# EXPERIMENTAL (RE)CONSTRUCTION AND USE OF A LATE CUCUTENI-TRYPILLIA KILN

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**Abstract:**
*This paper describes an archaeological experiment which took place in September 2017 in Stolniceni, Edineț County, Republic of Moldova, based on the recent discovery, in the Cucuteni-Trypillia site from the locality, of an exceptional two-chambered updraft kiln. First are presented the phases of the (re)construction of the complex, which strictly followed the dimensions and constitutive elements of the original discovery. After the kiln was finished and dried, a first attempt was made to fire a batch of about 50 vessels of various sizes. During over 10 hours of continuous firing, the kiln worked perfectly, with no incidents that could jeopardize the pottery. In the end, although the vessels seemed to be very well fired in an oxidizing atmosphere, it was proved that the temperatures reached in the kiln (measured with Orton temperature cones and confirmed by a series of XRD analyses) were inferior to those known (based on analyses) for Cucuteni- Trypillia ceramics. However, this first experimental attempt allowed some interesting observations, being a step forward in understanding this complex chaine opératoire of prehistoric pottery production.*

**Keywords**: *Cucuteni-Trypillia Culture; pottery kiln; experimental archaeology; firing temperatures; XRD analysis.*

## INTRODUCTION

The experiments carried out in 2017 were possible due to the identification, through magnetic survey (2015), and subsequently followed by an exhaustive archaeological research (2016) of an impressive pottery firing complex in the large Late Cucuteni–Trypillia settlement of Stolniceni I (Edineţ County, Republic of Moldova). The archaeological feature was composed of a two-chambered updraft kiln with an adjacent pit allowing the easier access to the fire chamber[1]. The kiln itself consists of a lower, buried fire chamber with two channels in which the fuel was burnt, and an upper chamber in which the pottery was stacked to be fired (Pl. I). The two chambers were partially separated in the past by two oval clay slabs which served also as stands for the pottery load (one was found *in situ*, collapsed inside a fire channel). Between the kiln and the pit, in front of the fireboxes was an oval clay platform – a hearth on which the combustion of the fuel took place during the firing (Pl. I).

Given the excellent state of preservation and investigation of the kiln, the first author's previous interest in pottery pyrotechnology/experimental archaeology[2] and the invitation made by the Stolniceni

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[1] For a thorough description of the kiln excavation, sizes and characteristics, see Tserna, Rassman, Rud' 2017.

[2] TENCARIU 2004; 2015: 159-186.

site's research team, a decision was taken to try a preliminary construction and use of an experimental kiln inspired by this remarkable discovery. The experiment took place near the Stolniceni village between 7-19 September 2017, it involved five archaeologists and, depending on the various stages of construction, two to five local day laborers. The raw materials used for the construction were clay (from a local source, located about one kilometre away), chaff, water, and willow twigs.

## THE CONSTRUCTION OF THE KILN

From the beginning, we must mention that, at this preliminary stage of experimentation the interest was focused especially on assessing the firing performances of such kiln and not so much on its construction using only prehistoric tools and means. Therefore, almost all the activities involved by the actual making of the kiln (digging, extracting, transporting and preparing the clay, building the vault etc.) were accomplished using modern tools and containers (spades, shovels, pickaxes, plastic buckets, plastic bags); as consequence, no special attention was paid to the timing of these steps. However, we kept a clear record of the amounts of raw materials used and, also, we tried to follow exactly the dimensions and constitutive details of the original kiln. As mentioned above, the kiln was constructed at the edge of the Stolniceni village, on a piece of land between the base of the archaeological team and a large fruit store[3], ca 3 km NE from the site.

First, a strip of land (~ 5 x 8 m, oriented E–W, Pl. II.1) was cleaned of vegetation and deepened by 40-70 cm, depending on the unevenness of the ground, until right above the sterile soil. Then, the elements of the kiln were marked on the ground and the soil was removed from the lower part of the upper chamber, the two fire channels, the firing platform in front of the kiln and the adjacent pit (Pl. II.2-3). As in the original kiln, several components (the base of the upper chamber and the fire channels and boxes) were plastered with a thin layer (1-2 cm) of sandy clay (Pl. II.4-5). Two slabs (quasi-oval shape, ~ 60 x 40 x 8-10 cm) of clay mixed with chaff (one made at the beginning of the construction, left to dry inside, the other made directly in the kiln, on a few sprigs) were placed above the fire channels, approximately in the middle of the upper chamber, so that enough space remained at the channels edges to ensure the draught during the firing (Pl. II.6). On what concerns the superior part of the upper chamber (the vault), the archaeological data were not so generous, since only a few pieces of burnt wattle and daub were found within the remains of the kiln. Our hypothesis (supported by countless other archaeological and ethnographic data) is that it probably was made also of clay mixed with chaff in the shape of a vaulted arch, with an opening above for placing the vessels inside and, of course, for the draught. Consequently, we built a wicker frame, placed it above the kiln and started to raise the vault in the technique of wattle and daub, with clay mixed with chaff and water (Pl. III.1-5). We stopped adding clay at a height of 80 cm above the ground, so that the upper opening measured 60 cm in diameter. For this stage of construction, we used roughly 500 kg of this mixture (of which 30 kg of chaff). After finishing the construction of the kiln (Pl. III.6), it was left to dry for two days, both naturally – under the sun, and artificially by making small fires on the firing platform (Pl. III.7).

The final dimensions[4] of the whole experimental complex were as follows: the upper chamber, at its base measured 170 cm (EW) x 175 cm (NS) in diameter, with a total height of 100 cm (of which 20 cm were below the surface and 80 cm belonged to the constructed vault); the two oval-shaped fire channels of the lower chamber measured 110 cm (N) and 105 cm (S) in length, with a maximum width of 35 cm (both) and 50 cm in depth; the fireboxes – the extensions of the channels dug horizontally towards the firing platform – quasi-rectangularly shaped, measured approximately 25 cm in height, 30 cm (N) and 28 cm (S) in length; the firing platform in front of the kiln measured 120 cm (the long axis – EW) x 105 cm (the NS axis), being

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[3] We thank Victor Băjereanu, the owner of the local business who offered accommodation and storage space for the archaeological team, also ensuring the place and support for the experiments.

[4] The depths are considered in relation to the surface of the experiment area flattened by excavation, not to the actual ground surface.

arranged at a depth of 75 cm; the adjacent pit, with a depth of 130 cm, had an oval shape of approximately 180 (EW) x 150 (NS) cm.

## THE FIRING

Since the beginning of the experiment, we also tried to make several ceramic objects to be fired in the kiln, using a local clay from a source near the archaeological site. The lack of both time and necessary skills resulted in only seven vessels of small and medium dimensions (manufactured in the coiling technique) and other eight objects (statuettes, miniature chairs, tokens) (Pl. IV.1-3), quantity far from being sufficient for a proper firing in a kiln of such dimensions. The problem was solved through the acquisition of 32 unfired vessels of medium to large sizes (Pl. IV.4-5) from Vasilii Gonciari, a well-known potter from Hoginești village, R. of Moldova. Another difficulty encountered was an acute crisis of firewood in the area; again, the support of the local land owner saved the day, by granting us unlimited access to its stock of dried apple wood resulting from cutting an orchard a few years ago. All these problems eliminated, we were ready for the firing.

Prior to raise the clay vault, to estimate the temperatures raised during the firing in different places of the kiln, we placed inside seven sets of Orton temperature cones, five on the base of the upper chamber, two on the back of the fire channels (Pl. II.6). Each set contained eight cones (018, 016, 014, 012, 010, 08, 06, 04), with bending temperatures starting from 712 to 1060 °C.

The firing started in the morning of 18 September, through an initial heating of the kiln without vessels inside, in order to eliminate the remaining moist (Pl. IV.6). After three hours, we started placing the vessels in the upper chamber, scattered across its surface (on the clay slabs, on the inner wall, on the edges of the channels – against the wall of the vault) both in vertical and horizontal position, some put one over the other (Pl. IV.7-8). We estimate that only around 40% of the kiln capacity was occupied by this batch. At 13:35, a small fire, of dried twigs and thin branches, was started on the firing platform, at about 50 cm in front of the fire boxes, in order to slowly, gradually raise the temperature inside the upper chamber (Pl. V.1-2). Bit by bit, the fire (made of the same soft wood) was pushed towards the fire boxes, but without going inside. Already, the draught seemed to work perfectly, the flames and the smoke being drawn inside. At one point, the fear that the upper opening is too wide – preventing the rise of temperature – has come true, so we partially covered it with two thin clay slabs, previously prepared for this scenario. At 15:10 we started feeding the fire with hard, apple wood. The pieces of wood were stacked obliquely towards the fire boxes (Pl. V.3-4), so the heat and flames were directed only onwards, into the kiln. From time to time, removing the embers and the ash was necessary. Around 19:30 the vessels from the back of the kiln have become incandescent, showing that the powerful draught has favoured the increase in temperature especially in this area (Pl. V.5). At 21:15 we decided to raise the stake by pushing the fire in the fireboxes, but not yet in the fire channels. This seemed to lead to an increase of temperature, but it has made more difficult the removal of the embers. Slowly, the fire was pushed further into the fire channels (Pl. V.6), which determined the strong flames to run through the upper chamber, sometimes going out through the opening on top of it; also, the sound of the draught became very impressive, like that of a steam locomotive. At 23:30 we stopped refuelling the fire, after fully loading both the fire channels and fire boxes with wood. 0.6 m$^3$ of hardwood (apple wood) and approximately 0.2 m$^3$ of softwood were consumed over the firing. Ensuring that there was no fire hazard, we let the furnace cool down over the night.

Next day, around 10:30, the kiln was still quite hot, the channels being filled with active embers. The vault did not collapse (although its wooden structure burned very quickly), looking red brick at the interior (Pl. VI.1-2,4). Above and around the fire boxes, the clay burned to red on seven to eight centimetres length, and so did the inner wall on its entire width (23 cm) (Pl. VI.5). The clay slabs intended to narrow the upper opening were strongly burned on the surface exposed to fire. Most important, the vessels looked well fired, in a perfect oxidising atmosphere, with no waste (Pl. VI.3,5). However, the Orton temperature cones on the surface of the upper chamber showed no changes, which indicated that the temperature did not exceed 700°C. The two sets placed on the back of the fire channels showed that here the temperature raised beyond

850°C (maybe reaching 900°C). Given the strong fire and the general aspect of both the kiln and the pottery, we were rather sceptic about the accuracy of the cones, so we verified the firing temperatures through archaeometric methods.

## ANALYTICAL PROCEDURES AND RESULTS

The *firing technology* applied by the Cucuteni artisans can be inferred from the mineralogical composition of the ceramic ware. The main factors, which influence the firing process, are represented by the maximum temperature, heating rate, soaking time, duration and thermal homogeneity. The determination of the *firing temperatures* is very useful for evaluating the performance of the kilns used in their manufacture and the technical skill of the Chalcolithic potters. Besides offering an answer to the previously mentioned archaeological research questions, this information is necessary for setting up experiments in which building and firing full-scale replicas of excavated pottery kilns are targeted.

Although the assessment of the *firing temperatures* represents one of the main focuses of pottery studies using archaeometrical methods there are some unsolved issues connected with its meaning and the scientific methods used for its determination. Previous studies have reported a large variation between the *maximum temperatures* reached in different parts of the kiln even in a single firing[5]. Another problem is related to the *soaking time* registered during firing since it drastically alters physical, microstructural and mineralogical properties of the ceramic product[6]. Accordingly, it is more appropriate to estimate an overall range of firing temperatures rather than high precision determinations of firing temperature. Hence, it is more suitable to use the term *equivalent firing temperature* to display the temperature range at which an identical mineralogical composition could have been produced[7].

The estimation of the *firing temperatures* can be pursued from the mineralogical composition based on the assumption that during firing the clays are subjected to a series of changes. These changes normally consist in the loss of water from the clay minerals and from other hydroxydes, the decomposition of the carbonates and the formation of new phases and crystalline minerals[8]. The nucleation of newly-formed minerals at certain specific temperatures can be determined by X-ray diffraction (XRD). Due to this fact, XRD is considered as one of the most reliable methods for inferring the firing temperature of ceramic artefacts.

In this way, we have determined the *equivalent firing temperature* based on their mineralogical composition for nine pottery samples located in different parts of the kiln and for one from the kiln's vault (Pl. VII.5). A small piece of each body (about 3 g) was cut with a diamond saw and was then ground in an agate mortar.

The mineral composition of both pottery and kiln samples were determined by XRD analysis using Shimadzu LabX XRD-6000 powder diffractometer with a diffracted beam graphite monochromator of CuK$_\alpha$ radiation ($\lambda$=1.5406 Å). The specimens mounted in reflection mode were analysed in ambient atmosphere over the range $2\theta$ = 5-80° with scanning angle rate of 0.03° and a 2 s/step count time. Identification of crystalline phases by XRD was carried out using the International Centre for Diffraction Data Powder Diffraction Files (ICDD PDF).

The mineralogical components of the pottery and kiln samples showed quartz, plagioclase, illite/muscovite, chlorite, calcite, dolomite, diopside as the main phases. Although the clay minerals (illite/muscovite and chlorite) are one of the first affected by firing induced transformations, when present they are an indicator for the low firing regime. According to the phases detected, the pottery and kiln samples divides into three groups: one group contains the samples listed in Pl. VII.1, a second group includes the samples presented in Pl. VII.2 and 3 and a third group (Pl. VII.4) which corresponds to the kiln sample.

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[5] THÉR 2013 with references therein; ERAMO, MAGGETTI 2013.

[6] NORTON 1931; NORTON, HODGDON 1931.

[7] TITE 1969.

[8] RICCARDI, MESSIGA, DUMINUCO 1999; CULTRONE *et alii* 2001; MARITAN *et alii* 2006.

A schematic representation of the mineralogical transformations showing the appearance and disappearance of minerals at a certain temperature range as previously reported in the literature[9] is presented in Table 1.

| Minerals | RT | 300°C | 350°C | 400°C | 450°C | 500°C | 550°C | 600°C | 650°C | 700°C | 750°C | 800°C | 850°C | 900°C | 950°C | 1000°C | 1050°C | 1100°C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| q | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 |
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**Table 1**: Diagram presenting the mineralogical phases detected in the pottery and kiln samples and their thermal transformations range (q=quartz, pl=plagioclase, il/m=illite/muscovite, cl=chlorite, ca=calcite, d=dolomite, di=diopside).

Chlorite is one of the first mineral phase, which began to decompose during the firing process at a relatively lower temperature. It starts to collapse between 500°C with the disappearance of the (002) reflection and continues to breakdown until the (001) reflection disappears at about 650°C[10]. Dolomite starts to decompose at around 650°C into calcite and magnetite and the decarbonation process continues for dolomite up to 700°C[11]. The dissolution of calcite and illite/muscovite was reported to end between 800-850°C[12]. In our pottery samples magnetite or hematite were not reported as secondary minerals related to the firing atmosphere present within the kiln. Although no specific Fe-bearing phases have nucleated due to the low temperature exposure, previous experimental analysis have reported the presence of both Fe(II) as related to chlorite and of Fe(III) as embedded within the chlorite and illite sites[13]. Diopside represents the only newly formed mineral, which appears due to the reaction of dolomite with quartz at 800-850°C[14].

All the pottery samples presented in Pl. VII.1 were located in the western part of the kiln, near the firing entrances. The mineralogical phases determined by XRD analysis are very similar and consists in illite/muscovite, chlorite, quartz, plagioclase, calcite and dolomite. Based on the absence of the (002) reflection of chlorite, and the highly intense (001) reflection of the same mineral we may assume an *equivalent firing temperature* higher than 500°C but lower than 650°C for the pottery samples located near the firing entrances.

Pl. VII.2 shows a group of pottery samples located in the backside of the kiln, also, on the western side. Unlike the samples located near the firing entrances, this group is characterized by the disappearance of both reflections of chlorite and of dolomite. Illite/muscovite even if shows a decrease in the peak intensity, is still detectable. The mineralogical transformations affected the initial clay minerals and the carbonates, which allows as to estimate an *equivalent firing temperature* that exceeded 700°C but without attaining 800°C.

The mineralogical composition of the sample taken from the vessel presented in Pl. VII.3 is very similar with the one of the group of potshards listed in Fig. 3. A slow difference in the firing temperature may be inferred from the diminishing of the illite/muscovite peak intensity, which allows the estimation of a temperature in the range of 750°C but without attaining 800°C.

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[9] MARITAN *et alii* 2006; MARITAN, MAZZOLI, FREESTONE 2007; TRINDADE *et alii* 2009.

[10] MARITAN *et alii* 2006.

[11] TRINDADE *et alii* 2009.

[12] RICCARDI, MESSIGA, DUMINUCO 1999; MARITAN *et alii* 2006.

[13] MARITAN *et alii* 2006.

[14] TRINDADE *et alii* 2009.

The mineralogical composition of the sample taken from the kiln displayed in Pl. VII.4 exhibits some differences in comparison with the pottery samples. Although exhibits the presence of the main illite/muscovite reflection peak displays also the appearance of diopside as a newly formed Mg-silicate. Based on the maintenance of the illite/muscovite and calcite and the appearance of diopside we estimate that the temperature range attained 800°C but without exceeding 850-900°C.

Thus, without any doubt, the Orton temperatures cones were also accurate, both methods showing that the temperatures obtained in the kiln were not as high as expected.

## OBSERVATIONS AND FINAL REMARKS

Strangely enough, even though such complex kilns were discovered quite often in the last decades in the Cucuteni – Trypillia area[15], the experimental work (which looks very tantalising) involving such items is rather disappointing (not to say almost non-existent[16]). Such approaches could provide useful insights from several points of view, including, first of all, the technological choices and challenges implied by constructing and using kilns, but also information about the social and economic context of pottery production, in terms of production scale, necessary manpower, raw material consumption etc.

In what concerns the kiln from Stolniceni, as mentioned before, its state of preservation and, most important, the technique of excavation and the rigor of the archaeological observations makes it a “Rosetta Stone” of any experimentalist. This first attempt (hopefully only the beginning of a long-term experimental project at Stolniceni), even if not perfect - due to smaller or greater errors, drawbacks and improvisations, allows a few observations and thoughts about the prehistoric ceramic pyrotechnology. First, one should observe the superiority of this kiln over other types of firing installations, in terms of thermal efficiency and ergonomics. The separation of the two chambers allows a gradually and slowly heating of the pottery, exempting it from any thermal shock and hence reducing the amount of waste. It also favours the development of high temperatures, of over 900 °C, proper for a pottery of good quality. Of course, this was not the case of our experiment because we made a mistake in making a too wide upper opening, which determined important loss of heat; also, the insufficient load of the kiln might have played a role in it. However, one can notice that both the Orton cones and the XRD analysis showed a higher temperature in the fire channels, in the back of the kiln (eastern part) and also at the upper part of the vault. For the fire channels, a higher temperature is easy to explain, because there burned the fuel. For the other two areas, the strong draught pushed the hot air towards the back and the upper part of the kiln.

For the future experiments, we intend to remedy these shortcomings and, for certain, try a different approach of the vault, in the sense that it should have a much narrower opening, or it might not be necessarily built of clay (which involves a lot of materials and work, and it is insufficiently supported by the archaeological evidence). Instead, the pottery load might have been insulated by large shards or other materials. Hence, with respect to the methodological rules of scientific experiment, a set of working hypotheses will be framed, followed by their systematic experimentation. The validation or, on the contrary, the invalidation of such hypothesis will provide necessary data for a plausible scenario of the *chaîne opératoire* of pottery firing.

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[15] TSERNA, RASSMAN, RUD’ 2017: 318-325.

[16] To our knowledge, the only attempts involving two-chambered kilns, relatively well-documented and following the scientific rigors of the experimental archaeology are those of Dragoş Gheorghiu, at Vădastra, Romania (GHEORGHIU 2002; 2007; 2014).

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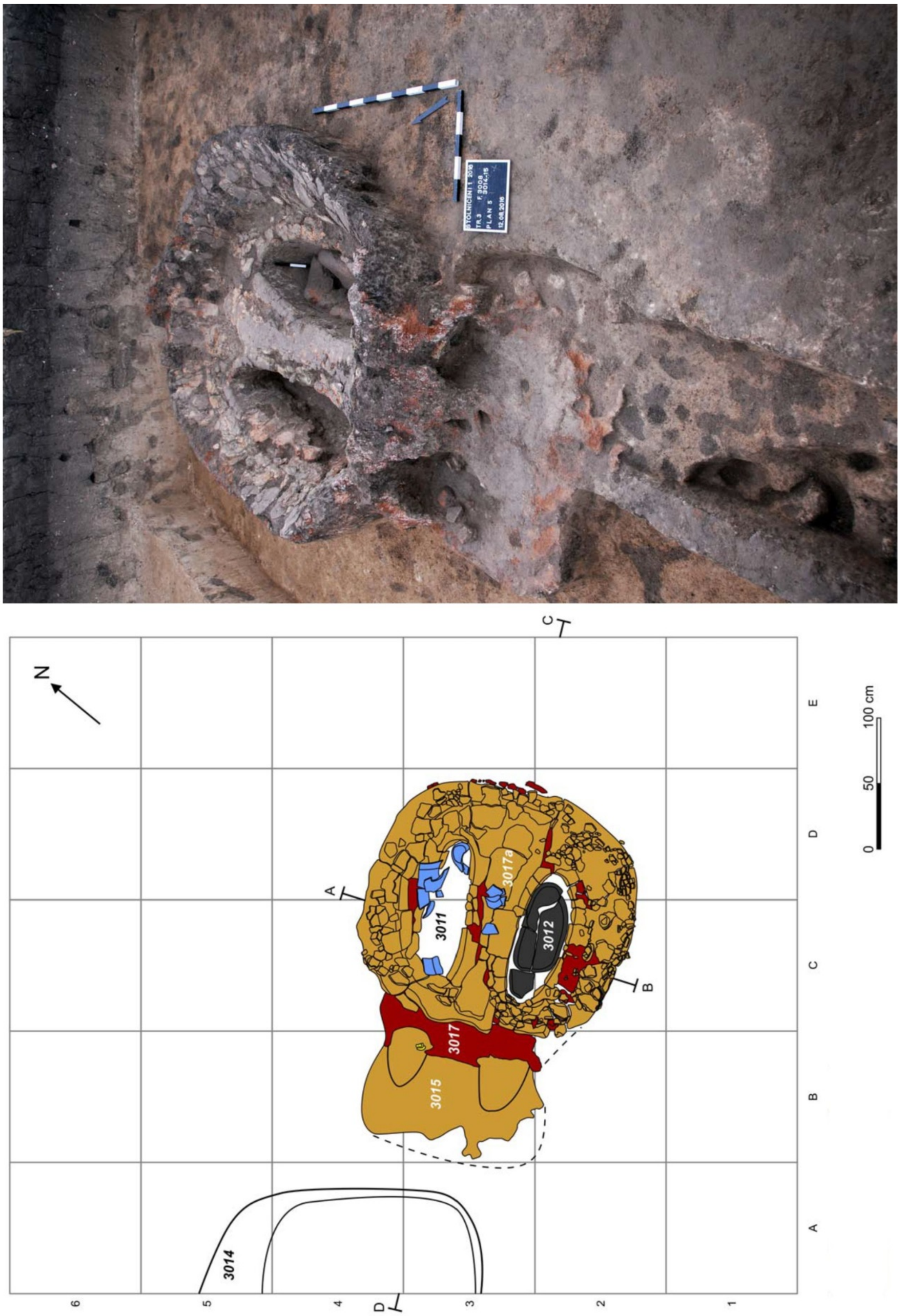


Pl. I. The two-chambered kiln discovered in Stolniceni I site (after TSERNA, RASSMAN, RUD' 2017).

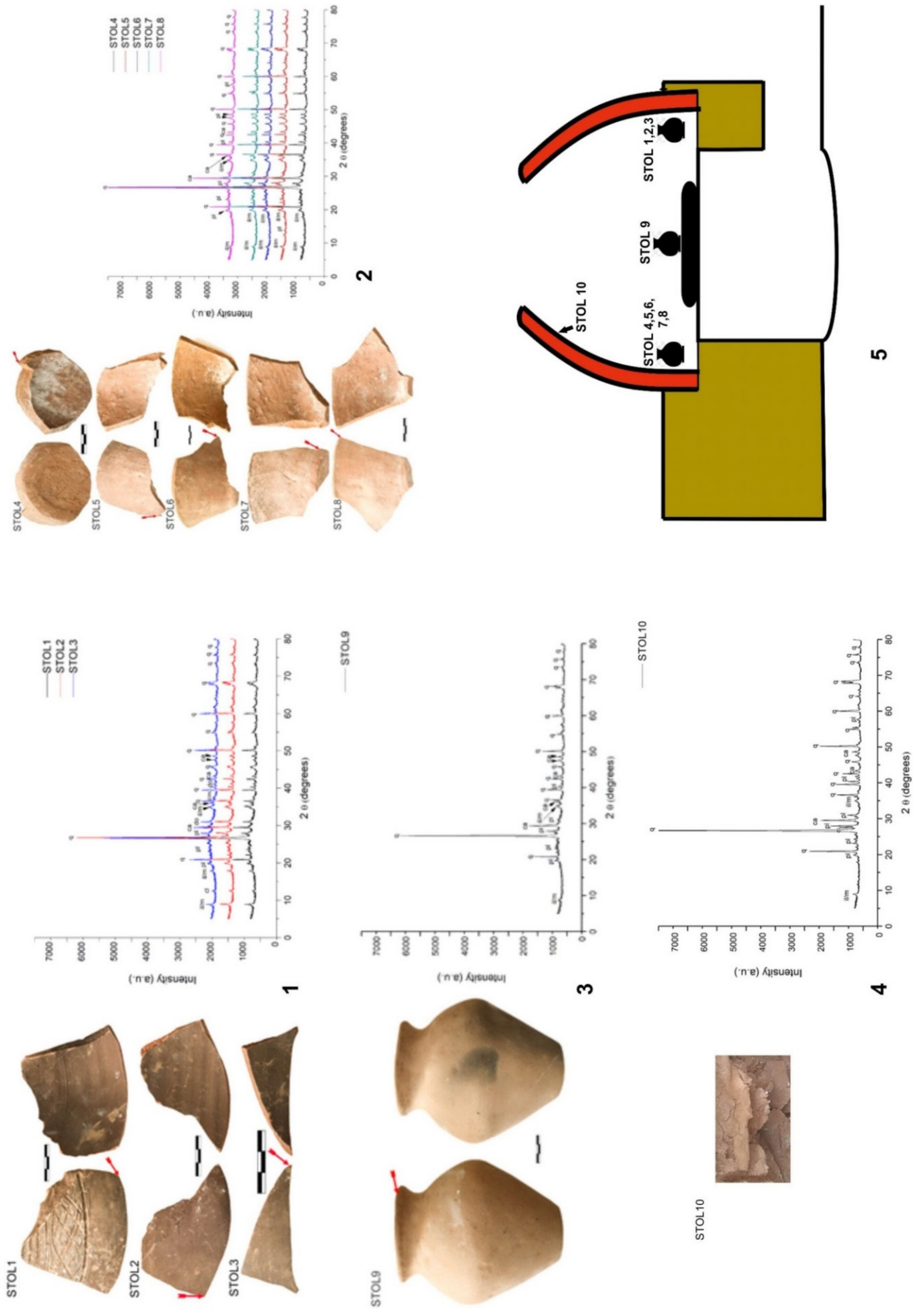
Pl. II. Construction of the experimental kiln: 1. Preparing the location; 2-3. Digging the buried constitutive elements; 4-5. Plastering the chambers with sandy clay; 6. The base of the upper chamber, with the two clay slabs and the Orton temperatures cones (photos by the authors).

Pl. III. Construction of the experimental kiln: 1-3. Building the wicker frame of the vault; 4-5. Raising the vault in the technique of wattle and daub, with clay mixed with chaff and water; 6. The kiln; 7. Drying the kiln (photos by the authors).

Pl. IV. 1-3. Making pottery to be fired in the kiln; 4-5. The unfired pottery, ready to be loaded in the kiln; 6. The kiln place, view from above; 7-8. Loading the kiln (photos by the authors).

Pl. V. The experimental firing: 1-2. Heating the kiln; 3-4. Firing; 5. Incandescent pottery, during the late phase of firing; 6. The final phase of the firing – the fuel is pushed into the fire channels (photos by the authors).

Pl. VI. The kiln and the pottery after firing (photos by the author).



Pl. VII. 1-4. Pottery samples and the XRD patterns of the main mineral components (q-quartz, cl-chlorite, il/m-illite/muscovite, pl-plagioclase, ca-calcite, do-dolomite, di-diopside); 5. Location of the samples inside the kiln during firing.