Neolithic settlement structures in Central Europe: case study of East Bohemia and the Morava River catchment

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ABSTRACT – The study examines the degree of similarity of Neolithic settlement structures in two geographically separated regions (eastern half of Bohemia, Morava River Basin) based on the analysis of 11 variables related to the environment and the settlement structures. The period studied corresponds to c. 4900–3400 BC. Although the results of most of the variables analysed using principal component analysis (PCA) do not show significant differences in the preference of settlement locations, the analysis of the individual variables points very clearly to major differences in settlement patterns. These are manifested in different settlement dynamics, accessibility to stone raw materials, and the spatial extent of occupation. The general conclusion is that although early agricultural societies are similar in general terms regarding the location of settlements, their individual aspects are quite different, which must have been reflected in lifestyles during the Neolithic.

KEY WORDS – Neolithic; settlement; chronology; central Europe

Introduction

After the end of the stage of the initial development of Neolithic society in central Europe, which is characterized by the Linear Pottery culture (LBK), the original symbolic style broke down into several regional factions in terms of the decoration of ceramic vessels. The existing research on Neolithic society in this region has been almost exclusively dependent on knowledge of pottery decoration, which serves as a basic chronological descriptor. In the traditional sense, then, symbolism on pottery is seen as a key reflection of social affiliation – archaeological culture, as a legacy of Romanticism in the form of...
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The theoretical approaches of Gustaf Kossina (1911) and Vere Gordon Childe (1925). In contrast to symbolic systems, the study of settlement structures was developed under the influence of processual archaeology as a manifestation of strategic adaptation to changes in environmental conditions, which became evident in archaeological research on the Neolithic in Central Europe from the 1980s onwards (Lenneis 1982; Rulf 1983). Despite the influence of processual archaeology, however, questions of human adaptation to the environment were shaped by the influence of cultural historicism, particularly with regard to perceptions of the chronological development of early agricultural societies.

The basic questions we address are: (1) What variables influence the development of settlement patterns in two geographically separated regions? (2) Can some variables be regionally distinguished? (3) What weight do the selected variables have for the study of settlement structures? (4) Do changes in ceramic style correspond to changes in settlement structures or some of the variables under study?

The beginning of the period (c. 4900 BC) included in the study corresponds to the end of the Early Neolithic, when there is a decline in human activity in many regions of central Europe, as reflected in the frequency of radiocarbon dates (Shennan 2018), and at the same time the symbolic Linear Pottery style (LBK) comes to an end. In terms of the traditional nomenclature of symbolic styles, the period we study corresponds to the Stroked Pottery (SBK), Lengyel Pottery (LgK), Jordanów/Epi-Lengyel Pottery, Michelsberg Pottery (mainly Bohemia) and the Funnelbeakers (TRB), which occur together with Retz-type pottery (mainly Morava River catchment).

In previous research on settlement structures the chronology was determined solely on the basis of symbolic systems, which are reflected in the morphology and decoration of pottery and are called ‘archaeological cultures’. However, these lack explanatory potential for understanding the dynamics of prehistoric societies (most recently Furholt 2021). However, due to their frequent occurrence, Neolithic symbolic systems captured in ceramic production are a useful means for understanding the chronology of settlements based on knowledge of their temporal occurrence using radiocarbon dates (Tramposťa, Květina 2020).

In this study, we focus on characterizing the changes in the settlement organization of human populations that inhabited two separate regions in central Europe: the Morava River Basin and the eastern half of Bohemia (Fig. 1). We hypothesise that Neolithic organization of settlements is part of the reflection of lifestyles conditioned primarily by the natural environment and by social behaviour patterns.

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Fig. 1. Area of interest and all studied sites from the period of c. 4900–3400 BC.
while the eastern part is artificially demarcated by the watercourses of the Vltava and Jizera rivers, which have an approximately north-south course. The number of analysed settlements in the area of c. 9000km\(^2\) is 597, which corresponds to an average density of 0.06 settlements/km\(^2\).

The second settlement area is the Morava River Basin, which is mainly located in Moravia, in the northern part of Lower Austria and in the westernmost part of Slovakia (Záhorie). This area is bounded by mountains and highlands to the west, north and east, while at the southern border the settlement area continues further. The number of analysed settlements in the settlement area of c. 19000km\(^2\) is 1556, which corresponds to an average density of 0.08 sites/km\(^2\).

The two settlement regions are located in similar geographical and climatic areas of the temperate zone of central Europe; the terrain relief is not categorically different, and we consider them comparable in terms of the natural environment.

**Data and methods**

**Chronology**

In the absence of a dominant successor interpretive model, the model of archaeological culture has been used until now, at least in the sense of the basic classification of material culture, while the change of ceramic style is taken into account as a unique chronological factor through whose transformation other changes in the structure of society can be captured. This a priori model is problematic because it does not assume the possibility of significant social changes during the existence of a given symbolic style.

On the other hand, we do not currently have a more appropriate chronological identifier that could better characterize the chronological position of most settlements.

In order to understand the chronological evolution of settlement transformations, we turn to three forms of describing individual settlements based on (a) symbolic systems on pottery (archaeological cultures - ceramic traditions); (b) basic subdivisions of ceramic typology (phases of archaeological cultures - ceramic groups) based on knowledge of their temporal occurrence (following Trampota, Krčelina 2020); and (c) knowledge of radiocarbon density data that reflect concentrations of human activities. While the chronological distribution is expressed in the aforementioned publication, the determination of the chronology based on the frequency of occurrence of radiocarbon dates is a sub-subject of this study. A similar analysis has already been performed for both Bohemia and the Moravian-Lower Austrian area (Timpson et al. 2014:553) using the summed probability distribution (SPD). Given the currently significantly higher amount of available radiocarbon dates for both areas, we performed a new SPD in OxCal (Bronk Ramsey 2009) using the IntCal 2020 atmospheric calibration curve (Reimer et al. 2020), which we interpreted using kernel density estimation (KDE; Bronk Ramsey 2017).

All \(^{14}\)C dates from anthropogenic contexts were included in the input radiocarbon database (see Supplementary material available at https://doi.org/10.4512/dp.49.15). All \(^{14}\)C dates related to the period between the beginning of the agricultural prehistory to the end of the TRB, c. 3550 BC, were considered. Only dates with a 1\(\sigma\) greater than 100 and dates measured from humic acids were excluded from the dataset. The resulting SPD and KDE plots are validated by the number of known settlements (Fig. 2).

In the Morava Basin, the structure of the radiocarbon dates is divided into three peaks representing three distinct units of population activity. The first peak corresponds to the occurrence of Linear Pottery (LBK), and the marked decrease in the frequency of radiocarbon dates at the end of the LBK around 4900 BC is a known phenomenon in other regions in western central Europe (Shennan 2018:104). The second peak is represented by the pottery styles with Stroked Pottery (SBK) and Lengyel pottery (LgK). At the end of this peak, some archaeologists use the term Jordanów culture or Epi-Lengyel. Between c. 4000 and 3800 BC, there is an apparent hiatus in human activity that has not been considered in archaeological research to date, as it cannot be detected outside the context of absolute dates. The last peak of human activity is associated with the Funnelbeakers (TRB) and Retz-type pottery. However, its termination is artificially based on the initial definition of the period under study, which is only associated with TRB, but actually continues in the context of at least Baden pottery.

The three identified peaks are a new chronological indicator which we henceforth refer to as Neolithic A, Neolithic B and Neolithic C (Neolithic A is not the focus of this study).

In Bohemia, the resulting model is far more problematic, as there are significant data biases. At pre-
sent, it is not possible to say whether there is a significant decline in the frequency of $^{14}$C dates during the transition from the LBK to the SBK, as the underdating of contexts associated with Linear Pottery is evident when comparing the number of settlements and the amount of radiocarbon dates. A subsequent significant peak is associated with Stroked Pottery or the study of rondel ditch fills. In this respect, we can speak of a heavy overestimation of the accumulation of $^{14}$C dates in favour of the one problem addressed. After the SBK period, there is a decline in both the frequency of $^{14}$C dates and the number of settlements, which indicates a different development compared to the situation in the Morava Basin. The possibility of a settlement hiatus after 4000 BC is reflected in the modelled dates, but the number of $^{14}$C dates from the Early Eneolithic is too low to obtain a relevant result. However, similar to the Morava Basin, there is a clear increase in the density of $^{14}$C dates and the number of settlements around 3800 BC. The resulting density curve of $^{14}$C dates is not representative in part, so we provisionally use the same model for Bohemia, which divides the Neolithic into periods A, B, and C.

For the analysis of settlement characteristics, we use this broad chronological concept in terms of long-term processes. We are interested in whether the settlement during each population phase was chronologically or regionally specific.

**Settlement data**

The choice of variables related to Neolithic settlements reflects the real possibilities of studying the data structures of the region. Some complex datasets are defined by institutions in three countries and may not be compatible or available. For this reason, pedological and geological data, in particular, which may be important for the formation of Neolithic settlements, are not taken into account. The studied variables form two groups – the first is labelled environmental variables, and in general it is comprised of variables determined by the environment and terrain surrounding the settlements; the second group is labelled social variables, and in general these are influenced by processes taking place in the Neolithic society.

The database of settlement sites ($n=2154$) is based on our desire to maximize the information potential with regard to Neolithic settlement sites. In addition to published sites, we acquired data from archaeological archives and some unpublished sources in museum collections. Data were obtained in the form of standard excavations, as well as collections from surface surveys. In its minimalistic form, the Neolithic settlement is defined by the repeated presence of ceramics that can be assigned with certainty to at least one of the ceramic traditions (archaeological cultures). Neither isolated lithic finds nor hoards or any cave finds are taken into consideration. The mi-
minimum distance separating two settlements is c. 200m.

The data is described in detail in a dedicated data article (Pajdla, Trampota 2021) and is also published in a separate repository under https://zenodo.org/record/5768049#.YydAhLRbXrY according to principles outlined in Ben Marwick (2017); the original repository is at https://github.com/petrpajdla/settlements.

Data is analysed in the R programming language (R Core Team 2022). To enhance transparency, the compendium containing code is published at the Zenodo data repository under https://zenodo.org/record/6703463#.YydBi7RBxPY according to principles outlined in Ben Marwick (2017); the original repository is at https://github.com/petrpajdla/settlements.

The most important software packages used in the analysis are the tidyverse family of packages (Wickham et al. 2019), sf (Pebesma 2018), and spatstat (Baddeley et al. 2015).

We approach the analysis as a multidimensional problem, dimensionality reduction (PCA) is used on the continuous input variables and, consequently, model-based clustering (mclust package, Scrucca et al. 2016) is used to define groups of similar settlements.

**Analysed environmental variables**

Altitude is derived manually from online map servers (https://geoportal.cuzk.cz, https://www.geoportal.sk, and https://www.niederoesterreich.at/karte), and also from a digital elevation model (DEM) to verify this approach. The values derived from DEM and by hand correlate well (R = 0.97). For the analysis, the values derived by hand are used.

The value of slope at the settlement location is derived from ASTER GDEM (NASA et al. 2019). ASTER GDEM is used because the territorial scope of the area of interest intersects several state boundaries, namely the Czech Republic, Slovakia and Austria, and obtaining and/or harmonizing individual digital elevation models with identical resolutions, etc., for each of the countries was not possible. The slope value is derived as a mean value in a buffer zone around each of the settlement sites with a radius of 300m.

The density of the watercourse is the preferred method of assessing the relationship between human occupation and water courses over the distance to a water course. The approach used is based on methods used to study road networks in modern urban areas (Lin et al. 2020). The watercourse density is derived from three individual layers for each of the countries, DIBAVOD (Fajtik et al. 2022) for the Czech Republic and Geofabrik for Slovakia and Lower Austria. The density of watercourses is estimated using kernel smoothed intensity from a line segment pattern with a kernel size of 2km. The mean value in a buffer zone with a radius of 300m around the settlements is recorded.

The topographic position index (TPI) is used (together with the slope) as a proxy for terrain fragmentation. It is derived from the digital elevation model using Wilson's approach (Wilson et al. 2007), i.e. TPI is the difference between the value of a given cell and a mean of eight surrounding cells. TPI effectively shows whether the surroundings of a site are flat, or the site is located on a hill (positive values) or in a valley (negative values). As in the case of slope, the TPI for a given settlement site is defined as a mean TPI value in its buffer zone with a radius of 300m.

**Analysed social variables**

Settlement density was calculated using kernel density estimation with a kernel size of 4km. Not that in the figures we used a kernel size of 10km.

The linear arrangement deals with settlements organized in linear formations along watercourses and on terrain contours, typically in the foothills of uplands. Settlements have not yet been analysed in this way on a larger scale. Settlement lines were manually defined in the GIS environment based on base layers from ZABAGED and Geofabrik (for Slovakia and Austria) for watercourses and a digital elevation model (OpenStreetMap) for terrain lines. The minimum number of settlements per line is three.

The location of sources of lithic raw materials in the studied areas (Fig. 3) is defined by Antonín Prichystal (2013). Subsequently, the distance of each settlement to each source during the periods when each raw material was exploited was calculated. Resource exploitation was categorized for each period as: none, sporadic, significant.

The hierarchical element of settlement structures is considered to be a palisaded or ditched enclosure, which is assumed to have had primarily an economic or fortification purpose. We do not include rondels typical for the first half of the 5th millennium BC in this category because of the distinctiveness of rondels from other enclosures – both with regard to the shape of the ditch and the single-phase occurrence within prehistory. The rondels have a V-shaped
ditch, whereas the settlement enclosure ditches are flat-bottomed. In the case of hilltop enclosures, then, we observe the remains of a stone wall. Rondels are specific in the context of agricultural prehistory because of their short-term, single-phase occurrence, while settlement enclosures are observed continuously.

The distance from each settlement to all enclosures has been calculated.

The presence of individual ceramic groups at individual sites was observed, for which we assume chronological succession. On the basis of the frequency of successive settlements we observe changes in settlement continuity.

**Results**

**Altitude**

The character of settlements in relation to altitude differs significantly in Bohemia and in the Morava Basin, both in terms of the evolution of preferences and in terms of data homogeneity. While in Bohemia the values of altitude are very similar for the mean and median, in the Morava Basin the mean and median are significantly different, reflecting the wide range of settlement values; in Bohemia they have a homogeneous character and thus less dispersion of values (Fig. 4). For developmental trends, there is a clear tendency in the Morava Basin to settle sites at higher elevations from the interval 4800–4600 BC (Early Lengyel), which gradually decreases to very low values in the interval 4200–4000 BC (Epi-Lengyel). A renewed increase in preference for higher altitudes is observed from 3800 BC (TRB) onwards.

On the other hand, in Bohemia there is a slight, steady decline in the preference for higher elevations from the beginning of the period under study to 3800 BC. As in the Morava Basin, we observe a preference for higher elevation settlements from 3800 BC onwards in relation to the TRB.

The described trends are consistent with the data defined by both ceramic traditions and ceramic groups.

**Slope**

The data categorized by ceramic tradition show a similar tendency for slope preference as for elevation, which is indirectly related. If we classify the data in more detail according to ceramic groups, there is a greater dynamic (Fig. 5). For both study areas, low
settlement slope values (Early SBK) are present at the beginning, followed by an increase from 4800 BC (Early Lengyel, Late SBK) and followed by a gradual decrease until 3800 BC. A reversal towards higher values occurs in Bohemia from 3800 BC and in the Morava Basin from 3600 BC. Towards the end of the period under study in Bohemia (Saalzmünde, Boleráz) the settlements are located on flatter sites, while in the Morava Basin (Boleráz) there is a clear preference for more sloping sites.

Watercourse density
The basic characteristics of the development of the relationship between settlement and watercourse density is the same for data categorized by both ceramic tradition and ceramic group. During the period 4900–4600 BC (SBK), settlements in Bohemia are located in areas of high watercourse density, followed by a sharp decline and a slightly downward trend in the rest of the period. In contrast, the situation in the Morava Basin is negatively correlated with this and the trend is exactly the opposite (Fig. 6).

Kernel density (KDE) of settlements
The density of settlements in terms of general trends is similar for the data categorized by ceramic tradition and ceramic group, but some changes in the short-
term trends are significant in the case of the ceramic groups (Fig. 7). In both regions, the beginning (Early SBK) is characterized by low settlement density. This is followed by an increase in settlement density, but in the Morava Basin the settlement density reaches almost twice the values in Bohemia. While in the period 4600–4200 BC (Late Lengyel) the values in Bohemia no longer reach the previous maximum, in the Morava Basin the density continues to increase, followed by a sharp decline in values in the period 4200–4000 BC (Epi-Lengyel). In the Morava Basin a settlement interlude follows in the period 4000–3800 BC, whereas in Bohemia the settlement hiatus is not yet evident in the radiocarbon dates. The lowest settlement densities, however, are shown by settlements in 3800–3600 BC in association with the beginning of the TRB, but this is probably related to the relatively small proportion of TRB settlements whose ceramic typology is more closely subdivided. During the TRB, settlement density increases slightly in both regions.

Beyond the statistical results, it is important to consider the spatial location of the main settlement clusters and their size. We categorize these data only in the context of ceramic typological groups. In Bohemia, the settlement core in the Early SBK period is located in the north of the settlement area in the

Fig. 6. Violin plots with KDE of watercourses in individual periods. Data are classified according to pottery groups.

Fig. 7. Violin plot with KDE of settlement sites in individual periods. Data are classified according to pottery groups.
broader vicinity of the Jičín Upland, an area that is somewhat less populated in other periods, especially in comparison with the Polabí (Elbe) region (Fig. 8). Subsequently, in the context of the Late SBK, settlement appears in several distinct settlement clusters on the right bank of the Elbe in eastern Bohemia and in the vicinity of Chrudim and Kolín. Settlement during the Late Lengyel (Fig. 9), albeit in smaller numbers, is organized very similarly, but the settlements are more concentrated in the broader vicinity of the Elbe. Settlement structure changes markedly during the Proto-Eneolithic (Fig. 9), when settlements are concentrated in the Polabí region between Prague and Kolín, while settlements in eastern Bohemia are sporadic. In Bohemia, TRB settlements occupy the area in central Bohemia south of the Elbe River and in eastern Bohemia west of the Elbe River. The sub-typochronological classification of TRB settlements is at a low level, but it can be assumed that the characteristics of settlements in 3800–3400 BC are similar to those of the TRB in general. The conclusion of the TRB (Fig. 10) is interesting in terms of settlement organization because of the occurrence of one distinct cluster in and around Prague characterized by Saalzmünde pottery, while a separate second smaller cluster of settlements is located in the Čáslav Basin and is characterized by Boleráž pottery.

In the Morava River Basin, the smaller number of settlements in the period characterized by the Early SBK are concentrated in the western half of the settlement area, while the area east of the Morava River shows almost no settlement activity (Fig. 8). Subsequently, in the context of the Early Lengyel there is an increase in the number of settlements concentrated mainly around Brno and in southwest Moravia. The area east of the Morava River is only sporadically settled, and in central Moravia there is also very sparse settlement, moreover the ceramic production is characterized by Late SBK. In the Late Lengyel period (Fig. 9), the settlement situation reverses: while in the southern half of the basin the density of settlements

Fig. 8. Settlement KDE of sites with SBK and Early Lengyel.
Neolithic settlement structures in Central Europe: case study of East Bohemia and the Morava River catchment

Decreases considerably and they are concentrated into more small settlement clusters, in the northern half of the basin (central Moravia) a large settlement cluster is formed. The area to the east of the Morava River is for the first time since the LBK more heavily populated. During the Epi-Lengyel (4200–4000 BC), the southern half of the Morava Basin is sparsely populated, except for the area along the right bank of the lower course of the Morava River. As in the previous period, settlement is concentrated in central Moravia. Between c. 4000 and 3800 BC, we assume a settlement hiatus, or a form of human presence that left no significant archaeological traces. In c. 3800–3500 BC (Early TRB, Baalberge, Retz-type), three unequal settlement clusters (Fig. 10) emerge in the vicinity of present-day Prostějov, Brno and Znojmo. The southeast of the studied area is sparsely settled, if at all. Towards the end of the period under study (TRB – Boleráz) we observe an increase in the concentration of settlements in central Moravia, with a small cluster in southwest Moravia and the lower course of the Morava River. The rest of the Morava Basin is not significantly populated.

**Linear arrangement – along terrain lines**

In terms of proportions, settlements are located along the terrain lines mostly in the period 4900–4800 BC (Early SBK), after follows a decline, especially in Bohemia. Here, settlements form slightly more distinctly along terrain lines from 4200 BC onwards (Proto-Eneolithic and TRB). In the Morava River catchment, on the other hand, the formation of settlements along terrain lines is a very fundamental phenomenon for the period 3800–3300 BC (TRB), with the main area where settlements are organized in this way being the southern and eastern margins of the Drahany Uplands (Fig. 12). Parallel to these, the linear organization of the hillforts forms a specific structure during the Boleráz phase.

![Fig. 9. Settlement KDE of sites with Late Lengyel and Epi-Lengyel/Jordanów/Proto-Eneolithic.](image-url)
**Linear arrangement – along water lines**

In terms of frequency, the organization of settlements along water lines appears less pronounced than for terrain lines. The only period and region where settlements are significantly located along water lines (Fig. 11) is 4900–4800 BC (Early SBK) in the Morava Basin. There is also significant settlement organization along watercourses in the Morava Basin during the Late Lengyel, c. 4600–4300 BC, but statistically this disappears in the face of the very high number of settlements during this time. The organization of settlements along watercourses and on terrain lines during the Late Lengyel is also significant (Fig. 12), but this is not statistically significant in the context of the large number of settlements.

**Hierarchical arrangement**

The analysis of the relationship between settlements and enclosed sites (Fig. 13) was carried out only in the context of data described by ceramic traditions, as the detailed chronology of many enclosed areas is unknown. The analysis shows that for most of the periods the distance between settlements and enclosures recorded in the Morava Basin is smaller, which is mainly due to the larger number of known enclosures. The opposite situation is in Bohemia during 4200–3800 BC (Proto-Eneolithic), when a large number of lowland enclosures are recorded in central Bohemia (Křížuf, Turek 2019). In the Morava River catchment, on the other hand, the distance to enclosed areas decreases significantly in 3800–3300 BC in the context of the TRB, when a number of new hillforts are established, often with evidence of a stone rampart. The spatial distribution of enclosures in the Morava Basin is interesting from the long-term perspective, with almost all of these enclosures located in the western half of the occupied area.

**Distance to raw material sources for chipped stone industry**

A comparison of the data distribution by ceramic tradition and ceramic group shows no
Neolithic settlement structures in Central Europe: case study of East Bohemia and the Morava River catchment

Structural differences. For the settlements in Bohemia, the mean and median values are above 100 km; their slight diachronic increase is probably not a reflection of a change in the relationship between sources and settlements in the context of such large distances.

In the Morava Basin, the situation is significantly different, mainly due to the proximity of the sources of raw materials for chipped industry. In the period 4900–4800 BC (Early SBK), a significant concentration of settlements is evident in the vicinity of chipped industry resources (Fig. 14), which is related to the depopulation of the eastern part of the Morava Basin, where resources are less abundant, and the localization of settlements in the western part, where more raw material resources are concentrated. Krumlovský les chert played a key role in this period. It is completely predominant in the chipped stone industry assemblages within a radius of at least 60 km (Trampota 2015.180–183) and is also significantly present at distances above 80 km (Olomouc-Slavonín; Kazdová et al. 1999), thus quantitatively the most abundant raw material and the one distributed over the greatest distances in the entire studied period. In subsequent periods, the distance to the resources increases in connection with establishing new sites in the whole settlement zone. The highest distance to the sources of raw materials for chipped stone tools is recorded in the period 4200–4000 BC (Epi-Lengyel), when the number of settlements decreases to the level of the period 4900–4800 BC (Early SBK), but their main concentration is in central Moravia, in a region relatively distant from the sources. As such, two types of relationships of settlements to the sources of the chipped stone industry can be observed in similarly few populations.

A distinct phenomenon since 3800 BC (Early TRB, Baalberge, Retz-type) is the mining and local distribution of chert from Stránská skála near Brno (Bartík et al. 2019), but the overall settlement pattern does not statistically correspond to this activity, although a small cluster of settlements forms around the source.

Distance to raw material sources for polished stone industry

As with the raw materials of chipped industry, the division of data by pottery traditions and pottery groups shows no structural differences.

In Bohemia, Jizera Mountain-type metabasite was an important resource during the Early Neolithic (Přichystal 2013.192), whose distribution radius extended beyond central Europe. The use of this raw material continues in the following period, but only on a regional scale in Bohemia (Šída 2007). In 4900–4800 BC (Early SBK), the settlement structure in relation to the sources of raw materials of polished stone industry is oriented more towards the vicinity of the source. In the subsequent period, however, no changes in settlement structures are evident in relation to the distance from the sources of raw materials.

In the Morava River Basin, settlements are not related to sources of stone raw material at all in 4900–4800 BC (Early SBK) and raw materials are generally located at a great distance, which reflects the low frequency of tools found. From c. 4800 BC onwards (Lengyel), a marked change follows, with settlements very much located in the vicinity of raw material sources for polished stone tools, which is strongly reflected in the archaeological record. Subsequently, the distance from the sources increases slightly, which is statistically due to the occupation of a wider area. Settlements are more strongly oriented in relation to the period.

Fig. 11. Linear arrangement of settlement sites along terrain lines (black) and along water lines (blue). The map shows merged lines for all periods.
3600–3300 BC (Boleráz phase), but this is not as pronounced in the occurrence of polished stone tools as during the Lengyel period.

Settlement continuity

The use of data from settlements defined by pottery traditions is not very suitable for the analysis of settlement continuity, as this division includes broad time categories and results in the appearance of often significant settlement continuity.

The first time period studied is artificially discontinuous, as we do not compare the data with the previous period (LBK). In the Thaya River basin (c. half of the entire Morava Basin), continuity between the Late LBK and the Early SBK is found for 37% of settlements (Trampota 2015.138).

Data classified by pottery groups (Fig. 15) show a higher proportion of continuously occupied sites in Bohemia than in the Morava Basin. In general, a higher proportion of continuously occupied positions can be observed when the number of known settlements is low; when population growth and/or settlement of new positions occurs, the proportion of continuously occupied positions is low.

TPI index

The structure of data is the same for pottery traditions and pottery groups. Values for most settlements in both regions are around zero, reflecting a preference for flat locations (Fig. 16). In the case of concave landforms (hills), a gradual transition to higher values is evident, especially in the Morava Basin, during the period of 4800–4400 BC (Lengyel), while in 3800–3400 BC (TRB) hilltop sites form a specific cluster of values (also less pronounced in Bohemia). Here the hillfort sites are separated, whereas in the earlier period hilltop settlement is not a defined category.

Results of multivariate statistics

The similarity of settlement structures based on long chronology (Neolithic B and Neolithic C) were analysed using principal component analysis. All variables except settlement continuity and the hierarchical arrangement of sites were included in the analysis. However, the results did not yield significant differences that could be interpreted according to the significant factors, nor according to clusters of points (Fig. 17), which are more a manifestation of random arrangement. As a result, the settlement patterns defined by long chronology did not differ in principle, and reflected similar preferences for locations suitable for agriculture.

Fig. 12. An example of the linear arrangement of settlement sites during Late Lengyel (above) and during Boleráz (below).
**Discussion**

**Importance of individual variables**

We evaluated the weight of each variable using the summed factor scores on the axes, which reflect 75% of the total variability. The number of axes varies, so the average value for each variable was calculated. From the results for the individual chronological classifications (Tab. 1), it is clear that the variables with the largest sum of factor scores are those that show great stability over time and do not change much. These are always the topographic position index and the settlements organized along terrain lines in Bohemia. In the Morava River catchment, these are also the topographic position index and the estimation of the kernel density of watercourses. These variables are therefore not very suitable for explaining the dynamics of settlement structures.

In contrast, variables that have the lowest sum of factor scores can be expected to have more variability and thus these variables may be important for understanding the organization of settlement structures at certain time intervals. A second possible explanation is then that they are generally insignificant. In Bohemia, these variables are mainly distance to sources of raw materials, especially chipped industry, and an estimate of the kernel density of settlements. In the Morava River Basin, distance to sources of raw materials of polished industry and altitude mainly have the lowest sum of factor scores. These two variables are chronologically highly variable in the Morava River Basin, while in Bohemia the variables with the lowest sum of factor scores have low explanatory potential.

**Difference between settlement structures in two regions**

Some of the observed variables are different in the two separate settlement regions and are important for understanding the unequal dynamics of the evolution of social organization, subsistence or lifestyle.

Analysis of the altitude of individual settlements reveals that areas up to 500m above sea level were commonly settled in in Moravia, whereas in Bohemia settlement was common only up to 350m above sea level, and only rarely at higher altitudes. This is not due to different geomorphological conditions, but another factor. A possible demarcation of settlement areas between Neolithic and Mesolithic populations comes into consideration, which leave archaeological traces on a limited scale. Parallel coexistence between Late Mesolithic and Neolithic populations in Bohemia can be considered in the context of Bohemia rather than in the Morava River Basin.

![Fig. 13. Distribution of enclosed sites in the studied area. Red – Early SBK, blue – Lengyel, black – Proto-Eneolithic, pink – TRB. TRB enclosed sites are exclusively elevated, others lowland.](image)

<table>
<thead>
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<th>region</th>
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</table>

Tab. 1. Table with the sum of factor scores of individual variables. The resulting value is the average value against the number of axes expressing 75% variability.
This is consistent with the relatively large number of known Mesolithic sites in Bohemia (Čuláková 2015. Fig. 10.10.3). In contrast, the number of Mesolithic sites in the Morava River Basin is very small (Svoboda 2008; Oliva 2018) and the chronological coexistence of the two distinct populations is unlikely. As such, in terms of the spatial extent of Neolithic settlement, the fact that the Morava River Basin experiences the most extensive settlement during the Neolithic in agricultural prehistory, which was only surpassed in extent after 1000 AD, is crucial. The situation is just the opposite in Bohemia. The Neolithic settlement area here occupies a relatively small area, which only increases significantly with the onset of the Bronze Age (Demján et al. 2022. Fig. 10). David Graeber and David Wengrow (2021.262–263) explain the rapidity of the Neolithic colonization of central Europe by the absence of human settlement. This colonization stopped mainly before the coastal areas, which were strongly occupied by Mesolithic populations. Whether we can draw a similar conclusion for the absence of Neolithic settlements in parts of Bohemia, especially in the south, is uncertain.

In our case we observe the secondary consequences of this colonization, which do not differ substantially in their extent from the original situation during the LBK.

Another important variable is the sources of stone raw materials. Jizera Mountain-type metabasite played an important role at the beginning of the studied period in Bohemia, but after 4800 BC there was a reversal, with the production of polished stone tools dominating quantitatively from sources in south Moravia, around which settlements were heavily concentrated.

In the eastern part of Bohemia, local sources were never used to a great extent for the production of chipped tools, and the vast majority (silicite of glaciogene sediments) came from Silesia or Saxony, an area separated by mountains. On the other hand, especially...

**Fig. 14.** Violin plot with distance between settlement sites and used lithic raw materials in individual periods. Data are classified according to pottery groups.

**Fig. 15.** Bar plot expressing share of continuity of settlement activities in relation to previous chronological phase.
In south Moravia, the sources of chipped stone industry were mostly part of a densely populated area, which was reflected in the quantity of their exploitation. The Epi-Lengyel period, when settlements were generally concentrated at a great distance from the exploited sources, is a significant deviation from this. This may indicate that stone artefacts were of low socio-economic importance at this time.

Another significant difference is the dynamics of settlement, which took place in different ways in the two regions. In Bohemia, settlement reaches its peak in the context of the Late Stroked Pottery (c. 4800–4500 BC), whereas in the Morava Basin it is not until the Late Lengyel (c. 4500–4300 BC). It follows that to understand the lifestyle of each society, it is necessary to study each region separately, and the lifestyle of Neolithic people cannot be generalized by similarities in symbolic expression using ‘archaeological cultures’.

The relationship between settlement site and slope gradient in the two regions follows a broadly similar pattern according to the expected population dynamics, which we estimate based on the frequency of the occurrence of radiocarbon dates combined with the number of settlement sites. In periods when we record low population density, mainly flat sites are occupied, while in periods of the estimated highest population density, sloping sites are also occupied.

**Pottery style as a social identity indicator?**

During the period under study, both areas are characterized by one decorative style, but there are exceptions. In central Moravia, there was in 4800–4600 BC a small cluster of settlements characterized by the Late SBK, while in the area further south there was dense settlement characterized by Early Lengyel pottery (Fig. 8).

Towards the end of the studied period, the settlement of the Čáslav Basin in central Bohemia is characterized by Boleráz pottery, with settlements with Saalzmünde pottery concentrated especially around Prague (Fig. 10). In both cases, the two groups with different symbolic styles are separated by an uninhabited or very sparsely inhabited area. In the results of the statistical analysis of settlement structures, apart from spatial location, these groups do not differ. This reflects the similar nature of lifestyle or subsistence, but in the social dimension there is an obvious geographical distance.

A distinct form of the relationship between two different decorative styles existed especially in the Morava Basin (and other parts of Lower Austria) in 3800–3400 BC, when Funnelbeaker pottery is often found in contexts together with Retz-type pottery (also known as *Furchenstichkeramik*). These two styles, completely different in vessel morphology and decoration, are not territorially exclusive but directly intertwined. While the Morava Basin is the south-eastern periphery of the distribution of Funnelbeakers, pottery of the Retz type is most often found in the western part of the Carpathian Basin.

Two different examples of the spatial occurrence of the different pottery styles thus illustrate the ambiguity of its interpretation.
Evolution of Neolithic settlements
The evolution of Neolithic settlements was clearly dynamic. The rate of change of settlement structures was greater than the change of symbolic systems – ‘archaeological cultures’. A weakness of the presented study of settlement structures is the fact that we frame the development of settlement structures on the basis of the development of particular pottery styles. While the pottery style is the most appropriate descriptor of settlements from a quantitative point of view, its disadvantage is its interval nature, which may not capture the other possible and even more rapid dynamics of the development of settlement structures. Nor can it be used as a prism to consider whether the transformation of settlement structures occurred gradually or in leaps. With the number of settlements analysed, it is not realistic at present to have a series of radiocarbon dates that would define the probabilities of the beginning and end of most settlements.

Conclusion
In this article, we have analysed the relationships between Neolithic settlement sites and the environment. The research covered a total of 2153 sites from two separate areas, the eastern half of Bohemia and the Morava River Basin for the period of c. 4900–3400 BC.

The two separate settlement regions studied differ fundamentally in their characteristics. What is striking is the different chronological development of the number of settlements, which in the Morava River Basin correlates relatively well with the long-term development of the frequency of radiocarbon dates, whereas in Bohemia only the development of the number of settlements can be relied upon at present. The two regions differ in the extent of settlement, with the Morava Basin being extensively settled, while the eastern half of Bohemia is only sparsely settled compared to later phases of prehistory. The two regions differ markedly in their access to raw material sources for the production of chipped and polished stone tools. In the Morava River Basin, the importance of amphibole diorite and porphyritic microdiorite for the first mass production of axe-hammers is particularly evident in the significant concentration of settlements around the source area.

The chronological evolution of most of the variables studied can be seen as proxy information of population dynamics. The evolution of settlement structures does not correlate with archaeological cultures, but

![Fig. 17. Result of principal component analysis on two main axes, data are classified based on long chronological segments.](image)
greater dynamics can be observed. The information found can be generalized to the European level by stating that the Neolithic had an insular character, the dynamics of the settlement development of each region is specific, and to understand the lifestyle of the people it is necessary to study these regions separately.

While it is not relevant for the Neolithic to work with the question of centrality in terms of individual sites, broader regions can be understood in this way. In this respect, these are defined by dense and long-term settlement, whereas the periphery is only heavily populated at the population maximum. In the Morava Basin, the central area can be defined as primarily the eastern edge of the Bohemian Massif, while Outer Subcarpathia and the Vienna Basin can be understood as Neolithic peripheries. In Bohemia, then, the central areas are the right bank of the Elbe in the upper reaches and the wider area of the left bank in central Bohemia.

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