sides of the center of the recipient (Fig. 3.27c). The layout of the coils at the base/body junction is identifiable based on the direction of the coil joints (Fig. 3.27d).

The distribution of the coarse particles can underline the revolving movement applied during coil shaping, particularly for the careful preparation of pastes with high plasticity.

Coils can be characterized by clayey aggregates laid out in an S-shape or a parallel orientation. This difference in layout indicates variability in the degree of compression exerted on the coils (Fig. 3.28). Coils that undergo slight deformation, like in the case of the pinching technique, tend to present a meso-structure with an S-shaped orientation, providing evidence of the revolving movement applied during the shaping of the coil. Coils that undergo medium deformation, like the case of the spreading technique, tend to present a meso-structure with a marked oblique orientation. Coils that undergo strong deformation, like the case of the drawing technique, tend to present a meso-structure with a vertical subparallel orientation.

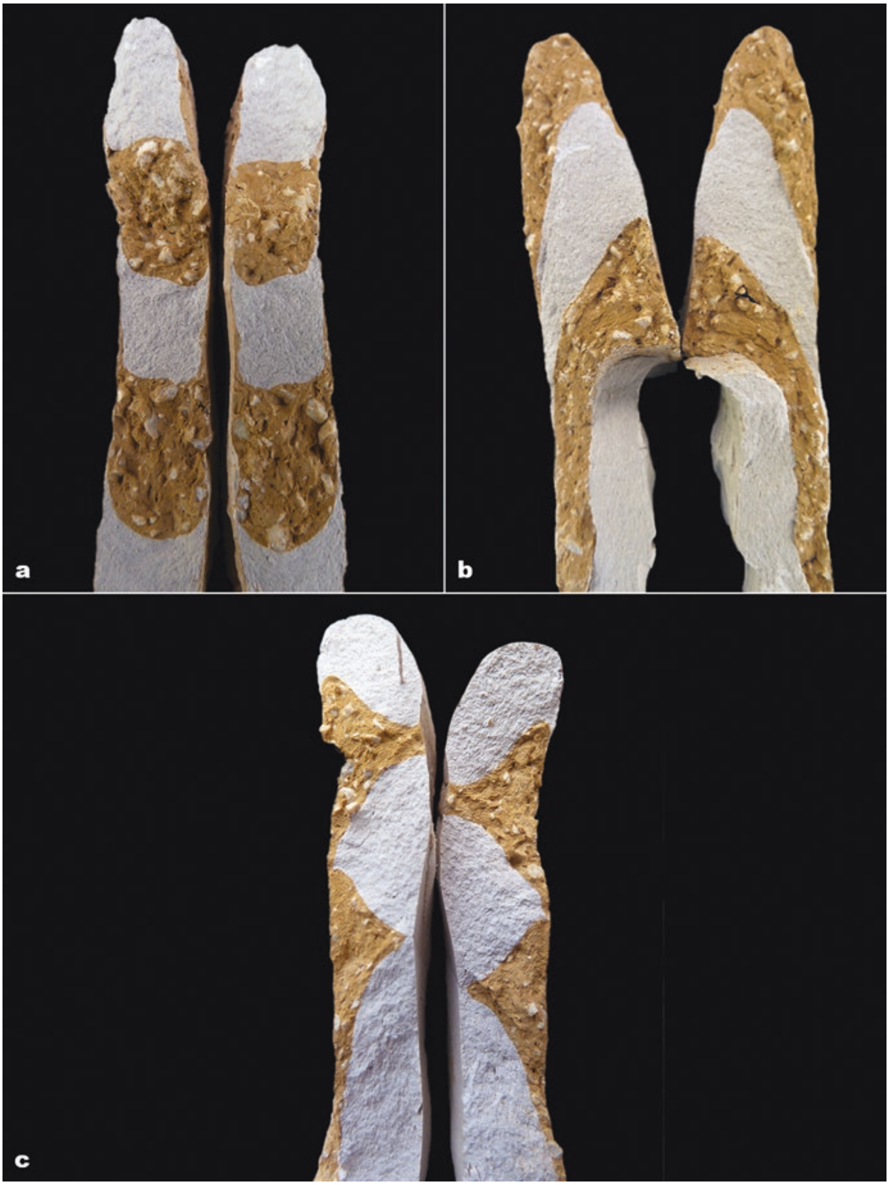

Fig. 3.26 Examples of joints of coils on experimental material: (**a**) horizontal and U-shaped joints obtained with coiling by pinching according to non-systematic gestures; (**b**) beveled joints obtained with coiling by spreading; (**c**) alternate beveled joints

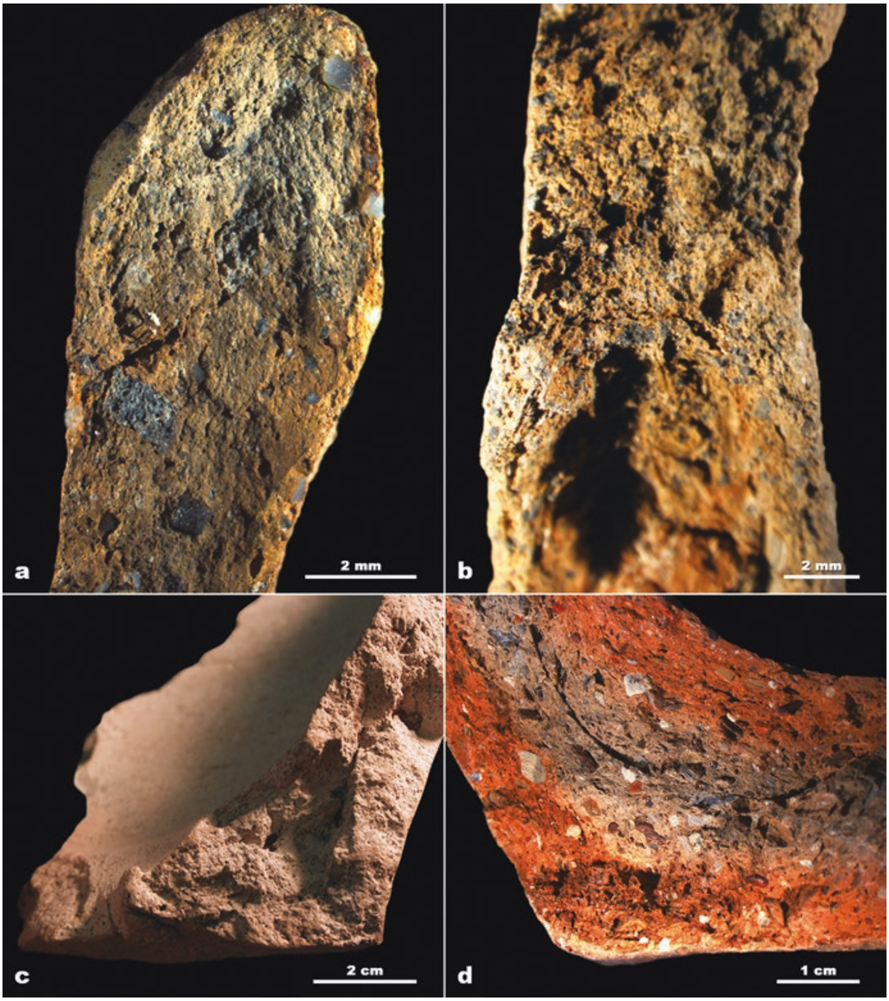

Fig. 3.27 Examples of joints of coils on archaeological material: (**a**) oblique fissure; (**b**) rounded fissure (convex); (**c**) double curvilinear fissures indicating the placing of two coils at the junction between the base and the body; (**d**) curvilinear fissure indicating the placing of a coil at the junction between the base and the body

In the fine mass, the juxtaposition of zones characterized by distinct microstructures, dense and poorly organized zones associated with zones with subparallel alignment, points to discontinuity and consequently to assembled elements. Large coils that undergo deformation by drawing tend to present fine fissures with subparallel orientation combined with a similar microstructure to that found on clay lumps deformed without RKE, that is, with little transformation and random orientation (Fig. 3.29).

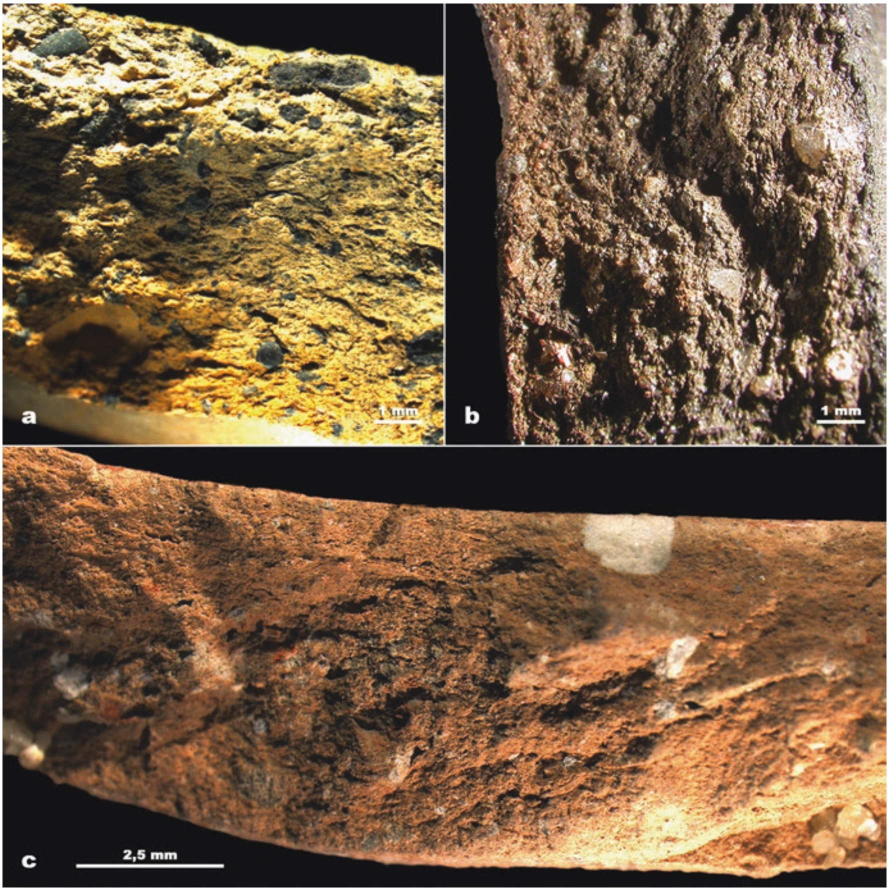

Fig. 3.28 Examples of microstructures associated with the coiling technique and observed with a stereomicroscope: (**a**, **c**) poorly deformed coils with a mesostructure in an S-shape; (**b**) microstructures contrasting subparallel fine fissures and a microstructure with random orientation (ethnographic Cushitic shard, Kenya; coiling by pinching, ©N. F. M'Mbogori)

Slab Technique

Like coiled roughouts, slab roughouts are made up of assembled elements. Consequently, all of the attributes indicating coil joints are also valid for indicating slab joints.

On the other hand, unlike for coils, slabs are not obtained by rolling, but by percussion. This results in a pore system where the orientation is parallel to the wall and, depending on the degree of percussion, in laminar fissuring. However, these characteristics are not unequivocal.

In fact, on one hand, elongated voids with preferential orientation subparallel to the elongation of the walls are also observed with the coil technique by drawing,

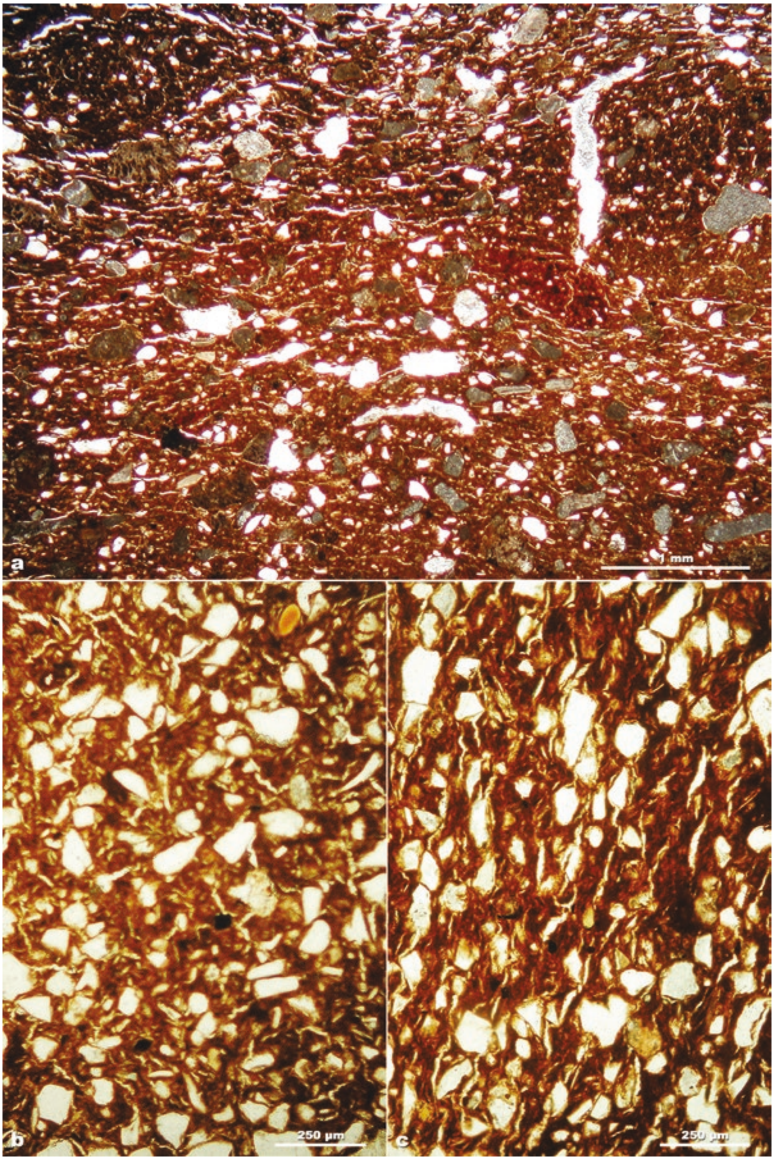

Fig. 3.29 Examples of microstructure associated with the coiling technique observed under the petrographic microscope: (**a**) fine mass, in non-polarized analyzed light, at a coil joint, underlined by a residual cavity orthogonal to the stretching axis; (**b**) microstructure typical of the weakly transformed internal part of the coil showing a random organization of clay domains; (**c**) microstructure typical of the elongated part of the coil, modified by discontinuous pressures, and showing fine fissures with a subparallel orientation associated with a microstructure formed of dense, elongated, imbricated clay domains

and on the other hand, laminar fissuring can also be obtained on coils preformed by percussion on wet clay.

In addition, it is important to point out the case of small- or medium-sized recipients made with a single vertically positioned slab which is then vertically joined. These recipients generally undergo strong subsequent deformation during leather-hard consistency preforming. For these recipients, it is extremely difficult to distinguish between a roughout made with a slab and a roughout made by modeling, unless fractures point to a preferential vertical orientation.

Lastly, one might wonder whether the morphology of the assembled elements allows to distinguish between coils and slabs. For large-sized recipients, the coils can be very big and can undergo a lot of thinning by drawing, until they attain comparable heights to slabs. In these conditions, the height of an assembled element cannot be used as a criterion for distinguishing between coils and slabs.

The slab technique is identifiable when several slabs make up the same row. In this case, the distinctive slab criteria are vertical and horizontal fractures and a compressed pore system with a subparallel tendency.

Roughing Out a Clay Mass Without RKE

Three roughing-out techniques without RKE on a clay mass can be identified: modeling, molding, and hammering. For these three techniques, first of all, it is essential to check whether the body of the recipient, or part of the body, is not made up of assembled elements but is made from a clay mass. The first discriminating criterion is thus, on the one hand, the absence of features indicating joints between assembled elements and, on the other hand, fractures with random orientation, due to the absence of zones of fragility linked to the assemblage of different elements. When fractures with preferential orientation are observable on parts shaped from a lump of clay, they indicate a junction between two molded parts or a junction between a molded (or modeled) part and a coiled part, for example.

Roughing Out a Clay Lump with Pressure

Roughing out a clay lump with pressure consists of modeling by pinching or by drawing.

Modeling by Pinching

Modeling by pinching is mainly used for making small recipients. The profile of these recipients presents differential thicknesses combined with an uneven relief characterized by alternating bumps and intermittent hollows spread relatively regularly over the surface and corresponding to interdigital pressures applied to the clay mass in order to thin it.

Modeling by Drawing

Macroscopic Attributes

The regularity of the final profile of the walls depends on the care taken during the shaping stage on leather-hard paste. It rarely attains the regularity of pottery made by molding over a convex shape (Fig. 3.30c). The base is thick and often irregular at the base of the pot, which can be explained by the fact that there is no control over thickness during shaping (Fig. 3.30d).

The relief of the internal surface can comprise depressions resulting from the pressures exerted with the fingers on the internal wall of the pottery during the hollowing and stretching of the lump of clay. These marks are generally masked during thinning and shaping operations, but they sometimes remain visible in the lowest zone of the internal wall. It is also possible to observe a small concavity in the center of the internal base of recipients modeled by drawing (Fig. 3.30a). This concavity forms when the clay lump is hollowed. According to Gelbert (2003b), this mark is rare as it is generally erased during finishing operations, but its presence is characteristic.

The relief of the external surface is uneven, with bumps indicating discontinuous finger pressure on the walls. When a forming support with a concave diameter is

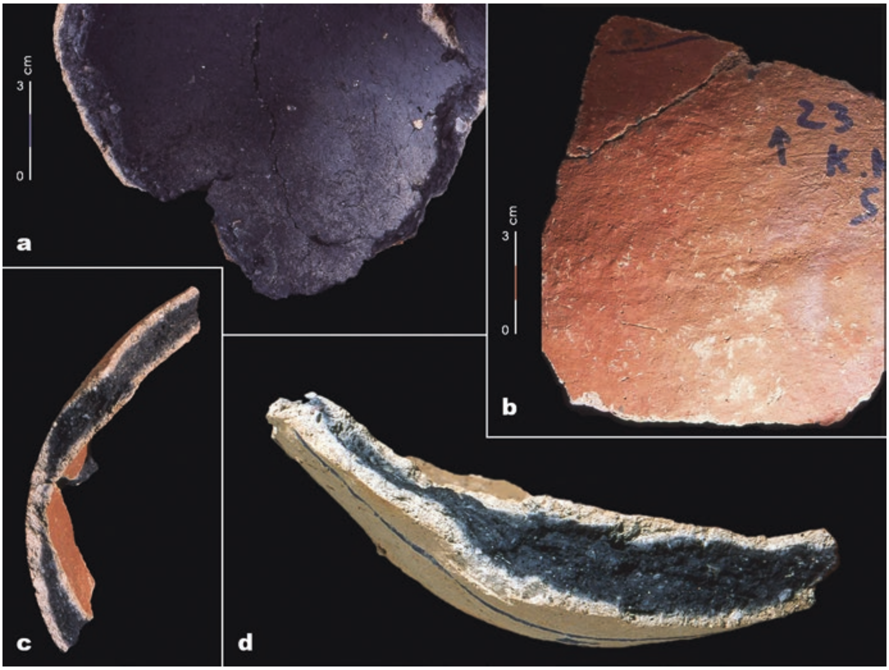

Fig. 3.30 Macroscopic diagnostic attributes of modeling by drawing: (**a**) small concavity formed when the clay is hollowed; (**b**) concentric horizontal depression created by the forming support; (**c**) irregular profile of the body; (**d**) irregular profile of the base (©A. Gelbert)

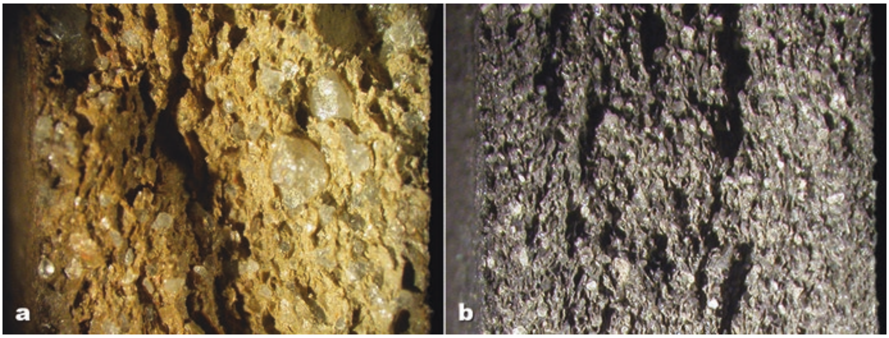

Fig. 3.31 Diagnostic microstructures of modeling by drawing – networks of elongated fissures and subparallel orientation of the asymmetric coarse fraction: (**a**) Bantu modeled ceramic; (**b**) Danish modeled ceramic

used, it leaves a concentric horizontal depression on the exterior of the base of the pot (Fig. 3.30b). This very characteristic trace is often erased during the finishing stage.

Microstructures

At this observation scale, the diagnostic traces are, on the one hand, the absence of discontinuity characteristic of coil joints and, on the other hand, a deformation of the clay domains of the paste characteristic of a vertical compression of a clay mass (Fig. 3.31). This consists of:

- Networks of elongated fissures following the direction of the stretching of the paste and showing a subparallel orientation to the elongation of the walls
- The asymmetric coarse fraction showing a subparallel orientation to the elongation of the walls
- Clay domains aligned along a subparallel orientation due to the stretching effect
- Occasionally, large aggregates of slightly transformed raw materials that point to lighter compression for modeling by drawing than for coiling

Roughing Out the Clay Mass with Percussion

Roughing out a clay mass with percussion includes molding and hammering. These two techniques present many similar traits.

Macroscopic Traits

The first trait indicating percussion is a profile of the lower part with regular curves characterized by thin and even walls from the base to the top (Fig. 3.32a). The molding and hammering techniques allow the artisans to control the thickness of the wall during shaping. This thickness often contrasts with the thicker upper part of the

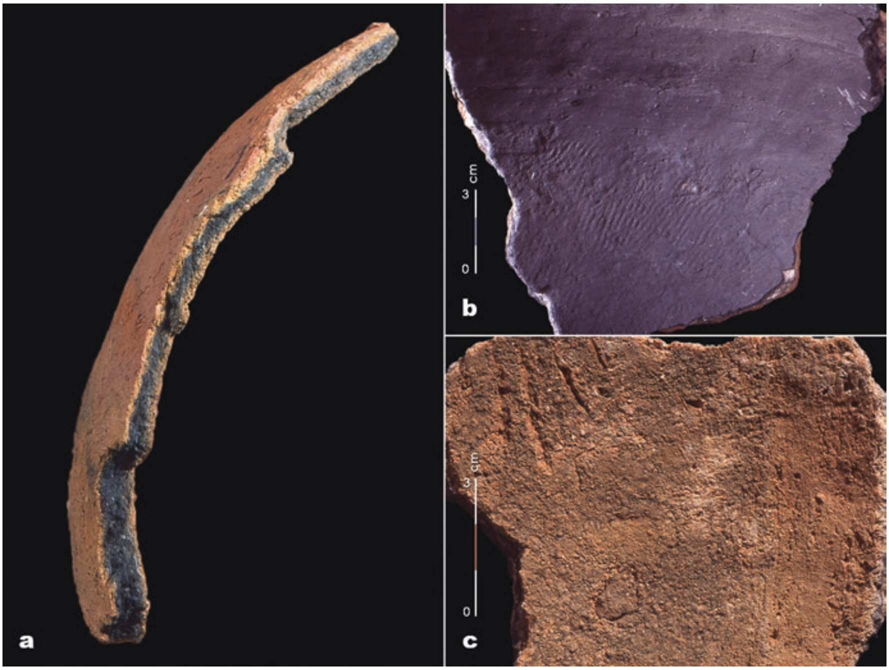

Fig. 3.32 Diagnostic features of fashioning by percussion: (**a**) regular profile; (**b**) imprint of the forming support; (**c**) anti-adhesive on the face in contact with the forming support

recipient when it is made with another technique. This junction can be located at different heights of the recipient. It leaves a visible joint on the internal wall, on the external wall, and/or on the side (Fig. 3.33c). This joint is also a preferential fracture zone in case of shocks.

The second trait is related to the relief of the outer or inner faces.

Whether the recipient is made by molding on a concave or convex mold or hammering on a concave mold, the part of the paste in contact with the mold bears its imprint (Figs. 3.32b and 3.33a). In contrast, the parts of the recipient that were neither molded nor hammered present a more irregular relief.

The third trait is the presence of percussion cupules on the inner face (Fig. 3.33b). These are present on recipients molded on a concave mold and on hammered recipients. These cupules correspond to the marks of the hammer used to stamp the clay onto the mold or to thin the clay mass by hammering. They can be associated with thin and irregular overthicknesses formed by moving the paste by percussion blows.

The fourth trait is the presence of an anti-adhesive on the inner and/or outer faces corresponding to the sprinkling of sand, mica, ashes, or grog during the percussion blows in order to prevent the hammer from sticking to the paste or the paste from sticking to the hammer (Fig. 3.32c). The blows exerted on the clay mass tend to slightly incorporate the anti-adhesive particles into the superficial external and/or internal layer of the paste.

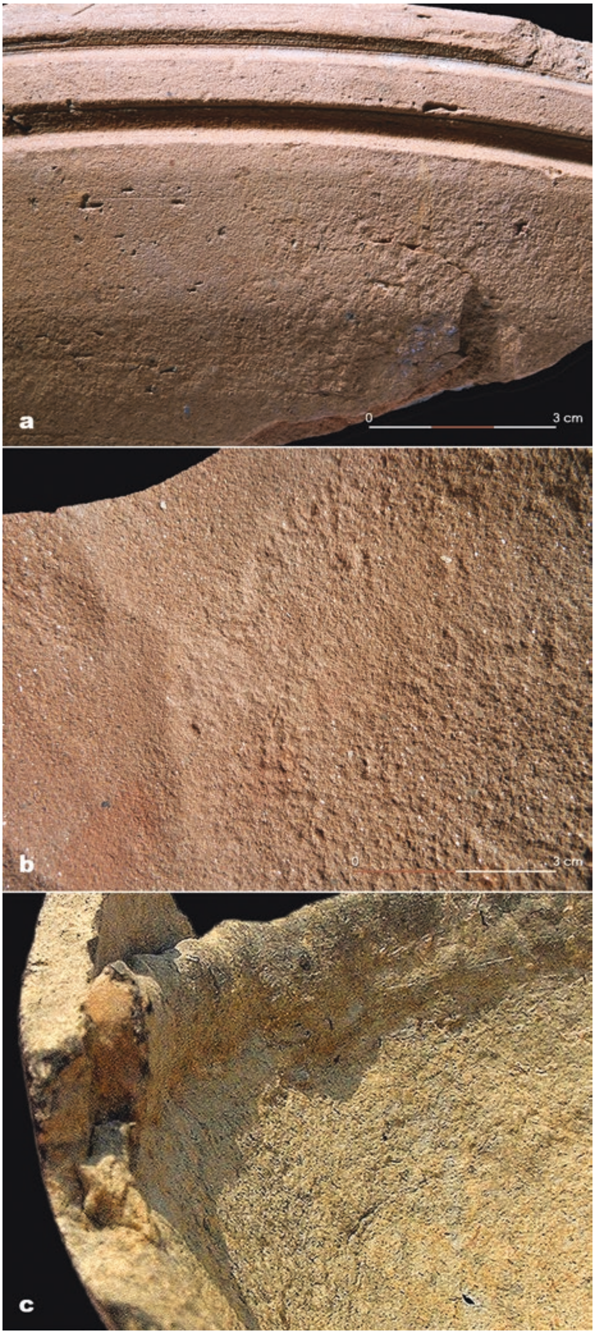

Fig. 3.33 Diagnostic features of fashioning by percussion: (**a**) imprint of the mold on the outer face; (**b**) percussion cupules; (**c**) connection between the lower and the upper part

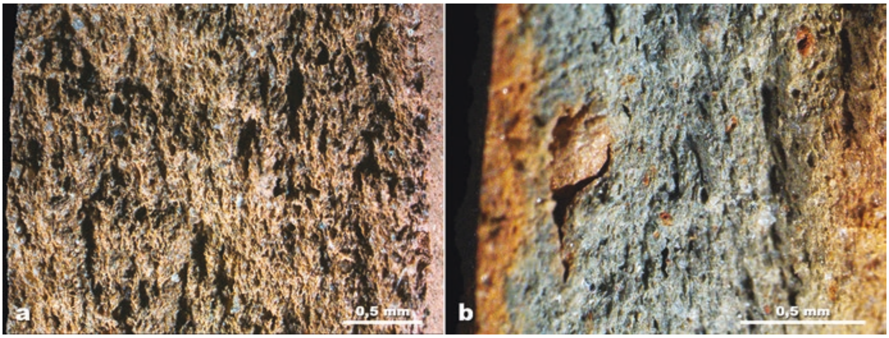

Fig. 3.34 Microstructures of pastes fashioned by percussion: (**a**) compressed paste by molding; (**b**) compressed paste by hammering (ethnographic series)

Lastly, the surface on which the percussion blows are exerted is characterized by micro-pull-outs.

Meso-structures

The compression exerted by percussion during molding and hammering presents characteristic traits. These have been observed in ethnographic series (Fig. 3.34). They are:

- Networks of fine elongated fissures showing a preferential orientation subparallel to the elongation of the walls
- Compression figures on the periphery of the coarse inclusions
- An asymmetric coarse fraction showing a preferential orientation subparallel to the elongation of the walls

The observation of ethnographic series shows a more marked flattening of the pore system for hammering than for molding, which characterizes stronger percussion.

Distinction Between Molding/Hammering on Wet Paste and Beating/Hammering on Leather-Hard Paste

The combination of cupules and macroporosity with a subparallel orientation to the elongation of the walls is a marker of percussion with tools with a convex surface. This type of percussion can be exerted on wet paste and on leather-hard paste (beating and hammering on leather-hard paste). In order to identify the state in which the paste was worked, it is important to consider the macroscopic traits indicative of leather-hard paste.

Distinction Between Molding and Hammering

It is possible in certain cases to distinguish between molding and hammering.

This is the case for convex molding with then the inner face showing an even relief or the imprints of the mold.

This is also the case when the paste is hammered on an anvil support leaving imprints. In this case, the rotation of the clay mass on itself to thin the walls produces characteristic imprints that do not appear for molding when the recipient is immobile.

Lastly, note that the absence of imprints is not a diagnostic trait for distinguishing between molding and hammering as the mold or the anvil can have an altered or non-decorated surface. In addition, the finishing operations carried out at the end of shaping the pottery can erase the impressions of the mold or the anvil support.

Preforming Without RKE

The first point to consider for preforming techniques without RKE is to distinguish between preforming wet paste and preforming leather-hard paste and, then for each of these actions, to differentiate between preforming by pressure and percussion.

As for the diagnostic characteristics, let us recall first of all that the organization acquired by the paste during roughing out is not significantly modified by the subsequent shaping, finishing, and firing operations. Consequently, evidences of shaping operations consist mainly of macroscopic traits observable with the naked eye or at low magnification, completed by microscopic observation in certain cases.

Secondly, let us recall that preforming techniques do not prejudice roughing out techniques in any way and therefore that the same preforming traces can be found on recipients whose roughouts are made with different techniques. From this point of view, roughing out techniques are not markers for identifying preforming techniques, apart from the molding technique which combines roughing out and preforming in a single operation.

Preforming Wet Paste

Preforming wet paste occurs directly after roughing out and consists in shaping the walls by pressure or percussion.

Preforming by Pressure

Preforming by pressure is visible in the deformation of the walls and in the transformation of the superficial layer of the inner and outer faces.

Among the traits characterizing recipients preformed on wet paste, note first of all oblong vertical or horizontal depressions or digital depressions on the inner faces (Fig. 3.35a). These depressions correspond to marks left by the fingers of one hand supporting the wall while the other hand shapes the recipient. This modification of the clay can only be obtained on wet paste.

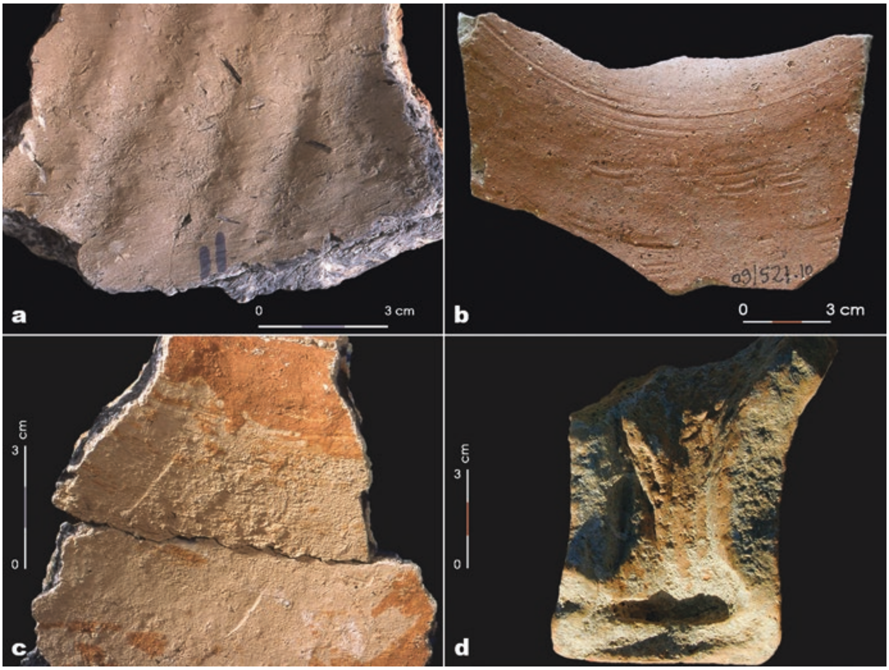

Fig. 3.35 Diagnostic features of preforming wet paste without RKE: (**a**) digital depressions on the inner face; (**b**) scraping striations; (**c**) marks of the cutting edge of the scraping tool; (**d**) compression folds

Compression folds on inner faces, preferentially toward the neck or the base, are a second trait (Fig. 3.35d). These folds form by compression of the diameter, either once the roughout is finished or when the outer base of a recipient is closed while the recipient is lying neck down. The orientation of these folds is either vertical or oblique, depending on whether a rotating movement accompanied compression. The faster the rotating movement, the more the folds will be oblique in relation to the vertical axis of the recipient. They form when pressures brake the rotation of the recipient, which occurs especially when the walls are not moist enough. Compression folds can only be obtained when the paste is wet.

A third characteristic of preforming wet paste is bands of striations running over the surface. These striations are with threaded, ribbed, or thickened edges and indicate a scraping operation with a hard pressure-applied tool on wet paste, which modifies the relief and leaves traces (Fig. 3.35b). The cutting edge of the tools can also leave marks perpendicular to the bands of striations (Fig. 3.35c). Generally, the bands of striations vary in their aspect depending on the temper, the profile of the tools, and the kinetics of the movement. In all cases, the surface of the paste is composed of protruding grains; the microtopography is fluidified or irregular depending on the water load of the tool.

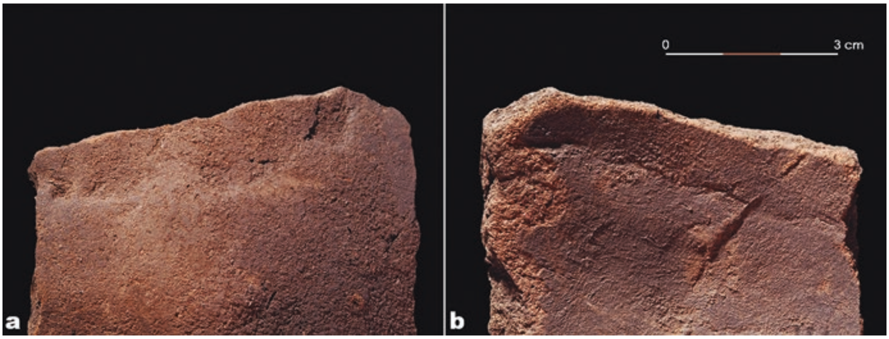

Fig. 3.36 Diagnostic features of percussion on wet paste without counter-paddle: (**a**) outer face, surface with inserted grains and with a microtopography alternating compact and irregular zones; (**b**) inner face, joints of coils weakly deformed and surface with prominent grains and irregular microtopography (©S. Oboukoff)

Preforming by Percussion

Preforming wet paste by percussion is applied to roughouts made from assembled elements (slabs or coils), or a mass of clay, and is characterized by surfaces with inserted grains, with a microtopography with alternating compact and irregular zones (depending on the degree of hygrometry of the paste), and no striations (Fig. 3.36a). On very wet paste, percussion creates networks of clay slurry crests.

When percussion is exerted on the external walls of a coiled preform, without using a counter-paddle on the internal walls, the latter present slightly deformed coil joints with surfaces with protruding grains, with an irregular microtopography and marked striation (Fig. 3.36b).

Preforming Leather-Hard Paste

Preforming leather-hard paste includes preforming by pressure and preforming by percussion.

In radial section, the macroporosity of recipients preformed using these two techniques is characterized by laminar fissuring subparallel to the elongation of the walls. This is linked to the strong pressure or percussion of the tools against the leather-hard wall, intended to deform the geometric properties of the roughout.

Preforming by Pressure (Pushing, Shaving)

Pushing

Preforming by pushing is visible on the inner face of recipients. It is characterized by a compact microtopography due to the covering of the coarse fraction during the movement of the leather-hard paste combined with a grainy surface (Fig. 3.37a).

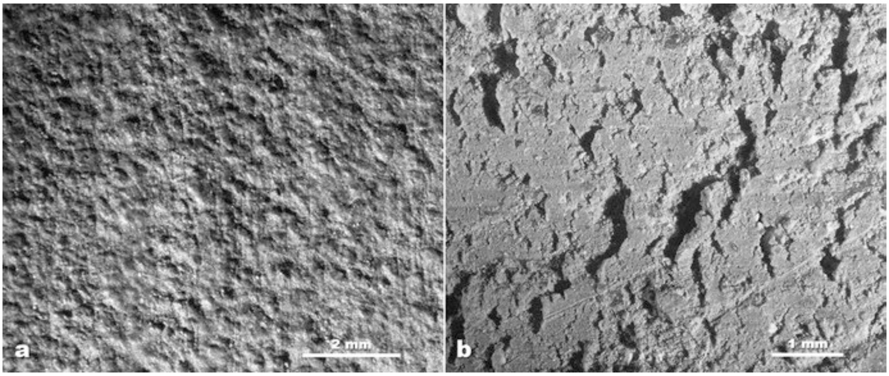

Fig. 3.37 Diagnostic features of preforming by pressure on leather-hard paste: (**a**) pushing, grainy surface with a compact microtopography; (**b**) shaving, compact microtopography, crevices, and erratic striations

This movement results in a succession of small compact zones (thickenings) with scalloped edges. The orientation is vertical or horizontal depending on the gestures. Fine striations follow the same orientation on the surface.

Shaving

Like scraping, shaving is an action combining friction and pulling out. The aim is to thin the walls. The tool profile is applied to leather-hard paste with no water. This results in pressing the projecting part of the coarse fraction into the paste, compacting the surface, pulling out non-plastic grains, and possibly moving or tearing the paste when the angle of the tool is too obtuse or when the paste is in an advanced state of desiccation (Fig. 3.37b).

This results in a superficial layer characterized by a surface with inserted grains, with a compact microtopography and erratic striation with deep striations with a compact bottom (Fig. 3.38a, b). In addition, shaving motions can create a discontinuous relief with planes intersecting the initial curve or a relief marked by crevices.

Preforming by Percussion (Beating/Paddling, Hammering)

Beating/paddling and hammering leather-hard paste involve exerting similar forces on a volume of paste with comparable degree of hygrometry. Consequently, it is difficult to distinguish them, unless paddle traces can be identified on the external surfaces of the recipients. The latter present a discontinuous external relief, alternating curved and flat surfaces, which can be combined with decorative imprints when wooden sculpted paddles are used.

On the outer face, i.e., the surface exposed to the percussion blows, beating/paddling and hammering are characterized by a surface with inserted grains combined

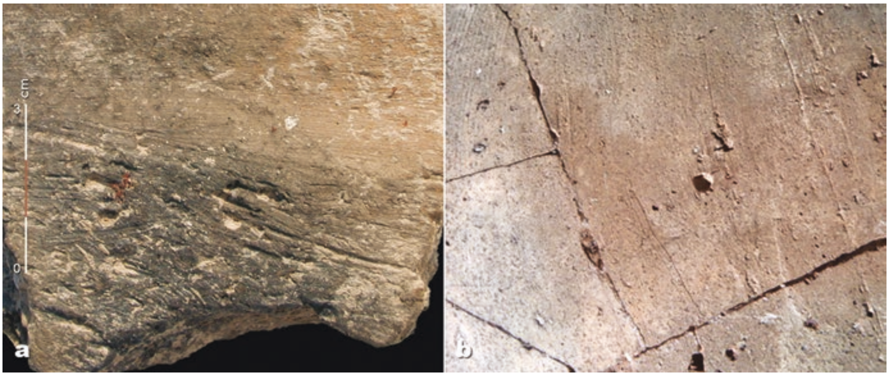

Fig. 3.38 Diagnostic features of shaving: (**a**, **b**) shaved surfaces characterized by pulled out and dragged inclusions creating deep striations

with a compact microtopography and the absence of visible striations (Fig. 3.39b). The compact zones can be irregularly intersected by pecked zones, corresponding to micro-pull-outs resulting from the percussion blows (Fig. 3.39a). When beating is carried out on paste that has not fully attained leather-hard consistency and is therefore still relatively moist, the paddle can print networks of clay slurry crests onto the paste and make the surface slightly lumpy with a fluidified microtopography, but still with no visible striations.

On the inner face, that is, on the surface in contact with a counter-paddle or a forming support, the paste presents a surface with deep micro-pull-outs combined with a compact microtopography with no visible striations. Pecking is found on beaten as well as on hammered recipients. In addition, when a counter-paddle is used, this can leave percussion cupule traces with relatively regular contours depending on whether a tool or the hand is used as a counter-paddle (Fig. 3.39c).

In both cases, the presence of anti-adhesive on the internal and external surfaces delimits the zone subject to percussion (Fig. 3.39d).

Lastly, when hammering is applied to recipients where the base was missing and preformed by discontinuous centripetal pressure on leather-hard paste, the external surfaces of the base can present irregular fissures resulting from external vertical compression on a base of irregular thickness (Fig. 3.39d).

Roughing Out with RKE

Roughing out with RKE corresponds to a single technique, i.e., wheel throwing. However, wheel throwing and wheel coiling produce similar macro-traces, namely, (Fig. 3.40):

– Parallel concentric striations on the inner and outer walls

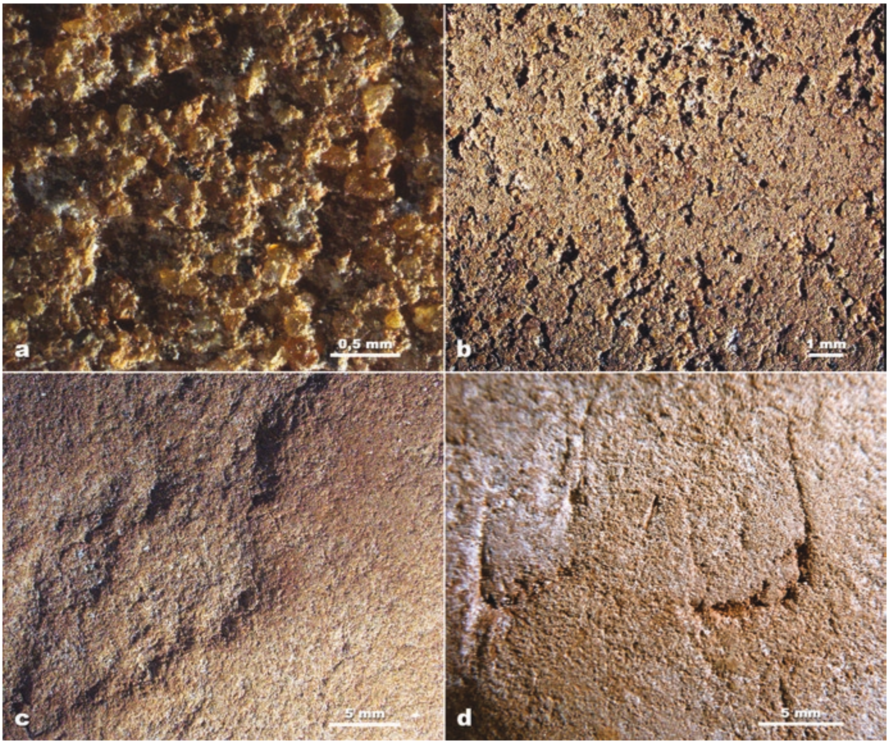

Fig. 3.39 Diagnostic features of beating: (**a**) micro-pull-outs; (**b**) surface with inserted grains, compact microtopography, and micro-pull-outs; (**c**) percussion cupule traces with irregular contours; (**d**) fissure due to vertical external percussion blows on a heterogeneous base (made from patches of clay) and presence of ash as anti-adhesive

- A regular profile characterized by a progressively reduced thickness from the base to the top and, at the same height, an even thickness between the right and left walls
- An undulating relief from the base to the top
- Oblique and radiating compression folds located on the compression zones: inner walls of the lower body or neck
- Ellipsoidal striations on the external bases corresponding to traces of removing the recipient with a string while it is rotating

In order to distinguish between wheel throwing and wheel coiling, it is important to simultaneously consider wheel-throwing and wheel-coiling markers. Even more so than for the other roughing-out techniques, the identification of wheel throwing is based on a closely integrated interpretation of the macro-traces and microstructures.

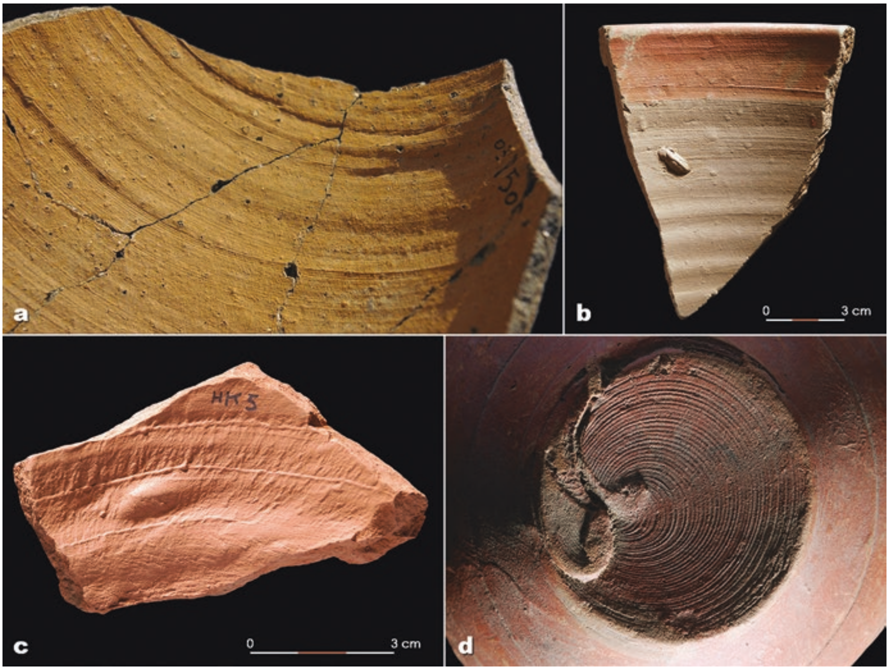

Fig. 3.40 Similar surface features produced by wheel coiling and wheel throwing: (**a**) parallel concentric striations on the inner and outer faces; (**b**) undulating relief from the base to the top; (**c**) oblique compression folds; (**d**) ellipsoidal striations on the outer base

Macroscopic Traits

There are some macroscopic traits indicating wheel coiling, which consequently distinguish between wheel throwing and wheel coiling. These are:

- A difference in thickness between the right and left walls due to a differential thickness of the coil. Such differences are impossible with wheel throwing as the thickness of the walls is determined by the pressure applied to a given point and then passed on over 360° with the help of the rotary movement. In the case of wheel coiling, on the other hand, thickness is first of all determined by the shaping of the coil; this thickness is then evened out by the pressures exerted with RKE. However, this uniformization is not necessarily complete and differences in thickness may subsist without affecting the rest of shaping.
- Curvilinear concentric fissures preferentially located on compression zones (Figs. 3.41a and 3.42a). They indicate coil joints that appear after compression operations. They can be accompanied by oblique compression folds.
- Slightly curvilinear concentric fissures (Figs. 3.41b and 3.42b). They indicate coil joints that were not obliterated by subsequent operations.
- Undulations in the form of bands (Figs. 3.41c and 3.42c). These undulations differ from the undulations produced by wheel throwing after an excessively fast

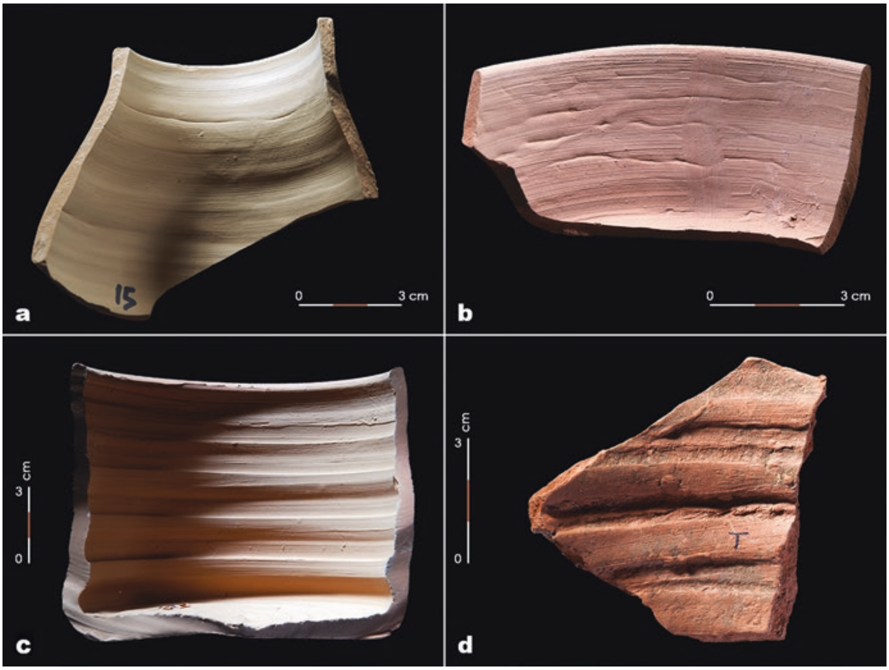

Fig. 3.41 Diagnostic traits of wheel coiling (experimental series): (**a**) fissure located on a compression zone; (**b**) slightly curvilinear short fissures; (**c**) undulations in the shape of bands produced during thinning coils with RKE; (**d**) undulations in the shape of bands produced during wheel throwing

rising of the pressures (Fig. 3.41d). The bands, with a rectangular cross section, form after pressures with RKE on the coils. Unlike wheel-throwing bands, their edges are not thickened.

– Horizontal fractures along the coil joint. However, it is important to distinguish between horizontal fractures corresponding to a coil joint and horizontal fractures resulting from hammering. In this latter case, the type of fracture is not significant of the roughing-out technique. In this way, the wheel-thrown and hammered roughouts can present horizontal fractures with a U-shaped section as though they were U-shaped coil joints.

Some traits are only produced with the wheel-throwing technique, such as networks of crevices with random orientation. These are tears with torsion produced by shear stress when the pressures applied on the clay walls rise up too fast (Fig. 3.43).

Meso- and Microstructures

Wheel-thrown pottery presents distinctive marks from wheel-coiled pottery, regardless of the type of clay material:

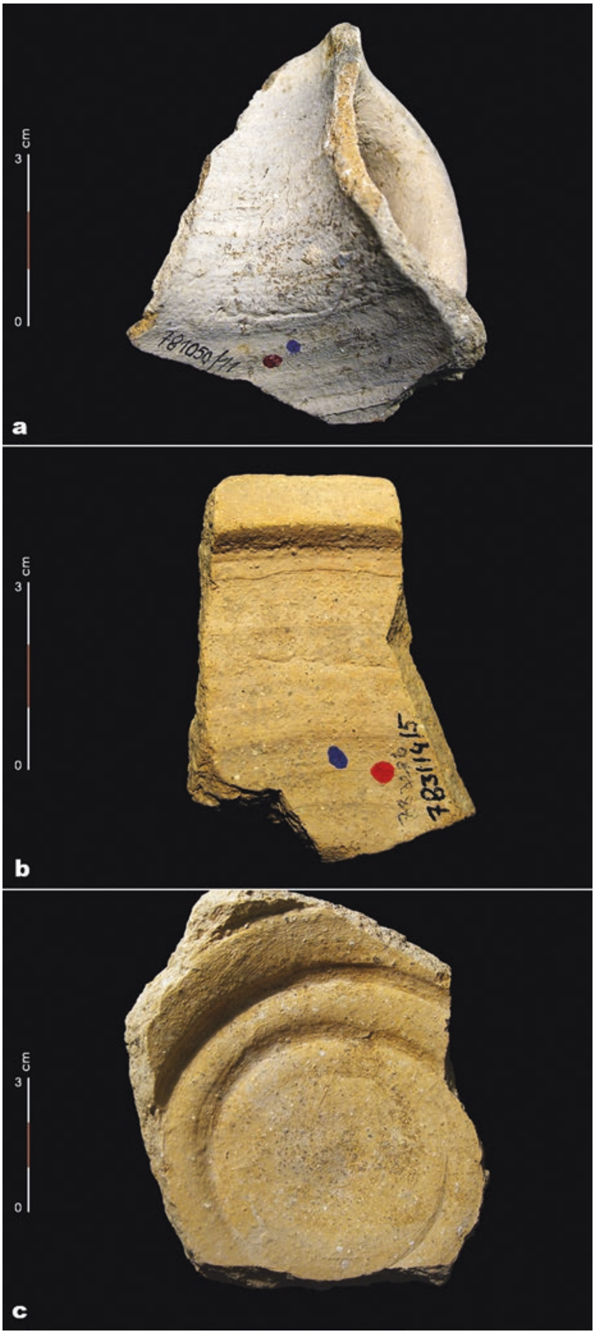

Fig. 3.42 Diagnostic traits of wheel coiling (archaeological series): (**a**) fissure located on a compression zone; (**b**) slightly curvilinear short fissures; (**c**) undulations in the shape of bands produced during thinning coils with RKE

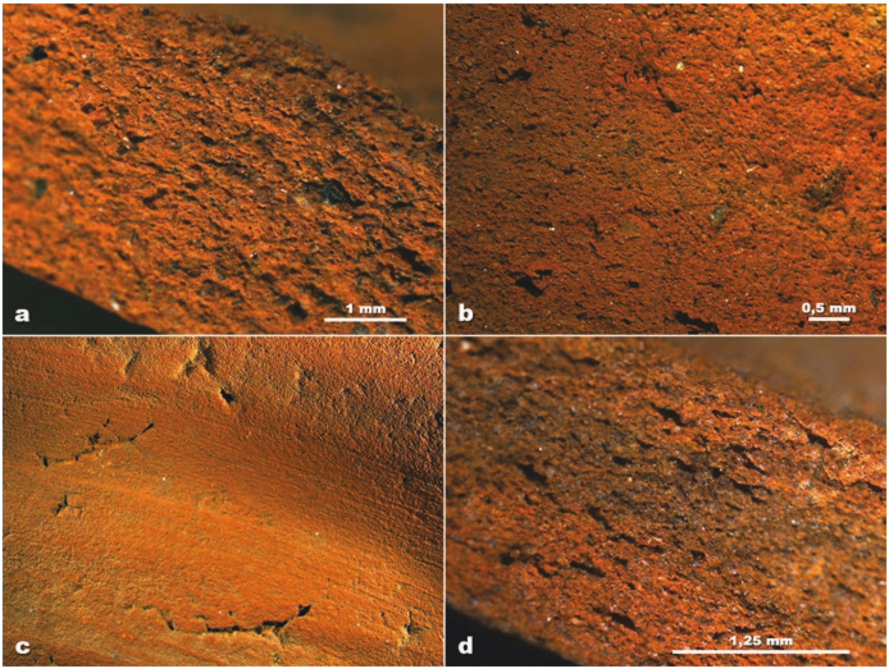

Fig. 3.43 Diagnostic meso-structures of wheel throwing: (**a**, **b**) dense homogeneous meso-structure, random orientation and distribution of the coarse fraction; (**c**, **d**) tears due to a too fast rising of the interdigital pressures and abundance of the elongated vesicles parallel to the walls

– An absence of horizontal or oblique fissures indicating coil joints, that is, radial sections that present no discontinuity on a meso-scale.
– A random orientation and distribution of the coarse fraction (Fig. 3.43a, b).
– A random distribution of the porosity and rare elongated vesicles parallel or subparallel to the walls. These vesicles tend to be present near the edges of the walls and form as a result of interdigital pressure during shaping operations. In the case of tears caused by over-rapid rising of the interdigital pressures, these vesicles become particularly abundant (Fig. 3.43c, d).
– A dense and homogeneous microstructure characterized by a close imbrication of the clay domains with no clear identification of their original morphology (Fig. 3.45).

The random microstructural arrangement results from the sliding of the clay domains with shear on the whole clay mass during roughing out. This sliding represents the micro-creeping of clay particles as a result of the considerable reduction in cohesion forces between the clay domains, on account of the quantity of water added during wheel throwing. In some zones, the parallel orientation of the different components (inclusions, voids, clay domains), along with the elongation of the walls, is the consequence of interdigital pressure during the final shaping operations.

In contrast, wheel-coiled pottery presents (Figs. 3.44 and 3.45):

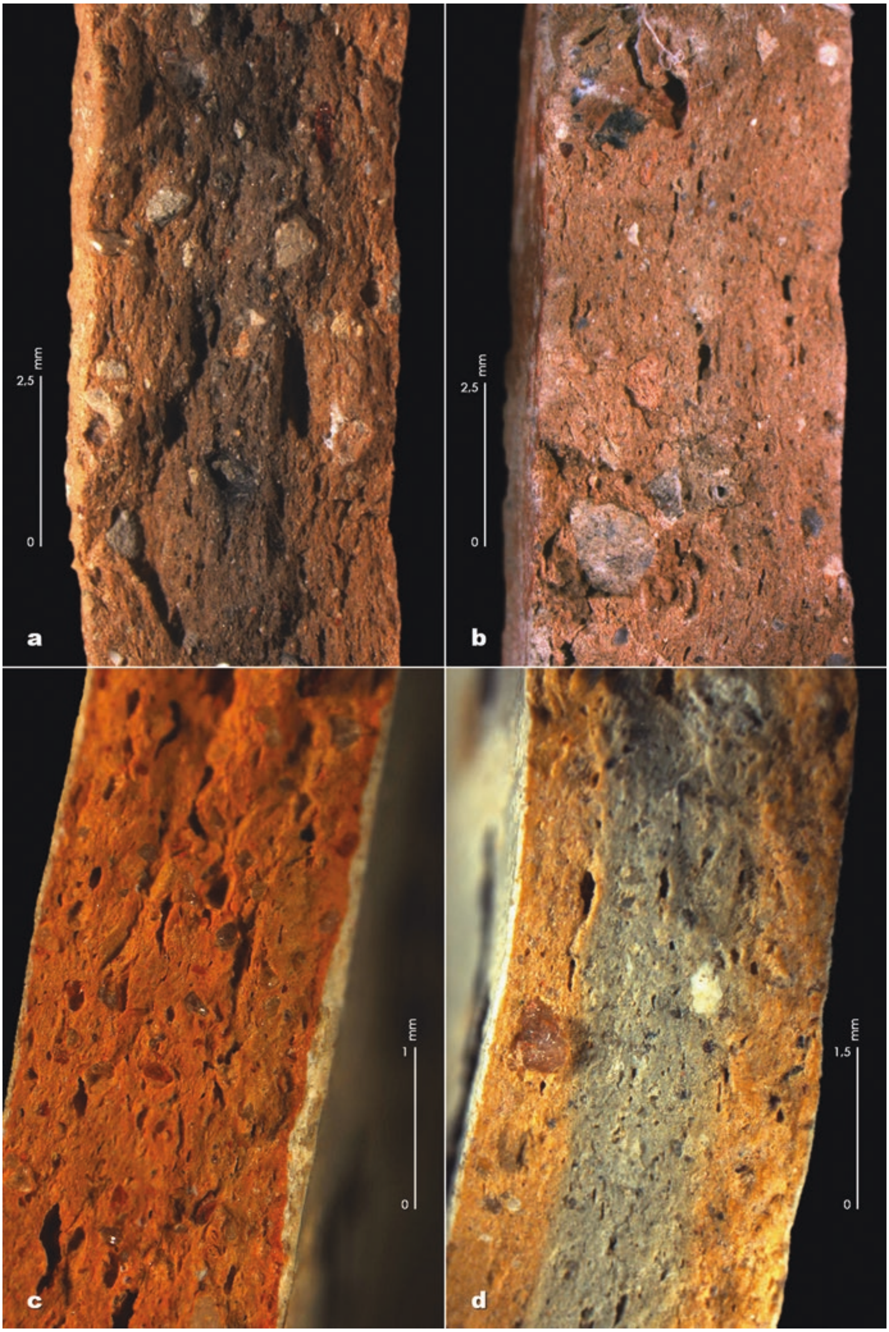

Fig. 3.44 Diagnostic meso-structures of wheel coiling: (**a**–**d**) elongated voids (vesicles, fissures) subparallel to the walls

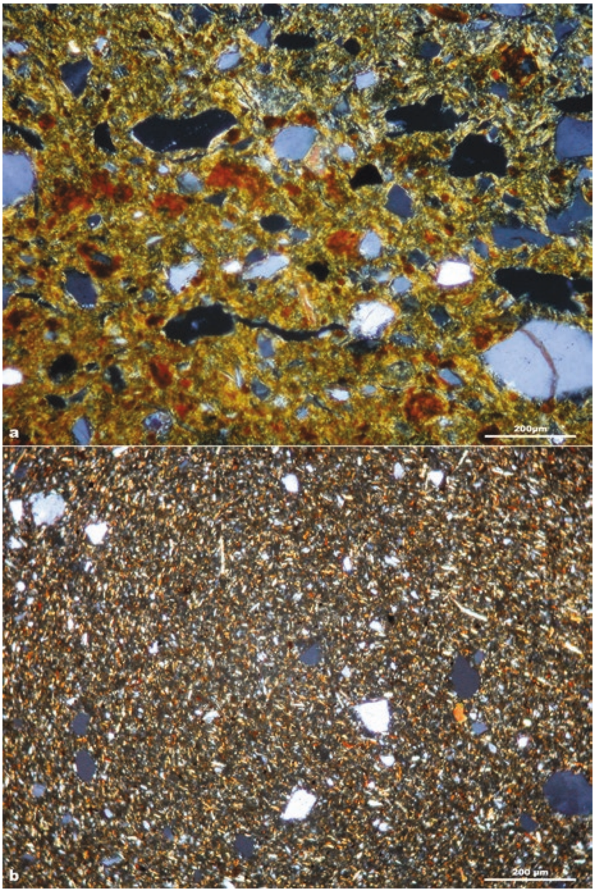

Fig. 3.45 Diagnostic microstructures of fashioning techniques with RKE: (**a**) wheel-thrown paste showing a homogeneous birefringence assemblage along the entire section, characterized by a close imbrication of clay domains, a random orientation and distribution of the coarse fraction; (**b**) wheel coiling of a very fine illite clay paste almost without coarse fraction; birefringence assemblage at a coil join underlined by an organization of micaceous flakes orthogonal to the clay domain walls; the microstructure of the adjacent clay domains shows a strongly compressed, dense organization

- Long horizontal or oblique fissures or cavities indicating coil joints.
- A porosity characterized by fine fissures subparallel to the extension of the walls.
- A random to subparallel orientation of the coarse fraction.
- A microstructure marked by regularly spaced structural discontinuities. These discontinuities are generally characterized by an abrupt contact between zones formed by randomly oriented large-sized aggregates or following a rotation movement and zones presenting fine parallel fissuring.

Paddled Wheel-Thrown Ceramics

Paddled wheel-thrown ceramics do not present any macroscopic characteristics indicative of RKE with the naked eye. This is the case in India where most of the recipients are first of all wheel-thrown and then paddled, while the paste is leather-hard. Only the necks present markers of the use of RKE.

Fig. 3.46 Wheel-thrown and paddled paste presenting both a subparallel alignment of the constituents and a random meso-structural pattern

Microscopic observation reveals a double organization characteristic of the successive wheel throwing and paddling operations (Fig. 3.46): (1) at the heart of the paste, the random microstructural arrangement of wheel throwing and (2) in the superficial zone of the walls, a subparallel alignment of the constituents and a compactness of the fine mass.

Preforming with RKE

Preforming with RKE includes wheel coiling and wheel molding.

Wheel Coiling: The Methods

The four preforming methods defined in Chap. 2 can be differentiated depending on what stage RKE is used at. In terms of the forces applied, these four methods are differentiated by force and the type of pressure, i.e., continuous or discontinuous. For the first method, the roughout is thinned and shaped without RKE. Pressures with RKE are applied continuously from the base to the top and only slightly modifies the morphology of the walls. In method 2, the degree of pressure is higher as it obliterates the traces of coil joints and thins the walls with RKE. For method 3, pressures are applied first of all to the coil joints to weld them and then to the whole wall to transform the recipient into a homogeneous volume. Finally, in method 4, pressures with RKE are applied as soon as the coil is placed, in order to progressively thin, shape, and transform the recipient into a homogeneous volume.

For this same system of compression, differences in forces are nonetheless sufficiently specific to identify each method based on diagnostic features (Fig. 3.47).

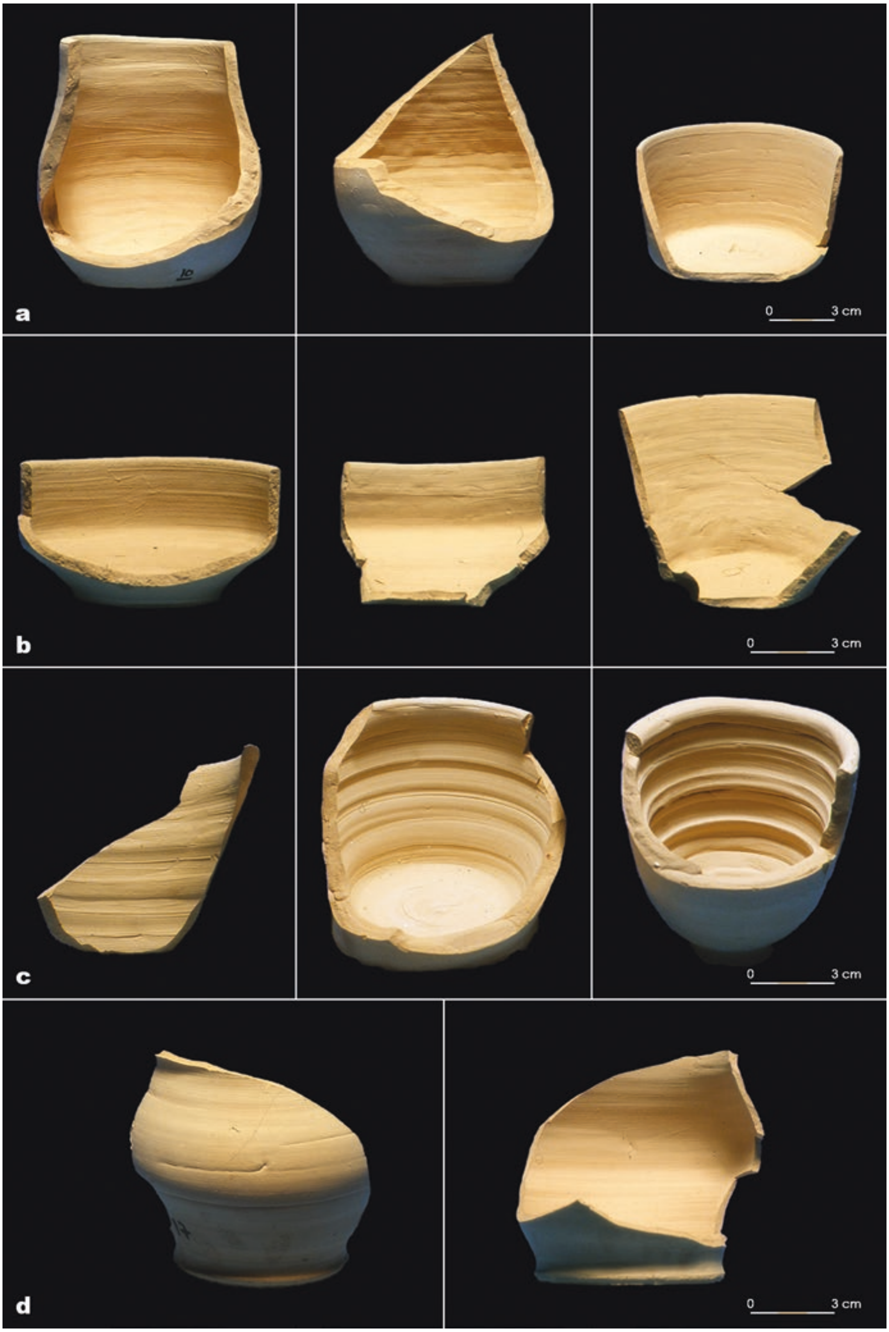

Fig. 3.47 Diagnostic features of the four wheel-coiling methods (experimental series): (**a**) method 1; (**b**) method 2; (**c**) method 3; (**d**) method 4

Macroscopic Traits

Method 1 is characterized by an irregular topography. The residual bumps and hollows correspond to discontinuous pressure exerted during roughing out and preforming, which were not "regularized" by pressure with RKE. No traces of joints are visible, as these were obliterated during thinning without RKE.

Method 2 is characterized by a slightly irregular topography and occasional curvilinear fissures. These fissures mark coil joints and take the form of isolated curvilinear oblique or horizontal or curvilinear concentric horizontal fissures.

Methods 1 and 2 produce recipients that can present a different topography on the inner and outer walls, on account of asymmetric pressure during thinning and shaping.

Method 3 is characterized by a high diversity of undulations due to the intermittent pressures applied to the coils. This type of pressure is specific to this method: continuous pressures combined with the centrifugal force on the non-joined coils tend to separate them rather than unify them. One of the most frequent type of undulation is the band shape with a curvilinear fissure. These bands form with finger pressures on the coil joint. These pressures create a band on either side of the joint which can remain visible as a fissure.

Moreover, depending on the degree of care applied to shaping, methods 3 and 4 are conducive to the formation of concentric horizontal fissures, with relatively rectilinear delineation (depending on the regularity of the coils), which can be visible on either side of the recipient. The presence of a visible sequence of parallel concentric fissures indicates that the coils were joined with RKE, by continuous pressures, and thus were not made using methods 1 and 2. The rectilinearity of the fissures should be sufficient to distinguish between methods 3 and 4, as method 4 gives rise to more rectilinear fissures on account of the use of RKE for placing the coils. Some of these fissures can be highly deformed by RKE, particularly in the compression zones, and present a very sinuous outline.

Method 4 is not only characterized by concentric horizontal rectilinear fissures corresponding to coil joints regularized with RKE but also by walls with a discontinuous external relief with very slight steps. These steps correspond to the placing of the coils on top of each other, which is a delicate operation and can be characterized by a misalignment between the upper and lower coil.

Meso- and Microstructures

For the studied experimental series, the fine mass is dense and homogeneous, formed by the close imbrication of the clay domains with a randomly distributed and oriented coarse fraction, as well as rare voids and vesicles, regardless of the method. Coil joints are marked by slight discontinuities. They are rectilinear, U-shaped, or oblique. They can also be marked by large vesicles when little care is applied to making them.

The difficulties encountered for the microstructural interpretation of diagnostic organizations of these methods is the consequence of the use of illitic (rigid), previously decanted clay material during experiments. In this case, the initial structural state is characterized by a compact arrangement of micrometric clay domains. It is difficult to interpret such a rigid and finely organized material. It nonetheless provides a set of coherent diagnostic attributes for identifying these different methods in archaeological series. These attributes allow for the differentiation between strongly compressed walls (methods 3 and 4) and less compressed walls (methods 1 and 2). The former are characterized by fissures and elongated vertically oriented vesicles parallel to the extension of the walls, as well as by a meso-structure with clearly alternating zones oriented parallel to the walls and less oriented zones (Fig. 3.48b). The latter conserve the coil meso-structure with few subparallel fissures (Fig. 3.48a). In this case, only the surface features reveal the use of RKE.

Wheel Molding

Wheel molding consists in placing a concave mold on the wheel and using RKE to thin the internal face of the slab.

This technique can be identified:

- Based on macro-traces (topography and surface) diagnostic of molding on the one hand and the use of RKE on the other hand
- Based on the double arrangement of meso- and microstructures: a zone with a flattened subparallel pore system on the mold side and a zone with a fine pore system parallel to the extension of the walls on the RKE side

Trimming

Trimming is a shaving operation using RKE. The diagnostic traits are thus comparable. The surface presents inserted grains, a compact microtopography, and deep and concentric striations created by pulling out the coarse fraction with RKE (Fig. 3.49). The relief can be discontinuous depending on the tool and its position.

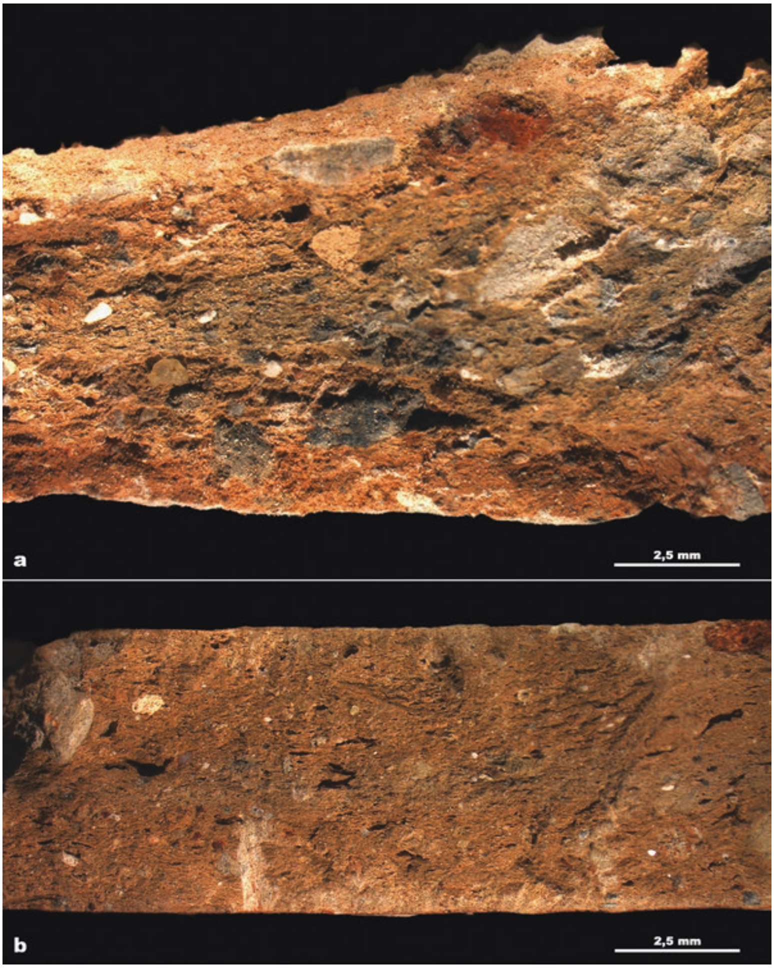

Fig. 3.48 Examples of deformation of wheel-coiled pastes: (**a**) weakly compressed paste with conservation of the coil microstructure (visible on the right); (**b**) strongly compressed paste with elongated voids subparallel to the walls

Other Tools of Observation

As indicated above, the orientation of the inclusions and the porosity are diagnostic traits of roughing-out and preforming techniques. As we saw, they are observable in fresh radial sections, under the stereomicroscope which is the best tool for a good visual inspection of the orientation of voids and inclusions. However, this is a destructive method and cannot be applied to whole ceramics. Moreover, it is often difficult to obtain photographs in a legible form that clearly show features such as

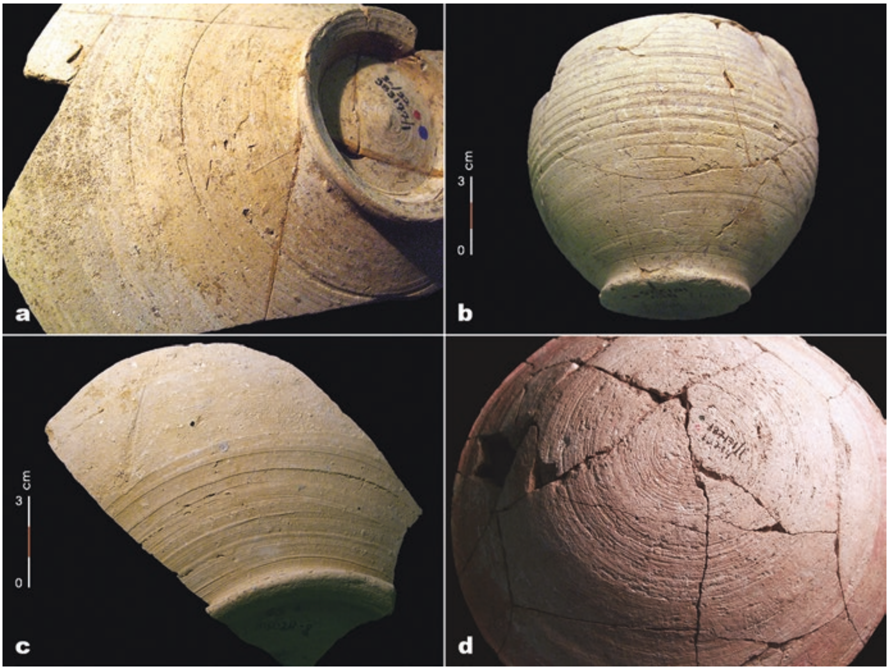

Fig. 3.49 Diagnostic features of trimming: (**a**–**d**) trimmed recipients with compact surfaces, concentric parallel deep striations created by pulling out the coarse fraction with RKE

fissures between two elements, porosity pattern, or inclusion alignment. Tools such as radiography or X-ray computed tomography (micro-CT or or µ-CT) offer new perspectives (see the inset on radiography and micro-CT by Pierret). In particular, micro-CT allows a good visualization of porosity and inclusion arrangement. This visualization tool can facilitate the interpretation of the void and inclusion patterns in terms of forming techniques. But this is only a visualization tool in the sense that the interpretation of the images is nevertheless still based on the principle that the different forms of deformation of the clay components can be classified according to the constraints associated with each fashioning technique and requires comparisons with experimental reference data. In this sense, as developed by Pierret in the inset, the void and inclusion orientation visible in the X-ray images is a good marker of forming techniques because it varies depending on the energy sources used to deform the walls. Thus it tends to be oblique when RKE is used. However, it may not allow a clear distinction between wheel throwing and wheel coiling. In this case, fissures indicating joins of coils remain the best markers to identify wheel coiling. Visual inspection of these fissures can be enhanced with micro-CT, but it can also be performed on potsherds with the techniques and observation scales presented in this manual.

Application of X-Radiography to the Identification of Fashioning Techniques (Inset)

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Radiography is an imaging technique using penetrating radiation, generally X-rays, to produce an image of the internal structure of an object. X-rays have been widely used for radiographic applications in the medical domain since their discovery by Röntgen (Röntgen 1896) but also for the nondestructive analysis of natural materials (e.g., wood, rocks, and soil) and manufactured materials (e.g., in the electronic, aeronautic, or food industries). X-rays are electromagnetic radiation similar to radio waves or to visible light, but with much shorter wavelengths (between 0.01 and 10 nm) and much higher energy. X-rays penetrate more when their wavelength is short. Their attenuation depends on the density of the electrons along the optical path they move along: X-rays are absorbed more when they cross dense and thick materials and/or materials composed of chemical elements with a high atomic number. In the usual radiographic applications, X-rays are produced with vacuum-packed tubes, in which the electrons, extracted by heating with a metallic filament, are accelerated by electric tension and accumulated on a metallic target. The slowing down of the electrons by the atoms of this metallic target gives rise to the emission of X-rays.

The contribution of X-radiography to earth and soil sciences was widely discussed by Hamblin (1962) and Krinitzsky (1970), who showed that certain sedimentary deposits with a solid and homogeneous aspect with visible reflected light often revealed complex structures with X-radiography. From a physical point of view, such structures reflect variations in porosity, water content, or mineral composition. In the domain of geo-archaeology, several authors took advantage of the simple application and nondestructive nature of X-radiography to analyze archaeological soils and sediments (Butler 1992; Dugmore and Newton 1992) or to evaluate the attributes of sedimentary deposits prior to subsequent specific analyses (Barham 1995). In the Kuk wetland, in the highlands of New Guinea, Denham et al. (Denham et al. 2009) used high-resolution X-radiography to analyze the infills of ditches and canals and to evaluate the degree of bioturbation.

The application of X-radiography methods to the study of archaeological ceramics goes back to the 1930s, with the publication by Titterington (Titterington 1935) of the image of sherds from Amerindian graves. However, the potential of X-radiography for the technological analysis of ceramics was only systematically evaluated at the end of the 1970s, by Rye, with the publication of a seminal article on this subject (Rye 1977; see also Rye 1981). Following on from Rye's pioneering work, several authors empirically confirmed the heuristic value of X-radiography for the identifi-

(continued)

cation of forming techniques (Carr 1990; Carr and Riddick 1990; Vandiver et al. 1991). However, although the first studies enabled the definition of the qualitative criteria related to the morphology and distribution of the porosity and/or mineral inclusions for identifying forming techniques, they did not provide any really decisive elements for differentiating wheel throwing from wheel coiling.

Combining X-radiography with the digital techniques of image processing and a physical analysis of the deformation of the ceramic paste during shaping, Pierret (Pierret 2001) proposed new qualitative and quantitative criteria to improve the technological interpretation of radiographic images of ceramics (Fig. 3.50). His work established that variations in the thickness of the walls of wheel-thrown recipients were very different to those of coiled recipients finished on the wheel (method 1). On the other hand, the differentiation between coiled recipients thinned and shaped on the wheel (methods 2, 3, and 4), on the one hand, and wheel throwing, on the other hand, turned out to be much more tenuous. However, this innovative methodological approach could establish the existence of three main diagnostic types of internal porosity distribution on sherds (Pierret et al. 1996):

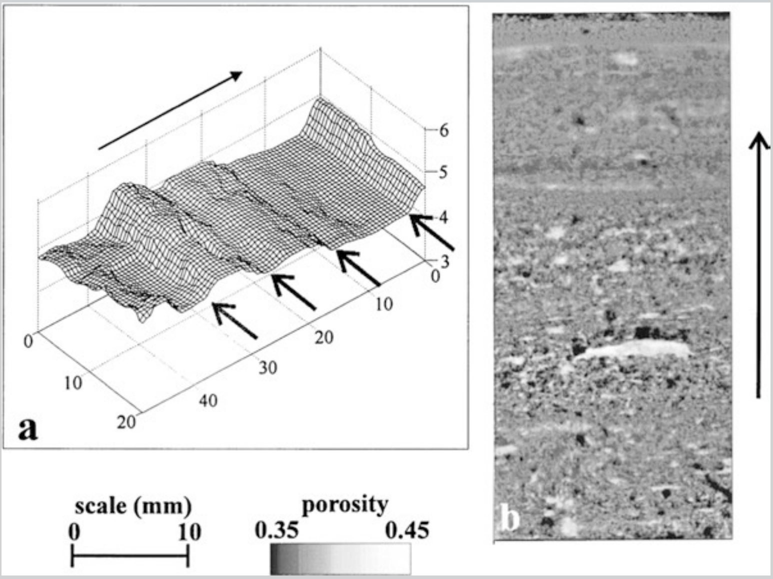

Fig. 3.50 Calibrated data for wheel-coiled vessel obtained from combining X-radiography with digital techniques of image processing: (**a**) perspective view of wall thickness. The long arrow above the plot indicates the sherd orientation (from base toward the top); the short arrows correspond to the discontinuities between the coils, after their wheel shaping; (**b**) porosity image of the same specimen. The arrow alongside porosity image indicates the sherd orientation (after Pierret et al. 1996)

- For wheel-finished recipients: mixture of pores stretched along an oblique axis in relation to the horizontal and pores elongated in a subhorizontal direction
- For wheel-thinned and shaped coils: pores stretched along a very oblique axis in relation to the horizontal
- For wheel-thrown recipients: pores stretched along a slightly oblique axis in relation to the horizontal

The inclination of the porosity (or of the solid elongated particles) in relation to the horizontal varies between wheel-thrown and wheel-coiled recipients, as the vertical and horizontal components of the movement of the potter's hand (or its relative speed in relation to the wall) are generally different for these two techniques. In this way, we have a dominant horizontal component for wheel throwing, as a result of the rapid rotation of the recipient, and a more marked vertical component for wheel coiling (for a more detailed description of the forces at work during the wheel throwing of a recipient, see the inset by Gandon et al., Chap. 2). Pierret and Moran (Pierret and Moran 1996) elaborated a method for measuring the internal porosity of sherds using digitalized radiographic images, allowing for more sensitive, reproducible, and comparable diagnostics.

Apart from the simple application and low cost of X-radiography, it also allows for the observation of the internal structure of large-sized sherds or even of whole ceramic objects. It is thus possible to evaluate the variability of certain traits – such as the preferential orientation of inclusions and porosity – and to weight the diagnostic value (Berg 2008, 199).

Now, if the present-day corpus of works demonstrates that X-radiography generally allows for the discrimination between wheel-thrown and wheel-coiled ceramics, it is nonetheless fitting to mention that some sherds do not present clearly interpretable diagnostic traits. This problem can be limiting for forms for which we only have sherds from certain parts of the profile. In this way, Berg (Berg 2008) underlines that, in a certain number of cases, estimated on average at 30%, the identification of the technique(s) used to produce a recipient remains impossible with radiographic images alone. Like for Pierret's conclusions (Pierret 2001), this observation argues in favor of a methodological approach combining several techniques and observation scales, in order to obtain complementary information on the conditions in which the raw material is deformed during fashioning.

Recently, Kahl and Ramminger (Kahl and Ramminger 2012) presented a detailed evaluation of the use of high-resolution X-ray computed tomography (micro-CT or μ-CT) for the technological analysis of a corpus of ceramics dating from the end of the Mesolithic to the beginning of the Neolithic, from a site in the north of Germany (Fig. 3.51). Unlike X-radiography, which produces a simple projected image of the analyzed object, tomography allows for the reconstruction of the volume of an object using a series of projected

(continued)

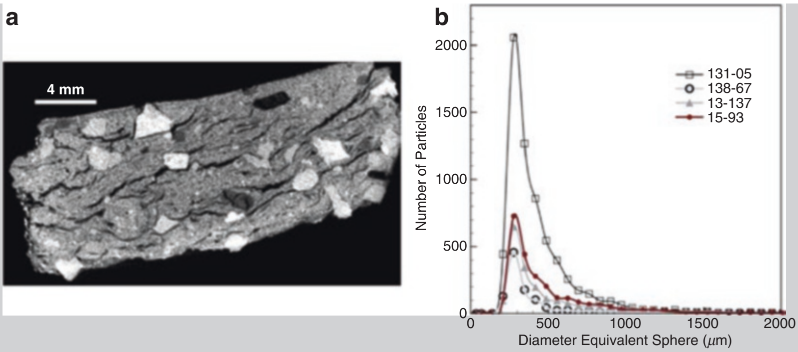

Fig. 3.51 High-resolution X-ray microtomography (μ-CT): (**a**) reconstructed image of a Neolithic pottery fragment from northern Germany; (**b**) example of quantitative analysis of four Neolithic shards from northern Germany – abundance of rock fragment temper in different size classes in the Neolithic pottery sherds (after Kahl and Ramminger 2012)

images acquired by turning the source of X-rays and the detector around this object. In this way, this method allows for a quantification of the internal tridimensional organization of the analyzed material, in particular, the spatial distribution, the geometry, and the topology of the porosity, thereby providing very precise markers for the identification of the fashioning techniques. In addition, micro-X-ray tomography allows for the identification, quantification, and morphometric characterization of the mineral and organic tempers.

With the advent of high-resolution X-ray imagery combined with the direct acquisition of digital data and the current massive storage possibilities of these data, the routine and wide-scale radiographic examination of archaeological ceramics should rapidly become a reality, opening the way to a normalization of analyses that were inaccessible up until now (Greene and Hartley 2007).

Diagnostic Features of Finishing Operations

Macro-traces allow for distinguishing between finishing operations on wet paste and finishing operations on leather-hard paste. Generally, these vary according to the technical operation but also depending on the nature of the clay material, the tool used, the quantity of water used, or the degree of hygrometry in which the paste is worked. The variability of the traces is thus high and they can often be polysemic (interpreted in different ways).

In this regard, it is important to note that the observation of the superficial layer of a recipient must be carried out over several zones in order to understand the formation mechanisms of the state of the surface of the recipients. In the same way, it is essential to take into consideration a combination of markers and not isolated markers which are generally polysemic.

The first distinction to make is between finishing operations on wet paste and on leather-hard paste.

Finishing on Wet Paste

Smoothing

Smoothing Without RKE

When a recipient roughed out and preformed without RKE is smoothed when wet, with no external water added either to the paste or the tool, the superficial layer is characterized by a surface with protruding grains, an irregular microtopography, and striations with threaded edges (Figs. 3.15, 3.16, and 3.17).

The surface with protruding grains is due to the rubbing action of the tool against the wet paste. Contrary to common belief, this action tends to make the grains stand out rather than pushing them in as the rubbing action is always, even very slightly accompanied by the removal of clay particles. This action thus participates in exposing the coarse fraction (Fig. 3.52a, b).

The irregular microtopography can be explained by “dry” smoothing and the absence of additional external water to fluidify it. The microtopography is more irregular when smoothing is carried out without water, with a tool with a thick profile (ceramic scraper type tool), and also presents overthicknesses linked to the movement of the clay during the passage of the tool (Fig. 3.52c).

The threaded striations are produced independently of the type of tools used, i.e., they occur with soft tools, such as the fingers or leather, but also with hard tools, such as scrapers in wood, calabash, or bone. The threaded aspect points to the absence of added water during the friction of the clay paste.

When a wet paste is smoothed with a tool impregnated with water, the superficial layer is also characterized by a surface with protruding grains, but in contrast, these are partially covered, the microtopography is fluidified, and the striations are partly ribbed (Fig. 3.52e). In fact, the more the smoothing tool is impregnated with water, the more the surface between the striations is fluidified and the thicker the clay slurry removed with the tool. The thickness of the ribbed striations thus depends on the added water. These form regardless of the type of tool used (finger, leather, wood, bone, calabash). The formation of bands of striations depends on the profile of the tool used. As well as ribbed striations, these bands can comprise striations with regular, irregular, or diffuse edges. Reticulated ribbed striations indicate finger prints (Fig. 3.52d).

Wet pastes smoothed without any added water can also present a surface with covered protruding grains. Such a lumpy surface was observed for pastes with high shrinkage during drying (example of a clay material from Jutland, Denmark) and with a coarse fraction of more than 1 mm. Shrinkage consequently results in making the largest grains stick out, but they nonetheless remain covered with a thin clay film (Fig. 3.52f).

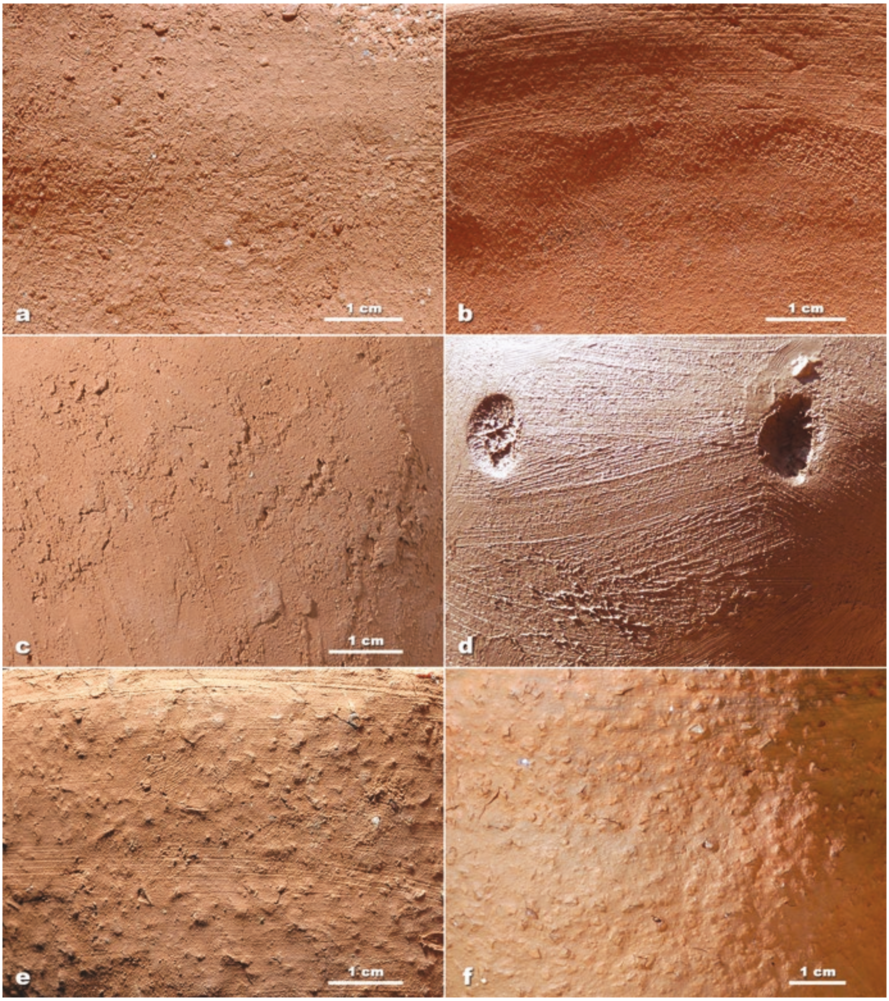

Fig. 3.52 Examples of surfaces smoothed without RKE: (**a**) wet clay smoothed with fingers without water; (**b**) wet clay smoothed with a pebble without water; (**c**) wet clay smoothed with a wooden tool; overthicknesses are linked to the movement of the clay during the passage of the tool; (**d**) reticulated threaded striations formed during smoothing with fingers laden with water on wet clay; (**e**) wet paste smoothed with water resulting in a surface with partially covered protruding grains, a fluidified microtopography, and partly ribbed striations; (**f**) lumpy surface of a paste smoothed without water, but with high shrinkage during drying making the coarse grains sticking out but nonetheless covered with a thin clay film

Smoothing with RKE

When smoothing is carried out with RKE, added external water is necessary, given the desiccation effect produced by the combined rubbing action of the fingers and the rotating movement. This results in a surface with protruding grains and a fluidified microtopography, continuously developed concentric horizontal ribbed

Fig. 3.53 Examples of surfaces smoothed with RKE: (**a**, **b**) surfaces smoothed with RKE characterized by concentric parallel ribbed striations and a fluidified microtopography

striations, and, possibly, clay slurry crests created during the diverse manipulations of the tools or the recipient (Fig. 3.53).

Finishing on Leather-Hard Paste

The finishing operations on leather-hard paste include smoothing and brushing. A leather-hard paste is a flexible paste and can be deformed, but is no longer sticky. Nonetheless, the degree of hygrometry can vary. Depending on this degree of hygrometry, the nature of the clay material, and the tool used, different traces are observable. We present the diagnostic traits of leather-hard paste below, regardless of paste type or composition.

Smoothing

Smoothing with a tool laden with water on a leather-hard paste re-humidifies the surface and thus produces traces specific to a smoothing on wet paste (ribbed striations and fluidified microtopography). However, the general compactness of the paste, combined with the deep striations resulting from the pulling out of the largest coarse fraction grains, should allow for the identification of working leather-hard paste (Fig. 3.54b).

Smoothing leather-hard paste has differential effects depending on the state of the smoothed surface and the tool used. It can result in walls with an irregular topography: whether there are remains of paste movement resulting from scraping during shaping which are not evened out during smoothing or whether the paste was brushed (see below).

Brushing

Brushing contributes to pulling out and bringing the coarse fraction to the surface. It is carried out on the outer face of the recipients. It results in a surface characterized by deep striations and floating coarse grains. Cracks can also appear.

Generally, the brushed surfaces are then smoothed with a tool laden with water. The coarse fraction, which is brought to the surface during brushing, is then covered with a fine film of clay slurry. This sequence of technical operations produces a surface with covered protruding grains, combined with a fluidified microtopography (Fig. 3.54a). The topography is irregular, given the differential covering of the brushed surface. This contrasts with the topography of the non-brushed internal surfaces.

Diagnostic Features of Surface Treatments

The characterization of surface treatments by friction requires observation at different scales, whereas the identification of most of the coating treatments requires physicochemical analyses. Various parameters are involved in the characteristics of the superficial layer of the paste, including the type of clay material, the quantity and type of tempers, the degree of hygrometry of the paste which is placed on a continuum, the type of tool, the gesture, the repetitiveness of the gesture, or the superposition of the technical actions. The diagnostic traits listed below can be observed at low magnification; they are pertinent for identifying the techniques used for surface treatments in accordance with the mechanical principles acting on the type of paste.

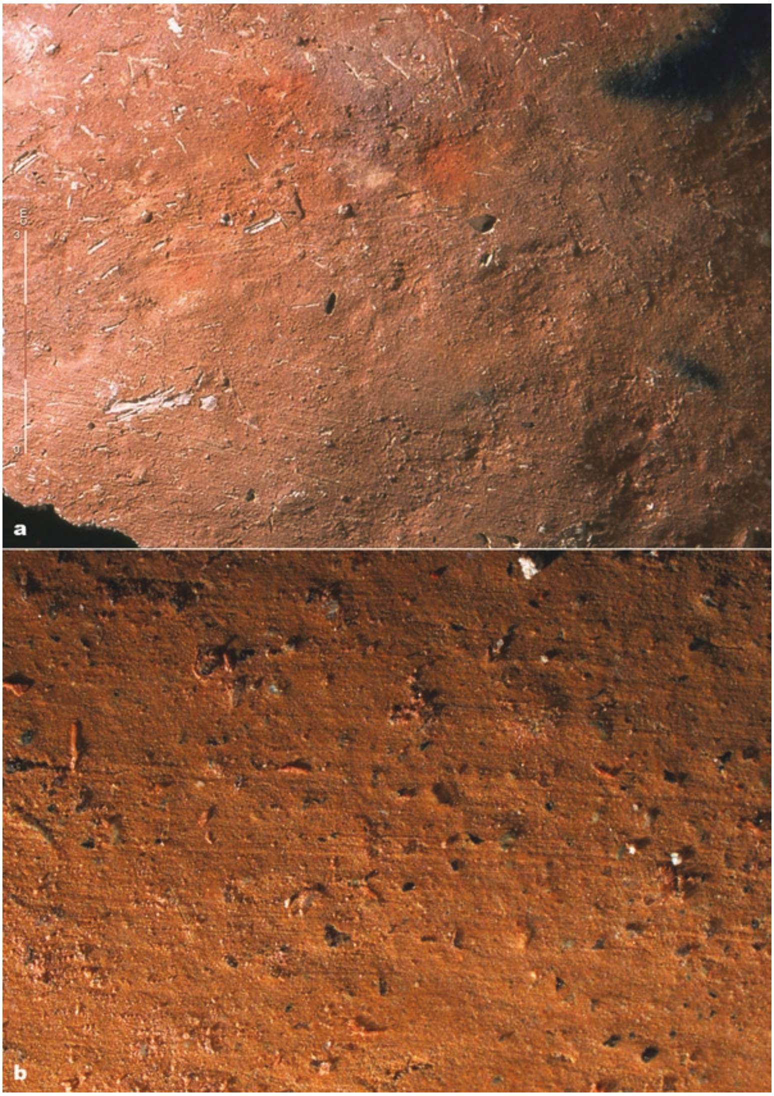

Fig. 3.54 Examples of finishing operations on leather-hard surfaces: (**a**) lumpy surface brushed with a corn cob and smoothed with the fingers laden with water (Senegal, ©A. Gelbert); (**b**) leather-hard paste smoothed with a piece of leather laden with water; the microtopography is compact and the striations are partly ribbed

Softening

Softening consists of rubbing a re-humidified leather-hard paste (prior to friction or with a tool laden with water) with a rigid tool. It results in the following characteristics: a surface with inserted grains, a compact microtopography with striations

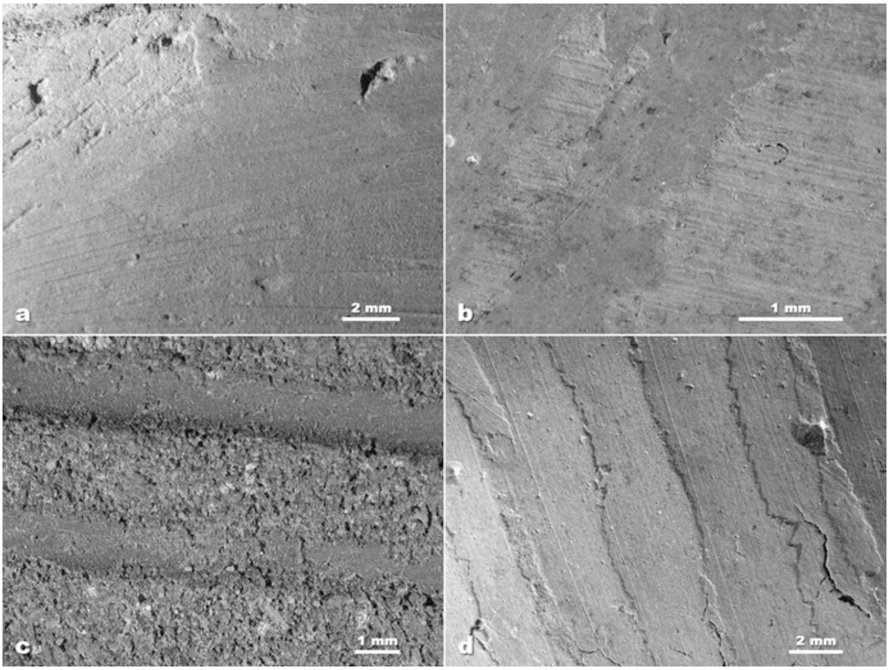

Fig. 3.55 Examples of surface treatment by friction: (**a**) previously shaved surface softened with a wooden stick loaded with water; (**b**) burnished strips on previously wet smoothed surface; (**c**) burnished strips on leather-hard hammered paste; (**d**) facets with scalloped edges formed during burnishing

with ribbed edges and an erratic layout, and very fine thickenings with scalloped edges linked to the movement of leather-hard clay (Fig. 3.55a). When the softened surface is not subsequently covered with slip, it presents a satin aspect.

Burnishing

Burnishing is obtained by friction with a rigid tool with no added water: the aim is to compact the surface and obtain a glossy effect. Besides the gloss, the main diagnostic traits are a surface with inserted grains and a compact microtopography with a set of striations combining deep striations with regular and/or scalloped edges and facets (overthicknesses) with scalloped edges created by the movement of leather-hard clay during the course of friction with a rigid tool (Fig. 3.55b, c). The latter protrude to varying degrees depending on the tool used, the pressure applied, and the degree of hygrometry of the paste (Fig. 3.55d). Generally speaking, the gloss effect depends on the clay material, the degree of hygrometry, and the polishing tool (Fig. 3.56).

Fig. 3.56 Examples of burnishing: (**a**) covering burnishing whose gloss indicates friction on dry paste; (**b**) partial burnishing whose weak gloss and overthicknesses indicate friction on leather-hard paste

Shining

Unlike burnishing, shining is carried out with a soft (flexible) tool. This results in a sheen over the surface of the paste. The aspect of this surface can be variable, depending on whether it was smoothed, shaved, trimmed, turned, beaten, or burnished prior to shining. In all cases, shining results in compacting and striating the clay surface and softens the asperities of the microrelief.

The identification of softening, burnishing, and shining tools involves, on the one hand, higher scales of observation than those used to describe the diagnostic traits listed here and, on the other hand, micro-wear studies of the tools associated with the archaeological recipients (van Gijn and Lammers-Keijsers 2010; Maigrot 2010; Torchy and Gassin 2010). The results are promising. We can mention, for example, the identification of sheep fleece as a shining tool during the Neolithic period in the South of France (Lepère 2014).

Clay Coating

The application of clay coating to a wet or leather-hard paste produces a surface combining protruding grains covered with a fine film of clay and floating grains, a fluidified microtopography, ribbed striations, and an irregular topography created by variations in the thickness of the clay coating or overthicknesses of clay coating (Figs. 3.57 and 3.58).

Floating grains are one of the most significant markers in so far as they are not part of the fine mass but deposited on the surface of the clay layer redistributed on the wall. The deposit of a fine clay film on the coarse fraction and the fluidity of the microtopography can be explained by the colloidal nature of clay coating.

The networks of crests correspond to accumulations of clay slurry during application.

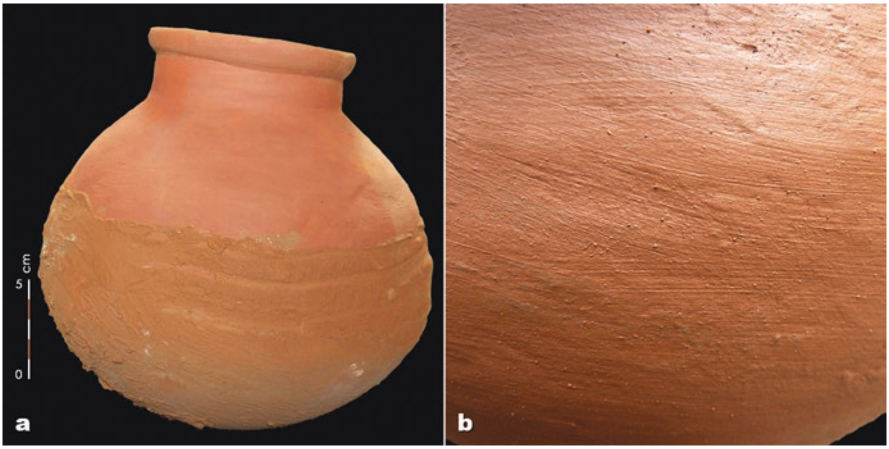

Fig. 3.57 Examples of surface treatments by coating: (**a**) cooking pot coated with clay slurry in order to protect the outer face from thermal shocks; (**b**) slipped surface with a piece of cloth; it is characterized by floating grains and traits similar to the ones of a smoothing with water on leather-hard paste

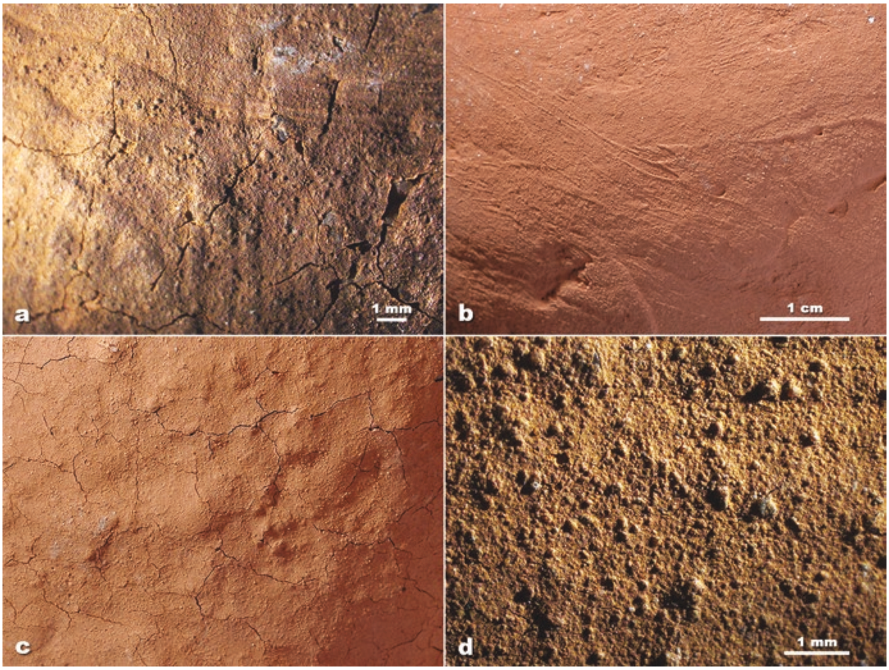

Fig. 3.58 Examples of clay-coated surfaces: (**a, b**) overthicknesses and floating grains; (**c**) clay coating applied with a wooden tool on wet paste; (**d**) clay coating applied with a piece of leather on leather-hard paste

The markers of clay coating are similar to those for wet smoothing on brushed paste. In order to distinguish between these two operations, it is essential to examine the surface carefully to identify the possible presence of brushed zones that were not completely covered by clay coating.

Slip

Slip can either be identified with the naked eye when the color of the slip contrasts with the color of the clay or on a microscopic scale. With optical microscopy, the slip presents a clearly dissociated microstructure from the ceramic paste, and from this point of view, it is easily recognizable.

Apart from the color, the application of slip is characterized by the same traits as those described for coating with liquid clay slurry (Fig. 3.57).

Coating with Organic Materials, Varnish, and Glaze

When a surface presents a glossy aspect that was not obtained by burnishing or shining, then physicochemical analyses must be used to determine the type of coating and to distinguish between vitrified slips, organic materials, or glaze (e.g., Tite et al. 1982; Tite et al. 1998; Tite 1999; Giorgetti et al. 2004; Gliozzo et al. 2004).

Diagnostic Features of Decorative Techniques

The study of decorative techniques consists in identifying in what state the paste was worked and therefore, at what stage the decoration was carried out, on one hand, and, on the other hand, the tools and gestures used to work the paste.

Like for coatings, the identification of the pigments used in the paints requires physicochemical analyses.

State of the Paste
Decoration can be produced on wet, leather-hard, dry, or fired clay.

Decoration by simple, tilted, or rolled impression, or by stamping, is only carried out on wet paste. Only paddled impression is carried out on leather-hard paste (Fig. 3.59e, f). Decoration by carving is carried out on leather-hard to dry clay. Decoration with added elements is applied to wet or leather-hard paste. Decoration by modeling is carried out on wet paste.

As for incised decorations, they can be made on wet, leather-hard, dry, or fired clay. It is possible to identify the state of the paste by examining the edges and the bottoms of incisions (Fig. 3.59). Incisions with thickened edges indicate a wet paste; incisions with scalloped edges and compact bottoms indicate a leather-hard consistency; fine incisions with scaled edges indicate a dry or a fired paste (Shepard 1965; Rye 1981; Balfet et al. 1983).

Fig. 3.59 Examples of incised and impressed decors: (**a**, **b**) incised decors on wet paste; (**c**, **d**) incised decor on leather-hard paste; (**e**, **f**) paddled decor on leather-hard paste (**e**: photo ©H. Wu; **f**: ©A. Favereau)

Incisions are generally applied after the slip and burnishing. On burnished pottery and pottery with slip, this results in incisions with scalloped or slightly scaled edges when they are made on clay with a leather-hard to dry consistency and with bottoms with no slip and with a compact microtopography.

Tools and Gestures

Generally, the identification of the tools and gestures involved in decorating pottery follows an experimental approach with the use of plasticine molds to check and illustrate the results obtained. First of all, this identification is based on the recognition of the active part of the tool in order to reconstruct the movement (Caneva 1987; Livingstone Smith 2010).

For impressed decoration, the active part can be identified by analyzing the morphology of the elements, the distances between these elements – a series of elements reflecting the active part of the tool – and, lastly, the relations between the series of elements, which determine the gesture, using digital images and vectorial drawing software (Livingstone Smith 2010). Several diagnostic traits emerge from this descriptive principle:

> "If all the impressed elements are identical in form, but spatially independent, then they are simple impressions made with an awl. On the other hand, if there is a spatial relationship between several equidistant elements, a more complex tool was used, such as a comb, a roller or a net. In this case, the identification of the tool used involves choosing several impressed elements on the same axis and then checking to see if these are associated in several places on the surface. If this is the case, we can extend the identification to determining the minimum number of systematically associated impressed elements. This group is the negative of the active part of the tool. If these associated elements on an axis are repeated side by side, a comb was used. If these elements occur in a cyclical way and each series is separated from the others by a series of distinct impressed elements, then a roller was used. In this latter case, the repetition cycle depends on the number of surfaces of the tool (trihedral, four-sided, five-sided, etc.)". (Livingstone Smith 2010, 125)

Recently, the study of the types of rollers used for impressions has benefitted from a broad comparative approach, leading to a reasoned classification (Haour et al. 2010; Livingstone Smith et al. 2010; Gallin 2013). A first division was made between rollers made of assembled materials (round fibers, flat fibers, etc.), rollers made with modified materials (wood, bone, inflorescences, fruit), and rollers made from non-modified materials (shell, springs, etc.). The rollers made up of materials assembled by twisting, folding, knotting, or plaiting were subdivided into two categories: simple tools and core tools. The simple tools were further subdivided according to the nature of the material used to make the tool (cord or flat fiber). The core tools were subdivided depending on whether the same fiber makes up the core and the envelope: tool on continuous core or tool on separate core (Livingstone Smith et al. 2010, 53). Plasticine imprints of all these objects were then taken. They were photographed and are excellent references for interpreting the patterns obtained by rolled impression.

The types of combs used for decoration by impression have also undergone experimental studies, and reference collections have been built up to determine the number of teeth in the comb and the movements used to manipulate them (e.g., Zapotocka 1978; Meunier 2012; Gallin 2013).

Other research has been carried out on the different genera and species of shell used in impressed decorations. A comparative approach showed that the detection of the form and size of the teeth, the space between the teeth, the number of teeth, and, lastly, the curve and the size of the imprint are criteria that should lead to the identification of the genus, but generally not the species (Manen and Salanova 2010).

Finally, for incised impressions, note that studies have been carried out on the variability of the patterns obtained depending on the types of tools and how they were used (Gallin 2013), as well as studies of the morphology of the incisions in relation with the tool used (Pomédio 2010).

Diagnostic Features of Firing Techniques

Ideally, characterizing firing structures and firing conditions involves the recognition of open or kiln firing, their layout, and operation as well as the arrangement of the recipients, identifying whether firing is oxidizing or reducing, the estimation of heating rates and firing temperatures, or the identification of the type of fuel used.

To this end, archaeological structures and the intrinsic properties of ceramics (mineralogy and microstructure) are analyzed, using analytic tools aiming in particular to characterize firing temperatures and thermal profiles (heating rate, maximum temperature, duration of firing, soaking and cooling time) (e.g., Tite 1969; Maniatis and Tite 1981; Bishop et al. 1982; Shoval 1994; Wagner et al. 1994; Moropoulou et al. 1995; Tite 1995; Duminuco et al. 1998; Cultrone et al. 2001; Thér and Gregor 2011).

Only the markers visible with the naked eye are discussed in this volume, that is, the colors of the surface and the radial section of the walls.

Surface Colors

The homogeneity of the color of pottery surfaces was considered for a while to be a criterion for distinguishing between open firing and kiln firing. However, this criterion soon turned out to be polysemic (Rye 1981): on the one hand, vertical updraft kilns with floors that are perforated with wide holes let the flames pass through, and the recipients can present different colors linked to firing; on the other hand, in both structures, the air can circulate differently, leading to variations in color with a formation of black stains; lastly, it is possible to obtain homogeneous colors, even with open firing (Fig. 3.60).

Colors of the Radial Section of the Walls

The radial section of the walls can be described in terms of the color of the three zones structuring it: the external margin, the core, and the internal margin. These colors vary depending on the firing atmosphere, the duration of re-oxidation in post-combustion phase, the thickness of the sherds, and the composition of the paste. In the case of an oxidizing atmosphere, the two outer margins are oxidized. As for the core, depending on whether or not the oxidation process has been completed, it is black, which is a sign of the reducing phase, or the same color as the margins. The inner margin can also remain black if the ceramics were rapidly removed from firing and therefore if the oxidation process did not have time to affect the whole thickness of the wall (Martineau and Pétrequin 2000). However, although the mechanism producing the re-oxidation of the margins and the core of the walls is relatively well known, it is less clear how this oxidation process acts differentially from one recipient to another or on the same recipient during the same firing. Factors such as the

Fig. 3.60 Examples of colors linked to firing techniques and atmospheres: (**a**) water jar with firing stains fired in oxidizing atmosphere in a vertical updraft kiln whose floor is made up of metallic blades (Jodhpur dist., Rajasthan); (**b**) recipients fired in open firing (Nagada, Uttar Pradesh, India); (**c**) in the forefront, recipients fired in reducing atmosphere, in the background, recipients fired in oxidizing atmosphere (Jodhpur dist., Rajasthan); (**d**) recipient with bicolored outer surface due to stacking the recipients on top of each other in the firing chamber (Tell Arqa, phase N, Lebanon)

arrangement of the fuel, the conditions of air circulation or the many processes at work in open firing, seems to play a certain role, in addition to the post-combustion time. As a result, at the present time, it is not possible to characterize a way of firing, a firing procedure or technique, based solely on how the margins and the core were affected by the oxidation process.

Lastly, let us note that sections with different colors, or on the contrary, with homogeneous colors, are found in open firing as well as in kiln firing and on ceramic recipients of equal hardness.

Oxidizing *Versus* Reducing Atmosphere

The color of the surfaces is the best indicator of the firing atmosphere. For an oxidizing atmosphere, the surfaces of the pottery are pale and vary from red to white, depending on the oxides contained in the clay (Rice 1987). For a reducing atmosphere, the surfaces are dark, varying from black to brown, depending on the type of clay material (Fig. 3.60c).

Recipients presenting black and red surfaces are fired in different atmospheres.

Recipients with red outer surfaces and black inner surfaces are fired with the opening against the opening or the bottom of another recipient, or with the opening against the ground, creating a reducing atmosphere inside the recipient.

Two processes can be used to obtain red recipients with black rims and black inner surfaces (Baba and Saito 2004). With the first process, recipients are fired with the opening facing down in a layer of organic materials (e.g., balls of cereal) covering the upper edge of the recipients. This layer of organic materials lies on a bed of wood. According to the principle of open firing, all of the recipients are then covered with fuel and an insulating material (wood, straw, and layer of mud). The ensuing firing is then oxidizing for the outer surfaces of the recipient and reducing for the external rim and the internal surface of the recipient, as the ball of cereal is consumed but does not burn, resulting in carbon deposits on these parts. For the second process, the recipients are first of all fired in an oxidizing atmosphere. When they are red and burning hot, they are removed from the fire and plunged into a hole filled with balls of cereals, with the opening facing down, which creates the required carbon deposit conditions for obtaining black internal surfaces and rims.

When, conversely, recipients are black on the outside and red on the external rim and internal surfaces, like for the "Khirbet Kerak Ware" (third millennium B.C., Southern Levant), the reverse process can be envisaged, i.e., positioning the recipient so that carbon is only deposited on the external surfaces.

Lastly, there are recipients with bicolored outer surfaces, which can be black on the upper part and red on the lower part or vice versa. The differences in color are linked to stacking the recipients on top of each other in the firing chamber, where the brown part corresponds to the part deprived of oxygen, on which the next recipient is stacked (Fig. 3.60d).

Reconstruction of the Chaînes Opératoires

The observation of the diagnostic traits of the *chaînes opératoires* requires the manipulation of a lot of sherds, as a single sherd can only indicate the finishing operations and bears no trace of the previous operations. Ideally, it also involves refits, as they allow for the analysis of the macro-traces on the different parts of the recipients, and the interpretation of the whole shaping and finishing *chaîne opératoire*, as well as bringing to light diagnostic characteristics that are only visible once the recipient has been refitted, such as the sequence of preferential fractures, for example.

An example of the reconstruction of a *chaîne opératoire* is given below in order to show how to present the diagnostic traits and the interpretation based on these traits. This example is a study carried out on the ceramic assemblages from the site of Tell Arqa (Roux and Thalmann 2016), a site occupied during the third millennium B.C. in the North of the Lebanon and excavated by Thalmann (2006). The *chaîne opératoire* is described from the beginning of the fashioning sequence and concerns the fabrication of jars from phase S (first half of the third millennium B.C.) (Fig. 3.61).

First of all, a ball of clay is flattened by percussion (tapping) until a thin, circular-shaped disc with a thickness of several millimetres is obtained. *Diagnostic traits*: in radial section, under the stereomicroscope, the base presents horizontal elongated subparallel voids over a height of several millimetres; horizontal fissures indicate a base made up of two assembled superposed elements (see below); on the outer face of the bases, the absence of fissure argues in favor of a modeled base.

The disc and the working plan are then sprinkled with ashes, an anti-adhesive, to prevent the clay material from sticking to the base. *Diagnostic traits*: whitish particles embedded in the hollows of the outer base.

The working plan is in basalt. *Diagnostic traits*: plasticine impressions on the basalt stones found *in situ* are similar to the uneven relief of the outer surfaces of the bases.

Once the clay disc is deposited on the basalt support, a coil is placed on the disc, followed by a coil placed on the periphery of the disc, followed by a coil deposited at the junction between the peripheral coil and the inner base. The coils are joined and thinned by discontinuous pressures. *Diagnostic traits*: in radial section, base with two superposed elements, the upper element presents oblique to vertical fissures indicating the spiral positioning of a coil above the disc; concentric overthicknesses on the inner base of the recipients showing the outline of a spiral coil; in radial section at the base/body junction, horizontal fissures indicating the peripheral coil and oblique fissure indicating the addition of a connecting coil; digital hollows juxtaposed at the start of the lower body indicating coil junction pressure and thinning.

Once the base is made, the body is formed with coils with a thickness of about 1.5 cm. The coils are placed on top of each other with the coiling by pinching technique and joined using discontinuous internal pressures. *Diagnostic traits*: on the inner walls, concentric horizontal fissures; in radial section, oblique fissures, uneven relief.

The inner face of the body is then scraped and smoothed with discontinuous pressures: the gestures are oblique to horizontal. *Diagnostic traits*: surface with protruding grains, deep striations covered with finer striations with threaded edges on an irregular microtopography, striations with a subhorizontal to oblique orientation.

The outer face is in turn scraped with the active hand applying a tool to the outer surface, while the passive hand is placed on the inner face to support the wall. The aim of the scraping is to erase the traces of joints and regularize the superficial layer of the paste. *Diagnostic traits*: on the outer surfaces, irregular microtopography, protruding grains, striations with threaded edges, deep striations with a vertical or multi-directional orientation;

Fig. 3.61 (continued) inner base at the junction base/body; (**e**, **f**) bumpy body and concentric fissures indicating discontinuous pressures on assembled elements; (**g**) oblique fissures visible in radial section; (**h**) fashioning of the neck with the help of a rotary movement after the fashioning of the body; (**i**) combing the outer face on wet paste after the shaping of the neck; (**j**) cross-combed pattern; (**k**) subparallel vertical depressions corresponding to the imprints of the passive hand supporting the wall while the active hand works on the outer face; (**l**) folding of the leather-hard disc on the lower body (overthickness over the combing)

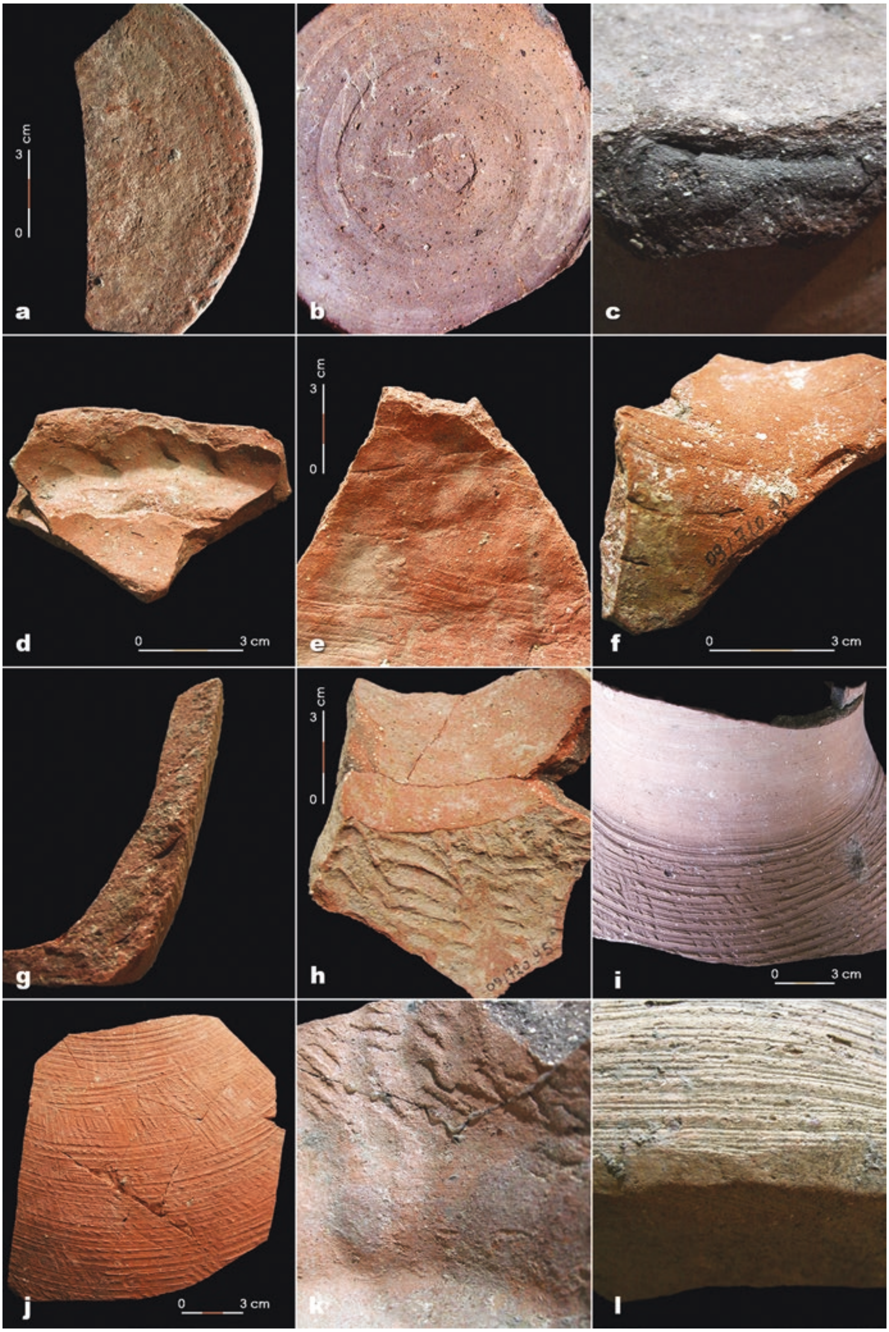

Fig. 3.61 Diagnostic traits of the ceramic *chaîne opératoire* of Tell Arqa (phase S): (**a**) basalt working plan imprint on the outer base; (**b**) concentric overthickness on the inner base linked to the placing of a coil above the disc; (**c**) view of the coil placed on the disc; (**d**) finger imprints on the

on the inner surfaces, subparallel vertical depressions corresponding to the imprints of the passive hand supporting the wall.

Once the body is preformed in this way, the neck is formed using the coiling technique by pinching. Smoothing is done with a continuous rotary movement. *Diagnostic traits*: smoothing striations on the neck overlying smoothing striations on the internal body, indicating an operation after the finishing of the body (and not at the same time); marked overthickness between the neck and the internal body; concentric horizontal subparallel ribbed bands on the inner and outer faces and fluidified microtopography indicating smoothing with the addition of more water than for the body.

The last coil of the neck is turned towards the exterior to form a lip. *Diagnostic traits*: on the outer face, horizontal fissures along the lip; in radial section, vertical oblong void dividing the lip in two.

After the shaping of the neck, the outer part of the body is subject to concentric combing, probably carried out with a rotating movement. *Diagnostic traits*: on the external surfaces, parallel concentric grooves.

When the recipients have handles, the latter are applied at the end of the shaping process by discontinuous pressures and attached by spreading the paste. The handles are made from coils. *Diagnostic traits*: no deformation of the inner surface; spreading the paste on the external surface.

The recipient is then left to dry, probably out of the working plan and with the neck facing down. *Diagnostic traits*: traces of overthickness significant of working a leather-hard paste on the outer base/body junction, indicating that the recipient was turned upside down.

At this stage, the edges of the disc (the base) are folded over the lower outer body. *Diagnostic traits*: overthickness over the combing indicating the folding of paste in continuity with the base, compact microtopography of the overthickness indicating it was worked when leather-hard.

Firing is oxidizing, with temperatures that must have reached at least 800°C, considering the hardness of the pastes.

References

Baba, M., & Saito, M. (2004). Experimental studies on the firing methods of black-topped pottery in predynastic Egypt. In S. Hendrickx & B. Adams (Eds.), *Egypt at its origins: Studies in memory of Barbara Adams: Proceedings of the International Conference "Origin of the State, Predynastic and Early Dynastic Egypt," Krakow, 28 August – 1st September 2002* (pp. 575–589). Leuven: Peeters Publishers.

Balfet, H. (1966). La céramique comme document archéologique. *Bulletin de la Société Préhistorique Française*, *63*, 279–310.

Balfet, H., Fauvet-Berthelot, M.-F., & Monzon, S. (1983). *Pour la normalisation de la description des poteries*. Paris: Editions du CNRS.

Barham, A. J. (1995). Methodological approaches to archaeological context recording: X-radiography as an example of a supportive recording, assessment and interpretive technique. In A. J. Barham & R. I. MacPhail (Eds.), *Archaeological sediments and soils: Analysis, interpretation and management* (pp. 145–182). London: Institute of Archaeology, UCL.

Berg, I. (2008). Looking through pots: recent advances in ceramic X-radiography. *Journal of Archaeological Science, 35*, 1177–1188.

Bishop, R. L., Rands, R. L., & Holley, G. R. (1982). Ceramic compositional analysis in archaeological perspective. *Advances in Archaeological Method and Theory, 5*, 275–330.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., & Tursina, T. (1985). *Handbook for soil thin section description*. Wolverhampton: Waine Research.

Butler, S. (1992). X-radiography of archaeological soil and sediment profiles. *Journal of Archaeological Science, 19*, 151–161.

Caneva, I. (1987). Pottery decoration in prehistoric Sahara and upper Nile: a new perspective. In B. E. Barich (Ed.), *Archaeology and the environment in the Libyan Sahara. The excavations in the Tadrat Acacus, 1978–1983* (pp. 231–254). BAR International Series 368. Oxford: Archaeopress.

Carr, C. (1990). Advances in ceramic radiography and analysis: applications and potentials. *Journal of Archaeological Science, 17*, 13–34.

Carr, C., & Riddick, E. B., Jr. (1990). Advances in ceramic radiography and analysis: laboratory methods. *Journal of Archaeological Science, 17*, 35–66.

Courty, M.-A., Goldberg, P., & Macphail, R. (1989). Soils and Micromorphology in Archaeology. In *Cambridge Manuals in Archaeology*. Cambridge: Cambridge University Press.

Courty, M.-A., & Roux, V. (1995). Identification of wheel throwing on the basis of ceramic surface features and microfabrics. *Journal of Archaeological Science, 22*, 17–50.

Cultrone, G., Rodriguez-Navarro, C., Sebastian, E., Cazalla, O., & De La Torre, M. J. (2001). Carbonate and silicate phase reactions during ceramic firing. *European Journal of Mineralogy, 13*, 621–634.

Denham, T., Sniderman, K., Saunders, K. M., Winsborough, B., & Pierret, A. (2009). Contiguous multi-proxy analyses (X-radiography, diatom, pollen, and microcharcoal) of Holocene archaeological features at Kuk Swamp, Upper Wahgi Valley. *Papua New Guinea. Geoarchaeology, 24*, 715–742.

van Doosselaere, B. (2011). *Poterie et histoire au temps des grands empires ouest africains. Etude technologique de l'assemblage céramique de Koumbi Saleh (Mauritanie 6e-17e siècles)*. Paris: Université de Paris I, Panthéon-Sorbonne. PhD.

Dugmore, A. J., & Newton, A. J. (1992). Thin tephra layers in peat revealed by X-radiography. *Journal of Archaeological Science, 19*, 163–170.

Duminuco, P., Messiga, B., & Riccardi, M. P. (1998). Firing process of natural clays. Some microtextures and related phase compositions. *Thermochimica Acta, 321*, 185–190.

Franken, H. J. (1970). A new approach to the study of pottery from excavations. *Archeologia, 21*, 1–8.

Franken, H. J. (1978). The analysis of ancient methods of potmaking. *Acta Praehistorica et Archaeologica Berlin, 9–10*, 77–78.

Gallin, A. (2013). CerAfIm. http://lampea.cnrs.fr/cerafim/ (accessed 14/12/2018).

Gelbert, A. (1994). Tour et tournette en Espagne : recherche de macrotraces significatives des différentes techniques et méthodes de façonnage. In J. Courtin & D. Binder (Eds.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes) (pp. 59–74). Juan-les-Pins: Editions APDCA.

Gelbert, A. (2003a). *Traditions céramiques et emprunts techniques dans la vallée du fleuve Sénégal. Ceramic traditions and technical borrowings in the Senegal River Valley*. English/French extracts at http://www.thearkeotekjournal.org/tdm/Arkeotek/en/articles_reedites/Traditions.xml. Paris: Editions de la Maison des sciences de l'homme, Editions Epistèmes.

Gelbert, A. (2003b). Ceramic surface features and fashioning techniques and methods. *The Arkeotek Journal (*www.thearkeotekjournal.org*)* Republished articles. Extract from Ceramic Traditions and Technical Borrowings in the Senegal River Valley, Éditions de La Maison Des Sciences de l'homme, Éditions Epistèmes, Paris, Bilingual CD.

van Gijn, A., & Lammers-Keijsers, Y. (2010). Toolkits for ceramic production: informal tools and the importance of high power use-wear analysis. *Bulletin de la Société Préhistorique Française, 107*, 755–762.

Giorgetti, G., Gliozzo, E., & Memmi, I. (2004). Tuscan black glosses A mineralogical characterization by high resolution techniques. *European Journal of Mineralogy, 16*, 493–503.

Gliozzo, E., Kirkman, I. W., Pantos, E., & Turbanti, I. M. (2004). Black gloss pottery: production sites and technology in northern Etruria, Part II: gloss technology. *Archaeometry, 46*, 227–246.

Greene, A., & Hartley, C. (2007). From analog to digital: protocols and program for a systematic digital radiography of archaeological pottery. In *Eur. Meet. Ancient Ceramics* (pp. 5–14). Budapest: Hungarian National Museum.

Hamblin, W. K. (1962). X-ray radiography in the study of structures in homogeneous sediments. *Journal of Sedimentary Research, 32*, 201–210.

Haour, A., Manning, K., Arazi, N., Guèye, S., Keita, D., Livingstone-smith, A., MacDonald, K., Mayor, A., McIntosh, S., & Vernet, R. (Eds.). (2010). *African pottery roulettes past and present: Techniques, identification and distribution*. Oxford: Oxbow Books.

Huysecom, E. (1994). Identification technique des céramiques africaines. In D. Binder & J. Courtin (Eds.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes 14) (pp. 31–44). Juan-les-Pins: Editions APDCA.

Kahl, W.-A., & Ramminger, B. (2012). Non-destructive fabric analysis of prehistoric pottery using high-resolution X-ray microtomography: a pilot study on the late Mesolithic to Neolithic site Hamburg-Boberg. *Journal of Archaeological Science, 39*, 2206–2219.

Krinitzsky, E. L. (1970). *Radiography in the earth sciences and soil mechanics*. New York-London: Plenum Press.

Lepère, C. (2014). Experimental and traceological approach for a technical interpretation of ceramic polished surfaces. *Journal of Archaeological Science, 46*, 144–155.

Livingstone Smith, A. (2001). *Chaîne opératoire de la poterie : Références ethnographiques, analyses et reconstitution*. Bruxelles: Université Libre de Bruxelles. PhD.

Livingstone Smith, A., Gosselain, O., Mayor, A., & Guèye, S. (2010). Roulettes modernes d'Afrique sub-saharienne. In A. Haour, K. Manning, N. Arazi, O. Gosselain, N. S. Guèye, D. Keita, A. Livingstone-smith, et al. (Eds.), *African pottery roulettes past and present.: Techniques, identification and distribution* (pp. 35–114). Oxford: Oxbow Books.

Livingstone Smith, A. (2010). Méthode d'identification des décors roulés. In A. Haour, K. Manning, N. Arazi, O. Gosselain, N. S. Guèye, D. Keita, A. Livingstone-smith, et al. (Eds.), *African pottery roulettes past and present: Techniques, identification and distribution* (pp. 117–130). Oxford: Oxbow Books.

Livingstone-Smith, A., Bosquet, D., & Martineau, R., Eds. (2005). *Pottery manufacturing processes: Reconstitution and interpretation*. Acts of the XIVth Congress UISPP, University of Liège, Belgium, 2–8 September. Oxford: Archaeopress.

Maigrot, Y. (2010). Étude comparative de deux séries en os impliqués dans la production céramique néolithique du Jura : Clairvaux XIV (Néolithique moyen) et Chalain 4 (Néolithique final). *Bulletin de la Société Préhistorique Française, 107*, 737–753.

Manen, C., & Salanova, L. (2010). Les impressions de coquilles marines à front denté dans les décors céramiques néolithiques. In C. Manen, F. Convertini, & D. Binder (Eds.), *Premières sociétés paysannes de Méditerranée occidentale : structure des premières productions céramiques* (Mémoires de La Société Préhistorique Française 51) (pp. 57–64). Paris: Société Préhistorique Française.

Maniatis, Y., & Tite, M. S. (1981). Technological examination of Neolithic-Bronze Age pottery from central and southeast Europe and from the Near East. *Journal of Archaeological Science, 8*, 59–76.

Martineau, R. (2000). *Poterie, techniques et sociétés. Études analytiques et expérimentales à Chalain et Clairvaux (Jura), entre 3200 et 2900 av. J.-C.* Dijon: Université de Franche-Comté. PhD.

Martineau, R., & Pétrequin, P. (2000). La Cuisson des poteries néolithiques de Chalain (Jura), approche expérimentale et analyse archéologique. In P. Pétrequin, P. Fluzin, J. Thiriot, & P. Benoit (Eds.), *Arts du feu et productions artisanales* (Actes des XXe rencontres d'Antibes) (pp. 337–358). Antibes: APDCA.

Meunier, K. (2012). *Styles céramiques et néolithisation dans le sud-est du Bassin parisien: une évolution Rubané, Villeneuve-Saint-Germain*. Paris: CNRS éditions, INRAP.

Moropoulou, A., Bakolas, A., & Bisbikou, K. (1995). Thermal analysis as a method of characterizing ancient ceramic technologies. *Thermochimica Acta, 269*, 743–753.

Pierret, A. (2001). *Analyse technologique des céramiques archéologiques : développements méthodologiques pour l'identification des techniques de façonnage. Un exemple d'application : le matériel du village des Arènes à Levroux (Indre)*. Thèse à La Carte. Villeneuve d'Ascq: Presses Universitaires du Septentrion.

Pierret, A., & Moran, C. J. (1996). Quantification of orientation of pore patterns in X-ray images of deformed clay. *Microscopy Microanalysis Microstructures, 7*, 421–432.

Pierret, A., Moran, C. J., & Bresson, L. M. (1996). Calibration and visualization of wall-thickness and porosity distributions of Ceramics using X-radiography and image processing. *Journal of Archaeological Science, 23*, 419–428.

Pomédio, C. (2010). *La céramique du Bajío, Guanajuato, Mexique : étude techno-stylistique de la céramique incisée du Cerro Barajas*. Paris: Université de Paris I, Panthéon-Sorbonne. PhD.

Rice, P. M. (1987). *Pottery analysis. A sourcebook*. Chicago/London: The University Chicago Press.

Röntgen, W. C. (1896). On a new kind of rays. *Science, 3*, 227–231.

Rosselló, J. G., & Trias, M. C. (2013). *Making Pots: el modelado de la cerámica a mano y su potencial interpretativo*. BAR International Series 2540. Oxford: Archaeopress.

Roux, V. (2017). Smoothing and clay coating: reference collections for interpreting southern Levant Chalcolithic finishing techniques and surface treatments. *The Arkeotek Journal*. www.thearkeotekjournal.org.

Roux, V., & Courty, M.-A. (1998). Identification of wheel-fashioning methods: technological analysis of 4th-3rd millennium BC oriental ceramics. *Journal of Archaeological Science, 25*, 747–763.

Roux, V., & Thalmann, J.-P. (2016). Évolution technologique et morpho-stylistique des assemblages céramiques de Tell Arqa (Liban, 3e millénaire av. J.-C.) : stabilité sociologique et changements culturels. *Paléorient, 42*, 95–121.

Rye, O. S. (1977). Pottery manufacturing techniques : X-Ray studies. *Archaeometry, 19*, 205–211.

Rye, O. S. (1981). *Pottery Technology. Principles and Reconstruction* (Manuals on Archaeology 4). Washington, DC: Taraxacum Press.

Shepard, A. O. 1965. *Ceramics for the Archaeologist*. Washington, D.C.: Carnegie Institution of Washington.

Shoval, S. (1994). The firing temperature of a Persian-period pottery kiln at Tel Michal, Israel, estimated from the composition of its pottery. *Journal of Thermal Analysis and Calorimetry, 42*, 175–185.

Thalmann, J.-P. (2006). *Tell Arqa, 1. Les niveaux de l'âge du Bronze*. Bibliothèque archéologique et historique 177. Beyrouth: Institut français du Proche-Orient.

Thér, R., & Gregor, M. (2011). Experimental reconstruction of the pottery firing process of Late Bronze Age pottery from North-Eastern Bohemia. In S. Scarcella (Ed.), *Archaeological ceramics: A review of current research* (pp. 128–142). BAR International Series 2193. Oxford: Archaeopress.

Tite, M. S. (1969). Determination of the firing temperature of ancient ceramics by measurement of thermal expansion: a reassessment. *Archaeometry, 11*, 131–143.

Tite, M. S. (1999). Pottery production, distribution, and consumption—the contribution of the physical sciences. *Journal of Archaeological Method and Theory, 6*, 181–233.

Tite, M. S., Bimson, M., & Freestone, I. C. (1982). An examination of the high gloss surface finishes on Greek Attic and Roman Samian wares. *Archaeometry, 24*, 117–126.

Tite, M. S., Freestone, I., Mason, R., Molera, J., Vendrell-Saz, M., & Wood, N. (1998). Lead glazes in antiquity – Methods of production and reasons for use. *Archaeometry, 40*, 241–260.

Tite, M. S. (1995). Firing temperature determination–how and why? In *The aim of laboratory analyses of ceramics in archaeology, April 7–9, 1995 in Lund, Sweden* (pp. 37–42). Stockholm: Kungliga vitterhets-, historie-och antikvitets akademien.

Titterington, P. F. (1935). Certain bluff mounds of western Jersey County, Illinois. *American Antiquity, 1*, 6–46.

Torchy, L., & Gassin, B. (2010). Le travail de la poterie en contexte chasséen : des outils en silex pour la production céramique ? *Bulletin de la Société Préhistorique Française, 107*, 725–735.

van der Leeuw, S. (1977). Towards a study of the economics of pottery making. In *Ex Horreo*, 4:68–76. Amsterdam: University of Amsterdam.

Vandiver, P., Ellingson, W., Robinson, T., Lobick, J. J., & Séguin, F. H. (1991). New applications of X-radiographic imaging technologies for archaeological ceramics. *Archeomaterials, 5*, 185–207.

Wagner, U., Gebhard, R., Murad, E., Riederer, J., Shimada, I., & Wagner, F. E. (1994). Kiln firing at Batan Grande: today and in formative times. In *Archaeometry of Pre-Columbian Sites and Artifacts: Proceedings of a Symposium Organized by the UCLA Institute of Archaeology* (pp. 67–84). Los Angeles: J. Paul Gutty Trust.

Zapotocka, M. (1978). Le décor de la culture néolithique de la Céramique Pointillée: technique, terminologie et qualité de la documentation. *Archeologické Rozhledy Praha, 30*, 504–534.

Chapter 4
Classification of Archaeological Assemblages According to the *Chaîne opératoire* Concept: Functional and Sociological Characterization

Ceramic assemblages are traditionally classified into morphological or morpho-stylistic types, or types combining shapes and petrofabrics. These classifications aimed at constructing chrono-cultural typologies. The obtained types result in the characterization of ceramic assemblages from a period and a place and thus represent relevant benchmarks for establishing relative chronologies, tracing boundaries between cultural groups and establishing links between groups.

The classification of assemblages using the *chaîne opératoire* concept is an original approach in that artifacts are no longer classified by shape and/or fabrics but rather in terms of technical processes and objects (shape and decoration). The aim is to reveal the technical traditions in the assemblage and, as a result, the social groups behind.

In this aim, the classification is ordered and includes three successive sorting stages (Fig. 4.1):

- Sorting by technical groups
- Sorting by techno-petrographic group, i.e., by petrographic groups within each technical group
- Sorting by techno-morphological and stylistic groups, i.e., by morphological and stylistic types within each techno-petrographic group

The first two sorting stages reveal the different *chaînes opératoires* present in the assemblage. The last sorting stage reveals the potter's intention which can be clarified by the functional analysis of the vessels. The combined analysis of the *chaînes opératoires* and the potter's intention leads to the characterization of ceramic assemblages in terms of technical traditions, i.e., in terms of inherited ways of doing a given functional range of containers. This is a prerequisite for evaluating the sociological complexity underlying the techno-stylistic variability of assemblages.

The combined analysis of technical groups and clay materials, in a high-resolution chrono-stratigraphic setting, should also lead to the use of the technical traditions themselves as particularly reliable chronological markers, namely, the

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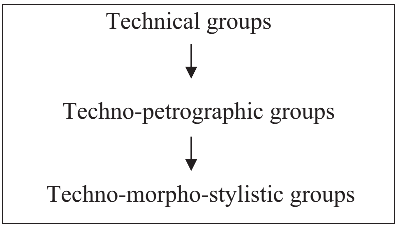

Fig. 4.1 Classification procedure of ceramic assemblages according to the concept of *chaîne opératoire*

ways of doing vessels and the associated clay material specifically used during a given period, given that materials in the environment are liable to modifications on the same temporal scale as cultural change (Roux et al. 2011).

The classificatory procedure according to the *chaîne opératoire* concept can face certain difficulties. However, it should lead in all cases to the establishment of groups representing the expression of technical traditions, even when the detailed reconstruction of *chaînes opératoires* is not feasible. Thus, it should deal with the methodological problems inherent in archaeological assemblages, namely, that it is not always possible to refit all types of vessels, knowing nonetheless that a recipient can be shaped using different techniques and thus that the reconstruction of the *chaîne opératoire* necessarily involves the examination of the different parts of the recipient; that not all ceramic sherds yield all the diagnostic attributes leading to the reconstruction of the whole *chaîne opératoire*; and lastly, that certain assemblages are made up of thousands, or even millions, of sherds, making it impossible to analyze each sherd in terms of *chaîne opératoire*.

4.1 Classification by Technical Groups

The initial sorting phase by technical group involves three operations:

- The classification of ceramics according to surface features
- The organization of the classes following a technical dendrogram-type tree
- The identification of forming and/or postforming *chaînes opératoires* expressed by the technical groups

The classification of ceramics by technical group is carried out by examining all the sherds laid out on a table with the naked eye. Groups are established based on a combination of surface features observable on the inner and outer surfaces of the sherds and the recurrence of this combination. This recurrence alone is liable to indicate an inherited way of doing vessels, transmitted and shared within a social group. According to this approach, a sherd can only belong to a single group as technical groups are mutually exclusive. When sherds present indecipherable surface features (e.g., surface features obliterated for taphonomic reasons), they make up a group of “indefinites,” to be redistributed at a later stage after reexamination.

The first criteria leading to the ordering of the variability of surface features differ from one assemblage to another, as each assemblage is, by definition, distinctive.

Accordingly, they can relate to forming, finishing, surface treatment, or firing surface features. In this way, there are assemblages where sorting first of all distinguishes between sherds fired in an oxidizing *versus* reducing atmosphere, or between sherds shaped with or without RKE (rotary kinetic energy), or between sherds shaped by molding *versus* coiling. In other cases, only finishing operations or surface treatments can differentiate between groups.

Once the first sorting has been completed, it is essential to examine to what extent some groups are not subgroups of broader groups or, conversely, to what extent subgroups should be established for classes characterized by a great variability of surface features. For example, we may have established different sherd groups for burnished and non-burnished sherds. Then, we may realize that the first are part of a wider class including sherds with slip, as opposed to sherds without slip, a class belonging itself to a group of vessels shaped with RKE, as opposed to vessels shaped without RKE. Or we may have established two classes, vessels shaped with and without rotary kinetic energy, and then, within the first class, it may appear necessary to distinguish between sherds with or without slip and, within the latter class, between burnished and non-burnished sherds.

Classification by technical groups is thus progressive. It must ultimately lead to the construction of a cluster tree whose branches are the expression of the *chaînes opératoires*. This tree can either be achieved according to the subdivision principle or according to the principle of aggregation. In the first case, groups are made up using a criterion that first of all unites the highest number of sherds, regardless of the order of the operations organizing the *chaîne opératoire*. Generally, at this level, we find the roughout techniques. Then, these groups are subdivided according to successive criteria until a level where no further criteria can divide the technical group. In the second case, the identified technical groups are progressively linked to each other using shared criteria until a criterion unites the highest number of sherds. Whatever method of classification is used, the result is a cluster tree with branches leading to distinct technical groups. This is a first view of the *chaînes opératoires* making up an assemblage or of the traditions. By first view, we mean that each technical group is nested into a set of technical operations, which at this stage of the analysis do not accurately describe the *chaînes opératoires* but distinguish the *chaînes opératoires* between themselves. As a result, a technical group and the combination of criteria describing the related branch of the tree are thus in a position to characterize specific *chaînes opératoires*.

In other words, once the technical tree of an assemblage is constructed, this is not the number and/or the nature of the variables which are pertinent for differentiating between the *chaînes opératoires*. It is rather the demonstration, using the technical tree, that a technical trait is the hidden part of a distinct *chaîne opératoire* of another. A single technical trait can thus lead to the attribution of sherds to distinctive *chaînes opératoires*. Ideally, technical trees are established according to the successive stages organizing forming and post-firing *chaînes opératoires*, but this is not a prerequisite. Figure 4.2 illustrates an example of a technical tree. The sherds were first of all classified into two technical groups: sherds preformed with or without RKE. Then, within the "preformed without RKE" category, sherds with outer faces

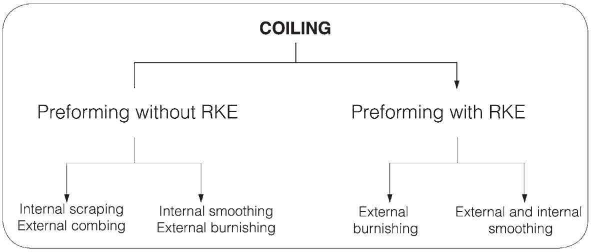

Fig. 4.2 Example of technical tree. The diagram distinguishes four technical groups which are the "visible" part of four distinct *chaînes opératoires*

presenting either combing traces (concentric incisions on wet clay) or traces of burnishing were distinguished. Within the "preformed with RKE" category, sherds were classified according to surface treatment: with or without burnishing.

When one branch of a technical tree only differs from another by a single operation, such as surface treatment, for example, it is the expression of a variant within the same tradition. This is the case in Fig. 4.2 for burnished and non-burnished ceramics; they are variants of *chaînes opératoires* characterized by common roughing-out and preforming techniques.

There is no need to be afraid of "constructing and deconstructing" these technical trees, "simplifying" them by looking for the technical stage representing the highest common denominator, and not detailing them too much. Technical tree and *chaîne opératoire* should not be confused. The scope is before all to unearth the cultural rationale underlying the variability of each assemblage. In other words, there is no need to fear grouping or divisions to order the variability of surface features in order to obtain a cluster tree which reflects at best the different *chaînes opératoires* involved in the fabrication of ceramic vessels.

The first sorting by technical group presents a huge advantage in that it is carried out with the naked eye. Consequently, it should lead to the processing of vast quantities of sherds, taking each one into account, including body sherds that cannot be related to a form. Once the researcher's eye is trained to observe the surface features on the sherds, and once these features have been clustered in technical groups, each sherd should rapidly be distributed between the different technical groups, in much the same way as a game of cards. At the end of this distribution, all of the sherds are spread among groups. It is thus possible to assess the quantitative importance of these groups, either in absolute numbers (number of remains or minimum number of individuals) or relative numbers (percentages in relation to each other).

Note that often the technical groups are defined on the basis of finishing operations, as each sherd presents surface features of the last operations carried out and does not necessarily bear the marks of roughing-out or preforming techniques. However, diagnostic traits can be identified as the examination of all the sherds belonging to a group progresses. The visibility of these traits is often due to potters' errors such as hasty movements, carelessness, oversights, or accidents. To us, these errors are beneficial as they provide information on the operations preceding final operations. They are frequently identified on not very visible surfaces to the potter's eye (the inner surface of closed vessels, the outer surface of open vessels).

For these same reasons, the identification of *chaînes opératoires* is not necessarily carried out during the sorting of technical groups. For example, we can differentiate between sherds presenting horizontal concentric lines on both surfaces and sherds with oblique striations on both surfaces, without being in a position to identify the different roughout techniques linked to the fabrication of the vessels belonging to these two groups. The interpretation of the *chaînes opératoires* can occur during the last stage, once the variability of the assemblage has been assessed. The sherds from each technical group are examined in detail with high magnification. The combination of several observation scales allows for the identification of the operations behind the observed traces, provides information on their sequencing, and ultimately, makes it possible to reconstruct the *chaînes opératoires* (see Chap. 3). In other words, the detailed reconstruction of the *chaîne opératoire* is often deferred, occurring progressively after the identification of technical groups, if data are appropriate. Indeed, there are cases where technical groups can be identified and even so it is impossible to reconstruct the detailed manufacturing process. When these technical groups are made up of comparable morpho-technical types, they can nonetheless be considered as the expression of different ways of doing vessels when they are mutually exclusive.

However, how can we consider that a complex of sherds was made using the same *chaîne opératoire* when only several sherds bear diagnostic surface features? The postulate is that all the sherds within an archaeological ceramic assemblage presenting the same attributes were made under the same conditions. Although the same traces can be produced using different techniques, methods or tools, groups of sherds with sets of analogous traits within the same assemblage, on the inner surface, the outer surface, or in cross-section, are necessarily related to analogous technical actions, given physical and cultural constraints. On the one hand, the same way of doing vessels on the same type of clay necessarily gives rise to comparable deformations and marks. On the other hand, the number of ways of doing vessels at a given site is generally limited. Thus, we can legitimately progress from the observation of several specimens to an interpretation of all the sherds comparable to these specimens.

Ultimately, two major pitfalls must be avoided during the classification of sherds by technical groups.

Firstly, it is important not to become submerged by descriptive criteria, as the application of too many or over-detailed criteria can lead to the multiplication of technical groups even though the variability of traces corresponds to idiosyncratic variants. The descriptive criteria should be related above all to the technical stigma and include the possibility of variants in movements, the inclination of the tool used, the quantity of water used, the effects of firing on color, etc.

Then, the examination must focus on the surface features on the inner and outer surfaces of all the sherds (neck, body, base), as each part of the recipient is liable to be subject to different operations, even though they are part of the same technical group. In other words, once the technical groups have been established, it is important to verify that certain traces are not confined to certain parts of the recipient. In this way, a base can present different traces from the body of the same recipient, given that different techniques were used during the shaping and finishing phases. It is generally possible to associate the different parts of a recipient using the

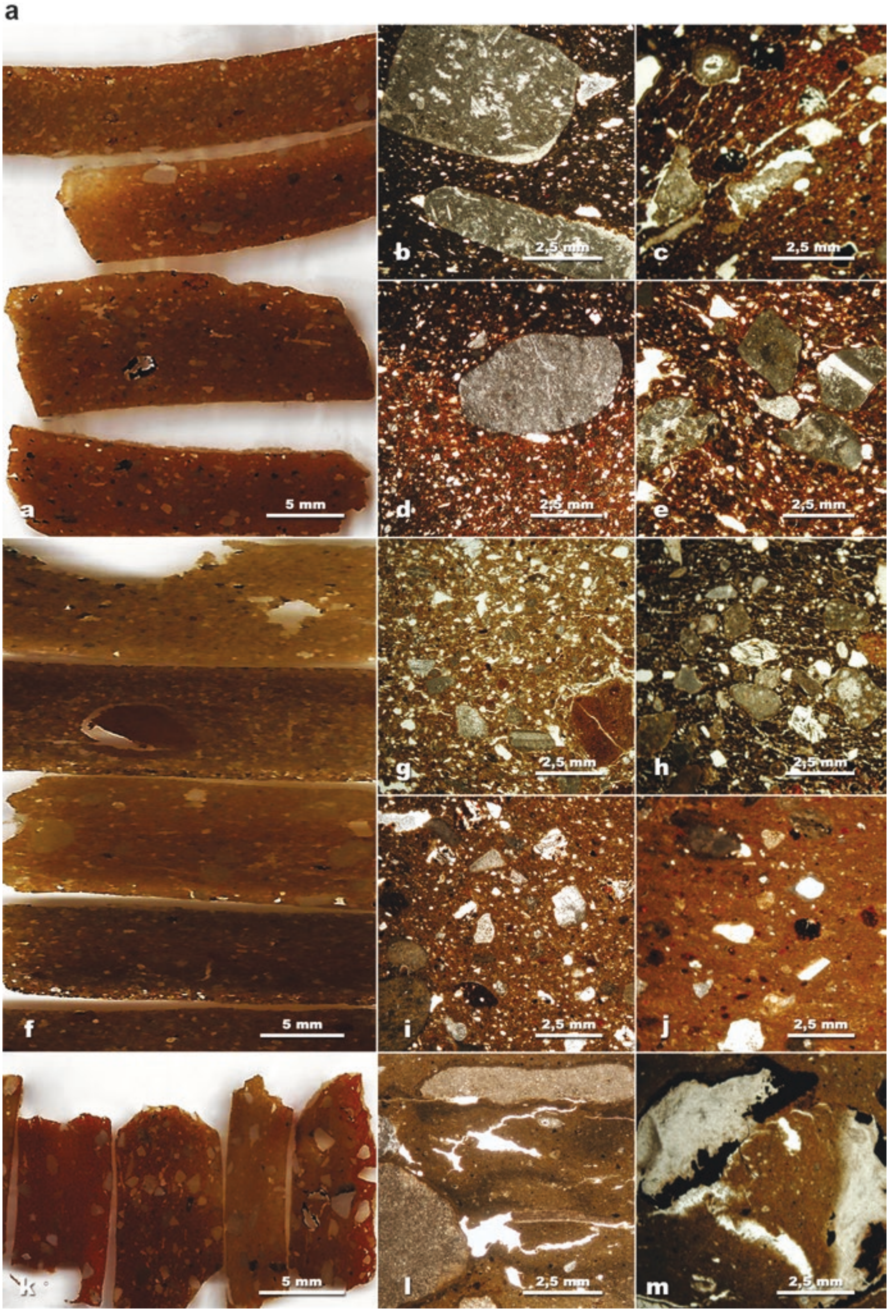

Fig. 4.3 (**a**) Example of open classification by techno-petrographic group (no classification of distinctive groups was possible because of a strong variability of the clay materials for the total clay assemblage): (*a*, *f*, and *k*) scan photos of thin sections illustrating the groups identified under the binocular microscope from fresh sections of fine chips; (*b–e* and *g–m*) photos of thin sections in plane analyzed light under the petrographic microscope illustrating here the petrographic

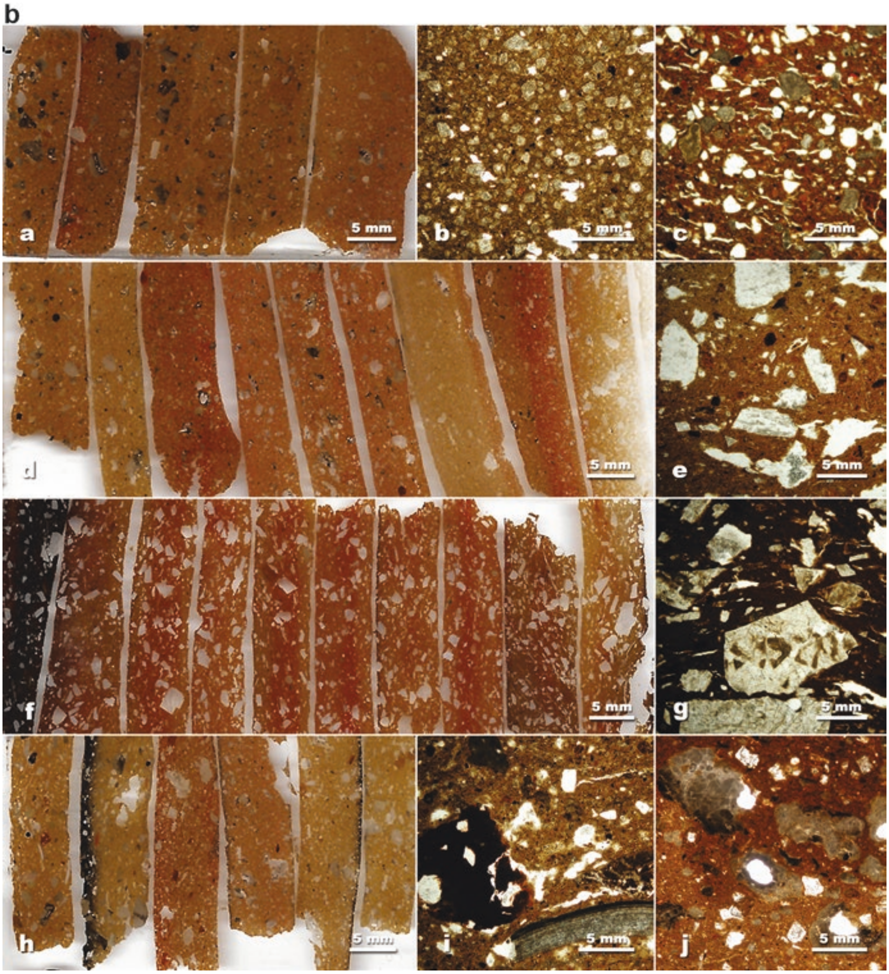

Fig. 4.3 (continued) variability for identified each group; the mineralogical characters show that this variability is distinctive of different sources; the identified techno-petrographic groups do not correspond to clearly identified clay sources. (**b**) Example of closed classification by techno-petrographic groups (the recognition of distinctive groups was possible): (*a*, *d*, *f*, and *h*) photos of thin-section scans illustrating the groups identified under the binocular microscope from fresh sections of fine chips; (*b*, *c*, *e*, *g*, *i*, and *j*) photos of thin sections in plane analyzed light under the petrographic microscope illustrating here the petrographic homogeneity of each group identified; the mineralogical characters show a distinctive provenance source for each techno-petrographic group; and each group corresponds to a distinctive raw material source

sherds from the base and the body, the lower and upper body, and the upper body and the neck. Ideally, vessels should be entirely refitted in order to take into account all the significant traces of the *chaîne opératoire*.

4.2 Classification by Techno-Petrographic Groups

Next comes the techno-petrographic classification. This is based on the classification of the petrofacies carried out beforehand (see Chap. 3). From a practical viewpoint, an exhaustive classification of the petrofacies involves studying all the ceramic material independently of size, form, style, or technical criteria. It results in a petrofacies framework documented by a database made up of "chips" and thin sections (Figs. 4.3a and 4.3b).

Ideally, this study is conducted at the same time as the excavation; in which case it is possible to sample each sherd as the excavation progresses in order to build up an exhaustive reference collection of the petrofacies present at the site.

Once the petrofacies catalogue has been established, the sherds belonging to different technical groups are then examined to identify the petrofacies class to which they belong and to characterize their petrofabrics. It is at this stage that clay preparation conditions are studied and that the whole *chaîne opératoire* is reconstructed, from the collection of the raw material until firing.

Figure 4.4 recalls the approach used for establishing, quantifying, and validating the techno-petrographic groups using different scales of magnification, first with a stereomicroscope and then by observing thin sections with a petrographic microscope.

Sampling Procedure

In theory, all the sherds in a ceramic assemblage should undergo techno-petrographic sorting, given that the initial population is not known. Thus, the closer the number of sherds examined is to the observable population, the more likely the technological variability of the assemblage is to be recorded. In view of this, it is preferable to take assemblages from different functional contexts (e.g., habitat *versus* funerary) in order to monitor this parameter as much as possible, as it can act on qualitative and quantitative variability.

However, when assemblages are very large, or when several assemblages corresponding to several tonnes of material have to be compared, or when the representativeness of the assemblage in relation to the initial excavated assemblage is unknown (which is frequent for ancient collections stored in museums), it seems reasonable to proceed with sampling using an empirical approach, that is, not statistical sampling based on random distribution but a reasoned selection in view

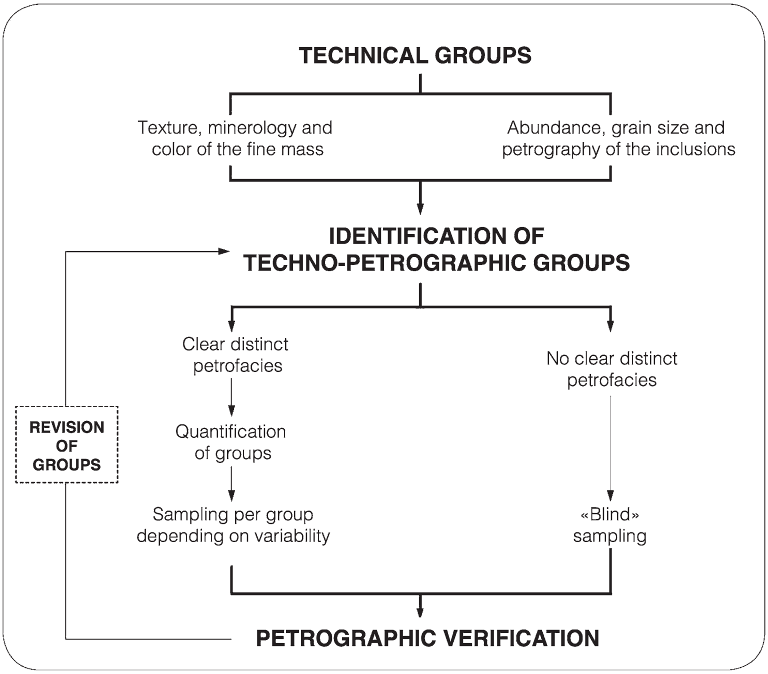

Fig. 4.4 Techno-petrographic classification of ceramic assemblages

Table 4.1 Stabilization principles of ceramic classification. During the course of time *tn*, the relative proportion of sherds per class stabilizes and can be considered as representative

Number of sherds studied per site	Class 1	Class 2	Class 3	Class 4
t1–50	34	10	5	1
t2–100	62	22	12	4
t3–200	130	46	18	6
	Dominant	Secondary	Minor	Marginal

of the technological aim, which is to quantitatively characterize the represented technical traditions. This reasoned selection consists in examining and classifying batches of sherds and stopping when the proportions from the different classes cease to change (for a given excavation context), whether the classes relate to technical groups or to techno-petrographic groups. An example is given in Table 4.1.

This selection procedure ensures the representativeness of the studied population in relation to the observable population. In other words, it ensures that the groups obtained quantitatively denote the different technical practices observable at the site.

These techno-petrographic classes are valid if there is evidence that they are the expression of different *chaînes opératoires* and depositional contexts.

4.3 Classification by Morpho-Stylistic Group

The morphological and decorative characteristics of all the sherds or vessels belonging to a techno-petrographic group are then examined in order to describe the finished products to which the *chaînes opératoires* apply. In other words, the classification of morphological types and decoration, which traditionally organizes the classification, only intervenes during the last stage, after technical and petrographic classification operations. The classes obtained portray the intentions of the potter, revealed by both the final product and the way it was made.

The aim of examining potters' intentions is to assess whether the variability of the *chaînes opératoires* is linked to the functional categories present in the assemblage or to the presence of several social groups.

Morphological Classification

The examination of shapes is the first approach to characterizing the range of vessels made by a group and in this way the conception of shapes for each category of container, on the one hand, and the morpho-functional repertoire of the assemblage on the other.

The description of shapes is carried out using specimens with complete profiles. It is based on codes that, depending on the authors, take account of simple geometric volumes, proportions, profiles, or an important number of variables related to the geometry of each part of the recipient (e.g., Shepard 1965; Gardin 1976; Balfet et al. 1983; Rice 1987; Orton et al. 1993). The result is either a description in terms of functional categories (e.g., jars, pots, bowls, etc.) or geometric shapes, which is advisable for clearly differentiating between the description and the interpretation (e.g., open vessels [O = DM] or closed [O < DM], with a continuous or carinated profile, with or without a neck, with straight or convex divergent walls, etc.). For a description of recipient profiles (neck, lower and upper body, feet) using elementary geometric terms, the propositions of Gardin (1976) (Fig. 4.5) correspond to pioneering works prefiguring the automatized typologies presented below.

The description of shapes is the essential prerequisite for their classification. The latter can be carried out using several procedures which, in all cases, take into consideration a set of attributes in an ordered way (e.g., Gifford 1960; Whallon 1972; Whallon and Brown 1982; Rice 1987; Orton et al. 1993; Whittaker et al. 1998; Read 2007; Santacreu et al. 2017). The description of the different classification procedures is detailed in several manuals and articles (e.g., Orton et al. 1993; Bortolini 2016). An example of a simple arborescent morphometric classification is presented in Fig. 4.6. Vessels are classified successively depending on whether they are open or closed or large or small and then according to assemblage-specific morphological variants.

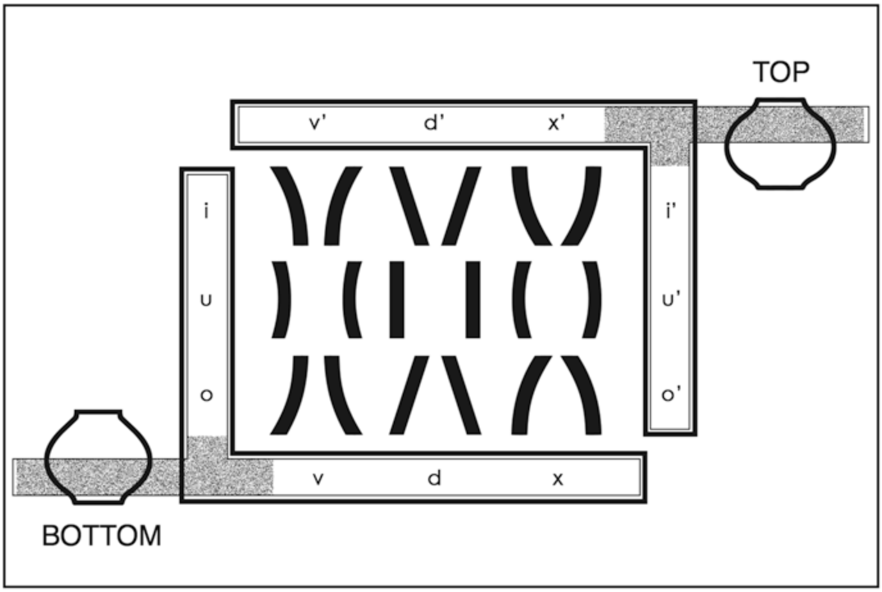

Fig. 4.5 Geometric description of the vessel profiles. (After Gardin 1976, 81)

Classification procedures have been subject to much debate in regard to the concept of "types" and their often arbitrary formalization (hence the debates on the "type-variety" classification method which organizes types following an inductive approach using diagnostic sherds with several similar, recurring, shared attributes; for an overview of these debates, see Bortolini 2016). In a seriation perspective, where we pass from an IO (intrinsic order) to an IO' order, and as a condition for a typology where we pass from an IO order to an XO order (classification using extrinsic data to establish chronological, cultural or functional typologies), the latest advances in the domain stem from research based on 2D and 3D scans (Saragusti et al. 2005; Karasik and Smilansky 2008). Using scanned images, these approaches propose a drawing of the profile of the recipient – for the 3D images, the sherd is positioned beforehand in relation to the symmetry axis of the recipient – as well as an algorithm that allows for an automatic classification of shapes based on a profile analysis and not only on several absolute and relative measurements (mainly made up of the diameter at the opening and, at the base, the maximum diameter, height, thickness, and ratios between these measurements). The profiles are analyzed as planar curves represented by three mathematical functions: radius, tangent, and curvature. Each of these parameters has a one-to-one correlation with the original profile, though it emphasizes features of different scales. The classification starts by measuring the distances between any pair of vessels in terms of the corresponding mathematical representations and summarizing them in a distance matrix. Cluster analysis is then used to reveal the inner variability of the assemblage and investigate grouping in the data (Gilboa et al. 2004; Karasik and Smilansky 2011; Smith et al.

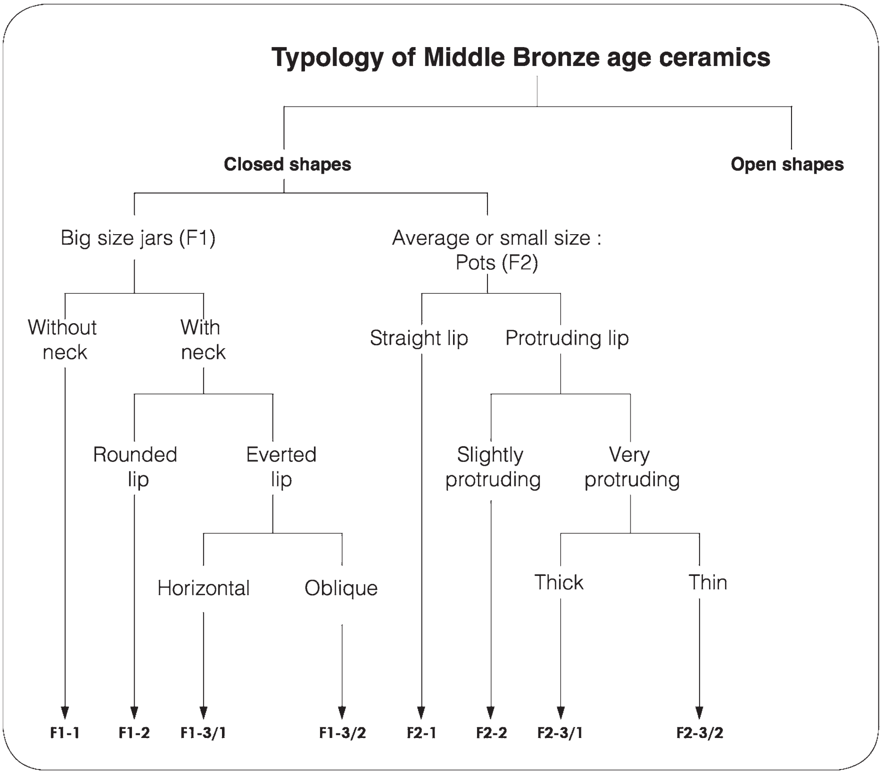

Fig. 4.6 Example of hierarchical classification based on different morphological attributes. (After Lyonnet 1997, Table VI, 59)

2014). In the resultant cluster trees, each line at the bottom of the tree corresponds to a single vessel. At the end of the classification, it is thus possible to obtain not just an exact image of the different morphological classes made by craftspeople at a given time *t* but also a measurement of the morphometric variability within each class that takes into account all the individuals (and which gives at the same time the minimum number of individuals per class). The measurement of metric variability is vital for evaluating the production context (see Chap. 5). It should also allow for objective comparisons between macro-regions.

This new technology presents the huge advantage of allowing for the processing of a considerable number of sherds (500 rim sherds scanned per day, as opposed to about 20 per day if the pieces are drawn manually), of positioning all the sherds with rim making up more than 15° of the original circumference, and lastly of providing digital, objectively accurate drawings, ready to be printed and ready to be used for calculations, in an automatized classification perspective.

Classification of Decoration

Once shapes have been classified, decorations are described and classified for each morphological type. This classification successively includes the description of the decorative techniques (see Chap. 3) and of the decorative grammar, given that these two decorative components are liable to evolve according to different mechanisms and can signify either borrowing through contact with craftsmen (borrowing of techniques and decorative tools) or through the circulation of objects (decorative grammar).

Decorative grammar refers to a structural approach to decoration developed over the past few decades (e.g., Shepard 1965; Gardin and Chevalier 1978; Plog 1980; van Berg 1988, 1994; Caneva and Marks 1990).

According to this approach, the classification of decoration successively takes into consideration:

- The location of decoration on the vase; decoration can cover the whole recipient or just several parts of a recipient – rim, lip, upper body, lower body, base, and related elements (prehensile elements, spout, foot).
- The general structure of decoration, i.e., the main divisions of the area bearing decoration; this general structure is supposed to be the most stable element, during the course of time and the transmission process (Gosselain 2011).
- The grammar of decoration provided by its decomposition into units, patterns, and themes (Shepard 1965). The idea is that decorations, like natural languages, are systems conceived as sets of elements equipped with rules organizing the interactions (van Berg 1988, 1994). Thus the decomposition of decoration reveals the elementary decorative unit and then examines how this unit is repeated and arranged to create patterns and how, in turn, these patterns are repeated and arranged to create themes.

The elementary units are made up of simple geometric elements: the dot, the line, the semicircle, the oval, the square, the diamond, the rectangle, the triangle, etc., which can be oriented in different directions (horizontal, vertical, oblique). The pattern is created by the repetition and the arrangement of one or several unit(s). Three main categories of patterns have been recognized: patterns in patches (isolated elements), in lines (simple lines and broken lines), and in weft (intersection or overlapping of parallel series of elements) (Gallin 2002, 2013). The themes can be simple or complex depending on the layout of the patterns and their repetition.

Numerous examples of this classification can be found in their applications, in varied chrono-cultural contexts (e.g., van Berg 1994; Bowser 2000; Binder et al. 2010; Manen and Salanova 2010; Gallin 2011; Meunier 2012; Wu 2012; Houbre 2013) (Fig. 4.7).

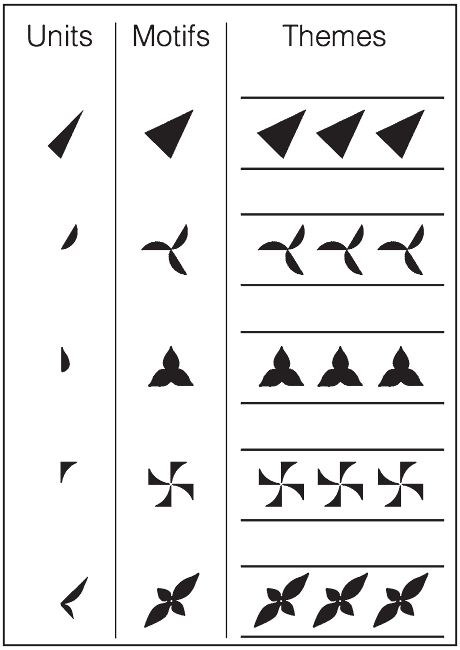

Fig. 4.7 Example of classification of decor in units, motifs, and themes. (After Shepard 1965, 272)

4.4 Techno-Stylistic Trees

The technical, techno-petrographic, and morpho-stylistic classification gives rise to techno-stylistic trees (Fig. 4.8). These trees describe both the technical processes (the *chaînes opératoires*) and the objects made according to these processes. They provide a controlled image of the different traditions constituting the ceramic assemblage. This image is both qualitative and quantitative, as we know the relative proportions of the sherds belonging to each branch of the tree.

Characterization of the technical traditions following another classificatory procedure can raise problems that are at times difficult to resolve. Thus, if technical, morphological, or petrographic classifications are carried out in parallel, it is then difficult to assess how they are interlinked and consequently what the technical traditions are.

Once techno-stylistic trees have been established, first, it is necessary to examine whether their variability is linked to functional or sociological factors, on the one hand, and if the sociological variability is simple or complex, on the other hand.

4.5 Functional *Versus* Sociological Variability

It is possible to distinguish between the functional variability and the sociological variability of an assemblage by examining the range of vessels made in each techno-petrographic group. There are two types of scenario: either the function of the

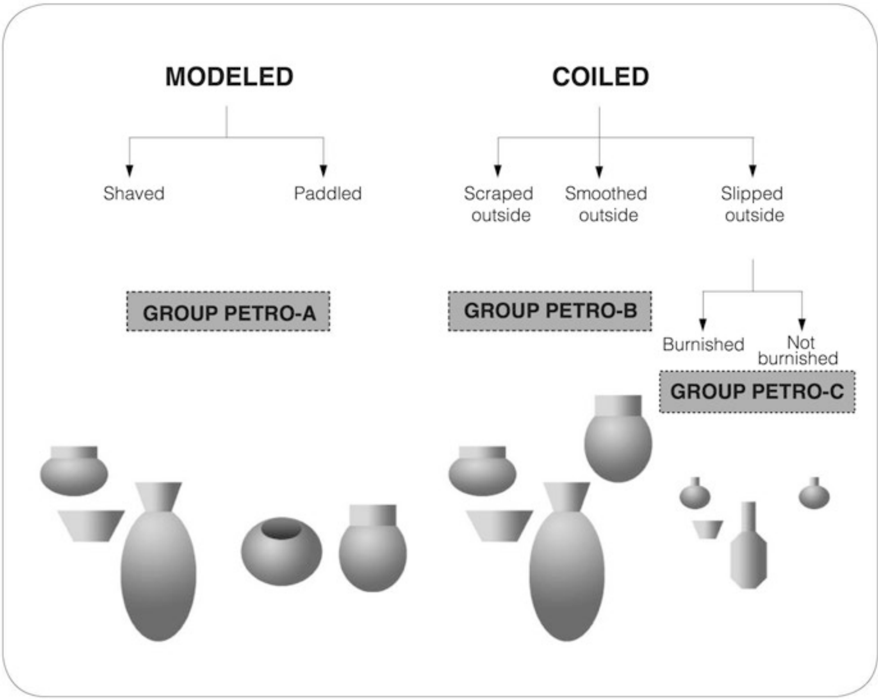

Fig. 4.8 Example of techno-stylistic trees. The tree on the left gathers modeled ceramics made up with the same clay materials. The preforming techniques vary depending on the function of ceramics (functional variability). The tree on the right gathers coiled ceramics whose preforming and finishing techniques covary with clay sources and relate to different functional categories (functional variability). Now the modeling and the coiling techniques apply to the same functional categories, signaling therefore two technical traditions corresponding to two social groups

vessels determines the variability of the *chaînes opératoires* or, by default, this variability is determined by social factors.

In other words, when a techno-petrographic group is associated with a single type of recipient (e.g., culinary vessels) and when the function of the recipient accounts for the difference in the *chaîne opératoire*, in this case, variability can be interpreted in functional terms as opposed to variability created by social boundaries.

An example is given in Fig. 4.8. The tree is made up of several *chaînes opératoires*. The *chaînes opératoires* characterized by the modeling technique regroup two techno-petrographic groups, spread over several functional categories. In this case, techno-petrographic variability can be correlated to the function of the vessels. The *chaînes opératoires* characterized by the coiling technique include four techno-petrographic groups spread over several functional categories. Techno-petrographic variability can thus also be correlated to the function of the vessels. On the other hand, if we compare coiling and modeling productions, we observe that they belong to the same functional categories. As a result, we assume that the variability of roughout, modeling or coiling, techniques is linked to cultural traditions and therefore to social factors, whereas the variability of the *chaînes opératoires* in each tradition is linked to functional factors.

The interpretation of the variability of the *chaînes opératoires* in relation to social factors logically associates one tradition to one social group. As elaborated in the introduction, the interpretation of technical traditions in terms of social groups is based on the well-founded regularity that ways of doing are socially learned with tutors usually selected within one's community. As a direct consequence, tutors' ways of doing are reproduced within each one's community and technological boundaries overlap social boundaries. In other words, biobehavioral and social constraints related to the learning process create communities of practice and explain that the boundaries of technological traditions overlap with those of communities of practice (e.g., Lave and Wenger 1991; Stark 1998; Bowser and Patton 2008; Stark et al. 2008; Roux et al. 2017). These communities may be of a different nature to be determined by the contextual data.

The relevance of the classification of assemblages using the *chaîne opératoire* concept to generate sociological and functional interpretations of techno-stylistic variability is illustrated below with a fictive example. This example compares the results obtained using a classification based on shapes and clay fabrics and the results obtained on the same assemblage classified using the *chaîne opératoire* concept.

> Imagine an assemblage with a classical range of morpho-functional types: culinary, storage, and tableware ceramics. Imagine then that some specimens undergo petrographic analysis and that we observe, for culinary ceramics, three petrographic groups A, B, and C; for storage jars, two petrographic groups A and B; and for tableware ceramics, two petrographic groups B and C, where the three groups A, B, and C correspond to local clay sources. Given this petrographic variability, which is not correlated to shape, one of the interpretations would be that an "A" group of potters exists, making culinary vessels and jars; a "B" group of potters, making culinary vessels, jars, and tableware ceramics; and a "C" group of potters, making culinary ceramics and tableware ceramics. Unless the same group of potters collected the clay material in different places, in a random or temporally deferred way. Another hypothesis would be that two groups of potters indifferently shared three sources of clay… Difficult to choose between these interpretations! And what criteria would enable us to decide? Imagine now that we consider the *chaîne opératoire* used to make these vessels and that we observe three *chaînes opératoires*: (a) a first *chaîne opératoire* dedicated to culinary vessels and jars made with clay A; (b) a second *chaîne opératoire* dedicated to culinary vessels, storage jars, and tableware ceramics, made with clay A for the first and clay B for the second; (c) and a third *chaîne opératoire* dedicated to culinary and tableware ceramics made with clay C. The first observation will be that different *chaînes opératoires* were used for comparable morpho-functional types and thus that the variability of the *chaînes opératoires* does not depend on the function of the vessels but on the potters' sociological composition. Consequently, we will be in a position to suppose that there are three distinctive producer groups that have different ways of doing things. Two groups share the same clay source (A). As for the variability of the clays (A and B) observed within the group using the second *chaîne opératoire*, it depends on the morpho-functional types. It must thus be related to functional variability.

Function of the Vessels

As underlined above, identifying the function of vessels contributes directly to the sociological interpretation of techno-stylistic trees. The function of a recipient can be analyzed in terms of use functions related to the mundane/utilitarian sphere, or sign functions related to the social and symbolic sphere. We also have to differentiate between the function guiding the fabrication of the recipient (the intention of the artisan) and the effective function of the recipient throughout its operating life. As a first approach, and in view of a functional *versus* a sociological analysis of techno-stylistic variability, it is important to discover the intent of the potter and the primary function of vessels, whether this is use- or sign-related. Establishing this function involves an analysis of the intrinsic as well as the extrinsic attributes of vessels. The intrinsic attributes are related to all the observable traits of ceramic vessels; in this case clay properties, geometric properties (shape, volume), surface treatments, decoration, and alteration traces. The extrinsic traits are related to contextual and/or comparative (historical or modern) data relative to the time, the place, and the function (in the case of comparative data) (Gardin 1980).

Shapes and Function

The geometric properties of vessels provide a first approach to function. The volume of each morphometric class, represented by a "prototype," can be calculated in an automated way using free-access software.[1] The calculation is based on whole profiles. It can also be based on scans of hand-drawn pieces.

A first evaluation of the function of vessels is feasible with reference to ethnographic data. These indicate that the repertoire theoretically includes:

- Storage vessels (liquid or solid)
- Transfer vessels designed for the transport of liquids or solids
- Consumption vessels, also called tableware
- Vessels for presentation and service
- Culinary vessels including vessels intended for the preparation of liquids and solids
- Vessels used for specific technical activities (processing organic and mineral matter, metallurgical and medicinal activities, vessels for salt, lamps, etc.)
- Specific culinary utensils such as lids, ladles, etc.

The use of ethnographic analogy for inferring the function of a recipient presumes that there are geometric traits presenting universal univocal links with the function of vessels. The demonstration of these links involves either comparing the shapes and functions of vessels belonging to different cultural contexts and estab-

[1] See, for example, www.weizmann.ac.il/complex/uzy/archaeomath/volumecalc.html.

lishing the shared morphometric traits leading to the identification of the function of vessels (Henrickson and McDonald 1983; de Ceuninck 1994) or showing that certain functions necessarily imply the presence of certain morphometric traits (Gouin 1994). Several studies have been carried out to this end. They show that ceramic typometric analysis allows for the identification of some of the main functional classes. Three main measurements come into play here: height, maximum diameter, and mouth diameter. The maximum diameter/mouth diameter ratio gives a better segregation than the maximum diameter/height ratio. In particular, it allows us to distinguish between vessels intended for transporting liquid and vessels designed for cooking (the opening of the first is narrower than that of the second).

G. de Ceunink (1994) provides an example of a study intended to bring to light cross-cultural functional classes, by comparing the ceramic assemblages of two ethnic groups living in Mali, the Peuls and the Somono. The first are breeders, and their vessels are characterized by simple, standardized shapes, with thin walls and a rounded base. The second are fishermen, and their vessels are characterized by varied, complex shapes, with thick walls and feet. The functional indigenous partition, sanctioned by a linguistic partition, indicates that different shapes can have the same function, whether or not they have the same name, and also that identical shapes can have different functions, whether or not they have the same name. From a methodological point of view, in order to find univocal links between a functional theme and a morphological property, de Ceunink looked for:

- The common (dimensional) denominator of functions contending for a sole and same morphological type of recipient
- The common (dimensional) denominator of the different shapes for a sole and same type of function

Eight functional themes were taken into consideration: cooking and serving food, washing or ablutions, transporting water, storing water, storing oil, storing rice, storing clay, and storing toys. The corpus was made up of 477 vessels. The following dimensions were taken: the maximum external diameter, external height, and internal and external opening. The results show that 12-dimensional classes could be retained, defined by a size interval for the maximum diameter, the mouth internal diameter, and the height. This interval enabled him to group vessels with the same function but different morphologies into a single and as small as possible dimensional class, in such a way that the dimensional classes take account of functional considerations. Certain classes were however equivocal and needed to be enriched by taking morphological traits into consideration to explain the function.

The opposite approach, consisting in deducing the morphological traits from the function, is illustrated by the studies of Gouin (1994) on the link between dairy products and recipient shapes. The initial assumptions are the following: on the one hand, the preparation processes of dairy products are “universal,” given the properties of milk; on the other, the geometric characteristics of the utensils used in the dairy *chaîne opératoire* present common denominators specific to the conservation of each product of the dairy chain (fresh milk, curdled milk, butter, buttermilk, clarified butter, fresh cheese, dry cheese, etc.). These common denominators were brought to light by comparing the vessels currently used in the dairy *chaîne opératoire* in the Orient and in India. When applied to vessels from the Harappan period (third millennium B.C.), which are part of the same geographic area, they allowed for the formulation of hypotheses regarding a considerable number of shapes, including perforated vessels. The latter were interpreted as cheese strainers, a hypothesis that was to be tested by the analysis of organic residues (Bourgeois and Gouin 1995).

Decoration and Function

Decoration can have a use function and/or a sign function. In the first case, it is identified based on the morphology of the decorative element and its position on the recipient. Thus, separately applied elements can be used as both prehensile and decorative elements, and incisions on the inner base of a recipient can be used both as a grater and for decoration (Arnold 1991).

In the case of a sign function, decoration can reflect a trend, an embellishment, an affirmation, or an individual mark, an apotropaic value, a group affiliation, a transmission of cultural information, a cosmological or religious expression, a commercial concern, etc. (e.g., Balfet 1965; Sackett 1977; Wobst 1977; Hodder 1982; Miller 1985; Herbich 1987; David et al. 1988; Sterner 1989; Dietler and Herbich 1994; Hegmon 1998; Bowser 2000; David and Kramer 2001; Gosselain 2008, 2011). Indeed, a decoration is, by definition, profoundly polysemous. From this point of view, it appears illusory to attempt to bestow "indigenous" intentions on archaeological vessels, that is to say, to explain why the decoration is there and the reasons behind the act of decorating, believed for some time to be linked solely to preoccupations of communication, identity affirmation, or the expression of the symbolic world of societies (Gosselain et al. 2010; Gosselain 2011).

It is nonetheless possible to proceed with an analysis of decoration from a functional perspective, resulting in the distinction between ceramics belonging to distinct functional categories within the assemblage.

This is the line adopted, for example, by Gallay (2013), who proposes decorative, technological, and spatial criteria for identifying prestigious vessels defined as objects "taken from the economic and commercial sector to become part of the social, political and religious networks where they lose their use value and acquire sign value" (Gallay 2013, 34). More specifically, Gallay suggests taking into consideration not only shapes and decoration but also the *chaînes opératoires* and diffusion zones in order to assess:

- First of all, the variability of the *chaînes opératoires* in relation to shapes as well as decoration
- Then, the distribution zones, restricted or wide, for each techno-stylistic group, and the possible distinction, depending on the zones, between decorated and non-decorated vessels
- Lastly, the "prestige" function of decorated vessels when for a given production zone, they stand out from the other vessels, not only by their shapes and *chaînes opératoires* but also on account of different distribution networks, where a restricted distribution indicates gifts for exceptional events such as marriages

Clay Properties, Surface Treatment, and Function

The composition of pastes and surface treatments directly influences the functional properties of ceramics, comprising mainly properties of resistance to mechanical and thermal shocks, thermal conduction, and impermeability (see Chap. 2). In this sense, these properties may indicate the potters' intentions and, indirectly, the function of the vessels. Surface treatments linked to impermeabilization can be identified by physicochemical analyses (see inset by Regert).

However, the analysis of the function of a recipient based on paste properties and surface treatments must be attentive to place the potter's "way of doing" in his/her cultural context. Indeed, this way of doing things can be guided by cultural habits that are only indirectly related to the function of the recipient. Thus, recipient burnishing does not necessarily mean that the potter intended to diminish the permeability of the walls; clay tempered with shells does not inevitably signify that the potter intended to make a recipient resistant to thermal shocks. In other words, the properties of vessels do not necessarily determine their function. To demonstrate that the property *i* was intentional in relation to the function of the recipient implies proving this through a global analysis of the assemblage, on a synchronic and diachronic axis, in order to take into consideration the cultural foothold of ways of doing and their evolution in the light of the required production.

Traces of Alteration and Function

The examination of alteration traces is a way of determining recipient function more accurately, whether they are linked to domestic or technical activities (production of resin, salt, metal, etc.) (Regert et al. 2003; Vieugué et al. 2008; Ard and Weller 2012).

By alteration, we mean any change affecting ceramics after physical or chemical processes. Two categories of processes underlie alteration phenomena: nonfunctional processes caused by human or nonhuman agents (postdepositional phenomena, trampling, frost, etc.) and techno-functional processes caused by human activities (cooking, barbecue, storage, cleaning, moving, etc.). The latter generate alteration traces produced by material attrition or accretion.

The analysis of alteration traces through use follows comparable principles to those developed in use-wear studies (Skibo 1992; Reid and Young 2000; Arthur 2003; Vieugué 2010). Use-wear traces are produced by mechanical actions (shock or friction) and/or physicochemical actions (action of fire or corrosive substances). They include chips, striations, abraded zones, flakes, pitting, and spalls. Studies by Skibo (1992) carried out on ethnographic vessels collected in the Philippines show that the striations observed on the outer surfaces of vessels derive mainly from cleaning actions and therefore do not, in this case, signify the function of the pots. On the other hand, thermal cupules on the inner surface allow us to observe that the pots were placed near a source of heat when the walls of the recipient were saturated in water (rice cooking). Chips on the sides of the vessels indicate an action where the contents were stirred with a utensil.

An archaeological example of alteration traces by use comes from Vieugué's studies (2010) on a corpus formed by vessels and utensils from the Neolithic site of Kovačevo in Bulgaria. The study of use striations led to the characterization of suspension modes (wounded and oblique), variable durations of use, as well as certain functions (grinding substances, ladles designed to draw liquids).

The alteration traces by material accretion include soot deposits and residues.

Soot deposits are present on vessels placed on the fire. Their description can be based on their location, shape, color, and extension. Generally speaking, the depositional process of soot on the inner and outer surfaces depends on the fuel (type of wood), the humidity of the outer walls, the presence of water in the recipient, as well as the methods of placing the recipient in relation to the flames, namely, above the fire, on the fire, and beside the fire (Skibo 1992; Kobayashi 1994). Depending on the cases, soot is deposited in different ways on the outer surfaces, either on the whole base and the lower body or only on the upper body (Hally 1983). Soot deposits can easily disappear due to oxidation and postdepositional processes (Skibo 1992). Therefore, their absence does not necessarily signify that vessels were not placed on the fire.

The analysis of residues by Regert is presented below (inset).

Organic Residues, Clues of the Function of Ceramic Vessels (Inset)

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Among the pointers liable to provide information on the function of vessels, residues have long been observed but have only been studied relatively recently as their identification requires advanced analytical chemical methods. Organic substances related to ancient pottery are either trapped within the porous matrix of ceramic vessels or still preserved as carbonized surface residues (Evershed et al. 1991a, 1992; Goldenberg et al. 2014). They were first mentioned towards the end of the nineteenth century and then during the first half of the last century, and several attempts were carried out for their identification with the methods available at that time – observation, determining fusion point, study of solubility, etc. (Cotte 1917). The first analytical studies began at the end of the 1970s using gas chromatography (GC) in order to investigate wine and oil conservation in Roman amphorae (Condamin et al. 1976; Condamin and Formenti 1978). During the 1990s, scientific teams adopted the study of the organic contents of pottery as their main research theme in the domain of molecular archaeology (Evershed et al. 1990, 1991a, b, 1992; Heron et al. 1991, Heron and Evershed 1993). This research first was founded on the identification of molecular assemblages and soon completed by isotopic approaches, which led to the characterization of the contents of vessels (Evershed et al. 1994). Then the development of soft ionization mass spectrometry techniques allowed the detailed characterization of substances (Mottram et al. 2001; Mottram and Evershed 2001; Garnier et al. 2002, 2009; Mirabaud et al. 2007). Even though micro-remains from plant or animal original (Duplaix-Rata 1997; Saul et al. 2013) as well as proteins may be preserved in ceramic vessels (Evershed and Tuross 1996; Craig et al. 2000; Regert et al. 2001b; Craig and Collins 2002; Solazzo et al. 2008), it is clear that lipids are

(continued)

the molecular components best suited for determining the content of pottery containers due to their remarkable degree of preservation and their high chemotaxonomic value (Eglinton et al. 1991; Dudd et al. 1999; Mottram et al. 1999; Evershed 2008). It is thus important to bear in mind that whole sections of the diet of past populations escape us; in particular cereal residues which cannot be detected by methods adapted to the characterization of lipids.

Presently, the organic materials identified in ancient ceramics are linked to dietary and culinary practices (animal fats, dairy products, marine animal resources, plant oils, fermented drinks, beehive products) and to the production of plant tars (Regert et al. 2003), dyes (McGovern and Michel 1990), or lighting (Evershed et al. 1997b).

1. From the Field to the Laboratory: Methodological Approach to Identifying Residues Preserved in Ceramic Vessels

Although hundreds of articles record the conservation of lipid residues in thousands of ceramic vessels from prehistoric times (Evershed 2008; Evershed et al. 2008a; Regert 2011 for a bibliographic overview), it is important to note that the conservation rate is generally relatively low and that it is not necessarily worthwhile analyzing an isolated sherd because it may present a visible residue on its surface, especially as analyses are destructive. It is common for sherd response rates to be less than 10%, and only specific contexts (lacustrine sites, frozen contexts, hot and dry conditions, cave sites, sediments with a high clay content) are conducive to good lipid conservation with rates of half, two-thirds, or even four-fifths of the studied vases (Regert and Mirabaud 2014). As animal fats were intensively used and are preferentially preserved, they are the most widespread substances in archaeological ceramics (Regert 2011). Determining the organic content of pottery must address clearly defined issues, by an interdisciplinary team, in order to define the series to be studied rather than randomly analyzing a small number of sherds.

1.1. Which Residues Are Found in Ceramics?

The residues found in ceramics can provide evidence of the different stages of the lifecycle of ceramics (Regert 2007) (Fig. 4.9): final fabrication phases (decoration, impermeabilization), use (culinary residues or residues resulting from technical activities), or recycling (repair patches). Note that organic matter incorporated in the clay body of vessels during fabrication is not generally conserved as it does not resist to pottery firing temperatures. Here we will focus on remains indicating the use of ceramics, generally presenting two distinct aspects linked to different uses:

- Black carbonized crumbly crusts, not really adhering to the pottery, generally indicative of culinary practices. These are present on the inner surfaces

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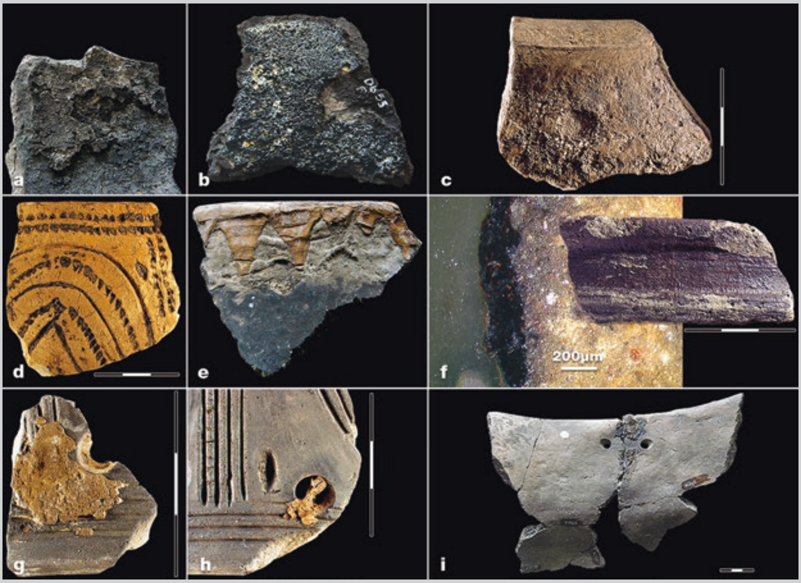

Fig. 4.9 Organic residues trapped into the porous walls of archaeological pottery: (**a**) and (**b**) food carbonized crusts; (**c**) birch tar adhesive; (**d**) incrusted pottery with birch tar; (**e**) birch bark glued using organic adhesive; (**f**) birch tar used for waterproofing the inner surface of pottery; (**g**, **h**, and **i**) adhesives used for repairing pottery. (Infography, A. Pasqualini; a, b, e, and i, photo ©P.-A. Gillioz; d, g, and h, photo ©D. Bosquet; c and f, photo ©M. Regert)

of containers and are not randomly distributed over ceramic profiles owing to the convection movements they have experienced (Duplaix-Rata 1997). In some cases, streaks are observed around the edges when the contents overflowed (*ibid*).

- Relatively homogeneous brown to black residues, adhering firmly to recipient walls, visible on the inner and sometimes outer wall of vessels, linked to the transformation or storage of exudates and plant tars (Regert et al. 2003) (Fig. 4.9).

If possible, as soon as vessels are discovered, or at least during their study and refitting, it is important to observe these types of residues when they have been preserved and to describe them, indicate their position on drawings of the vessels, and implement a conservation strategy to avoid their physical or chemical deterioration. In particular, if the recipient requires consolidation, restoration, or manipulation, it may be judicious to sample the visible residues, or at least part of them, and to stock them in accordance with the code of practice (cf. *infra*), in order to preserve these remains.

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1.2. How Is Sampling Carried Out?

Due to their organic nature, natural substances are sensitive to contamination, either within the sedimentary matrix during burial, by post-discovery handling, by restoring vessels, or by sample treatments preceding chemical analyses.

However, pottery is an extremely protective agent of organic environment molecules and migrations of biomolecules from the sedimentary matrix towards ceramics are negligible (Heron et al. 1991). When in doubt, it can be therefore useful to take sedimentary samples from the archaeological layers but also from sterile levels (several tens of grams) and to store them at −40 °C (in the freezer) in order to identify the organic content of the sedimentary matrix.

As for visible residues, they are generally either food-related carbonized crusts or adhesives, as we saw above. In the first case, the matter is partly carbonized, and the rate of lipid conservation is thus not necessarily optimal; in what case the operation consists in sampling several tens or several hundredths of milligrams with a sterile scalpel. This matter is then stored in a small glass vial (plastic must be avoided as it is organic; it is a contaminating agent and can, in particular, release phthalates). In the case of adhesive residues, a smaller quantity of matter is sufficient, and it is possible to obtain results with a pinhead quantity, although it is more comfortable to work with a sample of several milligrams. These residues must also be stored in a small glass tube. In all cases, it is important to indicate the location of the sample on the recipient profile.

As for sherds, which are the only source of information regarding pottery contents if no visible residues are preserved, about 2 g of matter is required. The first studies on sherds sampled from the edge, the body, and the base of vessels showed that the concentration of lipids in cooking pots decreased from the top of the recipient towards the base. However, the residues on the edge are also more damaged, and it is probably ideal to sample a sherd from the body. In many cases, if these studies take place after the excavation, any post-excavation treatments must also be taken into consideration: consolidation using organic polymers, refits with glue, and marking with ink and varnish. All these zones must be avoided. The ideal situation is to work closely with ceramic specialists in order to decide with them which samples should be taken and then sample sherds during the refitting phase but before gluing. In this way, it is possible to gain information regarding the position of the sherd without the addition of products used for treatment.

1.3. Which Analytical Strategies?

Analytical protocols are described in detail elsewhere (Charters et al. 1995; Regert et al. 1999, 2001b, 2008; Regert 2011) and have recently been improved to increase the rate of extraction (Correa-Ascencio and Evershed 2014). Here, we will outline the main procedures. First of all, it is important

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to bear in mind that an analytical strategy is developed at the same time as the research topic. It includes phases of choice, sampling, and sample preparation, followed by the analysis strictly speaking and the treatment and interpretation of data. Another important point: the preparation and analysis phases depend on the targeted chemical families. In other words, we prepare and analyze samples with different protocols depending on whether we are looking for lipids, proteins, resins, or polysaccharides. For lipids contained in ceramic vessels, the protocol can be resumed as follows: grinding samples after mechanically cleaning the sherd surface, extraction with an organic solvent and then chemical treatment (derivatization), and concentration and analysis using a separating method (gas chromatography, GC). This technique results in the separation of the different molecular components present in the sample. If necessary, the sample is then analyzed using GC coupled with mass spectrometry (MS), so that each component detected in GC can be analyzed in MS (obtaining a spectrum for each component which corresponds to a sort of identity card that can be used to identify it). Based on a set of molecular markers and their distribution and on reference collections compiled beforehand, it is possible to determine the natural origin of these components (biomarkers), their transformation by ancient societies (markers of anthropogenic transformation), their degree of alteration (alteration markers), and their level of contamination (contamination markers) (Evershed et al. 2008a; Regert 2011). In the case of very damaged fatty substances, only the main fatty acids are preserved (generally palmitic and stearic acids). As these components are particularly ubiquitous, their molecular structure cannot be linked to an exact origin. In this case, the measurement of the $^{13}C/^{12}C$ isotopic ratios, on each of the fatty acids, can then lead to the differentiation of the subcutaneous fatty substances of ruminants, nonruminants, and dairy products, using reference collections built up over the past 20 years. More recently, research groups have begun to develop reference collections for some wild species (Craig et al. 2012) and ichthyofauna (Craig et al. 2007).

2. The Different Identified Organic Substances

The links between molecular assemblages/isotopic signatures and natural origin are based on the following principles:

- For molecular assemblages: the hydrogen-carbonated skeletons (linear, cyclic, etc.) depend on biosynthetic processes and thus on the species that produced them; identification is based on the nature of the identified molecules, their association, and the distribution of molecular markers (Philp and Oung 1988; Evershed 2008).
- The isotopic signatures d^{13}C are linked to carbon sources at the base of the trophic network of the species considered and the isotopic splitting (Bocherens 1997) that occurs throughout the biosynthesis process.

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Table 4.2 presents the main natural resources identified up until now in archaeological ceramics and the criteria used to determine them.

Note that some of these substances are ubiquitous, such as subcutaneous animal fats and, to a lesser extent, dairy products (Evershed et al. 2008b; Dunne et al. 2012; Salque et al. 2013) and beeswax (Roffet-Salque et al. 2015). Others are found more occasionally: vegetable oils (Copley et al. 2001; Colombini et al. 2005; Garnier et al. 2009); marine products (Copley et al.

Table 4.2 Main natural substances identified up until now in archaeological ceramics and several of the molecular criteria used to determine them

Natural substance	Identification criteria	References
Subcutaneous animal fats	Fatty acids, mono-, di-, and triglycerides (limited distribution). Absence of mono-, di-, and triglycerides in very damaged matter	For details, see Regert (2011) and references therein
Dairy products	Fatty acids, mono-, di-, and triglycerides (widespread distribution). Absence of mono-, di-, and triglycerides in very damaged matter	For details, see Regert (2011) and references therein
Fatty substances from aquatic animals	Palmitic acid more abundant than stearic acid, presence of chain fatty acids including more than 18 carbon atoms, unsaturated tri-fatty acids (generally not conserved in archaeological contexts), presence of isoprenoid acids in small quantities, series of fatty acid isomers unsaturated in C_{16}, C_{18}, and C_{20} resulting in the alteration of tri-unsaturated acids	For details, see Regert (2011) and references therein
Beeswax	*n*-Alkanes (mainly C_{21}–C_{31}, C_{27}, odd number of carbon atoms), fatty acids (mostly C_{22} to C_{34}, C_{24}, odd number of carbon atoms), palmitic esters of C_{40} to C_{52}, di-, and triesters; alcohols and palmitic acid if hydrolyzed	Heron et al. (1994); Regert et al. (2001b); Garnier et al. (2002); Evershed et al. (2003)
Wine	Tartaric acid present in all types of wine is associated with syringic acid in white wines	Guasch-Jané et al. (2004, 2006a, b); Guasch-Jané (2011)
Cocoa	Theobromine and caffeine in smaller quantities	Hurst et al. (1989, 2002); Hall et al. (1990); Henderson et al. (2007); Crown and Hurst (2009)
Vegetable oils	Difficult to identify. Only three oils have original fatty acid compositions: palm oils (series of saturated fatty acids: mainly $C_{12:0}$, $C_{14:0}$, $C_{16:0}$, and minor quantities of $C_{18:0}$), ricin (acid Δ^9 12-hydroxy octadecanoic-ricinoleic acid), and radish (linoleic, oleic, gondoic, erucic, nervonic acids)	Copley et al. (2001); Colombini et al. (2005)
Birch pitch	Triterpenes from the lupane family	Regert et al. (2003), for example

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2004; Hansel et al. 2004; Craig et al. 2007; Evershed et al. 2008a); fermented drinks (Garnier et al. 2003; Guasch-Jané et al. 2004, 2006a, b; Guasch-Jané 2011); and cocoa for the American continent (Hurst et al. 1989, 2002; Hall et al. 1990; Henderson et al. 2007; Crown and Hurst 2009).

3. From Content to Function

The interpretation of contents in terms of recipient function is far from trivial, and the link between content and function is neither linear nor direct. Recipient contents are just one of several criteria used for assessing function and must be combined with all the intrinsic and extrinsic characteristics of the recipient in order to build up solid hypotheses (Regert et al. 2008).

One of the first articles on the link between contents and function was published in 1997 (Evershed et al. 1997a) and concerns the characterization of the contents of medieval vessels with different morphologies (Causeway Lane, Leicester, United Kingdom). These studies showed that low vessels with open shapes were intended to retrieve meat fats from roast pork, while only ruminant fats were used as fuel in conical-shaped lamps.

More recent studies have focused on the question of the function of the oldest ceramics. Results obtained by Craig and collaborators on about a hundred Jomon vessels form 13 sites in the Japanese archipelago, dating from 15,300 to 11,200 BP, showed that they were mostly used for the preparation of fatty matter from aquatic species, in particular from the marine coastline (Craig et al. 2013).

For a long time, a number of questions surrounded the function of ceramic objects with specific morphologies. Among these, we find a set of vessels with small perforations (2–3 mm diameter) that appear during the Neolithic in Europe from the sixth millennium before our era (Bogucki 1984; Salque et al. 2013). In a recent study, Salque and collaborators chemically analyzed the contents of a series of 34 of these perforated vessels, using 50 sherds discovered in Linear Pottery culture sites along the Vistula in Poland, and also took other shapes of vessels into consideration. It was found that among the perforated vessels containing lipids (40%), practically all of them (11 out of 12) had the molecular and isotopic characteristics of dairy products, clearly showing for the first time that these ceramics provided evidence of early cheese making at the end of the sixth and the beginning of the fifth millennia before our era (Salque et al. 2013).

In the case of conical Minoan vessels (Crete, around 1600–1450 B.C.), the combination of the form of vessels, the traces of soot on their surface, and the presence of beeswax demonstrated the use of the latter as fuel for lamps (Evershed et al. 1997b).

As well as vessels with very specific shapes (lamps, hives, perforated vessels), other pottery, generally made up of cooking vessels, also yielded beeswax. Most of the time, beeswax is detected mixed with animal fats (Charters et al. 1995; Regert et al. 1999, 2001a, b; Decavallas 2007). It is difficult to confidently determine the role of the beeswax in these vessels: it may provide

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evidence of the use of honey, which would thus have been an ingredient in Neolithic stews (Regert et al. 1999); but the beeswax may also corroborate the waterproofing of vessels. Whatever its role, the systematic presence of beeswax in ceramics provides evidence of the exploitation of hive products at the beginning of the Neolithic.

Lastly, recent research on the Neolithic lakeside sites of Chalain and Clairvaux distinguished different categories of vessels by combining morpho-stylistic characteristics, macro-wear, and lipidic content (Regert et al. 1999, 2001b, 2008; Mirabaud et al. 2007; Regert and Mirabaud 2014). This research showed that for vessels linked to serving or consumption, sufficient quantities of fatty matter could be trapped to be identified. Among culinary activities, it also differentiated between vessels with very different functions, including vessels with similar ranges of shapes. For example, it was possible to distinguish between vessels used for culinary preparations rich in animal fats and those used for the extraction of vegetable oils. Lastly, it brought to light close links between certain types of vessels (small bowls) and content (dairy products).

Conclusion

Although progress is still required in the characterization of certain substances potentially prepared, made, or consumed in ceramics, such as cereals, for example (Styring et al. 2013), over the past few years, research at the interface of organic geochemistry and archaeology has nonetheless opened unforeseen research paths for evaluating the function of pottery through the identification of the bio-resources that they contained. These works are mostly based on determining the molecular composition of lipidic components and the associations between stable carbon ($d^{13}C$) and nitrogen ($d^{15}N$) and even hydrogen isotopes. They have contributed to opening new horizons regarding the role of dairy products in the domestication process, by combining biogeochemical data with the study of faunal remains (Dudd and Evershed 1998; Evershed et al. 2002; Copley et al. 2003; Decavallas 2007; Regert 2015) and by bringing to light the long history of hive products, which began at least during the seventh millennium before our era in the Mediterranean world (Crane 1983; Heron et al. 1994; Evershed et al. 1997b, 2003; Regert et al. 2001b; Decavallas 2007; Regert 2015; Roffet-Salque et al. 2015). This research confirms the early exploitation of dairy products and beeswax and the ubiquity of subcutaneous animal fats by differentiating between fats from ruminants and fats from suids, detects indicators of fermented drinks, and determines the presence of aquatic resources in the oldest ceramics on the Asian continent.

Future research must now address several challenges, such as establishing correlations between content and the intrinsic and extrinsic characteristics of vessels in order to broach the function and functioning modes more systematically or finding new indicators of content, such as micro-plant remains like phytoliths or new isotopic or molecular markers.

4.6 Simple Variability *Versus* Complex Sociological Variability

When the techno-stylistic variability of assemblages is not determined by functional factors, it points to sociological variability. This can be simple or complex, depending on the number and the provenance of traditions. Evaluating this degree of complexity should allow for the interpretation of the sociocultural landscape of a region, on the one hand, and the possible functional complementarity of sites, on the other. In other words, it should allow for a restitution of the ancient social networks through the analysis of the social groups involved and their interactions.

In this aim, ceramic assemblages are analyzed in terms of techno-petrographic homogeneity *versus* heterogeneity. Theoretically, we distinguish two categories of ceramic assemblages – homogeneous assemblages and heterogeneous assemblages – where each category includes a larger or smaller number of techno-petrographic groups. Mixed assemblages can exist where sociological interpretation depends on the ratios between the homogeneous and heterogeneous components.

Homogeneous Assemblages

Homogeneous assemblages are defined as simple or complex.

Simple Homogeneous Assemblages

These assemblages are characterized by vessels made using the same technical tradition, that is, a *chaîne opératoire* with variants correlated to *n* functional types. The petrographic groups are homogeneous and present low variability, indicating that all the ceramic production is made in local clays, from sources close to the production site, located in similar ecological niches (e.g., the same side of the valley).

Simple homogeneous assemblages characterize sites where producers belong to a homogeneous social group, that is, a group that uses and transmits the same way of doing ceramics to individuals in the group. This case occurs in habitats with a single social component (whether they are producers or producers/consumers).

Simple homogeneous assemblages can also characterize consumer sites supplied by a producer distributing his production over a set of sites located in the same zone.

On a regional scale, the juxtaposition of distinct homogeneous assemblages characterizes the sociological mosaic of a region.

An example of this is "Nonant farm," a Middle Bronze Age settlement in Calvados in France (Marcigny and Ghesquière 2008). The ceramic assemblage comes from two habitat structures, which, after stratigraphic analysis, revealed an occupation of short duration, of about one generation, probably by one or two families. The technological study points to a single ceramic tradition characterized by vessels with a modeled base and the body and neck formed by coiling, by thinning operations resulting, in all cases, in wall thicknesses of between 7 and 9 mm, and at last by the same finishing techniques. This unique tradition presents no variants, including functional alternatives, and is the expression of the sociological homogeneity of a rural Middle Bronze Age settlement in France (Manem 2008, 2010).

Another example of sociological homogeneity comes from an urban site, the site of Hamdallahi, the ancient capital of the Fula Empire of Massina, in Mali, founded in 1820/1821 (Gallay et al. 1990). The habitations yield abundant fine-walled, more or less intact potteries bearing inner marks due to pounding with a hammer (pounding a concave shape), as well as very rare whole potteries decorated with comb-type imprints, including a lamp and an ablution bowl. By analogy with present-day ceramic traditions and given the proven link in the region between ceramic traditions and ethnic groups – in particular for roughout techniques – and between the ceramic range of compounds and the ethnic group of the occupants, archaeological ceramics with traces of pounding have been interpreted as part of the same Fula tradition, reflecting the sociological homogeneity of the capital. The rare comb-decorated whole potteries from the habitations are more difficult to interpret. Decoration evokes the Somono ethnic group. However, according to ethnographic data, the Somono do not diffuse their decorated ceramics on markets but offer them as gifts for weddings or other exceptional events. They would thus be gifts or presents from Somono populations (Gallay 2012a, b).

Lastly, in a regional perspective, the analysis of 23 assemblages from the recent Neolithic in west-central France provides another example of sociological homogeneity (Ard and Weller 2012; Ard 2013, 2014). When considered individually, these assemblages are homogeneous. At the macro-regional level, they reveal the existence of eight technical traditions, corresponding to eight distinct *chaînes opératoires*, extending from the Loire to Dordogne, related to chronological variability (different ways of doing things between the Matignon tradition and the ensuing Peu-Richard tradition), functional variability (a different way of making salt vessels) and cultural variability (different ways of doing vessels from the same morpho-functional category distributed between different geographical zones). For the recent Neolithic II (3400–2900 before J.C.), traditions clearly differentiate three cultural groups, taking into consideration their extension and territorial exclusivity. These are the Peu-Richard, the Seuil du Poitou group, and the Taizé group. These groups undergo different evolutionary dynamics with the absorption of the Seuil du Poitou group during the Final Neolithic by the group following the Peu-Richard (Artenac) and, conversely, the permanence of the Taizé. The technological analysis of the ceramic assemblages in terms of sociological variability enabled thus the author to restore the ancient social boundaries, to describe their evolution, and to propose at the end a real sociological regional history.

Complex Homogeneous Assemblages

These assemblages are characterized by vessels made using *n chaînes opératoires*, where the variants within each chain are correlated to *n* functional types. The petrographic groups are homogeneous but can possibly present strong variability. These traits suggest that ceramic production relies on clay materials from multiple sources, which are nonetheless all situated around the production site or within the radius of the exploited territory.

Complex homogeneous assemblages characterize sites with producers from distinct social groups, that is, sites with multiple social components. The functional interpretation of the site depends on petrographic, quantitative, and contextual data, i.e., urban site, port site, colony, economic exploitation site (temporarily occupied for economic reasons by craftsmen of different origins), refuge site, and site with several castes, tribes, clans, etc.

An example of this comes from the site of Khao Sam Kaeo, a port site located in the narrowest part of the Thai-Malaysian peninsula, bordered by the Bay of Bengal to the west and the Sea of China to the east, and settled between the fourth and the second centuries B.C. The material culture provides evidence of numerous exchanges with the Southeast Asian and Indian worlds but also a population with multiple social components (Bellina-Pryce and Silapanth 2006; Murillo-Barroso et al. 2010; Bellina et al. 2011). The ceramic assemblage reveals a diversity of ceramic traditions characterized by distinct *chaînes opératoires* applied to comparable and/or different morpho-stylistic categories (Bouvet 2012). These traditions differentiate between (a) locally produced vessels using two main *chaînes opératoires*, providing evidence of two social groups of different origins settling one after the other in Khao Sam Kaeo, (b) locally produced vessels with exogenous decoration in response to demand from foreign settlers at the site, and (c) vessels made using completely exogenous *chaînes opératoires*, pointing to exchange networks with Indian and Chinese zones.

Another example comes from a rural site in the north of Mesopotamia, the site of Tell Feres al-Sharqi, occupied for practically 1000 years, between 4700 and 3800 B.C. (Baldi 2015). The technological approach to ceramic assemblages shows that five local technical traditions coexisted during the Ubaid period. They are differentiated by roughout techniques, pounding for tradition 1 and modeling by drawing for traditions 2 and 3 (which have different finishing operations), thick coils for tradition 4 and fine coils for tradition 5. These traditions are associated with comparable functional ranges. Moreover, they are distributed in different workshops and potters' kilns, thereby arguing in favor of distinct productive units characterized by different technical practices, thus pointing to distinct social groups. The number of these traditions decreases throughout time as a corollary to the expansion of certain types of vessels and pastes, indicating the abandonment of pottery by several groups, which was then taken over by a dominant group, leading to significant changes in socioeconomic structures.

A last example comes from the study of the Neolithic ceramic assemblage from the site of Rosmeer (Limburg, Belgium) (Gomart and Burnez-Lanotte 2012; Gomart 2014). The analysis of the variability of forming techniques brought to light two distinct traditions. The first tradition, ROS1, is characterized by the use of coils with an alternating oblique configuration and the predominance of powdery grains used as tempers (interpreted as grog). The second tradition, ROS2, includes vases shaped by coils with external oblique overlap, mostly tempered with ground bone, at times with hematite or powdery grains. The association of these two traditions in the same structures reveals the possible contemporaneity of these productions and suggests the coexistence of two groups of producers with different social origins in the village.

Heterogeneous Assemblages

The heterogeneous assemblages are defined as simple or complex.

Simple Heterogeneous Assemblages

These assemblages are composed of *n* technical groups, are not correlated to functional types, and are characterized by heterogeneous petrographic groups presenting slight variability. Technical heterogeneity reveals diverse traditions. Petrographic heterogeneity indicates ceramic production on a meso-regional scale, and the low variability of this heterogeneity allows us to define the region in which the clay sources are located.

Complex Heterogeneous Assemblages

These assemblages are made up of *n* technical groups, are not correlated to functional types, and are characterized by heterogeneous petrographic groups with marked variability. Technical heterogeneity reveals diverse traditions. Due to petrographic heterogeneity, and marked variability, it is not possible to define a single region, and ceramic production sites are dispersed over a macro-regional scale.

Simple and complex heterogeneous assemblages point to the presence of consumers originating from the meso- or macro-region of the site. The functional interpretation of the site depends on petrographic, quantitative, and contextual data. Accordingly, it could be a consumer site importing vessels from diverse places, a market site, a gathering or aggregation site, and a ceremonial site.

An example of a simple heterogeneous assemblage is given by Goren (1995). This author studied the composition of ceramic assemblages from three Chalcolithic shrines in the Southern Levant (second half of the fifth millennium B.C.). The function of these sites had been established beforehand based on architectural traits and symbolic objects. The aim was to define the regional sphere of influence of these places. In order to do so, the ceramic vessels, identified as "offerings," or "offering containers," underwent petrographic studies. After identifying their provenance, three categories of places of worship were defined: a local center, En Gedi, characterized by ceramics from the Judaean Mountains; a regional center, Gilat, characterized by ceramics from the regions of the northern Negev and the Judaean Mountains; and an interregional zone, Nahal Mishmar, characterized by ceramics from the regions of the northern Negev, Judaea, and Transjordan. The results showing that the En Gedi sanctuary channeled a population originating from the Judaean Mountains have been supported elsewhere. A techno-petrographic analysis revealed a simple heterogeneous assemblage, made up of vessels from varied places situated in the meso-regional sphere (Roux and Courty 2007).

An example of a complex heterogeneous assemblage comes from the site of Abu Hamid, located in the Middle Jordan Valley (Roux and Courty 2005, 2007). The ceramic assemblage from the levels dated to 4300–3900 B.C. is characterized by marked technical variability and particularly by a wide diversity of surface aspects. This is similar to the diversity observed in the Southern Levant sites located in different ecological settings and having different functions (settlements, shrine, burial sites). Petrographic diversity is also important and corresponds to strong, uncontrollable geological variability, characterized by exogenous clay materials from a macro-region. In particular, we observe:

- The impossibility to identify a dominant petrofacies group and to pinpoint regional scale productions (the Middle Jordan Valley and its nearby surroundings).
- The very high number of types of exogenous and macro-regional petrofacies. These different types correspond to the dominant types found at other Chalcolithic sites in the Southern Levant.

Consequently, the techno-petrographic analysis of the ceramic assemblage of Abu Hamid shows that all the vessels are from different Chalcolithic sites in the Southern Levant. On a macro-regional scale, only the cave of Nahal Mishmar presents artifacts characterized by complex heterogeneity similar to that of Abu Hamid, but to a much lesser extent. In this cultural context, this site is interpreted as a gathering site.

Another archaeological example comes from the caves of the Duffaits culture and is dated to the Middle Bronze Age (1600–1300 B.C.) and located in the west-central zone and part of the Massif Central in France (Manem 2008, 2010). These sites are mostly represented by caves and rock shelters in the La Rochefoucauld karst (Charente). They were interpreted as habitats by some and as necropolises by others. The technological study of the ceramic material from the caves of Perrats, Duffaits, and Quéroy revealed complex heterogeneous assemblages with very diverse technical traditions, for so-called habitat caves as well as for necropolis caves (12 *chaînes opératoires* for the first occupation of Perrats Cave), thereby settling the question. This diversity points indeed to the participation of a large number of individuals for the fabrication of the material and, consequently, to the interpretation of the sites as places of gathering and not of habitat.

In another context, simple or complex heterogeneous assemblages can indicate nonproductive sites or market sites, where vessels come from different production centers spread over a province. A contemporary ethnographic example comes from Peru (Ramón 2011; Ramón and Bell 2013). In the La Libertad region (in Otuzco province), several nonproducing consumer sites present utilitarian vessels from four distinct traditions (Ramón and Bell 2013, 604, Fig. 7). The same heterogeneity is observed at market sites where pots issued from different traditions are sold beside each other (Gallay and de Ceuninck 1998).

Mixed Assemblages

These assemblages are partly made up of locally produced vessels and partly of vessels produced outside the local zone. The sociological interpretation of the site depends on the interpretation of each technical tradition in terms of production, distribution, and circulation modalities (see Chap. 6).

4.7 Conclusion

By way of conclusion, in order to optimize the interpretation of ceramic traditions, the analytical procedure must be pragmatic and flexible, that is, it must take into consideration the specific aspects of assemblages (extensive or limited, very or slightly fragmented, very or slightly eroded).

Successive sorting into technical groups, techno-petrographic groups, and techno-stylistic groups is possible on slightly fragmented assemblages. In the case of very eroded, or very fragmented assemblages, it is preferable to classify pieces using petrographic analysis. For homogeneous assemblages presenting identical techno-petrographic attributes, the classification will be morpho-stylistic. But the approach remains the same. Above all, it is based on a technological analysis where the different categories are based on different ways of doing ceramic vessels.

On another level, there are contingent situations where technological analysis can only be carried out after the morpho-stylistic classification of the assemblage. In this case, it is essential to examine the variability of the *chaînes opératoires* within each morpho-stylistic class, in order to reconstruct, a posteriori, the techno-stylistic tree.

Morpho-stylistic and petrographic analysis may also have been applied to the assemblage without taking the *chaînes opératoires* into consideration. In this case, it is first of all important to identify the *chaînes opératoires* used for the fabrication of the different morphometric classes and then to confirm that the petrographic analyses were carried out on representative samples of these *chaînes opératoires*, so that we can then, a posteriori, reconstruct the techno-petrographic groups and the techno-stylistic tree.

References

Ard, V. (2013). Ceramic traditions and cultural identities: West-Central France during the late Neolithic II period (c. 3400–2900 cal. BC). *Oxford Journal of Archaeology, 32*, 367–389.

Ard, V. (2014). *Produire et échanger au Néolithique. Traditions céramiques entre Loire et Gironde au IVe millénaire avant JC*. Documents Préhistoriques 33. Paris: CTHS.

Ard, V., Weller, O. (2012). Les vases de “type Champ-Durand”: témoins d’une exploitation du sel au Néolithique récent dans le Marais poitevin. In R. Joussaume (Ed.), *L’enceinte néolithique de Champ-Durand à Nieul-sur-l’Autise (Vendée)* (pp. 319–343). Mémoire de la Société de recherches archéologiques de Chauvigny 44. Chauvigny: Association des Publications Chauvinoises – A.P.C.

Arnold, P. J., III. (1991). *Domestic ceramic production and spatial organization: A Mexican case study in ethnoarchaeology*. Cambridge: Cambridge University Press.

Arthur, J. (2003). Brewing beer: Status, wealth and ceramic use alteration among the Gamo of South-Western Ethiopia. *World Archaeology, 34*, 516–528.

Baldi, J. S. (2015). *Aux portes de la Cité: systèmes céramiques et organisation sociale en Mésopotamie du Nord aux 5ème et 4ème millénaires*. Paris: Université de Paris I, Panthéon-Sorbonne. PhD.

Balfet, H. (1965). Ethnographical observations in North Africa and archaeological interpretation: The pottery of the Maghreb. In F. R. Matson (Ed.), *Ceramics and man* (pp. 161–177). New York: Viking Fund Publication in Anthropology.

Balfet, H., Fauvet-Berthelot, M.-F., & Monzon, S. (1983). *Pour la normalisation de la description des poteries*. Paris: Editions du CNRS.

Bellina, B., Epinal, G., & Favereau, A. (2011). Caractérisation préliminaire des poteries marqueurs d’échanges en Mer de Chine Méridionale à la fin de la préhistoire. *Archipel, 84*, 7–33.

Bellina-Pryce, B., & Silapanth, P. (2006). Weaving cultural identities on trans-Asiatic networks: Upper Thai-Malay Peninsula-an early socio-political landscape. *Bulletin de l’Ecole française d’Extrême-Orient, 93*, 257–293.

Binder, D., Convertini, F., Manen, C., & Sénépart, I. (2010). Les productions céramiques du Néolithique ancien : proposition d’un protocole d’analyse. In C. Manen, F. Convertini, & D. Binder (Ed.), *Premières sociétés paysannes de Méditerranée occidentale: structure des premières productions céramiques* (pp. 29–42). Mémoires de La Société Préhistorique Française 51. Paris: Société Préhistorique Française.

Bocherens, H. (1997). Signatures isotopiques dans le collagène des os anciens isotopic: Molécules anciennes. Problèmes biologiques. Problèmes historiques. *Comptes rendus des séances de la Société de biologie et de ses filiales, 191*, 493–510.

Bogucki, P. I. (1984). Ceramic sieves of the Linear Pottery Culture and their economic implications. *Oxford Journal of Archaeology, 3*, 15–30.

Bortolini, E. (2016). Typology and classification. In A. M. W. Hunt (Ed.), *The Oxford handbook of archaeological ceramic analysis* (pp. 651–670). Oxford: Oxford University Press.

Bourgeois, G., & Gouin, P. (1995). Résultats d'une analyse de traces organiques fossiles dans une "faisselle" harappéenne. *Paléorient*, 125–128.

Bouvet, P. (2012). *Interactions culturelles entre l'Asie du Sud-Est et l'Inde aux 4ème-2ème siècle avt J.-C.: étude technologique des céramiques de Khao Sam Kaeo (Thaïlande péninsulaire, province de Chumphon)*. Nanterre: Université de Paris Nanterre. PhD.

Bowser, B. J. (2000). From pottery to politics: An ethnoarchaeological study of political factionalism, ethnicity, and domestic pottery style in the Ecuadorian Amazon. *Journal of Archaeological Method and Theory, 7*(3), 219–248.

Bowser, J. B., & Patton, J. Q. (2008). Learning and transmission of pottery style: Women's life histories and communities of practice in the Ecuadorian Amazon. In M. T. Stark, B. J. Bowser, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 105–129). Tucson: The University of Arizona Press.

Caneva, I., & Marks, A. (1990). More on the Shaqadud pottery: Evidence for Saharo-nilotic connections during the 6th-4th millenium BC. *Archéologie du Nil moyen, 4*, 11–35.

Charters, S., Evershed, R. P., Blinkhorn, P. W., & Denham, V. (1995). Evidence for the mixing of fats and waxes in archaeological ceramics. *Archaeometry, 37*, 113–127.

Colombini, M. P., Modugno, F., & Ribechini, E. (2005). Organic mass spectrometry in archaeology: Evidence for Brassicaceae seed oil in Egyptian ceramic lamps. *Journal of Mass Spectrometry, 40*, 890–898.

Condamin, J., & Formenti, F. (1978). Détection du contenu d'amphores antiques (huiles, vin). Etude méthodologique. *Revue d'Archéométrie. Bulletin de Liaison du Groupe des Méthodes Physiques et Chimiques de l'Archéologie Rennes*: 43–58.

Condamin, J., Formenti, F., Metais, M. O., Michel, M., & Blond, P. (1976). The application of gas chromatography to the tracing of oil in ancient amphorae. *Archaeometry, 18*, 195–201.

Copley, M. S., Rose, P. J., Clapham, A., Edwards, D. N., Horton, M. C., & Evershed, R. P. (2001). Processing palm fruits in the Nile Valley-biomolecular evidence from Qasr Ibrim. *Antiquity, 75*, 538–542.

Copley, M. S., Berstan, R., Dudd, S. N., Docherty, G., Mukherjee, A. J., Straker, V., Payne, S., & Evershed, R. P. (2003). Direct chemical evidence for widespread dairying in prehistoric Britain. *Proceedings of the National Academy of Sciences, 100*, 1524–1529.

Copley, M. S., Hansel, F. A., Sadr, K., & Evershed, R. P. (2004). Organic residue evidence for the processing of marine animal products in pottery vessels from the pre-colonial archaeological site of Kasteelberg D east, South Africa. *South African Journal of Science, 100*, 279–288.

Correa-Ascencio, M., & Evershed, R. P. (2014). High throughput screening of organic residues in archaeological potsherds using direct acidified methanol extraction. *Analytical Methods, 6*, 1330–1340.

Cotte, J. (1917). Analyses de résidus organiques de l'époque néolithique (Caverne de l'Adaouste). *Bulletins et Mémoires de la Société d'anthropologie de Paris, 8*, 66–115.

Craig, O. E., & Collins, M. J. (2002). The removal of protein from mineral surfaces: Implications for residue analysis of archaeological materials. *Journal of Archaeological Science, 29*, 1077–1082.

Craig, O. E., Mulville, J., Pearson, M. P., Sokol, R., Gelsthorpe, K., Stacey, R., & Collins, M. (2000). Detecting milk proteins in ancient pots. *Nature, 408*, 312–312.

Craig, O. E., Forster, M., Andersen, S. H., Koch, E., Crombé, P., Milner, N. J., Stern, B., Bailey, G. N., & Heron, C. P. (2007). Molecular and istotopic demonstration of the processing of aquatic products in northern european prehistoric pottery. *Archaeometry, 49*, 135–152.

Craig, O. E., Allen, R. B., Thompson, A., Stevens, R. E., Steele, V. J., & Heron, C. (2012). Distinguishing wild ruminant lipids by gas chromatography/combustion/isotope ratio mass spectrometry. *Rapid Communications in Mass Spectrometry, 26*, 2359–2364.

Craig, O. E., Saul, H., Lucquin, A., Nishida, Y., Taché, K., Clarke, L., Thompson, A., Altoft, D. T., Uchiyama, J., & Ajimoto, M. (2013). Earliest evidence for the use of pottery. *Nature, 496*, 351–354.

Crane, E. (1983). *The archaeology of beekeeping*. London: Duckworth.

Crown, P. L., & Hurst, W. J. (2009). Evidence of cacao use in the Prehispanic American Southwest. *Proceedings of the National Academy of Sciences, 106*, 2110–2113.

David, N., & Kramer, C. (2001). *Ethnoarchaeology in action*. Cambridge: Cambridge University Press.

David, N., Sterner, J., & Gavua, K. (1988). Why pots are decorated. *Current Anthropology, 29*(3), 365–389.

de Ceuninck, G. (1994). Forme, fonction, ethnie: approche ethnoarchéologique des céramiques du delta inférieur du Niger (Mali). In D. Binder & J. Courtin (Eds.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (pp. 161–178). XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. Juan-les-Pins: Editions APDCA.

Decavallas, O. (2007). Beeswax in Neolithic perforated sherds from the Northern Aegean: New economic and functional implications. In C. Mee & J. Renard (Eds.), *Cooking up the past. Food and culinary practrices in the Neolithic and Bronze Age Aegean* (pp. 148–157). Oxford: Oxbow Books.

Dietler, M., & Herbich, I (1994). Ceramics and ethnic identity. Ethnoarchaeological observations on the distribution of pottery styles and the relationship between the social contexts of production and consumption. In J. Courtin & D. Binder (Ed.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (pp. 459–472). XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. Juan-les-Pins: Editions APDCA.

Dudd, S. N., & Evershed, R. P. (1998). Direct demonstration of milk as an element of archaeological economies. *Science, 282*, 1478–1481.

Dudd, S. N., Evershed, R. P., & Gibson, A. M. (1999). Evidence for varying patterns of exploitation of animal products in different prehistoric pottery traditions based on lipids preserved in surface and absorbed residues. *Journal of Archaeological Science, 26*, 1473–1482.

Dunne, J., Evershed, R. P., Salque, M., Cramp, L., Bruni, S., Ryan, K., Biagetti, S., & di Lernia, S. (2012). First dairying in green Saharan Africa in the fifth millennium BC. *Nature, 486*, 390–394.

Duplaix-Rata, A. (1997). Les dépôts alimentaires carbonisés. In *Les sites littoraux néolithiques de Clairvaux-les-Lacs et de Chalain (Jura): Chalain station 3, 3200–2900 av. J.-C. III*, ed. Pierre Pétrequin. Paris: Editions de la MSH.

Eglinton, G., Logan, G. A., Ambler, R. P., Boon, J. J., & Perizonius, W. R. K. (1991). Molecular preservation and discussion. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 333*, 315–328.

Evershed, R. P. (2008). Organic residue analysis in archaeology: The archaeological biomarker revolution. *Archaeometry, 50*, 895–924.

Evershed, R. P., & Tuross, N. (1996). Proteinaceous material from potsherds and associated soils. *Journal of Archaeological Science, 23*, 429–436.

Evershed, R. P., Heron, C., & Goad, L. J. (1990). Analysis of organic residues of archaeological origin by high-temperature gas chromatography and gas chromatography-mass spectrometry. *Analyst, 115*, 1339–1342.

Evershed, R. P., Heron, C., Charters, S., & Goad, L. J. (1991a). The survival of food residues: New methods of analysis, interpretation and application. In *Proceedings of the British Academy* (Vol. 77, pp. 187–208).

Evershed, R. P., Heron, C., & Goad, L. (1991b). Epicuticular wax components preserved in potsherds as chemical indicators of leafy vegetables in ancient diets. *Antiquity, 65*, 540–544.

Evershed, R. P., Charters, S., Heron, C., & Goad, L. J. (1992). Chemical analysis of organic residues in ancient pottery: Methodological guidelines and applications. In R. White & H. Page (Eds.), *Organic residues in archaeology: Their identification and analysis* (pp. 11–25). London: UKIC Archaeology Section.

Evershed, R. P., Arnot, K. I., Collister, J., Eglinton, G., & Charters, S. (1994). Application of isotope ratio monitoring gas chromatography–mass spectrometry to the analysis of organic residues of archaeological origin. *Analyst, 119*, 909–914.

Evershed, R. P., Mottram, H. R., Dudd, S. N., Charters, S., Stott, A. W., Lawrence, G. J., Gibson, A. M., Conner, A., Blinkhorn, P. W., & Reeves, V. (1997a). New criteria for the identification of animal fats preserved in archaeological pottery. *Naturwissenschaften, 84*, 402–406.

Evershed, R. P., Vaughan, S., Dudd, S. N., & Soles, J. (1997b). Fuel for thought? Beeswax in lamps and conical cups from Late Minoan Crete. *Fuel, 71*, 979–979.

Evershed, R. P., Dudd, S. N., Copley, M. S., Berstan, R., Stott, A. W., Mottram, H., Buckley, S. A., & Crossman, Z. (2002). Chemistry of archaeological animal fats. *Accounts of Chemical Research, 35*, 660–668.

Evershed, R. P., Dudd, S. N., Anderson-Stojanovic, V., & Gebhard, E. R. (2003). New chemical evidence for the use of combed ware pottery vessels as beehives in ancient Greece. *Journal of Archaeological Science, 30*, 1–12.

Evershed, R. P., Copley, M. S., Dickson, L., & Hansel, F. A. (2008a). Experimental evidence for the processing of marine animal products and other commodities containing polyunsaturated fatty acids in pottery vessels. *Archaeometry, 50*, 101–113.

Evershed, R. P., Payne, S., Sherratt, A. G., Copley, M. S., Coolidge, J., Urem-Kotsu, D., Kotsakis, K., et al. (2008b). Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature, 455*, 528–531.

Gallay, A. (2012a). *Potières du Sahel: A la découverte des traditions céramiques de la boucle du Niger*. Gollion, Suisse: Infolio.

Gallay, A. (2012b). Utilisation de la céramique d'origine somono et peul chez les pêcheurs bozo du Delta intérieur du Niger (Mali). *Afrique, Archéologie, Arts, 8*, 45–84.

Gallay, A. (2013). Biens de prestige et richesse en Afrique de l'Ouest: un essai de définition. In C. Baroin & C. Michel (Eds.), *Richesse et sociétés* (pp. 25–36). Colloques de La Maison de l'Archéologie et de l'ethnologie René Ginouvès 9. Paris: Editions de Boccard.

Gallay, A., & de Ceuninck, G. (1998). Les jarres de mariage décorées du Delta intérieur du Niger (Mali): approche ethnoarchéologique d'un "bien de prestige." In B. Fritsch, M. Maute, J. Müller, & C. Wolf (Eds.), *Tradition und Innovation: prëhistorische Archëologie als historische Wissenschaft : Festchrift für Christian Strahm* (pp. 13–30). Rahden: M. Leidorf.

Gallay, A., Huysecom, E., Honegger, M., & Mayor, A. (1990). *Hamdallahi, Capitale de l'Empire Peul du Massina, Mali: première fouille archéologique, études historiques et ethnoarchéologiques*. Sonderschriften Des Frobenius-Institut 9. Stuttgart: F. Steiner.

Gallin, A. (2002). Proposition d'une étude stylistique de la céramique imprimée de Kobadi. Définition de classes morphométriques des vases et analyse de la composition de leurs décors. *Préhistoires Méditerranéennes*: 117–134.

Gallin, A. (2011). *Les styles céramiques de Kobadi : analyse comparative et implications chronoculturelles au Néolithique récent du Sahel Malien*. Reports in African Archaeology 1. Frankfurt am Main: Africa Magna Verlag.

Gallin, A. (2013). CerAfIm. http://lampea.cnrs.fr/cerafim/ (accessed 14/12/2018).

Gardin, J.-C. (1976). *Code pour l'analyse des formes de poteries*. Paris: Editions du CNRS.

Gardin, J.-C. (1980). *Archaeological constructs: An aspect of theoretical archaeology*. Cambridge: Cambridge University Press.

Gardin, J.-C., & Chevalier, J. (1978). *Code pour l'analyse des ornements*. Paris: Ed. du CNRS.

Garnier, N., Cren-Olivé, C., Rolando, C., & Regert, M. (2002). Characterization of archaeological beeswax by electron ionization and electrospray ionization mass spectrometry. *Analytical Chemistry, 74*, 4868–4877.

Garnier, N., Richardin, P., Cheynier, V., & Regert, M. (2003). Characterization of thermally assisted hydrolysis and methylation products of polyphenols from modern and archaeological vine derivatives using gas chromatography–mass spectrometry. *Analytica Chimica Acta, 493*, 137–157.

Garnier, N., Rolando, C., Høtje, J. M., & Tokarski, C. (2009). Analysis of archaeological triacylglycerols by high resolution nanoESI, FT-ICR MS and IRMPD MS/MS: Application to 5th century BC–4th century AD oil lamps from Olbia (Ukraine). *International Journal of Mass Spectrometry, 284*, 47–56.

Gifford, J. C. (1960). The type-variety method of ceramic classification as an indicator of cultural phenomena. *American Antiquity, 25*, 341–347.

Gilboa, A., Karasik, A., Sharon, I., & Smilansky, U. (2004). Towards computerized typology and classification of ceramics. *Journal of Archaeological Science, 31*, 681–694.

Goldenberg, L., Neumann, R., & Weiner, S. (2014). Microscale distribution and concentration of preserved organic molecules with carbon–carbon double bonds in archaeological ceramics: Relevance to the field of residue analysis. *Journal of Archaeological Science, 42*, 509–518.

Gomart, L. (2014). *Traditions techniques et production céramique au néolithique ancien: étude de huit sites rubanés du Nord Est de la France et de Belgique*. Leiden: Sidestone Press.

Gomart, L., & Burnez-Lanotte, L. (2012). Techniques de façonnage, production céramique et identité de potiers: une approche technologique de la céramique de style non Rubané du site du Staberg à Rosmeer (Limbourg, Belgique). *Bulletin de la Société Préhistorique Française, 109*, 231–250.

Goren, Y. (1995). Shrines and ceramics in chalcolithic Israel: The view through the petrographic microscope. *Archaeometry, 37*(2), 287–305.

Gosselain, O. (2008). Mother Bella was not a Bella. Inherited and transformed traditions in Southwestern Niger. In M. T. Stark, B. Bower, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 150–177). Tucson: Arizona University Press.

Gosselain, O. (2011). Pourquoi le décorer? Quelques observations sur le décor céramique en Afrique. *Azania: Archaeological Research in Africa, 46*, 3–19.

Gosselain, O., Haour, A., MacDonald, K., & Manning, K. (2010). Introduction. In A. Haour, K. Manning, N. Arazi, O. Gosselain, S. Guèye, D. Keita, A. Livingstone-smith, et al. (Eds.), *African pottery roulettes past and present: Techniques, identification and distribution* (pp. 1–34). Oxford: Oxbow Books.

Gouin, P. (1994). Sources, principes et techniques de l'archéologie des laitages. In D. Binder & J. Courtin (Ed.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (pp. 147–160). XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. Juan-les-Pins: Editions APDCA.

Guasch-Jané, M. R. (2011). The meaning of wine in Egyptian tombs: The three amphorae from Tutankhamun's burial chamber. *Antiquity, 85*, 851–858.

Guasch-Jané, M. R., Ibern-Gómez, M., Andrés-Lacueva, C., Jáuregui, O., & Lamuela-Raventós, R. M. (2004). Liquid chromatography with mass spectrometry in tandem mode applied for the identification of wine markers in residues from ancient Egyptian vessels. *Analytical Chemistry, 76*, 1672–1677.

Guasch-Jané, M. R., Andrés-Lacueva, C., Jáuregui, O., & Lamuela-Raventós, R. M. (2006a). The origin of the ancient Egyptian drink "Shedeh" revealed using LC/MS/MS. *Journal of Archaeological Science, 33*, 98–101.

Guasch-Jané, M. R., Andrés-Lacueva, C., Jáuregui, O., & Lamuela-Raventós, R. M. (2006b). First evidence of white wine in ancient Egypt from Tutankhamun's tomb. *Journal of Archaeological Science, 33*, 1075–1080.

Hall, G. D., Tarka, S. M., Jr., Hurst, W. J., Stuart, D., & Adams, R. E. W. (1990). Cacao residues in ancient Maya vessels from Rio Azul, Guatemala. *American Antiquity, 55*, 138–143.

Hally, D. J. (1983). Use alteration of pottery surfaces: An important source of evidence for the identification of vessel function. *North American Archaeologists, 4*(1), 3–26.

Hansel, F. A., Copley, M. S., Madureira, L. A., & Evershed, R. P. (2004). Thermally produced w(o-alkylphenyl) alkanoic acids provide evidence for the processing of marine products in archaeological pottery vessels. *Tetrahedron Letters, 45*, 2999–3002.

Hegmon, M. (1998). Technology, style, and social practice: Archaeological approaches. In M. T. Stark (Ed.), *The Archaeology of social boundaries* (pp. 264–279). Washington, DC: Smithsonian University Press.

Henderson, J. S., Joyce, R. A., Hall, G. R., Hurst, W. J., & McGovern, P. E. (2007). Chemical and archaeological evidence for the earliest cacao beverages. *Proceedings of the National Academy of Sciences, 104*, 18937–18940.

Henrickson, E. F., & McDonald, M. M. A. (1983). Ceramic form and function: An ethnographic search and an archeological application. *American Anthropologist, 85*, 630–643.

Herbich, I. (1987). Learning patterns, potter interaction and ceramic style among the Luo of Kenya. *The African Archaeological Review, 5*, 109–136.

Heron, C., & Evershed, R. P. (1993). The analysis of organic residues and the study of pottery use. *Archaeological Method and Theory, 5*, 247–284.

Heron, C., Evershed, R. P., & Goad, L. J. (1991). Effects of migration of soil lipids on organic residues associated with buried potsherds. *Journal of Archaeological Science, 18*, 641–659.

Heron, C., Nemcek, N., Bonfield, K. M., Dixon, D., & Ottaway, B. S. (1994). The chemistry of Neolithic beeswax. *Naturwissenschaften, 81*, 266–269.

Hodder, I. (1982). *Symbols in action. Ethnoarchaeological studies of material culture*. Cambridge: Cambridge University Press.

Houbre, A. (2013). La grammaire des décors céramiques du Néolithique ancien danubien des bassins du Rhin, de la Meuse et de la Seine: entre norme et transgression. *Bulletin de la Société préhistorique française, 110*, 77–103.

Hurst, W. J., Martin, R. A., Jr., Tarka, S. M., Jr., & Hall, G. D. (1989). Authentication of cocoa in Maya vessels using high-performance liquid chromatographic techniques. *Journal of Chromatography A, 466*, 279–289.

Hurst, W. J., Tarka, S. M., Powis, T. G., Valdez, F., & Hester, T. R. (2002). Cacao usage by the earliest Maya civilization. *Nature, 418*, 289–290.

Karasik, A., & Smilansky, U. (2008). 3D scanning technology as a standard archaeological tool for pottery analysis: Practice and theory. *Journal of Archaeological Science, 35*, 1148–1168.

Karasik, A., & Smilansky, U. (2011). Computerized morphological classification of ceramics. *Journal of Archaeological Science, 38*, 2644–2657.

Kobayashi, M. (1994). Use-alteration analysis of Kalinga pottery: Interior carbon deposits of cooking pots. In W. A. Longacre & J. M. Skibo (Eds.), *Kalinga ethnoarchaeology: Expanding archaeological method and theory* (pp. 127–168). Washington, DC: Smithsonian Institution Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lyonnet, B. (1997). *Prospections archéologiques en Bactriane orientale (1974–1978)*. Mémoires de la Mission archéologique française en Asie centrale 2. Paris: Ed. Recherche sur les civilisations.

Manem, S. (2008). *Etude des fondements technologiques de la culture des Duffaits (âge du Bronze moyen)*. Nanterre: Université de Paris Nanterre. PhD.

Manem, S. (2010). Des habitats aux sites de rassemblement à vocation rituelle. L'âge du Bronze selon le concept de "chaîne opératoire". *Les Nouvelles de l'Archéologie*: 30–36.

Manen, C., & Salanova, L. (2010). Les impressions de coquilles marines à front denté dans les décors céramiques néolithiques. In C. Manen, F. Convertini, & D. Binder (Eds.), *Premières sociétés paysannes de Méditerranée occidentale : structure des premières productions céramiques* (pp. 57–64). Mémoires de La Société Préhistorique Française 51. Paris: Société Préhistorique Française.

Marcigny, C., & Ghesquière, E. (2008). Espace rural et systèmes agraires dans l'Ouest de la France à l'âge du Bronze: quelques exemples normands. In J. Guilaine (Ed.), *Villes, villages, campagnes de l'âge du Bronze* (pp. 256–278). Séminaire Du Collège de France. Paris: Editions Errance.

McGovern, P. E., & Michel, R. H. (1990). Royal purple dye: The chemical reconstruction of the ancient mediterranean industry. *Accounts of Chemical Research, 23*, 152–158.

Meunier, K. (2012). *Styles céramiques et néolithisation dans le sud-est du Bassin parisien: une évolution Rubané, Villeneuve-Saint-Germain*. Paris: CNRS éditions, INRAP.

Miller, D. (1985). *Artefacts as categories. A study of ceramic variability in Central India*. Cambridge: Cambridge University Press.

Mirabaud, S., Rolando, C., & Regert, M. (2007). Molecular criteria for discriminating adipose fat and milk from different species by nanoESI MS and MS/MS of their triacylglycerols: Application to archaeological remains. *Analytical Chemistry, 79*, 6182–6192.

Mottram, H. R., & Evershed, R. P. (2001). Elucidation of the composition of bovine milk fat triacylglycerols using high-performance liquid chromatography–atmospheric pressure chemical ionisation mass spectrometry. *Journal of Chromatography A, 926*, 239–253.

Mottram, H. R., Dudd, S. N., Lawrence, G. J., Stott, A. W., & Evershed, R. P. (1999). New chromatographic, mass spectrometric and stable isotope approaches to the classification of degraded animal fats preserved in archaeological pottery. *Journal of Chromatography A, 833*, 209–221.
Mottram, H. R., Crossman, Z. M., & Evershed, R. P. (2001). Regiospecific characterisation of the triacylglycerols in animal fats using high performance liquid chromatography-atmospheric pressure chemical ionisation mass spectrometry. *Analyst, 126*, 1018–1024.
Murillo-Barroso, M., Pryce, T. O., Bellina, B., & Martinón-Torres, M. (2010). Khao Sam Kaeo–an archaeometallurgical crossroads for trans-asiatic technological traditions. *Journal of Archaeological Science, 37*, 1761–1772.
Orton, C., Tyers, P., & Vince, A. (1993). *Pottery in archaeology*. Cambridge: Cambridge University Press.
Philp, R. P., & Oung, J.-N. (1988). Biomarkers: Occurence, utility, and detection. *Analytical Chemistry, 60*, 887A–896A.
Plog, S. (1980). *Stylistic variation in prehistoric ceramics*. Cambridge: Cambridge University press.
Ramón, G. (2011). The swallow potters: seasonal migratory styles in the Andes. In S. Scarcella (Ed.), *Archaeological ceramics: A review of current research* (pp. 160–175). BAR International Series 2193. Oxford: Archaeopress.
Ramón, G., & Bell, M. (2013). Re-placing plainware: Production and distribution of domestic pottery, and the narration of the pre-colonial past in the Peruvian Andes. *Journal of Anthropological Archaeology, 32*, 595–613.
Read, D. W. (2007). *Artifact classification: A conceptual and methodological approach*. Walnut Creek: Left Coast Press.
Regert, M. (2007). Elucidating pottery function using a multi-step analytical methodology combining infrared spectroscopy, mass spectrometry and chromatographic procedures. In H. Barnard & J. W. Eerkens (Ed.), *Theory and practice of archaeological residue analysis* (pp. 61–76). BAR International Series 1650. Oxford: Archaeopress.
Regert, M. (2011). Analytical strategies for discriminating archeological fatty substances from animal origin. *Mass Spectrometry Reviews, 30*, 177–220.
Regert, M. (2015). Exploitation des produits de la ruche pendant la Préhistoire en Europe et dans le monde méditerranéen. In E. Maire & D. Laffly (Eds.), *Abeilles et Paysages. Enjeux apicoles et agricoles* (pp. 33–43). Versailles, Editions Quae.
Regert, M., & Mirabaud, S. (2014). Substances naturelles exploitées sur les sites de Chalain et Clairvaux : nature et fonction des matériaux organiques amorphes. In R. M. Arbogast & A. Greffier-Richard (Eds.), *Entre archéologie et écologie, une Préhistoire de tous les milieux. Mélanges à Pierre Pétrequin* (pp. 79–91). Besançon: Presses Universitaires de Franche-Comté.
Regert, M., Dudd, S. N., Pétrequin, P., & Evershed, R. P. (1999). Fonction des céramiques et alimentation au Néolithique final sur les sites de Chalain: de nouvelles voies d'étude fondées sur l'analyse chimique des résidus organiques conservés dans les poteries. *Revue d'archéométrie*: 91–99.
Regert, M., Colinart, S., Degrand, L., & Decavallas, O. (2001a). Chemical alteration and use of beeswax through time: Accelerated ageing tests and analysis of archaeological samples from various environmental contexts. *Archaeometry, 43*, 549–569.
Regert, M., Dudd, S. N., Pétrequin, P., & Evershed, R. P. (2001b). Investigations of both extractable and insoluble polymeric components: Organic residues in Neolithic ceramic vessels from Chalain (Jura, France). In A. Millard (Ed.), *Archaeological sciences '97: Proceedings of the conference held at the University of Durham, 2nd–4th Setptember 1997* (pp. 78–90). Oxford: Archaeopress.
Regert, M., Vacher, S., Moulherat, C., & Decavallas, O. (2003). Adhesive production and pottery function during the Iron Age at the site of Grand Aunay (Sarthe, France). *Archaeometry, 45*, 101–120.
Regert, M., Mirabaud, S., Pétrequin, P., Pétrequin, A.-M., & Rolando, C. (2008). Mise en place de nouvelles stratégies analytiques pour la sauvegarde des informations chimiques conservées dans des céramiques archéologiques. *Technè*: 24–35.

Reid, A., & Young, R. (2000). Pottery abrasion and the preparation of African grains. *Antiquity, 74*, 101–111.

Rice, P. M. (1987). *Pottery analysis. A sourcebook*. Chicago/London: The University Chicago Press.

Roffet-Salque, M., Regert, M., Evershed, R. P., Outram, A. K., Cramp, L. J. E., Decavallas, O., Dunne, J., Gerbault, P., Mileto, S., & Mirabaud, S. (2015). Widespread exploitation of the honeybee by early Neolithic farmers. *Nature, 527*, 226–230.

Roux, V., & Courty, M.-A. (2005). Identifying social entities at a macro-regional level: Chalcolithic ceramics of south Levant as a case study. In A. Livingstone Smith, D. Bosquet, & R. Martineau (Eds.), *Pottery manufacturing processes: Reconstruction and interpretation* (pp. 201–214). BAR International Series 1349. Oxford: Archaeopress.

Roux, V., & Courty, M.-A. (2007). Analyse techno-pétrographique céramique et interprétation fonctionnelle des sites: un exemple d'application dans le Levant Sud Chalcolithique. In A. Bain, J. Chabot, & M. Mousette (Ed.), *Recherches en archéométrie: la mesure du passé*, BAR Int. Ser. (pp. 153–167.) Oxford: Archeopress.

Roux, V., Courty, M.-A., Dollfus, G., & Lovell, J. (2011). A techno-petrographic approach for defining cultural phases and communities: explaining the variability of Abu Hamid (Jordan Valley) early 5th millenium cal. BC ceramic assemblage. In Y. Rowan & J. Lovell (Eds.), *Culture, chronology and the chalcolithic: Theory and transition* (pp. 113–132). CBRL levant supplementary monograph series. Oxford: Oxbow Books.

Roux, V., Bril, B., Cauliez, J., Goujon, A.-L., Lara, C., de Saulieu, G., & Zangato, E. (2017). Persisting technological boundaries: Social interactions, cognitive correlations and polarization. *Journal of Anthropological Archaeology, 48*, 320–335.

Sackett, J. R. (1977). The meaning of style in archaeology: A general model. *American Antiquity, 42*, 369–380.

Salque, M., Bogucki, P. I., Pyzel, J., Sobkowiak-Tabaka, I., Grygiel, R., Szmyt, M., & Evershed, R. P. (2013). Earliest evidence for cheese making in the sixth millennium BC in northern Europe. *Nature, 493*, 522–525.

Santacreu, D. A., Trias, M. C., & Rosselló, J. G. (2017). Formal analysis and typological classification in the study of ancient pottery. In A. M. W. Hunt (Ed.), *The Oxford handbook of archaeological ceramic analysis* (pp. 181–205). Oxford: Oxford University Press.

Saragusti, I., Karasik, A., Sharon, I., & Smilansky, U. (2005). Quantitative analysis of shape attributes based on contours and section profiles in artifact analysis. *Journal of Archaeological Science, 32*, 841–853.

Saul, H., Madella, M., Fischer, A., Glykou, A., Hartz, S., & Craig, O. E. (2013). Phytoliths in pottery reveal the use of spice in European prehistoric cuisine. *PLoS One, 8*, e70583.

Shepard, A. O. (1965). *Ceramics for the archaeologist*. Washington, DC: Carnegie Institution of Washington.

Skibo, J. M. (1992). *Pottery-function: A use-alteration perspective*. New York: Plenum.

Smith, N. G., Karasik, A., Narayanan, T., Olson, E. S., Smilansky, U., & Levy, T. E. (2014). The pottery informatics query database: A new method for mathematic and quantitative analyses of large regional ceramic datasets. *Journal of Archaeological Method and Theory, 21*, 212–250.

Solazzo, C., Fitzhugh, W. W., Rolando, C., & Tokarski, C. (2008). Identification of protein remains in archaeological potsherds by proteomics. *Analytical Chemistry, 80*, 4590–4597.

Stark, M. T. (Ed.). (1998). *The Archaeology of social boundaries* (Smithsonian series in archaeological inquiry). Washington, WA/London: Smithsonian Institution Press.

Stark, M. T., Bowser, B. J., & Horne, L. (Eds.). (2008). *Cultural transmission and material culture. Breaking down boundaries*. Tucson: The University Arizona Press.

Sterner, J. (1989). Who is signalling whom? Ceramic style, ethnicity and taphonomy among the Sirak Bulahay. *Antiquity, 63*, 451–459.

Styring, A. K., Manning, H., Fraser, R. A., Wallace, M., Jones, G., Charles, M., Heaton, T. H. E., Bogaard, A., & Evershed, R. P. (2013). The effect of charring and burial on the biochemical composition of cereal grains: Investigating the integrity of archaeological plant material. *Journal of Archaeological Science, 40*, 4767–4779.

van Berg, P.-L. (1988). *Le poinçon, le peigne et filecode. Essai sur la structure du décor céramique dans le Rubané récent du nord-ouest*. Liège, Belgique: Université de Liège. PhD.
van Berg, P.-L. (1994). *Grammaire des styles céramiques du Rubané d'Alsace: wettolsheim-Ricoh I*. Zimmersheim: Association pour la promotion de la recherche archéologique en Alsace.
Vieugué, J. (2010). *Du vase aux tessons: formes et fonctions de la céramique du Néolithique ancien de l'habitat de Kovačevo (6200–5500 av. J.-C., Bulgarie)*. Paris: Paris I.
Vieugué, J., Mirabaud, S., & Regert, M. (2008). Contribution méthodologique à l'analyse fonctionnelle des céramiques d'un habitat néolithique: l'exemple de Kovacevo (6 200-5 500 av. J.-C., Bulgarie). *ArchéoSciences, 32*, 99–113.
Whallon, R. (1972). A new approach to pottery typology. *American Antiquity, 37*, 13–33.
Whallon, R., & Brown, J. A. (Eds.). (1982). *Essays on archaeological typology*. Evanston: Center for American Archeology Press.
Whittaker, J. C., Caulkins, D., & Kamp, K. A. (1998). Evaluating consistency in typology and classification. *Journal of Archaeological Method and Theory, 5*, 129–164.
Wobst, M. (1977). Stylistic behaviour and information exchange. In C. E. Cleland (Ed.), *For the director: Research essays in honor of J. B. Griffin* (pp. 317–342). Ann Arbor : Museum of Anthropology, University of MichiganMichigan.
Wu, H.-C. (2012). *Peuplement et dynamique culturelle à l'âge du Fer Ancien et Récent dans le Nord-Est et le Nord de Taïwan : approche technologique des assemblages céramiques du site de Chiwulan (Ilan, Nord-Est de Taïwan, 650–1850 EC)*. Nanterre: Université de Paris Nanterre. PhD.

Chapter 5
Technical Skills

From a technological perspective, studies focusing on skills are mainly related to the nature of skills and the characterization of the degree of expertise. They are presented here so that the results obtained can be used by technologists for the anthropological interpretation of technical traditions.

Studies of the nature of skills are, on one hand, related to the skills involved in forming with RKE (wheel throwing and wheel coiling) and, on the other hand, in forming without RKE (modeling and molding). The skills involved in forming techniques have been more widely studied than those involved in the other stages of the *chaîne opératoire*, as they require the progressive learning of specific motor and cognitive skills. They are thus a remarkable marker of learning niches and networks for characterizing social groups as well as technical changes. In this way, archaeological case studies indicate that their transmission may have occurred over long periods of time, which allows for the identification of well-defined social groups and, in the case of historical continuity, for the identification of ethnolinguistic groups by analogy with contemporary roughout techniques (Mayor 2010).

Research on the expertise theme addresses the question of skill variability through markers significant of manufacturing difficulties, execution awkwardness, or motor habits. These markers aim to assess indirectly the skill investment, the rate of ceramic production, or the organization of craft production.

5.1 The Nature of Skills

Before presenting studies of the skills involved in ceramic forming, let us first of all recall the definition of technical skills proposed by specialists in the domain, that is, experimental psychologists. According to them, technical skills are expressed by action and can be defined as the capacity of a person to reach a goal through the control of the mechanical constraints of the technical task through working postures and movements (Reed 1988; Bril 2002; Bril et al. 2012). They correspond to

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behavior acquired by learning (Bril 2002). In order to characterize the skills of craftsmen who have long since disappeared, the study procedure is the following. First of all, ancient objects are interpreted in terms of fabrication techniques with reference to experimental studies (see Chap. 3). Then, the skills involved in the fabrication techniques are studied in actualist situations following the principles of movement and cognition sciences. To do this, analogous techniques still in use today, that is to say, techniques with the same physical principles as ancient techniques, are taken as case studies. The acquisition of skills and of their nature is then analyzed using a protocol that identifies cultural distinctiveness and universal functioning, given the biobehavioral constraints imposed by the techniques and by our organism. The reference to universal functioning allows for the identification of regularities and thus, by retrodiction, for the interpretation of ancient fabrication techniques in terms of skills.

The protocols of skill studies are designed within the framework of fieldwork experimentation defined as follows by Bril (Roux et al. 1995; Bril et al. 2005). Field experimentation constitutes a compromise between laboratory experimentation and the observation of daily life situations. It involves the construction of an experimental situation that is based on tasks and environments that are familiar to the subject. The methodology, which is inspired by experimental psychology, must allow rigorous control of the parameters involved. It must permit a resolution of the dilemma presented by the combination of laboratory analysis and the natural context. In the first case, the following question is asked: to what degree can we generalize the results obtained from simple tasks that are completely devoid of all cultural meaning to real situations in daily life? In the second case, the daily life situations are characterized by the great diversity of factors involved. This makes it difficult, if not impossible, to individualize the different underlying mechanisms through observation alone. The goal of field experimentation is thus to associate the advantages of the two types of situations (field and experimentation) while trying to minimize the disadvantages and biases.

The general methodological principles that must be applied to the study of technical skills are recalled below:

- Studying the skills involved in the fabrication of objects excludes the possibility of relying on indigenous discourse reporting the difficulties involved, either from a potter or an experimenter. In both cases, the discourse is introspective; the person recounts what he/she thinks of the skills involved. These accounts have an *emic* interest regarding the perception of the tasks by the people involved, as this can vary according to experience and the context. On the other hand, they cannot be used to characterize the studied skills. The weakness of indigenous discourse in the scientific study of a phenomenon was shown at the beginning of the twentieth century. After this observation, experimental psychology began to develop. In human sciences, this position is not necessarily unanimously recognized. For example, according to the principles of participative ethnology, the involvement of the ethnologist in the studied facts is said to guarantee a better comprehension of these facts. This approach is part of the postmodernist and hermeneutic framework for which the validation of explanations of the studied phenomena is not necessarily empirically verified (for a critical analysis of participative ethnology, see, e.g., Olivier de Sardan 1988).

- Studying the learning and the nature of technical skills, as well as the relationship between the different learning stages and development of the child, requires collaboration with researchers working in this domain (Roux 1997, 2012). This is an epistemological necessity as objects do not speak for themselves and cross-cultural regularities must be constructed by distinguishing between factors attributable to culture (observation context) and universals (invariants). So how can we explain that collaborations are only rarely involved in the study of technical gestures, giving rise to rather unsatisfactory results, generally suffering from the absence of a proven methodological framework (Bril 1984, 1991, 2011)? For life science researchers, these results are indeed rather unsatisfactory, knowing that ethnographic observations alone are in no case sufficient for evaluating complex phenomena such as motor activities in general, and technical expertise in particular. This dissatisfaction is not always understood by human sciences which have devoted little work to human motor activities and still less to methodological reflections that have nevertheless been in progress for quite some time (Bril 1984; Grenier et al. 2001; Bril and Goasdoué 2009). Moreover, when this question is addressed, analysis is largely inferior to what we could expect (i.e., Warnier 2001), in spite of the conceptual and methodological progress of the "sciences of movement" since the pioneering works of Marey. However, it was as a result of close collaborations between human sciences and life sciences that the mechanisms explaining learning durations for technical activities, such as wheel throwing or stone knapping, were understood (Roux and Corbetta 1989; Roux et al. 1995; Bril et al. 2012). In particular, these collaborations enabled the study of elementary gestures, their sequencing, and the importance of their control for the expertise of craftsmen. Without these collaborations, only part of the "course of action" (sequence of gestures) was observed, which considerably biased the understanding of learning processes as ultimately, it became clear that technical control is above all the control of elementary gestures requiring frequent repetition and long years of apprenticeship. In contrast, the control of the "course of action," and thus of the method, is rapid and is directly related to the control of elementary gestures (Roux and Bril 2002a).

The Skills Involved in Wheel Throwing

The study of the skills involved in wheel throwing is part of the many questions raised by the emergence of this technique, its adoption, diffusion, or non-borrowing. It consisted in understanding the differences in learning durations between techniques using RKE and the others; the first take about 10 years whereas the second take 2–3 years, based on a study of the motor abilities involved in controlling the functional mechanical constraints of each family of techniques. In the first case, these constraints are related to the use of RKE combined with muscular pressure and limited for the second to applying these pressures (see Chap. 2).

This study involved field experimentation. It was carried out in India in collaboration with a researcher in experimental psychology (Roux and Corbetta 1989). The studied techniques were wheel throwing and coiling. The wheel throwing study involved on one hand a descriptive analysis of the gestures used for the production of the range of vessels learned during the course of apprenticeship and, on the other hand, psychomotor tests to evaluate the technical abilities deemed necessary for forming a recipient using RKE.

During the first stage, the investigation protocol consisted in asking 30 child and adult potters from the town of Uttam Nagar (New Delhi), divided into five stages of learning (6 people per stage), to make three copies of different vessels associated with each stage of apprenticeship. These are, for the first two stages, small dishes, for the next two stages, 10 and 20 cm tall flower pots, respectively, and for the last stage, 30 cm high flower pots. The whole production process was continuously filmed. The aim was to characterize the bimanual strategies developed during each stage using a descriptive grid taking into consideration the different forming stages, learning stages, the type of pot, and the structural and functional organization of the gestures (see Chap. 2 and Fig. 5.1). All the finished products were conserved for dimensional analysis.

The results (Fig. 5.2) showed that learning stages 1 and 2 are characterized by symmetric arm activity (the forearms are in symmetry in relation to the wheel rotation axis), by the implementation of bimanual complementarity in relation to the respective roles of each hand, as well as by the development of unilateral bimanual control (one hand is used to support whereas the other hand applies constant thumb/index thinning pressure). The difficulty raised by the acquisition of the ability to change from local thumb/index pressure to pressure in movement marks the passage from the first to the second stage. The following stages (3 and 4) are characterized by the development of bimanual bilateral control: on one hand the left hand develops stability by participating with the right hand in centring, hollowing, and thinning; and on the other hand, both hands must be able to produce a slow and regular movement to the right of the wheel rotation axis. This asymmetrical operation in relation to the wheel axis, with both hands active, represents the main difficulty involved in moving from the second to the third stage. The last stage is not characterized by new bimanual strategies but by the ability to apply strong pressures (centring large lumps of clay) and to modulate them according to pot dimensions and the technical operations.

In a second step, the study protocol consisted in evaluating the specificity of the motor abilities developed during the course of wheel throwing apprenticeship by conducting psychomotor tests on a population of potters and non-potters. The potters were made up of 30 people, children, and adults, divided into five apprenticeship stages. The non-potters included 30 individuals divided into age classes (8, 10, 12, and 14 years, adults).

Four perceptual motor tests were developed to measure the two main motor abilities required for mastering the wheel throwing technique: (1) maintaining the fore-

Fig. 5.1 Structural and functional organization of the gestures: (**a**) symmetric forearm movement and bimanual undifferentiated activity of the hands; (**b**) symmetric forearm movement and bimanual combined activity: one hand is active and the other one is passive, acting as a support; (**c**) asymmetric forearm movement, and bimanual combined activity of the two hands, one active and the other one acting as a support; (**d**) asymmetric forearm movement and bimanual combined activity of the two hands which are both active

arms in a stable position and (2) producing and maintaining constant pressures (Fig. 5.3).

1. Test of simultaneous symmetric pressures. *Aim*: to evaluate the ability required for successful centring, i.e., the simultaneous application, on each side of the wheel rotation axis, of horizontal symmetric pressures with both arms. *Description*: exerting pressures on plastic pears connected to Jacquet manometers and located on either side of a mortar positioned on the motionless wheel.
2. Test of simultaneous symmetric pointings. *Aim*: to evaluate the ability required for RKE forming, i.e., simultaneously maintaining both forearms firmly on

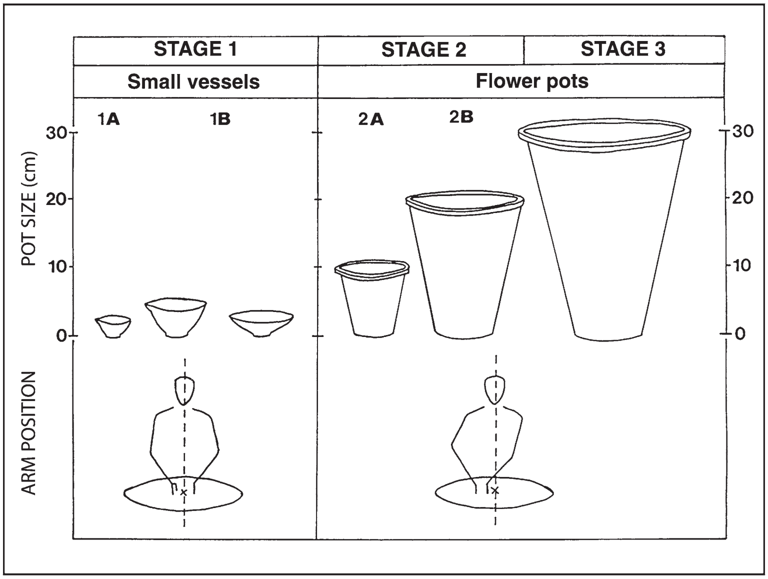

Fig. 5.2 Learning stages 1 and 2 are characterized by the implementation of bimanual complementarity in relation to the respective roles of each hand; the stage 3 is characterized by the implementation of an asymmetrical movement of the forearms in relation to the wheel axis (after Roux and Corbetta 1989, Fig. 1, p.16)

Fig. 5.3 Perceptual motor tests designed to assess the specificity of the motor abilities developed during the course of wheel throwing apprenticeship

either side of the wheel rotation axis so that they are not drawn away by the motion of the lump of clay. *Description*: holding a red marker in one hand and a black marker in the other and simultaneously keeping, on either side of the axis of rotation of the wheel while it is in motion, the two felt tips poised on a white sheet of paper affixed to the center of the wheel.

3. Test of asymmetric pointings. *Aim*: to evaluate the ability required for hollowing and thinning, i.e., keeping a steady hand at some distance from the wheel rotation axis while the other hand carries out a regular lateral displacement starting from the center of the wheel toward the steady hand. *Description*: on a sheet of paper affixed to the center of the rotating wheel, maintaining a red marker in place with one hand and moving a black marker with the other hand from the center toward the exterior.
4. Two-handed test of combined pressure in pointing. *Aim*: to evaluate the ability to maintain a stable position with one hand and a constant pressure with the other, necessary for the thinning of small dishes and learned during the first stage of apprenticeship. *Description*: apply pressure with the thumb and index finger on plastic pear connected to Jacquet manometer with one hand and with the other maintain a black marker in place on a sheet of paper stuck in the center of the rotating wheel.

The results obtained on populations of potters and non-potters (Fig. 5.4) highlighted that the motor abilities acquired during the course of wheel throwing learn-

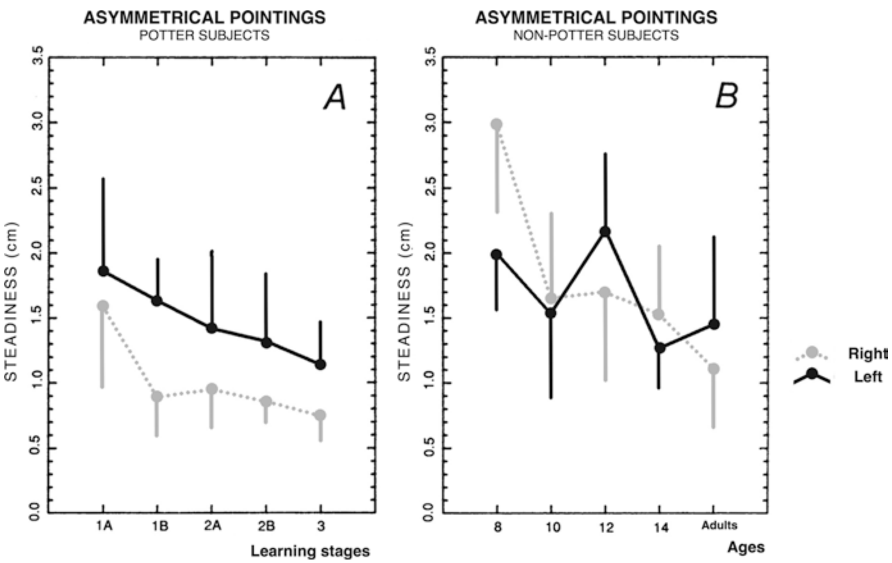

Fig. 5.4 Example of the results obtained with the perceptual tests: evolution of the steadiness of each pointing hand (means and standard deviations) as a function of learning stage for potters (panel A) and as a function of age for non-potters (panel B) (after Roux and Corbetta 1989, Fig. 7, p.64)

ing are specific and not mastered by populations who do not practice wheel throwing. These motor abilities comprise forearm stability, specialization of the hands, control of bimanual activities conducted in asymmetry in relation to the axis of the body, and controlling pressure combined with the rotation movement. These motor abilities are necessarily acquired progressively and thus slowly, like any elementary movement for which control, regardless of the technical activity, always takes much longer to acquire than that of the method (Bril et al. 2005). This obligatory progressive acquisition of the elementary movements explains why it takes practically 10 years of apprenticeship to master this technique. This duration seems to be a golden rule for many other motor and/or cognitive activities (Ericson and Lehman 1996).

In addition, a comparison with the motor skills developed for the coiling technique showed that the mastery of pressures exerted without the help of rotary kinetic energy (RKE) is considerably easier and is acquired rapidly. Gestures are organized around a single parameter – the moving hand – whereas the pottery remains immobile. Moreover, they are similar to gestures performed naturally right from childhood and in many domestic activities (Fig. 5.5). Therefore, the difficulty does not reside in the acquisition of the gestures but mainly in the ability to juxtapose the coils following the desired alignment in order to obtain the sought-after shape. In other words, the functional mechanical stresses related to the coiling technique are much less complex than those related to wheel throwing. As a result, the regulation parameters of these constraints are easier to control. This facility explains the fact that only 2 to 3 years of apprenticeship are required for coiling as opposed to 10 for wheel throwing.

The results obtained with wheel throwing can be generalized to all the techniques using RKE, such as, wheel coiling. The main difficulty with mastering wheel

Fig. 5.5 Teenagers learning how to make earths (Haryana, India)

throwing is indeed related to the control of the mechanical stresses imposed by the use of RKE. In order to evaluate the differences in skills between wheel throwing and wheel coiling, field experimentation was conducted in Spain, in the province of Zamora with potters practicing wheel throwing and wheel coiling (Gelbert 1997). The results indicate motor skills shared by all potters. These are related to controlling thinning and shaping with RKE, that is, to master the abilities whose apprenticeship durations differs between forming with and without RKE.

In brief, the periods of apprenticeship required for mastering wheel fashioning and coiling are radically different, not given cultural factors, but because of major differences in the mechanical constraints involved in each technique. Consequently, this result can be considered as cross-cultural and applied to ancient situations.

First of all, this finding allows us to consider that, in an archaeological assemblage containing equivalent functional types, vessels produced with and without RKE correspond to two distinct groups of craftspeople with different sets of skills.

Secondly, this result allows us to consider that assemblages comprising vessels formed with RKE were made by specialized craftspeople, namely, artisans whose ceramic production exceeded their own needs. In a context of multiple socioeconomic tasks, techniques involving a long apprenticeship, such as those based on mastering RKE, cannot be indeed practiced by all the individuals of a community; they are thus necessarily specialized, i.e., practiced by a subgroup of individuals who make objects consumed by the village or regional community (Roux 1990). This context is found from Neolithic periods onward where the multiplicity of tasks practiced by the group implies that it is impossible for each individual to learn and practice all of them (agricultural tasks, construction, multiple crafts [stone, ceramic, wood, etc.]).

Lastly, this result implies that the transition from coiling to wheel fashioning can be considered as the sign of a major change, either within the society (Roux 2003a) or a change in populations (Roux 2009, 2015), given that both techniques require radically different skills necessarily transmitted within distinct learning networks.

The Skills Involved in Modeling and Molding

Modeling and molding are two techniques involving different forces; pressure for the first and percussion for the second, either with or without a tool (see Chap. 2). The skills involved in these two techniques were studied by Gelbert (2003) (Fig. 5.6). The author sought to evaluate the difficulties involved in switching from one technique to the other in order to better understand the adoption of molding by potters originally using the modeling by drawing technique.

Field experimentation on this issue was conducted in Senegal with a focus on the difficulties raised by shifting from a *chaîne opératoire* based on modeling by drawing to a *chaîne opératoire* based on molding.

First of all, the shaping gestures involved in each of the *chaînes opératoires* were compared, in order to assess the variations in the repertoire of gestures of both communities of potters practicing modeling and molding, respectively. In order to

Fig. 5.6 Roughing-out techniques in the Senegal River valley: (**a**) modeling by drawing; (**b**) convex molding (Senegal, ©A. Gelbert 2003)

do so, seven potters using modeling by drawing (four) and molding (three) were video filmed. Each potter had to make three series of small-, medium-, and large-sized jars. Their only instructions were to apply their usual forming sequence. All the gestures were analyzed using the technological analysis grid presented in Chap. 2, that is, the position of the arms in relation to the axis of the subject, the functional organization of bimanual collaboration (combined or undifferentiated activity), the forces involved in describing the course and direction of the applied pressure, and the type of pressure applied to the clay (continuous or discontinuous). The results show that both *chaînes opératoires* share a set of gestures including forming and finishing gestures: percussion gestures (used for thinning modeled as well as molded roughouts) and brushing, shaving and smoothing gestures applied to leather-hard modeled and molded preforms. The gestures specific to each tradition are related to the position of the coils used for forming the upper body, thinning by scraping, rim finishing, and decoration.

Secondly, experimentation was carried out with four potters using modeling by drawing in order to evaluate any potential difficulties in adopting molding. Each potter had to make two jars using molding. After a description of the elementary gestures and being shown photographs, the potters were guided by oral indications throughout the sequence. No instructions were given for posture. The eight sequences were video filmed. Motor difficulties were evaluated during task implementation and based on the finished products. These difficulties were revealed either through accidents during the forming sequence (collapse of walls, cracking, etc.) or through end products that did not conform to the usual morphological criteria.

The final results showed that the transition to convex molding technique did not involve any motor difficulty, as potters using the modeling by drawing technique mastered the percussion and finishing techniques involved in molding. On the other hand, coiling the upper body presented difficulties as this required types of pressure that potters were not used to applying.

Gelbert concluded that the ease of acquisition of the skills involved in molding is one of the factors (comprising the fabrication speed) contributing to the adoption of the molding technique by potters formerly practicing modeling by drawing.

5.2 Expertise

When finished products are studied as the material expression of technical skills, the issue is not the nature of skills acquired during apprenticeship, but skill variability and the degree of expertise developed by the craftspeople, that is, their ability to produce elaborate, quality, or standardized objects. The evaluation of skill variability and the degree of expertise of craftspeople pave the way to rich fields of interpretation, including the ways production and transmission were organized.

Mechanical Constraints and Expertise

The starting point is that there are different degrees of execution difficulties depending on collapsing risks during the forming process (Rice 1984; Caiger-Smith 1995; Budden 2008). These risks appear to be directly linked to ceramic shape and size; some ceramics would be “easy” or “difficult” to make, with the degree of difficulty indicating the artisan’s degree of expertise. However, how can we measure the mechanical stresses denoted by the vessels? And how can we evaluate the link between mechanical stresses and the difficulty in making a recipient?

A recently proposed index for measuring the mechanical stresses present in the vessels produced is the Von Mises index borrowed from the modeling of structures such as dams, bridges, and boats. Gandon showed its relevance for evaluating the production difficulties of ceramics depending on their shape (Gandon et al. 2011).

Continuing on from an earlier work proposing a classification of wheel-thrown ceramic shapes according to how difficult they are to produce (Roux 1989), a new study was conducted with the aim of measuring wheel throwing difficulties, taking into consideration the global geometry of the object, and developing a method which can be applied not only to standard shapes but to all the ceramic shapes found in archaeology (Gandon et al. 2011).

In order to evaluate the variations of mechanical stresses according to recipient shape, mass, and clay properties, a model was developed based on the finite element method. This modeling method is commonly used in mechanics to predict structure collapse. Three elements were taken into consideration: the geometry of the object (exterior contour and thickness), the density of the clay (volume mass), and a mechanical behavior law (Young's modulus and Poisson's ratio) relating stresses operating in and on the object to the object's deformations.

The geometry of the object was measured on wheel-thrown recipient 2D profiles, which are theoretically symmetrical. The density of the material was characterized (1.95 g/cm^3). Clay reactions were modeled for a wet state, which is necessary for throwing a pot. The mechanical stresses (radial and axial traction-compression, and shearing) present in a recipient under its own weight at the end of throwing were calculated and then summarized with the Von Mises index, a classically used index for calculating the resistance of ductile materials. In order to find out the Von Mises index for a given recipient, the external profile and wall thickness are digitalized and then incorporated into a finite element structure calculation software.

In order to test the link between the mechanical stresses of a given recipient and the difficulty involved in making it, that is, in order to test the validity of the Von Mises index for evaluating the potters' level of skill, experiments were conducted with 11 French potters. The instructions were to reproduce five specimens of four shapes (cylinder, bowl, sphere, and conical vase) corresponding to different levels of difficulty according to the classification established by Roux (1989). Each of the four shapes was replicated with two weights of clay (0.75 and 2.25 kg). In this way, each potter made a total of 40 pots, for 8 distinctive experimental conditions. The aim was first to analyze the differences between the profiles' geometries of the models and those of the experimental pieces. The second step was to compare the levels of mechanical stresses (synthetized by the Von Mises index) of the models with those of the reproduced pots. We were then able to assess whether the geometry differences depend on the mechanical stresses, and thus whether these latter reflect execution difficulties.

All the experimental sessions were video filmed, and images of the experimental vessels were extracted for further analysis. Recipient thicknesses were measured from the photographs of cut vessels at four levels. The analysis took account of three dependent variables describing the vessels: absolute dimensions, relative dimensions (i.e., proportions), and the Von Mises index. Deviations from the models were calculated for the relative dimensions and mechanical stresses. In both cases, deviations from the models were calculated by taking account of the difference between reproductions and models.

The results demonstrate that reproductions reveal subtle but systematic geometrical deviations from the model shapes that allowed lowering the mechanical stresses. More difficult shapes show larger degrees of mechanical optimization (Fig. 5.7). The results obtained with the Von Mises index confirm and refine thus the analyses of wheel throwing difficulty based on the techno-morphological taxonomy

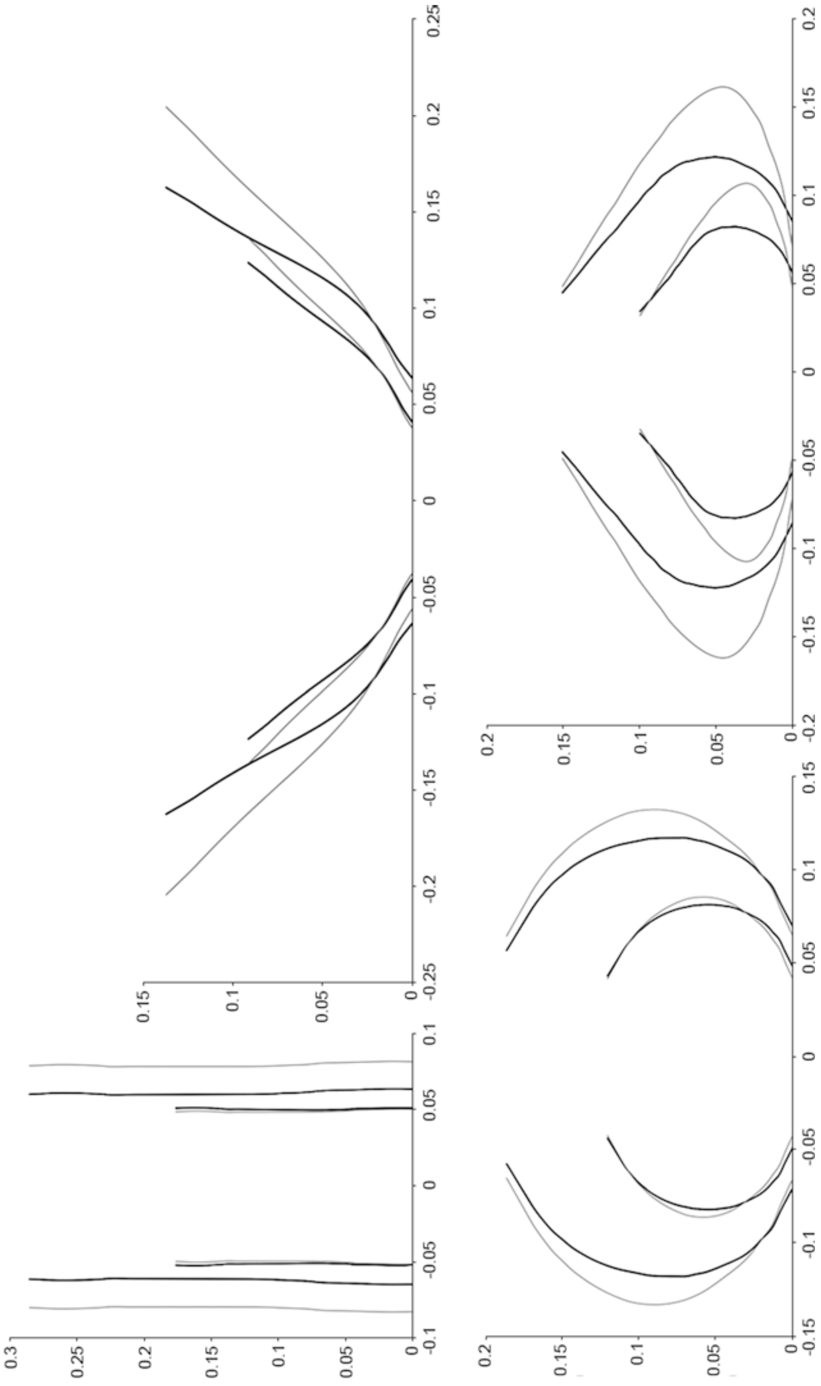

Fig. 5.7 Graphical representation, with scale in m (1/1 m), of model (gray) and average thrown vessels (black) for each of the four forms and two clay masses (after Gandon et al. 2011, Fig. 4)

of Roux (Roux 1989). By including both shape and mass at the same time, the Von Mises index facilitates an inter-classification of the vessels made under eight experimental conditions. The mechanical analysis of models indicates that large cylinders are more difficult to make than small cylinders, but less difficult than small spheres. The difficulty involved in making the small sphere is similar to that of the small bowl. The large sphere is more difficult to make than the small bowl, whereas the throwing difficulty of the latter is comparable to that of the small vase. The large vase is the most difficult piece to make. Therefore, each experimental shape presents different levels of mechanical stresses which induce varying levels of difficulty during their reproduction. The mechanical analysis of experimental pieces shows systematic deviations from models contingent on their mechanical stresses: these are always oriented toward mechanical optimization.

Overall, these results show that the Von Mises index is a pertinent index for measuring the mechanical stresses present in a wheel-thrown vessel as a result of its own weight and that these mechanical stresses induce varying throwing difficulties. The link between mechanical stresses and throwing difficulties has been demonstrated by the analysis of experimental pieces for which the geometrical deviations (from the models) systematically limit risks of collapse. This enables us to consider the Von Mises index as an index of throwing difficulty. It should allow us to assess the degree of skill developed by artisans when applied to archaeological assemblages.

The Von Mises index is applicable to all vessels made with RKE, including those that are wheel-coiled. This latter technique implies homogenization of the walls with comparable additions of water to those required for wheel throwing. Consequently, at the end of the process, the recipient presents the same risks of collapse.

The Von Mises index can be used for vessels made without RKE but should be weighted. Indeed, the walls clearly contain less water, and the risk of collapse is thus not so high. In addition, these risks can be limited by intermediate drying phases.

In the future, other parameters could be taken into account for a more overall vision of the difficulties involved in vessel making. It is clear that risks of collapse (measured by mechanical stresses) are an essential aspect, but other factors, such as the application of atypical gestures (and therefore less mastered), could also play an important role, particularly for complex shapes.

Skill Variability and Degrees of Skill

When ceramic assemblages reveal skill variability, one issue is whether this is a result of different degrees of skill, apprentices, and/or children (Crown 2001, 2014; Minar and Crown 2001). One of the irrefutable criteria for identifying fabrication by children on clumsily made vessels is the presence of imprints whose size distinguishes between fingerprints left by children or adults (Kamp 2001). Other criteria are related to the manufacture quality of pieces on one hand, and decoration, on the other (Crown 2001). These criteria are technological variables for examination of skill variability. A list of 12 key technological variables was established by Budden (Budden 2008) for the analysis of ceramics made without RKE (Table 5.1). This list raises the question of the distinction between productions made by low skill artisans and productions made by apprentices. The answer is to be found in the archaeological context.

In the case of a ceramic assemblage where all the pieces present defects, these cannot be attributed to apprentices, but to the low skill investment of the group in question.

In the case where only some functional categories present defects, then depending on the functional categories and defects, it can be possible to attribute them to apprentices. These cases generally occur on small pieces, or on a specific technological variable, such as decoration, for which quality can be evaluated by examining the mastery of drawing. When discrepancies occur between forming

Table 5.1 Twelve key technological variables for examination of skill variability (after Budden 2008)

Technical operations	Observations
Preparation of clay material	Voids in the clay matrix significant of poor wedging, surface voids, or inclusions (detritus) *unintentionally* breaking the finished surface of the pot, poorly sorted temper through the clay matrix
Manufacturing	Splitting at the rim; uneven finger indentations; poor coil/slab joins; coil/slab join fractures; clay patches as additions to improve wall thickness, rim evenness, or support handles and lugs; fracturing of the clay surface; inappropriate weight for vessel form
Wall thickness	Inappropriate wall thickness for the vessel form, e.g., too thin or too thick
Additions	Incorrect vertical or horizontal alignment. Additions such as handles that are either poorly formed or inappropriately attached may be strengthened by an additional patch of clay used to prevent slumping of the handle form or breakage once in use
Inner surface treatment	Variability in the degree of wiping, smoothing, coating, or burnishing
Outer surface treatment	As above
Decoration	Incised lines being "rubbed out" and then repeated. Decoration overshooting the design area. Applied decoration being inadequately bonded to the pot surface.
Rim deviation on the horizontal plane	Degree to which the vessel rim circumference is even on the horizontal plane
Rim symmetry	As above but measurement of the rim circumference seen from a plan view. Smaller- to moderate-sized pots can be assessed against a rim circumference chart
Handle symmetry	Alignment of the handles in relation to the vertical or horizontal axis of the recipient and in relation to other handles, when present
Profile symmetry	Asymmetry revealing poor control during forming
Firing	Overfired or underfired recipient revealing poor control of firing procedures

quality and the quality of decoration, with, for example, very well-mastered manufacturing techniques and, conversely, very awkward decoration, then it is possible to envisage the intervention of different actors for these two actions: experts for the first and apprentices/children for the second (Crown 2001, 2007). However, this interpretation should be weighted depending on whether all the ceramics or a subset of the assemblage are decorated. In the latter case, the poor mastery of drawing can be related to a lack of practice (drawing only rarely), regardless of the skill investment of the artisans in the ceramic production.

Note a case study where awkward ceramic funerary replicas, in reduced format, were found in association with children's burials. The poor mastery of the pieces correlated to the size of the vessels prompted the author to interpret them as vessels made by children for this exceptional burial event (Colomer 1995).

Lastly, diachronically, an in-depth study of skill variability and their correlation with *chaînes opératoires* can lead to the characterization of ways of doing with defects transmitted from one generation to another, and consequently, to the identification of potter lineages in charge of ceramic production.

That is how Vitelli (Vitelli 1989, 1993) examined the first ceramics from Franchti (Greece) in this way. Five techno-petrographic groups were identified on the basis of clay composition, finishing methods, prehensile elements, bases, rims and cooking modalities (leading to diverse states of oxidation or reduction). These techno-petrographic groups are present in other sites and lasted for several generations. In this respect, they do not correspond to random variability and suggest the existence of distinct lineages maintaining and perpetuating their own ways of doing over several generations.

It is important to point out that, in general, assemblages present few specimens with apprentices' defects. This can be explained by the possible recycling of vessels with anomalies, as well as by the transmission process, which generally entails supervision of how the apprentice is to gradually master the different technical tasks (Crown 2001; Kamp 2001). Indeed, investigations of the different technical actions, in contrasted cultural areas, have led to the observation that similar principles govern a sort of apprenticeship schedule of technical gestures, independently of the sociocultural context of the technical task (Roux and Bril 2002b). Given this apprenticeship schedule, the pieces made by apprentices are less visible. The principles underlying this schedule take account of the fact that the child must simultaneously assess:

1. The properties of the human body (which vary with age).
2. The properties of the tool, but also of the object on which the motor activity is exerted.
3. The properties of the motor task making the tool, the object, and the body interact.

The discovery of these properties by the learner is organized depending on the difficulty of the task. The apprenticeship stages are controlled by genuine work organization, leading the child to progressively acquire the required motor capacities to master the task (as described above for wheel throwing apprenticeship).

The transition from one apprenticeship stage to another is controlled by evaluating the finished products, which reveal the capacities developed by the child and thus indicate the sought-after goal. The intervention of the elders in the temporal organization of the apprenticeship is implicit but always follows the same rule: the succession of the proposed activities involves increasing complexity, and the transition to a higher stage, marked by the production of new objects or new technical operations, only occurs once the task from the previous stage has been mastered.

In an artisanal context, this rule gives a market value to apprentices' products in the same way as products made by experts. Thus, apprentices' productions can also be marketed in commercial networks. In this way, all the small lamps made in India by adults as well as by 10-year-old children, with just 1 or 2 years practice, are sold during the Festival of Lights (*diwali*). The whole Hindu population buys them, and the number of lamps sold in a single town can reach several hundred thousands. In other words, apprentices are never placed in a situation of failure with economic repercussions and make products with "functional" qualities, making them difficult to distinguish from objects made by accomplished potters.

In-depth studies should, in the future, make it possible to test the general way in which a social group introduces descendants to a progressive, controlled apprenticeship adapted to their development on one hand, and to the economic survival of the group, on the other.

Skill Variability and Individual Signatures

When ceramic assemblages reveal skill variability, the other issue is whether it expresses individual signatures. In archeology, interpreting morphometric variability in terms of number of individuals can provide supplementary information on the social organization of the production – domestic *versus* specialized production, size of the workshops, socioeconomic status of the potters, and distribution network.

As shown by a recent study (Gandon et al. 2018), potters develop individual motor skills leading to both low intraindividual and significant interindividual variations in ceramic morphometric traits. Such a development of individual motor skills, even within the same cultural group, leading to minor variations in shapes is directly related to the learning process. As evoked before, learning elementary movements can be viewed as an adaptation to the constraints of the individual, the task, and the clay material (Newell 1986; Reed and Bril 1996; Bril 2015). This process takes place under the guidance of a tutor, which imprints a cultural mark on motor behavior (Bril 2002; Gandon 2014). However, this cultural influence is not completely dominant. In fact, the role of the tutor is only to guide the novice. Executing a technical movement implies a mixture of common and individual strategies (Reed and Bril 1996; Parry et al. 2014; Rein et al. 2014). This explains that, despite belonging to the same learning niche, potters produce traditional ceramic shapes whose morphometric variability may correspond to individual signatures.

Highlighting individual signatures within standardized assemblages is possible with fine analytical tools. A study led in India (Roux and Karasik 2018) has consisted to first examine an ethnographic assemblage (2D images of jar silhouette) comprising 171 water jars made by 7 potters. The profiles of the upper part of the water jars were analyzed as planar curves represented by three mathematical functions – radius, tangent, and curvature (see Chap. 4). The classification started by measuring the distances between any pair of vessels in terms of the corresponding mathematical representations and summarizing them in a distance matrix. Cluster analysis was then used to reveal the inner variability of the assemblage and investigate groupings. The resultant cluster tree shows five subbranches indicating the production of five potters, therefore suggesting that profiles of the upper part of vessels, the ones that we measured, could possibly reveal individuals' signature and therefore the number of artisans involved in the variability of standardized ceramic assemblages. We applied the same analysis to a higher number of standardized water jars, 505, made by 18 potters. In this case, the resultant cluster tree does not always associate one subbranch with one production. However, it shows more numerous subbranches which amount in this case to 10. We concluded that, even within a standardized assemblage, there is a variability in the profiles which is the result of the number of the potters involved; the more potters, the more subbranches.

Further researches have now to be developed. In particular, 3D data could help to highlight interindividual variability better.

Motor Habits and Standardization

The morphometric standardization of ceramic vessels is a particularly significant marker for evaluating the intensity of ceramic productions, and, correlatively, the degree of craft specialization (Benco 1988; Longacre et al. 1988; Costin 1991; Rice 1991; Costin and Hagstrum 1995; Stark 1995a, b; Longacre 1999; Costin 2000).

The correlation between morphometric standardization and the intensity of ceramic production has been addressed by several ethnoarchaeological studies, which have raised the question of the different parameters affecting intra-type morphometric variability (Arcellin-Pradelle and Laubenheimer 1982, 1985; London 1991; Longacre 1991; Arnold and Nieves 1992; Kvamme et al. 1996).

As a result, at the present time, benchmark data exist for measuring production intensity and, indirectly craft specialization, in relation to the degree of standardization (Roux 2003b), with the understanding that production intensity affects motor skill patterns and thus the degree of standardization (Fig. 5.8), and can be correlated to different degrees of craft specialization (Fig. 5.9).

The procedure for obtaining benchmark data on the degree of standardization in relation to production intensity was the following. Investigations were carried out in India in areas where it was possible to vary the production rate parameter, given identical manufacturing techniques, and dimensional categories. These investigations were conducted in the south (Andhra Pradesh), where annual production rates

Fig. 5.8 Mass production of vessels in northern India (Uttar Pradesh)

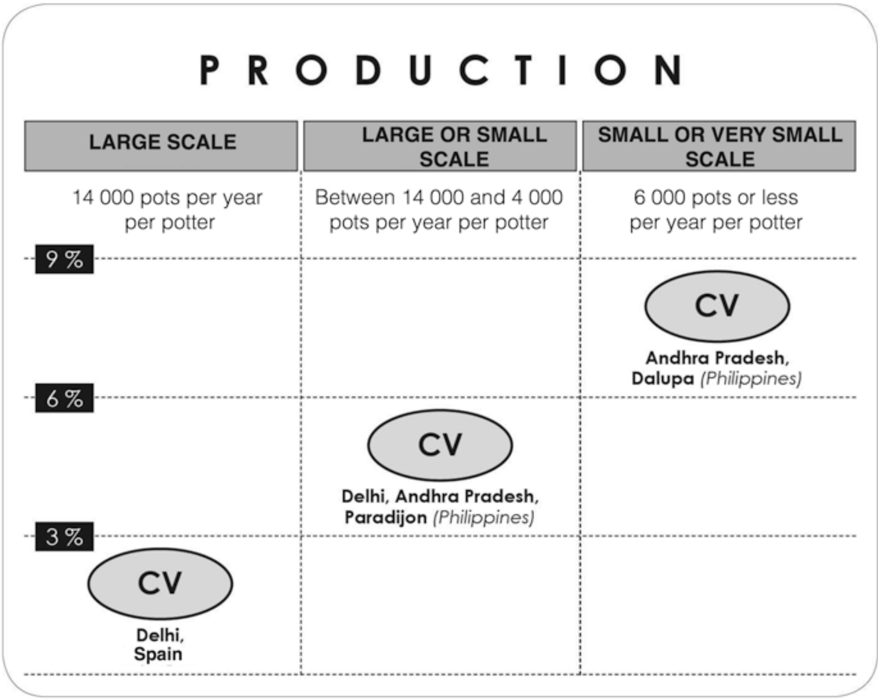

Fig. 5.9 Coefficients of variation (CV) of ceramic assemblages made up of less than ten production events. In archaeological situations, the cumulative effect of the intra- and intergroup variability should not be underestimated, and the CVs have to be weighted (after Roux 2003, Fig. 8, p.780)

are not high, with about 6000 vessels per potter, and in the north (Uttam Nagar, New Delhi) where, conversely, annual production rates are high with 15,000 vessels per potter. In both regions, vessels are wheel thrown and then paddled. In the south of India, dimensions were recorded for a total of 437 vessels, distributed across three-dimensional categories, made by six potters, and for a total of 180 vessels of the same size for the north of India, made by six potters. The dimensions taken were the height, maximum diameter, rim diameter, rim width, rim, and wall thickness. Their variability was analyzed for each pottery production in order to test the hypothesis that if the production rate affects motor skill patterns, then the vessels made by potters with the highest production rate should be the most standardized. Inter-potter variability was computed using variance analysis (ANOVA). The results underwent a posteriori statistic tests (the Scheffé and Games-Howell tests) that are very robust with populations that are not normally distributed and are useful for comparing heterogeneous variances on small samples. Intra-potter variability was calculated on the basis of coefficient of variation (CV), which is considered as the standard statistic in studies of variation and therefore as an excellent measure of standardization (Eerkens and Bettinger 2001).

The results show that inter-potter variability exists in both low and high production contexts. On the other hand, intra-potter variability is higher for potters with low production; the CV values range between 5% and 9%, and the highest CV corresponds to storage jars, i.e., the least produced vessels. This variability is much lower for potters with high production; the CV values are less than 3%.

These results were then compared to results obtained in different cultural contexts, in order to evaluate the *emic* factor in the normalization of ceramic morphometric characteristics, given that in Southern India, potters vary the dimensions of vessels in relation to family size and that in northern India, potters vary them in relation to the market. The CVs were then compared to the CVs obtained:

- For jugs made by a Spanish potter throwing up to 14,000 pots per year and for whom standardization is the demonstration of his skill (Arcellin-Pradelle and Laubenheimer 1982)
- On coiled and paddled vessels made by Filipino potters, who standardize size using a volumetric unit (about 100 ml), but in three different production contexts: domestic, part-time, and full-time (Kvamme et al. 1996)

The results confirm that very high production intensity, like in northern India and Spain, develops motor skill patterns conducive to obtaining series of vessels with at least two dimensions with CVs of less than 3%. For less intensive productions, like in Southern India and the Philippines, where potters work part-time or full-time, the CV values can vary between 3% and 6%, thereby pointing rather ambiguously to more or less intensive production rates. On the other hand, CVs between 6% and 9% indicate small productions (Fig. 5.9).

In archaeological situations, CVs are higher when they are not related to a single production event (an exceptional case that can occur, for example, with a production found in a kiln), but to multiple production events (productions spanning several years). They are, in all cases, a measurement of the motor skill patterns developed by potters, and from this viewpoint, a relevant measure for evaluating the high or low intensity of production.

These results were applied to Mesopotamian bowls found in Tell Leilan and in sites in the north of Mesopotamia dated to about 2200 B.C. (Blackman et al. 1993). In the first case, large waster stacks of bowls were found, corresponding to a single production event. Twenty-seven of these bowls were examined. Five dimensions were taken: rim diameter, wall thickness, vessel height, base diameter and base thickness. The CVs obtained are less than 10%. If we compare these results with those of ethnographic vessels, these CVs can be considered to be high and reflect rather low production rates. The hypothesis of low production rates is consistent with the CVs from a second series of bowls derived from a context of domestic waste from neighboring sites. These bowls could have been produced over a period spanning approximately 200 years. The CVs are around 18%. The authors interpreted these latter values in terms of non-centralized production. According to the ethnographic framework, the cumulative effect of intra and inter-group variability should not be underestimated: the CV of 18% could correspond to a CV of 9% for a case of single production event. The CVs of both series of bowls would thus display comparable production rates and would in no case represent different forms of production organization.

5.3 Conclusion

The characterization of archaeological ceramics in terms of skills is central to technological analysis: indeed the latter are direct markers of the apprenticeship chains through which technical tasks were transmitted. Consequently, their characterization should bring us closer to the transmission and transformation processes at work in traditions.

The study of skills has given rise to the construction of referentials, whose mobilization already makes it possible to enrich the interpretation of ceramic assemblages in terms of social groups, production organization, or changes in the transmission of traditions. However, there is still room for improvement in order to elaborate a technological approach including the analysis of learnt, invented, and transmitted gestures throughout the ages and across cultures.

References

Arcellin-Pradelle, C., & Laubenheimer, F. (1982). Une mission d'archéo-ethnologie: les ateliers de potiers traditionnels dans les provinces de Valencia et de Castellon (Espagne). *Techniques et Technologie. Sources Documentaires* 5. Institut de Recherches Méditerranéennes, Université de Provence, 27–56.

Arcellin-Pradelle, C., & Laubenheimer, F. (1985). La notion de série de production en céramique tournée. *Techniques et Technologie. Sources Documentaires*. Institut de Recherches Méditerranéennes, Université de Provence, 129–139.

Arnold, D., & Nieves, A. L. (1992). Factors affecting ceramic standardization. In G. J. Bey III & C. A. Pool (Eds.), *Ceramic production and distribution: An integrated approach* (pp. 113–214). Boulder: Westview Press.

Benco, N. L. (1988). Morphological standardization: An approach to the study of craft specialization. In C. Kolb & L. Lackey (Eds.), *A pot for all reasons: Ceramic ecology revisited* (pp. 57–72). Philadelphia: Temple University.

Blackman, M. J., Stein, G. J., & Vandiver, P. B. (1993). The standardization hypothesis and ceramic mass production: Technological, compositional and metrix indexes of craft specialization at Tell Leilan, Syria. *American Antiquity, 58*, 60–80.

Bril, B. (1984). Description du geste technique: quelles méthodes? *Techniques & Culture, 3*, 81–96.

Bril, B. (1991). Les gestes de percussion: analyse d'un mouvement technique. In D. Chevallier (Ed.), *Savoir-faire et Pouvoir transmettre. Transmission et apprentissage des savoir-faire et des techniques* (pp. 61–80). Paris: Editions de la Maisons des Sciences de l'Homme.

Bril, B. (2002). L'apprentissage de gestes techniques: ordre de contraintes et variations culturelles. In B. Bril & V. Roux (Eds.), *Le geste technique. Réflexions méthodologiques et anthropologiques* (pp. 113–150. Technologies/ Idéologies/ Pratiques). Ramonville Saint-Agne: Editions érès.

Bril, B. (2011). Retour sur «Description du geste technique». *Techniques & Culture, 54–55*, 242–244.

Bril, B. (2015). Learning to use tools: A functional approach to action. In L. Filletaz & S. Billet (Eds.), *Learning through and for practice: Contributions from francophone perspectives* (pp. 95–118). Cham: Springer.

Bril, B., & Goasdoué, R. (2009). Du mouvement sans sens ou du sens sans mouvement: rôle des finalités et des contextes dans l'étude des comportements moteurs. *Intellectica, 51*, 27–23.

Bril, B., Roux, V., & Dietrich, G. (2005). Stone knapping: Khambhat (India), a unique opportunity? In V. Roux & B. Bril (Eds.), *Stone knapping: The necessary conditions for a uniquely hominin behaviour* (pp. 53–72). Cambridge: Mc Donald Institute for Archaeological Research.

Bril, B., Smaers, J., Steele, J., Rein, R., Nonaka, T., Dietrich, G., Biryukova, E., Hirata, S., & Roux, V. (2012). Functional mastery of percussive technology in nut-cracking and stone-flaking actions: Experimental comparison and implications for the evolution of the human brain. *Philosophical Transactions of the Royal Society B: Biological Sciences, 367*, 59–74.

Budden, S. (2008). Skill amongst the sherds: Understanding the role of skill in the early to late middle bronze age in Hungary. In I. Berg (Ed.), *Breaking the Mould* (pp. 1–17). Oxford: Archaeopress.

Caiger-Smith, A. (1995). *Pottery, people and time*. Somerset: Richard Dennis.

Colomer, E. (1995). *Pràctiques socials de manufactura ceràmica: anàlisis morfomètriques i tecnològiques al sud-est de la Península Ibérica, 2200–1500 cal ane*. Barcelona: Universitat Autònoma de Barcelona.

Costin, C. L. (1991). Craft specialization: Issues in defining, documenting and explaining the organization of production. In M. B. Schiffer (Ed.), *Archaeological method and theory* (Vol. 3, pp. 1–56). Tucson: The University of Arizona Press.

Costin, C. L. (2000). The use of ethnoarchaeology for the archaeological study of ceramic production. *Journal of Archaeological Method and Theory, 7*(4), 377–403.

Costin, C. L., & Hagstrum, M. B. (1995). Standardization, labor investment, skill, and the organization of ceramic production in late prehispanic highland Peru. *American Antiquity, 60*(4), 619–639.

Crown, P. L. (2001). Learning to make pottery in the Prehispanic American Southwest. *Journal of Anthropological Research, 57*, 451–469.

Crown, P. L. (2007). Life histories of pots and potters: Situating the individual in archaeology. *American Antiquity, 72*, 677–690.

Crown, P. L. (2014). The archaeology of crafts learning: Becoming a Potter in the Puebloan Southwest. *Annual Review of Anthropology, 43*, 71–88.

Eerkens, J. W., & Bettinger, R. L. (2001). Techniques for assessing standardization in artifact assemblages: Can we scale material variability? *American Antiquity, 66*, 493–504.

Ericson, K. A., & Lehman, A. C. (1996). Expert and exceptional performance: Evidence from maximal adaptation to task constraints. *Annual Review of Psychology, 47*, 273–305.

Gandon, E. (2014). To what extent do traditional motor skills reveal a cultural model? Field experiments with expert French and Indian potters. *Annales de la Fondation Fyssen, 29*, 47–68.

Gandon, E., Casanova, R., Sainton, P., Coyle, T., Roux, V., Bril, B., & Bootsma, R. J. (2011). A proxy of potters' throwing skill: Ceramic vessels considered in terms of mechanical stress. *Journal of Archaeological Science, 38*, 1080–1089.

Gandon, E., Coyle, T., Bootsma, R. J., Roux, V., & Endler, J. A. (2018). Individuals amongst the pots: How do traditional ceramic shapes vary between potters? *Ecological Psychology, 31*, 1–15. https://doi.org/10.1080/10407413.2018.1438200.

Gelbert, A. (1997). De l'élaboration au tour au tournage sur motte: difficultés motrices et conceptuelles. *Techniques et cultures, 30*, 1–23.

Gelbert, A. (2003). *Traditions céramiques et emprunts techniques dans la vallée du fleuve Sénégal. Ceramic traditions and technical borrowings in the Senegal River Valley*. Paris: Editions de la Maison des sciences de l'homme, Editions Epistèmes.

Grenier, J. Y., Grignon, C., & Menger, P. M. (2001). *Le Modèle et le Récit*. Paris: Editions de la MSH.

Kamp, K. A. (2001). Prehistoric children working and playing: A southwestern case study in learning ceramics. *Journal of Anthropological Research, 57*, 427–450.

Kvamme, K. L., Stark, M. T., & Longacre, W. A. (1996). Alternative procedures for assessing standardization in ceramic assemblages. *American Antiquity, 61*(1), 116–126.

London, G. A. (1991). Standardization and variation in the work of craft specialists. In W. A. Longacre (Ed.), *Ceramic Ethnoarchaeology* (pp. 182–204). Tucson: The University of Arizona Press.

Longacre, W. A. (1991). Sources of ceramic variability among the Kalinga of Northern Luzon. In W. A. Longacre (Ed.), *Ceramic Ethnoarchaeology* (pp. 95–110). Tucson: The University of Arizona press.

Longacre, W. A. (1999). Standardization and specialization: What's the link? In J. M. Skibo & G. M. Feinman (Eds.), *Pottery and people: A dynamic interaction* (pp. 44–58). Salt Lake City: University of Utah Press.

Longacre, W. A., Kvamme, K. L., & Kobayashi, M. (1988). Southwestern pottery standardization: An ethnoarchaeological view from the Philippines. *Kiva, 53*, 101–112.

Mayor, A. (2010). *Traditions céramiques dans la boucle du Niger. Ethnoarchéologie et histoire du peuplement au temps des empires précoloniaux* (Journal of African Archaeology Monographs Series 7). Frankfurt am Main: Africa Magna Verlag.

Minar, C. J., & Crown, P. L. (2001). Learning and craft production: An introduction. *Journal of Anthropological Research, 57*, 369–380.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor skill acquisition*. Dordrecht: Martinus Nijhoff.

Olivier de Sardan, J. P. (1988). Jeu de la croyance et "je" ethnologique: exotisme religieux et ethno-égo-centrisme. *Cahiers d'Etudes Africaines, 28*, 527–540.

Parry, R., Dietrich, G., & Bril, B. (2014). Tool use ability depends on understanding of functional dynamics and not specific joint contribution profiles. *Frontiers in Psychology, 5*(306), 1–15.

Reed, E. S. (1988). Applying the theory of action systems to research to the study of motor skills. *Advances in Psychology, 50*, 45–86.

Reed, E. S., & Bril, B. (1996). The primacy of action in development. A commentary of N. Bernstein. In M. Latash (Ed.), *Dexterity and its development* (pp. 431–451). Hillsdale: Erlbaum Associates.

Rein, R., Nonaka, T., & Bril, B. (2014). Movement pattern variability in stone knapping: Implications for the development of percussive traditions. *PLoS One, 9*, e113567.

Rice, P. (1991). Specialization, standardization and diversity: A retrospective. In R. L. Bishop & F. W. Lange (Eds.), *The ceramic legacy of Anna O. Shepard* (pp. 257–279). Boulder, Colorado: University Press of Colorado.

Rice, P. M. (1984). Change and conservatism in pottery-producing systems. In *The many dimensions of pottery. Ceramics in archaeology and anthropology* (pp. 231–288). Amsterdam: Universiteit van Amsterdam.

Roux, V. (1989). Development of a taxonomy to measure throwing difficulties of prehistorical and protohistorical ceramic vessels. In *The Potter's wheel. Craft specialization and technical competence* (pp. 93–145). New Delhi: Oxford and IBH publishing.
Roux, V. (1990). The psychological analysis of technical activities: A contribution to the study of craft specialization. *Archaeological Review from Cambridge, 9*, 142–153.
Roux, V. (1997). Archéologie et cognition : habiletés impliquées dans les techniques du passé. *Journal des Anthropologues, 70.*, Anthropologie et cognition, 51–62.
Roux, V. (2003a). A dynamic systems framework for studying technological change: Application to the emergence of the potter's wheel in the southern Levant. *Journal of Archaeological Method and Theory, 10*, 1–30.
Roux, V. (2003b). Ceramic standardization and intensity of production: Quantifying degrees of specialization. *American Antiquity, 68*, 768–782.
Roux, V. (2009). The potter's wheel in Middle Bronze II in the Southern Levant: Technological study of the Beth Shean ceramics. *The Arkeotek Journal (*www.thearkeotekjournal.org*), 3*.
Roux, V. (2012). Pour une étude des habiletés techniques selon une approche interdisciplinaire. In S. de Beaune & H. P. Francfort (Eds.), *L'archéologie à découvert* (pp. 99–104). Paris: CNRS Editions.
Roux, V. (2015). Cultural transmission, migration and plain wheel made pottery in the MB II Southern Levant. In C. Glatz (Ed.), *Plain pottery traditions of the Eastern Mediterranean and near east. Production, use, and social significance* (pp. 69–90). Walnut Creek: Left Coast Press.
Roux, V., & Bril, B. (2002a). Observation et expérimentation de terrain: des collaborations fructueuses pour l'analyse de l'expertise technique. Le cas de la taille de pierre en Inde. In B. Bril & V. Roux (Eds.), *Le geste technique. Réflexions méthodologiques et anthropologiques* (pp. 29–48. Technologies/ Idéologies/ Pratiques). Ramonville Saint-Agne: Editions érès.
Roux, V., & Bril, B. (2002b). Des "programmes" d'apprentissage comparables pour des actions techniques différentes. In B. Bril & V. Roux (Eds.), *Le geste technique. Réflexions méthodologiques et anthropologiques* (pp. 231–242. Technologies/ Idéologies/ Pratiques). Ramonville Saint-Agne: Editions érès.
Roux, V., Bril, B., & Dietrich, G. (1995). Skills and learning difficulties involved in stone knapping: The case of stone-bead knapping in Khambhat, India. *World Archaeology, 27*, 63–87.
Roux, V., & Corbetta, D. (1989). Wheel-throwing technique and craft specialization. In *The Potter's wheel. Craft specialization and technical competence* (pp. 1–91). New Delhi: Oxford and IBH Publishing.
Roux, V., & Karasik, A. (2018). Standardized vessels and number of potters: Looking for individual production. In J. Vukovic & I. Miloglav (Eds.), *Artisans rule: Product standardization and craft specialization in prehistoric society* (pp. 20–39). Cambridge: Cambridge Scholars Publishing.
Stark, B. L. (1995a). Problems in analysis of standardization and specialization in pottery. In B. Mills & P. L. Crown (Eds.), *Ceramic production in the American Southwest* (pp. 231–267). Tucson: University of Arizona Press.
Stark, M. T. (1995b). Economic intensification and ceramic specialization in the Philippines: A view from Kalinga. *Research in Economic Anthropology, 16*, 179–226.
Vitelli, K. D. (1989). Were pots first made for foods ? Doubts from Franchti. *World Archaeology, 21*, 17–29.
Vitelli, K. D. (1993). *Franchti Neolithic pottery. Vol. 1*. Bloomington/Indianapolis: Indian University Press.
Warnier, J. P. (2001). A praxeological approach to subjectivation in a material world. *Journal of Material Culture, 6*(1), 5–24.

Chapter 6
Anthropological Interpretation of *Chaînes Opératoires*

The technological analysis of ceramic assemblages leads to interpretations we propose to address in this last chapter. They are located on a synchronic and diachronic axis, in the domains of anthropology and history.

Synchronic questions relate to the production, the distribution, and the circulation of ceramic vessels. They can be treated at a site level, but global views of the spatial distribution of technical traditions only emerge on a macro-regional scale, thus benefiting from an essential comparative angle.

Diachronic questions are relative to cultural history or to historical scenarios and affect the dynamics of traditions throughout time, on account of the transmission mechanism that makes it possible to establish a phylo- or ethno-genetic link between objects. The study of these questions prepares for the study of the evolutionary forces underlying the diversity of historical scenarios. These forces, or anthropological laws, are related to the order of development of techniques and to the actualizing conditions of historical scenarios. It is at this level that it is possible to compare societies belonging to diverse chrono-cultural areas.

6.1 The Socioeconomic Context

The study of the organization of ceramic production at a site is, by definition, based on locally made finished products and thus focuses on homogeneous assemblages. On the other hand, the study of the modalities of the distribution and circulation of ceramics applies to both homogeneous and heterogeneous assemblages, where the latter only reveal the distribution and circulation of objects and/or individuals (see Chap. 4).

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The Organization of Production

The study of production organization involves qualitative and/or quantitative data. The most widely addressed question is craft specialization and the different types developed (Costin 1991; Costin and Hagstrum 1995). The definition of craft specialization retained here, and widely accepted by the scientific community, is that of production exceeding the domestic needs of the producer. According to this definition, potter specialization can occur in a habitat context or in workshops. Several criteria have been proposed to identify this in an archaeological context: skills when these take considerable time to learn (see Chap. 5), production intensity characterized by the morphometric standardization of vessels (Roux 2003b) (see Chap. 5), the presence of potters' instruments in a limited number of habitation units, clay reserves stored in jars or heaps of broken ceramics intended to be used for making tempers or for covering open firing (Gallay forthcoming; Gallay 1994), or overproduction indicated by the distribution of vessels outside the production zone. The criteria allowing for differentiation between independent *versus* attached artisans are contextual and include functional criteria: in this way, when objects are made for an elite by artisans with long learning skills, or when potters' instruments are found in a palatial context, we can presume that the artisans worked for the elite in question (Roux 2009). Let us point out here, on the other hand, that high or low technical investment cannot be retained as a criterion of specialized *versus* domestic production, as specialized artisans can produce objects requiring little investment and nonspecialists can produce objects requiring high investment levels.

More detailed information on the techno-economic system implies understanding organizational practices through entanglements of *chaînes opératoires* and quantitative criteria (Duistermaat 2017). The latter refer to present-day data upon which archaeological vessels can be interpreted in terms of production rates, number of artisans, and then production organization.

The elaboration of quantitative frameworks for reconstructing production systems can proceed, first of all, without the assistance of computing tools. On the other hand, the exploitation of these frameworks follows a dynamic simulation and requires modeling. In the scope of this volume, we present the principles of a formal method for describing production and economy, known as "analysis of activities" (based at first on the work of von Neumann 1945).

The analysis of activities is a particularly relevant form of modeling in relation to the description of technical activities following the principle of the *chaîne opératoire* (Roux and Matarasso 1999; Matarasso and Roux 2000). It can be defined as a ranking system aiming to measure production systems, in order to consider alternative organizations (Chéneau Loquay and Matarasso 1991; Chéneau-Loquay and Matarasso 1997). According to the principles of this analysis, production systems, or techno-systems, can be described on three levels (Fig. 6.1):

- The elementary technical operations that they are composed of.
- The technical chains, or *chaînes opératoires*, corresponding to the suite of elementary operations followed to fabricate a unique type of object (vessels).

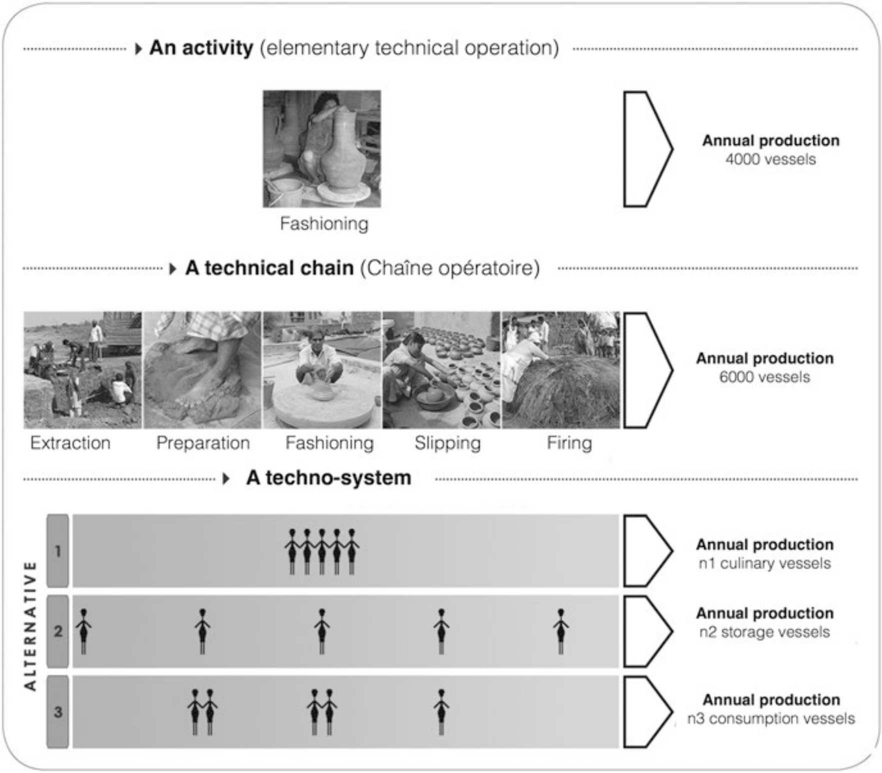

Fig. 6.1 Schematic chart of the principles of the analysis of activities for describing a techno-system (after Matarasso and Roux 2000)

- The techno-system connecting the different *chaînes opératoires* or technical chains. It is described on the basis of both technical chains and contextual data that give structure to the whole production.

The first two levels are analyzed as cultural invariants, whereas in the third level, the techno-system includes cultural features and expresses the diversity of the organization of activities.

For the first level, the segmentation of the *chaîne opératoire* into elementary technical operations or activities aims to connect these different operations through the circulation of goods between them, where the goods consist of what is consumed and produced, in order to propose a coherent summary of a complex system based on a set of elementary components.

In this aim, the different elementary technical operations forming each *chaîne opératoire* are described by creating a record of activities and goods (or items). The activities are the elementary technical operations. The goods are the things produced and consumed, ensuring links between the elementary operations. The rules governing the association of the different operations are that all the goods used for an operation must have been produced beforehand by other operations. This forms the basic restrictions of the analysis of activities.

The first step is the production of a table based on a first operation (e.g., crushing clay materials) and defining the nomenclature of the goods that this implies, where each good corresponds to a line. We attribute a "+" to produced goods and a "–" to consumed goods. Then, we proceed to the operations producing or consuming the goods linked to this first operation and so on (e.g., we specify that crushing clay material consumes dry clay materials and produces crushed clay material; then we indicate that dry clay materials are obtained by a "drying" operation and that the crushed clay material is consumed by the "sieving" operation). In this way, we construct a matrix where the horizontal nomenclature is a nomenclature of elementary technical operations and the vertical nomenclature is a nomenclature of goods (Table 6.1). We limit our analysis by stopping at the boundaries of the system we wish to study.

In the ceramic system, among the main consumed and produced goods, it is important to distinguish between vessels at different fabrication stages (rough-outs, preforms, finished surface vessels, treated surface vessels, decorated vessels, fired vessels); then between different forms of work, where each form corresponds to a level of qualification; and lastly, energy goods: raw material, plant fuels, tools, and instruments. As part of a table noting activities and goods, if we examine in more detail the example of clay preparation, the "crushing" operation uses "dried clay materials," "crushing work," and "crushing tool" and produces "crushed material." Then sieving operations occur which also consume specific tasks and produce sieved clay material. We continue in this way until the production of the final product of the *chaîne opératoire* (with hydration, tempering, wedging, roughing-out, preforming, finishing, surface treatment, decoration, drying, and firing operations).

The quantification of consumed and produced goods can be carried out based on actualist references and is therefore founded on empirically verifiable hypotheses. It is based on two statements (presented in Chaps. 2 and 5), which are that the development of the main actions organizing the successive transformation of clay materials into a finished product follows a universal order and that types of technical skills are also universal, on account of biomechanical constraints. In addition, the use of actualist frameworks for the construction of a quantitative model is possible when elementary technical operations are studied as cultural invariants, in order to

Table 6.1 Construction of a table defining the elementary technical operations and consumed and produced goods

Activities goods	Drying	Crushing	Sieving	Hydration	Tempering
Raw material	–				
Dried material	+	–			
Crushed material		+	–		
Sieved material			+	–	
Hydrated material				+	–
Tempered material					+

obtain quantitative transcultural data. From this perspective, the resources and constraints linked to the properties of the materials, the environment, and the subject are taken into consideration: for example, the possibilities of the raw material (how many pots can be obtained from a kilo of clay?) or production possibilities given the number of potters and forming techniques used (how many medium-sized pots can a potter make in a 6-h working day?), etc. Quantification relates to consumption (raw material, energy, duration of work, etc.) and to the production of technical activities (number of objects made in a day…). The many ethnographic contexts where ceramic vessels are still traditionally made supply ideal quantitative frameworks for quantifying the consumed and produced goods belonging to ancient ceramic techno-systems.

The units used for the quantification of the consumed and produced goods are conventional units. In this way, the most natural unit for the work involved in production is the yearly output of a single individual (a year's work can be arbitrarily correlated to several days or several months). For less homogeneous operations, such as firing, which can be carried out at inconsistent rhythms, consumption and production can be measured against a standard of tens, hundreds, or thousands of pieces. As for clay materials, tempering agents, and fuel, they can be measured in kilograms or tonnes. Labor is measured in person/day (the simplest convention even though the difference in units with the one used to measure the work involved in production can seem paradoxical). An example of a form describing activities and goods is presented below (Table 6.2). The data information in these forms is essential for evaluating the basis of the modeling carried out.

When the database has been filled in and the table is complete, the different data are processed after "limiting" all the activities for which we know the approximate level (by fixing "maximum levels" and minimum levels" with appropriate software, such as, at the time MEPP; Deflandre et al. 1987). In this way, we define the "limits" of the number of fired vessels produced, and we use the model to produce this number and deduce quantitative information on all the activities involved in the *chaîne opératoire*. These data should lead to evaluating the number of artisans

Table 6.2 Example of a form where the goods consumed and produced by the activity "wheel-coiling bowls" are quantified

Activities (elementary technical actions): Wheel-coiling bowls
Unit: one person/year (60 days working 5 h per day)
Consumed materials (goods)
Potter's work = 60 days (1 person/day)
Clay materials = 30 kg (50 g per bowl and a rate of 10 bowls per day for 60 days)
Tournette = 1 unit
Produced materials (goods)
Wheel-coiled bowls = 600 units (10 bowls per day for 60 days)

required for making a plausible quantity of vessels and, consequently, the possible socioeconomic situations when considering contextual data as well as skill-related data: domestic *versus* specialized production, specialized production in domestic context *versus* workshop production, regular *versus* occasional work, integrated or distributed production (the whole *chaîne opératoire* completed by the same individual or spread out between several individuals), etc.

By definition, archaeological data are problematic as we never really know how representative these data are, either spatially (excavated surface in relation to the whole site or all of the known and unknown sites) or temporally (the exact period during which ceramics were produced) (Gardin 1980). In order to address this problem, the aim is first of all to evaluate the overall number of vessels made using the same technical tradition at the site (calculating the minimum number of individuals [MNI]), in order to then estimate the percentage that this number could represent in relation to the initial population (1 for 100, 1 for 1000?), i.e., in relation to the total number of vessels that would have been produced at the time (taking account of the excavated surface or indicators of standardization). The latter number serves to evaluate hypothetical annual production.

For example, supposing that the MNI of archaeological vessels is 24,000, that this number is estimated at 1 for 10 of the initial population, and that the site was occupied for a duration of 100 years. If the model proposes a unit of 1 person/60 days work per year and a production of 10 vessels per day, the result will be an annual production made by 4 artisans (1 person/year making 600 vessels per year, therefore 60,000 vessels in 100 years, and 4 people/year making 240,000 vessels over 100 years). On the other hand, if the person/year unit is 120 days/year, the result would be an annual production made by 2 artisans (a person/year making 120,000 vessels in 100 years). If we now "juggle' with the representativeness of the vessels (1 per 100 or 1 per 1000), total production would be 2,400,000 or 24,000,000 vessels over 100 years. Depending on the person/year unit, they correspond to the production of 40, 400, 20, or 200 artisans. It is quite clear that we should opt for an estimate in keeping with the coherence of the figures obtained and the contextual data.

In addition, the evaluation of a hypothetical annual production should take account of the pottery renewal rate as ethnographic data indicate that ceramic lifespans are variable and are linked to function. Breakage risks are high for small pottery and pottery placed on the fire or manipulated on a regular basis (between 3 and 6 years), lower for pottery associated with water transport, and low for relatively immobile pottery used for storage (up to 100 years) (Nelson 1991; Mayor 1994; Stark 1995; Shott 1996; Tani and Longacre 1999).

In archaeology, the analysis of activities has been applied to the reconstruction of the techno-system of Harappan carnelian beads (Indus Valley, third millennium B.C.) (Roux and Matarasso 1999; Roux and Matarasso 2000). In the same vein, the production system of Gallo-Roman amphorae at Sallèles d'Aude (Aude, France) has been modeled (Jamet 2001). The approach is far from widespread; but a promising future lies ahead for techno-system modeling, as ethnographic situations yield abundant quantitative frameworks for a vast array of elementary technical operations, ranging from collecting clay materials to firing ceramics.

Distribution and Circulation of Productions

The distribution and circulation of productions indicate two forms of recipient movement. In the first case, vessels were acquired, either as a container or for their contents. The associated movement is part of a social and/or economic framework (gifts, commercial exchange, nonmarket exchange) by direct (direct acquisition from producers) or indirect distribution (through intermediaries). In the case of circulation, vessels were moved during the course of use. This associated movement is part of consumer movements.

In archaeology, there is considerable literature relating to distribution modalities and therefore differentiation between different forms of exchange (e.g., Renfrew 1993; Tite 1999). Gallay (2013) suggests classifying these using the opposition of Testart (2001, 2007) between commercial and noncommercial exchange: noncommercial exchange is exchange where social relations are predominant, whereas commercial exchanges are not intrinsically connected or conditioned by any noncommercial link. A schema of the different classes obtained is presented in Fig. 6.2. Gifts do not appear here; they represent a third form of distribution integrated into social, political, and religious networks but placed outside the economic and commercial domain (Gallay 2013, 34).

The identification of the distribution modalities (gifts and/or exchanges) using the technological approach is not addressed in this volume, as this question still presents many difficulties and has not yet been formalized. However, this approach should enable us to distinguish between distribution and circulation, and in some cases, to identify gifts or commercial exchanges.

In order to distinguish between distribution and circulation, two elementary mechanisms must be considered. The first states that all potters have their own "way of doing" and make a range of vessels in response to demand from their own social groups, either partly or fully. Let us recall that each social group's "way of doing" can be explained by the transmission process creating social borders, whatever the type of group. The second mechanism explains that the movements of vessels, combined with the "ways of doing," quantities, and types of vessels, generate specific spatial regional distributions of cultural components. These distribution areas consist of central areas where the ceramic tradition is homogeneous, signifying the original social groups, and peripheral areas with exogenous ceramic traditions stemming from commercial movements (Gallay and de Ceuninck 1998; Gallay 2007).

These two mechanisms give rise to a distinction between three zones: central, peripheral, and distant.

1. The *central zone* designates the geographic area where a tradition is produced and distributed (either by commercial or noncommercial exchanges). The identification of this zone involves the technological study of the clay materials and ceramic assemblages found regionally and/or in potters' workshops. This central zone is visible when consumers produce their own ware, or when consumers practically only use the local producers' vessels, or when workshops

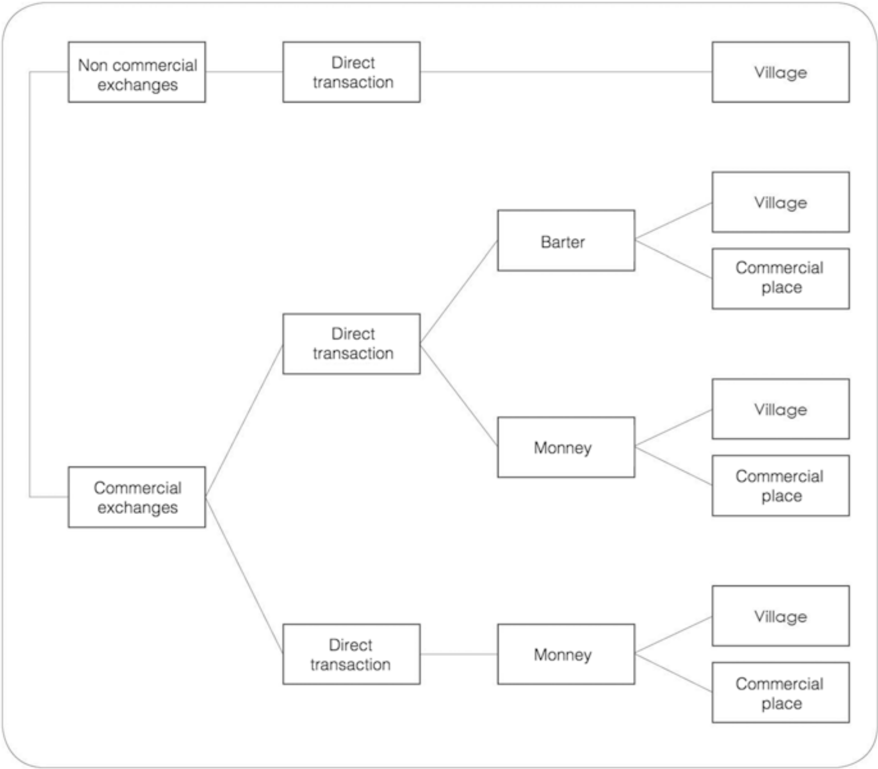

Fig. 6.2 Schematic chart of the modalities of distribution (after Gallay forthcoming). This is based on the opposition between commercial and noncommercial exchanges and, for commercial exchanges, on the opposition between direct and indirect transactions, with or without money, and in villages or in markets. These oppositions enable Gallay to define seven classes distributed between three types of exchange: noncommercial exchanges, barter, and commercial exchanges strictly speaking. The noncommercial exchanges include client relationships between casts and farming communities

clearly show that they are production centers. The first case occurs when ceramic production is domestic; possible movements of vessels between domestic units are not visible. The second and the third case occur in specialized production contexts where there is a disjunction between producers and consumers.

Locally produced traditions can present different quantitative and qualitative characteristics in terms of their position in assemblages (in the majority *versus* in the minority) and the origin of the technical and stylistic features (local *versus* exogenous). These characteristics should allow us to specify the type of distribution. Four main cases are considered here:

- The tradition under study is predominant, characterized by local clay materials (around the site), as well as a distinct *chaîne opératoire* and functional and stylistic range in that zone. Possible elements of exogenous influence denote the imitation of foreign traits by local potters. Vessels could have been acquired as part of commercial or noncommercial exchanges.

- The tradition under study is marginal, characterized by a local clay material, but including only "prestigious" vessels that stand out from other vessels by their shapes and *chaînes opératoires*, as well as different distribution circuits. Limited distribution indicates gifts for exceptional events, such as weddings (Gallay 2013).
- The tradition under study is in a minority, characterized by a local clay material, but also by a *chaîne opératoire* and finished products belonging to a wide functional range of exogenous origin. This case occurs when potters with foreign traditions move to settlements belonging to another tradition. In this case, when vessels of exogenous tradition are found alongside predominantly local tradition, the hypothesis of commercial exchanges can be advanced: indeed, when two communities are foreign to one another, this type of exchange prevails.

Several examples illustrate this case, such as Khirbet Kerak Ware (KKW) during the Early Bronze Age III in the Southern Levant (2800–2400 B.C.) (Philip 1999; Miroschedji 2000; Iserlis 2009; Zuckerman et al. 2009). This tradition is characterized by red- and black-burnished ceramics. It is different to local production not only on account of fabrication techniques but also shapes. The origin of this exogenous tradition would be the Kura-Araxes culture. However, for the sites in the north of the Jordan Valley and the Jezreel Valley (Tel Bet Yerah, Tel Hazor, Tel Beth Shean, Tell esh-Shunah, ʿAfula and Tel Qishyon), production is based on local clay materials and is thus local production, demonstrating that potters bearing exogenous traditions settled in the Southern Levant during the third millennium B.C.. KKW is also present in a zone peripheral to these production centers, where it is found in smaller quantities, with a limited range of forms and in exogenous clay materials, suggesting commercial distribution from the local production centers. This tradition lasted in the north of the Southern Levant for more than 300 years.

- The tradition under study is characterized by a local or meso-regional clay material and regional *chaînes opératoires*, forms, and decoration. This case occurs when itinerant potters make all or part of the ware consumed by the inhabitants of the region. The clay is local when it is taken near each settlement or regional when it is brought by the potter (e.g., for making unique vessels such as very large jars). It is easier to characterize itinerant potters when there is a mix of exogenous clay materials with local materials. The existence of itinerant potters is evidenced in both ethnography (Voyatzoglou 1973; Olesen 1994; Ramón 2011) and archaeology (e.g., Alden and Minc (2016) show that the composition of potters' ceramic tools [ring scrapers] differs from the composition of associated ceramic vessels suggesting that Proto-Elamite potters were itinerant). Itinerant potters can be associated with commercial exchanges when working at widely separated sites.

Common ceramics in the north of Mesopotamia during the third millennium B.C. provide an archaeological example of this (Boileau 2005). Based on a study of the ceramic assemblages from three sites located along the Euphrates, ʻAtij, Gudeda, and Mashnaqa, Boileau shows that ceramics referred to as common and made up of 90% of jars present standardized morphometric traits, that they are made in local clays (results from chemical analyzes), and lastly that the production rates of these vessels were low (hypothesis based on the MNI, fabrication time, and the total duration of site occupation). As the presence of standardized production with a low production rate is paradoxical (which, in essence, cannot lead to standardized morphometric production), the author concludes that the "same hands" made the vessels and therefore that they were itinerant potters.

Another example is the large Chalcolithic jars from the Southern Levant (second half of the fifth millennium B.C.). The jars from Abu Hamid and Gilat were made from the same clay originating from the Jordan Plateau, characterized by the presence of bioclasts. The fact that they were made with this clay suggests that the artisan travelled with his clay material, moving from the Jordanian Plateau toward the Middle Jordan Valley and the north of Negev (about a hundred kilometers as the crow flies), to make jars on site.[1]

2. *Peripheral and distant zones* from the central zone designate geographical areas with traditions that were not produced there. Within these zones, the distinction between distribution and circulation is based on the following parameters:

   - The relative quantity of the studied tradition – predominant, minor, marginal – calculated from the MNI
   - The composition of production; i.e., a functional range – complete or partial –, a specialized range, or isolated types
   - The recurrence of the tradition during the course of time

Three main cases emerge based on parameters related to numbers, assemblage composition, and recurrence throughout time.

(a) The assemblage is solely composed of vessels originating in neighboring production zones. This points to a consumer site and acquisitions by commercial or noncommercial exchange and, in the latter case, direct or indirect distribution from the production zone (producers or markets).

(b) The assemblage includes part of the functional range or a specialized range from exogenous sources and these recur throughout time. This indicates direct or indirect distribution. Geographic distance alone cannot exclude direct distribution by producers, using either specific means of transport (e.g., fluvial transport) or producer mobility, as they can travel during seasonal migrations, for example. On the other hand, this distance could indicate commercial exchanges, as noncommercial exchanges indicative of social relations between actors generally belonging to a circumscribed social structure take place in a restricted geographic area.

Pots known as "carefully made culinary pots" provide an example of exchanges during seasonal migrations at the Mesopotamian sites of Tel 'Atij, Gudeda, and Mashnaqa (Boileau 2005) during the third millennium B.C. Boileau shows that these vessels consist exclusively of two categories of cooking pots and five categories of large bowls whose forming and finishing *chaînes opératoires* are standardized. The whole set is made in two petrofabrics, including a basalt one present at the three sites. Petrographic analyses show that they are not compatible with the geological environment of the region but with the region of Ard esh Sheikh (volcanic zone located north of the sites). Given the recurrence of these vessels

[1] Non-published observations from V. Roux and M.-A. Courty

throughout site occupation and technical and morphometric standardization, the hypothesis advanced is one of acquisition from specialized producers coming regularly to the region during seasonal migrations.

(c) The assemblage presents a marginal and nonrecurring quantity of exogenous vessels. These parameters indicate recipient circulation along consumers, either by individuals or groups:

- When vessels are isolated types, scattered between several traditions, they indicate circumstantial circulation among individuals.
- When vessels include part of a functional range linked to an exogenous tradition, they indicate the circulation of mobile populations.

The site of Ovçular Tepesi is an example from Chalcolithic cultures from the south of the Caucasus and has yielded an assemblage mainly made up of local "Chaff Faced Ware" and marginal quantities of ceramics from the Kura-Araxes tradition in the same horizon (Marro et al. 2014). The latter are radically different from the first, as far as both the *chaîne opératoire* and shapes are concerned. They have been found in refuse contexts and intrusive tombs dug into habitat floors. The absence of other traits from the Kuro-Araxes material culture suggests temporary visits by the Kura-Araxes population, while the local population was absent from the site. Similar circumstances of this double visiting are shown at other sites in the macro-region (in Georgia and in the east of Turkey).

Of course, other cases are possible. But, whatever the case, taking account of the origin of the different stages of the *chaîne opératoire* should lead to the proposition of empirically verifiable behavioral explanations. In this way, in the Southern Levant, marginal quantities of several types of KKW (Khirbet Kerak Ware) ceramics were found in zones at some distance from the production zone but made with local materials. The interpretation of the assemblage went no further as no information was available on the *chaîne opératoire* (Zuckerman et al. 2009). In theory, two cases are possible: either the *chaîne opératoire* is local, in which case KKW bowls were copied by local potters, or the *chaîne opératoire* is KKW, in which case production was carried out by a KKW artisan. To interpret the circumstances in which a marginal exogenous production is made with local materials, it requires to take account of contextual data.

6.2 Cultural Histories

Material culture is constantly changing on account of the fact that it is always possible to modify learned behavior during situations involving inventions or interactions where actors integrate new procedures (Lave and Wenger 1991; Gosselain 2008; 2011).

In order to study the historical dynamics of change, the study of the diachronic variability of an assemblage must take into account both the *chaîne opératoire* and the finished product. These dynamics can affect manufacturing stages, shapes, and decorations differently, since the mechanisms behind these changes can vary according to the nature of the feature and the production context. In this way, in certain contexts, rough-out techniques can remain very stable, impervious to historical events, with conversely, rapid changes in shapes in response to changing demands, sensitive to sociohistorical events (Mayor 2010a, b, 2011). In other contexts, marked by considerable historical pressure, rough-out techniques can be less stable, and forms can change at the same rhythm as the latter (Dupont-Delaleuf 2011). In the domain of decoration, other dynamics can occur, resulting from social interactions that develop at different scales and in different settings (Gosselain 2011, 17). This differential dynamics according to production contexts and types of ceramic features testifies to the endogenous or exogenous evolutionary phenomena affecting groups of both producers and consumers.

> For example, in the middle valley of the Senegal River, present-day potters belong to two ethnolinguistic groups. They make ceramic vessels of the same shape with identical decorations but using different forming techniques (Gelbert 2003). Although these forming techniques appear to be stable, revealing the expression of the social identity of potters, forms, and decoration on the other hand portray a consumer history resulting in the standardization of demand, and consequently, a diffusion of morphological and stylistic traits over a vast regional area.

The study of the evolution of assemblages follows a two-stage approach. The first is the study of the filiation of archaeological assemblages. The aim is to establish links between assemblages in order to describe cultural lineages and evolutionary trajectories of technical traditions. The second is the study of the historical dynamics underlying assemblage evolution. The aim is to describe the historical scenarios behind the observed changes.

Cultural Lineages and Evolutionary Trajectories

Filiation Between Assemblages

Questioning the links between assemblages and consequently cultural lineages amounts to asking if the observed changes are continuous or not and identifying the nature of these changes.

Cultural lineages are defined here as traditions linked to each other by historical continuity (Shennan 2002, 72). They are distinctive, by definition, and must be reconstructed using filiation analyses between ceramic assemblages belonging to specific configurations of time (T) and place (L). The concept of cultural filiation was explicitly developed by Darwinian archaeology, which states that the evolution of cultural traits is the result of selection processes of transmitted traits (Mesoudi 2007; Mesoudi and O'Brien 2009; O'Brien and Bentley 2011; Shennan 2011). According to this approach, transmission is at the core of the evolutionary process, and the identification of this transmission is the prerequisite of studies focusing on the forces driving the selected traits. This identification raises the question of the signal enabling us to trace transmission between traditions and establish cultural lineages (Charbonneau 2018). Unlike the Anglophone school favoring quantitative models issued from population genetics and theoretical psychology and sociology (Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985), the Francophone tradition is rooted in an empirical approach, and the main signal used to trace cultural lineages is the *chaîne opératoire* (Haudricourt 1987; Creswell 1993; Pétrequin and Pétrequin 1999; Manem 2008; Shennan 2013) .

Chaînes opératoires are implemented through the biobehavioral skills acquired during the learning process. This results in an inherited way of doing and thinking. The continuity of the *chaînes opératoires* throughout time and identifying them on the archaeological material can then indicate whether or not historical continuity exists between two traditions.

Let us specify that techniques are in limited number, contrary to methods whose variability is – theoretically – infinite (see Chap. 2). Thus if techniques can be the object of convergence, on the contrary methods are more likely to be specific. As a result, this unique combination of sequences, gestures, and techniques makes technological traditions highly cultural and unique to social groups, therefore distinguishing between traditions linked through the transmission of information and convergent solutions to specific situations (O'Brien et al. 2001; Shennan 2002, 73).

In the domain of ceramic technology, the identification of cultural lineages begins with the study of assemblages issued from the same site. This involves a detailed analysis of the *chaînes opératoires* and technical gestures implemented to carry them out in order to trace ways of doing vessels handed down over the centuries. In other words, when assemblages from different periods are studied, cultural links between assemblages are not established on the basis of a comparison of shapes. In fact, shapes are the most likely element to evolve with demand, to be copied, and consequently to change rapidly. By contrast, the comparison of manufacturing methods and techniques should lead to assessing to what extent they are identical and were thus transmitted over a long period of time, hence suggesting a phylogenetic link between assemblages and therefore a same cultural niche or a same cultural group. Mobilities can be traced when this link is observed on a macro-regional scale, at times over considerable geographic areas.

The characterization of cultural lineages can be qualitative or quantitative. In the latter case, cladistics is the preferred approach, as it allows for the measurement of the phylogenetic signal linking assemblages, as shown by Manem's study (see inset).

The study of the ceramic assemblages of Tell Arqa, a third millennium B.C. site in the North Levant, provides an example of the qualitative analysis of cultural lineages (Roux and Thalmann 2016). This site, located in Aqqar plain in the north of the Lebanon, presents an occupation sequence spanning the beginning of the third millennium and the middle of the second millennium B.C. This sequence is organized into four main phases for the third millennium (T, S, R, P), dated from 3000 to 2000 B.C. These phases correspond to six periods, from the Early Bronze Age I to Early Bronze VI in the central Levant (a periodization established by Thalmann). The Early Bronze Age V (phase P) begins at around 2500 B.C. and attests to major changes marked by a hierarchical development of establishments in the Aqqar plain, optimization of agriculture, an increase in storage capacity, standardization of cereal processing procedures, an increase in the consumption of domesticated animals, and the importation of Canaanite blades. In order to assess the extent of the rupture between phase P and the preceding phases, a technological study was applied to the ceramic assemblages with a chrono-cultural typology indicating considerable changes from one archaeological level to another (Thalmann 2006).

The forming method used for all the vessels, apart from culinary vessels, is the same during the whole duration of site occupation. It consists in making a base from a clay slab on a basalt stand, on which one to two spiral coils are placed; the clay body is then roughed out using the coiling by pinching technique, followed by preforming with continuous or discontinuous pressure, depending on the vessels; once the body is preformed, the neck is roughed out using the coiling by pinching technique and preformed by continuous pressure. The sequence of operations presents three variants which recur identically throughout time: once the mouth is shaped, either the recipient is externally combed, then taken off the stand and left to dry with the mouth against the ground (variant for storage jars), or the recipient is removed from its stand with a string and left to dry with the mouth against the ground and is then burnished (variant for vessels used for transfer and consumption), or the recipient does not undergo any surface treatment (variant for small vessels, such as lamps or cups).

The main change observed during the course of the third millennium is the increasing use of RKE for thinning and shaping vessels. During the first phases, the rotating movement is used to remove vessels from their stand (string cut marks), and RKE is used to smooth small open vessels using continuous pressure. In phase S, the use of RKE is visible on small lamps and cups, and in phase R, on considerably more morphological types, including jugs and small jars of average size. The real technical leap occurs in phase P. From then onward, all the vessels are made using RKE, although deformation of the walls with RKE is more or less strong, depending on recipient dimensions. In this way, large combed jars are hardly deformed at all by RKE, unlike small vessels such as lamps. The introduction of the Palestinian tournette with a double turntable during phase R could correspond to the increase use of RKE, a period when Arqa was still facing south. The Palestinian tournette would have completed the rotary instruments used up until then, consisting of spinning stones. As for the generalization of the use of RKE in phase P, this could be related to the introduction of the Mesopotamian type tournette found out of context. The capacity of the latter to produce more RKE than the Palestinian tournette would explain the fact that RKE was used from phase P onward, including for preforming large jars. Although there is an increasing use of a new physical principle in shaping ceramic vessels, creating by definition a new lineage of objects, the adoption of this principle is nonetheless grounded in local pre-existing shaping *chaînes opératoires*. This leads to three observations:

- The same *chaînes opératoires* were transmitted from one generation to another over more than 1000 years. This transmission attests to real sociological continuity, or in other words, to the existence of a socially homogeneous group of potters who transmitted vertically the same technical tradition. This group of potters soon mastered the use of RKE and used it systematically from phase P onward.
- The observed technical change in phase P does not correspond to a sociological or population type rupture but to a cultural choice, consisting in extending a technique used from phase T onward to all of the production, using increasingly effective rotary apparatus. The adoption of exogenous rotary instruments could have occurred during the course of contacts established during trips made by the Tell Arqa potters in northern and southern directions, depending on the period.
- The morpho-stylistic changes evidenced for each phase take place in a technically stable context. From this point of view, they denote consumer, and not producer dynamics, with demand evolving during the history of the population of the site.

Modeling the Evolution of Technical Traditions and Learning Pathways with a Phylogenetic Approach[2] (Inset)

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In order to model the mechanisms of cultural evolution, specialists of evolutionary archaeology mainly use cladistics, also called phylogenetic systematics (Wiley and Lieberman 2011). The construction of a phylogenetic tree is based on a simple fundamental principle: lineage with modification. The appearance of a new taxon occurs through bifurcation from a pre-existing and older taxon. The taxon is the formal unit in phylogenetic analysis and is the equivalent of a species in paleontology (Darlu and Tassy 1993). The classification of taxa corresponds to hierarchical kinships and similarities between taxa depending on their age in relation to the common ancestor (O'Brien and Lyman 2000; O'Brien et al. 2003). In other words, two taxa will have the same kinship with a common ancestor excluding a third taxon, if these two taxa share a derived trait in relation to the common ancestor which is not present in the third taxon. The phylogenetic tree is thus founded on the shared derived traits constituting the taxa (Lyman and O'Brien 2006). This similarity is defined in two fundamentally different ways: it is identified as inherited (homology) or not (homoplasy) (O'Brien et al. 2001; Lipo et al. 2006). In the latter case, the similarity can correspond to a horizontal transfer. The plesiomorphic trait is an ancestral trait, whereas the apomorphic trait is a derived trait or state of trait. Each new branch is materialized by the presence of one or several apomorphic traits, in which case we speak of synapomorphy. Depending on the position of the trait in the lineage, it can be qualified as pleomorph or apomorph. When an apomorphic trait is transmitted to the next generation, it becomes a plesiomorphic trait. In other words, with the phylogenetic approach, it is possible to tangibly trace the pathway of an invention (apomorphic trait), to see if it was transmitted to the following generation (autapomorphy) or conversely if it was transmitted and transformed into an innovation (synapomorphy).

The application of the phylogenetic tree to techniques allows for the modeling of the diversity of *chaînes opératoires*, their evolution and their kinship in a cultural group (phylogenesis), and any possible extra-cultural transfers (ethnogenesis).

This research domain is particularly pertinent for the European Bronze Age, on account of the abundant cultures and complex interactions between them at that time (Harding 2000; Harding and Fokkens 2013). The Middle Bronze Age (1650–1350 B.C.) is qualified as a "dynamic" period (Mordant

(continued)

[2]This work is the result of a Marie Curie Actions research project (European Commission "Intra-European Marie Curie Research Fellowship") entitled "European Bronze Age Cultures and technical evolution: a phylogenetic approach."

1989). Metallurgy plays a crucial role in societies: the control and distribution of resources is considered to be the mechanism setting up local social power as well as the complex interaction of large ore exchange networks (Mordant et al. 1998; Harding 2000). However, the question remains as to whether ceramic traditions experience the same dynamics and whether learning pathways only evolve within each culture or conversely whether they are founded on cultural interactions.

Corpus

A first study phase focused on the Middle Bronze Age “Duffaits culture” complexes in the west-center of France and the “Channel-North Sea complex” around the Channel (France and the United Kingdom). The ceramic technical traditions of these two geographic zones were identified in earlier work based on the analysis of surface features (Manem 2008). Altogether, 63 shaping and finishing *chaînes opératoires* were identified on 1400 ceramics from 14 Bronze Age archaeological sites.

Method

First of all, a list of traits is elaborated in order to build up a matrix for phylogenetic analyzes inspired by other works (O’Brien et al. 2001, 2003; Collard and Tehrani 2005). In this aim, the 63 *chaînes opératoires* were coded using 263 traits. Each *chaîne opératoire* represents the equivalent of a terminal taxon. The definition of the different traits is based on a combination of the analytical results of the previously observed surface features significant of the *chaînes opératoires* (Manem 2008), and new criteria, in order to attain high analytical resolution. The 263 traits used were classified into four categories. The first category includes traits linked to “the physical modalities by which clay is fashioned” (see Chap.2) (e.g., trait 2 indicates the paddling technique, trait 7, compression by continuous pressures). The second category defines the methods used for shaping each part of the recipient, that is, “the orderly set of functional operations aimed to transform clay into vessels” (see Chap. 2) (e.g., trait 41 signifies that the modeling technique is applied to the base). The third category completes the second one by linking the different forming phases (base/body, body/mouth, base/body/mouth). The fourth category identifies finishing operations (e.g., trait 151 indicates the smoothing technique).

Traits are described in the form of two states: an absent state (0) and a present state (1) (e.g., taxon 1 = 00111010000). The evolutionary sense of a trait is a relative notion (Darlu and Tassy 1993). It can be from 0 toward 1 or from 1 toward 0: a primitive state can be 1 or 0, as can the derived state (Wiley and Lieberman 2011, Fig. 5.16). In other words, polarization, which marks synapomorphy and the direction of evolution, is not defined beforehand. It only depends on the traits of the outgroup taxon (ancestral taxon, situated in an ancestral chronological

(continued)

period serving as a comparison outside the studied group) (Wiley 1976; O'Brien et al. 2003, 149): a trait present in the outgroup taxon denotes a plesiomorphic or ancestral state. It will therefore take an "absent" state as an evolved state (or apomorphic) in the studied taxa (referred to as the ingroup).

The coding of the 63 *chaînes opératoires* based on the 263 traits was carried out with a MESQUITE (Maddison and Maddison 2011) software matrix, recording the absence (0) or presence (1) of these traits. This matrix represents 15,780 binary data. The chosen outgroup corresponds to taxon 10, representing the oldest *chaîne opératoire* and technical tradition, present from the Early Bronze Age onward in Perrats Cave (Gomez de Soto 1996).

Three successive analyses were conducted. The matrix was analyzed with the "permutation tail probability test" (PTP) (Archie 1989). If the result is equal or superior to 95%, the matrix can be considered to contain a phylogenetic signal. The second level of analysis consisted in building cladograms with TNT (Tree Analysis Using New Technology) (Goloboff et al. 2008) in order to identify the shortest tree or trees, i.e., those presenting the least change and the lowest number of homoplasy hypotheses. The third level of analysis was oriented toward the interpretation of the nature of the differences and similarities obtained in the parsimony analysis, based on indexes measuring the quality of the tree and its traits (CI/RI/Bootstrap).

Results

The PTP test reveals a result of 99%: the matrix contains a phylogenetic signal. The parsimony analysis results in three trees of minimum length. The tree of strict consensus (Fig. 6.3) shows that all the clades are sustained by one or several synapomorphies and by the bootstrap analysis. Levels of CI and RI taken on the tree of strict consistency are, respectively, 0.822 and 0.951. These two results clearly indicate that homoplasies are very rare (18%). A very large majority of the similarities are founded on a ramification mode linked to a common ancestor. In other words, all the results based on the PTP test, the CI, RI, and the bootstrap analysis demonstrate that the Middle Bronze Age cultural groups are in a phylogenetic or ramification process.

Moreover, a very large majority of the synapomorphies are concentrated in the Middle Bronze Age 1 period (MB1). In greater detail, the synapomorphies are twice as important at the beginning of the Middle Bronze Age as at the end. This signifies that there is, on one hand, a heredity process in relation to the Early Bronze Age but also that, very rapidly, technical traditions are implemented in two stages over a period of about a hundred years: firstly with behaviors requiring the development of movement practices and then with limited evolution consisting of adjustments that do not modify the geometry of ceramics.

In this way, Bronze Age cultures seem to be founded on authentic endogamous communities or clans that do not mix with each other in terms of

(continued)

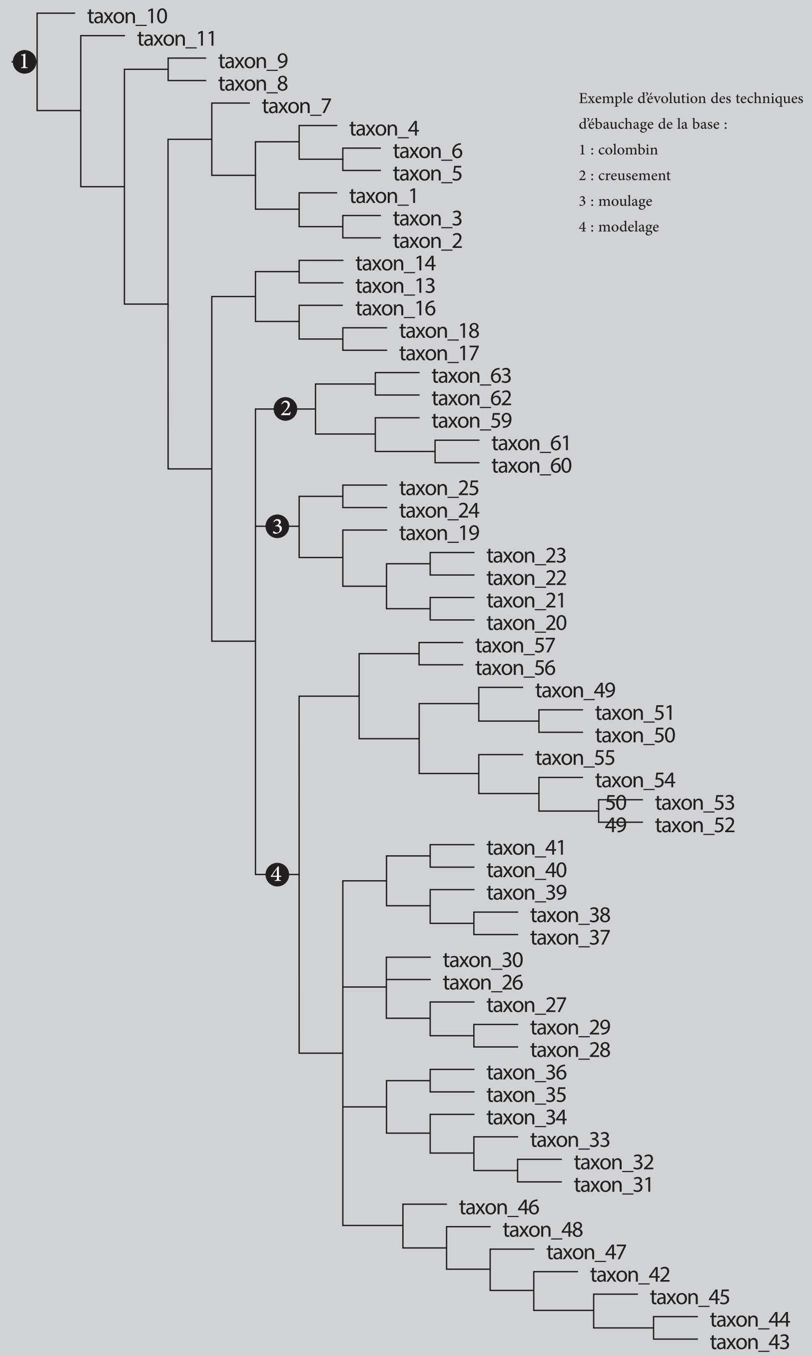

Fig. 6.3 Cladistic diagram (S. Manem)

(continued)

transmission, catalyzing the process of separation. In other terms, Middle Bronze Age cultures would be established on transmission mode n° 11 defined by Cavalli-Sforza and Feldman (Cavalli-Sforza and Feldman 1981, 59–60): "all societies are organized into groups that partially overlap, or communicate. Between some groups, however, overlap or communication may be minimal. Separation into groups with poor or absent intercommunication creates opportunities for independent evolution (…). These modes of transmission can obviously interact and produce transmission matrices of great complexity." Thus, although Middle Bronze Age societies are marked by large trade and exchange networks on a European scale, they appear, on the contrary, to be based on a vertical type transmission process as far as ceramic traditions are concerned. Moreover, they are strongly rooted in the Early Bronze Age. From generation to generation, Middle Bronze Age potters continue to transmit some archaic *chaînes opératoires* derived from the Early Bronze Age, without necessarily being conscious of it. These Early Bronze Age roots, associated with a separation process of social groups in time and space during the Middle Bronze Age, would undoubtedly explain why distant cultures from a geographic viewpoint – such as the Duffaits and the English – display certain shared technical traditions and why they evolved separately.

Absence of Filiation Between Assemblages

When assemblages follow on from each other in time and space but do not present links between ways of doing things, they point to changes in populations (if the absence of links concerns the whole assemblage) or in the sociological composition of populations (if the absence of links concerns part of the assemblage). Indeed, given the principle of learning with a model, the absence of transmission of ways of doing can be interpreted as a cultural rupture linked to the appearance and/or the disappearance of groups (populations or social groups). In this way, if an assemblage presents no earlier traditions and therefore no filiation with the preceding assemblage, it attests to the replacement of preceding groups by new groups. If, on the other hand, it presents continuity with earlier traditions combined with the emergence of a new tradition, the latter can be interpreted in terms of the appearance or the arrival of a new social group, depending on the contextual data, which can lead to locating or explaining the origin of the new tradition. Similarly, if an assemblage attests to the disappearance of a tradition characterized by distinct technical skills and finished products as compared to the predominant tradition, it points to the disappearance of the group practicing the way of doing in question, or in other words, the disappearance of the practice by the group in question (Roux and Courty 2013).

For example, in the Southern Levant, there is a genuine rupture between assemblages from the end of the third millennium B.C. (called Early Bronze IV or Intermediate Bronze Age) and assemblages from the beginning of the second millennium B.C. (called Middle Bronze

Age II). The first are characterized by shaping without RKE, globular or oval shapes with flat bases, and regional diversity. The second are characterized by the use of RKE for shaping all the vessels, shapes of north Levantine inspiration, the use of the tenon tournette, originating from Mesopotamia, and strong regional homogeneity. The absence of continuity in the technical and stylistic traditions of the Intermediate Bronze Age and the Middle Bronze Age II thus points to the arrival of new producers from the north, which is furthermore suggested by other aspects of the material culture (Roux 2015a).

Another example concerns the delicate question of continuity and/or discontinuity between the Late Chalcolithic and the Early Bronze Age I (abbreviated EBI) in the Southern Levant. This has been examined for the ceramic assemblages from the site of Modi'in Buchman, located in the center of Israel and containing an occupation sequence spanning the first half of the fourth millennium B.C. The results show that between the end of the Late Chalcolithic and the beginning of the EB I, there is continuity in ways of doing utilitarian vessels but a rupture in the fabrication of bowls with ceremonial value. The latter were wheel-coiled and disappear at the same time as other prestigious objects. These results argue in favor of a phylogenetic link between the Chalcolithic and the EB I populations, as well as a reorganization of societies during the course of a transitional period characterized by the disappearance of Chalcolithic religious signs and technical practices linked to the fabrication of these signs (Roux et al. 2013).

Evolutionary Trajectories

The evolutionary trajectories of techniques are established from cultural lineages and the discernable continuities or discontinuities at a macro-regional scale. These trajectories are determined by historical dynamics and thus do not necessarily follow the order of the development of techniques. They can thus testify to the progressive integration of a new technique and its definitive adoption, or conversely point to the adoption of new techniques that then disappear, to re-emerge later and then disappear again and, for example, are never integrated. Indeed, like cultural lineages, technical trajectories reflect upon historical scenarios and testify to the variability of these scenarios.

For example, the evolutionary trajectory of the wheel-coiling technique in the Southern Levant was described based on the study of a considerable number of assemblages (Roux 2008; Roux 2010). This technique was invented during the second half of the fifth millennium B.C., disappears during the EB I, reappears during the EB II, and is abandoned once again at the end of the EB III (Fig. 6.4). This trajectory can be explained by the limited number of potters mastering the wheel-coiling technique and therefore the restricted size of the transmission network, which no borrowing process ever contributed to increase. Faced with the specific historical upheavals of each period, this network was interrupted, and the technique disappeared. Indeed, the size of transmission networks plays a fundamental role in the maintenance of a technique. If this size is too limited, the technical system is fragile and does not resist major historical events, such as those that transform the socioeconomic structuration of a society. If, on the other hand, the size of the network is sufficiently important, the technical system is robust and can withstand historical dynamics. This is the case of the wheel-coiling technique in the Levant from the second millennium B.C. onward. This technique became predominant and was practiced in a context where all the artisans were specialized and thus durably resisted the numerous historical upheavals experienced by this region.

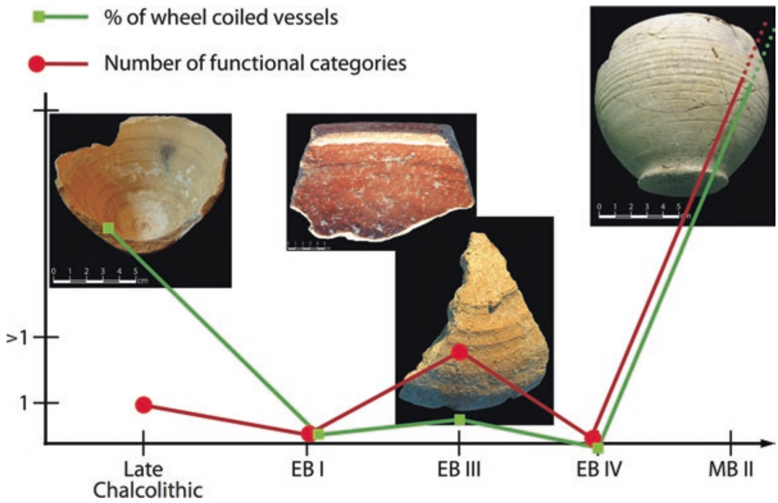

Fig. 6.4 Evolutionary trajectory of the wheel fashioning technique in the Southern Levant (after Roux 2010, Fig. 13.3, p.222)

Historical Scenarios: Innovation and Diffusion

Once the cultural lineages and evolutionary trajectories of techniques have been established, the following question is the historic dynamic at work in the observed changes. The term historic dynamic designates all the distinctive events driving changes in technical traditions. These events are historical scenarios. They are related to situations of innovation or diffusion.

Innovation

Situations of innovation present two cases. Either they are not intentional: this is the case for inventions resulting from random variation during the course of processes, such as "copying with error" (O'Brien and Bentley 2011; Gandon et al. 2014). They are observed within groups isolated from their center of origin (Shennan 2000). Either they are intentional. In this case, it is difficult to assess the processes, given not only the incomplete nature of archaeological data but also their complexity. Indeed, for the time scales concerned by archaeology, it is unthinkable to reconstruct "life stories" to recount all the successive events leading to the invention and adoption of a new trait. The dynamic approach is one of the ways to resolve this dilemma (Roux 2003a). This approach was developed in order to describe complex changes. It is currently applied in a number of disciplines, including in the human sciences, in domains such as developmental psychology (Thelen and Smith 1994). According to this approach, the changes taking place within any system in perpetual evolution are influenced by a multitude of factors interacting with each other in a complex way. The complexity of interactions is due to the fact that the systems themselves include many components that constantly interact with each other and with the environment in an extremely variable way. Like the general systems theory (from the 1970s and 1980s), supremacy is accorded to interactions between system components and to the system's potential to balance itself out. However, unlike the general systems theory, change is considered as a dynamic assemblage and not as a hierarchy of structures. It is impossible to discern no hierarchy or no privileged status among the implicated components. In addition, change is seen as a process of selection rather than a process of construction. In other words, change is not seen as a process of adaptation and balance inherent to a homeostatic system but as a property emerging from a complex set of interactions.

In the domain of technology, the three main constitutive components of the technical fact are:

- The technical task, defined in terms of *chaînes opératoires* and skills
- The environment, which supplies the clay material used in the technical task
- The subject, who implements the technical task and whose intention is determined by group demand

The properties of each of these components can be defined in terms of constraints operating on two levels: the constraints of the properties themselves and of the technical fact as a whole. Technical change is thus conceived as the result of a complex and dynamic process emerging from interactions between the properties of its three constitutive components, without it being possible to establish a hierarchy between them and without it being necessary to consider an underlying structure that could determine the result of the dynamic process. However, this does not mean that the technical facts are only determined by the constraints operating in the system. It is up to the subject to choose the different characteristics of the components. This level of choice corresponds to some extent to playing with the series of constraints from where the new system properties will emerge.

In this perspective, invention and innovation can be seen as properties emerging from the technical fact. By definition, invention is an individual phenomenon, whereas innovation corresponds to the adoption of invention at a collective scale, a distinction initially pointed out by the economist Schumpeter and largely used and accepted by technologists ever since (Gille 1978; van der Leeuw and Torrence 1989).

Invention results from a complex interaction between a new mode of action on materials (e.g., a new technique or method or a new tool) and the development of new skills. This interaction expresses individual cognitive activity which can be endogenous or stimulated by exogenous factors (change in demand and/or in the environment). In other words, invention is cognitive and can be considered, with reference to studies focusing on learning complex skills (Gibson 1979; Reed 1988; Bril 2002), as the result of an exploratory activity of the body-matter-energy system and as the discovery, during the course of action, of the possibilities offered by the environment. Inventors capable of this exploratory activity are expert individuals who are familiar with the constraints of the task (Ericson and Lehman 1996), that is, experts capable of forcing the system by going beyond the cultural representations that formed their "way of seeing and doing," resolving problems, and discovering new techniques and new skills, whether these problems appeared accidentally or were deliberately created by the inventor. These individuals, like any expert in any domain, are exceptional not only in terms of their skills but in terms of their rarity. In this way, in the ceramic domain, one potter among hundreds of potters in the region of Delhi proposed pyrotechnological inventions, transcending his own cultural representations and exploring different firing processes for the glaze of his vessels (the exceptional competencies of this artisan were rewarded by national awards) (Roux 2011).

Invention affects the evolution of the system when it becomes an innovation following its selection and thus its visible acceptance in time (van der Leeuw and Torrence 1989). Innovation is a historical phenomenon. It can be slow or rapid. It is the temporal race between these two phenomena interacting with each other – the individual and the group – that gives the system its ability to adapt and produce technical changes. From a methodological viewpoint, the dynamic approach reunites invention and innovation, by connecting real time and the long term and by recognizing that individual changes can affect the system as a whole.

An example of a study of technical innovation using the dynamic approach is the wheel-coiling technique in the Southern Levant, which appears in this region for the first time during the second half of the fifth millennium B.C. (Roux and Courty 1997; Roux 2003a). This technique was initially reserved for a single morpho-functional category, consisting of small open vessels with rectilinear walls referred to as "V-shaped bowls." These truncated cone-shaped bowls are found on habitat sites, sanctuaries, and in funerary contexts where they are systematically discovered in primary and secondary tombs.

In order to understand the link between invention and innovation, a study of the function of wheel-coiled bowls was first of all carried out at the site of Abu Hamid, a site located in the Middle Jordan valley. Firstly, the nontransfer of this shaping technique to other morpho-functional categories was underlined and interpreted as evidence of a difference in function for wheel-coiled bowls in comparison with ceramics made without RKE, as this absence of transfer does not correspond to any restriction linked to skills, instruments, or raw materials. Then, the production rate of V-shaped bowls was evaluated as low, and the wheel-coiling technique was considered to be not so rapid as compared to the coiling technique; the use of wheel-coiling could not thus be correlated to the concept of productivity. On the other hand, with reference to the skills involved, wheel-coiling was associated with an intention to make exceptional products. Lastly, the analysis of the provenance of the V-shaped bowls from Abu Hamid revealed that 90% of them were made in a clay material resulting from mixing different clays. Given that V-shaped bowls are systematically present in funerary contexts and taking into consideration all the abovementioned propositions, we thus presumed that these bowls had a ceremonial function, as opposed to mundane functions.

Following this analysis, the invention of wheel-coiling, that is, invention at an individual level, was interpreted in dynamic terms, as the result of a dynamic interaction between the task, discovery of the use of RKE for transforming clay walls; the subject, discovery of skills for shaping a recipient using RKE; and the environment, discovery of the transformation of clay materials using RKE. The innovation of wheel-coiling was then interpreted as the result of complex interaction between invention on an individual scale, a favorable environment, and a demand for objects with ceremonial value. This demand was supposedly triggered off by religious changes, marked in particular by the emergence of new religious beliefs.

Diffusion

Diffusion refers to the expansion of a technical tradition or isolated technical traits. The first case is one of demic diffusion, namely, caused by the movement of bearers of the tradition. The second case is one of cultural diffusion, namely, caused by borrowing (horizontal transmission, from adults to adults) of traits, which does not alter the overall *chaîne opératoire*. Indeed, ethnographic data indicate that the forms of diffusion are different depending on whether they concern the whole or part of the *chaînes opératoires*. Diffusions of traditions, and not of isolated traits, are associated with demic diffusions, as *chaînes opératoires* are never completely borrowed by a group who has its own technical tradition – which is in essence efficient (except in very rare cases attesting to the adoption of a new technical system in order to change status, Gosselain 2011). This is mainly due to skills developed during learning, which condition the artisans' perception as to how to obtain a finished product, and to the mechanism of transmission favoring a cognitive relationship between way of doing, vessel produced, and social identity (Roux et al. 2017).

Demic Diffusion

The diffusion of technical traditions is an invaluable way of tracing population movements. It can be studied through ruptures in traditions, as explained above, whereby the appearance of a new tradition can indicate the arrival of a new group. It can also be studied through diachronic variations in the spatial distribution of a tradition in relation to political, warlike, or socioeconomic pressures or climatic modifications influencing the occupation of the land.

In Dogon country, Gallay (Gallay forthcoming) observes in this way that the expansion or, on the contrary, the contraction of the ceramic production zone corresponds to movements back and forth between refuge settlements occupied in times of insecurity and expansion toward plains in times of peace. He also observes extended zones of ceramic productions corresponding to settlement spread out over all of the territories during favorable climatic periods or, conversely, restricted zones corresponding to constricted settlement during periods of drought.

When it is possible to chart the geo-historical expansion of a technical tradition – in the case, for example, of easily recognizable traditions such as the red and black Kura-Arax pottery – the rhythm of diffusion can be specified. This rhythm is variable depending on the modalities of producers' movements. The interpretation of these modalities should be enhanced by using actualist references.

An example of astonishingly fast diffusion comes from sub-Saharan Africa, from a domain other than pottery, but nonetheless a very relevant one for considering the effects of the movement of the bearers of a technical tradition. The tradition in question here is melting recycled aluminum, which diffused over a considerable geographical area in a period of about 50 years. This rhythm of diffusion can be explained by the fabrication conditions, involving apprentices during a relatively long period of time, the fact that it is possible to carry out this activity outside the caste system, and lastly, “leaping” movements from town to town, corresponding to the movements of apprentices-future bosses, given easy access to raw materials and the necessity of opening new workshops where competition is not too strong (Romainville 2009).

Cultural Diffusion

Diffusion through the borrowing of technical and/or stylistic traits is another situation. It provides information on interactions between actors. Depending on whether borrowing affects demand (style) or ways of doing vessels (the *chaîne opératoire*), it points to interactions between users and/or producers (here, domestic *versus* specialized production mode must be taken into consideration). The borrowing of shapes and/or decoration alone indicates a modification in demand and, consequently, the exposure of consumers to new objects creating new demand. It should be possible to define the terms of this exposure based on contextual data. As for the borrowing of exogenous elements of the *chaîne opératoire*, it points to interactions with potters from different traditions, as the exogenous variant is related to technical elements which are not within the scope of the consumer sphere, as, for example, the use of a specific instrument. For example, the borrowing of a new tournette by potters who conserve their way of doing things indicates contacts with new potters, independently of contact between consumers.

The dynamic approach can also be applied to the analysis of borrowing (Gelbert 2003). In the same way as for innovation, it is unthinkable to reconstruct all the factors explaining the adoption of a new trait in an ordered and hierarchical way. These factors include technical, social, and economic elements. Moreover, the reasons for borrowing are inherently very variable, depending on the different actors forming the social groups. In the ethnographic study carried out by Gelbert focusing on borrowings by two groups of potters in the middle valley of the Senegal River, it was possible with the dynamic approach not to rank the different factors affecting the borrowing process, with emphasis on characterizing their properties (properties of the technical task-environment-subject components of the borrowing) and identifying consistent borrowing conditions (mode of contact with the exogenous tradition, duration of immersion in the area of the exogenous tradition, scale of production).

As far as this last point is concerned, it is important to emphasize that the analysis of borrowing cannot be reduced solely to pointing out interactions between the different actors. It must also include an analysis of the borrowing/diffusion conditions. These conditions are related to the economic context and to the sociological composition of the producers who determine both the borrowing modalities of technical and/or stylistic traits and their rhythms of diffusion. These are the regularities treated below and which should considerably enhance our comprehension of the changes observed in archaeology when they are applied to archaeological data.

6.3 Evolutionary Forces

The history of changes is one of particular, non-reproducible scenarios. Nonetheless, we can assume that they are actualized according to forms and conditions conforming to general laws of evolution (Roux 2010; Gallay 2011).

These general laws include two categories of evolutionary forces: those underlying the forms and the order of the development of techniques and those underlying the diversity of historical trajectories, corresponding to the actualizing conditions of the technical change, namely, the conditions allowing to pass from state A to state B.

From a methodological viewpoint, bringing to light evolutionary forces is looking for regularities, often presented under the form of models. Indeed, it is at this level that models are built and then used to interpret the dynamics of historical patterns. It is important to recall here that models must be considered as reference tools using or providing atemporal regularities rather than hypotheses concerning historical scenarios. For example, the atemporal regularities used by an economic model include the number of vessels a man can make per day using a given technique; or the atemporal regularities provided by a sociological model include the modalities of diffusion of a technical trait depending on social networks. The construction of these models/regularities generally involves collaboration with sciences outside the domain of archaeology (e.g., anthropology, economics, sociology, demography).

When the model is applied to archaeological data, it takes into account data specifically related to the chrono-cultural context and consequently results in a specific historical scenario. In France, the tendency is to mistrust models, even though epistemological analyses over the past decades have shown that it is impossible to do without them, given the incomplete nature of archaeological data (Gallay 2011). Conversely, in Anglo-Saxon circles, models are extremely important objects of research. They are often criticized as their validity context is rarely tested on empirical data. Nonetheless, they pave the way for promising research, which could be considerably enhanced, in the future, by ceramic technology and ethnoarchaeology.

The Order of Development of Techniques

The first category of evolutionary forces is related to the technical tendency, as formalized by Leroi-Gourhan (Leroi-Gourhan 1971). This represents the order of development of techniques or the genealogy of physical principles owing to "technologics" (Boëda 2013). The latter reveal a general tendency toward less energy expenditure, given the "laws of evolution" by which techniques logically evolve from situations where the elementary operations underlying the fabrication of the object are first of all juxtaposed with a situation where these operations are in synergetic association with each other and cannot be separated (Simondon 1958;

Gille 1978; Deforge 1989; Creswell 1996). "The resulting correlative "laws" are that, all other things being equal, the object will tend toward a lesser volume, a lesser weight, a lesser number of parts, a reduced time of response, and a reduced price" (Deforge 1989, 281; our translation).

The history of ceramic techniques and their order of development still remain to be written. In the current state of research, a major developmental line has been identified. It is characterized by three successive technical "states," interlinked by a technologic that can be related to the progressive integration of rotary kinetic energy (RKE) in forming rough-outs. These states are forming assembled elements, wheel-forming assembled elements, and, lastly, wheel-throwing. For the latter technique, all the operations are carried out in synergy using rotary kinetic energy, consequently leading to considerable time-saving; this technique is the final culmination of the ceramic techniques previously characterized by series of "independent" operations (Roux and Courty 1998; Roux 2010). It cannot evolve anymore.

Conditions for Technical Change

The second category of evolutionary forces relates to the conditions passing from state A to state B. They are different from those explaining the tendency. They have to be characterized in order to understand the similarities or the differences in historical trajectories showing, for example, A-B-C-type evolutions or A-B-A-B-A-type evolutions. In other words, they are reproducible regularities allowing us to explain the transition from one technical situation to another. They can be brought to light by comparing actualizing contexts to technical changes. This comparison can either be made using archaeological case studies, and thereby benefit from the long-term time scale to evaluate the generality of regularity, or else with actualist situations and thereby benefit from explanations of observed regularity.

One of the first technologists to underline the importance of examining the context in which changes appear in order to bring to light the regularities underlying the historical pathways of techniques was Creswell, who suggests that inventions appear according to two modalities (Creswell 1994; 1996):

- Autonomous development, without having to cite social motivation; these are progressive inventions developing according to their own tendency (Simondon 1958; Leroi-Gourhan 1964; Gille 1978; Deforge 1989).
- Development in steps determined by social mutations. Changes by step follow a logarithmic function, and not a linear function. They can thus go beyond the limits imposed by the internal logic of techniques and introduce new lines of objects that respond to new physical principles. They can be quantitatively estimated. These inventions mark ruptures in the history of techniques.

In the domain of ceramic technology, it was possible to test Creswell's hypotheses. First of all, change by step was established for the passage from coiling to wheel-coiling and then from wheel-coiling to wheel-throwing, measurable by energy source and fabrication time (Roux and Courty 1998). Then the conditions for these changes by step were studied in order to examine whether the adoption of wheel-coiling was conditioned by social mutations. In order to do so, production contexts in which wheel-coiling was adopted were characterized in the Southern and Northern Levant: in both cases, production was in the hands of specialized artisans. This context, observed, respectively, for the fifth and third millennia B.C., came after a genuine social mutation in comparison with the domestic production context in operation during these periods (Roux 2010; 2013). By extending our observations to the second millennium, it was likewise highlighted that the widespread adoption of the wheel-coiling technique only occurred after the widespread specialization of the potter trade, a social mutation that took over two thousand years in the Southern Levant.

More generally, regularities between social structure and technical change can be found in the field of analytical sociology which focuses mainly on the relational structure of societies, namely, the social network, within which information is transmitted and diffused (Axelrod 1997; Valente 1999; 1996). The regularities produced offer hypotheses about the social structures favorable for changes. These regularities are looked for in archaeology because they provide explanations to correlates between social structure and changes, with the understanding that explanatory mechanisms underlying these correlates cannot be studied in archaeology given the lacunar aspect of the documentation. In other words, archaeological data may allow us to describe processes of change in terms of mode of transmission/selection (e.g., ethnogenesis or phylogenesis; unbiased or biased); however, they do not allow us to test why a specific social structure represents conditions favorable for change (e.g., why it favored or not social influence and led or not to assimilation). Such a test can be done only in the field of actualist studies, no matter the computational tools used, because explanatory mechanisms refer to individual actions that cannot be explored in the past.

The use of sociological regularities in the interpretative reasoning is the following: if ancient social structures and properties of the traits are comparable to those analyzed by present-day sociological studies, then it is possible to transfer the sociological regularities to the archaeological data and propose explanations to ancient processes of change such as diffusion, e.g., why a trait has not diffused between groups close spatially, or why a trait has diffused between remote groups, or why a trait has diffused more rapidly in one case than in another, or, put differently, why certain social structures have favored or not social influence and has led or not to assimilation. Needless to say, this type of analogical reasoning implies a first level of interpretation: the characterization of ancient network structures. This characterization is necessary for a comparison with simulated network structures in order thereafter to benefit, by analogy, of the regularities associating network structure and process of change (e.g., relationship between weak ties[3] and diffusion) and the explanations given to the role of social structure in the processes of change (e.g., why weak ties favor diffusion). In archaeology, network analysis has been applied mainly to reconstruct ancient interregional connections networks (Brughmans 2010,

[3] Ties can be strong or weak. In analytical sociology, "strong ties describe frequently activated relationships (such as family/kin ties) whereas weak ties are used to describe infrequently accessed connections (acquaintances)" (Collar et al. 2015, p. 23).

2013; Collar et al. 2015; Knappett 2011; Östborn and Gerding 2014). Local networks and therefore the relational structure of societies are less studied even though they are acknowledged to be determinant for understanding evolutionary phenomena (Blake 2014; Knappett 2018). This is partly due to difficulties in finding relevant proxies for inferring social relationships between sites. The same issue applies when investigating cultural groups or phylogenetic links (Perlès 2013; Shennan et al. 2015).

Indeed, not all the similarity attributes can socially connect sites; among them, technological traditions are the best candidates. Indeed, as explained in the introduction, technological traditions signal that individuals having the same tradition belonged to the same once "community of practice," i.e., a community sharing ways of doing (Lave and Wenger 1991). This term might seem awkward when used for connecting sites since communities of practice are defined as groups of people who interact regularly (Wenger 2000), whereas in archaeology it is problematic to demonstrate regularity of interactions. Community of practice is to be better understood as a process, a mechanism which explains how traditions are created (in the course of learning), perpetuated, or modified (Gosselain 2008). In archaeology, similarity between ways of doing can be seen as the result of this process, however spread out in times and places, and therefore signaling before all communities made up of individuals who learned and taught a same craft tradition within the framework of historically determined social links. Spatial patterns of these communities can be the result of both historical and sociocultural processes: population expansion and/or sociocultural circulation of individuals (e.g., through matrimonial alliances). On the contrary, dissimilarity in craft techniques between sites signals different communities, that is communities whose individuals do not share the same practices and therefore are not part of the same social group. Similarity or dissimilarity in craft techniques can thus link sites and bring to light social communities and locally driven networks, similarity indicating strong ties, and dissimilarity, weak ties. The overall spatial arrangement of technological traditions reflects population structure[4] (e.g., Hodder 1985; Stark 1998; Stark et al. 2008).

Let us recall that wherein ceramic technological traditions, the longest stage to learn is the forming stage because of the general difficulty of mastering motor skills (see Chap. 5). Forming techniques are taught with a tutor over years usually within private spaces, while shapes, decorative features, or even clay recipes can be learned through individual learning after seeing objects in public spaces and/or discussing with retailers (e.g., interactions with shopkeepers) (Roux 2015b). As a consequence, forming techniques tend to be more resistant to change than easily transmissible traits such as style (shapes and decor of objects) (e.g., Gallay 2007; Gelbert 2003; Gosselain 2000; Hegmon 1998; Mayor 2010a; Roux 2015b; Stark et al. 2000). In this respect forming technique is a better variable to connect over space and time individuals/communities from the same social group, than shapes and decoration

[4]This term "population structure' refers to "instances where individual subpopulations/groups exhibit low within and high between variability" (Shennan et al. 2015: 103).

whose evolutionary mechanisms make them more subject to rapid changes and diversity.

In social network analysis, assessing connections between groups implies not only to assess the similarity between groups but also to examine the embeddedness of the network and therefore the network topology. Embeddedness is "an indicator of how a particular individual or social group will socially interact by either choosing to network with many other individuals or only a few" (Borck et al. 2015, 37). The examination of embeddedness quantifies "how a particular group is likely to interact with its neighbors at a given point in time and how that may affect the network and actors during later temporal intervals" (Borck et al. 2015, 37). A qualitative approach to embeddedness is the composition of the ceramic assemblages at the macro-regional scale. This composition may testify to interactions between communities at different scales. In this aim, ceramic assemblages need to be analyzed in terms of techno-petrographic homogeneity *versus* heterogeneity (see Chap. 4). The techno-petrographic analysis of ceramic assemblages at a macro-regional scale should enable us indeed to highlight whether there are movements of individuals between sites and whether these movements indicate interactions. In a macro-region where sites are recognized as epicenters of interactions, these sites indicate strong network embeddedness.

In brief, technical traditions allow not only to trace social connections between sites but also to characterize social topology and population structure. They are a highly meaningful variable for reconstructing ancient social network and thus benefit by analogy from the sociological regularities explaining why some conditions (the relational structure of societies) are favorable for technological change processes such as nondiffusion, early adoption, and diffusion of techniques.

Among sociological regularities of interest in archaeology, let us cite the conditions for nonborrowing of techniques between social groups (Flache and Macy 2011; Roux et al. 2017; Flache 2018), the conditions for weak ties to act as bridges and new techniques to penetrate cohesive social groups (Mills 2018; Roux et al. 2018), the conditions for slow *versus* rapid diffusion of techniques (Manzo et al. 2018), or the conditions for new social norms to be adopted at the population level without large-scale coordination (Centola and Baronchelli 2015).

When applied by analogy on archaeological cases (where ancient network could be determined), these sociological regularities can explain processes of change such as nonborrowing of the wheel-coiling technique for millennia in the Mediterranean region (Gauss et al. 2016), borrowing of the tournette by northern Levant potters from Southern Levant potters and its rapid diffusion in the region (Roux and Thalmann 2016), or sharing new religious norms in the Late Chalcolithic Southern Levant without politico-religious coordination (Roux 2019).

Other sociological regularities are still waiting to be constructed on the diffusion of techniques with a view to enhancing our understanding of changes, such as they are observed in archaeology. In this perspective, let us point out the importance of ethnoarchaeological research for testing empirically the role of the social conditions in the diffusion process of the technical traits.

Explanatory Mechanisms

The study of the foundations of regularities involves revealing the underlying explanatory mechanisms. In functional terms, a mechanism answers the need to know how regularities are engendered (Manzo 2007, 45). It is by explaining regularities that they can attain the status of "evolutionary laws" (Gallay 2011). Studies of the mechanisms underlying regularities involve changing scale and going down to the individual level. They are carried out in domains other than archaeology (Roux 2017).

The mechanisms explaining the technical tendency and the order of development of techniques must be sought in the universal constraints of matter, the utility principle, and neurological conditioning[5].

The mechanisms explaining the regularities related to processes of change must be sought out in social and experimental psychology. There are three categories of mechanisms:

(a) The mechanisms explaining variation through copying error (Eerkens and Lipo 2005; Hamilton and Buchanan 2009; Schillinger et al. 2017); in the field of pottery, experiments have shown that there is a cultural selection of motor skills during apprenticeship leading to copying errors and therefore variability of shapes whose amplitude and directions depend on both the difficulty of the task and the cultural learning niches of the potters (Gandon et al. 2014).

(b) The mechanisms of elementary selection explaining differential selection of traits in the course of transmission. Cavalli-Sforza and Feldman (1981) and Boyd and Richerson (1985) have shown that selection operations exist during the course of transmission and that these drive the observed changes. The transmission process can take place between people of different generations (vertical or oblique transmission) or of the same generation (horizontal transmission). Selection modalities during the course of the transmission process in the context of Darwinian archaeology have been listed and reduced to the five following modalities (O'Brien and Bentley 2011; Shennan 2011; Lycett 2015):

- Natural selection of traits (selection in accordance with chances of survival or reproduction of the individuals and/or groups adopting these traits)
- Biased selection of traits:

– Selection of traits for their properties (content bias).
– Selection of traits for their use context (context bias); two models are considered: (a) a model-based bias – prestige, success, similarity, or others; (b) a frequency-based bias: conformity, saturation, rarity.

- Random selection of traits

[5] see A. Gallay on the notion of tendency, http://www.archeo-gallay.ch/7a_Inedits.html, http://www.archeo-gallay.ch/7a_Lectures17.html

These selection behaviors operate at an individual scale and reflect microevolutions. Their effect in time are quantified (e.g., copying the most prestigious, conforming to the majority; Mesoudi 2009) and offer reference patterns of variability depending on the modes of transmission (e.g., Bentley and Shennan 2003; Bettinger and Eerkens 1999; Jordan and Shennan 2003; Shennan and Wilkinson 2001; Tehrani and Collard 2009). The resultant quantitative models aspire to explain the large-scale patterns observed in the archaeological record by extrapolating microevolutionary processes in times and places (Mesoudi 2007; Mesoudi and O'Brien 2009; Mesoudi 2009) and investigating the spatial and temporal structure of cultural variation, the ways in which the variations observed throughout time were created and the forms of selection (Shennan 2002; Collard et al. 2006; Collard and Shennan 2008; Shennan et al. 2015).

(c) The mechanisms of complex selection explaining differential selection of traits in the course of individual actions in relationships with contexts of interactions (Manzo et al. 2018). Social networks provide actors with opportunities, but the way these opportunities are translated into large-scale patterns depends on the concrete behaviors of actors with identifiable attributes (like social status and technical skills). These mechanisms are studied with formal models in the field of analytical sociology. These formal models use simulation methods, including multi-agent system.[6] The ambition of this method is to unveil the mechanisms explaining how regularities (the conditions favorable for processes of change) are created, knowing that it is not enough to produce a result for claiming that the activated individual actions are the explanatory factors. For this reason individal actions are considered in relationship with different types of interactions (the interdependence structures) in order to understand better how some individual actions can generate macro-social regularities. Thus for the purpose of explaining the social conditions favorable for innovation or diffusion of cultural traits, individual actions are simulated within different network structures (i.e., homogeneous *versus* heterogeneous; Flache and Macy 2011; Granovetter 1983; Rogers 1962). In these models, the content of the information is also measured (Rogers 1962), the spread of information considered as depending on both the network structures and the content of what is being transmitted (Centola 2015; Centola and Macy 2007). Like the models used in evolutionary archaeology, simulations from analytical sociology are based on individual actions grounded in sociopsychological rules. However, because these individual actions are considered in different contexts of interactions, and thus the meso-level modeled for understanding the micro-macro problem (Manzo 2007, 51), the regularities produced can offer well-founded hypotheses about the social structures favorable to changes.

[6] "A multi-agent system is made up of a set of n elementary units (named "automata" or "agents"). The researcher can program both the behavior of these units, either singly or grouped into subsets, and the way the units (or group of units) interact in time. The aim of the technique is to observe how the system of interaction between agents evolves and its final "emerging" configuration" (Manzo 2007, 49).

To summarize in simple terms, these different categories of mechanisms, elementary *versus* complex, underly, for example, on the one hand (a) models against which archaeological variability is interpreted in terms of "selection of traits for their properties" (the elementary mechanism is the content bias mechanism) and on the other hand (b) models explaining why specific conditions are favorable for "the adoption of new technical traits" (the complex mechanism is the actor's behavior – the content bias mechanism – in relationship with the social relational structure, e.g., weak ties as opposed to strong ties).

Research into the regularities-mechanisms axis is still in the early stages. It involves close interdisciplinarity with psychology and sociology. It also requires empirical tests. It deserves to be extensively explored if, one day, we wish to bring to light evolutionary laws explained by social facts.

6.4 Conclusion

Thus, the potency of the *chaîne opératoire* concept lies not only in its ability to explore the functional and sociological variability of ceramic assemblages (see Chap. 4) but also to show the cultural and historical implications of this variability. The concept is based on the ethnographically and sociologically proven premise that the technological choices involved in producing objects (in this case pottery) reflect deep-seated social group behavior and identity. By accessing and understanding these choices, the archaeologist is able to gain important new insights into ancient society and culture.

The methodology offered in this book goes beyond the mere identification of the techniques used and employs classification of the pottery assemblage according to technical processes, rather than the traditional focus on morpho-stylistic types. While shapes remain important from a functional or a cultural viewpoint, if we want to understand an assemblage in sociological terms, shapes cannot be the starting point. For a long time, defining pottery types by shape alone was used with efficacy to establish relative chronologies. However, the typological approach is limited in that it cannot address questions pertaining to sociocultural processes, nor can it provide important information concerning the producers themselves.

Technology has proven to be the approach *par excellence* to assess anthropological questions, because its starting point is the tradition practiced by potters, that is, the way of doing things as it is transmitted throughout generations within one's social group. Such tradition is, in essence, part of what we call a "lineage of practices." This lineage of practice is highly visible in the archaeological record, regardless of its duration which can sometimes span several millennia. Such entrenched conservativism can be explained by the sociopsychological rule of transmission, according to which one always learns the craft from a tutor who is traditionally selected within one's social group. As opposed to the conformity of technical traditions, vessel shapes and decoration can reflect short-term historical events and the dictates of consumer and contextual demands, which skilled artisans can respond to by their dint of expertise. This accounts for the success of seriation for establishing detailed chronologies.

The evolution of technical traditions thus reveals what affects producers (or producers/consumers if they are one and the same) and is therefore a remarkable indicator of the history of these producers. But, once again, this history can only be assessed if assemblages are classified and analyzed in terms of technical traditions, making such sociological interpretation possible.

In the heated debate on the equation stating that "pots equal people," which is a rather fuzzy reference to assumed relationships between (mostly) ethnic groups and pottery, technology enables us to propose with conviction the equation "pots equal potters." But potters are never merely just one of the components of the studied societies. Thus when it is possible to assess the socioeconomic status of artisans using technology – based on, for example, the skills involved and quantitative data – or to trace distribution circuits of the circulation of objects through cross analyses of traditions with raw material sources, the link between the socioeconomic potter system and, for example, the sociopolitical system in operation is not yet necessarily established. The advantage of technology is that it clarifies the questions that are accessible through pottery, a ubiquitous material on archaeological sites for which it is tempting to extract more information than it can actually hold.

But awareness of an inherent reductionism in archaeological material must not dismiss the heuristic nature of technology for achieving a much better cultural and anthropological understanding of ancient societies.

In this aim, rather than another scientific arsenal widely used as a gauge of scientificity, above all we need reference interpretative models. The efficacy of the approach developed here enables us to establish the first levels of sociological interpretation, but, on the other hand, interpretative models are still too scarce to explain any macro-regional or long-term ceramic variability.

We must now reconcile Francophone and Anglophone approaches; the first focusing on reconstructing historical processes and their diversity, the second composed of models waiting to be applied on relevant empirical data. From this point of view, cultural technology is still in the early stages of the exploration of diverse research fields, including elaborating models to bring to light the laws of evolution underlying the challenging diversity of historical scenarios.

References

Alden, J. R., & Minc, L. (2016). Itinerant potters and the transmission of ceramic technologies and styles during the Proto-Elamite period in Iran. *Journal of Archaeological Science, 7*, 863–876.

Archie, J. W. (1989). A randomization test for phylogenetic information in systematic data. *Systematic Biology, 38*, 239–252.

Axelrod, R. (1997). The dissemination of culture a model with local convergence and global polarization. *Journal of Conflict Resolution, 41*, 203–226.

Bentley, R. A., & Shennan, S. J. (2003). Cultural transmission and stochastic network growth. *American Antiquity, 68*, 459–485.

Bettinger, R. L., & Eerkens, J. (1999). Point typologies, cultural transmission, and the spread of Bow-and-arrow technology in the prehistoric Great Basin. *American Antiquity, 64*, 231–242.

Blake, E. (2014). Dyads and triads in community detection: A view from the Italian bronze age. *Les nouvelles de l'archéologie, 135*, 28–32.

Boëda, É. (2013). *Techno-logique & technologie: une paléo-histoire des objets lithiques tranchants*. Préhistoire au Présent. s.l.: Archéo-éditions.

Boileau, M.-C. (2005). *Production et distribution des céramiques au IIIème millénaire en Syrie du Nord-Est*. Paris: Editions Epistèmes et Editions de la Maison des sciences de l'homme.

Borck, L., Mills, B. J., Peeples, M. A., & Clark, J. J. (2015). Are social networks survival networks? An example from the late pre-Hispanic US southwest. *Journal of Archaeological Method and Theory, 22*, 33–57.

Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. Chicago: University of Chicago Press.

Bril, B. (2002). Apprentissage et contexte. *Intellectica, 2*, 251–268.

Brughmans, T. (2010). Connecting the dots: Towards archaeological network analysis. *Oxford Journal of Archaeology, 29*, 277–303.

Brughmans, T. (2013). Thinking through networks: A review of formal network methods in archaeology. *Journal of Archaeological Method and Theory, 20*, 623–662.

Cavalli-Sforza, L. L., & Feldman, M. W. (1981). *Cultural transmission and evolution: a quantitative approach*. Princeton, NJ: Princeton University.

Centola, D. (2015). The social origins of networks and diffusion. *American Journal of Sociology, 120*, 1295–1338.

Centola, D., & Baronchelli, A. (2015). The spontaneous emergence of conventions: An experimental study of cultural evolution. *Proceedings of the National Academy of Sciences, 112*, 1989–1994.

Centola, D., & Macy, M. (2007). Complex contagions and the weakness of long ties1. *American Journal of Sociology, 113*, 702–734.

Charbonneau, M. (2018). Technical constraints on technological evolution. In B. Buchanan, M. I. Eren, & M. J. O'Brien (Eds.)., in press. *Convergent evolution and stone-tool technology*. Cambridge, Massachusetts: MIT Press.

Chéneau Loquay, A., & Matarasso, P. (1991). Une représentation globale et systémique des zones rurales du Tiers Monde. *Les Cahiers de la recherche-développement*: 45–63.

Chéneau-Loquay, A., & Matarasso, P. (1997). *Approche du développement durable en milieu rural africain*. Paris: Editions L'Harmattan.

Collar, A., Coward, F., Brughmans, T., & Mills, B. J. (2015). Networks in archaeology: Phenomena, abstraction, representation. *Journal of Archaeological Method and Theory, 22*, 1–32.

Collard, M., & Shennan, S. J. (2008). Patterns, processes, and parsimony: Studying cultural evolution with analytical techniques from evolutionary biology. In M. T. Stark, B. J. Bowser, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 17–33). Tucson: The University Press of Arizona.

Collard, M., & Tehrani, J. (2005). Phylogenesis versus ethnogenesis in Turkmen cultural evolution. In R. Mace, C. J. Holden, & S. J. Shennan (Eds.), *The evolution of cultural diversity: A phylogenetic approach* (pp. 109–132). Walnut Creek: Left Coast Press.

Collard, M., Shennan, S. J., & Tehrani, J. J. (2006). Branching, blending, and the evolution of cultural similarities and differences among human populations. *Evolution and Human Behavior, 27*, 169–184.

Costin, C. L. (1991). Craft specialization: Issues in defining, documenting and explaining the organization of production. In M. B. Schiffer (Ed.), *Archaeological method and theory* (Vol. 3, pp. 1–56). Tucson: The University of Arizona Press.

Costin, C. L., & Hagstrum, M. B. (1995). Standardization, labor investment, skill, and the organization of ceramic production in late prehispanic highland Peru. *American Antiquity, 60*(4), 619–639.

Creswell, R. (1993). Of mills and waterwheels. In *Technological choices: Transformation in material cultures since the Neolithic* (pp. 181–213). London/New York: Routledge.
Creswell, R. (1994). La nature cyclique des relations entre le technique et le social. Approche technologique de la chaîne opératoire. In B. Latour & P. Lemonnier (Eds.), *De la préhistoire aux missiles balistiques. L'intelligence sociale des techniques* (pp. 275–289). Paris: Editions La découverte.
Creswell, R. (1996). *Prométhée ou Pandore? Propos de technologie culturelle*. Paris: Editions Kimé.
Darlu, P., & Tassy, P. (1993). *La reconstruction phylogénétique. Concepts et méthodes*. Paris: Masson.
Deflandre, J., Jamet, M., Matarasso, P., & Valette, F. (1987). *MEPP4.0. Logiciel de Mod,lisation en Economie Physique et Prospective*. CNRS Meudon-Montpellier: Laboratoire Modèles d'économie physique.
Deforge, Y. (1989). Postface: Simondon et les questions vives de l'actualité. In G. Simondon (Ed.), *Du mode d'existence des objets techniques* (pp. 269–331). Paris: Aubier.
Duistermaat, K. (2017). The Organization of Pottery Production: toward a Relational Approach. In A. M. W. Hunt (Ed.), *The Oxford handbook of archaeological ceramic analysis* (pp. 114-147). Oxford: Oxford University Press.
Dupont-Delaleuf, A. (2011). *Styles techniques des céramiques de la protohistoire en Asie Centrale: méthodologie et études de cas*. Nanterre: Université de Paris Nanterre. PhD.
Eerkens, J. W., & Lipo, C. P. (2005). Cultural transmission, copying errors, and the generation of variation in material culture and the archaeological record. *Journal of Anthropological Archaeology, 24*, 316–334.
Ericson, K. A., & Lehman, A. C. (1996). Expert and exceptional performance: Evidence from maximal adaptation to task constraints. *Annual Review of Psychology, 47*, 273–305.
Flache, A. (2018). Between monoculture and cultural polarization. Agent-based models of the interplay of social influence and cultural diversity. *Journal of Archaeological Method and Theory, 25,* 996-1023.
Flache, A., & Macy, M. W. (2011). Small worlds and cultural polarization. *The Journal of Mathematical Sociology, 35*, 146–176.
Gallay, A. (1994). Sociétés englobées et traditions céramiques. Le cas du pays Dogon (Mali) depuis le XIIIe siècle. In D. Binder & J. Courtin (Eds.), *Terre cuite et Société. La céramique, document technique, économique, culturel* (pp. 435–458). Juan-les-Pins: Editions APDCA.
Gallay, A. (2007). The decorated marriage jars of the inner delta of the Niger (Mali): Essay of archaeological demarcation of an ethnic territory. *The Arkeotek Journal (www.thearkeotek-journal.org), 1*, 1.
Gallay, A. (2011). *Pour une ethnoarchéologie théorique*. Paris: Editions Errance.
Gallay, A. (2013). Biens de prestige et richesse en Afrique de l'Ouest: un essai de définition. In C. Baroin & C. Michel(Eds.), *Richesse et sociétés*, (pp. 25–36). Colloques de La Maison de l'Archéologie et de l'ethnologie René Ginouvès 9. Paris: Editions de Boccard.
Gallay, A. (forthcoming). *Les traditions céramiques dogon (Mali) : une étude ethnoarchéologique*.
Gallay, A., & de Ceuninck, G. (1998). Les jarres de mariage décorées du Delta intérieur du Niger (Mali): approche ethnoarchéologique d'un "bien de prestige." In B. Fritsch, M. Maute, J. Müller, & C. Wolf (Eds.), *Tradition und Innovation: prëhistorische Archëologie als historische Wissenschaft : Festchrift fr Christian Strahm* (pp. 13–30). Rahden: M. Leidorf.
Gandon, E., Roux, V., & Coyle, T. (2014). Copying errors of potters from three cultures: Predictable directions for a so-called random phenomenon. *Journal of Anthropological Archaeology, 33*, 99–107.
Gardin, J.-C. (1980). *Archaeological constructs: An aspect of theoretical archaeology*. Cambridge: Cambridge University Press.
Gauss, W., Klebinder-Gauss, G., & von Rüden, C. (2016). *The Transmission of Technical Knowledge in the Production of Ancient Mediterranean Pottery*. Vol. Sonderschriften Band 54. Wien: Österreichisches Archäologisches Institut.

Gelbert, A. (2003). *Traditions céramiques et emprunts techniques dans la vallée du fleuve Sénégal. Ceramic traditions and technical borrowings in the Senegal River Valley*. English/French extracts at http://www.thearkeotekjournal.org/tdm/Arkeotek/en/articles_reedites/Traditions.xml. Paris: Editions de la Maison des sciences de l'homme, Editions Epistèmes.

Gibson, J. J. (1979). *The ecological approach to perception*. London: Lawrence Erlbaum.

Gille, B. (1978). *Histoire des Techniques*. Paris: Gallimard.

Goloboff, P. A., Farris, J. S., & Nixon, K. C. (2008). TNT, a free program for phylogenetic analysis. *Cladistics, 24*, 774–786.

Gomez de Soto, J. (1996). Grotte des Perrats à Agris (Charente). In *Etude préliminaire* (pp. 1981–1994). Chauvigny: Editions A.P.C.

Gosselain, O. (2000). Materializing identities: An African perspective. *Journal of Archaeological Method and Theory, 7*, 187–217.

Gosselain, O. (2008). Mother Bella was not a Bella. Inherited and transformed traditions in Southwestern Niger. In M. T. Stark, B. Bower, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 150–177). Tucson: Arizona University Press.

Gosselain, O. (2011). Fine if I do, fine if I don't. Dynamics of technical knowledge in Sub-Saharan Africa. In B. W. Roberts & M. Vander Linden (Eds.), *Investigating archaeological cultures: Material culture, variability, and transmission* (pp. 211–227). New York/London: Springer Science+Business Media.

Granovetter, M. S. (1983). The strength of weak ties: A network theory revisited. *Sociological Theory, 1*, 201–233.

Hamilton, M. J., & Buchanan, B. (2009). The accumulation of stochastic copying errors causes drift in culturally transmitted technologies: Quantifying Clovis evolutionary dynamics. *Journal of Anthropological Archaeology, 28*, 55–69.

Harding, A. F. (2000). *European societies in the bronze age*. Cambridge: Cambridge University Press.

Harding, A. F., & Fokkens, H. (2013). *The Oxford handbook of the European bronze age*. Oxford: Oxford University Press.

Haudricourt, A. G. (1987). *La technologie science humaine. Recherches d'histoire et d'ethnologie des techniques*. Paris: Editions de la Maison des Sciences de l'Homme.

Hegmon, M. (1998). Technology, style, and social practice: Archaeological approaches. In M. T. Stark (Ed.), *The Archaeology of social boundaries* (pp. 264–279). Washington D.C: Smithsonian University Press..

Hodder, I. (1985). Boundaries as strategies: An ethnoarchaeological study. In *The archaeology of frontiers and boundaries*. New York: Academic Press.

Iserlis, M. (2009). Khirbet Kerak ware at Bet Yerah: Segregation and integration through technology. *Tel Aviv: Journal of the Institute of Archaeology of Tel Aviv University, 2009*, 181–195.

Jamet, M. (2001). Approche par la modélisation du complexe de potiers de Sallèles d'Aude. In *Vingt ans de recherches à Sallèles d'Aude. Le monde des potiers gallo-romain*, ed. F. Laubenheimer, 257–284. Institut Des Sciences et Techniques de l'Antiquité. Besançon: Presses Universitaires de Franche-Comté.

Jordan, P., & Shennan, S. J. (2003). Cultural transmission, language, and basketry traditions amongst the California Indians. *Journal of Anthropological Archaeology, 22*, 42–74.

Knappett, C. (2011). *An archaeology of interaction: Network perspectives on material culture and society*. Oxford: Oxford University Press.

Knappett, C. (2018). From network connectivity to human mobility: Models for Minoanization. *Journal of Archaeological Method and Theory, 25*, 974–995.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Leroi-Gourhan, A. (1964). *Le Geste et la Parole. Technique et Langage* (Vol. 1). Paris: Albin Michel.

Leroi-Gourhan, A. (1971). *Evolution et techniques. L'Homme et la matière. 1ère édition 1943* (Vol. 1). Paris: Albin Michel.

Lipo, C. P., O'Brien, M. J., Collard, M., & Shennan, S. J. (2006). Cultural phylogenies and explanation: Why historical methods matter. In C. P. Lipo, M. J. O'Brien, M. Collard, & S. J. Shennan (Eds.), *Mapping our ancestors. Phylogenetic approaches in anthropology and prehistory* (pp. 3–16). New Brunswick/London: Aldine Transaction.

Lycett, S. J. (2015). Cultural evolutionary approaches to artifact variation over time and space: Basis, progress, and prospects. *Journal of Archaeological Science, 56*, 21–31.

Lyman, R. L., & O'Brien, M. J. (2006). Seriation and cladistics: The difference between anagenetic and cladogenetic evolution. In C. P. Lipo, J. M. O'Brien, M. Collard, & S. J. Shennan (Eds.), *Mapping our ancestors: phylogenetic approaches in anthropology and prehistory*, (pp. 65–88). New Brunswick/London: Aldine Transaction.

Maddison, W. P., & Maddison, D. R. (2011). *Mesquite: A modular system for evolutionary analysis* (version 2.75). http://mesquiteproject.org.

Manem, S. (2008). *Etude des fondements technologiques de la culture des Duffaits (âge du Bronze moyen)*. Nanterre: Université de Paris Nanterre. PhD.

Manzo, G. (2007). Variables, mechanisms, and simulations: Can the three methods be synthesized. *Revue Française de Sociologie, 48*, 35–71.

Manzo, G., Gabbriellini, S., Roux, V., & M'Mbogori, F. N. (2018). Complex contagions and the diffusion of innovations: Evidence from a small-N study. *Journal of Archaeological Method and Theory, 25*, 1109-1154.

Marro, C., Berthon, R., & Bakhshaliyev, V. (2014). On the genesis of the Kuro-Araxe phenomenon: New evidence from Nakhchivan (Azerbaijan). *Paléorient, 40*, 131–154.

Matarasso, P., & Roux, V. (2000). Le système techno-économique des perles de cornaline. Modélisation des systèmes complexes de production par l'analyse d'activités. In V. Roux (Ed.), *Cornaline de l'Inde. Des pratiques techniques de Cambay aux techno-systèmes de l'Indus* (pp. 333–412). Paris: Editions de la maison des sciences de l'homme.

Mayor, A. (1994). Durées de vie des céramiques africaines : facteurs responsables et implications archéologiques. In *Terre cuite et Société. La céramique, document technique, économique, culturel*, ed. D. Binder and J. Courtin, (pp. 179–198). XIVe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. Juan-les-Pins: Editions APDCA.

Mayor, A. (2010a). *Traditions céramiques dans la boucle du Niger. Ethnoarchéologie et histoire du peuplement au temps des empires précoloniaux*. Journal of African Archaeology Monographs Series 7. Frankfurt am Main, Germany: Africa Magna Verlag.

Mayor, A. (2010b). Ceramic traditions and ethnicity in the Niger bend, West Africa. *Ethnoarchaeology, 2*, 5–48.

Mayor, A. (2011). Impressions de vanneries et technique du martelage sur forme concave: Anthropologie et histoire d'une technique dans la boucle du Niger. *Azania: Archaeological Research in Africa, 46*, 88–109.

Mesoudi, A. (2007). Using the methods of social psychology to study cultural evolution. *Journal of Social Evolutionary and Cultural Psychology, 1*, 35–58.

Mesoudi, A. (2009). How cultural evolutionary theory can inform social psychology and vice versa. *Psychological Review, 116*, 929.

Mesoudi, A., & O'Brien, M. J. (2009). Placing archaeology within a unified science of cultural evolution. In S. J. Shennan (Ed.), *Pattern and process in cultural evolution* (pp. 21–32). Berkeley/Los Angeles: University of California Press.

Mills, B. J. (2018). Intermarriage, technological diffusion, and boundary objects in the U.S. Southwest. *Journal of Archaeological Method and Theory, 25*, 1051-1086.

Miroschedji, P. (2000). La céramique de Khirbet Kerak en Syro-Palestine: état de la question. In C. Marro & H. Hauptmann (Eds.), *Chronologies des pays du Caucase et de l'Euphrate aux IVe–IIIe millénaires* (pp 255–278). Varia Anatolica 9. Paris: Institut d'Etudes Anatoliennes.

Mordant, C. (1989). Préface. In C. Mordant (Ed.), *Dynamique du Bronze moyen en Europe occidentale* (Actes Des Congrès Nationaux Des Sociétés Savantes) (Vol. 9). Paris: Ed. du C.T.H.S.

Mordant, C., Pernot, M., & Rychner, V. (1998). *L'Atelier du bronzier en Europe du XXe au VIIIe siècle avant notre ère. Production, circulation et consommation du bronze* (Vol. 3). Paris: Editions du CTHS.

Nelson, B. A. (1991). Ceramic frequency and use-life: A highland Mayan case in cross-cultural perspective. In W.A. Longacre (Ed.), *Ceramic ethnoarchaeology* (pp. 162–181). Tucson: The University of Arizona Press.

O'Brien, M. J., & Bentley, R. A. (2011). Stimulated variation and cascades: Two processes in the evolution of complex technological systems. *Journal of Archaeological Method and Theory, 18*, 309–337.

O'Brien, M. J., & Lyman, R. L. (2000). *Applying evolutionary archaeology: A systematic approach*. New York: Kluwer Academic/Plenum Publishers.

O'Brien, M. J., Darwent, J., & Lyman, R. L. (2001). Cladistics is useful for reconstructing archaeological phylogenies: Palaeoindian points from the southeastern United States. *Journal of Archaeological Science, 28*, 1115–1136.

O'Brien, M. J., Lyman, R. L., Glover, D. S., & Darwent, J. (2003). *Cladistics and archaeology*. Salt Lake City: Univ of Utah Press.

Olesen, A. (1994). *Afghan Craftsmen: The cultures of three itinerant communities*. Copenhaguen: Thames and Hudson, New York, and Rhodos International Science and Art Publishers.

Östborn, P., & Gerding, H. (2014). Network analysis of archaeological data: A systematic approach. *Journal of Archaeological Science, 46*, 75–88.

Perlès, C. (2013). Tempi of change: When soloists don't play together. Arrhythmia in 'continuous' change. *Journal of Archaeological Method and Theory, 20*, 281–299.

Pétrequin, A.-M., & Pétrequin, P. (1999). La poterie en Nouvelle-Guinée : savoir-faire et transmission des techniques. *Journal de la Société des océanistes, 108*, 71–101.

Philip, G. (1999). Complexity and diversity in the southern Levant during the Third Millenium BC: The evidence of Khirbet Kerak Ware. *Journal of Mediterranean Archaeology, 12*, 26–57.

Ramón, G. (2011). The swallow potters: seasonal migratory styles in the Andes. In S. Scarcella (Ed.), *Archaeological Ceramics: A Review of Current Research* (British Archaeological Reports) (pp. 160–175). Oxford: Archaeopress.

Reed, E. S. (1988). Applying the theory of action systems to research to the study of motor skills. *Advances in Psychology, 50*, 45–86.

Renfrew, C. (1993). Trade beyond the material. In C. Scarre & F. Healy (Eds.), *Trade and exchange in prehistoric Europe. Proceedings of a conference held at the University of Bristol, April 1992* (pp. 5–16). Oxford: Oxbow Books.

Rogers, E. M. (1962). *Diffusion of innovations*. New York: Free Press.

Romainville, M. (2009). Les routes africaines de l'aluminium. *Techniques & Culture, 51*, 74–97.

Roux, V. (2003a). Ceramic standardization and intensity of production: Quantifying degrees of specialization. *American Antiquity, 68*, 768–782.

Roux, V. (2003b). A dynamic systems framework for studying technological change: Application to the emergence of the potter's wheel in the southern Levant. *Journal of Archaeological Method and Theory, 10*, 1–30.

Roux, V. (2008). Evolutionary trajectories of technological traits and cultural transmission: A qualitative approach to the emergence and disappearance of the ceramic wheel-fashioning technique in the southern Levant during the fifth to the third millenia BC. In M. T. Stark, B. Bowser, & L. Horne (Eds.), *Cultural transmission and material culture. Breaking down boundaries* (pp. 82–104). Tucson: Arizona University press.

Roux, V. (2009). Wheel fashioned ceramic production during the third millenium BCE in the southern Levant: A perspective from Tel Yarmuth. In S. A. Rosen & V. Roux (Eds.), *Techniques and people: Anthropological perspectives on technology in the archaeology of the proto-historic and early historic periods in the Southern Levant* (pp. 195–212). Paris: De Boccard.

Roux, V. (2010). Technological innovations and developmental trajectories: Social factors as evolutionary forces. In M. J. O'Brien & S. J. Shennan (Eds.), *Innovation in cultural systems. Contributions from evolutionary anthropology* (pp. 217–234). Cambridge, MA/London: The MIT Press.

Roux, V. (2011). Habiletés et inventions: Le comportement "intelligent", un facteur aléatoire dans l'évolution des techniques. In R. Treuil (Ed.), *Archéologie cognitive : Techniques, modes de communication, mentalités* (pp. 173–188). Paris: Maison des Sciences de l'Homme.

Roux, V. (2013). Spreading of innovative technical traits and cumulative technical evolution: Continuity or discontinuity? *Journal of Archaeological Method and Theory, 20*, 312–330.
Roux, V. (2015a). Cultural transmission, migration and plain wheelmade pottery in the MB II Southern Levant. In C. Glatz (Ed.), *Plain pottery traditions of the Eastern Mediterranean and Near East. Production, use, and social significance* (pp. 69–90). Walnut Creek: Left Coast Press.
Roux, V. (2015b). Standardization of ceramic assemblages: Transmission mechanisms and diffusion of morpho-functional traits across social boundaries. *Journal of Anthropological Archaeology, 40*, 1–9.
Roux, V. (2017). Not to throw the baby out with the bathwater. A response to Gosselain's article. *Archaeological Dialogues, 24*, 225–229.
Roux, V. (2019). Technical traditions, relational structure of societies and evolution process. The Late Chalcolithic of southern Levant as a case study. In M. Saqalli & M. Vander (Eds.), *Qualitative/quantitative distinctions in social modelling*. Linden: Springer.
Roux, V., & Courty, M.-A. (1997). Les bols élaborés au tour d'Abu Hamid: Rupture technique au 4e mill. avt J.-C. dans le Levant sud. *Paléorient, 23/1*, 25–43.
Roux, V., & Courty, M.-A. (1998). Identification of wheel-fashioning methods: Technological analysis of 4th-3rd millenium BC oriental ceramics. *Journal of Archaeological Science, 25*, 747–763.
Roux, V., & Courty, M.-A. (2013). Introduction to discontinuities and continuities: Theories, methods and proxies for a historical and sociological approach to evolution of past societies. *Journal of Archaeological Method and Theory, 20*, 187–193.
Roux, V., & Matarasso, P. (1999). Crafts and the evolution of complex societies : New methodological perspectives for modeling the organization of production. An Harappan example. In M. A. Dobres & C. R. Hoffman (Eds.), *The social dynamics of technology: Practice, politics and worldviews* (pp. 46–70). Washington, DC: Smithsonian Institution Press.
Roux, V., & Matarasso, P. (2000). Les perles en cornaline harappéennes. Pratiques techniques et techno-système. In *Cornaline de l'Inde. Des pratiques techniques de Cambay aux techno-systèmes de l'Indus* (pp. 413–438). Paris: Editions de la MSH.
Roux, V., & Thalmann, J.-P. (2016). Évolution technologique et morpho-stylistique des assemblages céramiques de Tell Arqa (Liban, 3e millénaire av. J.-C.) : stabilité sociologique et changements culturels. *Paléorient, 42*, 95–121.
Roux, V., van den Brink, E. C. M., & Shalev, S. (2013). Continuity and discontinuity in the Shephela (Israel) between the Late Chalcolithic and the Early Bronze I: The Modi'in "Deep Deposits" ceramic assemblages as a case study. *Paléorient, 39*, 63–81.
Roux, V., Bril, B., Cauliez, J., Goujon, A.-L., Lara, C., de Saulieu, G., & Zangato, E. (2017). Persisting technological boundaries: Social interactions, cognitive correlations and polarization. *Journal of Anthropological Archaeology, 48*, 320–335.
Roux, V., Bril, B., & Karasik, A. (2018). Weak ties and expertise: Crossing technological boundaries. *Journal of Archaeological Method and Theory, 25*, 1024–1050.
Schillinger, K., Mesoudi, A., & Lycett, S. J. (2017). Differences in manufacturing traditions and assemblage-level patterns: The origins of cultural differences in archaeological data. *Journal of Archaeological Method and Theory, 24*, 640–658.
Shennan, S. J. (2000). Population, culture history, and the dynamics of culture change. *Current Anthropology, 4*, 811–835.
Shennan, S. J. (2002). *Genes, memes and human history: Darwinian archaeology and cultural evolution*. London: Thames & Hudson.
Shennan, S. J. (2011). Descent with modification and the archaeological record. *Philosophical Transactions of the Royal Society B, 36*, 1070–1079.
Shennan, S. J. (2013). Lineages of cultural transmission. In E. Roy, S. J. Lycett, & S. E. Johns (Eds.), *Understanding cultural transmission in anthropology: a critical synthesis* (Methodology and history in anthropology) (Vol. 26, pp. 346–360). Oxford: Berghahn Books.

Shennan, S. J., & Wilkinson, J. R. (2001). Ceramic style change and neutral evolution: A case study from Neolithic Europe. *American Antiquity, 66*, 577–593.

Shennan, S. J., Crema, E. R., & Kerig, T. (2015). Isolation-by-distance, homophily, and “core” vs. “package” cultural evolution models in Neolithic Europe. *Evolution and Human Behavior, 36*, 103–109.

Shott, M. J. (1996). Mortal pots: On use life and vessel size in the formation of ceramic assemblages. *American Antiquity, 61*, 463–482.

Simondon, G. (1958). *Du mode d’existence des objets techniques*. Paris: Aubier.

Stark, B. L. (1995). Problems in analysis of standardization and specialization in pottery. In B. Mills & P. L. Crown (Eds.), *Ceramic production in the American Southwest* (pp. 231–267). Tucson: University of Arizona Press.

Stark, M. T. (Ed.). (1998). *The Archaeology of social boundaries* (Smithsonian series in archaeological inquiry). Washington, WA/London: Smithsonian Institution Press.

Stark, M. T., Bishop, R. L., & Miska, E. (2000). Ceramic technology and social boundaries: Cultural practices in Kalinga clay selection and use. *Journal of Archaeological Method and Theory, 7*, 295–332.

Stark, M. T., Bowser, B. J., & Horne, L. (Eds.). (2008). *Cultural transmission and material culture. Breaking down boundaries*. Tucson: The University Arizona Press.

Tani, M., & Longacre, W. A. (1999). On methods of measuring ceramic uselife: A revision of the uselife estimates of cooking vessels among the Kalinga, Philippines. *American Antiquity, 64*, 299–308.

Tehrani, J. J., & Collard, M. (2009). On the relationship between interindividual cultural transmission and population-level cultural diversity: A case study of weaving in Iranian tribal populations. *Evolution and Human Behavior, 30*, 286–300.

Testart, A. (2001). Échange marchand, échange non marchand. *Revue Française de Sociologie, 42*, 719–748.

Testart, A. (2007). *Critique du don: Études sur la circulation non marchande*. Paris: Syllepse.

Thalmann, J.-P. (2006). *Tell Arqa, 1. Les niveaux de l’âge du Bronze* (Bibliothèque archéologique et historique 177). Beyrouth: Institut français du Proche-Orient.

Thelen, E., & Smith, L. (1994). *A dynamic system approach in the development of cognition and action*. Cambridge MA: M.I.T. Press.

Tite, M. S. (1999). Pottery production, distribution, and consumption—The contribution of the physical sciences. *Journal of Archaeological Method and Theory, 6*, 181–233.

Valente, T. W. (1996). Social network thresholds in the diffusion of innovations. *Social Networks, 18*, 69–89.

Valente, T. W. (1999). *Network models of the diffusion of innovations* (2nd ed.). Cresskill: Hampton Press.

van der Leeuw, S. E., & Torrence, R. (1989). *What’s new ? A closer look at the process of innovation* (Vol. 14). London: Unwin Hyman.

von Neumann, J. (1945). A model of general economic equilibrium. *Review of Economic Studies, 13*, 1.

Voyatzoglou, M. (1973). The potters of Thrapsano. *Ceramic Review (London), 24*, 13–16.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization, 7*, 225–246.

Wiley, E. O. (1976). *The phylogeny and biogeography of fossil and recent gars (Actinopterygii: Lepisosteidae)* (Miscellaneous Publication- University of Kansas, Museum of Natural History) (pp. 1–111). Lawrence: University of Kansas.

Wiley, E. O., & Lieberman, B. S. (2011). *Phylogenetics: Theory and practice of phylogenetic systematics*. Hoboken: Wiley-Blackwell.

Zuckerman, S., Ziv-Esudri, A., & Cohen-Weinberger, A. (2009). Production centres and distribution patterns of Khirbet Kerak Ware in the Southern Levant: A typological and petrographic perspective. *Tel Aviv: Journal of the Institute of Archaeology of Tel Aviv University, 36*, 135–180.

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