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MEDIEVAL GLAZED CERAMICS FROM KRAKÓW-NOWA HUTA-ZESŁAWICE, SITE 88, LESSER POLAND VOIVODESHIP. THEIR FORMAL AND TECHNOLOGICAL ANALYSIS

ABSTRACT

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This study analyses medieval glazed ceramics from Site 88 in Kraków-Nowa Huta-Zesławice, focusing on their formal and technological aspects. The research examines macroscopic features, chemical composition, and production techniques, comparing them with finds from other sites in Lesser Poland. Results indicate a local glazing tradition in Lesser Poland linked to metallurgical activities, with continuity from the 11th to the 14th century. The study expands knowledge of the distribution and production of glazed pottery in medieval Poland.

Keywords: glazed pottery, specialists analysis, Middle Ages, Lesser Poland
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1. INTRODUCTION

The occurrence of glazed ceramics in early medieval Poland is a phenomenon of exceptional character. The discovery of the first glazed vessels, dated to the mid-11th century, sparked debate over their origin and production technology. Initially, due to the small number of finds, it was believed that the production of this type of ceramics was incidental and limited to a small area on the border of Lesser Poland and Upper Silesia. However, with the systematic increase in the number of discovered artefacts and their detailed analysis, including the research presented in this article, it has become possible to gain a better understanding of the scale of this phenomenon in Polish lands during the early medieval period.

The main objective of this study is to analyse the assemblage of glazed ceramics from Site no. 88 in Kraków-Nowa Huta-Zesławice (Fig. 1: A), focusing on the macroscopic characteristics and chemical composition of ceramic bodies and glazes. These results will be compared with analyses of glazed ceramics from other important sites, such as Dąbrowa Górnicza-Łosień, Dąbrowa Górnicza – Strzemieszyce, Sosnowiec, Lelów, and Bytom. This research will provide new data and contribute significantly to the ongoing discussion on the phenomenon of glazed vessels in this part of Poland

The presented assemblage of glazed ceramics, consisting of 64 fragments from 42 vessels, was recovered during rescue excavations conducted in connection with the planned construction of the S7 expressway (Moczydło – Szczepanowice – Widoma – Zastów – Kraków section). Site no. 88, located to the west and north of the boundary of the now-defunct brickyard in Zesławice, encompassed part of a plateau and the slopes of an elevation with a maximum height of 238.6 m above sea level (Fig. 1: B).

The remains of medieval settlement, both early and late, were located on the slope of an elevation descending southwestward toward the valley of the Dłubnia River. They were identified in the western part of the excavation, on both sides of the road leading to Krapkowice, which crossed the site along a north-south axis. The medieval remains were recorded over an area measuring 180 meters in length, divided into six sections (A, B, C, D, X, Y) (Fig. 1: B). Fragments of glazed vessels were discovered in 12 features (Table 1; Fig. 1: C).

The chronology of the features was determined based on the artefacts found within them, primarily ceramic vessel fragments. Using the results of technological and formal-stylistic analysis, the period of the settlement's occupation was established as the late 11th to the early 14th century. To further refine the chronology, two phases of construction (specifically ceramic production) were distinguished. The earlier phase (group 1 of the glazed pottery), containing vessel fragments dating from the late 11th century to the first half of the 13th century, and the later phase (group 2 of the glazed pottery), dated from the 13th to the 14th century.

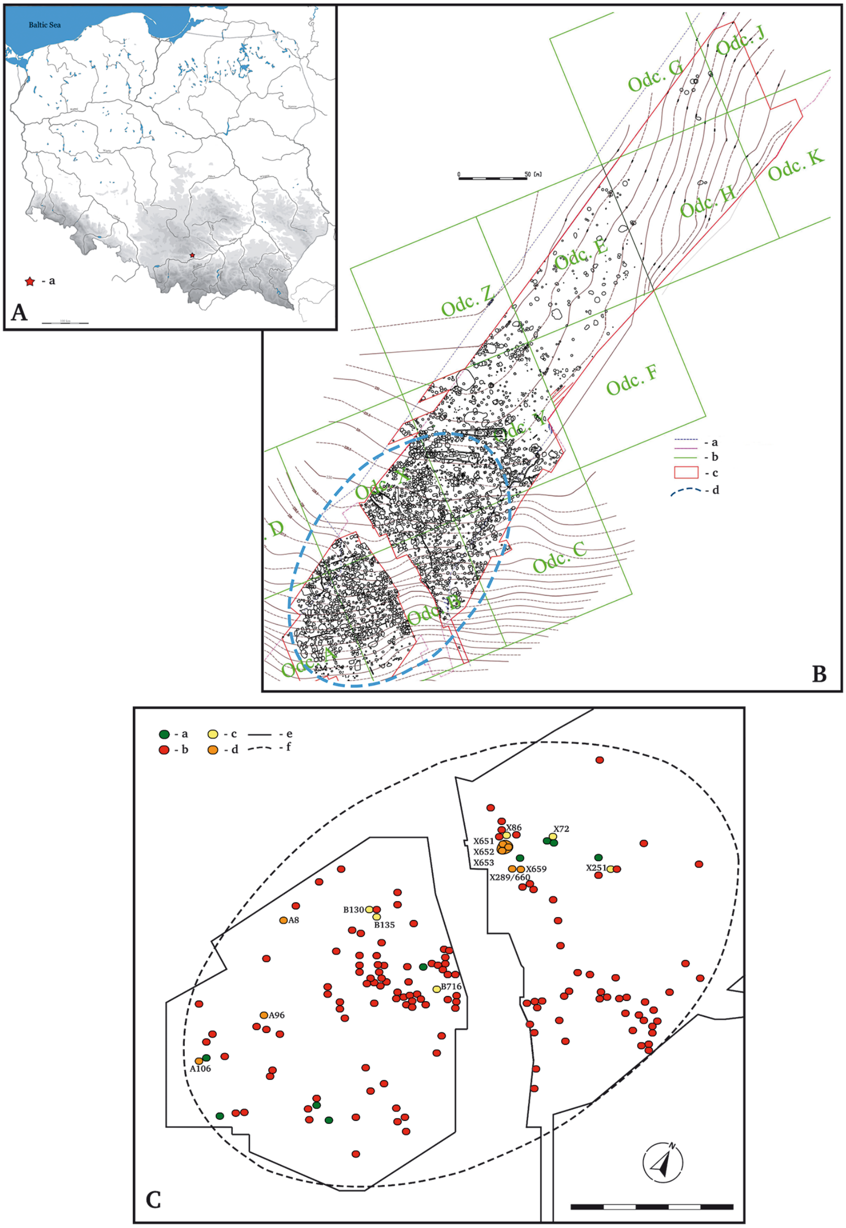


Fig. 1. A – Location of Site 88 at Kraków-Nowa Huta-Zesławice in Poland (a); B – Hiposmetric map of the site (a – area of the investment; b – trenches; c – d – area of the concentrated medieval features); C – Distribution of medieval features containing glazed pottery within the medieval settlement area (a – Early medieval features; b – late medieval features; c – early medieval features with glazed pottery, Group 1; d – Late medieval features with glazed pottery, Group 2; e – trenches; f – area of the medieval settlement). Drawing B. S. Szmoniewski, L. Żygadło

Table 1. Kraków-Zesławice, site 88, Lesser Poland Voivodeship. Characteristics of the features with glazed pottery

Ordinal number	Number of a feature	Dimensions Length and Width [cm]	Function	Glazed Pottery (Quantity)	Non-glazed Pottery (Quantity)	Other artefacts	Chronology	Plates
1	A8	221x164x75	Household pit	3	65	2 iron objects	Group II	
2	A96	630x382x79	Sunken featured structure	1	21	-	Group II	
3	A106	500x470x129	Household pit	1	8	-	Group II	Fig. 5: 1
4	B130	162x140x108	Hearth	3	28	-	Group I	
5	B135	224x178x102	Household pit	2	19	Fragment of iron knife blade	Group I	Fig. 3:3
6	B716	153x123x181	Household pit	2	79	-	Group I	
7	X72 (X63/64)	320x98x132	Household pit	3	70	Iron knife blade	Group I	
8	X86	160x88x64	Oven	2	360	Iron object; whetstone	Group I	
9	X251	574x558x185	Sunken featured structure	1	128	Fragment of a stone grinding plate; Iron fitting (?); 3 fragments of a Millstones	Group I	
10	X289/X660	359x195x70	Household pit	1	4	-	Group II	Fig. 5:4
11	X651/652/653	700x450X180	Sunken featured structure	17	185	-	Group II	Fig.3: 2 Fig.3: 4 Fig. 4: 1-3
12	X659 (X52/62)	624x450x70	Sunken featured structure	9	76	Iron knife blade; ground stone; quern stone	Group II	Fig.3: 1 Fig.5: 2, 3 Fig. 13

2. CONTEXTS IN WHICH GLAZED VESSELS WERE FOUND

The features in which glazed pottery was discovered are preserved in a severely damaged state, which, at this stage, hinders detailed formal analysis. Therefore, the most essential information regarding the discovery context is presented in Table 1.

Glazed ceramics were discovered in three sections – A, B, and X – across 11 underground features. In sections A and B, the ceramics were found exclusively in the fills of Features A8, A96, A106, B130, B135, and B716. These were sunken features that did not form any clusters, except for Features 130 and 135, which were adjacent to each other. In Section X, fragments of glazed vessels were found both within the features and in the layers above them. They were concentrated within the grid areas X51-X52-X53-X61-X62-63 and X83. One prominent feature stands out in this section (X651, X652, X653) (Table 1; Fig. 1: B, C).

3. THE GLAZED POTTERY FROM LESSER POLAND – AN OVERVIEW

The first glazed vessels in Polish territories were discovered in the 1930s at a unique cemetery in Strzemieszyce Wielkie, a district of Dąbrowa Górnicza (Marciniak 1929-1932, 238-241; Marciniak 1960, 141-186), dated to the mid-11th to mid-12th century. Among the dozen or so vessels, two cylindrical pieces stood out, adorned with wavy ornaments and a band glazed in a lemon-yellow hue, from vessels resembling small buckets. In the post-war period, there was a systematic increase in the number of sites yielding glazed ceramics, with the highest concentration on the border between Lesser Poland and Upper Silesia. In Kraków, the earliest glazed vessels discovered are dated to the second half of the 11th century (Okół and Wawel; *cf.*, Wałowy 1979, 55). The frequency of glazed ceramics in assemblages from the in pre-location period of Kraków in this initial phase was below 1% (0.3%). Still, it increased to approximately 5% in assemblages from the first half of the 13th century (Radwański 1968, 67). In later phases of the early Middle Ages, the proportion of glazed ceramics in Kraków ceramic assemblages did not exceed a few percent (Radwański 1968, 68).

Unfortunately, we do not have data on the percentage share of glazed pottery at other sites within the studied area. So far, the largest assemblage of such ceramics, comprising several hundred fragments, comes from Dąbrowa Górnicza-Łośnia, Sites 2 and 8 (Rozmus and Bodnar 2004, 26; Bodnar *et al.* 2005, 59). Therefore, the assemblage of glazed pottery from Kraków-Nowa Huta-Zesławice not only represents the first such discovery beyond the Kraków settlement microregion but also constitutes the first comprehensive study of this type of pottery from western Małopolska.

Currently, 20 sites containing glazed ceramics are known from this area. Particularly interesting is the glazed pottery from the western part of the Kraków region, which indicates a local glazing tradition distinct from that known in Rus'. Glazed ceramics from Lesser Poland and Upper Silesia have been discovered at several types of sites, including production settlements, settlements and strongholds, as well as inhumation cemeteries. They were most frequently found at production settlements – specifically at metallurgical sites associated with early medieval lead smelting or trade in this raw material. The establishment of such sites, dating from the mid-11th century, was facilitated by shallow or

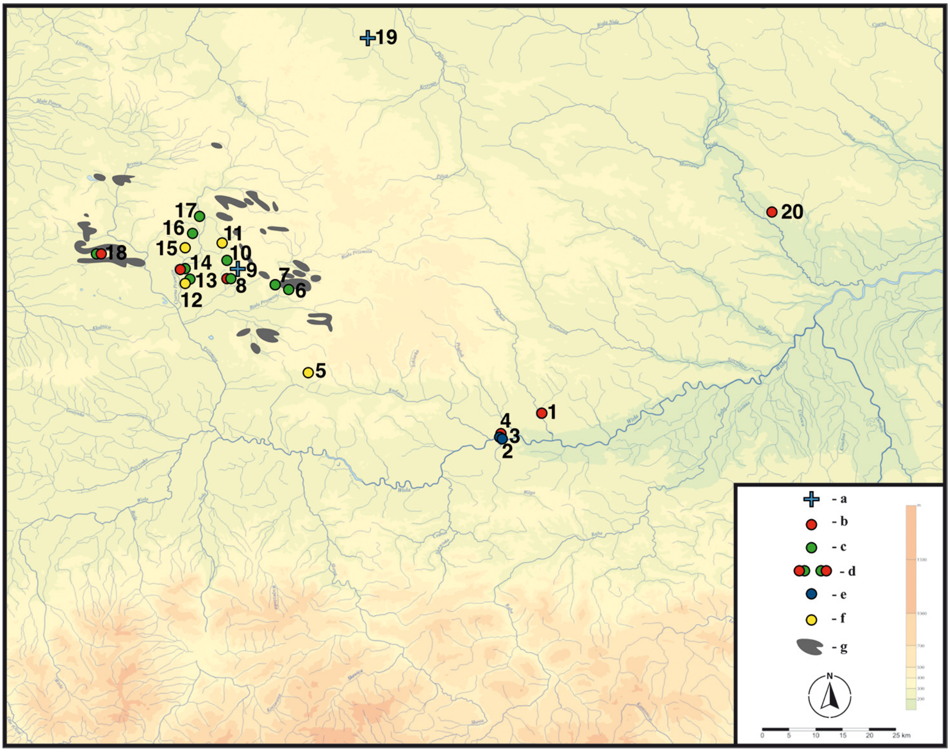


Fig. 2. Distribution of Early Medieval sites containing glazed pottery in Upper Silesia and Western Lesser Poland (a – cemetery; b – settlement; c – settlement with production zone, kilns; d – hillfort; f – sites identified during surface prospection (Polish Archaeological Record)
1. Kraków-Nowa Huta-Zesławice, Lesser Poland Voivodeship ; 2. Kraków -Wawel, Lesser Poland Voivodeship; 3. Kraków-Okół, Lesser Poland Voivodeship; 4. Kraków – Rynek, Lesser Poland Voivodeship; 5. Stare Bukowno, Lesser Poland Voivodeship; 6. Sławków, Silesian Voivodeship; 7. Bytom, Silesian Voivodeship; 8. Dąbrowa Górnicza-StrzemieszyceWielkie, Silesian Voivodeship, Silesian Voivodeship 9. Dąbrowa Górnicza-StrzemieszyceWielkie, Silesian Voivodeship; 10. Dąbrowa Górnicza-Łosień, Silesian Voivodeship; 11. Dąbrowa Górnicza-Tucznawa Przymiarki, Silesian Voivodeship; 12. Sosnowiec, Park Sielecki, Silesian Voivodeship; 13. Sosnowiec-Zagórze, Silesian Voivodeship; 14. Będzin, Silesian Voivodeship; 15. Malinowcie, Silesian Voivodeship; 16. Przeczyce, Silesian Voivodeship, Silesian Voivodeship; 17. Siewierz, Silesian Voivodeship; 18. Bytom, Silesian Voivodeship; 19. Lelów, Silesian Voivodeship; 20. Wiślica, Świętokrzyskie Voivodeship. Drawing B. S. Szmoniewski

surface deposits of lead ores containing silver compounds (Fig. 2). The primary raw material was galena (PbS), which was processed to obtain lead and silver. At these sites, glazed ceramics appear with varying frequency, indicating technological connections to metallurgical processes. In the case of the analysed glazed ceramics, the key material used for glaze production was lead oxide (litharge, PbO), obtained during the roasting of galena (PbS → PbO). Litharge was an intermediate stage in the process of extracting pure lead from lead ores containing lead sulphide (PbS) (Rozmus and Garbacz-Klempka 2017, 267, 268).

In the literature, two dominant theories explain the origins of glazed pottery production. The first theory posits that it was a result of local production, independent of external influences, and linked to the exploitation of local zinc and silver ores in the Olkusz region (Bodnar *et al.* 2005; 2006; Auch 2012). The second theory suggests that glazing technology was transferred from Kievan Rus', where it arrived from Byzantium. However, recent comparative analyses increasingly challenge the latter theory, highlighting significant differences in techniques, forms, and decorations between Rus' and the glazed pottery of Lesser Poland (Auch 2012, 239). Moreover, the latest research results confirm the use of lead deposits from the Olkusz area for glaze production, which rather indicates local production of this type of pottery (Szmoniewski *et al.* in print).

The phenomenon of glazed ceramics from Lesser Poland also stands out in comparison to early medieval pottery from Western Europe. It is worth noting that in the area of present-day Germany, glazed vessels did not become widespread until the 12th century (Höltken 2000, 17). Although glazing technology was known in Western Europe outside the Byzantine and Rus' territories as early as the 11th century, glazed vessels were primarily produced in present-day Belgium, Italy, and France – regions located at a considerable distance from the area under study (Verhaeghe 1969, 108; Whitehouse 1980, 68, 69; Husi 2003, 31; Jesset 2003, 62).

4. ANALYSIS OF GLAZED POTTERY – GENERAL CHARACTERISTICS (Figs. 3-5, 13)

A detailed analysis was conducted on 42 vessels, comprising 64 fragments. Among these, 19 fragments were classified into group I (Early Middle Ages) and 23 into group II (Late Middle Ages). The quantitative proportions of glazed pottery relative to unglazed forms are as follows:

– group I (Early Middle Ages): Glazed pottery accounts for only 3% of the total, while unglazed pottery dominates with 97%,

– group II (Late Middle Ages): The proportions shift significantly, with glazed pottery fragments making up 23% and unglazed fragments comprising 77% (Fig. 6). Most of the glazed vessels were preserved as small fragments, with only six reconstructed to a greater extent, from the rim to the lower part of the body (14%).

Fig. 3. Kraków-Zesławice, Site 88, Lesser Poland Voivodeship. Selection of glazed ceramics. 1 – Feature X659 (Sample 3); 2 – Feature X651 (Sample 10); 3 – Feature B135 (Sample 13); 4 – Feature X651/652 (Sample 16). Photo B. S. Szmoniewski

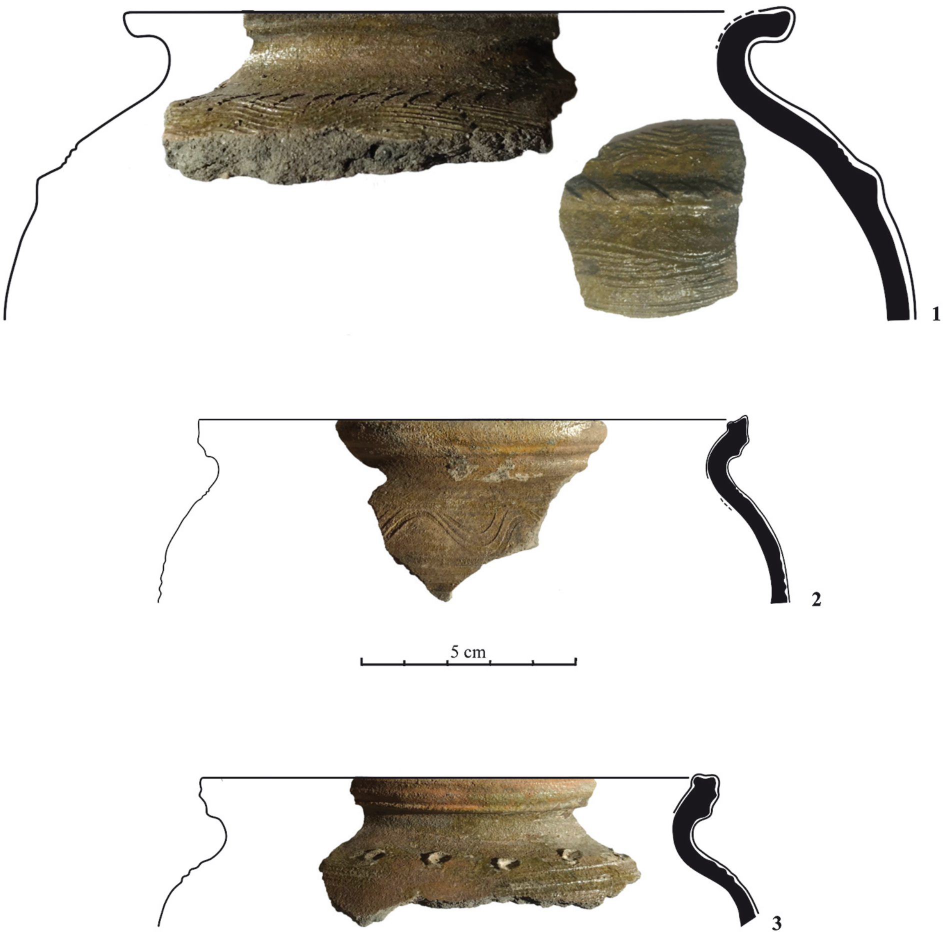


Fig. 4. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Selection of glazed ceramics. 1-3 Feature X651/652, 1 – (Sample 15). Photo B. S. Szmoniewski

About 9% of the vessels were represented by rims preserved together with a part of the neck. Rim fragments combined with fragments of the body, most often up to the break line, constituted approximately 28% of the vessels. Isolated body fragments, without the rim, accounted for 21%. The percentage of bottoms, including fragments with the base part of the vessel preserved, was 9% of the analysed collection. The glazes displayed a variety of colours, including shades of yellow, brown, olive, and greenish. In both groups of glazed vessels, glazes in various shades of green, ranging from light green to dark olive, predominated. This colouration could be achieved by adding a significant amount of iron oxide to the mixture (*cf.*, Auch 2016, 239). In many cases, the glazed surface was significantly degraded, making it difficult to determine the original colour (Figs 3-5 and 13).

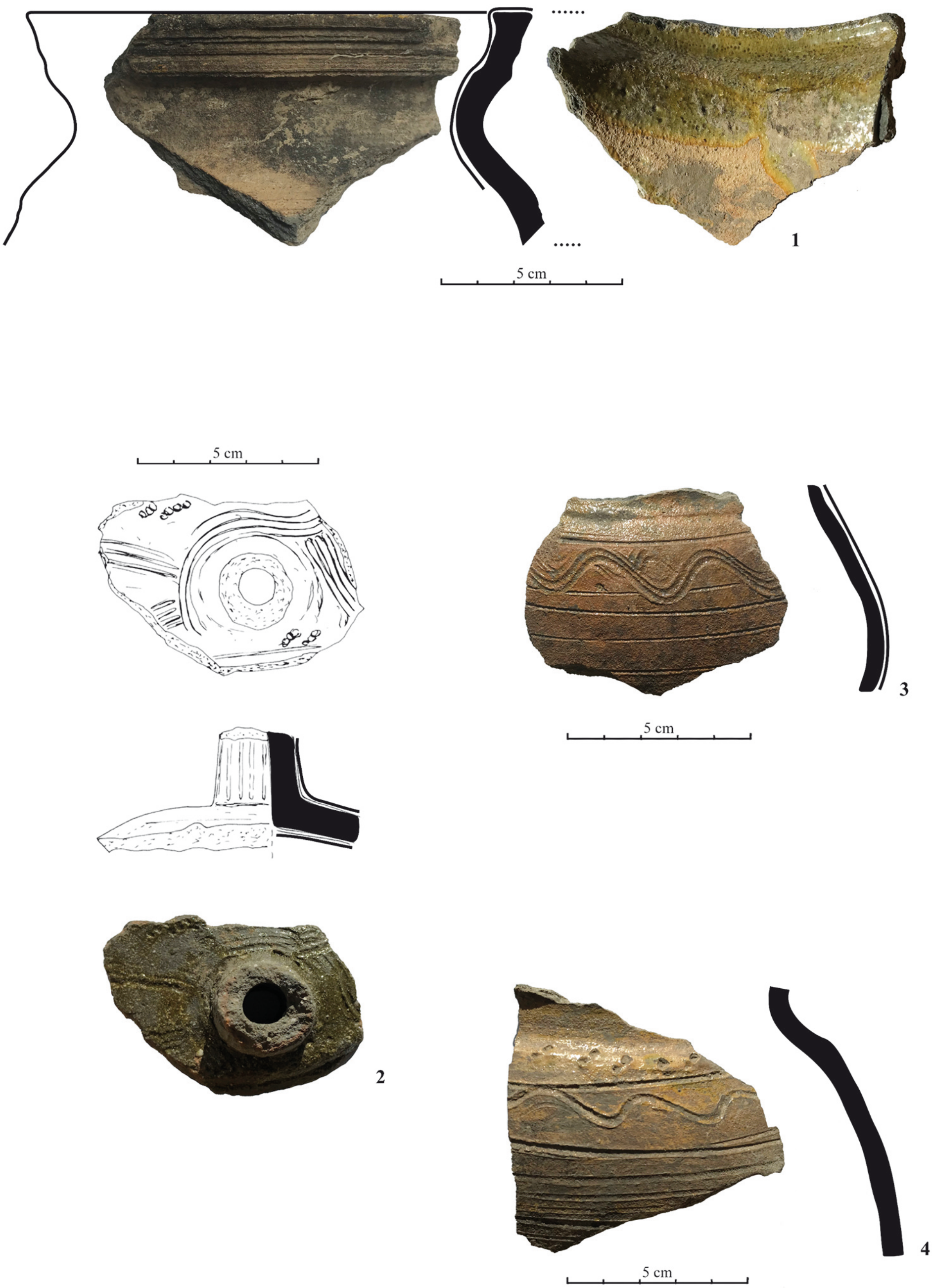


Fig. 5. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Selection of glazed ceramics. 1 – Feature A106 (Sample 7); 2 – feature X659 (Sample 11); 3 – X659 (Sample 5); 4 – Feature X289/X660 (Sample 2). Photo B. S. Szmoniewski

4.1. Group I – Early Middle Ages

The majority of the glazed vessels in group I, originating from early medieval contexts, were made from ceramic fabric designated as Type 2. This fabric contains a fine-grained sandy temper with particles up to 0.5 mm, occasionally mixed with individual medium-sized grains, accounting for 52.63% of the analysed vessels. The second most common group was Type 1 (31.58%), characterised by a high content of fine-grained temper (up to 0.5 mm), which was weakly visible on the fracture surface of the walls and evenly distributed; some grains appeared as sharp-edged. Together, these two types constitute approximately 84% of all analysed vessels. The recipes of both of these fabrics are based on the dominant addition of very fine-grained mineral particles, evenly distributed throughout the clay mass. These fabrics can be classified as progressive and were also used in the production of completely wheel-turned vessels with the more modern stylistics typical of the late medieval period. Vessels made from fabric Type 3, distinguished by a very high mineral content, accounted for about 15% (15.79%) (Fig. 7). The ceramic recipes used in the production of glazed vessels classified by us as Group I did not differ from those employed in the manufacture of unglazed wares. As with the glazed ceramics, three types of fabrics – Types 1, 2, and 3 – were the most commonly used, accounting for approximately 97% of the vessels. More than half (57%) of the vessels without any traces of glaze on their surface were made from fabric Type 1, 25.5% from Type 2, and 14.7% from Type 3. Fractures in the vessel walls in Group I were observed, with a slight colour variation. The vast majority of

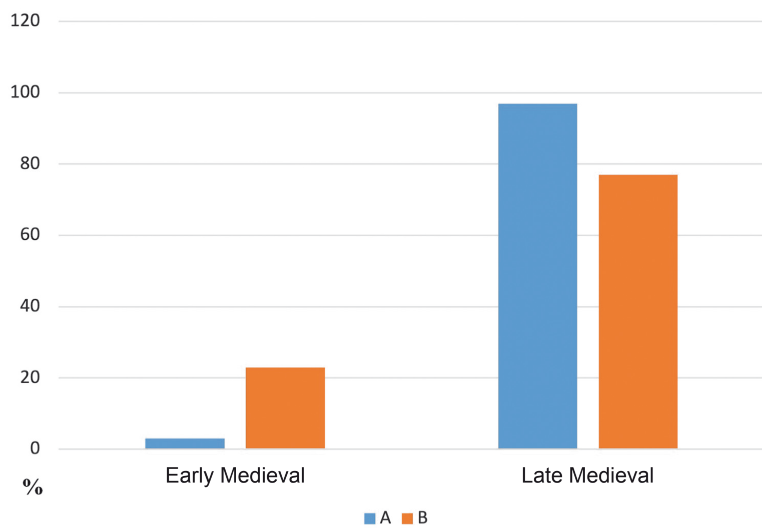


Fig. 6. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Correlation between the presence of the glazed (A) and non-glazed pottery (B). Drawing K. Zamelska-Monczak

vessel wall fractures (84.2%) displayed a three-coloured stratification. The inclusion of fine-grained sand is quite common in ceramic materials from pre-location Kraków as early as the 11th century (Radwański 1968, 17, figs. 27-32; Radwański 1975, 301, figs 117-122). In this regard, the ceramics from Kraków-Nowa Huta Zesławice do not differ from those of nearby Kraków from the same period. This clearly indicates the existence of a specific pottery tradition in this part of Lesser Poland.

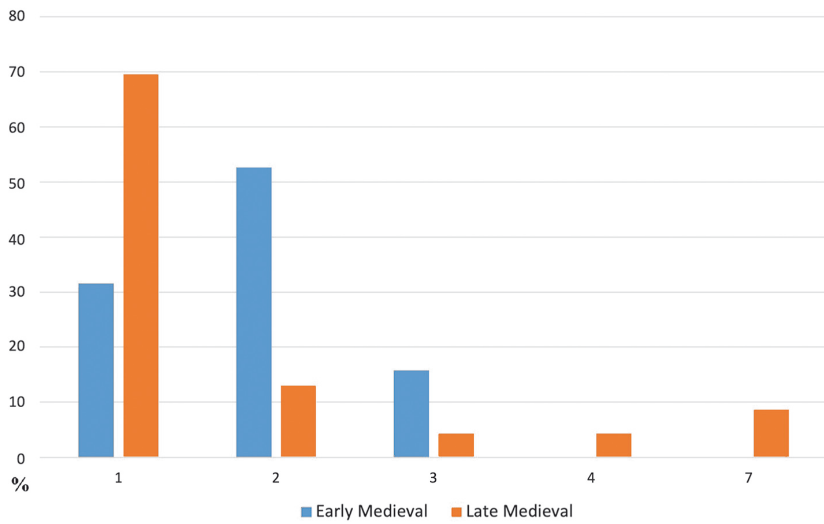


Fig. 7. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Frequency of ceramic fabric group 1-7. Drawing K. Zamelska-Monczak

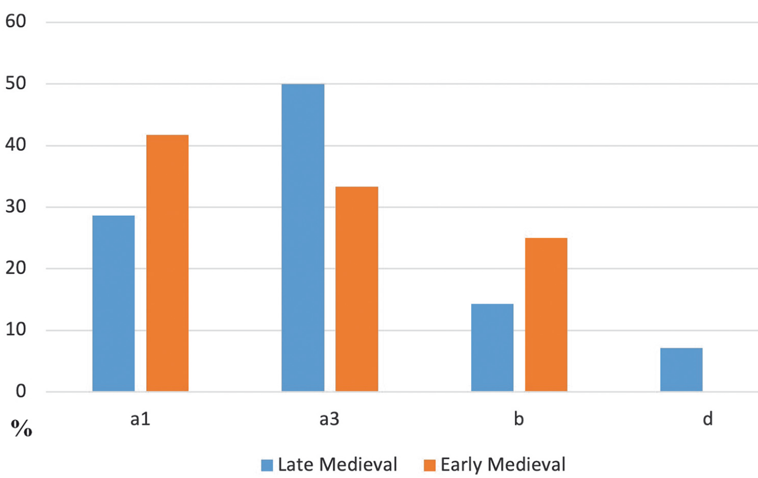


Fig. 8. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Frequency of the main vessel types in the assemblages: a1 – vessels with a distinct neck; a3 – vessels without a distinct neck; b – vessels with a cylindrical neck; d – vessels with a 'spout'. Drawing K. Zamelska-Monczak

The glazed vessels exhibited a diversity of forms (Fig. 8); however, their range of shapes did not differ significantly from that of the remaining ceramic assemblage. Among the early medieval vessels (Group I), the most common type, accounting for 41.7%, was type a.1. These vessels featured a four-part structure consisting of a rim, neck, upper body, and lower body. Vessels without a neck (type a.3) constituted 33.3%, while those with a cylindrical neck (type b) made up 23%. The frequency of these latter forms appears to be high, not only in comparison to the unglazed forms within this assemblage, the percentage of which hovers around 6.5%, but also in relation to other Early Medieval ceramic assemblages.

The dominant vessel category in Group I was characterised by wall thicknesses of 4-6 mm. Nearly half (47.4%) of the items had walls measuring 5 mm thick. The frequency of vessels with 4 mm and 6 mm wall thicknesses was similar, at approximately 20% each (26.3% and 21.1%, respectively) (Fig. 9).

The classification of vessel rims (Fig. 10) followed the system proposed by Paweł Rzeźnik, which differentiates rim types based on the shaping of the external and internal surfaces of the rim and the form of the lip edge (Rzeźnik 1995, Fig. 28). In Group I ceramics, Group III rims, characterized by a shaped inner rim surface and lip edge, represented 40% of the total. The remaining rim types were less frequent. The second most numerous group was Group IV, in which shaping included both the inner and outer surfaces of the rim and the lip edge. The least frequent was Group II, defined by shaping limited to the outer rim surface and the lip edge (Fig. 11). The vessel rims classified into Groups 3 and 4

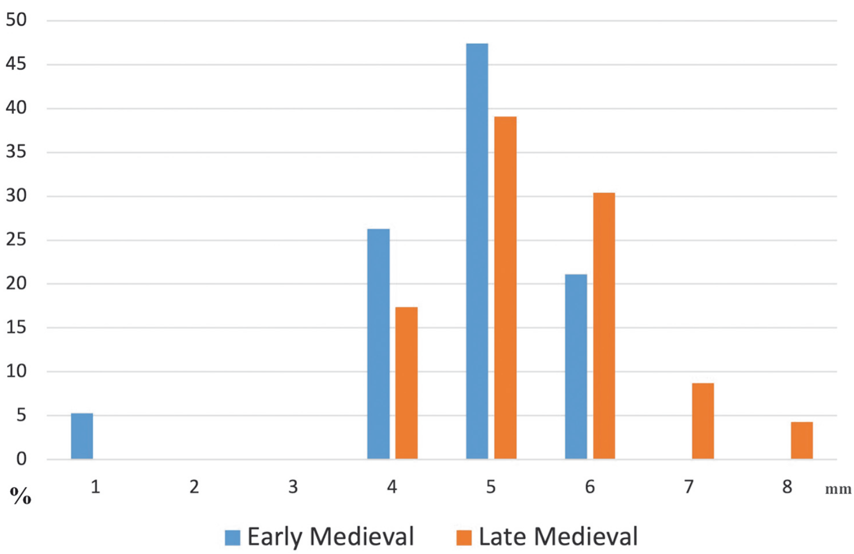


Fig. 9. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Distribution of vessel wall thickness in millimetres. Drawing K. Zamelska-Monczak

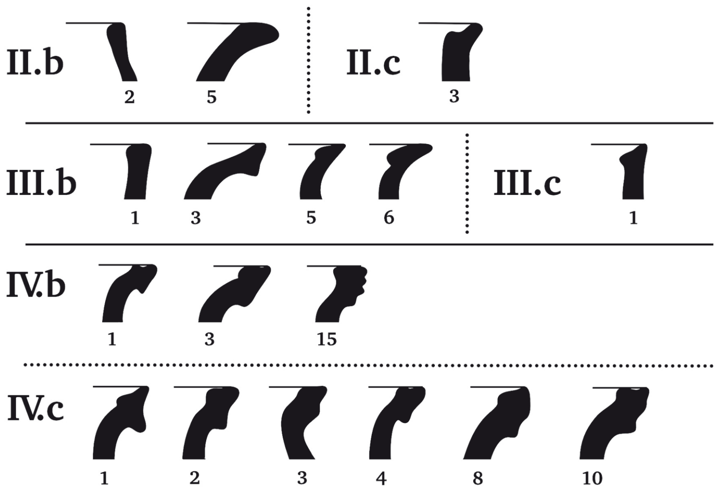


Fig. 10. Kraków-Zesławice, Site 88, Lesser Poland Voivodeship. Groups of rims. Drawing B. S. Szmoniewski

show connections to vessel rims from Kraków, where they are similar to profiled specimens, particularly Types 29, 30, 32, and 35. The chronology of these types is mainly dated to the 11th century, and primarily to the 12th to 13th centuries (Radwański 1968, 62, 64; fig. 39). The glazed vessels in this group were highly diverse in terms of both ornamental composition and motifs and patterns used. Considering that wheel-turned vessels typically featured extensive ornamentation covering larger areas of the surface in varied arrangements, the complete design could be reconstructed for only a small subset of the items. Identified decorations included flat circumferential grooves made with a stylus, appearing either alone or in combination with a band above them. This band often took the form of a wavy line applied with a stylus or comb. On three vessels, the grooved decoration was supplemented with several bands located in the upper part of the body. These bands featured diagonal comb impressions, wavy lines, or short horizontal strokes made with a stylus. One distinctive vessel had raised plastic bands on the neck, accompanied by a line of diagonal imprints and wavy lines created with a stylus.

The glaze varied in coverage, applied to different parts of the vessel: just the interior, the exterior, or both. In Group I ceramics, glazing was most commonly limited to the upper parts of the vessels, particularly around the rims. Approximately 47.4% of fragments were from vessels glazed only on the exterior, while slightly fewer (42.1%) showed glazing on both sides. Vessels with interior glazing alone were the least common, comprising just 10.5% of the fragments (Fig. 12). No correlation was observed between vessel form and the extent of surface glazing. The glazes exhibited colour variation. Shades of yellow, brown, olive, and greenish hues were identified, along with transparent glazes. In many cases, the glazed surface was heavily deteriorated, making it difficult to determine the original colour.

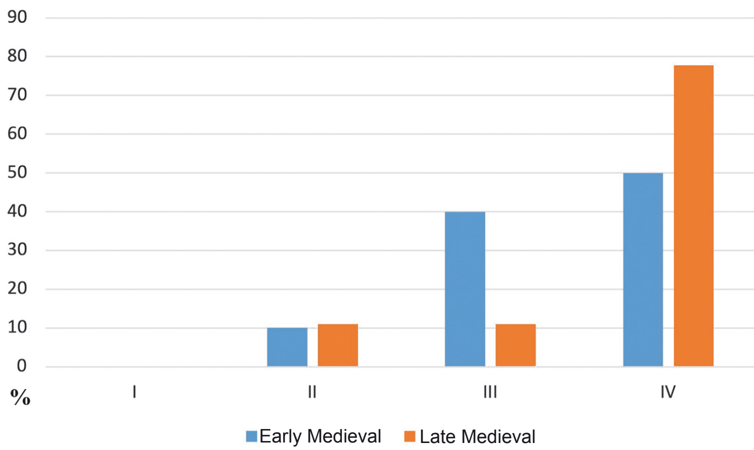


Fig. 11. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Frequency of rims of groups II-IV. Drawing B. S. Szmoniewski

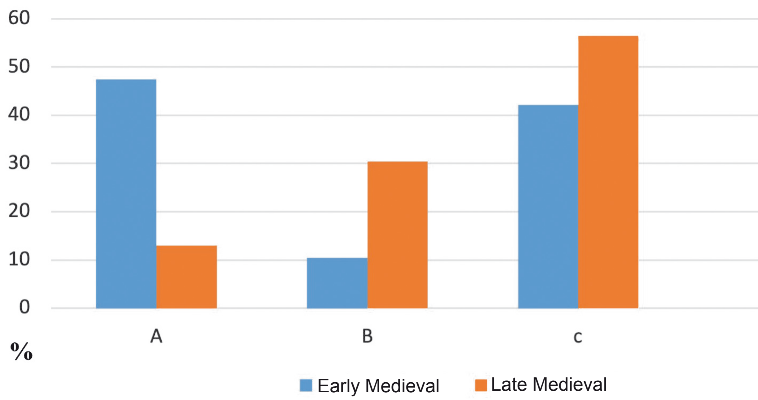


Fig. 12. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Extent of glazing on the surface of vessels. A – external surface, B – internal surface, C – glazing on both internal and external walls. Drawing K. Zamelska-Monczak

4.2. Group II – Early Phases of the Late Middle Ages

Among the glazed vessels in Group II, associated with late medieval contexts, the majority were made using ceramic fabric No. 1, which accounted for nearly 70% (69.57%) of the assemblage. The ceramic recipe classifications are consistent across both Group I and Group II ceramics. Ceramics in this group were also produced using fabric No. 2 (13.04%) and, in individual cases, fabric No. 3 (characterized by a very high proportion of fine and medium-sized inclusions; significant mineral additives visible as a “friable” texture in the fracture), No. 4 (medium quantity of fine inclusions with medium-grain particles), and

No. 7 (a very high proportion of medium-grain inclusions, predominantly sand with grains up to 2 mm, and occasional charcoal fragments, distributed evenly and tightly packed in the clay). Overall, the glazed vessels in Group II demonstrated greater diversity in the ceramic fabrics used for their production (Fig. 7). For unglazed vessels in Group II, fabrics designated as Type 1 (55.4%) and Type 2 (28.4%) were also preferred. This indicates that the potters' preferences regarding ceramic recipes were similar for both glazed and unglazed vessels.

Examination of vessel wall fractures of vessels in Group II revealed slight variation, with the vast majority (91.3%) exhibiting a tri-coloured stratification in the cross-section. Half of the vessels from late medieval contexts (Group II) were forms without a distinct neck. The frequency of vessels with a neck was 28.6%, while those with cylindrical necks made up 13% (Fig. 8). The number of glazed vessels with cylindrical necks in this assemblage is lower than in Group I, yet remains relatively high. For comparison, the proportion of unglazed forms of this type within the same assemblage was 7.9%. One exceptional vessel form identified in this group featured a small cylindrical funnel, attached to the vessel wall, with an external diameter of 2.77 cm and an internal diameter of 2.03 cm (Fig. 5: 2). This unique item was found in a context dated to the late Middle Ages.

4.2.1. Dominating Characteristics of Group II Glazed Ceramics

The dominant category in both Group I and Group II glazed ceramics comprised vessels with wall thicknesses of 4-6 mm. Vessels with 5 mm-thick walls were the most prevalent, accounting for nearly 40% of the assemblage. The proportion of vessels with 6 mm-thick walls was also significant at 30.4%. Vessels with thinner walls (4 mm) were less common, comprising 17.4% of the collection. Ceramics with thicker walls, ranging from 7 to 8 mm, appeared only sporadically (Fig. 9).

In Group II ceramics, 78% of vessel rims belonged to Type IV, characterised by pronounced profiling. This trend became more widespread in medieval ceramics, especially in rims with an overhanging lip. Types II and III rims were comparatively rare (Figs 10 and 11). The vessel rims from this group of glazed ceramics show connections to rims from Kraków, particularly to Types 29, 35, and 51, whose origins date back to the early medieval period and can be broadly dated from the 12th to the 13th century and later (Radwański 1968, 62, 64, figs 38, 39). In Group II of glazed ceramics, the glaze most often covered both the external and internal surfaces of the vessel (56.5%), only the internal surface (30.4%), and, least frequently, only the external walls (13%) (Fig. 12).

Group II glazed ceramics exhibit greater diversity in decorative composition than Group I. However, it should be noted that the complete decorative scheme could be reconstructed for only seven vessels (Figs. 3: 1, 2; 4: 1-3; 5: 3, 4). In addition to circumferential surface grooves created with a stylus, there was also the so-called frieze ornament, featuring a single band of diagonal imprints below the rim. On one vessel, above the grooves, three bands were observed: two wavy lines and a line of diagonal comb imprints. A composition was also used in which a strip of a wavy line was applied between grooves, at the height of the most significant bend of the vessel's body. The two glazed vessels stood out from the others in the group with their extensive, multi-motif ornament. One composition consisted of horizontal bands of diagonal imprints and wavy lines, further enhanced with a plastic strip of triangular cross-section, decorated with an additional line of impressions (Fig. 4: 1). The second composition featured numerous surrounding grooves, interspersed in the upper part of the vessel's body with multiple wavy lines and circular imprints (Fig. 5: 4). Unfortunately, the small number of vessels preserved well enough to allow identification of the ornament composition does not permit detailed comparative analysis. In Group II, the colour palette of glazes was less varied. Green glazes dominated, ranging from light green to dark olive shades, accounting for 91% of the collection. The glaze most commonly covered both the exterior and interior surfaces of the vessel (56.5% of the vessels), less frequently only the interior surface (30.4%), and occasionally only the exterior walls (13%). No correlation was observed between vessel form and the extent of glazed surface coverage.

4.3. Production and Glazing Techniques

Observations of the surfaces and cross-sections of vessel walls, forms, and unobliterated marks associated with their shaping indicate that all glazed vessels from the site in Nowa Huta-Zesławice were made on a potter's wheel, using the completely turned technique. On the two slightly concave bottoms of glazed vessels from Group II, so-called circular rings were present. These features are associated with the initial stage of forming and centring the vessel's base. The circular rings on the bottoms of the glazed vessels varied in shape: they could resemble a flattened "band" with a surrounding groove running from the interior side of the base or take the form of a rounded roller, slightly visible and irregular. On one base from this group, traces of inclusions in the form of fine sand were observed. Two bases from Group II showed marks from the movement of forming/kneading the clay associated with shaping the base and attaching the clay to the wheel's disc. One base also displayed lines at the joints of clay strips, horizontal or diagonal smoothing traces on the inner wall surfaces, and (on the external surface) imprints of a wooden texture, probably from the wheel's disc. Irregular, deeply incised grooves were also preserved inside one of the bases (Fig. 13).

It is difficult to determine unequivocally which method was used for glazing the vessels from Kraków-Nowa Huta-Zesławice. The glaze structure is heterogeneous, and discolourations are visible on the surfaces, which may result from the uneven distribution of colouring oxides or differences in access to the vessel walls during firing (Auch 2016, 103). Given the relatively broad chronological framework, several methods might have been employed. It is challenging to determine whether powdered lead compounds were applied directly or combined with an organic substance or clay (Fig. 18). Some vessels, particularly those with a thicker glaze layer, were probably coated with a thin, watery suspension of powdered lead compounds, colouring oxides, and organic substances. Such organic substances could have included starch from wheat flour or barley meal (Auch 2012, 233). Cracking of the glaze and the presence of pinholes may indicate the use of this method (Fig. 5: 1). The latter could have resulted from the release of air/gas from dried walls (Auch 2016, 103, with references). With some probability, the microbubbles observed in sample 13 (Fig. 18) may have originated similarly. It is also possible that, in some cases, powdered lead compounds were applied to slightly dried vessels, which were then fired in a single step. The varied thickness of the glaze layer may suggest this approach.

Fig. 13. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Vessel bottom from the feature X659. Photo K. Zamelska-Monczak

5. GLAZED CERAMICS IN THE LIGHT OF SPECIALISED RESEARCH

5.1. Instruments and Analysis

The most formally interesting fragments of glazed ceramics were selected for analysis. The technological analysis was performed using Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS). The research was conducted at the Laboratory of Archaeometallurgy and Conservation of Archaeological Artefacts, Institute of Archaeology, Jagiellonian University, utilising a Tescan Vega 3 XMU microscope equipped with an Aztec X-Max 50 EDS system. Cross-sections of the artefacts were prepared and coated with a thin silver layer to enhance conductivity. SEM imaging in backscattered electron (BSE) mode was performed at 20 kV, while EDS measurements were conducted at a working distance of <15 mm. The beam current and magnification were adjusted based on the sample surface morphology.

For area analysis, the acquisition time was optimised based on the sample characteristics, with EDS mapping conducted for at least 15 minutes. EDS spectra were collected with a dead time of 10% and a count rate of 8000 cps. A standardless calibration method (Trincavelli *et al.* 2014) was applied for oxide content analysis, with a lower limit of detection (LLD) of 0.1 wt%. The chemical composition analysis focused on the technological zones, specifically the glaze and clay. EDS spectra were acquired from specific points (glaze) and surface areas (clay) up to 1500 × 2000 micrometres, with measurements adapted to the material's heterogeneity. The obtained EDS results for both clay and glaze are presented in Tables 2 and 3. Phase composition analysis of pottery was conducted using the powder X-ray diffraction method (pXRD) on an X'Pert Pro diffractometer at the Faculty of Geology, University of Warsaw, with the following parameters: current of 30 mA, voltage of 40 kV, CoKα anode, step size 0.026 2θ, start position 4.01 2θ, end position 75.00 2θ, with no monochromator used. The results were interpreted using X'Pert HighScore Plus software, with access to the ICDD PDF-2 (RDB 2008) database.

5.2. Results. Technological Aspects

5.2.1. Glazing

Analysis of the chemical composition of the glazes from vessels found at the Kraków-Nowa Huta-Zesławice settlement (Site 88) revealed that, in all cases, their recipes were based on lead oxide (PbO). The content of this compound in the analysed glazes is relatively high, exceeding 60%. In several samples, it even exceeds 70% (Table 3, Fig. 14). An important component, alongside lead oxide, is silica, whose content typically ranges from 17% to 30%. However, in one case, a value of 11.05% was recorded (Table 2).

Table 2. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Chemical composition of Pb-glaze on pottery (EDS, in wt%±1σ). '-' not determined, below detection limit (<0.1wt%)

Object no.	SEM mag	EDS point no.	Al_2O_3	SiO_2	CaO	Fe_2O_3	PbO	MgO	Na_2O	P_2O_5	K_2O	TiO_2	MnO
1	×100	1	5.1 ±0.2	18.9 ±0.3	0.5 ±0.1	1.54 ±0.2	74.1 ±0.3	-	-	-	-	-	-
		2	4.7 ±0.2	17.9 ±0.3	1.3 ±0.1	1.65 ±0.2	74.1 ±0.3	0.6 ±0.1	-	-	-	-	-
		3	5.0 ±0.2	17.4 ±0.3	0.6 ±0.1	1.76 ±0.2	74.9 ±0.3	0.5 ±0.1	-	-	-	-	-
2	×160	1	9.0 ±0.2	31.6 ±0.3	1.6 ±0.1	3.96 ±0.2	53.0 ±0.4	0.7 ±0.1	-	-	0.6 ±0.1	-	-
		2	5.4 ±0.2	21.9 ±0.3	1.0 ±0.1	2.42 ±0.2	68.5 ±0.4	0.6 ±0.1	-	-	0.5 ±0.1	-	-
		3	7.1 ±0.2	21.0 ±0.3	1.2 ±0.1	3.19 ±0.2	66.5 ±0.4	0.6 ±0.1	-	-	0.8 ±0.1	-	-
3	×200 2-side glaze	1 (right side)	6.6 ±0.2	20.9 ±0.3	0.8 ±0.1	1.98 ±0.2	68.2 ±0.4	0.5 ±0.1	0.6 ±0.1	-	0.7 ±0.1	-	-
		2	3.2 ±0.2	11.9 ±0.2	0.5 ±0.1	2.53 ±0.3	82.1 ±0.4	-	-	-	-	-	-
		3	4.2 ±0.2	15.3 ±0.3	0.5 ±0.1	1.54 ±0.2	77.1 ±0.4	0.5 ±0.1	0.6 ±0.1	-	0.4 ±0.1	-	-
		1a (left side)	5.7 ±0.2	19.5 ±0.3	1.0 ±0.1	2.31 ±0.2	70.7 ±0.4	0.6 ±0.1	-	-	0.3 ±0.1	-	-
		2a	5.5 ±0.2	18.9 ±0.3	1.3 ±0.1	2.42 ±0.2	71.5 ±0.4	0.6 ±0.1	-	-	-	-	-
4	×200	1	10.5 ±0.2	30.7 ±0.3	0.99 ±0.1	2.31 ±0.2	51.3 ±0.4	0.3 ±0.1	-	-	4.2 ±0.1	-	-
5	×300	1	8.1 ±0.2	23.9 ±0.3	1.1 ±0.1	1.98 ±0.2	62.6 ±0.4	0.6 ±0.1	0.5 ±0.1	0.6 ±0.1	0.9 ±0.1	-	-
		2	0.6 ±0.1	23.6 ±0.3	1.3 ±0.1	2.09 ±0.2	67.4 ±0.4	0.6 ±0.1	-	-	-	-	-
6	×200	1	5.6 ±0.2	18.7 ±0.3	0.5 ±0.1	1.65 ±0.2	73.1 ±0.4	0.6 ±0.1	-	-	-	-	-
		2	8.8 ±0.2	18.2 ±0.3	0.5 ±0.1	1.25 ±0.2	71.0 ±0.4	0.5 ±0.2	-	-	-	-	-
		3	4.9 ±0.2	17.0 ±0.3	0.6 ±0.1	1.32 ±0.2	75.7 ±0.3	0.7 ±0.1	-	-	-	-	-
7	×200	1	2.8 ±0.2	19.3 ±0.3	2.4 ±0.1	4.4 ±0.2	67.3 ±0.4	0.5 ±0.1	-	3.7 ±0.2	-	-	-
		2	3.6 ±0.2	23.3 ±0.4	1.1 ±0.1	4.18 ±0.2	67.1 ±0.5	-	-	0.5 ±0.2	0.6 ±0.2	-	-
8	×200	1	4.3 ±0.2	17.6 ±0.3	0.5 ±0.1	1.87 ±0.2	75.6 ±0.3	-	-	-	0.4 ±0.1	-	-
		2	4.7 ±0.2	17.5 ±0.3	0.5 ±0.1	1.65 ±0.2	74.8 ±0.4	0.5 ±0.1	-	-	0.6 ±0.1	-	-
		3	2.3 ±0.1	12.2 ±0.2	1.1 ±0.2	3.52 ±0.2	80.8 ±0.4	-	-	-	0.5 ±0.1	-	-

Object no.	SEM mag	EDS point no.	Al_2O_3	SiO_2	CaO	Fe_2O_3	PbO	MgO	Na_2O	P_2O_5	K_2O	TiO_2	MnO
9	×150	1	5.0 ±0.2	22.4 ±0.3	0.6 ±0.1	1.76 ±0.2	70.0 ±0.4	0.5 ±0.1	-	-	-	-	-
		2	4.1 ±0.2	20.7 ±0.3	0.8 ±0.1	1.98 ±0.2	71.5 ±0.4	0.5 ±0.1	-	-	0.6 ±0.1	-	-
		3	3.3 ±0.2	17.2 ±0.3	0.5 ±0.1	2.53 ±0.2	73.3 ±0.4	-	1.1 ±0.1	-	1.1 ±0.1	-	-
10	×300	1	4.7 ±0.2	26.6 ±0.3	1.1 ±0.1	2.31 ±0.2	63.4 ±0.4	0.5 ±0.1	-	-	0.7 ±0.1	-	-
		2	9.7 ±0.2	24.8 ±0.3	1.1 ±0.1	4.51 ±0.2	56.7 ±0.4	0.7 ±0.1	-	-	1.5 ±0.1	-	-
		3	7.0 ±0.2	36.4 ±0.4	0.9 ±0.1	2.53 ±0.2	48.6 ±0.4	0.5 ±0.1	0.5 ±0.1	-	2.1 ±0.1	-	-
		4	11.5 ±0.2	32.8 ±0.3	8.9 ±0.2	8.69 ±0.2	18.0 ±0.4	1.3 ±0.1	1.9 ±0.1	7.4 ±0.2	3.8 ±0.1	-	3.8 ±0.2
11	×100	1	5.2 ±0.2	23.2 ±0.3	0.6 ±0.1	1.54 ±0.2	69.0 ±0.4	0.6 ±0.1	-	-	-	-	-
		2	5.6 ±0.2	22.7 ±0.3	0.8 ±0.1	2.42 ±0.2	67.3 ±0.4	0.7 ±0.1	-	-	0.3 ±0.1	0.5 ±0.1	-
		3	5.5 ±0.2	23.9 ±0.3	0.8 ±0.1	1.54 ±0.2	67.3 ±0.4	0.6 ±0.1	-	-	0.6 ±0.1	-	-
12	×100	1	6.3 ±0.2	23.1 ±0.3	0.9 ±0.1	1.87 ±0.2	66.8 ±0.4	0.7 ±0.1	-	-	0.5 ±0.1	-	-
		2	4.8 ±0.2	24.9 ±0.3	0.9 ±0.1	2.31 ±0.2	66.7 ±0.4	-	-	-	0.6 ±0.1	-	-
		3	5.9 ±0.2	23.6 ±0.3	1.2 ±0.1	2.31 ±0.2	66.4 ±0.4	0.7 ±0.1	-	-	-	-	-
13	×150	1	3.5 ±0.2	16.0 ±0.2	10.1 ±0.2	1.76 ±0.2	58.2 ±0.4	0.8 ±0.1	-	9.5 ±0.2	0.4 ±0.1	-	-
		2	2.8 ±0.1	11.5 ±0.2	13.0 ±0.2	5.06 ±0.2	55.3 ±0.4	0.5 ±0.1	-	12.3 ±0.2	-	-	-
		3	4.6 ±0.2	19.5 ±0.3	6.0 ±0.2	1.65 ±0.2	61.9 ±0.4	0.6 ±0.1	-	5.6 ±0.2	0.3 ±0.1	-	-
		4	3.6 ±0.2	13.4 ±0.2	11.0 ±0.2	2.09 ±0.2	59.3 ±0.4	1.2 ±0.1	-	9.7 ±0.2	-	-	-
		5	8.2 ±0.2	25.8 ±0.3	2.7 ±0.1	1.87 ±0.2	55.6 ±0.4	0.5 ±0.1	2.9 ±0.2	2.2 ±0.2	0.4 ±0.1	-	-
		6	4.1 ±0.2	16.6 ±0.3	0.7 ±0.1	1.98 ±0.2	76.4 ±0.3	0.5 ±0.1	-	-	-	-	-
		7	4.7 ±0.2	17.2 ±0.3	0.8 ±0.1	2.09 ±0.2	74.4 ±0.4	0.5 ±0.1	-	-	0.6 ±0.1	-	-
14	×60	1	6.8 ±0.2	26.4 ±0.3	0.9 ±0.1	5.72 ±0.2	58.3 ±0.4	1.3 ±0.1	-	-	0.6 ±0.1	0.6 ±0.1	-
		2	5.8 ±0.2	22.3 ±0.3	0.9 ±0.1	4.95 ±0.2	64.3 ±0.4	1.0 ±0.1	-	-	0.6 ±0.1	0.6 ±0.2	-
		3	7.5 ±0.2	29.9 ±0.3	1.2 ±0.1	3.63 ±0.2	55.3 ±0.4	0.8 ±0.1	1.3 ±0.1	-	0.6 ±0.1	-	-

Table 2.

Object no.	SEM mag	EDS point no.	Al_2O_3	SiO_2	CaO	Fe_2O_3	PbO	MgO	Na_2O	P_2O_5	K_2O	TiO_2	MnO
15	×400	1	7.8 ±0.2	30.0 ±0.3	1.5 ±0.1	2.53 ±0.2	55.0 ±0.4	1.0 ±0.1	0.9 ±0.2	-	1.2 ±0.1	-	-
		2	5.5 ±0.2	28.9 ±0.3	1.2 ±0.1	1.98 ±0.2	61.0 ±0.4	0.6 ±0.1	-	-	1.0 ±0.1	-	-
16	×500	1	7.8 ±0.2	26.7 ±0.3	1.1 ±0.1	2.64 ±0.2	60.0 ±0.4	0.9 ±0.1	0.5 ±0.1	-	0.7 ±0.1	-	-
		2	6.2 ±0.2	23.1 ±0.3	1.2 ±0.1	3.19 ±0.2	66.1 ±0.4	0.4 ±0.1	-	-	-	-	-
		3	11.1 ±0.2	31.8 ±0.3	1.2 ±0.1	2.42 ±0.2	50.0 ±0.4	1.1 ±0.1	1.3 ±0.2	-	1.4 ±0.1	-	-
17	×200	1	4.9 ±0.2	22.2 ±0.3	0.6 ±0.1	1.76 ±0.2	69.8 ±0.4	0.5 ±0.1	-	-	0.5 ±0.1	-	-
		2	5.5 ±0.2	24.4 ±0.3	0.7 ±0.1	1.76 ±0.2	66.6 ±0.4	0.6 ±0.1	-	-	0.6 ±0.1	-	-
		3	4.5 ±0.2	23.3 ±0.3	-	1.21 ±0.2	70.5 ±0.3	0.6 ±0.1	-	-	-	-	-

Among the remaining components, iron oxide stands out as a colouring agent. Its proportion directly affects the colour of the glaze: a content of approximately 1 to 2% gives it an olive or dark green hue, while higher concentrations, exceeding 2%, result in shades of olive-brown and brown. It seems that iron oxide was intentionally introduced as a pigment. In some cases (Sample 10), the high iron oxide content may be due to contamination of the glaze sample during preparation. Figure 14 graphically presents the results of the chemical composition analysis of the glaze provided in Table 2. The obtained results have been compared with available literary data on high-lead glazes in early medieval ceramics from Lesser Poland (Auch 2012; Szmoniewski *et al.* in print). The comparison includes all results from the EDS analysis (*cf.*, Table 2 – orange circles on Fig. 15) as well as the averages from the measurements (orange circles on Fig. 14: b, c). As shown in Fig. 14, most of the analysed glazes can be classified as non-alkali Pb-glass. The glazes on ceramics numbered 4, 10, 14-16 correspond to the composition of Central European Pb-ash glass (*cf.*, Fig. 14: c). These glazes have an increased content of alkalis, *i.e.*, Na_2O and K_2O, as illustrated in Fig. 15. The points corresponding to the EDS spot measurements on the glazes that deviate in composition (Nos 4, 12, 28, 29, 45, 46 and 50, Table 2, Fig. 14: a, b – yellow markers) are associated with the increased content of Na_2O and K_2O in the glaze. According to Römer-Strehl *et al.* (2004, 82), high-lead glazes with a similar chemical composition (around 70% PbO) have melting temperatures of 710-740°C, which correspond to Groups I and II in our case, as shown in Figure 15. A decrease in the content of lead and alkalis increases this temperature. For lead glazes containing 45-60% PbO and 1% Na_2O+K_2O, the melting temperature range is 820-1030°C (Cooper and Lewenstein eds 1988, 41-59), corresponding to

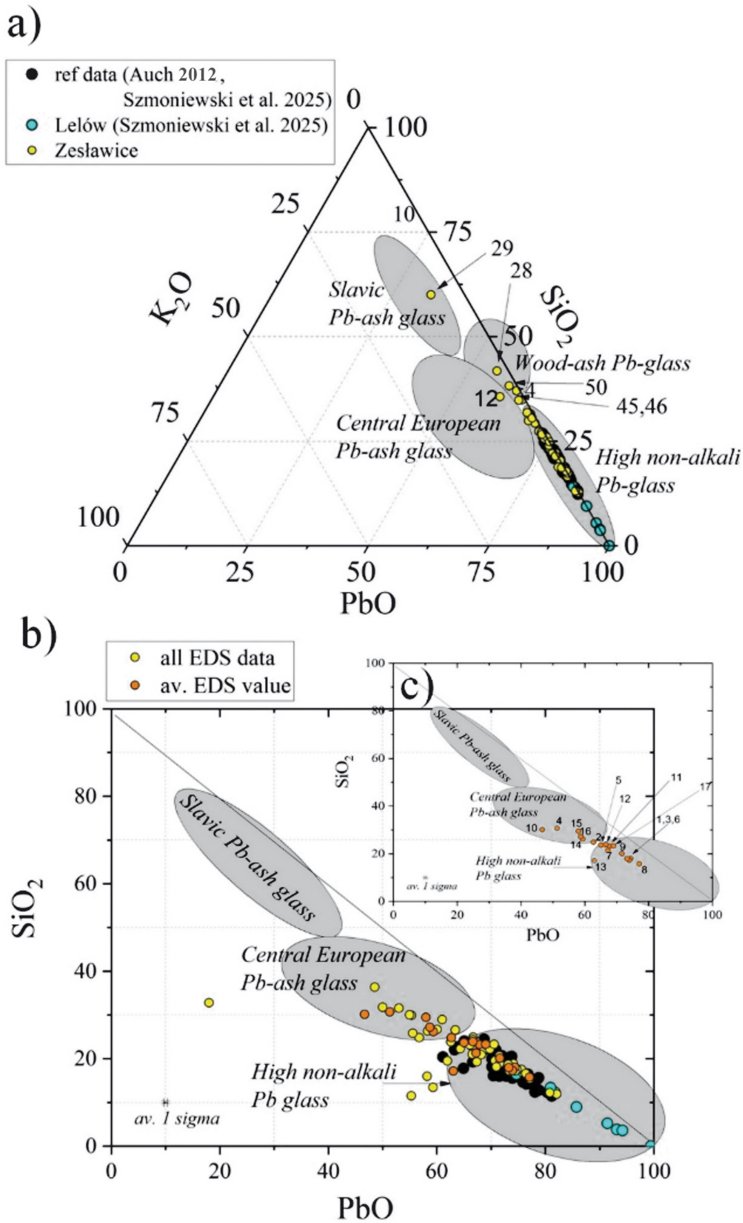


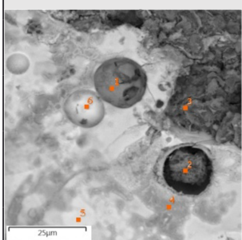
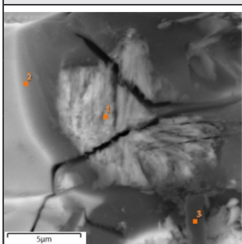
Fig. 14. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. EDS results obtained for Pb-glaze: (a) Ternary diagram showing the PbO, SiO_2, and K_2O content in the glaze (wt%, normalised to 100%); (b) PbO vs. SiO_2 content (wt%) in the glaze. The glaze data are compared with the technological study of lead glass for early medieval glass by Mecking (2013), Pb-glaze on early medieval ceramics by Auch (2012) and Szmoniewski *et al*. (2025), (c) PbO vs. SiO_2 content (wt%) in the glaze, taking into account the average value for n-measurements/object (Nos 1-17). Drawing E. Miśta-Jakubowska

Table 3. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. Chemical composition of clay (EDS, in wt%±1σ). '-' not determined, below detection limit (<0.1wt%)

Object no.	SEM mag	EDS point no.	EDS area [μm]	Al_2O_3	SiO_2	CaO	FeO	MgO	Na_2O	P_2O_5	K_2O	TiO_2
1	×100	1	500/600	18.9 ±0.2	66.1 ±0.3	-	7.2 ±0.2	1.8 ±0.1	0.6 ±0.1	0.7 ±0.1	2.3 ±0.1	0.9 ±0.1
		2	1000/500	18.0 ±0.2	68.8 ±0.3	1.7 ±0.1	5.8 ±0.1	1.8 ±0.1	0.6 ±0.1	0.4 ±0.1	2.1 ±0.1	0.9 ±0.1
		3	500/1000	19.3 ±0.2	64.5 ±0.3	2.0 ±0.1	7.2 ±0.2	1.9 ±0.1	0.5 ±0.1	0.6 ±0.1	2.6 ±0.1	1.1 ±0.1
2	×160	1	irregular	15.6 ±0.2	69.2 ±0.3	2.4 ±0.1	6.6 ±0.1	1.3 ±0.1	0.6 ±0.1	0.8 ±0.1	2.8 ±0.1	0.8 ±0.1
		2	1000/500	15.8 ±0.2	68.5 ±0.3	2.5 ±0.1	6.3 ±0.2	1.3 ±0.1	0.6 ±0.1	0.9 ±0.1	2.8 ±0.1	0.9 ±0.1
3		1	750/1000	13.9 ±0.1	74.1 ±0.3	2.1 ±0.1	4.7 ±0.1	1.2 ±0.1	0.4 ±0.1	0.9 ±0.1	1.9 ±0.1	0.8 ±0.1
		1a	700/1000	14.9 ±0.2	72.8 ±0.3	2.0 ±0.1	5.4 ±0.1	1.2 ±0.1	0.5 ±0.1	0.5 ±0.1	2.0 ±0.1	0.8 ±0.1
4	×200	1	500/500	17.5 ±0.1	69.4 ±0.3	1.5 ±0.1	4.8 ±0.1	0.8 ±0.1	0.8 ±0.1	-	3.6 ±0.1	0.8 ±0.1
5	×300	1	500/500	20.5 ±0.2	62.3 ±0.3	2.7 ±0.1	8.2 ±0.2	1.5 ±0.1	0.7 ±0.1	1.2 ±0.1	1.8 ±0.1	1.1 ±0.1
		2	1000/1000	14.7 ±0.2	75.6 ±0.3	1.5 ±0.1	4.2 ±0.1	1.4 ±0.1	0.4 ±0.1	-	1.5 ±0.1	0.6 ±0.1
6	×200	1	250/350	12.7 ±0.2	78.1 ±0.3	1.8 ±0.1	3.6 ±0.1	1.3 ±0.1	0.4 ±0.1	-	1.6 ±0.1	0.6 ±0.1
		2	500/500	17.4 ±0.2	70.1 ±0.3	2.4 ±0.1	4.8 ±0.1	1.6 ±0.1	0.5 ±0.1	-	2.1 ±0.1	1.1 ±0.1
		3	250/250	17.3 ±0.2	70.3 ±0.3	2.5 ±0.1	4.8 ±0.1	1.5 ±0.1	0.5 ±0.1	0.4 ±0.1	2.0 ±0.1	0.7 ±0.1
7	×200	1	750/500	19.6 ±0.1	67.0 ±0.2	1.9 ±0.1	5.7 ±0.1	1.8 ±0.1	0.5 ±0.1	0.5 ±0.1	2.2 ±0.1	0.8 ±0.1
8	×200	1	750/500	16.8 ±0.1	69.2 ±0.2	2.1 ±0.1	5.0 ±0.1	1.6 ±0.1	0.8 ±0.1	1.2 ±0.1	2.4 ±0.1	0.9 ±0.1
		2	500/500	13.1 ±0.1	73.6 ±0.3	2.0 ±0.1	5.7 ±0.1	1.2 ±0.1	0.6 ±0.1	1.5 ±0.1	1.9 ±0.1	0.6 ±0.1
9	×150	1	750/1250	14.9 ±0.2	69.8 ±0.3	1.7 ±0.1	6.3 ±0.2	0.6 ±0.1	0.6 ±0.1	0.6 ±0.1	2.3 ±0.1	1.0 ±0.1
10	×300		300/700	16.5 ±0.2	63.4 ±0.3	2.6 ±0.1	10.3 ±0.2	1.4 ±0.1	0.3 ±0.1	1.2 ±0.1	3.1 ±0.1	1.1 ±0.1
11	×100	1	1500/2000	14.6 ±0.1	74.6 ±0.3	1.3 ±0.1	4.5 ±0.1	1.3 ±0.1	0.6 ±0.1	-	2.3 ±0.1	0.7 ±0.1
12	×100	1	1500/1500	15.3 ±0.2	73.2 ±0.3	1.6 ±0.1	4.4 ±0.1	1.5 ±0.1	0.8 ±0.1	0.5 ±0.1	1.9 ±0.1	0.7 ±0.1
13	×150	1	500/1200	16.7 ±0.2	67.2 ±0.3	2.7 ±0.1	6.6 ±0.1	1.7 ±0.1	0.6 ±0.1	1.7 ±0.1	1.9 ±0.1	0.9 ±0.1
		2	1000/500	16.7 ±0.2	68.7 ±0.3	2.4 ±0.1	6.0 ±0.1	1.6 ±0.1	0.5 ±0.1	1.5 ±0.1	1.8 ±0.1	0.8 ±0.1
		3	700/700	14.5 ±0.2	71.5 ±0.3	2.1 ±0.1	6.6 ±0.2	1.4 ±0.1	0.4 ±0.1	0.6 ±0.1	2.0 ±0.1	0.9 ±0.1

Object no.	SEM mag	EDS point no.	EDS area [μm]	Al_2O_3	SiO_2	CaO	FeO	MgO	Na_2O	P_2O_5	K_2O	TiO_2
14	×60	1	1000/1000	14.5 ±0.2	74.2 ±0.3	1.6 ±0.1	4.3 ±0.1	1.3 ±0.1	0.8 ±0.1	0.6 ±0.1	2.2 ±0.1	0.6 ±0.1
		2	1000/1000	16.5 ±0.2	70.3 ±0.3	2.0 ±0.1	5.2 ±0.1	1.7 ±0.1	0.7 ±0.1	0.6 ±0.1	2.2 ±0.1	0.8 ±0.1
15	×400	1	300/200	11.2 ±0.1	76.3 ±0.3	1.1 ±0.1	6.2 ±0.1	1.0 ±0.1	0.5 ±0.1	-	3.0 ±0.1	0.6 ±0.1
16	×500	1	300/350	19.5 ±0.2	65.6 ±0.3	1.7 ±0.1	6.2 ±0.1	1.7 ±0.1	0.8 ±0.1	0.4 ±0.1	2.7 ±0.1	1.0 ±0.1
17	×200	1	300/750	14.1 ±0.1	75.7 ±0.3	1.2 ±0.1	3.9 ±0.1	1.4 ±0.1	0.6 ±0.1	0.5 ±0.1	2.1 ±0.1	0.7 ±0.1

Table 4. Kraków-Zesławice, site 88, Lesser Poland Voivodeship. Chemical composition of bubble area in Pb-glaze for object 13 (EDS, in wt%±1σ). „-' not determined, below detection limit (<0.1wt%)

EDS sampling point/ SEM mag	EDS point no.	PbO	Al_2O_3	SiO_2	CaO	FeO	MgO	Na_2O	P_2O_5	K_2O	TiO_2
 ×2.7kx	1	58.5 ±0.6	3.4 ±0.2	15.0 ±0.3	5.6 ±0.2	12.2 ±0.5	-	-	5.4 ±0.3	-	-
	2	31.7 ±0.4	2.4 ±0.1	7.5 ±0.2	23.1 ±0.2	8.8 ±0.2	1.7 ±0.1	-	24.7 ±0.3	-	-
	3	10.1 ±0.3	20.6 ±0.2	46.6 ±0.3	4.9 ±0.1	6.0 ±0.2	2.1 ±0.1	1.0 ±0.1	5.2 ±0.2	3.4 ±0.1	0.4 ±0.1
	4	54.3 ±0.4	3.7 ±0.2	16.7 ±0.2	10.7 ±0.2	2.4 ±0.2	1.1 ±0.1	-	11.1 ±0.2	-	-
	5	70.5 ±0.3	4.8 ±0.2	18.3 ±0.3	2.5 ±0.1	1.4 ±0.2	0.5 ±0.1	-	2.1 ±0.2	-	-
	6	61.3 ±0.4	2.7 ±0.1	17.9 ±0.3	6.3 ±0.2	5.6 ±0.2	0.3 ±0.1	-	5.5 ±0.2	0.6 ±0.1	-
 ×12.9kx	1	67.3 ±0.4	2.2 ±0.1	10.1 ±0.2	7.3 ±0.2	1.7 ±0.2	-	-	9.2 ±0.2	-	-
	2	64.7 ±0.4	5.5 ±0.1	25.4 ±0.3	1.1 ±0.1	2.9 ±0.2	0.4 ±0.1	-	-	-	-
	3	16.7 ±0.3	17.2 ±0.2	52.4 ±0.4	2.5 ±0.1	2.0 ±0.1	0.3 ±0.1	7.8 ±0.2	-	0.6 ±0.1	-

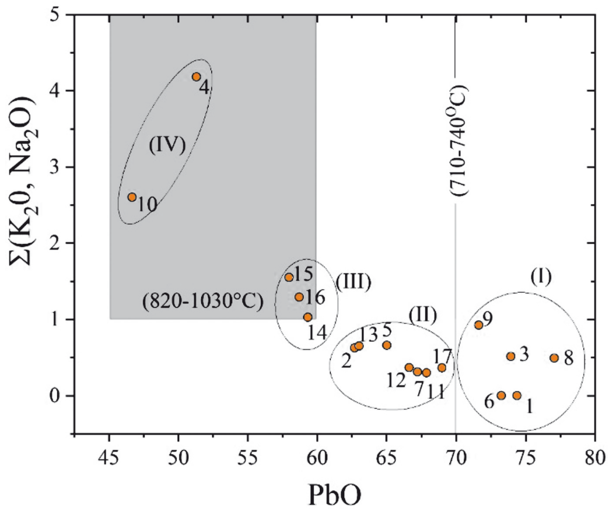


Fig. 15. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. EDS results. PbO vs. ΣK_2O, Na_2O content (wt%) in the glaze. The diagram distinguishes four groups based on data on the melting temperatures of lead glazes (after Römer-Strehl *et al*. 2004; Cooper and Lewenstein ed. 1988). Drawing E. Miśta-Jakubowska

Fig. 16. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. SEM-BSE images of P- and Ca-rich structure bubbles in the Pb-glaze matrix registered for Sample no. 13. They are presented in two areas (a) and (b). In the images, the successive zoomed-in areas are marked with an orange outline, starting with the smallest on the right: a – mag×150, 1.6kx, 7.1kx; b – ×150, 2.5kx, 12.9kx. Drawing E. Miśta-Jakubowska

Groups III and IV. Additionally, an increased content of P_2O_5 and CaO was recorded in micro-areas (see Table 4) for some of the analysed glazes (Nos 5, 7, 10 and 13 from Table 2), which does not align with the division of glazes presented in Figure 15. Figure 16 shows SEM imaging of example structures for which such an analogy was observed.

As seen in Figure 16, these structures have a bubble-like shape but are also fibrous (as shown in the lower right corner of Fig. 16). They are present on the inner side of the glaze, so they should be associated with the glazing process itself rather than secondary treatment or the use of the vessel. Figure 17 shows the concentration of lead, phosphorus, calcium, and carbon in the lead glaze. Notable enrichment in phosphorus (24.7±0.3 wt%, Table 4, p. 2), calcium (23.1±0.2 wt%, Table 4, p. 2), and carbon is observed in the bubble area in the right corner of the SEM image (Fig. 16).

5.2.2. Ceramic clay

As shown in Table 3, the clay composition of the analysed pottery fragments is similar. The standard deviation of the obtained results is slight, with the following values (in weight %) for the components: Al_2O_3 2.3, SiO_2 4.1, CaO 0.5, FeO 1.4, MgO 0.3, Na_2O 0.1, P_2O_5 0.4,

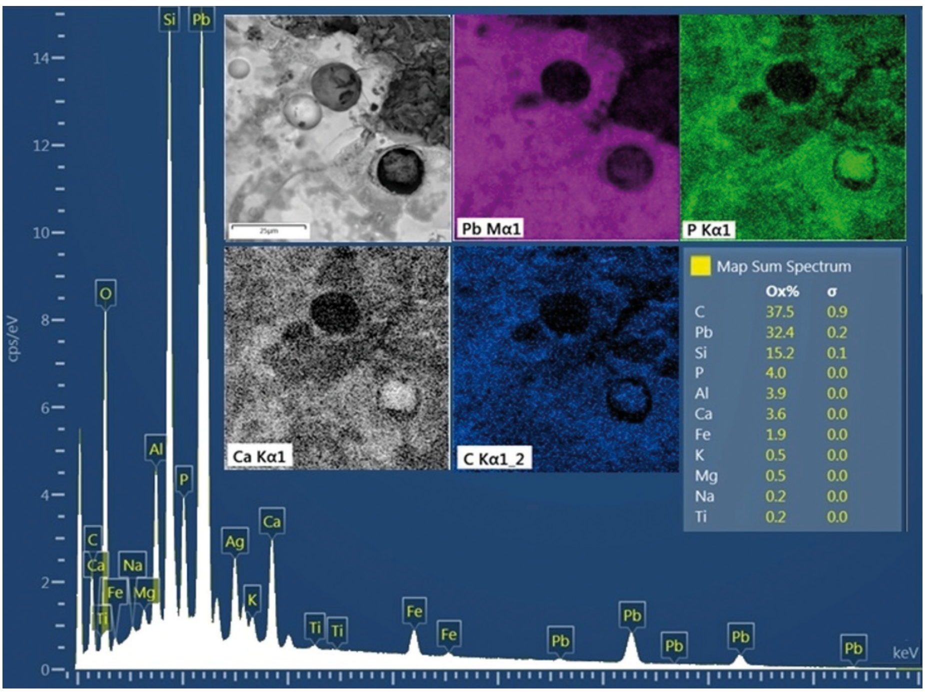


Fig. 17. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. SEM-EDS distribution of lead (Pb), phosphorus (P), calcium (Ca) and carbon (C) in bubble P, Ca-rich area of the Pb-glaze of Sample 13, is shown with EDS spectra and results. Drawing E. Miśta-Jakubowska

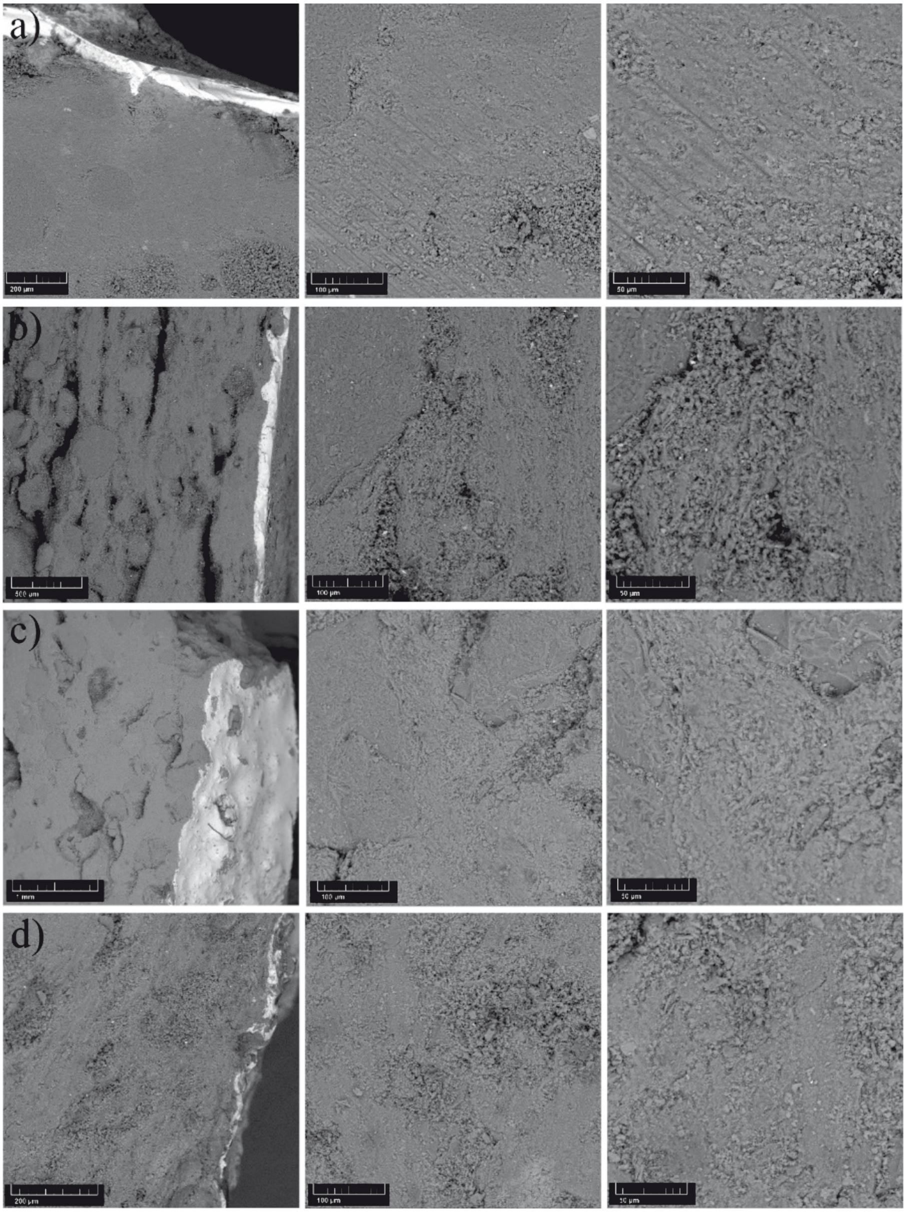


Fig. 18. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. SEM-BSE images showing the morphology of ceramics and glaze (first column of the figure) and ceramics distinguished based on glaze composition groups (Nos I-IV, *cf*., Fig. 15). a – Group 1 (Object 6: mag×200, 500, 1.0kx), b – Group 2 (Object 11: mag×100, 500, 1.0kx), c – Group 3 (Object 14: mag×60, 500, 1.0kx), d – Group 4 (Object 10: mag×30,500, 1.0kx). Drawing E. Miśta-Jakubowska

K_2O 0.5 and TiO_2 0.2. Figure 18 presents the SEM morphology of the clay (cross-sections) for sample fragments of ceramics, categorised based on the differentiation of glaze composition into Groups I – IV (*cf.*, Fig. 15).

The morphology of the clay indicates a low degree of vitrification in the ceramics for all groups distinguished according to glaze composition (*cf.*, Fig. 18). Based on the similar composition of the ceramic body and its microscopic analysis (Fig. 18), it can be inferred that the same clay deposit may have been used for the production of the vessels, which is also confirmed by the pXRD analysis results (Fig. 19) described below.

Identifying the presence of a particular mineral using pXRD is a valuable method for assessing the firing temperature of pottery. Based on the presence or absence of various minerals, it is possible to determine the temperature at which the ceramics were fired.

In the pXRD results of the bulk powdered pottery samples, the peaks of quartz, plagioclase, and alkali feldspar were recorded in every pottery sample. The presence of feldspar

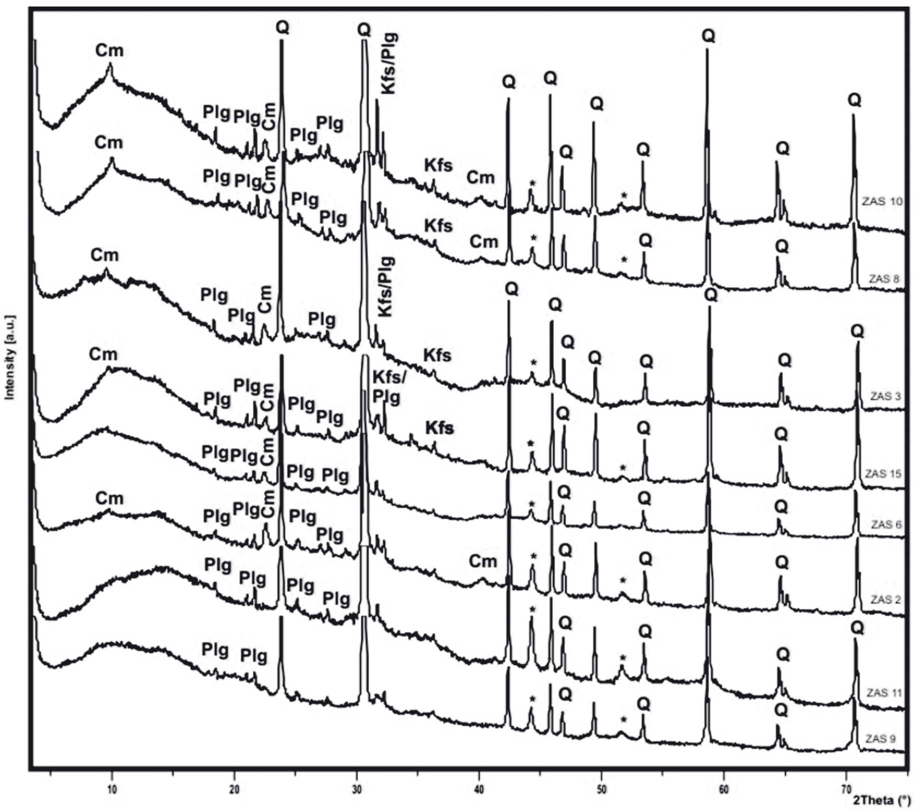


Fig. 19. Kraków-Nowa Huta-Zesławice, Site 88, Lesser Poland Voivodeship. X-ray deffractogram of spectra of pottery: Q – quartz, Plg – plagioclase, Kfs – K-feldspar, Cm – illite, * – peaks originating from silver used for sputtering samples during observation under an electron microscope. Drawing R. Siuda

indicates that the pottery's firing temperature did not exceed 1100°C (Quinn 2013; Maritan *et al.* 2006). Based on pXRD studies, it was found that the content of clay minerals (illite), a main component of typical ceramic raw materials used in the past for ceramic production, varies across samples. For ceramics fired at the lowest temperatures, the diffractogram shows peaks characteristic of undecomposed layered silicates (illite) (Nos ZAS_2, 3, 8, 10, 15). As the temperature increases, illite decomposes. This process causes the gradual disappearance of the mineral's characteristic peaks. In ceramics fired at the highest temperature, these reflexes disappear entirely, which is related to the decomposition of layered silicates. At the same time, in samples fired at high temperatures, the appearance of a broad peak in the low angular range (from 4 to 16 2 Theta) is observed (Nos ZAS_6, 9, 11). The peak of this type indicates partial vitrification of the minerals present in the ceramics. The presence of illite indicates that the firing temperature of some ceramics was around 800°C (Nos ZAS_2, 3, 8, 10, 15). For samples where the mineral was not found, the temperature had to be high enough to melt some minerals but below the spinel crystallisation temperature (about 950-1000 °C – Nos ZAS_6, 9, 11). The modal composition of the analysed pottery indicates that clay raw material from local glacial till was most likely used. Crushed granitic rocks rich in plagioclase and potassium feldspar were most likely used as the temper.

6. CONCLUSIONS

The study of medieval glazed ceramics from Site 88 in Kraków-Nowa Huta-Zesławice provides significant insights into the production and distribution of glazed pottery in Lesser Poland. The discovery of 64 fragments from 42 vessels, dated to the late 11th-early 14th centuries, expands understanding of this phenomenon beyond the previously known centres on the Lesser Poland-Upper Silesia border. Macroscopic and chemical analyses indicate that the glazes were lead-based, with compositions consistent with local production traditions rather than external imports. The findings suggest a connection between glazed pottery production and early medieval metallurgical activities in the region, particularly linked to lead processing. The study also confirms a technological transition from early medieval to late medieval glazed ceramics, with shifts in fabric composition, vessel forms, and glaze application methods. Comparative analysis with other sites, such as Dąbrowa Górnicza, Sosnowiec, and Bytom, highlights the regional specificity of Lesser Poland's glazed ceramics, distinguishing them from those of Kievan Rus' and Western Europe. The study supports the hypothesis of a local glazing tradition that developed independently, facilitated by access to lead ores from the Olkusz region. Advanced instrumental analyses, including SEM-EDS and pXRD, confirm that the ceramic fabrics were made from local raw materials and fired at 800-1000°C. The presence of high-lead glazes and their technological characteristics suggests knowledge transfer and innovation within the local pottery-making communities.

The findings from Kraków-Nowa Huta-Zesławice, Site 88 mark an important addition to the distribution of glazed ceramics in Poland, showing their expansion eastward beyond Kraków. The results contribute to ongoing discussions on the origins, production techniques, and trade connections of medieval glazed pottery in Central Europe.

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