Research Article

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Waste Around Longhouses: Taphonomy on LBK Settlement in Hlízov

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Abstract: The research investigates the waste management and taphonomy of a Linear Pottery Culture (c. 5600–4900 BC) settlements. Waste deposition significantly shaped the archaeological record of the Early Neolithic in Central Europe and its reconstruction fundamentally influences our perception of the settlement space and the daily life of Neolithic people. Traditionally, it has been assumed that individual households discarded waste near their longhouses. However, findings from the site Hlízov (Czech Republic) reveal a more complex waste management system, with designated disposal areas and differential treatment of various waste types. Additionally, two overlapping waste distribution networks were identified, indicating distinct models of production and waste management organisation. These settlement-wide networks were discovered due to the abandonment of the rigidly used house unit model, which appears to be inadequate for this site.

Keywords: Linear Pottery culture, Bohemia, waste, lithics, taphonomy

1 Introduction

Waste management is an important cultural issue that defines us as a society. It is also a behaviour pattern that fundamentally shaped the sites of the Early Neolithic in Central Europe – in particular the settlement of the LBK (*Linear Pottery Culture*, c. 5600–4900 BC). Efforts to comprehend waste management are therefore a crucial step toward understanding the taphonomy of settlements, and consequently, a deeper understanding of Neolithic society as a whole.

Although studies on the chronology, socio-economics or identity of Neolithic communities have been carried out for more than a century, we are still unable to provide robust answers to many of the fundamental questions relating to the formation of the contexts studied. This is because these works are based on a set of well-known and traditional assumptions that simplify waste management and settlement taphonomy and thus allow a high level of abstraction. Therefore, the aim of this article is to examine the taphonomy and waste management of the LBK settlement in Hlízov (Czech Republic) and to test these assumptions.

1.1 LBK Settlements and Their Taphonomy

The formation of LBK settlements is a complicated process that is difficult to understand. The surface layers of the settlements are not known, and thus, our entire archaeological evidence consists only of buried pits and their

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fills. Thus, in contrast to the tell-settlements, for example, we have no evidence of interiors or artefacts found *in situ*, which would allow a more straightforward interpretation. It is therefore necessary to focus on the question of how pits in LBK settlements were created, what material entered them and how they can be interpreted.

From the very beginning of the large-scale excavations of the LBK settlements, models were developed to answer these questions and to provide a framework for possible interpretations (Boelicke et al., 1988; Lüning, 1995; Modderman, 1970; Soudský, 1962). The dominant one was the *house unit* model, based on the idea that the pits around the house were filled with household waste and thus formed a homogeneous unit. Data from individual pits in the *house unit* are thus quantitatively and qualitatively representative and chronologically homogeneous (Hachem & Hamon, 2014, p. 164; Ilett, 2012, p. 71; Pavlů, 1977, p. 28, 2000). An alternative to this model was the *Hofplatzmodell*, which assumed the activity of a community from one house in a larger area (Lüning, 1995).

Since the 1980s, these models have been the subject of a number of studies dealing with the taphonomy of settlements and their testimony (Hamon et al., 2013; Květina, 2010; Last, 1998; Pavlů et al., 1986, pp. 310–314; Rulf, 1997; Stäuble, 1997). In these works, arguments and examples supporting the validity of the house unit or, on the contrary, rejecting it, appear side by side. The consistency of the model is supposed to be proved by the following observations: the rapid and one-phase filling of pits (Allard et al., 2013), the connection of finds on both sides of a house identified through refitting or the significant distance between individual houses and groups of pits (Gomart et al., 2015, pp. 232–233). Studies adopting this model thus sometimes also see the house unit as the representative equivalent of a social unit – the household, whose aspects of life can be reconstructed from mobile artefacts (Hachem & Hamon, 2014). At the same time, they often see the structure of the finds as the result of human activities rather than complex and indirect processes (Allard et al., 2013, p. 14).

On the other hand, some of the studies present data that show the house unit model is dysfunctional (at least at some levels). There are examples that show the dispersal of artefacts over large distances within the settlement (Domboroczki, 2009, p. 83; Stäuble, 1997, p. 84), the possible long time span during which the pits were open (Květina, 2010), the presence of intrusions from other time horizons (Domboroczki, 2009, p. 81; Rulf, 1997; Vondrovský, 2021, pp. 104–108) or heterogeneous pit fill structures (Pilař & Květina, 2023). In these studies, the reconstruction potential of the Neolithic households or activity areas is considered limited.

Individual taphonomic studies have come to different, and in some cases contradictory, conclusions. This is because, despite similarities in some formal signs (architecture, tools, symbols), LBK settlements are diverse and vary in their structure. This also means that the model of the *house unit*, which may be valid in some sites or regions (Lenneis, 2008), is completely inadequate in others (Stäuble, 1997). Since it is impossible to find a universally valid model, the model must be replaced by a set of methods and procedures that allow individual situations to be properly interpreted. It is therefore necessary to ask to what extent the formation of the assemblage was influenced by – direct individual human activities? natural processes like erosion? or patterns of waste disposal by Neolithic communities?

1.2 Waste and LBK Communities

In the archaeological context, waste can be defined as objects – artefacts and ecofacts, that have definitely left a living society that used/produced them (Neustupný, 2007, p. 53). Waste can be distinguished in a number of ways, including its intentionality, type of transformation, or nature. The classical divisions in archaeology include primary waste (found *in situ* at the site of activity), secondary waste (intentionally placed at the specific site), and tertiary waste (i.e. the redeposition of waste that was part of a layer or other unit) (Kuna, 2015, p. 281; Schiffer, 1972, p. 161). In this context, we can speak of a taphonomic path of waste, the length of which increases with its successive transformations (Vondrovský, 2021, p. 67). For example, a flake that has just been knapped from the core has a taphonomic path of zero. Conversely, if a flake is deposited on a waste-heap that degenerates into a cultural layer in subsequent years, its taphonomic path would be long.

At the same time, the path of waste is not always one-way. We can define temporary waste, i.e. objects that have not been definitively discarded and are left in an accessible place to be reused, used as a source of material or repaired (Beck, 2009, p. 85; Deal, 1985, p. 253). Of course, the study of waste cannot be separated from the many natural influences (n-transforms; Schiffer, 1983, p. 692) that played a role during the functioning of the settlement, but also long after (e.g. trampling, erosion or bioturbation). The movement and transformation of waste in the settlement thus creates a complex network that cannot be disentangled in retrospect. However, it is possible at least to characterise the main trends in the waste observed based on its structure and formal characteristics. This will enhance the understanding of both the waste itself and the waste management behaviours of the communities studied.

For the purposes of this article, we will assume that waste management existed in LBK sites. Some form of waste management is found in virtually all known traditional agricultural societies (Murray, 1980), and it is hard to imagine that it was not present in intensively occupied neolithic sites. If we move away from this basic premise and try to imagine what waste management might have looked like in a Neolithic society, we reach the limits of our modern empirical knowledge. It is therefore important at this stage to include ethnoarchaeological observations in our considerations, which can provide a more colourful picture of what this behaviour might have looked like. In the case of sedentary societies, we observe that the settlement space tends to be cultivated according to certain cultural patterns (Beck, 2009; Deal, 1985). The focus tends to be on actively used spaces, such as house interiors or courtyards (Deal, 1985, p. 259; Hayden & Cannon, 1983, p. 126; LaMotta & Schiffer, 2013, pp. 21–22; Murray, 1980, p. 495). Conversely, outside these highly cultivated zones, various forms of waste are found at virtually all sites of human activity (e.g. fields, roads, manufacturing or mining sites; Arthur, 2009, p. 42; Beck & Hill, 2004). However, by its very nature, waste tends to be difficult to read archaeologically outside settlements. Areas of intensive waste disposal varied from case to case – sometimes special separate and relatively remote dumps are created (Beck & Hill, 2004, p. 312); in other cases, waste could directly surround the occupied house (Bickle, 2020, p. 181; Hayden & Cannon, 1983). Waste is also often not perceived as a single unit, and different types of treatment can be observed. For example, more effort could be devoted to the removal of nuisance or hazardous waste, and conversely, some non-nuisance waste may remain in a primary position or minimal effort is devoted to its removal (Hayden & Cannon, 1983; LaMotta & Schiffer, 2013, p. 21). However, some settlement assemblages may not have originally been perceived as waste, but rather as deliberate deposits imbued with symbolic significance (Hofmann, 2020a). In the context of the LBK, this symbolic or magical dimension has been underscored by the presence of complete and still-functional tools arranged in distinctive patterns (Hamon, 2008) or the presence of specific quantitative and qualitative refuse in some pits (Ritter-Burkert, 2020). Similarly, intact items have been documented within singular stratigraphic contexts, particularly in the abandonment layers of wells (Elburg, 2011). In Neolithic enclosure ditches, particular discard patterns are frequently observed, often characterized by accumulations of material wealth, as seen at Herxheim (Zeeb-Lanz, 2016) or Menneville (Farruggia et al., 1996; Thevenet et al., 2023). Nevertheless, it remains challenging to definitively distinguish whether such depositions held magical or mundane significance (Hofmann, 2020b, p. 12). At Hlízov, no such distinctive elements appear to characterize the deposition processes.

In the case of the Neolithic, we can imagine that different types of waste were deposited in different parts of the settlement area. Waste may have been deliberately dumped in heaps, left to lie loose in certain areas (Hayden & Cannon, 1983, p. 128) or, for example, thrown directly into pits. From these deliberately defined locations, it could have been transported elsewhere. For example, the movement of animals or the play of children (Bickle, 2020, p. 181; Deal, 1985, p. 262) could be a factor. Gradually, through erosion and trampling (Gifford-Gonzalez et al., 1985), a *cultural layer* formed on the settlement site – a surface layer of dirt containing a mixture of residues from the everyday life of the LBK settlement (Hachem, 2000, p. 308). Although we might expect this colourful picture, full of different areas containing waste at different stages in its taphonomical path, the archaeological reality is different and all we have are pits (with few exceptions of preserved cultural layer: Domboroczki, 2009, pp. 105–107; Hachem, 2000, pp. 308–309). But the link between waste management and the pit fills we find is still missing.

1.3 Time to Fill the Pits

In addition to asking which wastes were deposited in the pits, it is also necessary to ask when the pits were filled and what were the dynamics. This question is crucial, especially for the use and comparison of quantitative data (which are often used to establish a chronology) obtained from pit fills. For instance, the high concentration of artefacts in a pit may indicate short-term intense activity as well as long-term occasional activity.

This question has also been addressed by a number of scholars in the past. The majority, however, tend to accept that the dynamics of pit filling were relatively rapid and in a single-phase. The rapid filling of pits (3–5 years) is for example suggested by Allard et al. based on the analysis of antler, pottery and stone tools (Allard et al., 2013). However, this study operates on the assumption that waste – specifically antlers – was deposited in pits immediately after being obtained and that pottery and stone tools were regularly discarded in similar quantities as observed in the ethnographic analogies referenced. Exact data from soil archives can bring more information about these processes. Such data are for example available from the site Groitzsch and Rötha, where the micromorphology of the pit fill was studied (Heinrich et al., 2019). The results show that there are no layers in the pit fill that would indicate a long period of the pit being open.

At the other end of the spectrum, there is research that assumes long periods of pit filling – in some cases even longer than the period of the use of the house. This is suggested, for example, by the change in the quantitative representation of stone tools at Bylany (Květina, 2010). However, even the results of this study cannot be considered indisputable due to the problematic chronology of the settlement (Květina & Končelová, 2011, p. 215; Pilař & Květina, 2023, p. 36).

The studies mentioned above mainly reconstruct the filling rate by studying the artefacts and ecofacts that fill the pits. While these data allow the study of important phenomena such as multiphase filling or type of deposited waste, they do not provide a more accurate indication of filling speed. Relevant results can be obtained, for example, from pedological, micromorphological analyses and optically stimulated luminescence dating, that would provide an exact, if not yet chronologically precise, insight. But these are lacking at present in the LBK sites in more representative quantities.

The question of the dynamics and the time length of the formation of the pit fills cannot be answered with certainty today. However, it can be assumed that it varied from one pit to another, just as the mechanism of filling the pits varied from one pit to another (Pilař & Květina, 2023). It is generally assumed that most of the pits around the houses were dug together with the construction of the houses and served as a source of daub. Even if this was the case, it is not certain that all pits were used simultaneously. Some pits (or parts of them) may have been opened later and served as a source of daub for house repairs. Similarly, not all pits ended their role with the exploitation of clay; in some cases, open pits were the site of daily activities, as illustrated, for example, by the presence of ovens (Pilař & Květina, 2023, pp. 33–34). This function must also have played a part in the overall time taken to fill the pit.

1.4 Crisis of the Current Models?

Problems with the nature of pit fills, the speed and mechanism of their formation undermine the long-used models that have been the basis of LBK settlement research for decades – the idea of the representativeness of pits or house units is now the basis of a number of regional chronological systems (Beneš et al., 2019; Ilett et al., 1982; Pavlů et al., 1986), but also of studies devoted to Neolithic society and its economy (Hachem & Hamon, 2014; Pavlů, 2000).

If we were to generally accept the most sceptical version of LBK settlement taphonomy, the pits would be filled with a random selection of artefacts over a long period of time, with no spatial context and virtually no information about the community that lived in the specific house. The information value of Neolithic settlements would then be very low.

However, we believe that the filling of settlement pits is not entirely random and that a systematic study of their structure may allow us to understand them, at least to some extent. This approach will certainly not explain the formation of all pits, and in many cases, it will not allow a complete interpretation of the situation. However, for some pits at least, it will be possible to answer questions about waste management behaviour, the mechanism of their formation and/or the spatial structuring of the settlement. In this way, they become the

basis for the raising of more complex questions about Neolithic society. In this study, the above-mentioned approach will be applied to the case of the Hlízov settlement, where the following questions will be addressed:
1. How did the LBK communities manage their waste?
2. Did they treat different types of waste in the same way?
3. How were the different fills of the pits formed?
4. Are the mechanisms and dynamics of pit formation comparable?
5. Is the house unit model applicable in the case of Hlízov?
6. To what extent are the individual artefacts indicative of the society that shaped them?

2 Materials and Methods

2.1 Materials

2.1.1 Hlízov – Small LBK Settlement

The site of Hlízov in eastern Central Bohemia was chosen as a case study. During systematic research in 1982–1986, a small, early LBK settlement consisting of three long houses and a group of 26 sunken features was uncovered (Pavlů, 2002, pp. 45–116). In addition to Neolithic objects, several Bronze Age features were found during the research. However, these more recent components were sufficiently distant from the Neolithic, so the LBK settlement at Hlízov can be considered relatively isolated and undisturbed by more recent human activity. It is for this reason that this site has been chosen as an ideal place for the research of the above questions. From a regional perspective, Hlízov is located in a warm fertile area that has been intensively inhabited since the Neolithic. Four kilometres to the north of Hlízov, the Elbe River, the largest river in Bohemia, flows and has been an important communication corridor since Prehistory.

In total, 34 features were found during the survey that can be associated with the LBK settlement. It is possible to identify 3 longhouse plans and 25 pits of various sizes and shapes. Most of the features found were within Area A (Figure 1), but two Neolithic features were isolated from it, 160 m to the east (Area B).

None of the houses found can be said with certainty to have been excavated entirely (Figure 2). While houses 12 and 14 had preserved post holes and external ditches, a typical feature of the architecture of the early LBK, house 13 had only three central rows of columns. It could be a relic of an unfinished house, and the archaeological record shows only a phase of construction without external walls and pits for clay extraction. The presence of a possibly younger house between two older ones would correspond for example to the similar situation in the nearby Miskovice settlement (Last, 1998; Pavlů, 1998). It is also possible that it was an atypical building, lacking surrounding structures such as lateral pits. However, we cannot comment further on the house in either case due to its unusual nature and the absence of representative artefact assemblages.

It is assumed that there was another house to the east of the excavated area (No. 35). Of this one, only the south-western part, consisting of a piece of a trench and a side pit (No. 32), was probably uncovered (Pavlů, 2002, p. 47). Although pit 32 has not been excavated entirely, the greater part of it has been explored. Despite the presumed presence of other pits around house 35, their assemblages were not excavated. For this reason, the rich assemblage from Pit 32 is included in this study as the only representation of a material with a close spatial relationship to house 35. However, a more detailed characterization of this house will be avoided for this reason.

The presence of other houses and significant concentrations of settlement pits in the vicinity is unlikely. During the excavation, survey trenches were excavated with an orientation that should have revealed other similar finds.

In addition to the houses, 24 pits have been excavated, most of them in the vicinity of houses 12 and 14. These pits vary in shape, size, and depth; however, they all have bowl-shaped and irregular bottoms, and none were regularly shaped like storage structures (Šumberová, 1996, p. 67). Although 24 features were recorded,

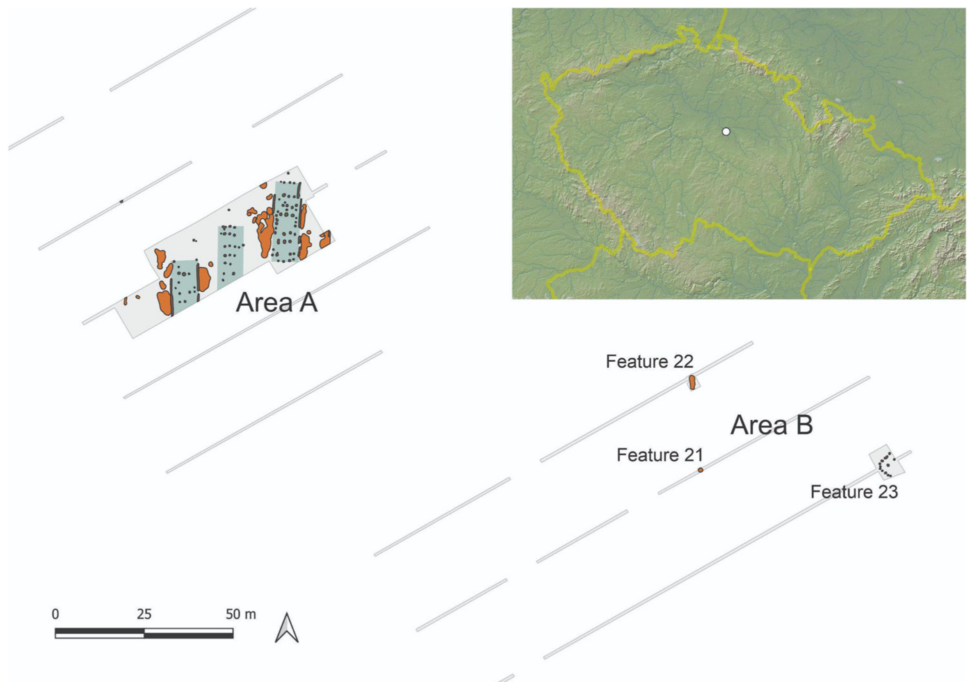

Figure 1: Plan of excavated areas. Upper-right corner – map of the Czech Republic with the position of the site (GMRT – Ryan et al., 2009).

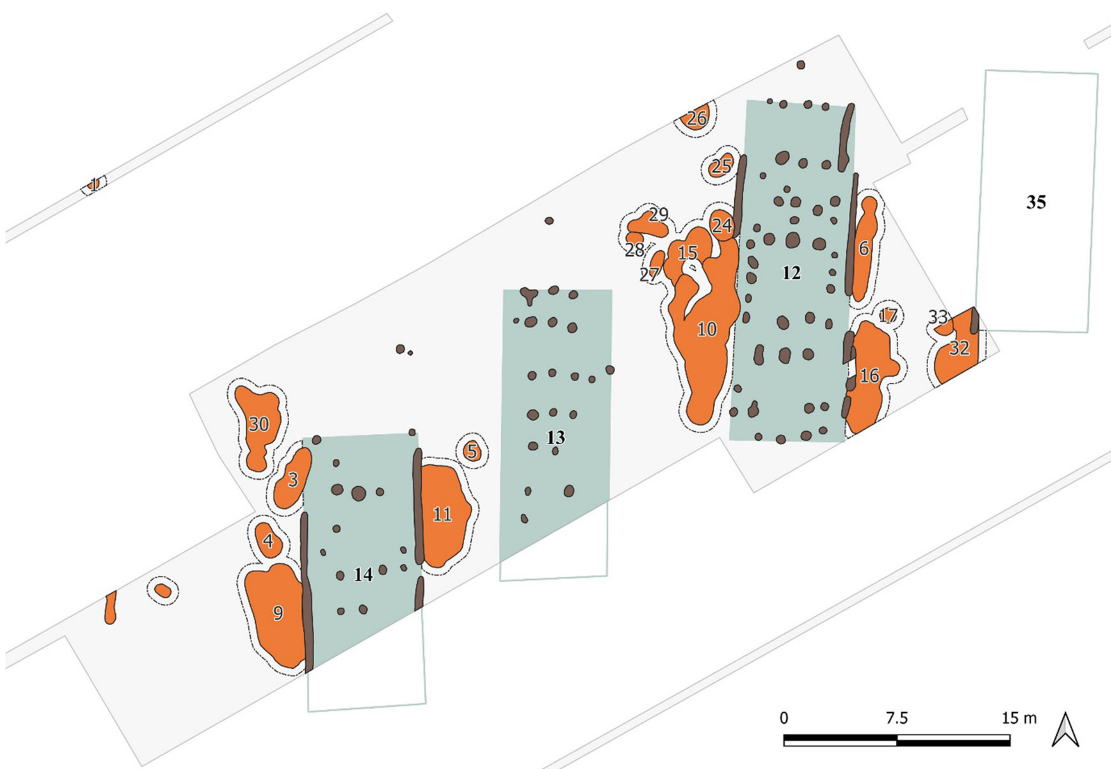

Figure 2: Map of Area A of the Hlízov site where Houses 12, 13, and 14 have been almost fully excavated and pit 32 probably belonging to another house, named House 35. The dashed line shows the hypothetical extent of the pits in the Neolithic period.

they may have looked different in the Neolithic period. Due to the erosion of the original terrain level on the site (that is common for the majority of LBK settlements – Květina & Hrnčíř, 2013, p. 326), some of the features must have originally been bigger and thus connected into larger pits. Today, we can only see the bottoms of some of them (Figure 2 – dashed line). Thus, the groups of pits were probably originally larger sunken units that ran along the sides of the two houses. Instead of numerous smaller pits, the features can be imagined as long lateral pits, typical of LBK. The most noticeable are lateral pits 9 and 11 for house number 14, pits 10 and 16 for house 12, and pit 32 for house 35. These pits were excavated in sectors and mechanical layers during the fieldwork, allowing the structure of their fills to be studied.

2.1.2 Artefact Assemblage

Pottery and lithic assemblages were examined. The occurrence of other artefacts and ecofacts on the site, such as polished stone tools, ground stones, or supply materials (unworked non-local stones), was also observed.

The collection of Neolithic pottery found at the settlement consists of 1088 fragments, of which 563 specimens can be identified. Twenty-one sunken pits containing pottery were examined across the site. However, only 8 of these contained a representative assemblage that would be usable in statistical analyses (i.e. 15 or more fragments).

The lithic industry found at the settlement consists of 143 artefacts representing a weight of 275 g. The material was uncovered from 8 pits and two pieces are coming from the surface. Almost all the material was discovered in one pit (n = 120). The other structures provide less than 8 stones.

In addition, 2 polished axes, 6 abraders, 2 grinding tools, 23 fragments of ground stones (abraders/grinding tools), 10 PRTs (pebble rock tools), and 60 non-local stones for possible tool production (weighing a total of 10.5 kg) were found at the settlement.

The bone assemblage consisted of approximately 50 fragments. However, the bones were very poorly preserved and did not allow detailed osteological analysis. Despite this, 10 bones of large herbivores (mostly cows) were selected from the assemblage and sent for C14 dating. Due to the poor preservation of the collagen in the bones, the C14 dating did not provide any usable data.

2.2 Method

2.2.1 Pottery Analysis

2.2.1.1 Description System

The ceramic assemblage was observed at two levels – the level of individual vessels and sherds. Different matrices were created for each group and related to each other. The qualitative characteristics of individual ceramic vessels were documented for each ceramic specimen. These attributes correspond to previously used descriptive systems (Supplementary 1, Květina & Pavlů, 2007; Pavlů et al., 1986) Linear decoration has been documented on several levels. Individual decorative elements, decorative styles (Květina & Končelová, 2011, p. 200) and the form of decoration (curvi/rectilinear) were observed. In addition to style, the technical implementation of the decoration was documented – the width of the engraved line (in tenths of a millimetre) and its profile (U or V shape profile).

For the shape of the vessels, the type of rim and possible neck curvature were observed. These characteristics were then assigned to typical LBK shape groups – pots, bowls, and bottles (Pavlů, 2016, p. 393). Metric characteristics such as length, thickness, weight and the degree of curvature were documented for each ceramic fragment. If more fragments came from a single vessel, the type of association was also documented. Individual fragments were also assigned values corresponding to the degree of abrasion. However, due to the low technical level of early LBK pottery assemblage, this category was not investigated further.

2.2.1.2 Fragmentation

For individual sherds, the degree of fragmentation was observed. The tracking of fragmentation assumes that a highly fragmented assemblage has undergone multiple transformations or destructive events that have gradually broken the originally large sherds (Kuna, 2015, p. 282). Thus, the greater the fragmentation of a ceramic set, the longer the taphonomic path of the artefacts can be assumed (Vondrovský, 2021, p. 67).

To record the degree of fragmentation, indexes are conventionally used that attempt to compensate for different fragmentation tendencies in different vessels. The first to be used was the SW (size/wall) index, expressed as the ratio of the longest measurable dimension of the sherd to the thickness of its wall (Květina, 2005). However, this index is misleading for sherds with significantly thin or thick walls. Therefore, an alternative index was created, the Fragmentation Index (IF), which, unlike the SW index, works with the weight and thickness values of the shard and compensates for the index's tendency to distort extreme values of wall thickness (Kuna & Němcová, 2012, p. 185; Pilař, 2022, p. 61). Although the IF was able to resolve the original SW index distortion and is very useful for example, for simulating the gradual fragmentation of assemblages (see Kuna & Němcová, 2012, p. 189), we do not consider it the optimal way to characterise fragmentation. This is because it ignores the value of fragment length, which strongly influences fragment tendency to break (Gifford-Gonzalez et al., 1985), and in some cases, it gives the same value to a rounded and a long, narrow shard, which has different tendencies to break up. It was therefore decided to create a new index, which would again work with the length and thickness of the ceramic shard but would eliminate the possible tendency of the index to correlate with extreme values of wall thickness.

The calculation of the new Length Fragmentation Index (LFI) is similar to the SW index, except that the wall strength value is dynamically adjusted for different values. For the SW index, extremely thin sherds had very high values and, conversely, thick-walled ceramics had low values. This phenomenon was compensated for by the unlinear lowering of the wall thickness value. The resulting formula is as follows:

$$\mathrm{LFI} = \left(\frac{S}{W^{0.345}}\right)/25.5.$$

This formula can easily be used for example as Excel expression = $(S/W^{0.345})/25.5$. The wall (W) square root value was modelled on a set of 16,000 ceramic fragments from the Neolithic period for which the necessary metric values were given. The ceramic collections come from the sites of Prague – Krč, Bylany, Hlízov and Statenice.[1] No correlation was found between the resulting values and the wall thickness of the fragments when using the above formula (Table 1). Dividing the resulting value by 25.5 was chosen to average the LFI value to 1. The LFI is thus a convenient way to express the fragmentation of a shard using a single number.

2.2.1.3 Refitting

Refitting – the dispersal of fragments from individual vessels – has been observed for the entire ceramic assemblage. The aim of this method is to trace the links between the fragments and to see where the ceramic assemblage may have been dispersed by different processes (see above). This approach thus introduces a dynamic element into the observation of an otherwise static archaeological situation (Cziesla, 1990, p. 17).

The study of refitting has a long tradition in archaeology. It is typically applied to bones, stone tools or ceramics and is used, for example, to determine the separation of stratified layers (Morin et al., 2005; Plutniak, 2021) or more generally to characterise a situation taphonomically (Kuna & Němcová, 2012, p. 197; Květina & Končelová, 2011b, p. 63). The scattering of fragments has also been interpreted in some cases as the result of symbolic behaviour – for example, social enchainment, in which fragments were actively moved within and between sites (Chapman, 2000, p. 138). Refitting testimony varies from material to material – in the case of chipped industry, production sequences are traced, and refitting illustrates the transfer of waste/products from production (Cziesla, 1990, p. 15). In contrast, the refitting of pottery and bones reflects the dispersal that occurred only at the end of their primary function (Morin et al., 2005; Plutniak, 2021). Although it is possible to

1 We would like to thank Václav Vontrovský for providing data from the site Prague – Krč.

Table 1: Table of the dependence of the fragmentation indexes (SW index, IF, LFI) on the ceramic wall thickness

WALL (mm)	Count	SW (mean)	IF (mean)	LFI (mean)
2	3	18.3333	4.22	1.13
3	81	11.3169	2.09	0.91
4	557	9.7446	2.60	0.95
5	1,716	8.8566	2.91	1.00
6	2,128	7.9499	2.97	1.01
7	2,789	7.2060	3.10	1.01
8	2,582	6.5233	2.94	1.00
9	1,781	6.1308	3.17	1.02
10	1,827	5.6296	3.05	1.00
11	781	5.2088	2.99	0.98
12	594	4.9851	2.98	1.00
13	372	4.6208	2.83	0.97
14	178	4.5983	3.15	1.02
15	112	4.3940	3.37	1.02
16	28	4.7366	4.15	1.14
17	28	4.0000	2.60	1.00
18	13	3.4145	2.30	0.89
19	7	3.1880	1.73	0.86
20	5	3.7000	2.63	1.04
21	2	3.3810	2.61	0.97

The data used come from four Neolithic sites at which this relationship was observed.

look for direct connections between the pottery and bone fragments, they cannot be assembled into meaningful sequences as in the case of the chipped stone industry.

In the case of pottery refitting, several categories of association were used, based on the type of association or its probability. These categories are based on the work of Bollong (1994, p. 18), but have been simplified for the purposes of this article (Figure 3):

1. Direct connection of two sherds.
2. Similarity of two sherds based on their similar wall thickness, colour, ceramic texture, curvature and decoration.
3. Similarity of two sherds based on their equal wall thickness, colour, ceramic texture, curvature, but without decoration.
4. Sherd without probable refitage – "orphan" sherd.

Of the categories used, only the first is "connection" (Plutniak, 2021, pp. 5–6). However, categories at the level of "similarity" must also be used – the set studied was of poor quality and heavily abraded, so most of the more distant refits were made up of categories 2 and 3. Nevertheless, it would be a mistake to overlook this relationship, even if it is limited by its empirical nature.

Refitting can be evaluated in a number of ways, but graphical representation remains essential as mathematical representations are not always fully informative (Plutniak, 2021, p. 4). Although different ways of presenting data can change the meaning of the data (Bollong, 1994, p. 18), there is no ideal visualisation that can be applied universally. Therefore, combining several seems to be a reasonable approach.

A common practice in LBK settlement research is the use of simple diagrams (classic examples are e.g. Allard et al., 2013; Stäuble, 1997, p. 84). These diagrams are a simple but clear way of expressing relationships, which are then interpreted empirically. However, this approach becomes unusable with large amounts of data. A good alternative is therefore the use of network analysis, where individual sherds/components are converted into nodes and their links into edges (Knappett, 2013). Network analysis methods make it possible to track the location of individual nodes in the network, identify clusters, bridges or isolated groups. Thus, network analysis provides a fast and efficient method of exploring relationships that is applicable to large volumes of data. The disadvantage is that it is less readable for spatial data.

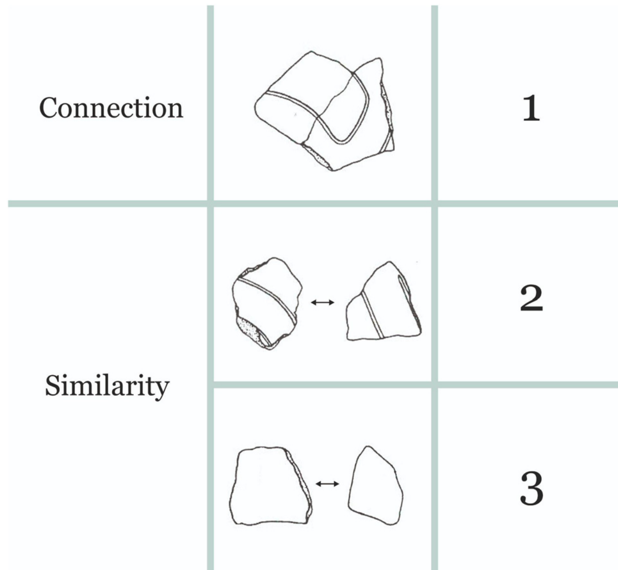

Figure 3: Refitting Categories. On the left are the connection/similarity categories used by Plutniak (2021). On the right are the three categories used in the Hlízov database and in the middle is a graphical representation of them.

This study thus used the plotting of data at the level of individual spatial units (division by objects, layers and their sectors, Supplementary 2) into a Fruchterman–Reingold plot to analyse the underlying data distribution and connectivity. Subsequently, the connections were plotted in a *Geographic information system* (GIS) to understand the real spatial distribution of connections.

Several approaches can be used to quantitatively characterise contexts based on refitting data. In general, we can describe the levels of internal cohesion of a spatial component or the degree of admixture with other components. The TSAR method was recently developed to detail the cohesion and admixture between two spatial units (Plutniak, 2021). However, it requires highly detailed data collection, such as recording directly adjacent sherds, making it impractical for large-scale assessments. To simplify the process, a method using the ratio of intra- and inter-joints to characterise cohesion was employed. Unlike the "mixing" value of Morin et al. (2005), which used the ratio of inter-layer refitted fragments to all refits in a layer, this study used the percentage of intra vertices (or "self-loops") within each spatial unit. The resulting cohesion ratio reaches 100% when all refits are within the same spatial unit and drops below 50% when most refits connect fragments from different units.

However, the cohesion ratio can be distorted in some cases. An object divided into many smaller units is likely to have lower values than an object with a few large sectors. At the same time, this value can vary considerably for spatial units that are poorly represented. However, it is useful for comparing units of similar size, or for general characterisation of cohesion and mixing.

2.2.1.4 Density

Density is an important value for the study of depositional processes and for the characterisation of the fill itself. The use of this method has a long history in the archaeology of neolithic settlements (Last, 1998; Rulf, 1993). Working with this value is based on several premises:

- That if an object was infilled by the same assemblage, by the same mechanism and with the same dynamics, the densities of artefacts and ecofacts in its different layers and parts should be comparable.
- That the different mechanisms of pit filling leave a typical structure that is reflected in the density of artefacts/ecofacts. Specifically, intentional waste deposits have higher density values (Beck & Hill, 2004, p. 305) than components that received waste indirectly, e.g. by erosion, and that lie outside the zone of waste deposition (Vondrovský, 2021, p. 68).

Working with densities is preferable in settlement research, because it automatically compensates for the different sizes of individual pits and converts them to a comparable value. However, to do this, it is necessary to first determine the volume of the object. For this study, a simplified method was used that converts the complex geometry of prehistoric pits into truncated cones. The surface area, base area, and depth of the pit are then used to calculate the volume of the truncated cone, corresponding to the volume of the pit. Although this is not as accurate as, for example, using 3D models (Pilař, 2022), the resulting deviation is marginal compared to older methods (Last, 1998; Rulf, 1993), as the values being compared differ by a several fold.

Only the frag/m^3 value was used to characterise the ceramic assemblage. The expression weight/m^3 was not used because this value is implicit in the expression of the fragmentation of the assemblage.

Despite the efficiency of the method, the results should be seen in relative terms. This value is very variable from site to site, or even in different parts of the same site. What is considered a high density in one site may be a very low value in another (Kuna et al., 2022, p. 5; Pilař & Květina, 2023, p. 29). Therefore, the values obtained are only significant in a particular context and are not universal.

2.2.2 Study Method of Lithic Industry

To evaluate the composition of the lithic industry, we questioned the representativity of the productions *chaînes opératoires* (operational chain – hereafter CO) on the site. This approach is based on technological analysis of the artefacts that aims at determining the intentions of the knappers and the gestures made to reach these intentions (Pelegrin, 1995). This is possible by reading diacritical schemas on the artefacts (order and sense of the removals negatives) to determine the place of the studied artefacts in the different sequences of the production. In the best cases, physical refitting enables one to get a detailed description of the operative chains. In the absence of such possibility, mental refitting offers a less precise (Pelegrin, 1995) but still relevant picture, to discuss the general organisation of the production and the presence or absence of stages of the CO at a location.

This work is of course conducted after sorting the raw materials. They are frequently treated differently during the Neolithic (Binder & Perlès, 1990). The identification of the raw material has been conducted by the naked eye. Raw materials are very well studied in the Czech Republic and surrounding regions. All the characteristics of the different outcrops documented in the area are described and documented at different scales by Přichystal (2013). The macroscopic classification has been reviewed by Miroslav Popelka – Institute of Archaeology, Charles University. Sometimes, for specific raw materials, their characteristics are so specific that it is possible to work at another level, one of blocks or macro-features groups (Denis, 2019). This allows the possibility to go beyond the refitting by highlighting links between the artefacts.

We compared the composition of the lithics through quantitative and qualitative data. The quantity is measured by the number and weight of artefacts to evaluate the density per pit (see above).

The typological classification allows us to assess the nature of discarded artefacts, and we evaluate the representativity of the CO by constructing techno-economic diagrams (Geneste, 1985; Perlès, 2016) when the artefacts are numerous enough to be statistically representative. Otherwise, data were treated simply by presence or absence.

2.2.3 Statistics and Software

Excel, Power Query, and Access were used for data collection and manipulation. Further, Jamovi, SPSS, and R software were used for statistical and network analysis. QGIS was used for spatial analysis and visualisation.

In addition to descriptive methods, statistical testing was performed. For this purpose, ANOVA with Tukey's *post hoc* comparison method was used (Ostertagova & Ostertag, 2013, p. 258). The conditions for these tests – normality and homogeneity of data were checked using Kolmogorov–Smirnov and Shapiro–Wilk normality tests and Levene's homogeneity test. If the conditions were not met, the sample size was checked (Ostertagova & Ostertag, 2013, pp. 258–259).

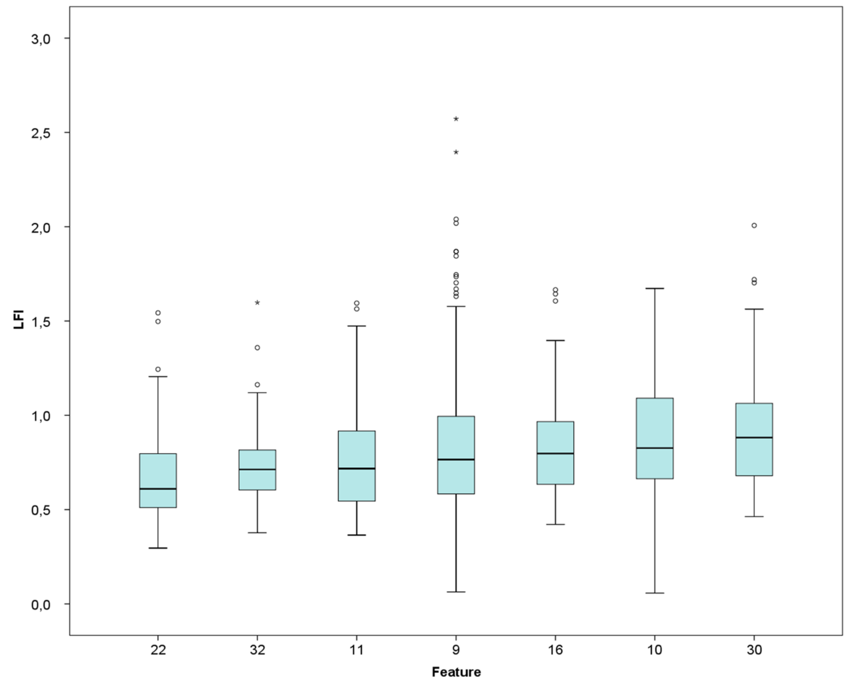

Figure 4: Fragmentation of pottery in individual pits. Boxplot visualisation.

Next, network analysis was used and was performed in R with the library “igraph.” The Fruchterman–Reingold layout was used (Hevey, 2018, p. 310).

Factor analysis was used for the final synthesis of the results, for which varimax rotation was used (Shrestha, 2021, p. 7). Clusters of features with similar factor loadings were then visualised in space using QGIS.

3 Results

3.1 Pottery Analysis

3.1.1 Pottery Fragmentation

Overall, the assemblage can be characterised as above-average fragmentation. The average LFI value of the Hlízov pottery is 0.8, which is considerably lower than the value of the Neolithic settlements on which the index was calculated (the average was set at 1.0 – check Section 2.2.1.2). At the same time, it is more fragmented than the pottery from Bylany, a densely built-up settlement, where the LFI was 0.98 (Pilař and Květina, 2023). However, this value may not necessarily be the result of different waste management, but could, for example, be caused by a lower quality of local pottery.

Fragmentation varied considerably from feature to feature (Figure 4 and Supplementary 3). Differences are also visible in individual parts of the fill. However, there is no clear spatial pattern in the settlement between pits with high and low fragmentation rates.

3.1.2 Density

The density of pottery fragments is highly variable for individual features (Supplementary 4). Some pits were practically free of ceramics (density up to 5 frag/m^3), but others reached up to 20 times these values (83 frag/m^3).

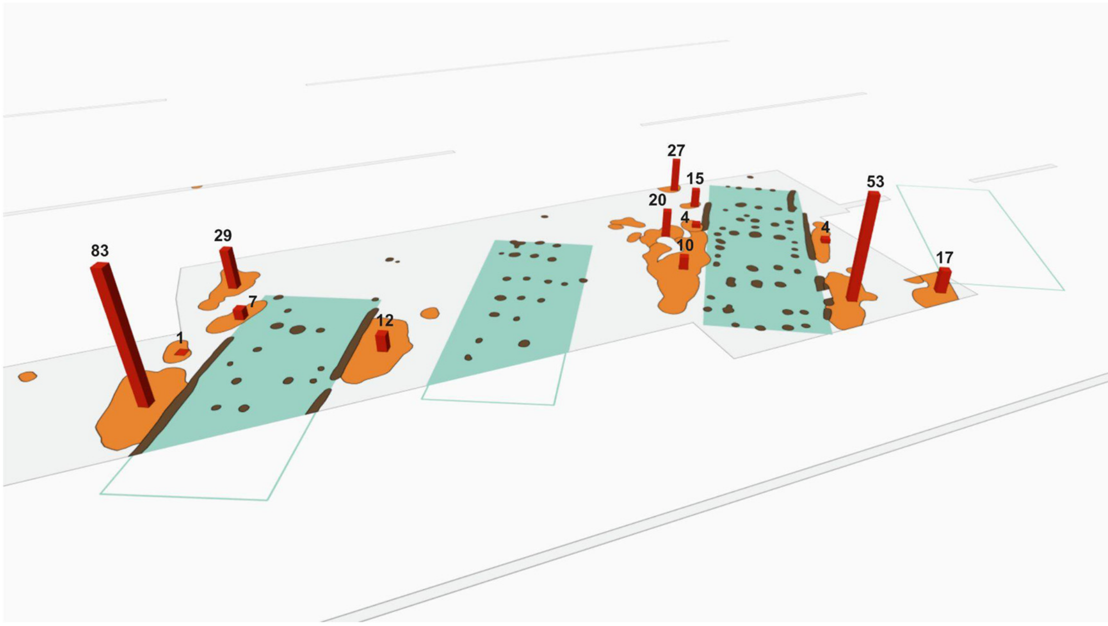

Figure 5: Pottery density in individual pits visualised by bars.

The pottery densities do not create a clear pattern in space. However, it is interesting to note that both houses 12 and 14 have one lateral pit with an extremely high concentration of pottery (Figure 5). The presence of similar "dominant pits" with a high concentration of waste has already been observed in Miskovice or Bylany (Last, 1998, p. 26; Pavlů et al., 1986, p. 307).

3.1.3 Vessel Shape, Decoration and Its Technique

According to relative chronology, the set of pottery corresponds to the transition of early and middle LBK in Bohemia. Elements of early LBK are, for example, the presence of wide engraved lines or the frequent occurrence of thin-walled bowls instead of globular pots (Neustupný, 1956; Pavlů & Zápotocká, 2007, p. 29). Among the elements associated with middle LBK are the presence of *notenkopf* punctures (present only on one sherd), decoration with thin engraved lines, or a higher proportion of thin-walled pottery (Pavlů, 2002, p. 63). Evidence of the early LBK influence can be observed also in the more archaic architecture of the houses.

Although the fragmentation of the pottery does not allow a clear reconstruction of the decorative motifs, the frequent presence of two parallel lines meeting in a V-shape, from which they diverge into two arcs, indicates the presence of the typical "A" style. This motif on the bowls is considered typical of the beginning of the Middle LBK (Jíra, 1910, pp. 74–75; Pavlů & Zápotocká, 2007, p. 31; Soudský, 1954, pp. 89–91).

The main shapes of the vessels in the assemblage can be characterised as follows (Figure 6, Table 2):

Thin-walled globular-shaped vessels made up 15% of the assemblage and were mostly decorated with engraved curvilinear decoration. Thick-walled coarse pots made up 10% of the assemblage and had knobs and occasional technical decoration (nail marks). Thin-walled bowls were the most common, accounting for 54% of the assemblage. 40% were decorated with engraving. Both recti and curvilinear lines occurred, but they could be part of the same motif ("A" style). Less common were thick-walled bowls (8%, knobs, engraved decoration), bottles (4%, engraved decoration), and storage jars (8%, knobs, handles). The prevalence of bowls contrasts sharply with, for example, the Bylany assemblage, which represents the majority of the Middle and Late LBK, where bowls make up only 20% of the assemblage (Pavlů, 2000, p. 141).

When focusing on the decorative elements and their technique (Květina & Končelová, 2011, p. 200), the ensemble appears homogeneous; 98% of all Hlízov linear decoration is made up of engraved lines only. This

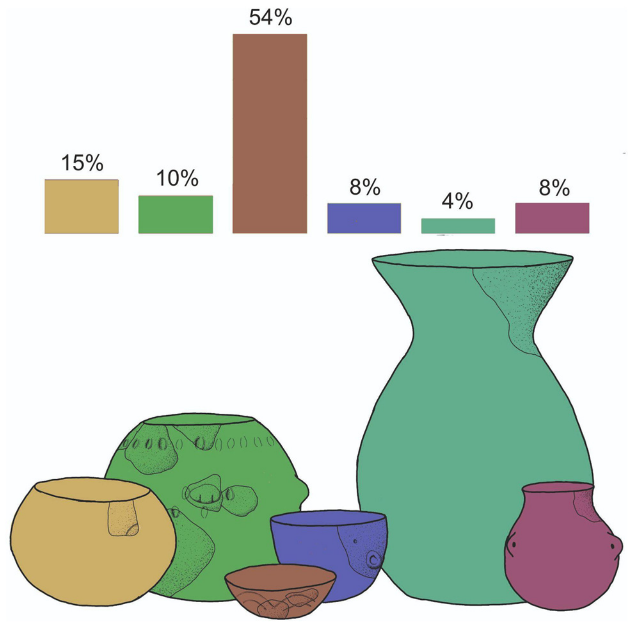

Figure 6: Main vessel types representation.

Table 2: Main vessel types representation

Fine globular vessels	Coarse globular vessels	Fine bowls	Coarse bowls	Storage vessels	Fine bottles
15%	10%	54%	8%	4%	8%

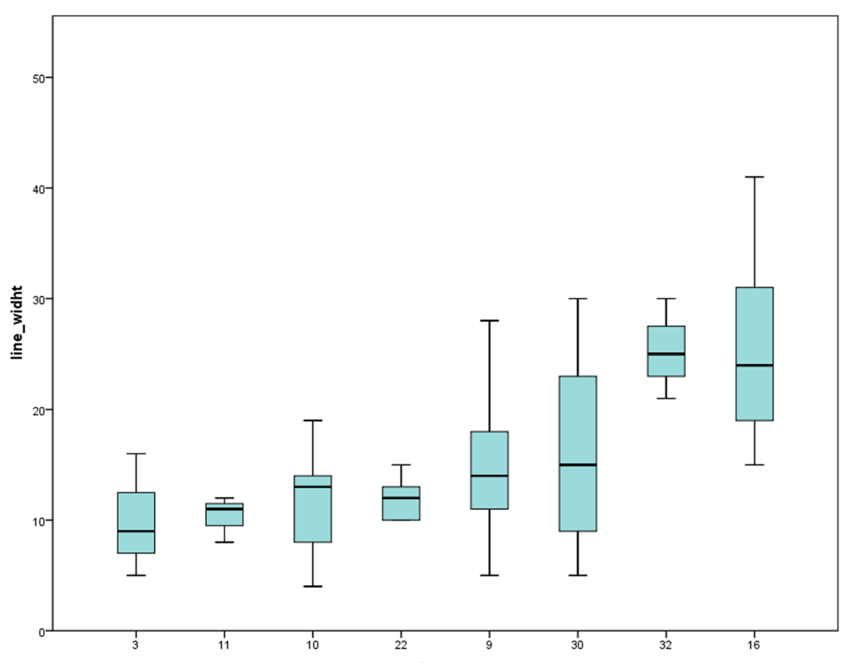

Figure 7: Width of engraved lines on pottery decoration. Boxplot visualisation.

complete uniformity of the decoration creates a contrast with most LBK sites in Bohemia, where the chronology is based on the relative proportion of linear decorations (Pavlů et al., 1986, pp. 340–352).

But the engraved lines differ. According to the descriptive system, we distinguish between "grooves" – wide lines typical for early LBK and classic thin lines that disappear only in the final LBK (Pavlů et al., 1986, pp. 340–352; Vencl, 1961, p. 102). But the boundary between these styles is unclear, and its identification varies from person to person. Therefore, a more detailed approach has been taken, based on the metric and morphological characteristics of the engraved line (width and cross-section).

Differences in the technique of decoration proved to be distinctive, and the use of thin engraved lines, executed with U- and V-shaped tools, and wider grooves executed only with U-shaped tools can be observed on the settlement. This indicates the use of two different toolkits, probably by two different communities/learning networks. The empirically defined categories of groove × line (gamma × delta in the descriptive system; Pavlů et al., 1986) overlap slightly in line width, but approximately 2 mm can be given as the dividing line.

The differences are particularly noticeable when examining the technique in individual pits. Grooves appeared exclusively in pits 16, 32, and partly 30, while most of the representative pits 3, 9, 10, 11, and 22 contained mostly thin lines (Figure 7). Features 32 and 16 thus represent a separate group in terms of their decoration technique, and pit 30 contains a combination of both technical implementations (Figure 9).

3.1.4 Refitting

A graph built at the spatial unit level creates a discontinuous network (Figure 8). However, most of the nodes are connected to one main network, but 4 nodes are completely isolated and another three, creating their own small networks.

Figure 8: Pottery refitting network between individual excavated units. Fruchterman–Reingold visualisation was used.

In the centre of the main network lie the units of feature 9, which also have the highest degree of centrality. Around it are nodes of other features, but do not create a completely connected network – many units are not connected to the rest of the network directly, but through *bridges*. Feature 16 is thus connected to the main network indirectly through feature 30. Features 10 and 11 are slightly more connected to the network centre, but their units form a looser, less connected network. It is important to note that in these pits only the upper layers are connected to the centre of the network.

When this refitting network is transferred to the map (Figure 9), one can see that the pits in the settlement are connected to each other. Although the connections might be expected to respect the *house unit*, a significant number of edges connect distant pits "belonging" to different houses.

However, as mentioned earlier, the joints do not form a completely connected network, and on closer inspection, we can observe the disconnected nature of pits 32 and 16, which both lie to the east of house 12. Together with pit 30, which forms a bridge with the main hub of the network, pit 9, they form an interesting group that absolutely overlaps with the results of the decoration technique analysis (Section 3.1.3). Pits 32 and 16 thus form a separate group which has its own distinctive decoration technique and which is not connected to the pits to the west. A mixture of materials from both groups was deposited in pit 30. While house 14 is surrounded by style 1, house 12 is on the border of two groups. House 32 cannot be characterised in this way because it is represented by a single pit (no. 32).

On the basis of refitting and cohesion level (Supplementary 5), we can characterise different structures of the pit infill. The most connected is the fill of pit 9, which forms a complete network – all its units are connected to all the others (Figure 10 – right). A low level of cohesion (below 35%) accompanies this phenomenon. This is the result of a process in which an already highly mixed pottery assemblage entered the pit. Moreover, in the context of the size of the pit, this was clearly not a one-off event, but a trend. Filling in pits 10, 11, or 16, where the network is not fully connected, gives a different picture (Figure 10 – left). The connections

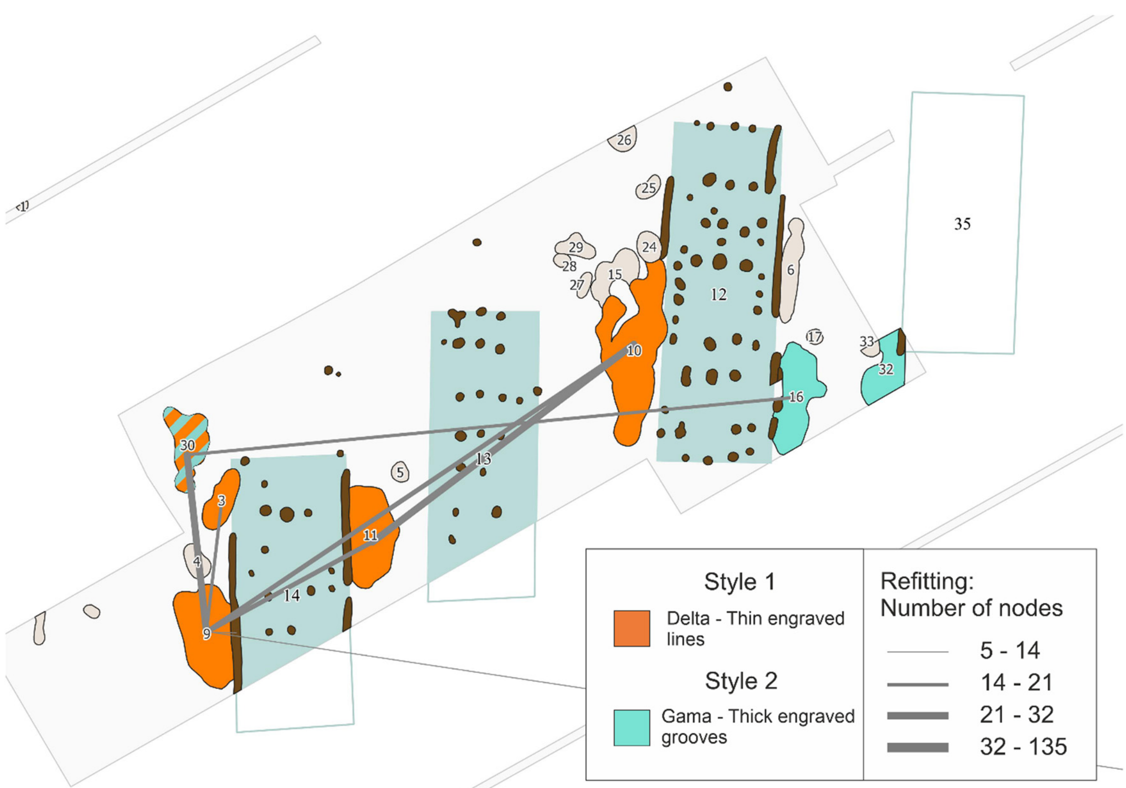

Figure 9: Pottery refitting network visualised on settlement plan. Pit 9 is loosely connected to pit 22 (Area B – not shown in picture). Colour groups show two decoration techniques (Section 3.1.3). All visualised intra-feature connections correspond to refit category 2 (similarity of shred and decoration, without physical connection; Section 2.2.1.3).

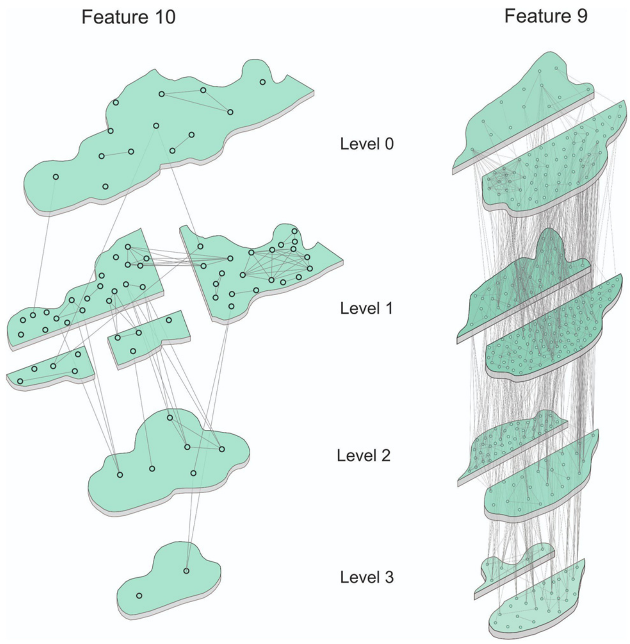

Figure 10: Pottery refitting network between individual excavated units. Left – lightly interconnected feature. Refits usually connect only neighbouring units (Feature 10). Right – a highly interconnected pit. All units of the object are connected to each other (Feature 9).

between the units may be the result of several phases of filling or of filling with several unmixed assemblages. Thus, the units forming "bridges" may be the place where two natural (e.g. stratigraphic) layers are mechanically connected. Higher levels of cohesion are also associated with this pattern (mean values spread between 45 and 71%).

Other pits cannot be well characterised in this way because they contain small quantities of pottery or have few spatial units. But generally, their fills tend to be interconnected. There was no situation at the site where the layers were strictly separated from each other, which would be a clear indication of multiple phases of infill/infill by different assemblages (similar to Pilař & Květina, 2023, p. 31).

3.2 Lithic Industry Analysis

3.2.1 Quantitative Analysis of the Material

The lithic industry is mostly concentrated in pit 32 ($n = 120$), which is the south-western pit of House 35 (Figure 11). The pits surrounding houses 14 (pits 3 and 9) and 12 (pit 16) are not nearly as rich since they have respectively delivered 9 and 6 lithic artefacts. Two artefacts have been discovered in pit 23 which is related to a younger cluster of postholes from the Bronze Age in area B.

This quantitative distribution was compared with the volume of the pits to assess the density of lithic material (Table 3).

The table demonstrates that the quantity of lithics discarded is not related to the volume of the pits. Pit 32 undeniably has a concentration of waste. It contains many more artefacts than pit 9 that is bigger or pit 16 that has about the same volume. There could be a difference when comparing the number or the weight of the artefacts. This is connected with the nature of the artefact discovered. Cores are heavier than small chips but both artefacts could have the same meaning in terms of representativity of local production. To better understand waste management, qualitative observations must indeed be considered.

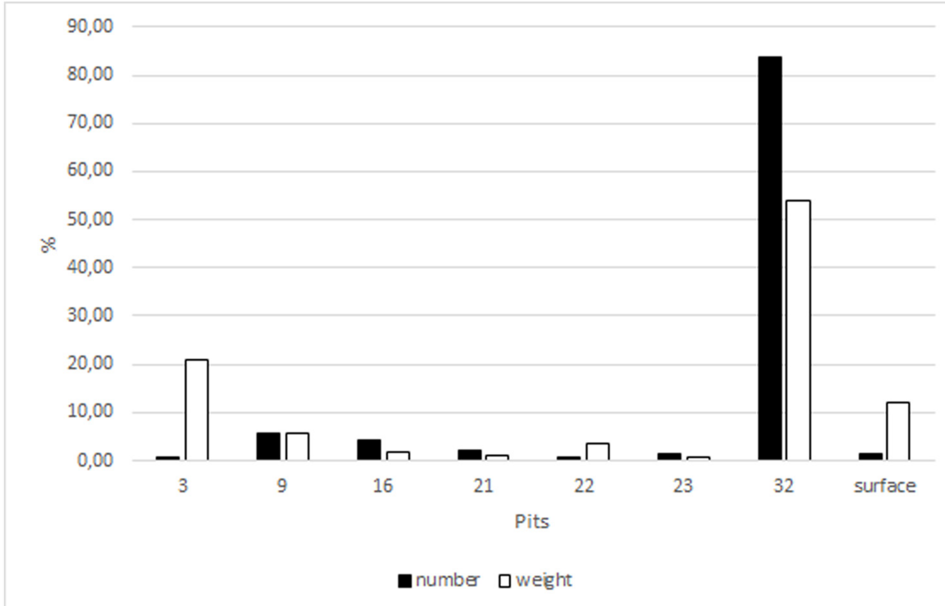

Figure 11: Repartition of the lithic industry on the site. House 35 = pit 32; House 14 = pits 3 and 9; House 12 = pit 16 (Figure 2).

Table 3: Evaluation of the density of lithic artefacts per pits based on their volume

Feature	Number	Weight (g)	Density (N)	Density (weight)
3	1	57.9	0.51	29.69
9	8	15.99	1.35	2.7
16	6	5.07	2.11	1.79
21	3	2.85	15	14.27
22	1	9.8	0.53	5.21
32	120	148.61	38.22	48.33

3.2.2 Refitting and Raw Materials Similarities

Refitting has been tested on this assemblage because the complementarity or proximity between the artefacts seemed very favourable (Figure 12). Despite this impression, no evident physical refitting could be carried out.

The identification of the raw materials exploited in Hlízov can be used to refine the understanding of waste management. Three main raw materials have been identified on the site (Figure 13): (1) the Skršín quartzite; (2) the Jurassic-Cracow flint and (3) the Erratic silicites (SGS). This area of Bohemia lacks good quality outcrops of siliceous raw materials. The closest sources could be found between 88 and 120 km with the belt of erratic silicites. But we can't be sure of the exact location of the procurement of this raw material. The most dominant raw material in Hlízov is the Skršín quartzite that can be found 120 km from the site. Finally, Polish Cracow flint outcrops are distant (300 km) from the sites. These distances are considerable and used to qualify exogenous raw materials regarding stone tools productions (e.g. Mateiciucová, 2008; Allard & Denis, 2021 for the LBK).

It remains quite difficult from a statistical point of view to compare the different features due to the low number of artefacts (Table 1 in Supplementary 6). The Skršín quartzite is largely dominant in the assemblage (more than 75%, n = 108), but this is especially true for the pit 32 (83%, n = 100). Jurassic Cracow flint and SGS have been identified in almost all the pits in small quantities (respectively, 18 and 11 pieces in total). Pit 3 has only delivered one artefact in Cracow flint. The pit 16 is the only one on the site to have delivered burnt

Figure 12: General overview of the Skršín quartzite artefacts from pit 32. Photography: D. Pilař.

artefacts (n = 3). This classification was analysed a bit deeper by identifying some groups among the distinct individualised raw materials, through specific macro-features characteristics. However, this was not possible for each of the raw materials, except Skršín quartzite and the Jurassic Cracow artefacts. Within these two materials, it was possible to distinguish different facies according to the characteristics of the raw material

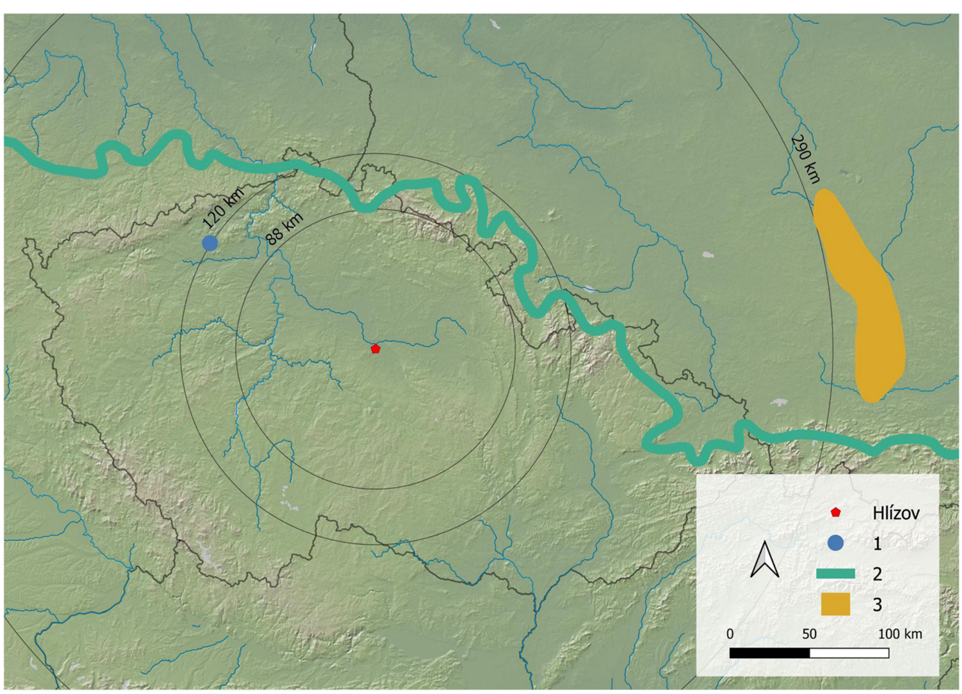

Figure 13: Map localising the different sources of raw materials exploited in Hlízov based on Přichystal, 2013. Number 1 in blue: Skršín quartzite outcrops; Number 2 in green: Erratic silicite potentialities; Number 3 Jurassic-Cracow flint outcrops (GMRT – Ryan et al., 2009).

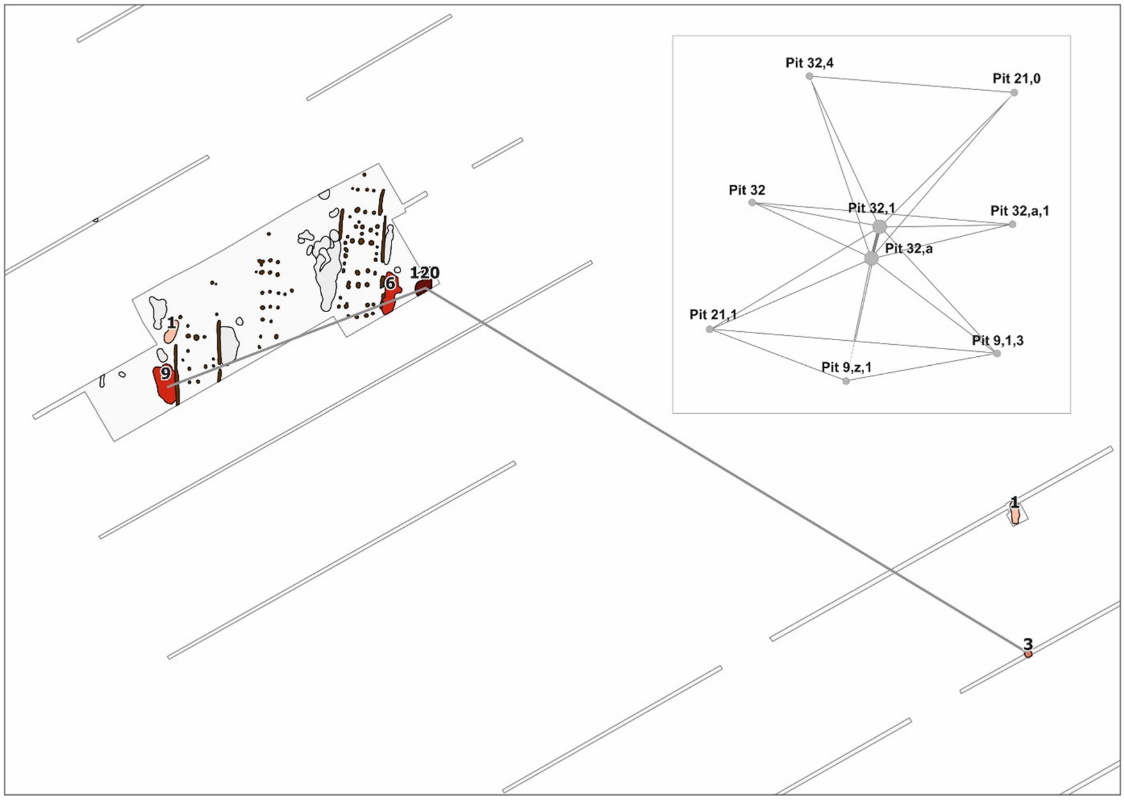

Figure 14: Macro-features matching method and network analysis highlighting similarities between the different pits and the degree of cohesion in and between the pits. The number of chipped stones is displayed for each pit.

(colour, texture, and inclusions). Without presuming the value attributed to these facies (same block and same micro-deposit), we formed sub-groups of raw material that we used to carry out a network analysis (Figure 14) in order to better understand whether similarities could be identified between the different pits.

This parameter would suggest a very high cohesion of pit 32 with lots of similarities of the materials inside this pit. It also demonstrates some rare similarities between pits and more specifically between pits 32, 9 and pit 21. Pit 16 gathers all the burnt artefacts identified on the site, underlying a specific pattern regarding waste management. However, it hides potential relations with other pits because macro-features can no longer be identified after burning.

3.2.3 Typo-Technological Observations

We will now specify how the Hlízov lithic waste is composed, regarding some typo-technological observations. Two elements will be used in this perspective:

(1) The toolkit composition (Table 2 in Supplementary 6).
(2) The representativity of the different stages of the operational chain.

Houses are formally assigned according to pit position.

Table 4 counts the number of tools and the waste from the tools identified in the collection. Only 16 tools have been identified which is a very low number (11.5%), especially as we counted the pieces bearing macroscopic scars interpreted as resulting from their use. A use-wear analysis would be required to confirm this attribution. The composition of the toolkit is surprisingly not very varied. One scraper has been identified in

Table 4: Comparison of the number of tools, waste from them and unmodified artefacts according to the different pits

	House 14		House 12	House 35			
Raw material	**3**	**9**	**16**	**32**	**21**	**22**	**Total**
Tool/Used	—	2	—	14	—	—	16
Waste of tool	—	—	1	1	—	—	2
Raw blank	1	6	5	105	3	1	121
Total	**1**	**8**	**6**	**120**	**3**	**1**	**139**

pit 32. Two sickle blades belong to pit 9 and pit 32. The other pieces are non-very specified retouched pieces. No tool has been identified in pit 16 that could again underline its specificity regarding the other houses.

It is now possible to state which stages of the production are represented on the site. It was previously stated that the raw materials can almost all be considered as exogenous but some sequences of the debitage took place locally.

Most of the artefacts, when their technical characteristics are relevant, are attributed to a blade or bladelet *chaînes opératoires* (simplified database in Supplementary 7, column 10). This can be diagnosed thanks to the diacritical schemas and the determination of the percussion techniques. Most of the debitage is conducted by indirect percussion. It appears frequent that the cores are then reused primarily as tools (hammerstones for example) or knapped to produce a few flakes that can be retouched. Nine techno-economic categories were created that allow identification of which of the sequences are represented on the site:

(1) Flakes from the shaping-out;
(2) Flakes from the crest preparation;
(3) Flakes from the maintenance of the core;
(4) A specific category designated for the rejuvenation of the platform;
(5) Blades;
(6) With isolation of blades that have transversal negatives from the crest preparation or a natural or cortical facet;
(7) With isolation of blades that are more dedicated to correct an accident or help to obtain better convexities;
(8) All the pieces that do not have enough specific characteristics to be more precisely attributed to a stage of the production;
(9) Cores and flakes that have been reused.

Studies by raw material and by pit were used to identify specific waste management (Supplementary 8).

All the blade CO in Skršín quartzite is represented in pit 32 (Figure 15), except the very first flakes of the shaping-out of the blocks. Blocks could have been introduced on the site marginally preformed. The comparison between the number of artefacts and their weight allows the highlighting of whether the representation of the CO is almost complete, there is very little waste, except for the reuse of the cores attributed to the end of the CO. The flakes are on average less than 0,6 g (orange lines in Table 1, Supplementary 8).

In pit 9, two artefacts are in Skršín quartzite but only one can be attributed with certainty to blade production, the second one is less clear but may also be (Table 2 in Supplementary 8). Both flakes are knapped by direct hard hammerstone. One is a big flake of 44 mm in length, 42 mm in width and 10 mm thick that can be attributed to the shaping-out of a block. The second one has 25% natural surfaces and could also be related to this stage. Not only did the characteristics of the raw material bring the flakes from pit 9 closer to a block or micro-facies from pit 32 (Figure 14), but a form of complementarity also appeared between the two pits. The missing stage from pit 32 is represented in pit 9, demonstrating a form of spatial segmentation of the waste in relation to the stages of the blades CO. In addition, the nature of the massive flake is quite different from the contents of pit 32, which is characterised by small elements. Despite the size of the blank, this flake is rough and was not selected as a tool blank.

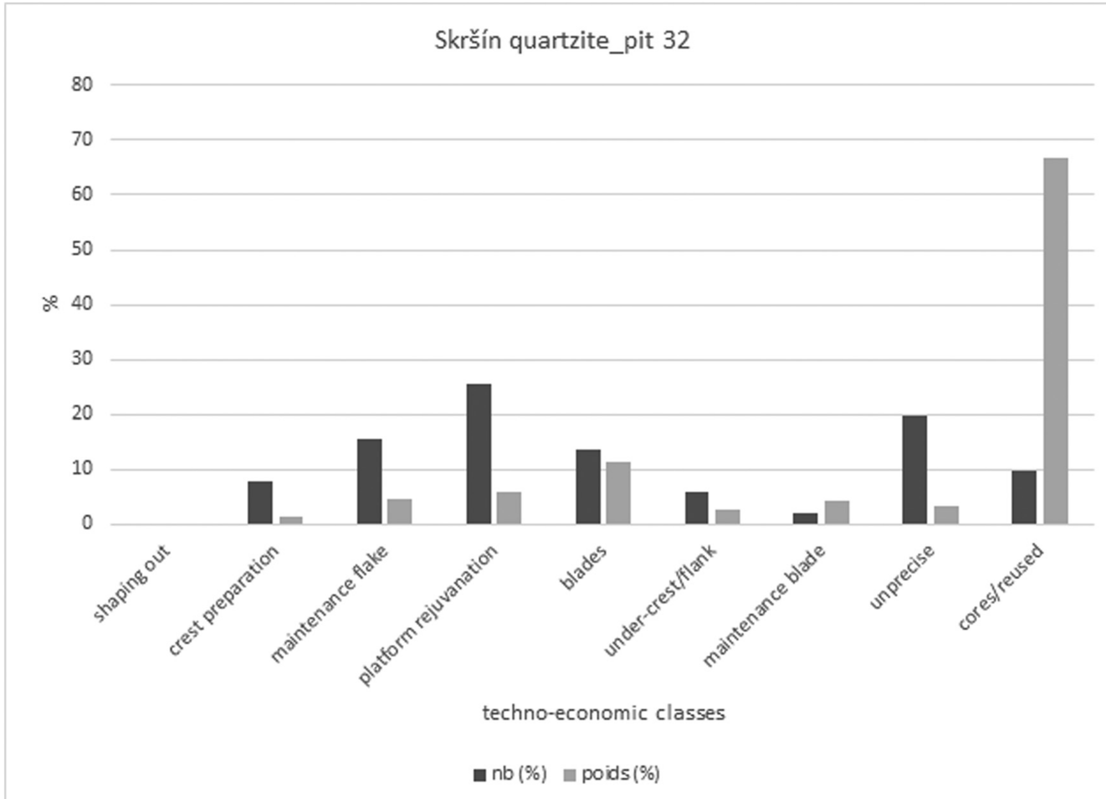

Figure 15: Techno-economic diagram of Skršín quartzite based on the different stages of the blade production identified in pit 32.

Figure 16: Small blade cores. Number 1, Jurassic Cracow flint discovered in pit 3. Number 2, SGS discovered in pit 32.

Table 5: Quantitative variation of the weight (in g) of the different artefacts according to their raw material based on a comparison to the mean

	House 14		House 12	House 35	
Average piece weight	**3**	**9**	**16**	**32**	**Total**
Skršín quartzite	—	4.25	0.08	1.13	1.39
Jurassic Cracow	57.9	2.39	0.09	0.54	4.4
SGS	—	0.68	3.1	4.81	3.98

One flake has been identified in pit 16. It is a very small one (less than 0.1 g), knapped by indirect percussion but it can't be precisely attributed to a stage of the operational chain. However, by its very nature, it is very close to the elements identified in pit 32.

Only 18 pieces have been discovered of Jurassic Cracow flint (Table 3 in Supplementary Material 8). The paucity of this corpus means that we have to be very cautious when dealing with quantitative data. It can at least be appreciated through the weight of the material (ca. 69 g in total). From a quantitative point of view, Table 5 demonstrates that, as for pit 9 for the Skršín quartzite, pit 3 delivered many more artefacts than all the other pits. This is particularly true for pit 3 where the only artefact discovered is a core (Figure 16, number 1), whose micro-facies have nothing to do with the material from the other pits. Slight differences appear when comparing the different pits (Table 3 in Supplementary 8). Pit 16 only contains a small fragment of the bladelet. Pit 3, as just mentioned, only contains material from the end of the CO. Pits 9 and 32 are quite comparable and pit 21, located in the southern cluster, is the only pit that contains a flake related to the shaping out of a block. So, either the blocks are introduced in the process of debitage with already knapped flakes, or there is a spatial segmentation of the production. The small number of pieces does not allow any clear indication in favour of either hypothesis.

SGS raw material exhibits a different pattern compared to the other material regarding the weight of the artefacts (Table 5). The largest pieces are preserved in pits 32 and 16, particularly due to the presence of a core in pit 32 (Figure 16, number 2). Cores could be also introduced in the process of debitage (Table 4 in Supplementary 8). However, for this raw material, the shaping-out of the blocks is not very sophisticated, so this could also explain the absence of this stage on the site. Some flakes with 20–30% natural surfaces or cortex are identified. A form of complementarity between pits occurred regarding this raw material. Indeed, blades from the full sequence of debitage are only identified in pit 9 and are missing in pit 32. In pit 16, the SGS artefact identified is not related to blade production but to the exploitation of a small block as splintered pieces.

3.3 Macrolithic Tools, Polished Tools and Supply Material

The small number of findings in this category does not allow for a more robust statistical analysis. Therefore, only their frequency in individual pits is considered. Most features contained no finds or only a small number (1–2 finds). We can distinguish only 4 pits that contained a larger number of this category of finds – pits 9, 10, 16, and 32.

Pit 32 contained fragments of a broken polished axe, abraders, hammerstone and a small amount of supply material. Most of the finds can therefore be associated with the processing of stone tools. This pattern overlaps with the chipped stone manufacturing waste assemblage also found in the pit.

Pit 10 contained a different type of material. A large quantity of supply material was found there along with a lower stone used for grinding and hammerstone. This pit also contained no chipped stone. Thus, only stone material associated with large macrolithic tools was deposited in its fill.

The last two pits, 9 and 16, are structurally similar. They contained smaller quantities of supply material, fragments of polished tools, grindstones and hammerstones. They contained different categories of artefacts, but in small quantities. They were apparently perceived as a site for the deposition of lithic material, but their role was apparently marginal.

The assemblage of these lithic finds thus creates its own pattern on the settlement. In some cases, this overlaps with the trends described above, and in other cases (e.g. feature 10), it creates its own unique pattern.

3.4 Cross-Material Analysis

After the analysis of the individual artefact types, the data have been compared. The aim was to see if the trends found for each type of waste overlap and if they are spatially organised in any way. Factor analysis was used to analyse the main characteristics (Feature volume, Pottery fragmentation, Pottery density, Macrolith/Polished tools N, Chipped stone density) of selected representative objects (Pits 3, 9, 10, 11, 16, 21, 22, 30, 32).

Three components explaining 94% of the variability were extracted through factor analysis, and the pits were divided into 4 groups (but only 3 of them are relevant for interpretation – Figure 17 and Supplementary 9). The most significant variables during the analysis were ceramic fragmentation, chipped stone density, and ceramic density.

In terms of spatial distribution, extracted groups 1 and 2 are both in the vicinity of houses 12 and 14 (Figure 18). Group 1, representing high concentration of ceramic waste deposition, and medium concentration of stone waste deposition, both occur in the central/southern part of the house but lie on opposite sides.

Group 2 in turn includes the two largest pits 10 and 11. Despite their size, however, they represent low concentrations of deposition of all forms of waste. Group 2 also includes the smaller pits 3 and 30. These pits lie on the sides of the central and northern areas of houses.

Group 3 is represented by pits 32 and 21. These pits are of marginal significance in terms of pottery waste but contain high concentrations of stone artefacts. However, the positions of this group do not create a clear structure. Pit 32 lies near the south-west corner of house 35 and pit 21 lies in Area B – 150 m east of the group of houses.

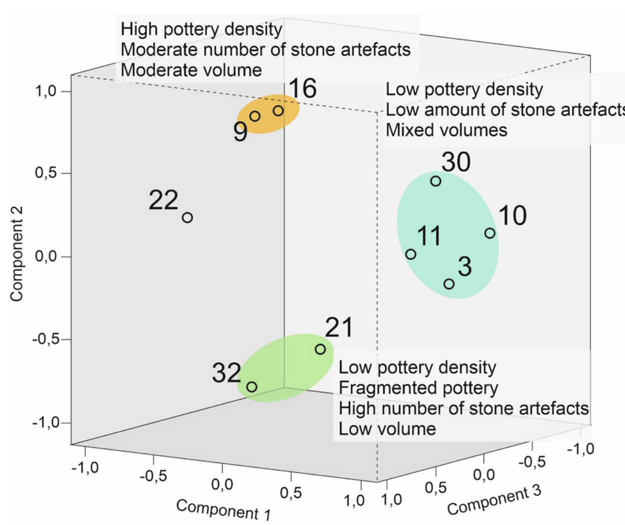

Figure 17: The result of a factor analysis that divides the studied pits into three clusters based on their characteristics. Result explains 94% of variability. For analysis details, refer to Supplementary 9.

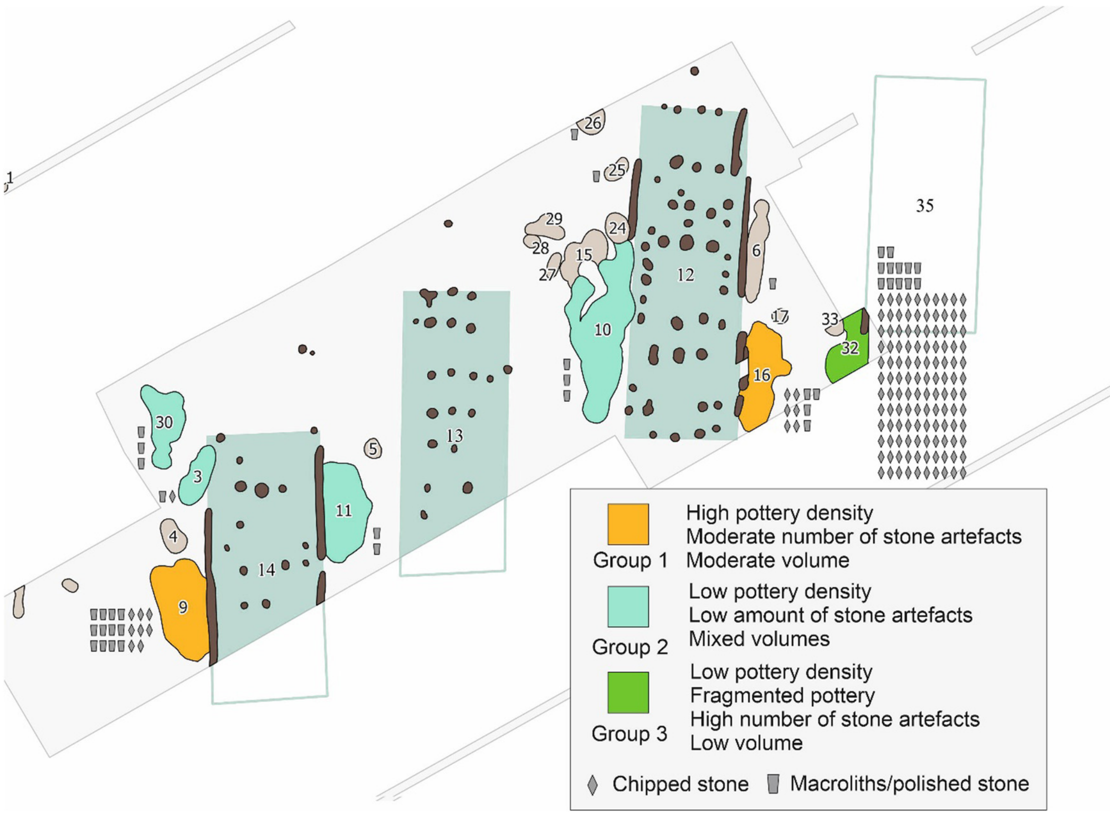

Figure 18: Groups defined by factor analysis displayed on the settlement plan.

4 Discussion

4.1 Interpretations of Different Types of Waste

On the basis of these results, it is possible to demonstrate the informative value of different types of waste.

Chipped stones are a very effective source of information for studying CO, the treatment of production waste, long-distance trade or tool use. However, in many cases it is not possible to follow a "taphonomic path" – i.e. in the case of lithic waste, dynamic transformations do not occur to the same extent as, for example, in the case of ceramics. Thus, when using the categories of primary, secondary and tertiary waste, we can only be guided by the assemblage found and not by the characteristics of the individual objects.

In the case of the chipped stone assemblage from Hlízov, no primary waste can be identified. This would be highlighted by the quantity of the CO waste, spatially distributed suggesting the knapper location, as it can be found in some Palaeolithic sites (e.g. Pigeot, 2004 in Etiolles). In the case of pit 32, we can assume that the waste was not transported over long distances and that production took place in the vicinity. The composition of pit 32 suggests secondary waste. We may not exclude the classification of secondary waste either for pits 9 or 3, because specific sequences of the CO are represented there. On the contrary, the heterogeneity suggests the random composition of pit 16 would fit the definition of tertiary waste deposition.

Macrolithics and polished stone tools in Hlízov can have various interpretations. Large and heavy grinding tools can be considered the result of intentional deposition – the question is whether these tools were discarded because they could no longer be used or for example for symbolic reasons (Hamon, 2020). They are in both cases probably not tied to the location of the activity.

Other macrolithic tools such as fragments of abraders or hammerstones are much smaller and could theoretically have entered the pit fill as tertiary waste along with the pottery. However, their state and the composition of the assemblage do not answer this question. In this respect, macrolithic tools are not an ideal source of information to address taphonomic questions.

On the other hand, the assemblage of polished stone tools is similar in its meaning to chipped stones. A set of fragments of a broken polished axe was found in pit 32 next to waste from the production of chipped stones. This shows that it is also secondary waste, indicating deliberate disposal.

However, the most common category of waste that was examined was **pottery**. Ceramics are a suitable type of artefacts for taphonomy research because they continue to break down after their initial breakage and are affected by all the surrounding transformations. Thus, when comparing two assemblages of the same pottery, trends that reflect the taphonomic trajectory of both assemblages can be clearly observed. Based on the characteristics of the Hlízov assemblages, we proposed the category of secondary waste in addition to tertiary waste in some of the pits. This distinction can never be made fully, but we can characterise the ideal type of intentionally deposited pottery. Such vessels should have low levels of fragmentation and abrasion, and a larger proportion of them – not just a single fragment – should have reached the pit (Kuna, 2015, p. 282). The problem is that, in addition to intentionally discarded vessels, tertiary waste also entered the pits at the same time. Thus, in Neolithic settlements, we do not find assemblages that could be classified as purely secondary waste, but as an assemblage of tertiary waste with the presence of secondary waste (Pilař & Květina, 2023, p. 35).

Secondary waste is an ideal category for interpreting activities, production traditions and, to some extent, their spatial distribution. However, its association with specific houses/communities depends on the chronological/taphonomic model used (see below), as the same pattern may have a number of possible causes. However, secondary waste unfortunately does not carry any information about the exact location of activities – its location is the result of decisions about waste management made by Neolithic people.

Most of the pottery found can be classified as tertiary waste. Although this category also cannot be determined precisely, we assume that most of the highly fragmented orphan sherds came to the pit more or less accidentally from their original place of deposition. Thus, most of the original vessels have remained outside of their archaeological contexts and have not survived to the present day. Unfortunately, the interpretative value of tertiary waste is rather low due to its long taphonomic path. It is possible, for example, that they were transported from a nearby waste heap – in which case their interpretation could be similar to that of secondary waste – but it is also possible that they are artefacts that have been in the area of the settlement for a long time or have been transported over long distances. Thus, we can only conclude that these artefacts were used in the Hlízov settlement, while a more precise chronological and spatial context remains unknown.

Primary waste is the best possible type of waste to interpret the activities and their location. In the case of Hlízov, and in most LBK settlements, however, we cannot assign any of the finds to this category. Nevertheless, because all these artefacts necessarily result from the same occupation, we can compare the different patterns to discuss more deeply the waste management in Hlízov.

4.2 Waste Management Behaviour

The results presented clearly show that different types of waste were treated differently.

Ceramics, the most common type of waste, were deposited most intensively in the lateral pits (Group 1 – Pit 9 and 16) in the south/central part of the houses. These pits contained a mixture of secondary waste, such as large reconstructable pieces of vessels, which were discarded directly. In addition, there was a high concentration of tertiary waste in the fill. Typical examples of this category are the common orphan sherds. Such quantities of tertiary waste could theoretically have entered the pits from nearby waste heaps (Pilař & Květina, 2023, p. 35).

Outside of these waste-dominated pits, pottery was entering most of the pits on the settlement. However, most of them lacked the secondary waste category. Thus, these pits (Groups 2 and 3) were probably not perceived by Neolithic people as a place for depositing ceramic waste, nor was there much pottery left in their vicinity (low density of pottery in the fill).

The treatment of waste from **chipped stones** must have been very different. First, there are very few tools, so the waste is mostly constituted by production sequence activities rather than the activity of use, which is unusual for LBK sites (Allard et al., 2013). Secondly, the absence of refitting would argue that lithics are constituted by secondary waste deposits. We can underline a very high cohesion in pit 32 with lots of similarities within the micro-facies materials. If the material is not reflecting a direct rejection of a knapping episode but a secondary deposit, it is a secondary deposit of a coherent knapping episode or knapping episodes, especially regarding Skršín quartzite. Furthermore, the elements of Skršín quartzite and Jurassic Cracow flint are quite small and could have resulted from a careful cleaning of the last residual elements of the knapping activity area. Finally, the other pits show signs of different waste management. The small quantities of artefacts selected – tools and production waste – were certainly not the result of a short intensive activity such as in pit 32. But two distinct patterns can be distinguished between pit 9 and pit 16. Pits 32 and 9 seem to present a kind of complementarity, especially regarding Skršín quartzite, with the testimony of the first flakes of the debitage in pit 9 and the rest of the waste in pit 32. A selection of certain stages of the CO seems to constitute the waste from pit 9. Pit 16 is quite isolated in this scheme. Pit 16 gathers all the burnt artefacts identified on the site, underlying a specific pattern. The SGS artefact identified there is different from the dominant blade production. For the Skršín quartzite, a small flake that is comparable to the constitution of pit 32 assemblage has been identified. The different and highly variable nature of the composition of this assemblage suggests that the waste from pit 16 may not have been intentionally discarded.

The third category is **macrolithic tools and polished stone tools**, which partly follow the above trends. Waste from the production of ground axes was deposited in the same pit as waste from chipping (Pit 32), and this type of waste also occasionally entered pits used for dumping pottery. The only exception was a lateral pit with a quern and raw material for macrolith production (Pit 10). In the case of querns and heavy stone material, it is difficult to imagine a scenario other than deliberate deposition. For smaller artefacts, such as axe production flakes, it is possible to consider the possibility of tertiary waste, which may have followed a similar path as pottery.

Although we can assume the intentionality of deposition for some finds – for example, large refittable pieces of vessels, heavy querns, sets of flakes from a single coherent knapping episode – this category is very problematic for some types of finds. While we can suppose greater fragmentation and abrasion for ceramics along the long taphonomic path, chipped stone tools do not change qualitatively. Some studies show that chipped tools were deliberately discarded after being damaged by long use (Allard et al., 2013; Allard & Cayol, 2022). However, for stone production, it is mostly the quantitative aspects and the characteristics of the assemblages that allow us to discuss the intentionality, not the erosion aspects.

The results of the analyses show how waste management was spatially structured. The already mentioned phenomenon is the intensive deposition of ceramic waste together with other categories in the lateral pits at the south/central part of the houses. This phenomenon is not unique and a higher concentration of finds on the southern side of the houses was observed in both Bylany and Miskovice (Last, 1998, p. 26; Pavlů et al., 1986, p. 307). This meant that the area around the houses was not uniformly perceived as a waste disposal zone. Instead, a single area was allocated for this purpose. However, the structure of the lithic waste deposits in the settlement was different. We can observe one intensively used location, close to one of the houses (House 35). The other houses also had lithic waste in their vicinity, but in much smaller quantities. Thus, in contrast to the pottery, the waste of lithics (and apparently its Skršín quartzite production) had in the settlement space, a much more centralised character.

The results demonstrate the coexistence of different patterns regarding waste management as shown by the different materials discarded (which corresponds to some earlier observations – Květina, 2010, p. 361). This overlapping of different patterns demonstrates that the waste management at the settlement is not driven by standard rules but by the different social groups who process or use the different materials (chipped and polished stone tools versus pottery versus querns). While the functional explanation presented here, rooted in the concept of waste management, offers the most compelling interpretation of the observed patterns, it does not fully preclude alternative perspectives. Symbolic behaviour, for instance, may also have played a role in shaping these phenomena, as suggested in other studies (Chapman, 2000; Hofmann, 2020a). To fully explore this possibility, however, a broader, comparative analysis across LBK sites would be required to provide a more nuanced understanding.

4.3 Connection of House With Surrounding Pits

At first glance, the site encourages the association of pits with individual houses. Two clearly identifiable longhouses (12 and 14) are surrounded by clusters of pits, separated by a wide belt without any. It is also this logic that was applied when the site study was first published in 2002 (Pavlů, 2002). The results of this article, the refitting, the use of pottery decoration technique and the typo-technological analysis of the chipped stones suggest a much more complex picture of the settlement space.

Refitting and pottery decoration technique analysis divides pits into two groups (see above: Section 3.1.3), this connects both houses 12 and 14, and refutes the idea of two separated house units. Typo-technological analysis of chipped stones also shows similarity and complementarity of assemblages between pit 32 (House 35) and 9 (House 14). In contrast, chipped stones in pits 16 (House 12) and 32 (House 35) seem to be isolated despite their physical proximity. How can these results be interpreted and how can we imagine the development of the settlement? Several possible models suggest themselves:

Chronological Model

One possibility is that the individual houses and pits were not contemporaneous. For example, we can imagine that houses 35 and 12 were built first, using some of the pits in the area. When these pits were filled in, house 14 was built and used simultaneously with house 12. This would explain the refitting of pottery from the pits near these houses. This model would be consistent with the current idea of the chronology of the pottery decoration, which shows the pottery from pits 32, 16, and 30 to be older. The complementary of the chipped stones from pits 9 and 32 could, according to this model, be explained by the longer taphonomic trajectory of the finds from pit 9. However, this more traditional model is not the only possible explanation.

Cultural Model

Another possibility is that the houses on the settlement were built at the same time and that the observed variability is the result of two communities living side by side – or rather two coexistent traditions reflected in the material culture. The two clusters that occur in the pottery refitting may therefore be the result of different pottery production practices and different waste disposal sites that occurred at the same time. The complementarity of the chipped stone production chain of the two houses would then indicate the interconnectedness of the two groups in the processing of stone tools. In other words, lithic production was centralised at the village level rather than at the household level as suggested elsewhere (the hierarchical structures suggested by de Grooth, 2013; Kegler-Graiewski & Zimmermann, 2003). The idea of diversity at the same stage has also been suggested in other sites (Gomart, 2014, pp. 126–133; Hachem & Hamon, 2014).

Behavioural Model

The behavioural model is the last one we will mention. In this model, the observed variability could be simply the result of different behaviours – the treatment of waste. For example, if differently decorated vessels were perceived differently, they might also have been deposited in other parts of the settlement. This pattern of behaviour could then create two clusters around the contemporary houses, similar to those observed in the case of Hlízov. Regarding stone tool patterns, the variability observed between the different raw materials could also be explained using this model.

In addition to these models, there are certainly many other possibilities that could explain the results. At the present stage of our understanding, we are not in a position to select the most likely of these.

It is crucial to discuss the variability of the data across the settlement and to examine the networks that connect individual houses. If we were to assume spatially defined house units in the first place, we would miss a lot of important data and the results mentioned above would not be identified at all. Using this approach, although we are not able to characterise individual houses in detail (as Hachem & Hamon, 2014; Pavlů, 2000 do), we are able to observe the whole settlement better and more critically. Here we see that it is perhaps better to step back from individual houses and households and look at the site as a whole. Otherwise, we are left with a situation where we can't see the settlement for the houses.

5 Conclusion

By investigating the small LBK settlement in Hlízov, we have studied the taphonomy of the site and how Neolithic communities managed waste. Our research aimed to describe the structure of the pit filling, to compare different types of finds, and to test the current concept of settlement space.

The results indicate that each type of waste was managed differently. Waste from stone tool production was more centralised within the settlement, whereas ceramic waste was distributed around the houses. The pit fills varied significantly, suggesting that different mechanisms and assemblages of artefacts contributed to their formation. However, the speed of their formation could not be determined from the available data. Distinct waste management zones were observed within the settlement area. Pits near the southern/central parts of the houses were intensively used for depositing ceramic waste and occasionally stone objects. In contrast, waste from stone tool production was placed in a specific pit with very little pottery. The other remaining pits around the houses contained waste less frequently and were not perceived by Neolithic people as areas for deliberate waste disposal.

The relationships between the individual pits in the settlement have been investigated by refitting, research into pottery decoration techniques and chipped stone productions. The results show that two partially overlapping networks existed side by side, but operated across spatially defined house units. This phenomenon can be explained for example by the presence of two different communities or by the asynchronous development of the site. This led to the methodological abandonment of the house unit model. Although this approach does not allow a detailed study of individual houses and households, it offers a more comprehensive and critical understanding of the overall functioning of the Neolithic settlement.

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