6 OPERATIONAL SEQUENCE IN THE POTTERY PRODUCTION PROCESS

We must remember that the fundamental source of every production process, which should also be the focus of our analysis, is the potters themselves; they are active agents who make the technological choices and perform the technical acts.
(Sillar & Tite 2000: 9)

TECHNOLOGY AND TECHNOLOGICAL CHOICE

The previous chapter makes it clear that the manufacture of every single vessel faces the potter with a whole range of technological choices, including the selection of raw material (clay) and tempers, tools, forming technique and firing method. Every potter, or group of potters, participating in the pottery production process in any way, influences the final appearance of the vessel. When making a ceramic vessel, they are all faced with several options, and, for certain reasons, they make conscious or unconscious choices (Sillar & Tite 2000). The task of an archaeologist is to analyse and interpret those technological choices, and investigate how they evolved, changed, and fitted into the wider social concept.

One of the best approaches is the reconstruction of the production process, examining each step in the operational sequence (*chaîne opératoire*): a series of technological operations which transforms a raw material (clay) into a usable product (vessel). This approach, applied in research on pottery technology since the 1970s, has allowed us to distance ourselves from a merely typological analysis of ceramic material, and it has opened up some new perspectives (Shepard 1985; Rice 1987; Rye 1988).

Ever since Matson's *Ceramic Ecology* approach was accepted (Matson 1965), an interest has been present in understanding pottery production and the reasons that stood behind its transformation over time (For an overview, see Tite 1999; Loney 2000). This processual thinking has attempted to establish how important the links are between certain parameters involved in pottery production and usage, and environmental features (availability and quality of raw material). In this respect, the consideration of the potter's technological choices focuses on environmental circumstances, rather than on social factors (Albero 2014: 129–130).

Today, the operational-sequence concept as applied in the research of pottery technology is unthinkable without ethnoarchaeology, archaeometric analysis and experimental archaeology, which together provide answers to the questions *why* the potter made a certain technological choice and *what* the consequences of his choice were, in terms of economics, society, and production. The research of pottery technology began with examination of the physical properties of clay, tempers, surface treatment and firing conditions, using various archaeometric analyses and emphasizing their importance (Tite 1999; 2008; Sillar & Tite 2000; Spataro 2002; Kreiter 2007; Miller 2007). In the middle of the 1980s, various experiments focused on questions as to how individual technological choices – such as the selected tempers and surface treatments – influenced final vessel properties (Bronitsky & Hamer 1986; Schiffer & Skibo 1987; Skibo et al. 1989; Schiffer et al. 1994; Schiffer 2004; Pierce 2005). Among other things, Skibo and Schiffer (Schiffer

1975; Skibo & Schiffer 2008) proposed the *behavioural chain* concept. In contrast to the operational sequence, which encompasses only the process of manufacturing a vessel (Lemonnier 1986), this concept follows the object: production activities and interactions, reuse, recycling and final discard. Although mutually related, the latter approach is particularly useful for the use-alteration analysis.

Ethnoarchaeological research has enhanced our understanding of the way in which past societies functioned, because such research provides an ideal framework for studying links between the past and the present, and it can also help us test some theoretical structures and interpretations (Kramer 1985; Gosselain 1992; Gosselain & Livingstone Smith 1995; Stark 1998; 1999; 2003; Stark et al. 2000; Roux 2003; 2011). A special contribution of ethnoarchaeology goes in the direction of defining production organization and craft specialization, helping us understand better to what extent pottery is a consequence of social interaction between potters or groups of potters (Arnold 1985; 1991; 2000; Stark 1991; Costin 2000). Such questions are rarely visible in the archaeological record, especially when it comes to the link between supply and demand, division of labour or distribution method. These issues will be discussed in more detail in the second part of the book (Chapter 17).

Pottery manufacturing, that is, the related operational sequence, can be divided into seven phases which are all interlinked and interact with the society in which the pottery is produced. A linear analysis is by no means sufficient, because each technological choice is caused by a range of social, economic, ideological and traditional factors that shape the cultural perception of what options are available (Sillar & Tite 2000) (*Fig. 2, p. 44*). Pottery technology is based on the selection and preparation of raw material, manufacturing technique, modification and vessel finishing, and surface decoration. It will depend on the type of clay and the skill, knowledge, habits and affinities of the potter (Banning 2000: 161).

PROCUREMENT AND PREPARATION OF CLAY

Procurement of raw material is the first of the technological choices a potter needs to make. It has long been established, by research on technological processes and changes, that clay was not extracted by chance, and that potters chose a specific clay deliberately and selectively, for specific reasons, and based on its properties (Costin 2000).

The clay's procurement depended on a range of factors, primarily on environmental features (geological and topographic characteristics of the landscape) and the vicinity of the available resources, on the potter's ability to recognize high-quality clay and his skill at turning it into a high-quality ceramic vessel which will serve its purpose. Other secondary factors that can influence raw-material procurement are associated with control over resources, restricted access to resources, the potter's social status, ideological and traditional beliefs, settlement organization, etc. (Arnold 2000; Costin 2000; Livingstone Smith 2000; Sillar & Tite 2000; Stark 1999; 2003).

The potter's various technological choices come together in the paste recipe, which regulates the process of pottery production. It is a result of the potter's knowledge and experience, a range of social norms and technological and traditional practices. Changes in pottery technology, which can also affect paste recipes, can be caused by social and environmental changes, method of learning frameworks and transfer of the knowledge, passed down from generation to generation, through time and space. On the other hand, many recipes have remained unchanged, as a result of social practices, experience and cultural traditions. Various steps in the pottery production are a direct consequence of the potter's technological choices.

The analysis of the clay recipe has become a standard methodology in the study of pottery material because it goes beyond the mere classification and description of ceramics and comes closer to the concept of technological choices that potters were making in their everyday lives (Albero 2014a).

The procurement of clay includes extraction and transport of clay to the location in which it will be processed, which is why clay was procured mostly from the settlement's close surroundings (Gibson & Woods 1997). Recent ethnoarchaeological studies have established that the average distance of clay exploitation (distance between the location of resource extraction and the location of vessel production) is 3-4 km. Based on extensive research into distances to sites of extraction of clays and tempers, three distinct thresholds of energy that potters use to procure their clays have been proposed. The procurement distance preferred by most communities is 1 km. The second threshold of energy used, that is, the distance the potter needs to cover, is 3 km for temper sources, and 4 km for clay sources. The longest distance lies at 7 km for both clays and tempers (Arnold 2000).

The vicinity of available and high-quality raw material makes it possible for the potter to invest the largest part of his energy in making and shaping vessels, rather than travelling to the location of raw materials. In cases in which the location was distant, potters could store their clays, because clay can be stored for between several months and as much as a year without losing the properties required for its processing. To be sure, clay must be stored in a proper way (it should be kept in a cool place, wrapped in plant fibres or some kind of textile), away from locations that are at risk of freezing. Such conditions allow the clay to remain relatively wet, even if it has not been previously prepared, and ready to be worked when the need arises (Albero 2014: 66). Ethnological studies carried out in Slavonia, in the village of Golo Brdo, near Požega, have revealed that old potters extracted clay in the autumn and spring and stored it in their cellars, while they produced their pottery in the summer. In this particular case, the raw-material location was very distant: the potters of Golo Brdo travelled no less than 18 km to procure high-quality clay (Lechner 2000: 297).

The results of ethnoarchaeological studies suggest that, at prehistoric sites, the distance a potter had to cross to procure raw material (clay) was minimal, and that clay was transported to settlements semi-wet. Some ethnoarchaeologial studies have demonstrated that, in areas in which alluvial clay deposits were present, clay was extracted in the immediate vicinity of settlements, cleaned of large gravel and organic-material inclusions on the spot, and transported to settlements shaped into balls, ready for forming (Rice 1987: 121). One such example comes from Laos, where extracted clay was left in the sun to dry, and then crushed and cleaned of diverse 'unwanted' inclusions and mixed with water (Shippen 2005).

Clay is extracted from vertical pits, where the humus layer which covers and contaminates the clay is removed first. In hilly regions, it is dug out directly from the profile, that is, from the slope of the hill. Pits can be 1-8 m deep. The preparation includes separation techniques, removal of organic and mineral substances naturally contained in the clay (> 5 mm), or tempering the clay with such materials to improve the paste properties (Albero 2014). The more clay modification is necessary to arrive at the final product, the more varied will be the methods of its preparation, and this will result in a wide range of paste recipes. The opposite is also true, of course (Roux

2011: 81). On the other hand, some clays require no modification before they can be prepared for processing (Knappett 2005: 678).

A number of ethnoarchaeological studies testify to the fact that some potters add no temper to their clay paste: for example, Kalinga potters in the Philippines (Longacre 1981: 54; Stark et al. 2000), potters in the eastern mountain ranges of Guatemala (Rice 1987: 121), and those in Japan (Velde & Druc 1999: 144). The only condition for a clay to be good is that it is plastic enough for further processing. However, in some communities in central Cameroon, the first criterion for further exploitation of clay is its colour (which can be white, green or brown), and then its plasticity. Each potter takes the clay on the basis of his own preferences and wishes, fires a test vessel made from the raw material he has collected, and only then decides if the clay is good enough for further exploitation (Gosselain 1992: 565). Some communities combine several types of clay to obtain the desired quality of paste. For example, in eastern Peru, three types of clay (white, red and black) and three tempers are mixed together for the production of jars and bowls (Rice 1987: 121), and at times only two (Velde & Druc 1999: 149). In Japan, traditional potters also combine several types of clay to obtain the desired results (Velde & Druc 1999: 144), while in Cameroon (Wallaert-Pêtre 2001: 477) and western Kenya (Dietler & Herbich 1989: 152) some communities also use two types of clay. In Guatemala, different types of clay are used for different purposes: yellow clay for making storage pots, and white clay for other kinds of vessels (Arnold 2000). A similar example has been recorded in Slavonia, where traditional potters in the village of Feričanci, near Osijek, used to extract three types of clay from three distinct sites, located 1–3 km from the settlement. The yellow clay, of the poorest quality, was used for all types of vessels but those that would be exposed to fire, and it was not tempered. The white clay was of the highest quality; it was not tempered either, because "it had its own rock in it", that is, it contained sand. The blue clay was used only for cooking vessels, and only this type of clay was tempered with sifted river sand, because the clay was 'lazy', which means that it was not 'stretchy' (Lechner 2000: 333–334). Therefore, the provenance of the clay, or procurement of the raw material, should not be taken for granted because, as shown above, the potter's choice is a function not only of the vicinity of the available high-quality resources, but rather of a range of mutually interrelated factors.

PROCUREMENT AND PREPARATION OF TEMPERS

Deliberate clay tempering with various admixtures (minerals, organic matter) aimed at improving the quality of the clay depends on the type of natural clay and the final shape and function of the prospective vessel. Diverse tempering increases porosity, reduces the vessel's shrinkage and deformations upon drying, eliminates micro-cracks and improves firing performances (Bronitsky & Hamer 1986: 90; Rice 1987: 74).

Deliberate tempering consists mostly of various types of non-plastic materials, such as sand (quartz, volcanic sand), gravel (diverse lithoclasts), organic material (leaves, crushed shells) and grog. The characteristics of the most frequently-used tempers were discussed in earlier chapters.

Once the potter has selected the clay and the material he will temper it with, he proceeds by mixing the tempered clay with water, to obtain a homogenous paste that will be plastic and workable.

SHAPING THE PREPARED PASTE INTO A SPECIFIC FORM

Before the clay was shaped into the desired form, the paste was carefully selected, to correspond to the function of the vessel-to-be. The potter was also guided by the tradition and needs of his community for a specific product (shape of the vessel). The demand for certain types of vessels depended on the time of year and the community's economic activities. It has already been said that technological choices, such as the selection of the type and quantity of tempering, can influence a number of other aspects, of both the production and the use of the vessel. For example, cooking vessels are made of heavily tempered clay, which makes their manufacturing much more demanding. Thus, the potter needs to find the best solution that will comply with all the requirements of the vessel.

Having prepared his paste, the potter begins to shape his vessel, using one of the three hand-building techniques:

a) pinching technique, suitable for shaping small vessels with oval or rounded bases. A thumb is inserted into a hand-shaped globular lump of paste, and the other hand is used to turn the paste. By turning and squeezing, the wall of the future vessel is shaped, and its height and thickness are defined (*Fig. 3, p. 48*).

b) coil-building technique, used to produce simple asymmetrical vessels with soft profiles. The coils are formed horizontally, by rolling the clay on a hard surface, or vertically, by rolling it between two hands (*Figs 4, 6, pp. 48, 49*).

c) slab-building technique, which was used to produce highly profiled vessels (Zlatunić 2005: 70-71) (*Figs 5, 7, pp. 48, 49*).

Each of these techniques leaves marks on the vessel's interior and/or exterior that allow us to identify how it was made. The complex forming process and its importance in the production of the pottery can be studied both microscopically and macroscopically, and, where possible, using a combination of the two methods. The microscopic analysis includes examination of thin sections of pottery, especially of the joints of clay slabs or coils, and identification of temper and pore orientation, which is another indicator of the forming technique (Albero 2014: 77–79).

The forming technique can also be identified on the basis of the way and place in which the vessel broke, i.e. where the fractures appeared (*Figs 6, 7, p. 49*). Although vessels usually break in the places which are most stressed, in places where pieces of clay of various degrees of plasticity were put together, fractures are particularly recognizable in vessels made using the slab-building and coil-building techniques (Albero 2014; Vuković 2014).

On some vessels, the forming technique is visible to the naked eye, while some others require more attention and analysis to identify the way in which they were made. One good example is a vessel recovered at the site in 8a Matija Gubec Street, where the coil-building technique was recognized only after a photogrammetric model had been made using the *Agisoft PhotoScan* software program. The final mesh model, which consists of 645,761 polygons, was made using the *MeshLab* program, which presented it from various angles. The picture thus obtained shows clear traces of forming, which could not be observed on the vessel under examination (*Fig. 8, p. 49*).

This phase of pottery production also includes removing imperfections before drying, or shape modifications. This step, which is often replaced by surface treatment, involves finalization of the vessel's shape and removal of imperfections on both the interior and the exterior sides (uneven walls, removal of excess clay, covering cracks, etc.). This phase of forming includes finishing the vessels when the clay is leather-hard, which means neither dry nor wet. It can be done by hand or using tools made of wood, stone (pebble) or wet cloth.

The use of the potter's wheel in vessel production is also recognizable and visible on the vessels' surface. A slowly rotating potter's wheel was used primarily for the final modelling of vessels that were hand-thrown, and whose shape was finished on a rotational device. One of the earliest records of the use of a rotational device, which could be obtained in four ways, is the coil-building technique, where the shaping was completed on a slow potter's wheel, and included thinning the walls and shaping a rim (Roux 1998: 749).

Shaping of vessels using a mould is yet another method of pottery modelling, and it can still be observed in traditional pottery-making communities. The mould can be concave or convex, depending on whether the clay is put over the mould or in it, and it can be used to shape the whole vessel or just one part (usually, the lower section). The moulds can be specially made of clay or wood, or created from pieces of broken ceramic vessels (Rice 1987: 126).

DRYING

Water must be added to the clay paste to obtain a paste that can be shaped into a vessel. The amount of water that clay can take usually varies between 15% and 50% of its weight (Albero 2014: 80). Drying is a rather sensitive process; it can cause cracking and deformation of vessels if it is not done properly. The majority of deformations that occur in pottery during its drying are caused by water. During the drying, the water which made the clay more plastic evaporates, and the clay particles come closer to one another and cause the vessel to shrink.

Different types of clay take different times to dry. Coarse-grained clays (such as kaolinites) dry much faster than those which are more plastic and fine-grained (montmorillonites). The drying time also depends on the size of the capillaries through which water reaches the surface and evaporates. Since vessels become smaller, or shrink, during their drying, deformations and cracks appear if one part of the vessel dries more quickly than another. Similarly, if pottery is dried in the sun, water will evaporate faster from the vessel's exterior than from its interior, and this will cause shrinkage of the exterior of the vessel. For this reason, pottery should be dried in a place which is not exposed to direct sunlight, at least in the initial phase of drying (Rye 1988: 21–24).

It can take between several days and several weeks for pottery to dry, depending on the clay properties, wall thickness, season and paste preparation (Albero 2014: 80).

SURFACE TREATMENT

Surface treatment is the last step before the vessel is fired, and it usually takes place at the end of the drying phase. In pottery production, this step actually includes two actions: surface treatment and decoration, where the latter is for purely ornamental purposes. Despite the popular view that the value of surface treatment is merely aesthetic, it has a strong impact on the pottery's performance and belongs among the potter's technological choices: it reduces permeability, and it increases heating effectiveness and resistance to mechanical damage (Skibo 2013: 47–51).

Experiments and analyses have shown that cooking vessels with treated external and internal surfaces feature greater resistance to thermal shock. On the other hand, textured surfaces negatively affect the heating rate in those cases in which vessels are highly permeable (Young & Stone

1990). The vessel's internal surface is usually smoothed, whereas its external surface is treated with deep textures, such as barbotine. The most frequent surface treatment is polishing, or burnishing, aimed at closing off surface pores and making the vessel less porous. This is achieved by rubbing a hard tool (most often, a pebble) over a ceramic surface when the clay is leather-hard, resulting in a high lustre of the vessel (Velde & Druc 1999: 85). Polishing causes minerals to compact and assume an orientation parallel to the vessel's wall, thus preventing crack propagation in the vessel's body. When their internal surface is treated, vessels become water-resistant, their heat effectiveness is higher, and they are more resistant to thermal shock. Therefore, it is not surprising that cooking pots were treated in this way in all geographical areas and in all periods of time (Skibo 2013: 52). As a rule, cooking vessels are fired at lower temperatures, so those whose internal surface has not been treated will be permeable, and their heat effectiveness will be lower, which is contrary to the purpose of such vessels.

Another surface treatment that was often applied to prehistoric pottery is barbotine or surface roughening technique. The barbotine technique consists of texturing the object's surface, before its firing, with semi-liquid clay or clay dissolved in water; the layer is applied by fingers dragged over the surface. Such application results in diverse high 'ridges' on the surface, depending on the thickness of the semi-liquid clay layer. The barbotine surface treatment is functional, rather than decorative, which puts a question mark over its traditional categorization into decoration techniques.

It has already been said, in the previous chapter, that texturing the external surface with barbotine increases pottery's resistance to thermal cracks and fractures, and to mechanical damage (Schiffer et al. 1994; Skibo & Schiffer 1995). This notion supports the fact that the surface of the majority of vessels of the Vučedol Culture, discussed in this book, which fall into the category of pots – vessels that were used for thermal preparation of food – was treated with barbotine. Due to their 'relief' surface, such vessels were easier to carry, because one's fingers fitted into the ridges left in the rough, uneven external surface after the firing.

Such vessels usually do not excite much 'enthusiasm' in archaeologists, because they are considered ugly, cumbersome and definitely uninteresting. However, it is precisely those vessels that reveal the potter's technological ability, or, as J. M. Skibo (1995; 2013) put it, his "technological sophistication". The production of cooking vessels, as emphasized previously, requires much more effort, knowledge, skill, time and technological awareness than of other vessels which might be more aesthetically pleasing to the eye. We could say that a special interest in cooking vessels, in those 'ugly' pottery sherds, is a key link between those archaeologists who endeavour to reconstruct pottery production through the study of other aspects besides just the traditional typological-chronological frameworks.

Pre-firing surface treatment also includes various slips. A slip is a liquid suspension of clay (and/or other materials) in water, applied in a thin layer to the whole vessel before its firing, and resulting in reduced wall permeability (Rice 1987: 149).

Various methods of decoration also belong to surface treatments executed before firing. In addition to their aesthetic function, decoration techniques can also have a practical utilitarian function, since certain kinds of decoration can modify the vessel's shape, more than its surface (Rice 1987: 144). Different techniques require clay in different conditions (soft, leather-hard, hard). The techniques applied to raw, unfired surfaces are: *incision, impression, application, modelling, incrustation* and *painting.* The incision technique can be further divided into several variants: grooving, fluting, regular incising, comb incising, furrowing, notching (deep incising) and puncturing. These techniques differ in the type and shape of tools used (round, pointed, angular), pressure exerted on the treated surface (at an acute or right angles), condition of the clay (soft, leather-hard, hard), and the potter's experience and preference (Horvat 1999: 29–30). The techniques listed below are only those applied on the material that will be discussed in the second part of the book.

Incision techniques:

Regular incising – A sharp-tipped implement is strongly pressed at an acute or right angle, so that it cuts the clay surface. The cross-section of the incised lines is shaped like a regular or asymmetrical letter 'V'. The effects obtained by incision vary significantly depending on the drying phase in which they were executed. Raised and irregular edges indicate that the surface was wet, while clean lines reveal that the incisions were made on a leather-hard surface, and very shallow, thin lines demonstrate that the surface was dry (*Fig. 9, p. 52*).

Furrowing – This is a combination of incision and impression techniques. Short lines are incised into a leather-hard ceramic surface using the blunt tip of an awl, and thereafter the awl is pulled back over the same line in short intervals. The result visible on the finished pottery is not incision marks, but lines with shallow or deep impressions, usually filled with incrustation. For this reason, this technique is often classified as an impression technique.

Grooving – A blunt-tipped implement is applied at an acute or right angle. The cross-section of incised lines has the shape of a regular or asymmetrical letter 'U'. The grooves are mostly deep and wide, although they can also be shallow and narrow.

Notching – This technique corresponds to the main criteria for an incision technique. A narrow implement is used to cut the object's surface, and then the surrounding surface is carved out, or cut out, to obtain the motif. The surface is then flattened, smoothed, or filled with incrustation. With this technique, clay is removed from the object (*Fig. 10, p. 53*).

Puncturing – Punctures are impressed into leather-hard clay using a tool with a blunt tip, which leaves various motifs on the pottery surface. The motifs differ based on the type and shape of the tool, and the angle and strength of pressure exerted on the treated surface. The most frequent motifs made using the puncturing technique are elongated, rectangular, circular and triangular shapes (*Fig. 11, p. 53*).

Impression technique:

Impressions interfere with the object's surface, by making the rest of the surface raised and relief. A tool is impressed into leather-hard clay and the negative image of the motif left in the clay is called an *imprint*. Impressions can also be made on an applied band. There is a wide choice of tools that can be used for impressions, from those easily accessible, such as fingers, nails, shells, seeds and stalks, to special instruments purposely made to produce motifs (*Fig. 12, p. 53*).

Appliqué technique:

This technique consists of semi-hard appliqués placed on leather-hard surfaces. Deformations, such as smeared clay, often appear along the appliqué's edges or around it (in the area of contact between the appliqué and the object's surface). The applied decoration can be both functional and decorative. There are several types of appliqués: various protrusions, bands, loops, rod-like projections applied to certain parts of vessels; they can be pulled out of the vessel's body, or made in a mould, and added to the vessel at a later stage (Horvat 1999: 37–38). Experiments have demonstrated that the potters who produced Bronze Age vessels of the Vinkovci Group applied conic boss-shaped appliqués directly from the mould to the vessel's wall, which left regular circular incisions (grooves around the bosses) (Kudelić 2015). Various types of appliqués on vessel walls were also functional, because they facilitated the holding and handling of the vessels.

Modelling technique:

Modelling refers to adding extra clay to a vessel already shaped, with a view to producing a three-dimensional decoration. The clay is added to a leather-hard surface and shaped with fingers or certain types of tools. The vessel's surface is modelled in parallel with the vessel's modelling. The applied decoration can be of diverse geometrical shapes, or in the form of anthropomorphic or zoomorphic figures (Rye 1988: 94; Horvat 1999: 39). The modelling technique is also used to produce various types of handles.

Incrustation technique:

This technique is never used on its own, but rather in combination with the furrowing and notching techniques, since the incrustation – which can be prepared from various materials – is inserted into a carved-out or incised surface (*Fig. 56, p. 121*). White incrustation was made of ground-up shells, limestone or animal bones, while a red colour was obtained using mixtures rich in metal oxides (for example, hematite). The archaeometric analysis of white incrustations on pottery of the Kostolac and Vučedol cultures and on Transdanubian Incrusted pottery has shown that the white colour was obtained from deer-antler powder and shells of fresh-water molluscs of the Unionidae family (*Unio sp.)* (Kos et al. 2013).

Painting technique:

Both fired and unfired pottery can be painted. Paints are made from iron-oxide compounds which oxidize during firing and result in various colours. For example, hematite will be red, manganese compounds brown, or, in combination with graphite, black (Horvat 1999: 41–42).

FIRING

Firing is the final step in pottery production, and the pottery's characteristics greatly depend on it. Given that this phase is irreversible, for a potter, this is the most important step in the production process. During firing, the material is subject to various physico-chemical changes which affect the vessel's properties and its final appearance. The two main factors which determine the final microstructural properties of a vessel are the paste and the firing method (Albero 2014: 87).

The purpose of firing is to subject the pottery to a sufficiently high temperature for a sufficiently long period of time to ensure complete destruction of minerals contained in the clay. High temperatures will enhance the pottery's hardness, colour and quality. The minimum temperature varies for different minerals, ranging between 500°C and 800°C. When heated to temperatures higher than this, clay acquires the properties of ceramics: hardness, porosity and resistance to various chemical and physical changes (Rye 1988: 96).

The changes that occur during firing depend on:

- *time* – the duration of the heat exposure necessary for chemical reactions;

- *temperature* – chemical reactions occur at a specific temperature, and if the temperature is above the optimal value, it can cause deformations and cracks in the pottery;

- *atmosphere* (during heating and cooling) – this depends on the quantity of air available during firing, which is necessary for a certain quantity of fuel to burn (Horvat 1999: 46).

When exposed to certain temperatures, various clays and clay minerals behave differently, depending on their chemical composition, and on the atmosphere, time and method of firing. Despite the differences, several common characteristics can be identified regarding changes and reactions occurring within the pottery's structure when subjected to heat:

- heating to 200°C – In the initial phase of firing, when pottery is heated from room temperature to 200°C, water evaporates from the paste in the form of water vapour. In general, vessels do not shrink in this phase.

- heating from 200 to 400°C – At these temperatures, organic matter present in the paste oxidizes. In combination with oxygen, the carbon contained in organic substances forms carbon dioxide, which is released into the atmosphere. As a result of oxidation, the space which was filled with organic matter before the firing is now empty, and the pottery is porous.

- heating from 450 to 600°C – This is the dehydration phase, during which water evaporates from the clay. At temperatures between 500 and 600°C, many materials included either naturally or secondarily in the clay disappear in the form of gases: carbon, salts, carbonates, sulphides. This causes shrinkage during the gradual drying, in which the vessel can lose more than 15% of its original pre-firing mass.

- heating from 430 to 850°C – In this phase, clay minerals are thermally broken down and synthetized, in that clay particles at temperatures this high begin to change, melt and combine among themselves. At temperatures above 900°C, clay minerals lose their structure completely and form new silicate minerals. The temperature must be above the threshold which will allow the sintering process to begin, and enough time should elapse for the process to be completed. The final result of sintering will be a harder, denser and less permeable wall. All products made of clay which were fired at such temperatures can be considered ceramic products. When analysing the approximate temperature of firing of 'archaeological' pottery, information about some minerals which can be found in clay either as primary or secondary inclusions can be helpful, since those minerals change their form at precisely specified temperatures: quartz (passes through three structural modifications: at 573°C, 867°C and 1250°C); calcite (740–800°C); kaolin (585°C); halosite (558°C); montmorillonite (678°C).

- heating from 750 to 850°C – Most of the organic material present in the clay will burn off in this phase. At temperatures above 700°C, most clays can be described as fired, and for many types of vessel the firing process ends at this stage.

- 950°C – At temperatures above 900-950°C, the process of melting, or vitrification, begins. It only occurs at such high temperatures, when silicate minerals and oxygen are so hot that they begin to melt into a liquid mixture, thus creating a glassy structure. Following vitrification, the fired clay is less porous and more compact, and is extremely strong after cooling. The process rarely begins at temperatures below 900°C, and it therefore cannot be identified on prehistoric pottery. At temperatures up to 900°C all the carbon will burn up, except for graphite, which can withstand heating to 1200°C.

- heating from 1050 to 1200°C – At these temperatures, feldspar begins to melt. Pores in the pottery walls are closed, and porosity is rapidly reduced.

- the firing process is terminated when no more new fuel is added, or when the remaining fuel burns away (Rice 1987: 102–104; Sinopoli 1991: 27–33; Horvat 1999: 50–52; Goffer 2007: 241–243).

Cooling is a very important step in the pottery production process, because it can cause cracking and change of colour. In the case of open firing, vessels can be cooled in two ways: gradually, which means that they are left on the fire until it is completely extinguished; and in the air, where they are taken out of the fire and left in the air, but in the immediate vicinity of the firing pit or fireplace. The latter process will cause changes in colour caused by contact with the air, resulting in red and/or brown patches on the vessel's surface.

Pottery-firing technology can be divided into two categories:

1. Open firing, without structure (in an open fireplace or in a pit), together with the fuel (*Figs 13, 14, p. 56*). This technique requires a lot of skill to be efficient. The maximum temperature that can be achieved by this firing method is up to 900°C (and it is usually between 500 and 900°C). Thus, the quality of pottery which contains shell or calcite temper, for example, will deteriorate at temperatures above 800°C. Once the firing is under way, it is impossible to control the atmosphere, the maximum temperature is reached very quickly, in less than half an hour, but the temperature peak is short-lasting (Tite 2008: 219; Albero 2014: 105–107).

The positions in which fuel and vessels are set before firing can influence the passage of air, but it is very difficult to maintain a real oxidizing atmosphere throughout the firing process. Due to the unbalanced and uncontrolled atmosphere, the pottery is poorly fired and more charred. While the fuel burns, the vessels are exposed to the air. Abrupt cooling can cause cracks in the rims of wide-mouthed pots, which is why they are often fired upside-down. When inverted, their rims heat up more slowly, and they are also insulated by ashes and embers during cooling. Firing in a pit is especially suitable for producing black pottery because of the lack of air, while oxidation can be achieved by exposing the vessel to the air while its temperature is still high (Rye 1988: 98). Under such conditions, pottery rich in organic material can achieve a reducing atmosphere within its walls (Albero 2014: 107).

From a practical point of view, open firing has certain advantages. Kilns are static, always in the same place, whereas open firing can be performed in different places, depending on the weather and spatial circumstances. In contrast to kiln firing, which belongs among spatially limited activities, open firing is a spatially flexible activity which enables potters to move the firing location, and they are often constrained to do so to improve firing conditions (Arnold III 1990). Such moves are prompted by constant and rapid changes in the direction of the wind, which causes uneven firing temperature, resulting in the cracking of vessels (Rye 1981; Rice 1987). The firing location cannot be changed only if the space available in the settlement is limited and the demand for products higher, which will also impact the organization of the production. For this reason, the selection of the location for open firing, and its spatial flexibility, depend on spatial and weather-related features, and only to a lesser extent on technological aspects (Arnold III 1990: 928).

2. Closed firing (or kiln firing), where the pottery is separated from the fuel. The advantages of kiln firing are: the ability to achieve temperatures in the range between 1000 and 1300°C, a controlled atmosphere and controlled duration of the temperature rise. The maximum temperature is reached within an hour, sometimes longer. However, that temperature can be maintained over a longer period, up to half an hour (Tite 2008: 219–220). The first kilns came into existence when protective structures and vaulting were raised above fireplaces. These made it possible to maintain the temperature and isolate the firing place from cold air. Later, the fireplace was separated off from the firing chamber, and when chimneys, exhaust ducts and partitioning grids were added, the draining of smoke from the firing chamber was improved, resulting in a full oxidizing or reducing atmosphere (Horvat 1999: 47–50).

Various archaeometric analyses enable us to establish the firing method and temperature, on the basis of structural changes which occurred in minerals at specific temperatures, and decomposition of other natural or deliberately added tempering (carbonates, clay minerals, organic substances etc.). In this field, the contribution of experimental archaeology has been significant.

POST-FIRING TREATMENT

The last phase in the pottery production involves the painting of vessels, using natural materials from the surrounding area, such as minerals resulting from the decomposition of iron oxides (hematite, magnetite). Diverse coatings should also be mentioned here, such as wax, resins and plant juices, which were applied to vessels to make them less permeable, as mentioned in the previous chapter.

An interesting example has been recorded in Slavonia, in the village of Novo Selo, near Požega, where potters fired *pokljuke*[1] and, immersed them, while they were still hot, in a liquid mixture of hot water, soot and wheat flour. Once taken out, they were additionally coated using a cloth dipped in soot, to obtain a high gloss and to cover places of unequal colour on the vessels. This procedure was called *farbanje (colouring)*, but also *kalaisanje (tempering)*, and since tempered vessels are considered stronger (Lechner 2000: 316–317), this procedure was probably traditionally associated with quality enhancement, and not only with the glossy-surface effect.

As we can see, various technological choices depend on the purpose or function of the vessel, and not only on its mechanical and thermal properties, and they are determined by whether the prospective vessels will be used for storing, cooking, serving or transporting. Different criteria will determine the pot's size and shape, its wall thickness, and the quantity and type of tempering.

Finally, it is worth emphasizing that, in the entire *chaîne opératoire*, the major role is played by the potter, whose technological choices shape the final vessel. His knowledge, experience and understanding of what is technologically achievable and socially acceptable profile his technology, depending on his social context and the geographical features of his environment (Sillar & Tite 2000; Tite 2008). In addition, there is a difference between individual choice and social choice (Sillar & Tite 2000: 9–10). The individual choice of each potter depends on his social background, perception, acquired knowledge and skills. However, even innovation requires an understanding and knowledge of previous technological processes, and it will also depend on the potter's skill to implement in practice what he has learned.

There have always been, and there always will be, potters who are better and those who are not, and their skill in pottery manufacturing will depend as much on the potter as on the vessel.

1 Pokljuke are earthen lids (so-called 'bells'), which were used for baking bread and meat in the fireplace. Other names in Croatian are peka, pekva, cripnja, crepulja, sač (Lechner 2000: 304).

For some vessels, it will be necessary to invest more knowledge, skill and energy than for others (depending on how complex they are), and the so-called technological signature, or the technological understanding of each single potter, will leave its mark in the vessel's record.

Surely, it would be difficult to imagine a potter spending his days measuring, experimenting and 'compiling notes' on certain types of clay, proportions of tempering and sizes of grain, until he obtains an ideal paste. Still, there is no doubt that bad experiences with certain clays and tempers did occur and that potters made their technological choices with the goal of developing a recipe whose quality would be sufficient for a specific type of vessel and the function it should serve. As archaeological and ethnoarchaeological examples demonstrate, technological choices depended on a number of interrelated factors: the production's environmental, economic, social, political, ideological and traditional contexts.