RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

A pottery kiln from the second half of the 13th century in Žďár nad Sázavou – Staré Město (Czech Republic): Technological analysis of its batch

Hrnčířská pec ze druhé poloviny 13. století ze Žďáru nad Sázavou – Starého města: Technologická analýza vsádky

Karel Slavíček – Kateřina Těsnohlídková – Martin Košťál – Dominika Václavíková – Kristýna Trnová

This study investigates a medieval pottery kiln and its fill excavated at a 13th-century settlement site near the Žďár Cistercian monastery. The short 30–40 year lifespan of the settlement provides valuable insight into how pottery was made and appeared in a chronologically specified timeframe of the mid-13th century. The kiln was a single-chamber type, either with an open-topped or domed superstructure with a very narrow stoking channel in terms of height. Technological analysis of the pottery inside the kiln points to consistent production techniques utilising a combination of coiling and early rotational devices with rapid firing practices. The interpretation of the forming technique is backed by 3D scanning, which quantifies the wall thickness variability over various vessel body parts. Cross-analysis with settlement finds shows a uniform ceramic morphology and technological nuances, with petrographic data suggesting both local and external material influences. The study enhances the understanding of the socio-economic dynamics during medieval colonisation based on the case of the Žďár region and provides a benchmark for regional ceramic research.

Middle Ages – Bohemian-Moravian Highlands – Žďár nad Sázavou – pottery kiln – pottery production – petrography – XRF analysis

Tato studie zkoumá středověkou hrnčířskou pec a její výplň odkrytou v rámci sídliště ze 13. století poblíž cisterciáckého kláštera ve Žďáru. Krátká 30–40letá existence sídliště poskytuje cenný vhled do způsobu výroby a vzhledu keramiky v chronologicky vymezeném časovém horizontu poloviny 13. století. Pec byla jednokomorová buď s otevřenou, nebo klenutou nástavbou s výškově velmi úzkým topným kanálem. Technologický rozbor keramiky uvnitř pece ukazuje na konzistentní výrobní postupy kombinující výrobu z válečků s ranými rotačními zařízeními a s rychlým výpalem. Interpretace techniky tvarování je podpořena 3D skenováním, které kvantifikuje variabilitu tloušťky stěn na různých částech nádoby. Srovnání se sídlištními nálezy ukazuje na jednotnou morfologii keramiky a technologické nuance, přičemž petrografická data naznačují jak místní, tak vnější materiálové vlivy. Studie rozšiřuje poznání socioekonomické dynamiky během středověké kolonizace na případu Žďárska a poskytuje východisko pro regionální výzkum středověké keramiky.

středověk – Českomoravská vysočina – Žďár nad Sázavou – hrnčířská pec – hrnčířská výroba – petrografie – XRF analýza

Introduction

Staré Město, the predecessor of today's town of Žďár nad Sázavou, was among newly founded settlements in the bordering area between Bohemia and Moravia colonised in the 13th century. One of the significant archaeological discoveries at the site was a pottery kiln

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and its batch. Such archaeological contexts are quite rare and generally only five medieval kilns have been excavated in the region (*Zatloukal 1998*, 28–30; *Nekuda 2000*, 110–112; *Kochan et al. 2021*; *Zimola 2021*, 102–117; *Duffek et al. 2022*). The discovery of a pottery kiln in a fully excavated settlement allows for a comparison between the kiln's contents and the finds from settlement contexts. This is made more efficient due to the short-term occupation of the site. A comprehensive interdisciplinary approach involving natural science analyses and experimental archaeology aims to assess the kiln and the pottery found inside, not only within the context of typo-chronology but also the *chaîne opératoire* and regional geology. Since the pottery workshop was part of a settlement with multiple homesteads, ceramic consumption and production can be also examined. Specifically, we will address these questions:

1. Kiln reconstruction and functionality:
   To what extent are ethnographic and archaeological analogies, along with archaeological experimentation, relevant to the reconstruction of the original appearance and function of the kiln?
2. Associated artefacts and workshop layout:
   Is it possible to link archaeological artefacts found in the vicinity of the kiln to pottery production?
   If so, how was the pottery workshop spatially organised during that period?
   How extensive might its production or on-site ceramic consumption have been?
3. Kiln contents and usage:
   Does the ceramic assemblage represent the last firing batch, its remnants, or flawed vessels? Alternatively, could the pottery vessels or their fragments have been reutilised for levelling the kiln floor?
   Does this represent a single-event failure, such as a botched firing, or the abandonment of the kiln followed by its one-off or gradual fill?
4. Local ceramic production:
   What was the local pottery production in terms of raw material provenance, morphology, and production technology?
5. Comparative analysis:
   How does the pottery found in the kiln fit into the context of all ceramic finds on the plot and, more broadly, on the site?

Staré Město site and the kiln

The Staré Město site is located on the northern edge of the town of Žďár nad Sázavou in the central part of the Czech Republic (49°34'11.858"N, 15°55'51.684"E). Today, the site is partly covered by the buildings of a satellite housing estate and partly situated on field parcels along the road from the Klafar spring towards Starý Dvůr. Based on records in the *Cronica Domus Sarensis*, the existence of the settlement is dated to the early period of the nearby Cistercian monastery. The settlement is assumed to have been established in 1252–1257 and abandoned in 1262–1276. Subsequently, the settlement is believed to have been relocated to today's centre of Žďár nad Sázavou. If this were the case, Staré Město would have been inhabited for just a single generation. However, we cannot rule out a slightly longer existence, although archaeological research, which has essentially uncovered the entire area of the settlement, suggests short-term inhabitation without the superposition of archaeological features (see, for example, *Ludvikovský et al. 1964*, 188–194; *Richter 1982*, 254; *Zatloukal 1999a*, 201–203; *Geisler 2004*; *2005*; *2006*).

The site was more closely investigated by M. Richter, who conducted the first extensive excavations (*Richter 1974*, 231–240). Further excavations were carried out by the Institute of Archaeological Heritage Brno under the supervision of M. Geisler in the 1990s, and particularly in 2004–2006 due to the construction of a satellite housing estate (*Zatloukal 1999a*, 193–207). Thus, most of the settlement area has been excavated, but only some parts have been evaluated and published thus far – materials from the 1990s campaign by *Zatloukal* (*1999a*) and pottery from the 2004 excavation season by *Těsnohlídková* (*2021*, 205–257). The entire site is now being comprehensively assessed as part of D. Václavíková's doctoral thesis. The publication and preliminary evaluation of the kiln structure were included in the doctoral thesis of K. Těsnohlídková and in a study in the *Přehledy výzkumů* journal (*Těsnohlídková 2021*, 278–280; *Těsnohlídková 2022*, 61–109). The current state of knowledge on medieval ceramic production in the region was summarised by *Čapek et al.* (*2022*, 138–146).

The remnants of a pottery kiln (feature no. K 1548) were excavated in 2006. However, this feature was not identified as a pottery kiln in the field documentation. It was only in 2020, during a more detailed processing, that it was possible to interpret the original purpose of the kiln. Subsequent research has helped to identify additional potential structures associated with pottery production, thereby defining a probable pottery workshop at the site. In addition to pottery production, a stonemason's workshop and ironworking, encompassing both smelting and blacksmithing, was documented at the site. These crafts were undoubtedly associated with the emerging Cistercian monastery (*Malý – Gonda 2017*, 36; *Kovář 2006*, 65; *Geisler – Malý 2005*, 107–110). The non-agricultural activities confirm the market character of the Staré Město settlement.

Relic of pottery kiln

The pottery kiln had a simple, single-chambered construction embedded into the sandy ground (cf. *Procházka 2015*, 217; *Čapek – Preusz 2019*, 323, tab. 2). The base dimensions of the kiln were 1.2 × 0.95 m with a preserved depth of 0.5 m (*Fig. 1*). The structure had a rectangular layout with rounded corners orientated NNE–SSW. The walls were vertically inclined to slightly embedded, with the floor slightly sloping towards the firing hole. The walls and the floor of the kiln were fired to red, grey, and black shades, with the fired layer on the walls being around 2 cm thick and thinner on the floor. The stoking channel, in the form of a sunken tunnel, connected the main kiln structure with the front kiln pit, which was, however, not identified during the excavation. Channel dimensions were larger by the kiln and decreased towards the front kiln pit. At the kiln's mouth, the pit was 30–40 cm wide and approximately 20 cm deep, while it was about 10 cm wide at the exterior side (*Fig. 2*; *Geisler 2006*, 35).

The fill of the structure was, besides soil, composed of small stones, charcoal, bricks, and fragments of ceramic vessels deposited in at least two layers. Above the fired floor was a continuous carbonised layer with a thickness of 1–3 cm. The structure did not contain any daub or other elements indicating the kiln's construction. Given the relatively low

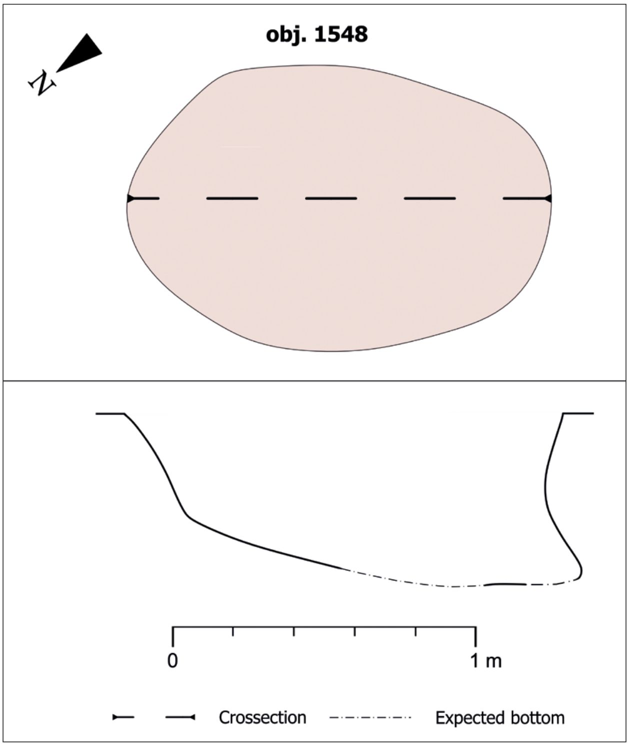

Fig. 1. Pottery kiln, feature no. 1548 (after *Geisler 2006*, fig. 23–24, modified).

firing quality of pottery at the site, the daub might not have been adequately fired and thus not preserved. Several bricks found in the uppermost part of the fill are likely unrelated to the structure's construction and are of a more recent age given the fact they were not in direct contact with medieval pottery. Moreover, finds of medieval bricks are rare at the site. No traces related to the separation of fill and fuel were identified (*Geisler 2006*, 35).

Settlement context of the kiln

Based on preliminary evaluations, the site encompassed 14 dwelling plots organised in two parallel rows. The pottery kiln likely belonged to the dwelling situated roughly in the middle of the southern row adjacent to a stonemason's workshop and seemingly to an ironworking area (*Fig. 3*). The problem is that the 'pottery' plot was located at the border of two separate excavation areas. Each was documented using a different method; hence, there is a possibility of discrepancies between the plans or that some structures might have been overlooked on the peripheries of the research areas or beneath accumulated layers, much like the front kiln pit (*Zatloukal 2000*, 53–56; *Geisler 2005*).

Several other structures were adjacent to the identified kiln K 1548, predominantly settlement pits surrounded by postholes (*Fig. 4*). The kiln and features K 1546, K 1549, K 1550, K 1551, K 1553, K 1563, K 1565 and K 1566 along with the adjacent postholes might constitute a pottery workshop or specialised production area. There was also a well nearby (feature K 1570).

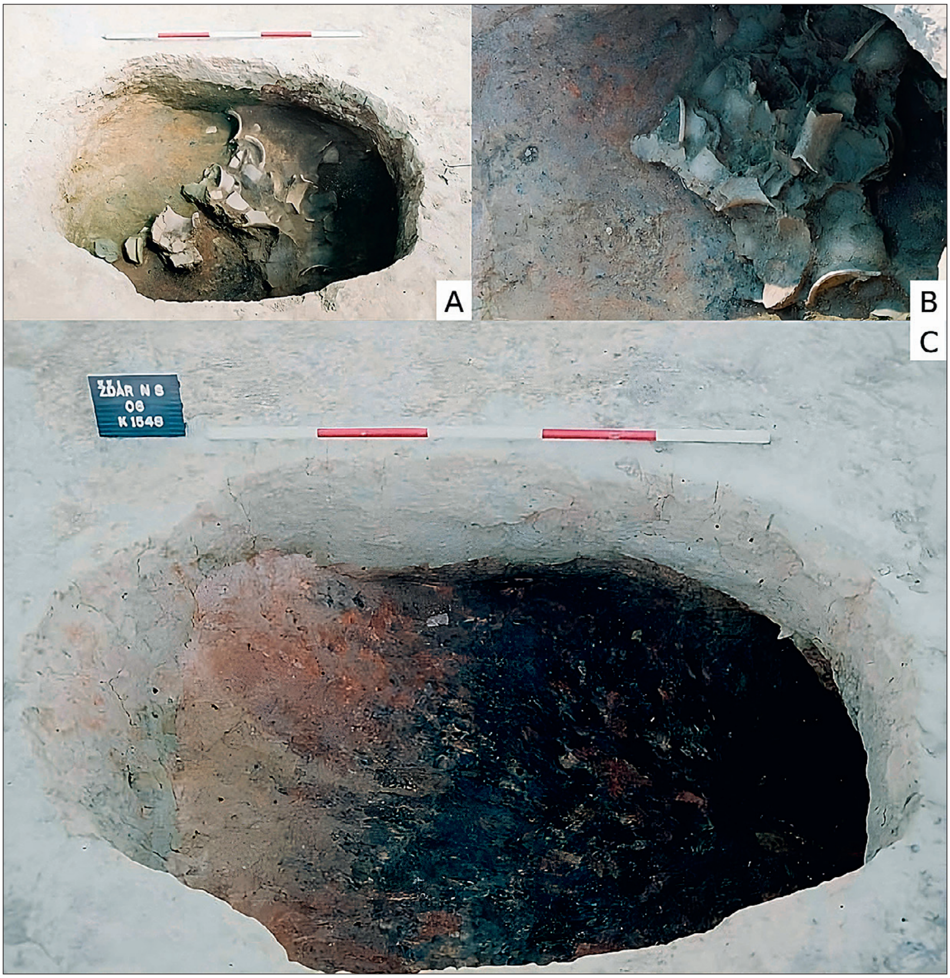

Fig 2. Photographic documentation of the pottery kiln from the excavation report (modified after *Geisler 2006*, tables 12, 14, 16): A – layer of broken ceramic vessels; B – fragments of pottery in the front part of the kiln; C – scorched kiln bottom after excavation.

The surrounding pits formed two distinct clusters in relation to the kiln. The first cluster located in immediate proximity to the kiln consists of features K 1546, K 1550, K 1551, and K 1553. Pit K 1546 directly correlated with the kiln and likely had a structural connection with it. A part of the K 1546 fill was composed of regularly laid out stones, suggesting the presence of a wall or masonry. This wall might have been part of the structure providing roofing to the working area before the kiln. None of the other features in this cluster had any clear structural components and their specific functions thus remains ambiguous. Similarly, the purpose of the second cluster comprising three features situated approximately 5 m from the first cluster – K 1563, K 1565, and K 1566 – could not be discerned. In conjunction with postholes, these three pits formed a rectangular layout hinting at a light above-ground structure.

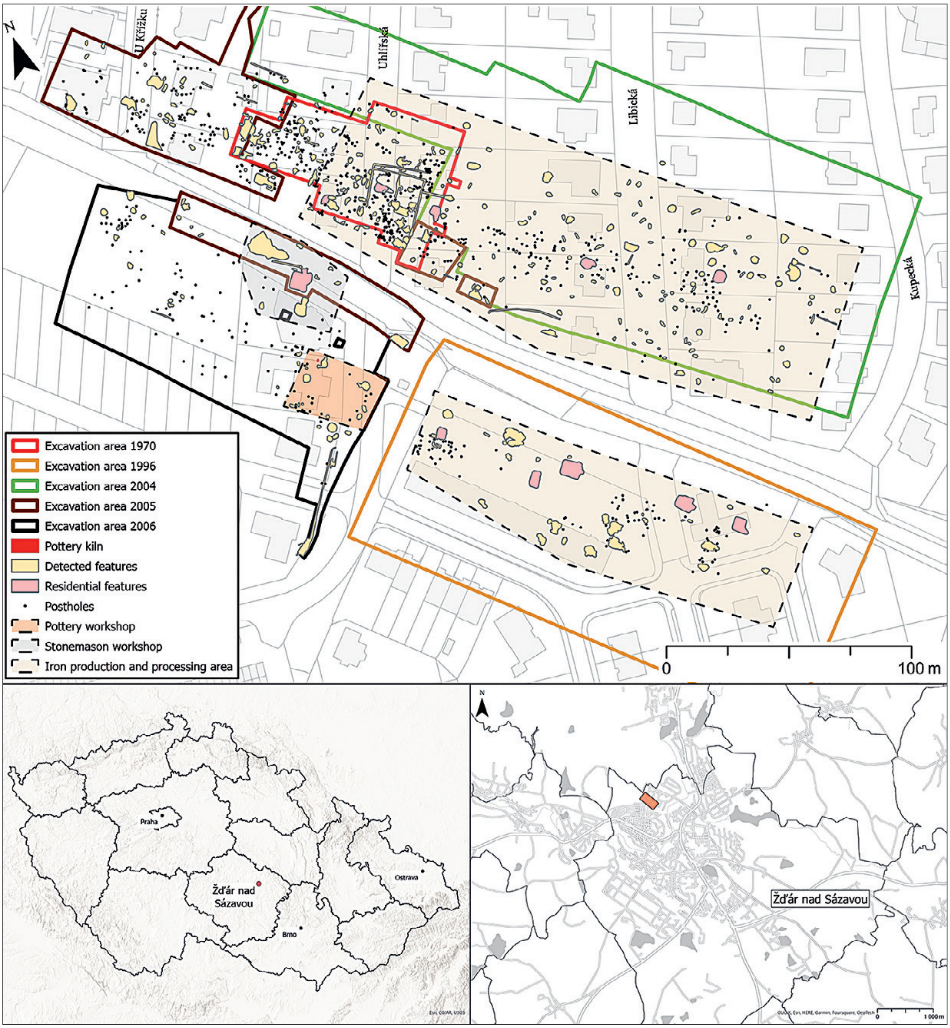

Fig. 3. Location of the Staré Město site and spatial context of the pottery kiln.

To identify a specific residential structure or basement affiliated with the pottery workshop is challenging. This is a complex issue particularly due to disruptions caused by recent construction work on the site (K 1514). Moreover, structures such as K 1521 and K 1512 might pertain to the stonemason's workshop situated roughly 20 metres to the northwest.

Adjacent to the relics of a wooden cellar (K 1521) lies a square-like feature (K 1522). It was interpreted either as a pit or cistern with an assumed timber lining. The low share of waste pits in the fill, combined with the square layout and wooden structure, raises the possibility that the structure was used for clay storage. Such depots are known from later medieval periods and subrecent ethnography parallels (*Buko 1990*, 90–91; *Richter – Krajíc 2001*, 68). The pit was sunk deep into the bedrock, reaching a depth of 2.2 m, but it could result from the over-excavation of the pit. Given its location, this feature seems to be more

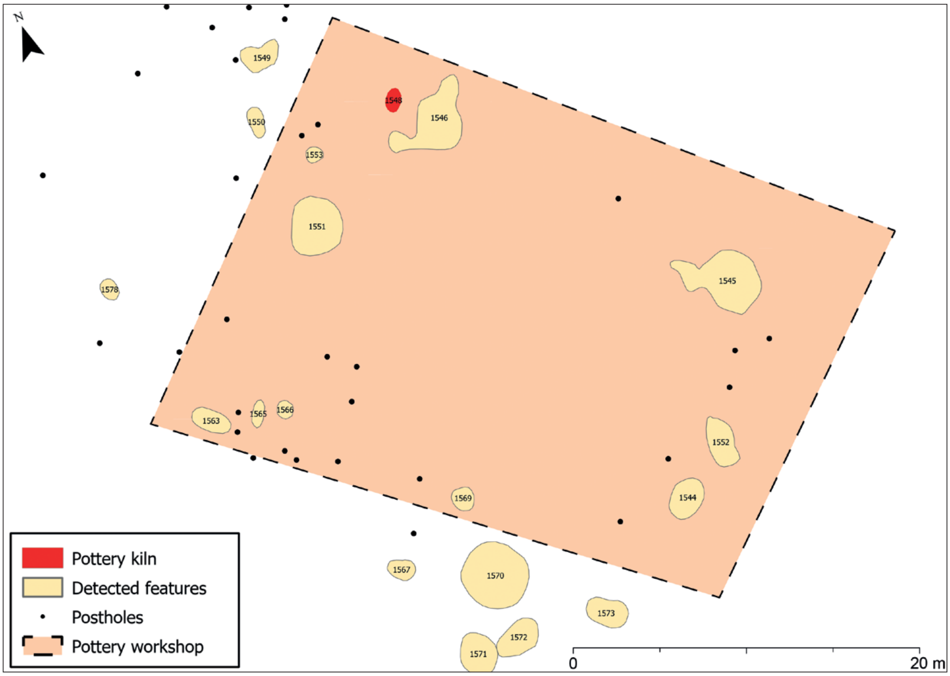

Fig. 4. Detail of the pottery workshop with kiln (f. 1548) and other associated archaeological features.

closely associated with the stonemason's dwelling, where it might have functioned primarily as a cistern.

Geological setting of the site

From a geological perspective, the site falls within the Moldanubian Zone. According to lithostratigraphic division, rocks of the Moldanubicum are generally split into monotonous and varied groups (*Mísař et al. 1983*; *Franke 1989*; *Vrána et al. 1995*; *Cháb et al. 2008*). The monotonous Ostrong unit represents former sediments, likely of a flyschoid complex. It is represented mainly by muscovite, muscovite-biotite, and biotite-sillimanite paragneiss and migmatite occasionally with cordierite, gneiss, and less often quartzite, erlan, orthogneiss, and eclogite. The varied Drosendorf unit primarily consists of paragneiss and bodies of metamorphosed sediments such as metaquartzite, graphitic gneiss, marble, dolomite, and erlan. It also includes amphibolite and orthogneiss. The varied Gföhl unit then contains rocks such as orthogneiss, granulite, leucocratic migmatite, serpentinite, amphibolite, peridotite, eclogite, and skarn.

More specifically, the Staré Město site falls within the Strážek Moldanubicum subregion (*Fig. 5*). The Strážek Moldanubicum belongs almost entirely to the varied group (*Mísař et al. 1983*). In the immediate vicinity of the area of interest, there are mainly migmatite to orthogneiss, less paragneiss, granite, and granodiorite to quartz diorite. Bodies of carbonate rocks – erlans and crystalline limestones – are located about 2 km west of the area of interest. They are also present in the form of smaller bodies in the broader surroundings

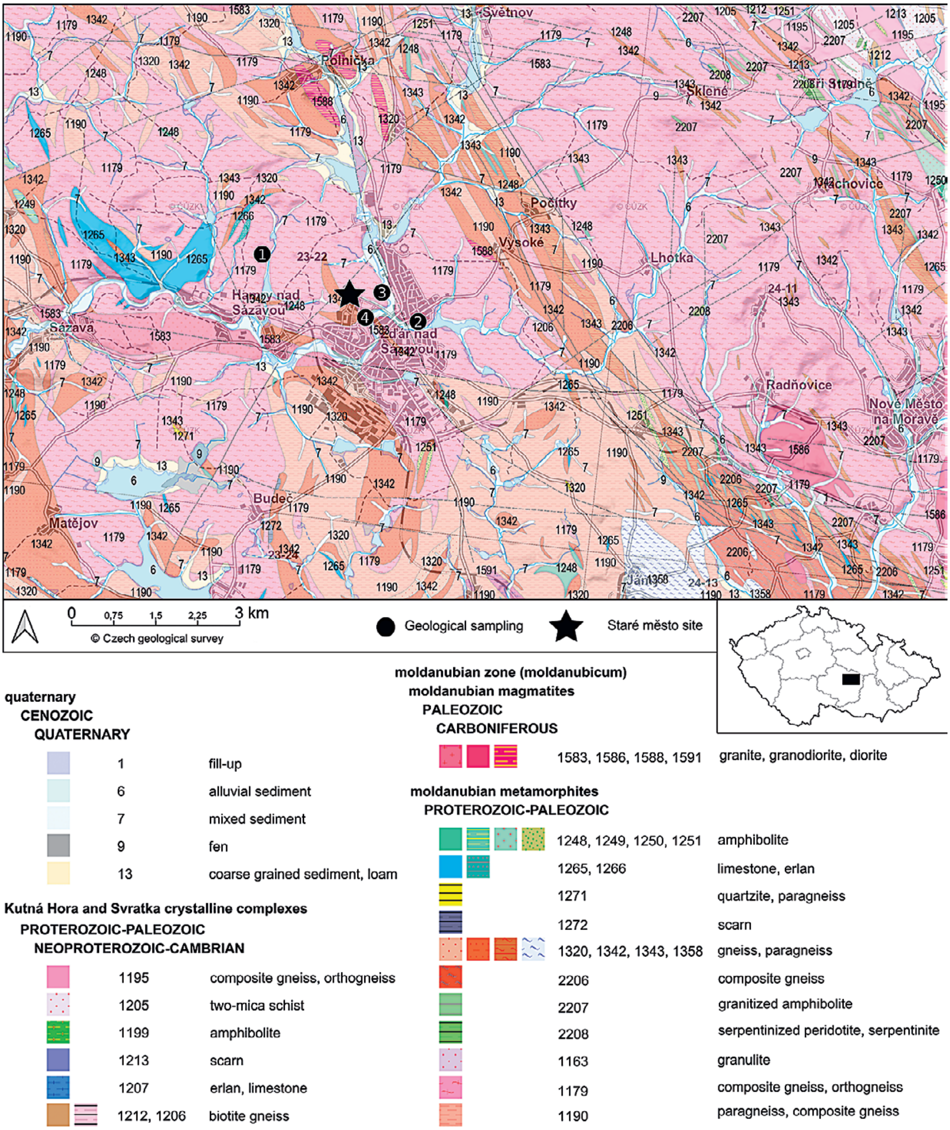

Fig. 5. Geological map of the area surrounding the site with marked locations of geological sampling (1–4; Czech geological survey 2023, modified).

of the site along with small bodies of amphibolite, serpentinite to serpentinised peridotite, skarn, and quartzite. In the vicinity of Nové Město na Moravě (10 km to the east), there are bodies of magmatite corresponding to granite to quartz syenite.

Approximately 8 km to the north and northeast, the rocks already belong to the Kutná Hora-Svratka crystalline complex. The rock spectrum here is primarily represented by two-mica paragneiss to orthogneiss, biotite gneiss, two-mica mica schist, accompanied by smaller bodies of amphibolite, carbonate rock, and quartzite.

Analysed material

The analysed material consisted of a pottery assemblage retrieved from the kiln. The first assessment categorised the material into two main components: first, complete or partially preserved vessels that were directly linked to the kiln (16 specimens); and second, fragments, which could not be reassembled into (nearly) complete vessels and other fragments that likely entered the kiln in an already fragmented state reflecting activities around the kiln during its operation or its subsequent decay or filling (629 fragments).

The selection of analysed ceramic samples took into account the presence of different ceramic groups and classes within the kiln (*Tab. 1*; *Fig. 6*). Since some of the applied methods are destructive and the number of findings was limited, it was decided not to sample complete or partially preserved vessels. Nine fragments of vessel bellies were selected, which, based on macroscopic comparison, could likely belong to the preserved vessels. Seven were from sandy ceramic classes, and two were graphite tempered. Additionally, five fragments from vessels represented only by broken pieces in the assemblage were analysed. These comprised two rim fragments of bell-shaped lids (ceramic class – CC 2 and 3), a fragment of a kettle (CC 3), a bottle fragment (CC 3), and a piece of either a jug or kettle (CC 4). The final sample was a fragment of a brick found in the kiln's infill.

Four sediment samples were collected to define the petrography of alluvial sediments from river streams in Žďár nad Sázavou (*Fig. 5*). The first of these (sample 22) was derived from the sediment of an unnamed watercourse flowing north to south between Dívka and Mikšovec ponds, less than 2 km west of the Staré Město site. This stream feeds into the Sázava River, from which samples 24 and 25 originated. Sample 25 was taken from the Sázava riverbed upstream of its confluence with its left-bank tributary Staviště. Sample 24 was collected further downstream past the confluence. Sample 23 was taken from the Staviště Stream bed.

For a comprehensive evaluation of ceramic production at the site, results from previous analyses of pottery from settlement contexts were also utilised (*Čapek – Slavíček 2022*). Initially, these were revised in light of new insights from the kiln contents, followed by a comprehensive discussion.

Methods

The pottery was evaluated using a unified descriptive system designed for pottery produced in the area of the Bohemian-Moravian Highlands in the 13th and first half of the 14th century. This system builds upon the most widely used approaches for medieval pottery from Brno and South Bohemia, facilitating potential comparisons and connecting with previously evaluated ceramic collections at the site. Modifications were made only to accommodate the concentration of intact and fragmentarily preserved vessels. The morphological analysis of the ceramics adheres to contemporary standards for describing medieval pottery (*Čapek – Těsnohlídková 2020*; *Těsnohlídková 2022*, 81–85, 91–107).

The technological analysis was grounded in the determination of ceramic classes and groups, with an expanded description of characteristics that respect the operational sequence. It focused most closely on post-forming technology markers, which are most effectively observed on well-preserved vessels. They make it possible to examine the relationship

ID	Accession number	Vessel type	Ceramic class (CC)
1	66/06-349/112	Pot	3
2	66/06-349/112	Pot	3
3	66/06-349/112	Pot	3
4	66/06-349/112	Pot	3
5	66/06-349/112	Pot	3
6	66/06-349/112	Pot	3
7	66/06-349/112	Pot	9
8	66/06-349/112	Pot	10
9	66/06-349/112	Pot	3
10	66/06-349/33	Pot-lid	2
11	66/06-349/34	Pot-lid	3
12	66/06-349/50	Flagon with a stirrup handle	3
13	66/06-349/22	Bottle	4
14	66/06-349/37	Jug	4
15	66/06-349/15	Brick	x

Tab. 1. Analysed samples.

between forming traces on various parts of the vessel. Forming traces were described at six specific points: on the inner parts of the rim and neck, on the inner body separately above and below the maximum belly diameter (if there was a difference), on the inner and outer base, and around the circumference of the base. Potential traces preserved on the external body of the vessels were also recorded. Similar traces appeared on all vessels, and they were therefore evaluated together, with any peculiarities being noted.

Chemical composition analysis of the ceramics was conducted using a Rigaku NexCG energy dispersive fluorescence spectrometer (ED-XRF). This spectrometer is equipped with a 50 W Pd tube and a silicon drift detector (SSD) capable of resolutions up to 145 eV. To counter element quantification errors from matrix-based discrepancies, a specialised calibration library for ceramics and soils was utilised, employing standard reference materials from various international institutes. The samples were prepared as pressed powder pellets. The total carbon content was determined through loss on ignition (LOI) using the exposure of powdered samples to 550 °C for five hours following the method outlined by *Heiri et al.* (*2001*).

Standard thin sections (30 µm) were analysed by an Olympus BX 51 polarising optical microscope. The thin section analysis followed the procedures described in *Quinn* (*2013*). Inclusion abundance was expressed as a semiquantitative score using the adjusted guidelines of *Sauer* and *Waksman* (*2005*).

The obtained element concentrations (*Supplementary material 1*) and semi-quantities of rocks and minerals (*Supplementary material 2*) were statistically evaluated by principal component analysis (PCA) using the FactoMiner package in R (*Lê et al. 2008*). The PCA results were further used for hierarchical clustering (*Husson et al. 2010*).

The ceramic assemblage was documented using oblique lighting photography and Reflectance Transformation Imaging (RTI). A Nikon D750 camera with a 60mm Nikkor f/2.8 G ED AF-S Micro lens on a vertical stand was utilised for both methods. Images were colour-calibrated using a calibrated scale. To analyse technological and use-wear traces on the vessels, RTI method involved calculations with Relight software and visualisation with RTI Viewer.

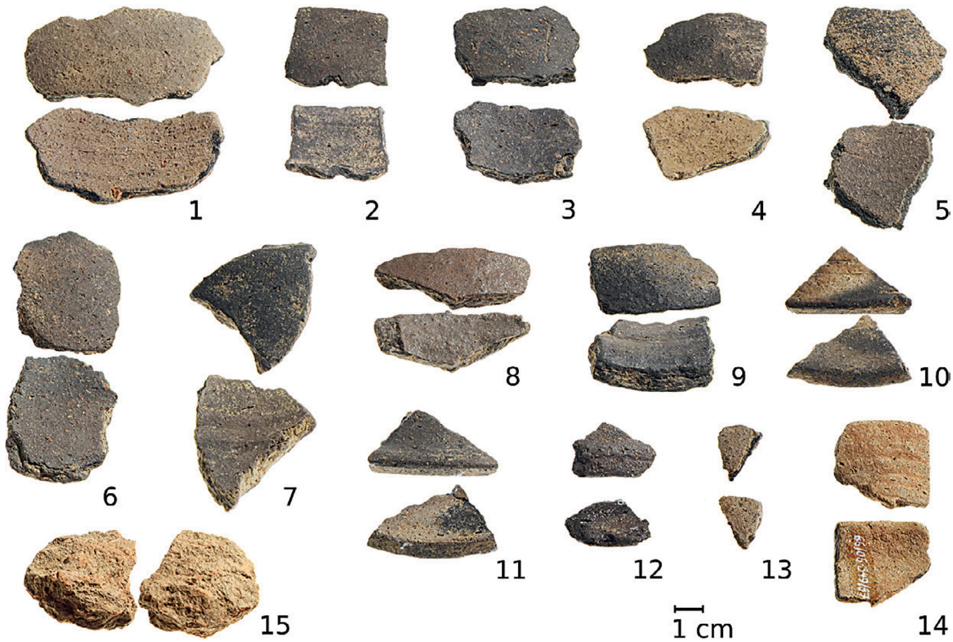

Fig. 6. Samples selected for archaeometry.

Several pottery vessels were virtualised using an Artec Leo 3D scanner,[1] offering a resolution of 1 mm or lower. Out of 16 partially or fully preserved vessels, the three best-preserved ones were documented. The scanner's consistent accuracy enabled the tracing of shaping marks across the entire profile of the vessel, even in the challenging conditions of repositories. On the other hand, spatial data might be lacking on vessels with complex profiling, particularly beneath the neck, where the scanning beam has limited reach. The raw data from the 3D scans were processed with ArtecStudio 16 software.

The vertical cross-sectional plane method was applied for a detailed morphometric description of vessels. This approach provides insights into the thickness variation of the vessel's vertical profile and allows for conventional graphical shape representation. Restoration additions were excluded from these virtual cross-sections. Virtual cross-sections were created using Blender software. The process involved segmentation and extraction using the modified Mesh Boolean Node function. This method intersects a cross-sectional plane with the vessel, yielding the required data. Data processing included the automated export of individual cross-sections and semi-automatic removal of virtual artefacts.

A single virtual cross-section per plane is not enough for precise morphometric analysis (cf. *Thér – Wilczek 2022*). Therefore, 180 vertical cross-sections were employed, equating to one section per degree of a circle. The rotation axis, situated at the centre of the

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[1] Data was acquired using technological equipment obtained for the purpose of the research project 'The Formation of Multi-Ethnic Complex Societies in Early Medieval Moravia. Collective Action Theory and Interdisciplinary Approach (GX21-17092X)'.

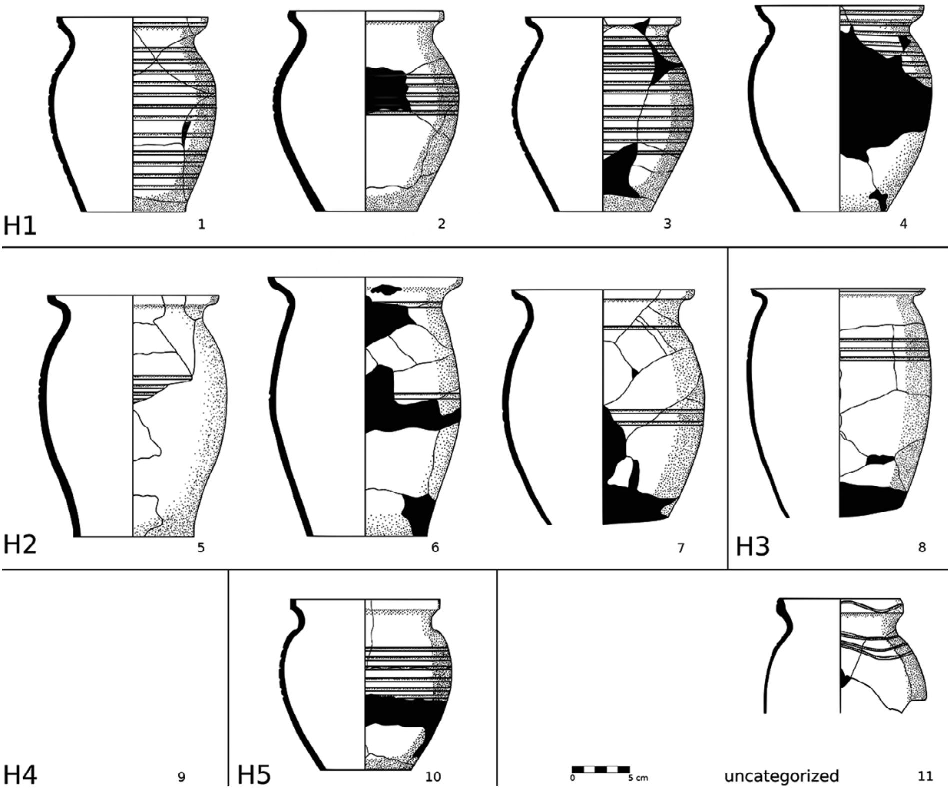

Fig. 7. Types of pot torsos found in the kiln and their affinity to ceramic classes (CC): 1 – 66/06-349/1 (CC 4); 2 – 66/06-349/2 (CC 2); 3 – 66/06-349/3 (CC 3); 4 – 66/6-349/6 (CC 3); 5 – 66/06-349/7 (CC 3); 6 – 66/06-349/8 (CC 3); 7 – 66/6-349/10 (CC 3); 8 – 66/06-349/9 (CC 10); 9 – 66/6-349/5 (CC 3); 10 – 66/6-349/4 (CC 9); 11 – 66/6-349/14 (CC 3).

vessel's base exterior, was used to adjust these planes. This axis is also crucial for converting metric data from 3D space to a single planar projection, enhancing the accuracy and interpretability of the morphometric data.

To accurately estimate wall thickness in the vertical cross-sections, a measuring line perpendicular to the vessel wall's current direction was employed at each point. This technique accounts for the vessel's profile variability, enabling more precise data categorisation by determining the elevation of measurement points. Due to significant restoration on many scanned vessels negatively affecting shape integrity, only three specimens were chosen for this analysis (66/06-349/1, 66/06-349/4, 66/06-349/2).

Data processing for each cross-section involved categorising each measuring line according to specific vessel parts, as defined by *Procházka* and *Peška* (*2007*): v3 (from the rim edge to the narrowest part of the neck), v4 (from there to the maximum belly diameter), and v6 (from the maximum belly diameter to the bottom). To address potential artificial outliers produced during line measurement rendering, the interquartile range (IQR) method was employed. This approach ensures a more accurate and reliable representation of the vessel wall thickness across different sections.

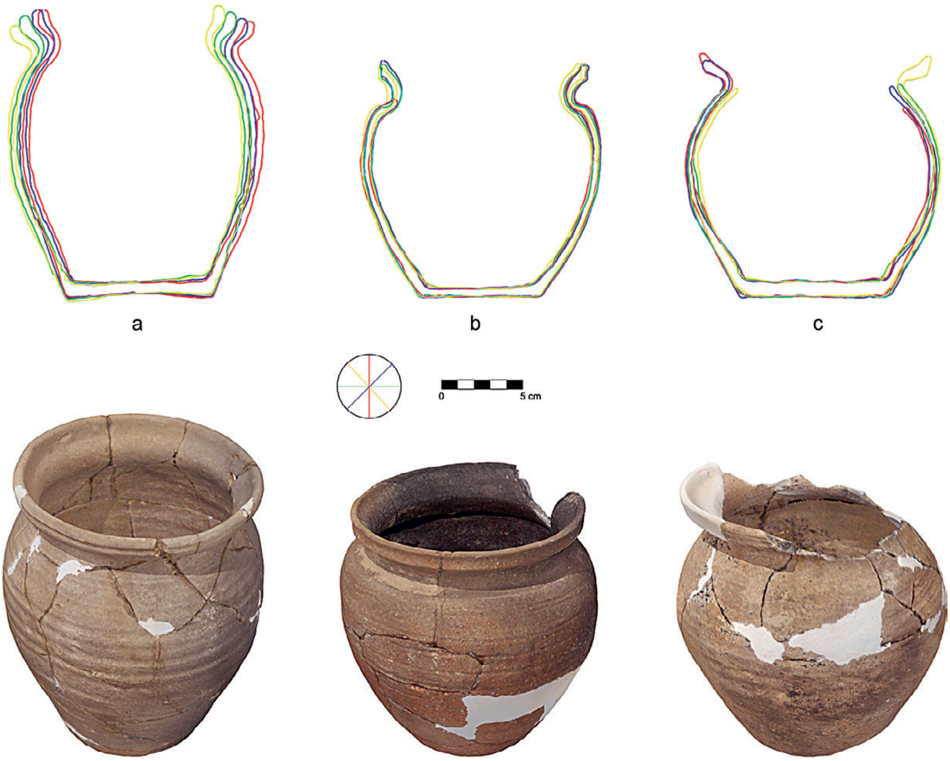

Fig. 8. 3D scans of pots. a – 66/06-349/1; b – 66/06-349/4-var2; c – 66/06-349/5. – Cross-sections along the vertical axis show the irregularity of shape and overall visualisations, respectively.

For the visual interpretation of the kiln construction, polygonal modelling methods were utilised (see *Saldaña 2015*, 149 in detail). It was based on technical drawings and analogous archaeological situations. This interpretation aims to present a basic idea of the technological form of the studied object rather than to create an exact model of the past situation, which is fragmentary, entropic, and heavily transformed in the archaeological record.

Results

Ceramic analysis of complete and partially preserved vessels

A total of 16 pots were identified in the category of complete and partially preserved vessels (*Fig. 7*). Twelve of these were preserved at 60–95%, while the remaining four were 30–40% intact but had complete necks or bases with parts of the body. Only eight vessels provided a full set of measurements (*Tab. 2*). Three allowed for 3D wall thickness analysis (*Fig. 8*), though gypsum restoration limited this method. All specimens were reconstructed from multiple fragments; none were found intact. Photos show they were already partially broken upon excavation, suggesting breakage occurred during the deposition, likely during the filling of the archaeological context (*Fig. 2: A, B*).

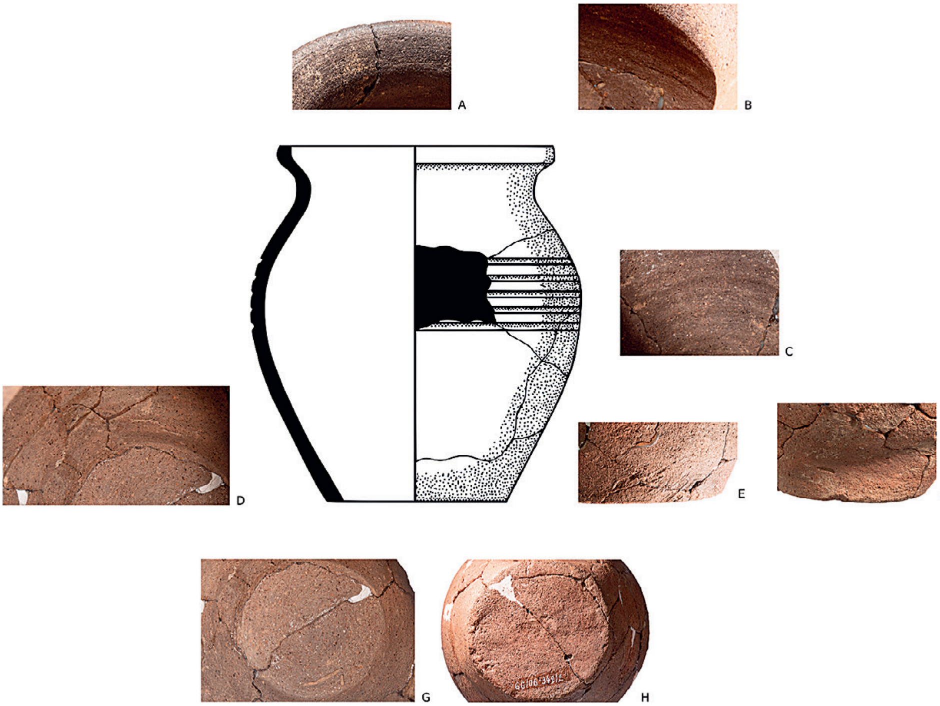

Fig. 9. Technological traces on pot 66/06-349/2 (CC 2) and their location: A – traces of rapid rotation on the neck and rim; B – wall undulations appear inconclusively as depressions/rings in the sub-neck area; C – clear depressions evidencing coiling below the maximum body diameter; D – depressions in the wall above the bottom in combination with lines and hollows at joint locations; E, F – technological traces above the bottom caused by manipulation with the vessel: E – 'scratching' likely formed by the removal of the partially attached bottom from the base using an unspecified tool; F – indentations caused by manipulation with the insufficiently dried vessel, also visible on the inner side; G – inner side of the bottom with traces of rotation, a distinctly separated coil is apparent above the bottom; H – outer side of the bottom with evidence of attachment and cutting off of the bottom around its perimeter; the imprint of a wooden board and a thin layer of dusting are visible on the bottom surface.

Sandy pottery was highly predominant (88%). Twelve vessels were assigned to CC 3 (medium-grained sandy) and two to CC 2 (fine sandy) class. The remaining two vessels contained graphite: one with matte grains (CC 9) and the other with shiny grains (CC 10; *Tab. 3*). In addition to sandy temper, most of the vessels contained small red grains (clay pellets). Traces of burnt organic matter appeared on vessel surfaces regardless of their affinity to pottery classes. Large temper grains or holes from these grains were less frequent (up to ca. 5 mm).

Traces of grooves from papillary lines or a fine tool predominated on the rim and neck (*Fig. 9: A, B*). These were found on 13 of the 16 observed vessels. There were also traces of temper displacement on one of the CC 3 vessels. On three CC 3 vessels, we observed no grooves on the rim and neck, which is likely related to the state of preservation and susceptibility of the pottery to surface abrasion.

Flat features on the vessel bodies most frequently manifested as depressions were evident in 11 instances. These depressions were noticeable mostly on the lower parts of the

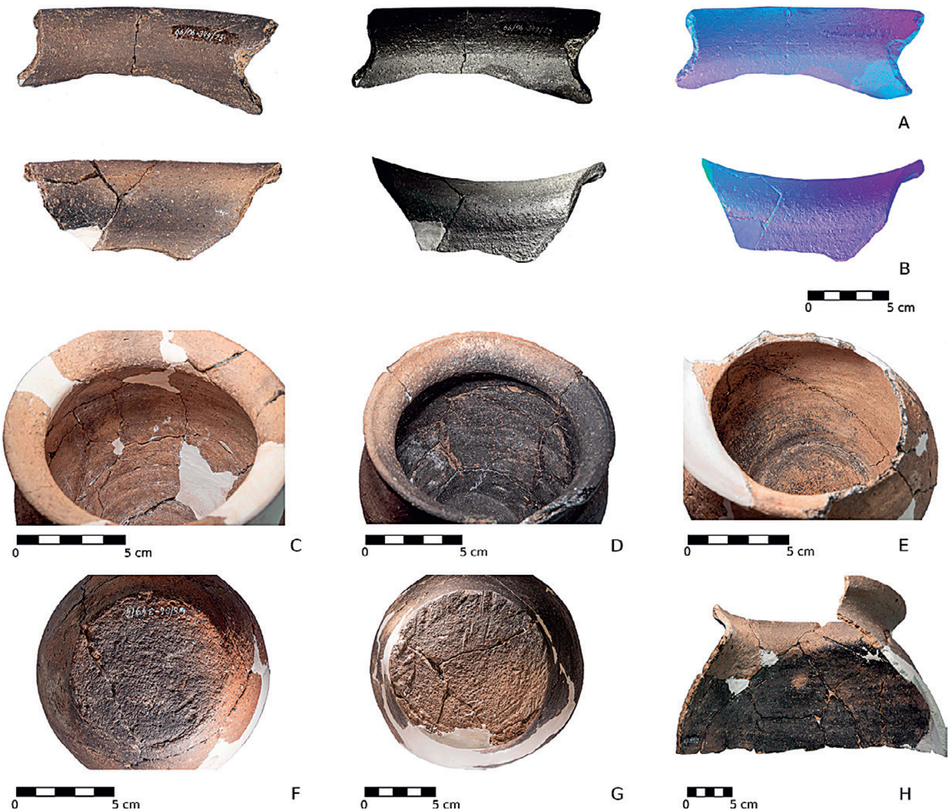

Fig. 10. Detailed documentation of forming markers: A, B – quick rotation marks on necks, from left to right: photograph, Reflectance Transformation Imaging (RTI), RTI normal map, vessels 66/06-349/23a (CC 10) and 66/06-349/23b (CC 3); C, D, E – marks on the inner wall surface, vessels 66/6-349/3 (CC 3), 66/6-349/4 (CC 9), and 66/6-349/5 (CC 3); F – traces of dusting and fixation of bottom to the board preserved around the bottom rim, vessel 66/6-349/4 (CC 9); G – traces of dusting and cutting off the board, vessel 66/6-349/7 (CC 3); H – oxidised surface of the rim and upper part of the neck, while reduced firing remained inside due to another pot inserted inside, vessel 66/6-349/13 (CC 13).

vessel bodies (*Fig. 9: C–F*; *Fig. 10: C, D*). Depression/ring markings were documented in nine instances. They appeared more often on the upper half of the vessels and were accompanied by distinct depressions in the lower body sections (*Fig. 9*; *Fig. 10: E*). There were visible lines at the joints of the coils in five cases, in six instances recesses indicating their joining, and twice we recorded that the wall was uneven (*Fig. 10: C, D*). From the exterior, six vessels displayed signs of being compressed due to handling when the clay was not sufficiently dry. The compression was so pronounced that it was noticeable from the inside, in one instance even producing a crack in the inner wall (*Fig. 9: D, F*).

Concentric rings were found on the inner bases of three vessels, suggesting that the base was smoothed during faster rotation. In individual cases, there was a raised centre, a dip in the middle, or evidence of a blade shift during rotation. All inner bases were modified during faster rotation based on their appearance (*Fig. 9: G*). The external base offers insights into how the vessel was attached to the potter's turntable. The outer surface of the

Accession number	Type of pot	Ceramic class	Preservation (%)	Rim type	Neck type	Rim decoration	Body decoration	Maximum belly location	Pot height	Rim to transition of neck and belly	Rim to maximum belly	Bottom to maximum belly	Maximum difference of heights within pot	Rim diameter	Neck diameter	Maximum belly diameter	Bottom diameter	Maximum difference of diameters within pot	Body fragment thickness
60/06-349/6	H1	3	70	VZ.2.2	A		grooves	upper third	186	26	87	99	8	148	112	160	83	11	4–6
60/06-349/1	H1	2	95	V.2.4	A	1 groove	12 grooves	upper third	168	29	79	100	15	132	104	148	90	2	4–6
60/06-349/3	H1	3	90	S.1.1	A		12 grooves	upper third	171	32	80	91	5	135	117	150	85	1	4–6
60/06-349/2	H1	2	95	S.2.2	A		5 grooves	upper third	181	32	78	104	6	134	108	165	90	2	6–9
60/06-349/15	H1	3	60	S.1.1	A		3 grooves	upper third	x	29	86	x	12	125	99	145	x	4	4–9
60/06-349/10	H2	3	70	S.1.1	A/B		4 grooves	half	x	35	105	x	5	160	130	178	x	10	6–8
60/06-349/8	H2	3	85	S.2.2	A		1 groove	half	223	30	105	126	15	175	141	150	106	10	4–6
60/06-349/7	H2	3	80	S.1.1	A		5 grooves	half	212	26	88	126	8	160	136	180	108	10	4–6
60/06-349/9	H3	10	90	S.1.1	A		2 groove	upper third	x	24	100	x	5	190	168	200	x	10	6–8
60/06-349/12	H3	3	60	S.1.1	A		1 wave, 3 groove	upper third	x	32	90	0	6	190	24	220	0	10	4–9
60/06-349/5	H4	3	80	VZ.2.2	A		5 grooves	half	150	28	80	73	3	140	15	152	88	5	3–6
60/06-349/4	H5	9	95	VZ.1.9	B		2 waves, 5 grooves	upper third	138	27	57	85	4	127	13	143	77	0	7

Tab. 2. Description of the decoration and metric values (in mm) for complete and fragmented pots.

base was rougher, likely achieved by dusting, which was clearly evidenced in four instances. Around the external perimeter of the base were traces of attachment to the board (four instances), traces of being cut from the board (four instances), or the effect of an inset base, suggesting the clay was pulled over and attached to a board (*Fig. 9: E, H*). In two cases, a faint and relatively worn impression of a wooden board was observed (*Fig. 9: H*). These features were only present on sandy vessels. Both vessels of the graphite classes had marks on their bases worn away by abrasion. The only feature observed around the base was a prominent coil above the base present on three vessels – two sandy and one graphite.

The varying dimensions among the vessels point to imperfect centring during the wheel shaping process. Across all ceramic classes, the common deviations were 5–15 mm in height and 5–10 mm in diameter. Wall thickness showed notable variation, particularly between the maximum belly diameter and the bottom (index v6 in *Fig. 11*), and from the neck to the rim (index v3). The section between the belly and neck, however, shows more uniformity. The variation in thickness for indices v3 and v6 ranged between 50 and 80%. Asymmetry studies on three pots revealed different degrees of deviation from the rotational axes (*Košťál – Slavíček 2023*). The most asymmetric pot showed a deviation of up to 15% at the neck and 8% at the maximum belly diameter (*Fig. 11: A*). The other two pots were more symmetric, with deviations below 5% at both measured points (*Fig. 11: B, C*).

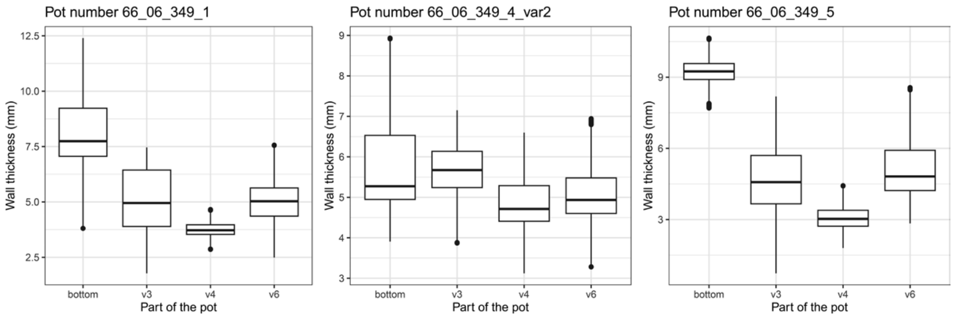

Fig. 11. Boxplot showing the variability in vessel wall thickness visualising data obtained by 3D scanning (indices of vessel parts: v3 represents the section from the rim's edge to the narrowest part of the neck, v4 spans from the narrowest part of the neck to the point of maximum belly diameter of the pot, and v6 covers the area from the maximum belly diameter down to the bottom of the vessel).

The vessels from the kiln were not significantly overfired; however, they bore traces of both oxidising and reducing firing (*Tab. 4*). Every vessel exhibited both characteristics to varying degrees. The oxidising marks indicated that during the later stages of the firing process, an oxidising atmosphere was in effect, and parts of the vessel with oxidising traces were left exposed. The reduced areas either did not reach the necessary temperature or were covered by another vessel, hidden within the fuel, or leaning against the kiln wall (*Fig. 10: D, F, H*).

The study identified five distinct pot types based on their shapes and dimensions (*Figs. 6–7*). Type 1 features bulbous pots with the widest part in the upper half, Type 2 includes slimmer pots with a central maximum belly diameter, and Type 3 consists of slimmer pots with a maximum belly diameter in the upper half. Types 4 and 5 are smaller and more bulbous, with a maximum belly diameter in the middle and upper half, respectively. All types have a smooth neck-to-body transition, except Type 5, which has a sharply angled neck. Of the pots preserved at 60% or more, twelve could be classified (*Tab. 2*).

Dimensional analysis focused on height, proportions, and diameters was key for classification (*Tab. 2*). Heights varied from 14 cm on Type 5 to 21–23 cm on Type 2 pots. Rim diameters also differed. The smallest Type 1 diameter was 13.5 cm on average with a deviation of 10%. The largest Type 3 diameter was 19–20 cm. Base diameters were all in the range of 8–11 cm for all types.

Ceramic analysis of fragmentary collection

Among the 629 fragments from the kiln, two lower fragmentation categories predominated, covering fragment surface areas up to 9 cm² and 9–36 cm². They were evenly distributed, with 48% (302 pieces) for the former and 47% (298 pieces) for the latter. Larger fragments with surface areas of 36–81 cm² accounted for 4% (26 pieces), and those of 81–144 cm² comprised only 1% (3 fragments). In 53 cases, it was possible to join two to three fragments, in nine cases four to five fragments, and there was one instance each of joining six to seven and eight to nine fragments. It can be assumed that not all fragments were successfully reattached, particularly due to the relatively poor firing quality and the fragility of the sherds.

Ceramic class (CC)	Kiln – complete vessels and torsos	Kiln – fragmentary assemblage	Settlement
1	2	–	–
2	8	10	13
3	41	71	75
4	3	1	–
5	< 1	–	–
6	< 1	–	–
7	3	–	–
8	1	–	–
9	13	< 1	6
10	11	< 1	6
11	1	–	–
12	17	–	–
13	–	–	–
14	–	18	–

Tab. 3. Representation of individual ceramic classes in the ceramic assemblage from the kiln and the settlement (values in %).

In the fragmentary material, the CC 3 class was predominant and comprised 71% of the assemblage (*Tab. 3*). Another sandy class, CC 2, accounted for 10% of the fragments. One per cent of the collection was the sandy oxidised class CC 4. Graphite classes were represented only by individual pieces, cumulatively constituting 1% of the assemblage. Mica ceramics were not found within the kiln. Overfired fragments representing the remaining 18% were classified as CC 14. Generally, it can be summarised that fragments of sandy ceramics predominated, making up 99% of the collection compared to 1% of ceramics macroscopically identified as graphite-tempered.

Technological traces observed on the fragments correspond to the characteristics of the complete vessels presented above. Within the material of both sandy and graphite ceramics, we identified large temper pieces up to 5 mm or pores after they popped out. Evidence of burnt fibres or pieces of organic inclusions, especially on the inner walls, is also available. Small red grains (around 1 mm) appeared quite frequently as well.

Traces of forming were only observable on sandy fragments and, as with the complete vessels, these features evidenced a production method combining coiling with rotation. Depressions were the most frequently observed feature (on 30 fragments), followed by indentations (8 fragments), lines, or ambiguous depressions/rings (5 fragments each). In one instance, depressions were accompanied by lines, and in another by papillary grooves. Features on the bottoms were described on eight sandy fragments: five had pronounced ridges above the base; in two instances, there were traces of the vessel's attachment to the potter's board around the perimeter, and one sherd had traces of the vessel's base being cut from the board. All described instances bore apparent traces of dusting.

Firing conditions were determined for 485 fragments (after mending; *Tab. 4*). Of these, 102 exhibited signs of slight overfiring, which could have also originated from normal non-defective firing in the kiln. Of the seven fragments of graphite pottery, five were reduced during firing and two had an oxidative final phase of firing (one on both sides and one on the exterior only). Among the 386 fragments of sandy ceramics, 80% showed signs of the oxidative final phase of firing; 60% were on both sides (231 fragments), 12% on the exterior (48 fragments), and 8% on the interior (30 fragments). Reductive firing was

Type of firing	Kiln – complete vessels and torsos	Kiln – fragmentary assemblage	Settlement
Oxidative final phase	100	64	70
Reducing firing		14	21
Oxidising firing			2
Combined firing		1	3
Black core		3	1
Sandwich effect			1
Unintentionally smoked			1
Slightly overfired		18	1

Tab. 4. Representation of different firing types of sandy and graphite pottery in the assemblage from the kiln and the settlement (values in %).

Rim type	Kiln – Complete vessels and torsos	Kiln – Fragmentary assemblage	Settlement
Simple			5
Simple edged		21	11
Collar			11
Oval		8	4
Folded		13	1
Roof-shaped	75	18	13
Everted	25	37	44
Everted-low		3	11

Tab. 5. Representation of rim types for sandy graphite pottery (values in %).

identified in 14% cases (53 fragments), a weak black core was present in 4% of cases (17 fragments), and 2% were determined to have mixed firing conditions (7 fragments).

Vessel shapes were determined based on characteristic fragments, with a total of 65 instances where the shape could be discerned. Among sandy ceramics, 41 fragments were identified as pots and seven as bell-shaped lids. In six cases, the fragments likely belonged to jugs, while in four cases the vessel form remains unidentified. One instance involved a low bowl, flat lid, or potsherd. For graphite ceramics, pots were determined in three cases and for overfired ceramics in six cases (*Tab. 5*; *Fig. 12*). Bell-shaped lids were formed with rim types POZ.4.1 (twice), 4.3, and 5.2, with one having a measurable diameter of 150 mm (CC 3). A preserved handle had a diameter of 15 mm. The collection also included one fragment of a flat lid POP.2, which could belong to a low bowl or potsherd (*Těsnohlídková 2021*, appendix 28). The rims of pots were classified concerning the ceramic class and for those where the preserved part was higher than 15% of the original circumference. The largest ceramic class 3 was represented by 29 rims: eight simple-edged and everted low rims each, five basic variants of everted, three roof-shaped, three folded, one oval, and one collar rim. Three rims were recorded in the sandy class CC 2: two roof-shaped and one folded. The only preserved rim of graphite pottery (CC 9) was an everted low subtype 3. For the overfired pottery, six rims were determined: two everted and roof-shaped each, one folded and one oval. The diameters of the pots were in the range of 120–180 mm, and the preserved parts of 14 out of 39 rims exceeded 15% of the vessel's neck circumference, with eight instances above 25% and one rim above 50%.

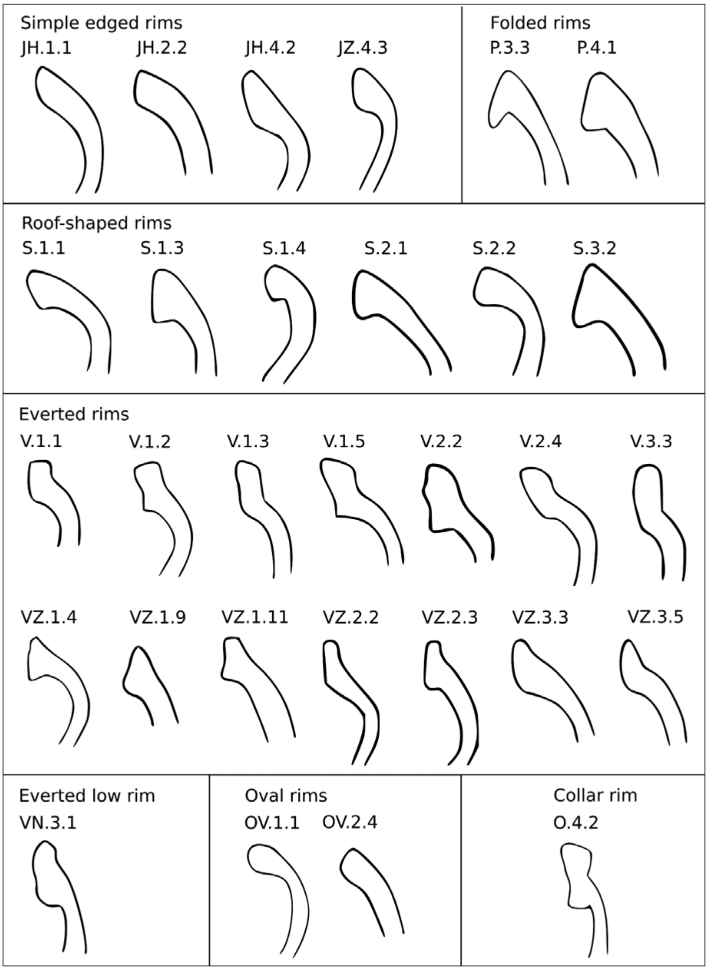

Fig. 12. Typology of pot rims represented in the ceramic assemblage with the designation of ceramic class.

Decorations were preserved on 35 belly fragments of sandy pottery. They were decorated exclusively by grooves, except for one fragment decorated by incisions. Decorations on the rims were found in nine instances on sandy pottery (1–3 grooves, wavy lines) and once on graphite pottery (wavy line with a groove). Decorations predominated on everted rims, with four cases each on everted and low everted rims, and in one case on low rims. One collar rim was also decorated.

The preserved bases were highly fragmentary. More than 15% of the original circumference was preserved in only three cases, which belonged to the CC 3 class. Two bases had a diameter of 100 mm and one 120 mm.

Ceramic petrography

Significant petrographic homogeneity characterises the majority of the samples. The exception is represented by graphite pottery sample 8 and sample 15, which comes from a brick and serves as a reference sample. This homogeneity is articulated not only through the statistical evaluation of the semi-quantitative values of the petrographic analysis but also through the chemical composition (*Figs. 13*, *14*; *Tabs. 6*, *7*). The homogeneity of the main fabric produced by the kiln is slightly disrupted by sample 5, which is coarser compared to the rest.

Samples 1–4, 6, 7 and 9–14

Gneiss is the most abundant rock type among aplastic inclusions occurring as common to frequent. Granitoids and metaquartzite occur occasionally or commonly across the samples. In terms of minerals, quartz and biotite are frequent and abundant (*Fig. 15: A, B*). Muscovite is less commonly found, appearing from trace to occasional amounts. Alkali feldspars and plagioclase are also present (common to frequent), with the latter being slightly more abundant than the former in general. A few accessory minerals were also identified. Amphibole was found only in samples 3 and 4, and occurred occasionally. Garnet was identified in sample 11. In addition, plant remains were detected in samples 1, 3, 6, 7, 9, 11, and 12 (*Fig. 15: D*).

All samples have a weakly parallel or parallel microstructure. Aplastic particles are poorly sorted, and their grain size distribution is bimodal. The matrix is homogeneous and non-calcareous. The base clay body includes up to 5% of silt or fine-sized grains of minerals. The important feature is the presence of short fragments of biotite flake stacks. All samples were intentionally tempered with sand-sized rock fragments and minerals that are mostly subangular or subrounded. Mineral temper content varies in the range of 5–15 % (compare *Fig. 15 A and C*). Most of the samples have oxidised layers on both inner and outer surfaces, while the core has remained reduced (*Fig. 15: A–C*). One sample was completely oxidised (no. 13) and one completely reduced (no. 3). Four samples have a smoked outer surface from the reducing phase in the final stage of the firing process (nos. 4, 7, 10, 11). Biotite mostly exhibited medium, sometimes strong pleochroism.

Sample 5

Among rock fragments, gneiss is the most abundant. Granitoid occurs commonly and metaquartzite is occasional (*Fig. 15: E, F*). Minerals are represented by abundant quartz and biotite. Muscovite is occasional. Plagioclase and alkali feldspars are both frequent. Accessory minerals are represented with common garnet and occasional amphibole. The clay body includes occasional plant remains.

The microstructure of sample 5 is unparalleled. Poorly sorted aplastic inclusions appear to have unimodal size distribution. These inclusions are equant, subangular to subrounded and quite abundant (up to ~30% of the sample). The outer surface layer is oxidised, while the core and inner surface remain reduced. Biotite flakes exhibit strong pleochroism.

Sample 8

Sample 8 exhibits a unique petrographic constitution characterised by a prevalence of graphitic metaquartzite fragments (*Fig. 15: G, H*). Metaquartzite appears commonly, while gneiss was observed only occasionally. In terms of the mineralogical composition, the sample is markedly dominated by graphite. Quartz is abundant. Other minerals, including alkali feldspars, plagioclases, biotite, and muscovite, are occasional. The accessory mineral amphibole was noted to occur occasionally.

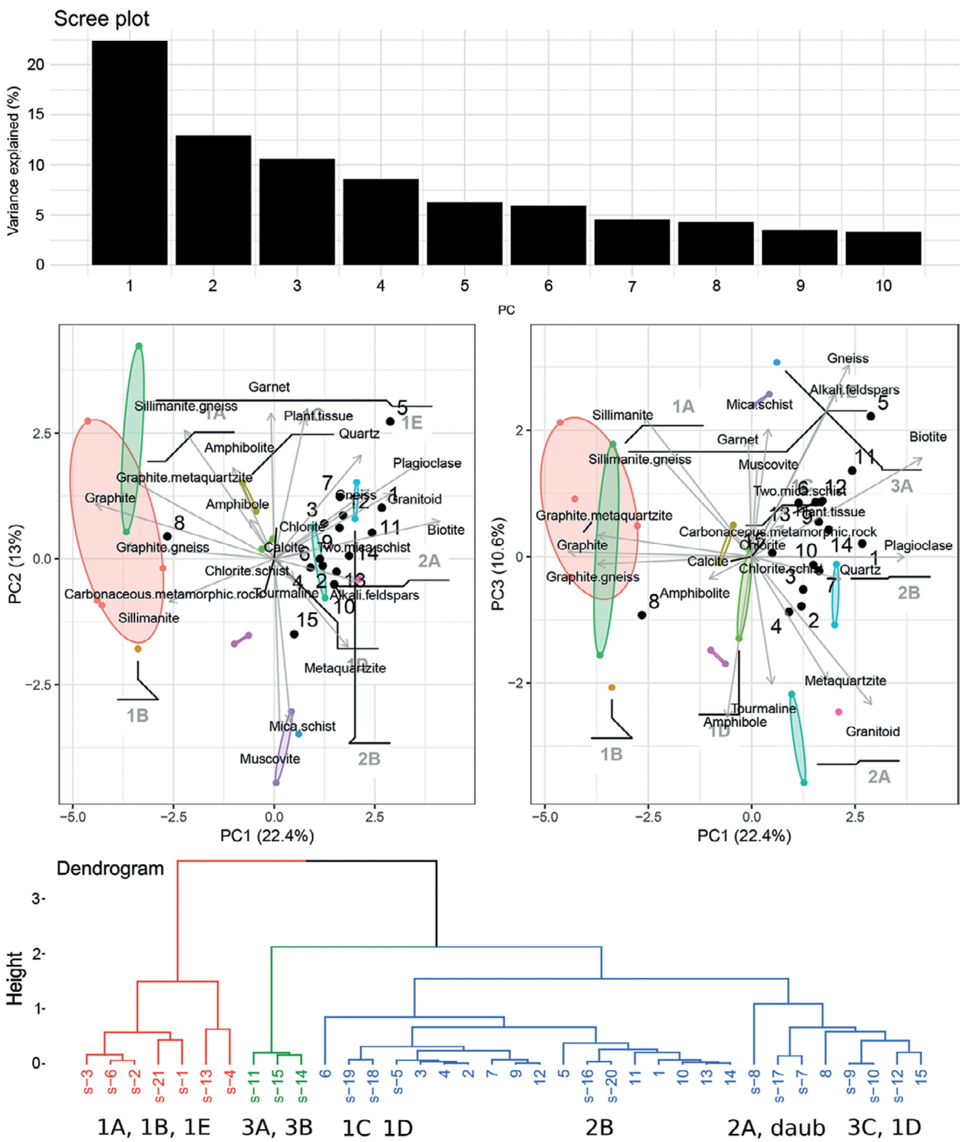

Fig. 13. Statistical analysis of the petrographic composition expressed in semi-quantities: top – scree plot followed by scatter plots contrasting the first PCA component with the second and third; bottom – hierarchical clustering dendrogram derived from the results of the principal component analysis.

Microstructure is weakly parallel. Aplastic inclusions are very poorly sorted with a strongly bimodal grain size distribution. The main ceramic body includes ~5% of naturally occurring silt-sized mineral grains and rock fragments. Sand-sized rock fragments and graphitic grains used as temper are elongated to equant and subangular. They make up ~20% of the whole ceramic mass. The layers close to the outer and inner surfaces were oxidised while the core of the sample section was reduced. Biotite pleochroism is weak.

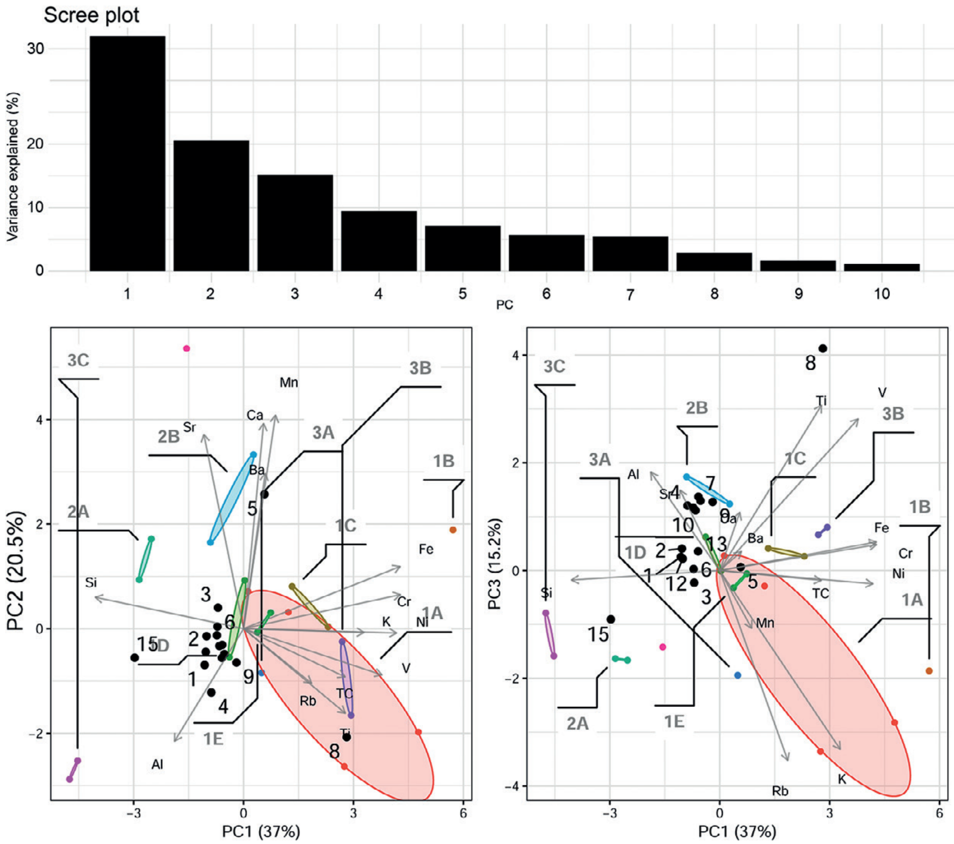

Fig. 14. Principal component analysis of the chemical composition. Top: scree plot followed by scatter plots contrasting the first PCA component with the second and third.

Sample 15 (brick)

Inclusions are composed of abundant metaquartzite and common granitoids or gneiss (*Fig. 15: I, J*). Among mineral grains, quartz is the most abundant, being observed as frequent. Alkali feldspars are common and prevalent over occasional plagioclase. Biotite is common and muscovite occasional. The sample includes common sillimanite.

The brick exhibits an unparalleled microstructure. The clay mass is coarse and includes 20% of inclusions and 10% of sand-sized temper. The overall grain size distribution is slightly bimodal. Sand is composed mostly of quartz, metaquartzite and granitoids fragments of an elongated shape varying between angular and subangular. The sample is completely oxidised. Biotite pleochroism is weak.

Petrography of alluvial sediments

Sázava River

Both samples of river sand taken from the Sázava riverbed are petrographically identical. The most common rocks are biotite gneiss and metaquartzite. Traces of granulites

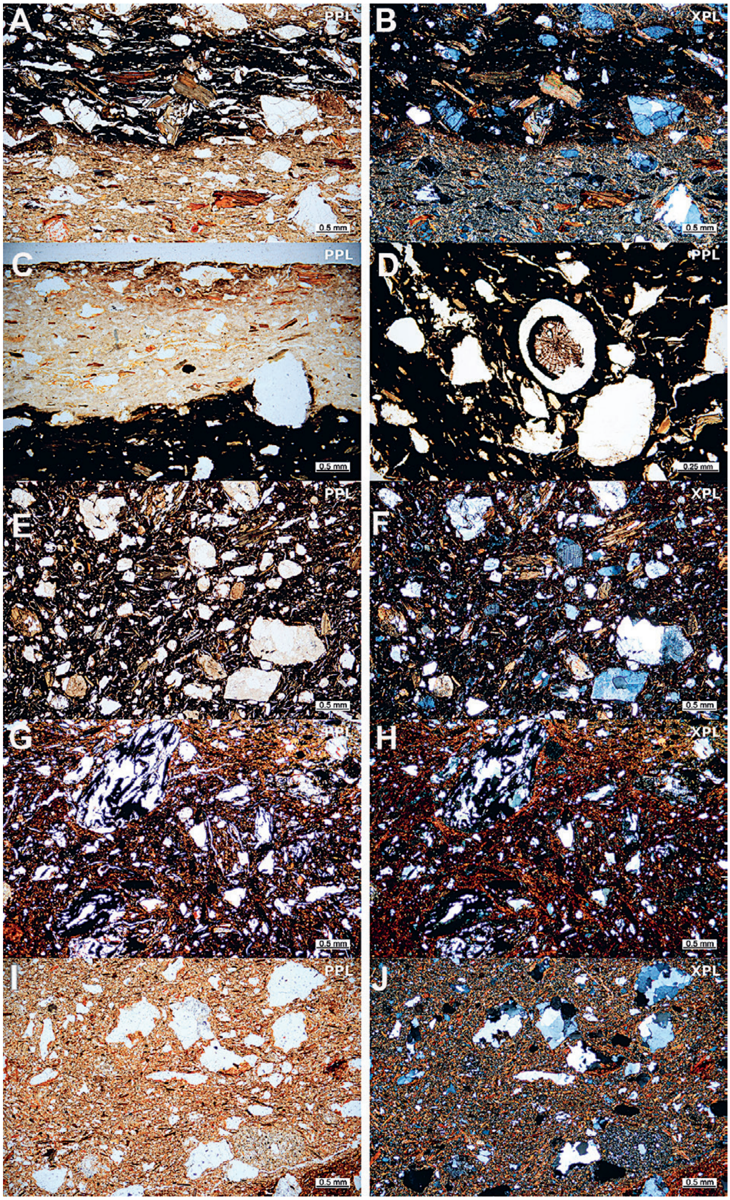

Fig. 15. Photomicrographs: A, B – sample 14 representing the main fabric group, an oxidation layer beneath the vessel surface with numerous biotite flakes and fragments of metaquartzite in the ceramic matrix; C – sample 11 showing a pronounced oxidised layer, ceramic matrix contains a lower amount of aplastics demonstrating variability within the main fabric group; D – unburned organic tissue in the reduced core of sample 11; E, F – sample 5 with unimodally distributed aplastics represented by biotite flakes, fragments of gneiss, granitoid rocks, quartz, and feldspars; G, H – graphite pottery (sample 8) displaying a significantly lower content of biotite compared to the main fabric, including isolated graphite grains and fragments of graphitic metaquartzite used as a temper; J – intrusive brick sample 15 showing a different microstructure compared to the pottery, the predominant rock fragments are metaquartzite with a lower amount of granitoids and gneiss, the entire sample was oxidised.

and granitoids are observed in the sample taken downstream. Among the minerals, quartz is most abundant. Plagioclases and alkali feldspars are common and present in similar proportions, as are muscovite and biotite. Traces of amphibole and chlorite were detected in the sample taken upstream.

Staviště Stream

The sand from the Staviště Stream bed was the most petrographically diverse. The most common rocks are gneiss, biotite gneiss, but also gneiss with sillimanite. Amphibolites are relatively abundant. Less frequent are chlorite schists, metamorphic rocks with carbonate, or standalone carbonates. Quartz grains are very abundant, and fragments of amphiboles and plagioclases are relatively common. Alkali feldspars are less common. Biotite predominates over trace amounts of muscovite. Traces of calcite and sillimanite are also present.

Unnamed stream between the Dívka and Mikšovec ponds

The collected deluvio-fluvial sediment from the unnamed stream west of the site is sandy-loamy, hence it contains fewer larger rock fragments in comparison to the other studied sediments. Rock fragments are represented only by metaquartzite and traces of granitoids. Among the minerals, quartz predominates, while other minerals are present in small and trace amounts. These include biotite, muscovite, plagioclase, alkali feldspars, amphibole, and tourmaline.

Discussion

Pottery kiln

The form and usage of the kiln can be reconstructed based on the preserved archaeological context, characteristics of the ceramics, ethnographic analogies, and experimental archaeology (*Fig. 16*). The preserved part, which was dug into the ground, has its closest analogy in Jihlava in the preliminarily published kiln from the U Skály site (*Kochan et al. 2021*).

Key features include the fired base, bottom walls, and rear heating channel, while other construction elements are missing. The side walls are inwardly narrow at the front, suggesting a back chimney and loading opening. The floor's slight slope from back to front indicates airflow in that direction. The absence of daub hints at a temporary or one-time covering, but the bulging back wall and heating channel suggest a permanent dome structure, likely made of clay plastered over a wicker frame, as seen in ethnography and experimental reconstructions (*Těsnohlídková 2021*; *Čapek et al. 2022*, 74–75). The missing plaster could be due to lower firing temperatures and short peak heat.

The heating channel, not fully excavated, appears to narrow towards its mouth, similar to the Jihlava – U Skály kiln (*Kochan et al. 2021*, 122). This design suggests the use of narrow, long fuel like branches or wood chips. Vessels may have been interleaved with fuel during loading, while the channel served primarily for air supply or occasional refuelling to extend combustion. The characteristics of pottery from the kiln (dark cores, mixed firing, and oxidising surface) indicate a dynamic firing method, potentially without constant refuelling. This involves igniting fuel around and possibly also between vessels and

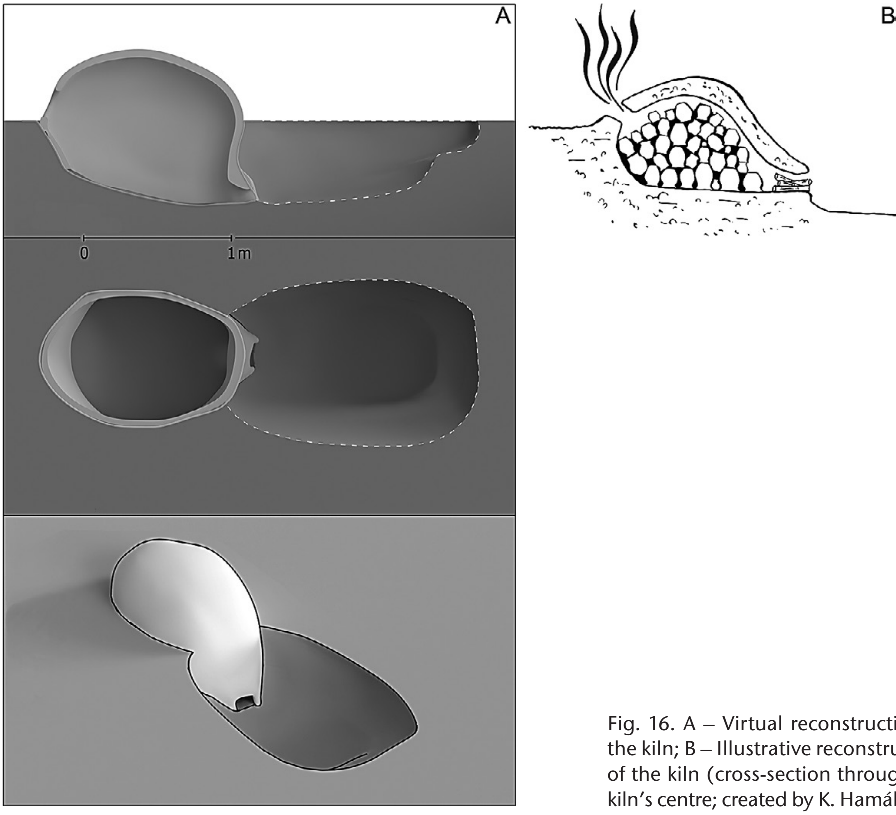

Fig. 16. A – Virtual reconstruction of the kiln; B – Illustrative reconstruction of the kiln (cross-section through the kiln's centre; created by K. Hamáková).

allowing it to fully burn out (e.g., *Roux 2019*; *Těsnohlídková 2021*, 165–167). The ceramic material, akin to brick clays with possible graphite admixtures, seems suited for this firing method characterised by short duration and generally lower temperatures (*Těsnohlídková 2021*, 172–174).

The size of the firing chamber, which determined the capacity of the kiln, remains unknown. In single-chamber kilns, space in the front must be allocated for fuel. The similar Jihlava – U Skály kiln held a full batch of 50–60 complete vessels (*Kochan et al. 2021*, 120). In contrast, the chronologically earlier kiln from Uherské Hradiště – Sady had an almost fully preserved dome. A vertical two-chambered kiln, it featured a furnace below the firing chamber with an elliptical base (100×120 cm), closely resembling the Žďár kiln. The dome height matched its base diameter. *Varadzin's* (*2010*, 31) general observations on kiln curvature provide a basis for estimating firing chamber heights. Considering that the Žďár kiln was sunk 50 cm below the ground, the above-ground part was likely 50–100 cm high.

Potter's workshop

The spatial definition of the potter's dwelling at the site is considerably challenged by the current state of research. Our discussions about its definition remain speculative. The closest features are seemingly related to the kiln and the presence of a clay deposit can be also considered. A residential structure associated with the kiln was likely situated under a later building or in close proximity to the stonemason's workshop. The potter's workshop itself might have been an above-ground structure potentially spatially linked to the cluster of spherical pits. However, some of these structures might have been located on vacant land towards the southeast part of the settlement. This area either remained unexcavated or a mistake in field documentation is also possible.

To reconstruct the appearance of the potter's workshop, we can partially rely on other archaeological findings from our region and Eastern European ethnography (see *Holubowicz 1950*; *1965*; *Bobrinskij 1978*; *Zatloukal 1999b*; *Varadzin 2010*). More comprehensive archaeological records of pottery workshops are known primarily from later periods, when they predominantly took the form of roofed structures (*Richter – Krajíc 2001*; *Procházka 2015*; *Čapek – Preusz 2019*). Within a reasonable distance from the pottery kiln, one can anticipate storage for clay ageing (*Goš 1973*), which might have been a dug-out, wooden-lined pit or an above-ground wooden structure. Clay processing might also take place in pits or above ground (*Goš 1982*). Instruments used for pottery shaping are only rarely archaeologically documented. There might also have been a facility for drying pottery, possibly in the form of an oven (*Zatloukal 1998*). Pits containing pottery waste, sometimes repurposed clay pits, are also known (*Goš 1983*; *Měchurová 1991*; *Vyšohlíd 2015*). Although kilns are the most common evidence of pottery production, simpler devices for pottery firing that are harder to archaeologically detect can be also assumed in the 13th century (see *Procházka 2015*; *Čapek – Preusz 2019*; *Těsnohlídková 2021*).

Ethnographic data suggest that the production capacity of a single workshop could be sufficient for supplying surrounding villages, and in the case of the Staré Město potter's workshop, the Žďár monastery as well. *Holubowicz* (*1965*) estimates that a family of five in the Early Middle Ages would require 20 vessels annually. Assuming a batch of 50 vessels per firing, even with a 10% defect rate, only six to seven firings would be necessary each year for a settlement with 14 households. According to Holubowicz's data, a potter would need 9–13 days for the entire production process from clay extraction to firing. Thus, these six or seven firings would take approximately 78–91 days or about 2.5–3 months of work to supply just the settlement. If pottery was provided for the local market supplying other villages in the region and the monastery, it is necessary to consider a greater amount of time invested in the pottery-making process (*Holubowicz 1965*). It is questionable if the remaining time was spent by the potter in agricultural activities to provide himself and his family with food. The total volume of pottery produced on-site can be estimated by the duration of the settlement's existence. If the record in *Cronica Domus Sarensis* is accurate, the settlement's duration in the 3rd quarter of the 13th century could be in the range of 10–24 years, which means that the total consumption of the Staré Město settlement would have been 3,000–8,400 vessels (*Ludvikovský et al. 1964*; *Zatloukal 1999a*).

Interpretation of pottery from the kiln

Determining the significance of the pottery found in the kiln hinges on interpreting the type of the deposit itself. The complete and mended vessels share similar morphological and technological attributes. Only three types of pots are represented, each by multiple specimens. The limited variability of rims suggests rapid sequential manufacturing. Almost all pots share the same type of neck offset from the belly and exhibit similar decorative motifs, while predominantly featuring undecorated rims. The majority of the ceramic material is sand-tempered without graphite, except for two specimens. Of the 14 analysed samples, 12 were made from the same raw material. Consistency in forming and firing technologies is evident. While it is uncertain if these vessels are from a single batch, their similarities indicate they were likely produced within a relatively short timeframe.

The limited number of vessels suggests they were not part of a complete kiln batch, as it is apparent from a comparison with similar contexts (*Kochan et al. 2021*, 120). Interpreting kiln batch finds is a complex issue; pots in their primary position are a crucial aspect of research (*Čapek – Preusz 2019*, 344–346). The vessels found may have been flawed or aesthetically unappealing, unlikely to be marketable, yet they were not complete failures. All exhibit signs of an oxidative final phase of firing with a dark core, and reductive firing. This pattern can also be recognised in material from other settlement features (*Těsnohlídková 2021*, 228–230; *Tab. 4*). Aesthetic displeasure is hinted at by manipulation marks on six vessels. In one case, a pronounced indentation led to a crack in the inner wall, possibly affecting functionality. However, in the other five instances, the indentations were minor and did not significantly alter the vessel shapes.

If the pots excavated in the kiln were vessels rejected by their maker, they might represent a secondary deposition following the kiln's active phase. This interpretation is supported by the fragmentary nature of part of the fill, including unsalvageable pieces totalling 629 fragments, some being small sherds. The rim shapes in this collection are more varied than those of the complete vessels, aligning more closely with the general rim pattern of the settlement than with the rim types of complete and torso-preserved vessels from the kiln (*Těsnohlídková 2022*, 241–243). While a few fragments might have unintentionally entered the kiln during operation, most of them, including bricks, were likely intentionally deposited after its termination.

Local production description

Morphology

The analysis of pottery from the kiln provides new insights into local production, especially the results obtained from complete pots. The kiln contents have significantly expanded the inventory of whole pots at the site, enhancing the ability to classify pot types based on dimensions and body profiling. This is a step forward from the previous classification method based on the position of the maximum belly diameter, which faces some limitations (*Zatloukal 2000*). It raises the question of whether these types represent a specific and short time period.

The occurrence of overlapping rim types across different pot shapes and varied rims within a single pot type indicates that rim shaping might not have been deliberate in terms of style, but rather showed tendencies toward reinforcing the neck or facilitating stable lid placement.

Of 16 analysed vessels, 15 were decorated with grooves. This proportion seems lower in the settlement assemblage, possibly because the decorations were limited to small areas of the belly. Complete motifs and combinations of decorative elements are more discernible on whole vessels. Although the dataset is limited, it suggests a chronological trend: the popularity of decorated rims and wavy lines on shoulders seems to decrease over time.

Tab. 6. Summarisation of the main fabric chemical composition.

	mean	sd	min	max
SiO_2	55.10	2.60	51.13	59.90
Al_2O_3	23.52	1.02	21.73	24,94
Fe_2O_3	4.98	0.16	4.60	5.18
K_2O	2.00	0.23	1.75	2.30
CaO	0.98	0.07	0.90	1.14
TiO_2	0.78	0.02	0.73	0.81
V	131	6	120	143
Cr	86	4	81	93
Mn	311	37	262	372
Ni	44	3	38	50
Cu	47	3	43	55
Ga	39	3	34	44
As	14	1	13	16
Rb	163	25	129	202
Sr	91	4	82	95
Ba	638	187	380	994
Pb	28	2	26	30

This finding offers a potential avenue for inferring typochronological trends in local pottery production.

Ceramic technology – tempering and provenance of raw materials

Only ceramic classes of local provenance were found in the kiln. The lower occurrence of graphite pottery (both among whole vessels and in the fragmentary assemblage) could suggest its decline assuming that the vessels from the kiln come from the last phase of the settlement's existence. Residues of plant tissues, exhibiting wood-like structures, were detected in low quantities in the ceramic body of sand-tempered pottery. These may represent charred remnants that were unintentionally incorporated into the clay, even though the technique of charcoal tempering was historically employed (*Gregerová – Procházka 2007*, 271; *Wallis et al. 2011*).

The base material for non-graphite pottery was likely loam or possibly clay loam. A significant diagnostic characteristic is the pronounced presence of stacks of biotite, which are quite short in length. It is important to consider whether this feature was already present in the original ceramic clay. Given the shape of the flakes and their frequency, this is highly probable. If the biotite was added to the clay as part of the temper, then the temper grains themselves would also have to contain biotite-rich rocks, which is not entirely the case. The temper consisted of sand containing quartz from feldspar rocks, often without biotite. The increased content of biotite in the brick, however, indicates a natural occurrence in the clay and at the same time a local origin of the raw material (see *Tab. 6* for the chemical composition of the main fabric).

The rocks used as a temper often exhibit a notable grain orientation, indicating they are metamorphosed rocks, i.e. gneiss. However, a substantial portion of rock fragments did not have grain orientation, and these rocks were identified as granitoids. This identification is apparently not accurate, as even gneiss bodies contain positions that do not demonstrate any orientation at such a scale as small fragments in ceramics. The site is situated directly on bedrock formed by Moldanubian gneiss. The local origin of these rocks is confirmed by the accessory minerals found in the ceramics – amphibole and garnet, which are typical components of Moldanubian gneiss. As for granitoids, they form the bedrock only a few kilometres upstream of the Sázava River, on whose bank the site is located. The presence of granites in the Sázava sediment was also confirmed by an analysis of sand extracted directly from the riverbed. The partially rounded shape of the grains confirms that the grains used for tempering were carried over some distance by the river.

Morphologically, graphite pottery is not specific in terms of technology; it bears the same characteristics (apart from the addition of graphite). Similarly, a comparison of graphite and sandy ceramics from the site does not reveal significant differences. The presence of graphite pottery among the complete vessels in the kiln does not necessarily imply that these were vessels from a different batch. The technological features of the ceramic vessels from the kiln, pertaining to both shaping and firing, match the features observed in sandy and graphite pottery from the settlement. It can be assumed that throughout the duration of the settlement, there was no substantial transformation in the pottery technology.

The only representative of graphite ceramics analysed from the fill differs from the rest solely in material aspects. The biotite content is significantly lower compared to the rest. Therefore, the clay must have been acquired from a different location or a biotite-poorer stratum, which could be, however, still described as loam or clay loam. The temper used was isolated graphitic grains and flakes and graphitic rocks, specifically graphitic metaquartzite. Lenses of graphitic rocks are common for the variegated series of the Moldanubian zone, but their presence has not yet been proven in the immediate vicinity of Žďár. The closest proven outcrops are Cikháj, Herálec, Netín, Víden̆, and Zvole, which are located 8–20 km away (*Burkart 1953*). There are two possible explanations: graphite was either imported to the site or graphite was extracted from unknown outcrops located in the developed area of today's city. Other components of the temper are non-graphitic rocks, specifically gneiss, which are found in both the eluvial sediment at the site as well as in Sázava alluvial sediment.

Ceramic technology – vessel forming

The analysis of complete vessels significantly enhances the understanding of vessel forming technology at the Staré Město site. It reveals a link between papillary ridge and groove impressions on vessel necks and coil traces in the lower parts of vessels along with signs of dusting and base attachment or removal. Coil traces are found mostly at the less accessible lower inner walls and below the neck. It suggests that these areas were smoothed only after the vessel's completion or before finalising the rim.

Technological traces, which are observable also in fragmentary materials, are complemented by vessel dimensions and discrepancies in measurements. Variations up to 1 cm in the diameters of rims, necks, and maximum bellies diameter, as well as variations up to 1.5 cm in the vertical position of these elements, indicate underutilisation of rapid rotation and profile turning in shaping.

The parallel orientation of inclusions, indicative of the use of rotational energy at some shaping stage, is less pronounced in material from Staré Město than in fully wheel-thrown vessels. This suggests that rotational energy from the wheel or turntable was applied only during final shaping, as supported by 3D analysis. The upper body of the pot shows less wall thickness variability, while the lower part varies more due to coil remnants. Further-more, complete symmetry along the rotational axis, typical for fast wheel usage, is absent; the pots exhibit significant asymmetry. This points to a technique in which the process began with coiling, followed by a wheel or turntable used for final shaping. It means that the potter integrated both traditional hand-building and wheel techniques.

Ceramic technology – firing

The analysed ceramics was fired heterogeneous technique characterised by a smaller share of reduction, dark cores and an oxidised layer by the surface. The oxidised layer appears irregularly. This indicates that the firing temperatures and duration were insufficient for full burnout of the graphite or organic temper, particularly in the core of the sherd. Experimental archaeology suggests such patterns emerge during a rapid, single-time firing without additional stoking, which could take place in open hearths or partially enclosed spaces. This method involves significant temperature spikes and brief peak temperatures. Therefore, it demands ceramic materials resistant to thermal shock, like the brick clays akin to Žďár pottery combined with a suitable temper (*Těsnohlídková 2021*, 299–300).

The position of some vessels within the kiln could be tentatively determined, yet a detailed reconstruction of the kiln loading method cannot be inferred from the archaeological context. Reduced-fired parts were either covered by other vessels, leaned against the kiln wall, or covered with charred fuel. If the pottery was from a single batch, its arrangement within the kiln appeared irregular and lacked regular patterns.

Rapid firing processes and short maximum temperature durations were typical for pottery production in the 13th century. It applies both to the Staré Město site and the larger area surrounding it called the Bohemian-Moravian Highlands region. This contrasts with late-medieval advancements marked by improved ceramic properties (increased plasticity, finer grain, possible mica admixture) aligning with the demands of fast wheel throwing. The new material required more controlled firing with gradual temperature rises because of its lower thermal shock resistance. Partial sintering at high temperatures reduced permeability, but it requires kilns capable of these conditions. They highlight the dominance of professional pottery emerging with the colonisation of peripheral regions of Bohemia in the 13th century. These advanced kilns started to appear already in traditional production period, but their full potential in enhancing pottery quality was not yet fully realised by pottery producers.

Pottery from the kiln in the context of the settlement

Morphology

The shapes of vessels found in the kiln morphologically correspond to the finds from the settlement, as pointed out by *Těsnohlídková* (*2022*). Pots are predominant forms accompanied by bell-shaped and flat lids, miniature vessels, a spouted pitcher, a jug, and a bottle. The pots had everted and roof-shaped rims, which were represented in a similar proportion. A simple-edged rim appears only sporadically. If we assume the kiln termination coincided with the end of the settlement, there might have been a gradual increase in the number of roof-shaped rims. This hypothesis could be supported by a higher occurrence of roof-shaped rims in sandy and mica pottery compared to graphite pottery, as mentioned earlier. In terms of the recess of the neck from the belly, the smooth recess (type A) predominates in the kiln as well as in the pottery from the rest of the Staré Město settlement.

The sharp recess (type B) is rare in the kiln compared to overall production. The decoration observed in the kiln is consistent with local production but notable differences appeared in the proportion of decorated rims.

Ceramic technology – tempering

From a technological standpoint, the vessels found in the kiln closely align with the sandy and graphite components of local ceramic production. The graphite component is minimally represented (only two pots). Morphologically, graphite pottery cannot be distinguished from non-graphite pottery, and it also shows similar technological characteristics, except for the graphite additive. The traces of formation align with those of the settlement material. Firing traces reconstructed for the material in the kiln with no significant signs of over-firing and with a dominance of oxidation firing also match the majority of the local production. These traces might indicate no significant technological transformation during the short lifespan of the settlement.

Petrographic examination categorised settlement ceramics into three main petrofabric groups: graphite-based (1), non-graphite sandy (2), and 'exotic' mica-rich and glazed (3). Each petrofabric is further classified according to specific inclusions or technological firing traces. Most petrofabrics were identified as locally sourced. However, the origin of graphite-based ceramics (petrofabric 1) is uncertain due to the unknown local graphite sources. The closest known graphite-bearing rock outcrops are 8–20 km away. And yet, the presence of graphite lenses in the Moldanubian variegated series suggests local sources might have been available in the past. Petrofabric 1B, with a high muscovite content, likely did not use exclusively local materials. Suitable rock outcrops are at least 10 km away, in the Kutná Hora – Svratka crystalline complex. For sandy petrofabric 2, local origin was confirmed by petrographic analysis of nearby river sands. The 'exotic' petrofabric 3, rich in muscovite and mica schist, is the only clearly non-local type having origin in production or just the material in the Kutná Hora – Svratka geological complex. This suggests either local production with imported materials or production in the region where these rocks are common.

The non-graphite pottery found in the kiln petrographically corresponds to petrofabric 2B (see *Fig. 13*, *14*; *Tab. 1*). The chemical composition is not entirely identical, which was manifested in the PCA component 2. The settlement's petrofabric 2B has a comparatively higher content of Ca and Sr. However, when disregarding these two elements, as indicated by the scatter plot of the first and third components, the composition of the kiln's non-graphite pottery and petrofabric 2B is congruent. The first PCA component is mainly shaped by the negative correlation between Si and metals, predominantly Fe, Cr, and Ni, while the third PCA component is shaped by Ti and Al vs. Rb, Mn, and K. The other non-graphite petrofabric 2A is petrographically somewhat similar to the kiln pottery but is distinguished by a lower content of gneiss fragments and biotite. A difference in the manufacturing technology is also evident. The 2B petrofabric was fired at a higher temperature, as indicated by its vitrified matrix. The difference in chemical composition is apparent and is mainly reflected in the higher Si content in petrofabric 2A.

The graphite pottery from the kiln is petrographically most similar to petrofabric 1A. However, it markedly deviates by chemical composition due to its high Ti content, which was prominently exhibited in the second PCA component. The scatter plot of the first and second components affirmed its affinity to 1A in chemical composition.

An intriguing observation is that the chemical composition of the non-graphite pottery from the kiln has brought petrofabric 2B closer to certain graphitic petrofabrics, specifically 1D and 1E. The 1D pottery contains a relatively small amount of graphite, and most importantly, the matrix character aligns with the non-graphite pottery from the kiln. The clay for this pottery most probably originated from the same source, suggesting that it was produced on-site and graphite was brought into the local workshop. Pottery belonging to petrofabric 1E has a distinct base matter; its biotite content is no longer increased. The chemical composition of the non-graphite pottery from the kiln also aligns with sample 13 from the settlement (petrofabric 1A), which differs slightly in its petrography. However, it fits perfectly in the geological context of the settlement and its surroundings.

The analysis of the kiln fill has shown that the local workshop produced pottery goods made from at least two distinctly different types of clays – one with a naturally high biotite content and one without biotite. The biotite content is not contingent upon whether graphite was added to the ceramics or not. Non-graphite petrofabric 2A has a lower biotite content, whereas graphite 1D has a biotite content consistent with non-graphite pottery 2B and most of the kiln fill. The chemical composition analysis demonstrates the variability in the chemical composition of local production. Only mica petrofabrics 3A and 3B with muscovite and mica schist as well as graphite 1B (which was identified just from sample 1) are apparently different and not directly local. Whether these were produced on-site with raw materials (especially the temper) being brought in, or they represent pottery imports, remains inconclusive at this point. The mica or mica pottery might have originated from the vicinity of Škrdlovice (*Čapek – Slavíček 2022*). Similarly, the interpretation regarding the origin of glazed pottery 3C remains open; it is too fine-grained for petrographic determination and its chemical makeup significantly differs from the rest of the collection.

Conclusion

The medieval pottery workshop in Staré Město, while speculative in its exact layout due to research limitations, was likely a hub for ceramic production serving both the settlement and the nearby Žďár monastery. Drawing from archaeological and ethnographic references, it is assumed that the workshop had roofed structures with storage and processing areas. While pottery found in the kiln exhibit similarities, variations in their quality hint at the inclusion of both market-worthy and flawed pieces. This dichotomy possibly indicates a secondary deposition of unsatisfactory vessels after the kiln had completed its primary function. Overall, the pottery workshop played an essential role in the 13th-century settlement, emphasising its cultural and economic significance.

Comprehensive analysis of whole vessels from the kiln has provided a clearer understanding of the local pottery morphology, revealing a variety of pot shapes and decoration trends. Despite the limited representation of graphite pottery, both graphite and sandy pottery exhibit consistent technological features. It suggests minimal transformation in production techniques over time. The pottery seems to be formed by a method combining coiling with rotational energy, perhaps from a turntable or rudimentary wheel. Firing practices from this period were notably rapid, with a focus on short durations at peak temperatures.

Examination of the kiln pottery in the context of the settlement finds provided an in-depth understanding of the technological and morphological nuances of ceramic production.

Morphologically, the pottery in the kiln and settlement contexts was consistent. Technologically, it is evident that there were subtle shifts in production methods, especially concerning the use of graphite clay. The petrographic analyses of settlement ceramics reveal a multi-faceted material base emphasising both local and potentially external influences. The presence of non-local petrofabrics, especially those rich in muscovite, contributes to the long-standing research question of Czech medieval archaeology concerning material sourcing and technological exchange in pottery production.

The archaeological excavations of the Staré Město site offer a profound glimpse into the nuanced layers of the past. The work showcases a brief yet significant period of habitation on the northern periphery of present-day Žďár nad Sázavou. The archaeometric analysis of pottery enabled a close look into many details of local pottery production. This paper aims not only to serve as a thorough base for the future research of socio-economic relationships within the Žďár region colonised in the 13th century, but also as a cornerstone for regional ceramic research covering the entire Middle Ages.

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KAREL SLAVÍČEK, Institute of Archaeology of the Czech Academy of Sciences, Brno, Čechyňská 363/19, CZ-602 00 BRNO, Czech Republic; Masaryk University, Faculty of Science, Department of Geological Sciences, Kotlářská 267/2, CZ-602 00 Brno, Czech Republic; slav.karel@sci.muni.cz
KATEŘINA TĚSNOHLÍDKOVÁ, Institute of Archaeology of the Czech Academy of Sciences, Brno; Čechyňská 363/19, CZ-602 00 Brno, Czech Republic; tesnohlidkova@arub.cz
MARTIN KOŠŤÁL, Masaryk University, Faculty of Arts, Department of Archaeology and Museology, Arna Nováka 1/1, CZ-602 00 Brno, Czech Republic; 462845@mail.muni.cz
DOMINIKA VÁCLAVÍKOVÁ, Charles University, Faculty of Arts, Department of Archaeology, nám. Jana Palacha 1/2, CZ-116 38 Praha 1, Czech Republic; vaclavikova.dominika@gmail.com
KRISTÝNA TRNOVÁ, Masaryk University, Faculty of Science, Department of Geological Sciences, Kotlářská 267/2, CZ-602 00 Brno, Czech Republic; kristynatrna@gmail.com