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LBK settlement network in the eastern part of the Wiśnicz Foothills

ABSTRACT

The Foothills of the Northern Carpathian region were an important part of the ecumene of the Linear Pottery Culture (LBK), as witnessed by the repetitive pattern of settlement in such areas. Multiple sites associated with this archaeological culture can be found near the Raba basin in the region of Wieliczka and Bochnia, as well as in the Rzeszów Foothills. Among these, the complex of LBK sites in the Dunajec basin stands out, as most distant from settlement centres. The sites also represent a different settlement system than clusters uncovered in the upland areas: the sites are mostly located in the highest points in local topography and show a higher degree of centralisation. This study aims to include chronological data to the analysis of changes in this settlement system, with the use of a collection of radiocarbon data from the LBK sites in the foothills area of SE Poland. The general model of a probability distribution for the phenomenon was constructed and confronted with the data from individual sites from the Wiśnicz Foothills region. On this basis, a spatiotemporal simulation was performed, to illustrate changes in the settlement network changes over six centuries of the LBK activity. Additionally, regions threatened with higher erosion possibilities were identified, in which possible archaeological traces were not preserved. According to the known distribution of sites in space, these regions were populated with semi-randomly generated sites to perform a second simulation. While the available data allow only limited insight into the problem of settlement system changes over time, the approach used in the study seems to be relatively robust in visualising and identifying general patterns of this phenomenon. It provides an interesting exploratory method, allowing the formulation of further research questions concerning the changes in the LBK settlement system in the foothills area.

KEYWORDS
Linear Pottery Culture, Neolithic, Settlement Patterns, Spatial Simulations, Carpathian foothills

I. INTRODUCTION

A few decades after the pioneering studies by Paweł Valde-Nowak, and subsequent studies covering the foothills area of the Northern Carpathian region it is now clear, that this zone was an important part of ecumene of the Linear Pottery Culture (LBK; Valde-Nowak 1988). The core areas of settlement consist of loess uplands of central Europe. The LBK materials are sometimes found outside of this zones, suggesting some level of exploration, and exploitation of other landscape zones (Kozłowski, Nowak 2019, 61-63 – there older literature). Multiple sites associated with this archaeological formation can be found near the Raba basin in region of Wieliczka and Bochnia, as well as in the Rzeszów and Przemyśl Foothills (Fig. 1, Czekaj-Zastawny 2008, 111-112 and Map 1; Pelisiak 2018: 32, 71). In the other areas of LBK, the foothill landscape was also settled, as can be seen in Altenburg Land (Cappenberg 2020: 259, fig. 2). Among the clusters of sites from the upper Vistula River Basin, the complex in the Dunajec basin stands out as most distant from settlement "centres", but seemingly less extreme than area of the Poprad Valley, where traces of LBK were also found (e.g. Soják 2000). Analysed area can in fact be understood as natural extension of the loess upland habitat (Valde-Nowak 2020, 173). Nonetheless, settlements of the Wiśnicz Foothills represent slightly different settlement system than clusters uncovered in the upland areas: the sites are mostly localized in the highest points in local topography and show a higher degree of centralization (Kukułka 2001; Czekaj-Zastawny 2008; Valde-Nowak 2009, Czekaj-Zastawny *et al*. 2020). Up to this point, only sites in Biesiadki 16 (no traces of houses), Łoniowa (traces of 1 house – see Table 1 for list of LBK sites) 18, Gwoździec 2 (traces of 4 houses) and Żerków 1 (no traces of houses) have been excavated (Czekaj-Zastawny *et al*. 2021; Kalita *et al*. 2016; Valde-Nowak 2009). The spatial aspects of this settlement system, concerning the distribution of sites in relation to natural factors such as soil types, slopes, insolation and water channels had already been explored on a few occasions (e.g. Cappenberg 2014, 2020; Oberc, Jędrysik 2021). This study aims to include chronological data to the analysis of this settlement system. As direct chronometric measurements are unevenly distributed among sites, the general chronology

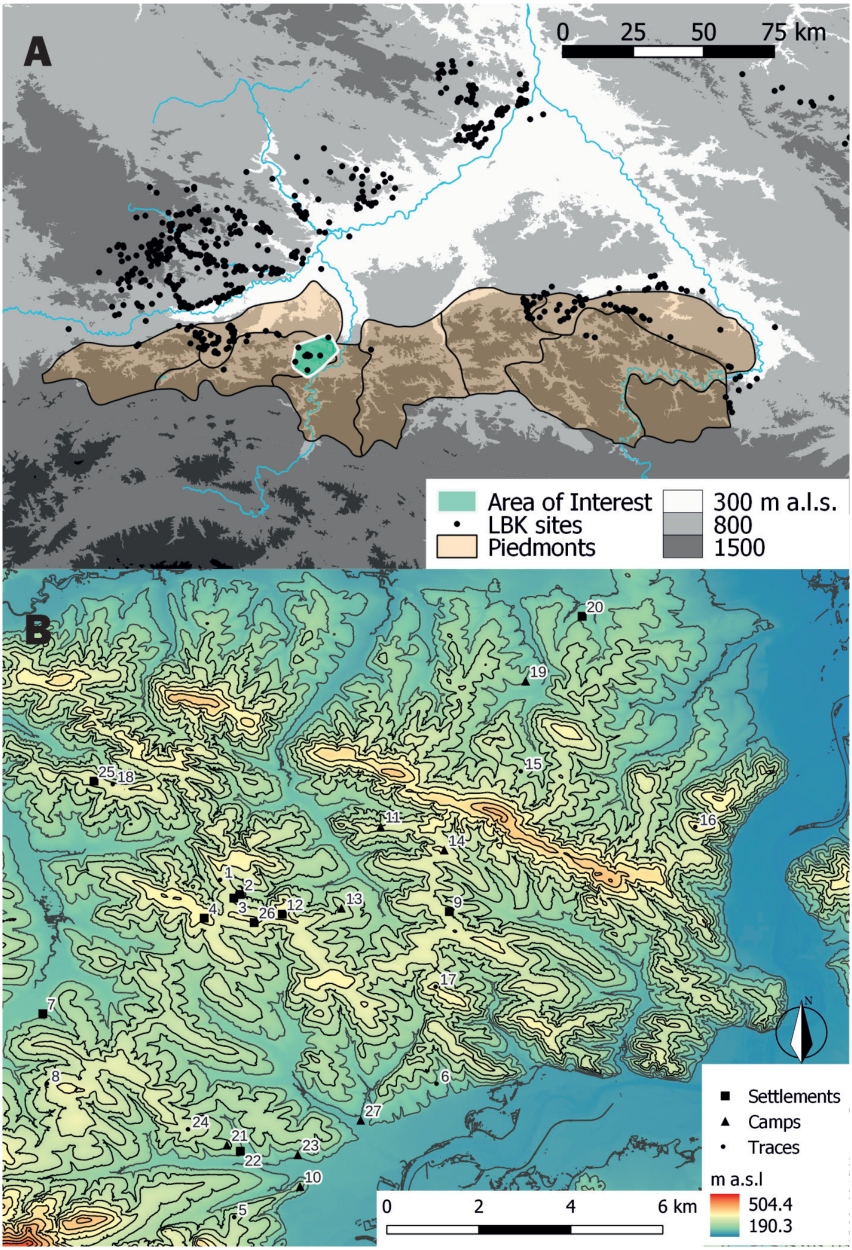

FIG. 1. A: Localisation of area of interest against the background of the LBK ecumene in SE Poland (After Czekaj-Zastawny 2008, map 1 with changes). B: Localisation of sites in the eastern part of the Wiśnicz Foothills region (after Polish Archaeological Record, functions after Czekaj-Zastawny 2008; see Table 1)

of LBK settlements in the foothills' belt needs to be established. Moreover, a picture of this settlement network is disturbed by the presence of patches of land devoid of traces of Neolithic activity, and with a high potential of erosion. Therefore, additional procedures have been conducted to outline these areas to populate it with potential archaeological sites. This has allowed to repeat a simulation of spatiotemporal activity in the Eastern part of Wiśnicz Foothills area in the era of LBK to compare with previous results.

Chronological model: data and assumptions

To reconstruct changes of the LBK settlement patterns in time, a fuzzy logic approach has been used, based on the probability distributions of radiocarbon dates in consecutive centuries (cf. Nakoinz 2012 for fuzzy logic approach; Shennan *et al.* 2013, Tompson *et al.* 2014 for using radiocarbon data as archaeological proxy). First, a chronological model was built, based on 51 radiocarbon dates from LBK sites in foothills areas (Brzezie 17, Gwoździec 2, Targowisko 11, Łoniowa 18, Żerków 1, Zagórze 2 and Zwięczyca 3; Table 1 and Table 2). From these sites, chronometric determinations with standard deviation below 100 radiocarbon years were used. The model was developed in the Bchron package for R Language (BchronDensity; Haslett, Parnell 2008). The algorithm have been chosen over the OxCal Sum Calibration and KDE models due to its higher sensitivity to local peaks in probability distribution. As has been shown in previous studies, the relationship between the changes in pottery and absolute chronology are complex, especially in this area (Czekaj-Zastawny, Oberc 2021; Oberc, Czekaj-Zastawny, Rauba-Bukowska 2022). Therefore, relative chronology based on pottery stylistics was not employed in this analysis.

Recent chronological models of LBK suggest, that it likely appeared in the Northern Carpathian region around or after 5400 BC (Jakucs *et al.* 2016, Kozłowski, Nowak 2019). Although the resulting probability extends up to the date 4500 BC (Fig. 2, red), a comparison with a radiocarbon date from the feature of Malice culture (MLC) from Łoniowa 18 (Valde-Nowak 2009: 23, Tab 1, sample Ło 1 = Poz-15978; Fig. 2, blue) and the analysis of the LBK dates from Wiśnicz Foothills suggest a low probability of a LBK activity in the area later than 5000 BC (Czekaj-Zastawny, Oberc 2021). Therefore, some radiocarbon determinations from Brzezie 17 and Gwoździec 2 have been excluded, according to the remarks made previously on the subject (Czekaj-Zastawny, Oberc 2021; Oberc, Czekaj-Zastawny, Rauba-Bukowska 2022). The modelling of the decline

TABLE 1. Settlements, camps and traces of activity in study area

No.	AZP Code	Site Name	Function (after Czekaj-Zastawny 2008)
1	106-63/57	Biesiadki 11	Trace
2	106-63/58	Biesiadki 12	Settlement
3	106-63/59	Biesiadki 13	Settlement
4	106-63/62	Biesiadki 16	Settlement
5	107-63/38	Czchów 10	Trace
6	106-64/21	Faliszowice 1	Trace
7	106-63/4	Gnojnik 4	Settlement
8	106-63/14	Gosprzydowa 6	Trace
9	106-64/27	Gwoździec 2	Settlement
10	107-63/73	Jurków 5	Camp
11	105-64/5	Łoniowa 1	Camp
12	106-63/80	Łoniowa 18	Settlement
13	106-63/85	Łoniowa 23	Camp
14	105-64/25	Łoniowa 8	Camp
15	105-64/77	Łysa Góra 38	Trace
16	105-64/213	Milówka 12	Trace
17	106-64/18	Niedźwiedza 10	Trace
18	105-63/29	Okocim 7	Trace
19	105-64/52	Sufczyn 25	Camp
20	105-64/97	Sufczyn 32	Settlement
21	107-63/40	Tworkowa 16	Camp
22	107-63/43	Tworkowa 19	Settlement
23	107-63/86	Tworkowa 39	Camp
24	107-63/20	Tworkowa 4	Trace
25	105-63/28	Uszew 19	Settlement
26	106-63/65	Żerków 1	Settlement
27	107-63/107	Złota 7	Camp

of LBK, as well as its internal periodisation are highly affected by the shape of calibration curve, consisting of two subsequent plateaus in the analysed period (Fig. 3). Therefore, a produced Bayesian model should be understood more as a consistency check for the remaining radiocarbon determinations on the basis on data frequency. Resulting start boundary agrees with the finding from the Lesser Poland, as well as with data concerning expansion of LBK

TABLE 2. Radiocarbon dates included in the study (grey – data included in final chronological model; after Oberc, Czekaj-Zastawny and Rauba-Bukowska 2022, Tab. 1)

No.	Sample Code	Site	Feature	Lab Code	BP	Std	Sampled Material	References
1	Brz_ 17/?-2	Brzezie 17	?	Poz-47715	6170	40	foodcrust residue on pottery	Czekaj-Zastawny 2014: 94
2	Brz_ 17/158/B	Brzezie 17	feat. 158/B	Ki(Kiev)-11290	5780	70	charcoal	Czekaj-Zastawny 2008: Tab. 1
3	Brz_ 17/216/B	Brzezie 17	feat. 216/B	Ki(Kiev)-11295	5640	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
4	Brz_ 17/2170-1	Brzezie 17	feat. 2170 (house XVIII)	Poz-39841	6170	40	charcoal	Czekaj-Zastawny 2014: Tab. XI
5	Brz_ 17/2175-1	Brzezie 17	feat. 2175 (house XVIII)	Poz-39485	6140	40	charcoal	Czekaj-Zastawny 2014: Tab. XI
6	Brz_ 17/2183-1	Brzezie 17	feat. 2183 (house XVIII)	Poz-39484	6070	40	charcoal	Czekaj-Zastawny 2014: Tab. XI
7	Brz_ 17/2186-2	Brzezie 17	feat. 2186 (house XVIII)	Poz-39483	6090	40	charcoal	Czekaj-Zastawny 2014: Tab. XI
8	Brz_ 17/238/C-1	Brzezie 17	feat. 238/C	Ki(Kiev)-11286	6215	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
9	Brz_ 17/238/C-2	Brzezie 17	feat. 238/C	Ki(Kiev)-11287	6180	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
10	Brz_ 17/238/C-3	Brzezie 17	feat. 238/C	Ki(Kiev)-11291	6140	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
11	Brz_ 17/238/C-4	Brzezie 17	feat. 238/C	Ki(Kiev)-11293	5720	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
12	Brz_ 17/238/C-5	Brzezie 17	feat. 238/C	Ki(Kiev)-11297	5660	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
13	Brz_ 17/2464/A	Brzezie 17	feat. 2464/A	Poz-47716	6200	40	foodcrust residue on pottery	Czekaj-Zastawny 2014: 94
14	Brz_ 17/317/B-1	Brzezie 17	feat. 317/B	Ki(Kiev)-11298	6260	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
15	Brz_ 17/317/B-2	Brzezie 17	feat. 317/B	Ki(Kiev)-11288	6130	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
16	Brz_ 17/317/B-3	Brzezie 17	feat. 317/B	Ki(Kiev)-11292	5840	70	charcoal	Czekaj-Zastawny 2008: Tab. 1
17	Brz_ 17/377/A	Brzezie 17	feat. 377/A	Ki(Kiev)-11296	6190	70	charcoal	Czekaj-Zastawny 2008: Tab. 1

cont. Table 2

cont. Table 2

No.	Sample Code	Site	Feature	Lab Code	BP	Std	Sampled Material	References
18	Brz_ 17/499/B	Brzezie 17	feat. 499/B	Ki(Kiev)-11289	5830	80	charcoal	Czekaj-Zastawny 2008: Tab. 1
19	Brz_ 17/samp. 8066	Brzezie 17	Sample 8066	Poz-73759	6270	50	Tritucum dicoccon	Muller-Bieniek *et al*. 2019
20	Gwo_c 2/10	Gwoździec 2	feat. 10	Poz-47948	6540	90	plant remains	Czekaj-Zastawny, Oberc 2021, Tab. 45
21	Gwo_c 2/102	Gwoździec 2	feat. 102	Poz-111652	6195	35	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
22	Gwo_c 2/108-1	Gwoździec 2	feat. 108	Poz-86052	6340	40	charcoal	Czekaj-Zastawny, Oberc 2021, Tab. 45
23	Gwo_c 2/108-2	Gwoździec 2	feat. 108	Poz-86053	6340	40	cerealia (charcoal?)	Czekaj-Zastawny, Oberc 2021, Tab. 45
24	Gwo_c 2/120	Gwoździec 2	feat. 120	Poz-111651	6230	40	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
25	Gwo_c 2/125	Gwoździec 2	feat. 125	Poz-111654	6270	50	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
26	Gwo_c 2/1-3	Gwoździec 2	feat. 1	Poz-73758	6310	40	Tritucum dicoccon	Muller-Bieniek *et al*. 2019
27	Gwo_c 2/130-1	Gwoździec 2	feat. 130	Poz-96580	6240	40	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
28	Gwo_c 2/130-2	Gwoździec 2	feat. 130	Poz-96581	6120	50	charcoal (Tilia sp.)	Czekaj-Zastawny, Oberc 2021, Tab. 45
29	Gwo_c 2/135-1	Gwoździec 2	feat. 135	Poz-96585	6300	40	foodcrust residue on pottery	Czekaj-Zastawny, Oberc 2021, Tab. 45
30	Gwo_c 2/135-2	Gwoździec 2	feat. 135	Poz-96582	6280	50	cariopsis (Bromus sp.)	Czekaj-Zastawny, Oberc 2021, Tab. 45
31	Gwo_c 2/137-1	Gwoździec 2	feat. 137	Poz-96583	6190	40	cariopsis (Triticum dicoc-cum)/charcoal	Czekaj-Zastawny, Oberc 2021, Tab. 45
32	Gwo_c 2/137-2	Gwoździec 2	feat. 137	Poz-111849	6190	40	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
33	Gwo_c 2/155	Gwoździec 2	feat. 155	Poz-112628	6170	40	charcoal (Corylus Avellana)	Czekaj-Zastawny, Oberc 2021, Tab. 45
34	Gwo_c 2/156	Gwoździec 2	feat. 156	Poz-112629	6200	40	charred wood (Corylus Avellana)	Czekaj-Zastawny, Oberc 2021, Tab. 45
35	Gwo_c 2/162	Gwoździec 2	feat. 162	Poz-111891	6150	40	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
36	Gwo_c 2/164	Gwoździec 2	feat. 164	Poz-111659	6170	40	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45

No.	Sample Code	Site	Feature	Lab Code	BP	Std	Sampled Material	References
37	Gwo_c 2/165	Gwoździec 2	feat. 165	Poz-111660	6190	40	cariopsis (Triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
38	Gwo_c 2/23-1	Gwoździec 2	feat. 23	Ki-13642	6330	60	charcoal	Czekaj-Zastawny, Oberc 2021, Tab. 45
39	Gwo_c 2/23-2	Gwoździec 2	feat. 23	Ki-13645	6270	60	charcoal	Czekaj-Zastawny, Oberc 2021, Tab. 45
40	Gwo_c 2/24-1	Gwoździec 2	feat. 24	Ki-13644	6290	60	charcoal	Czekaj-Zastawny, Oberc 2021, Tab. 45
41	Gwo_c 2/24-2	Gwoździec 2	feat. 24	Ki-13643	6240	60	charcoal	Czekaj-Zastawny, Oberc 2021, Tab. 45
42	Gwo_c 2/90	Gwoździec 2	feat. 90	Poz-111658	6300	40	charcoal (Corylus Avellana)	Czekaj-Zastawny, Oberc 2021, Tab. 45
43	Gwo_c 2/91	Gwoździec 2	feat. 91	Poz-86054	6190	35	charcoal (Quercus)	Czekaj-Zastawny, Oberc 2021, Tab. 45
44	Gwo_c 2/96	Gwoździec 2	feat. 96	Poz-86056	6180	40	Fraxinus (charcoal?)	Czekaj-Zastawny, Oberc 2021, Tab. 45
45	Gwo_c 2/CL_I	Gwoździec 2	Cultural Layer I	Poz-111653	6270	40	glimae (triticum dicoccum)	Czekaj-Zastawny, Oberc 2021, Tab. 45
46	Łon_ 18/111	Łoniowa 18	feat. 111	Poz-15982	6230	40	?	Valde-Nowak 2009: Tab. 1.
47	Łon_ 18/23	Łoniowa 18	feat. 23	Poz-15979	6220	40	?	Valde-Nowak 2009: Tab. 1.
48	Łon_ 18/88	Łoniowa 18	feat. 88	Poz-15981	6340	40	?	Valde-Nowak 2009: Tab. 1.
49	Żer_w 1/21/06	Żerków 1	feat. 21/06	Poz-18662	6210	40	?	Valde-Nowak 2009: Tab. 1.
50	Zwi_a 3/36-1	Zwięczyca 3	feat. 36	Poz-16475	6240	40	?	Czekaj-Zastawny 2008: Tab. 1
51	Zwi_a 3/36-2	Zwięczyca 3	feat. 36	Poz-16477	6170	40	?	Czekaj-Zastawny 2008: Tab. 1

Table 2

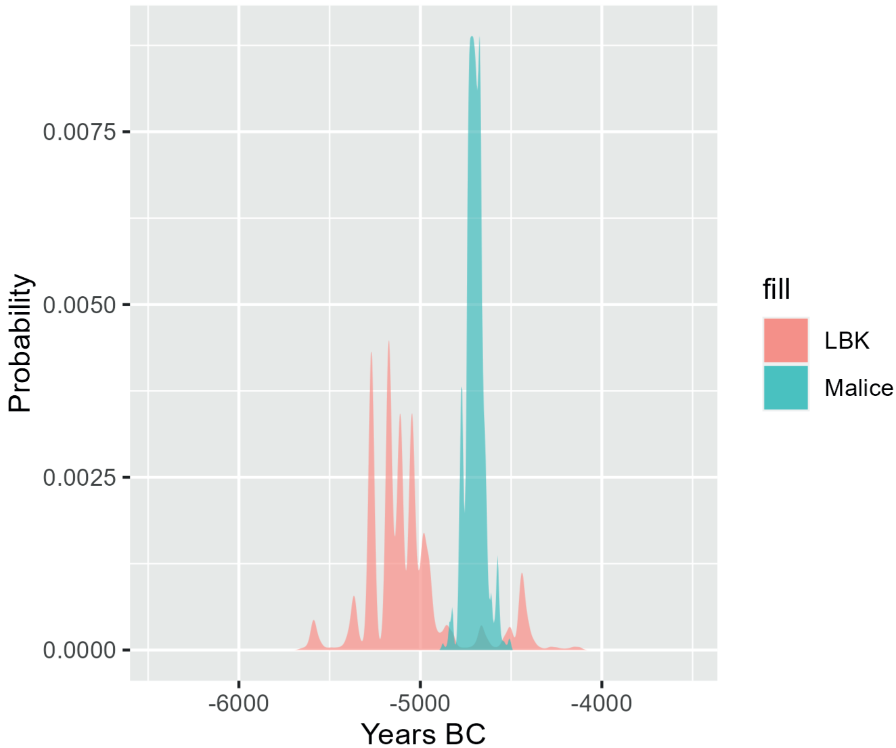

FIG. 2. A plot presenting raw chronological model of LBK in the foothills area (red) against the calibration of a radiocarbon dating MLC (Łoniowa 18)

(see Jakucs *et al.* 2016; Kozłowski, Nowak 2019: 45, Stadler, Kotova 2019, 237, Tab. 14.8). The end boundary is the more complicated problem. Exclusion from the model some of the late determinations from Brzezie 17 set an decline of the LBK settlement system a bit earlier, than is generally agreed upon (comp. Oberc, Czekaj-Zastawny, Rauba-Bukowska 2022). At the same time, because the presence of pottery associated with subsequent Lengyel-Polgar Circle (L-PC) has been previously confirmed in this area (Valde-Nowak 2020; 2022), the question of the mode of cultural change in this area arises. The later archaeological cultures are, however, represented by only singular radiocarbon determination, as mentioned above, hindering the possibility of simulating this process in the same way. Therefore, the date 4800 BC, representing the beginning of the main probability distribution peak of MLC dating from Łoniowa 18, has been used as a *terminus ante quem* for LBK activity.

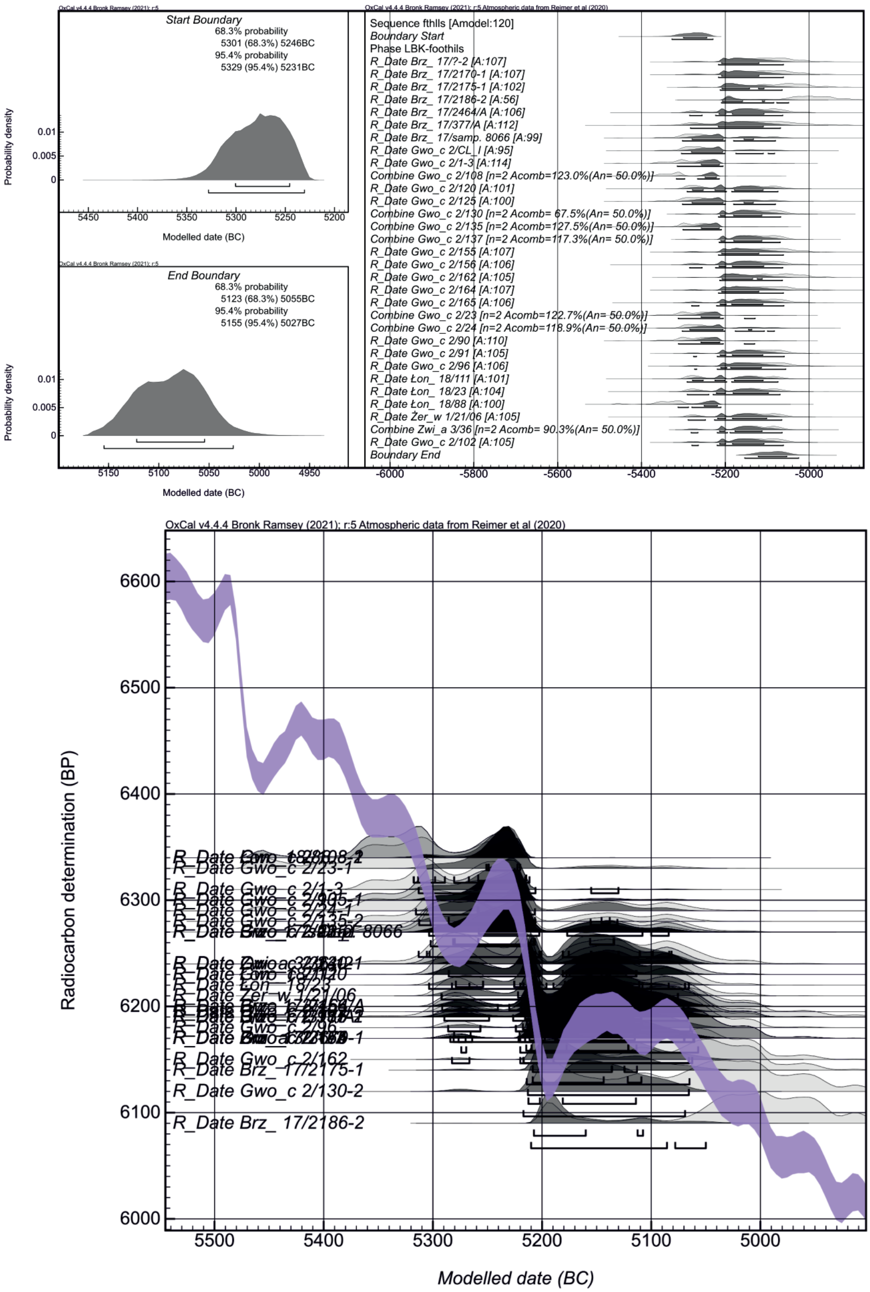

FIG. 3. Calibration and an outcome of radiocarbon data modeling used in the simulations

According to these assumptions, the distribution of the probability was therefore remodelled and normalised to the period between 5400-4800 BC and binned into 100-year ranges. The span of 100 years allow to see general changes in occupation without including too much of possible errors generated by the calibration and modelling process (such as effects of a shape of the calibration curve on the outcome). Sites in Gwoździec, Łoniowa, and Żerków (Table 1 and Fig. 1B: 9, 12 and 26) were given unique distributions, based on the dates obtained from the sites (Fig. 4). In the case of Gwoździec, a distribution has been calculated on the basis start and end boundaries resulting from Bayesian modelling of occupation of the site (Czekaj-Zastawny, Oberc 2021: 326, Fig. 179), resulting in certainty (within given assumptions) of being active in 53rd century BC.

The Spatiotemporal simulation of occupation and Dynamic LBK Settlement Network.

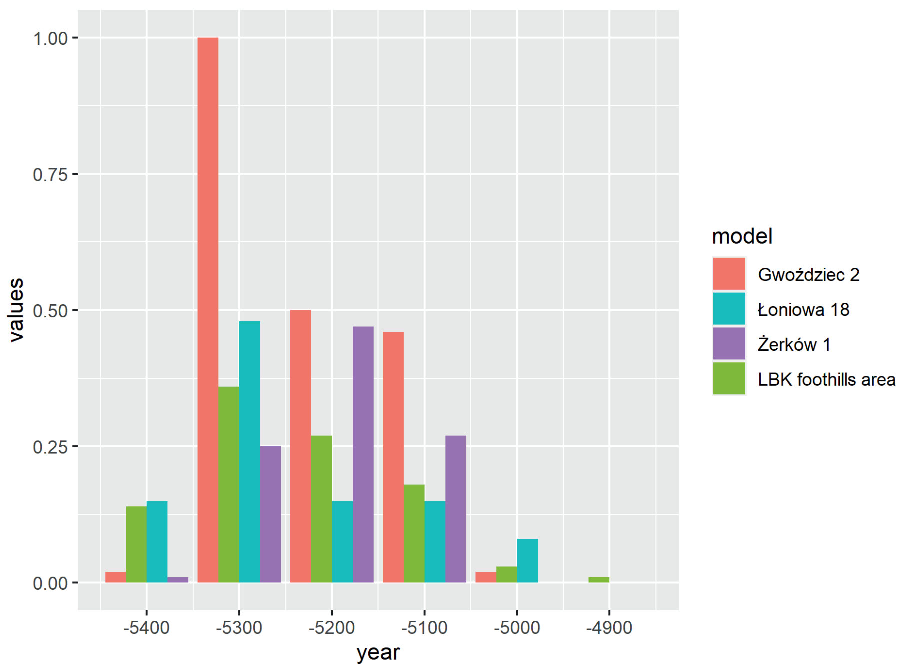

FIG. 4. A column plot of the binned probability distribution from the LBK sites in the easter Wiśnicz Foothills area, and normalised model of LBK in from foothills area

The results are presented in the form of heatmaps produced by the spatial Kernel Density Estimation module of QGIS. The radius parameter was set to 4 km, derived from the generalised results of anisotropic cost of movement estimation (*r.walk* algorithm in GRASS 7; Franceschetti *et al*. 2004), set for all sites identified as LBK settlements, with a limit of 1 hour of movement. In addition to using DEM as an input TWI (Topographic Wetness Index) raster layer, weighed as 1/10 of the original value, was used as an additional (friction) cost representing potential bodies of water. The resulting distances of such a walk simulation set the boundaries of mostly used areas around 4 km from settlements. It is worth noting, that usually a figure of 5 km is used to represent an outline of activity area for Neolithic settlement (also derived from a supposed 1-hour long stride; comp. Vita-Finzi *et al*. 1970). The exact value was probably modified by the vegetation, outline of fields, maintained paths and other factors, that are difficult to include in the simple simulation. The modelled binned probability distribution for each century between 5400 and 4800 BC was used as a weight for the heatmaps, and the rest of the parameters were set on default. The resulting images should therefore be understood as a spatial distribution of the most likely used areas in a given century. Although in the data from the Polish Archaeological Record and other studies of the area, the sites are divided between different functional classes (settlements, camps, trace of activity), the basis for this distinction is mostly the number of finds in the field survey. Only four of the LBK sites have been excavated (settlements), and there is almost no representation of what an LBK camp should be in this area (comp. Czekaj-Zastawny 2008: 76-80). Therefore, no additional weights have been added to represent this distinction, and simulated activity should be understood in a broad sense as a usage of this area for permanent (?) presence of occupation and agricultural and other activities, as evidences from excavated sites show.

The network model was constructed to narrow down previous results to the individual clusters of sites, represented by those identified as settlements (both excavated and during field surveys). It is assume, that the settlements with higher scores were more likely to be used simultaneously within one century. To simulate this, the shortest path algorithm was used on the down-sampled cost raster produced by *r.walk* algorithm. A score of "importance" of every path between settlements was calculated as mean values of binned probability distributions assigned to its start and end points in a given century and divided by log10 of the total calculated movement cost. This measure represents the idea, that settlers were more likely to interact with closer than more distant neighbours. Technically, in the case of binned probability distributions drawn from the same chronological model for multiple sites, this scoring system is a mean of the diversification of outcomes. In the broader theoretical sense, an "organic", rather than planned growth of the settlement network is assumed for LBK societies.

The resulting picture shows, that the central cluster of Biesiadki-Łoniowa-Żerków sites (Fig. 1B: 2-4, 12, 26) possibly was established as early as in the 54th century BC (Fig. 5). Of all the connections between the settlements, the 10 with the highest scores are localised between these sites (excluding Żerków). These top score values are in range 0.35-0.64. In the following century, the eastern cluster seems to host some part of overall activity, with a possible tertiary role of the southern one. In this case, the ten paths with highest score connect the central cluster (with visibly higher values in range 1.26-1.64; again, excluding the site in Żerków) with the settlement in Gwoździec (Fig. 1B: 9) with the central cluster, and in subsequent highest scores with other peripheral sites. In the 52nd century BC, the network is more balanced, with lesser differences between "peripheral-peripheral" and "peripheral-central" connections. At the same time, most of the activity is still associated with the central cluster, with a lesser role of the eastern part. Intensification is seen in the southern sub-cluster – the region of Tworkowa 19 (Fig. 1B: 22). Top connection scores are in range 0.93-1.23. In the 51st century BC, the network is visibly sparser, characterised by generally lower scores of connections; the ten highest scores are in range 0.61-0.82. The relatively high probability of activity of sites in Gwoździec and Żerków against the general distribution sets the central and eastern parts as a focus of LBK activity. On the other hand, a relatively high concentration of sites in the region of Tworkowa (mostly identified as camps) also sets this area apart. The whole system slowly fades throughout the next two centuries, what can be illustrated by the low values of top connectivity scores. For 50th century they are in range 0.11-0.14, and for 49th 0.02-0.05.

The erosion and "missing" sites

The second aim of the study was to estimate the effect of soil erosion on the observed network. The problem has been shown for example during analysis of finds from Gwoździec (Kukułka 2001, Kenig, Oberc, Kotula 2021). As a measure of the susceptibility of the area to erosion, LS-Factor was used (a measure of length and steepness of slopes; see Panagos *et al.* 2015). Most analysed sites have been found in areas of relatively low values (Fig. 6A).

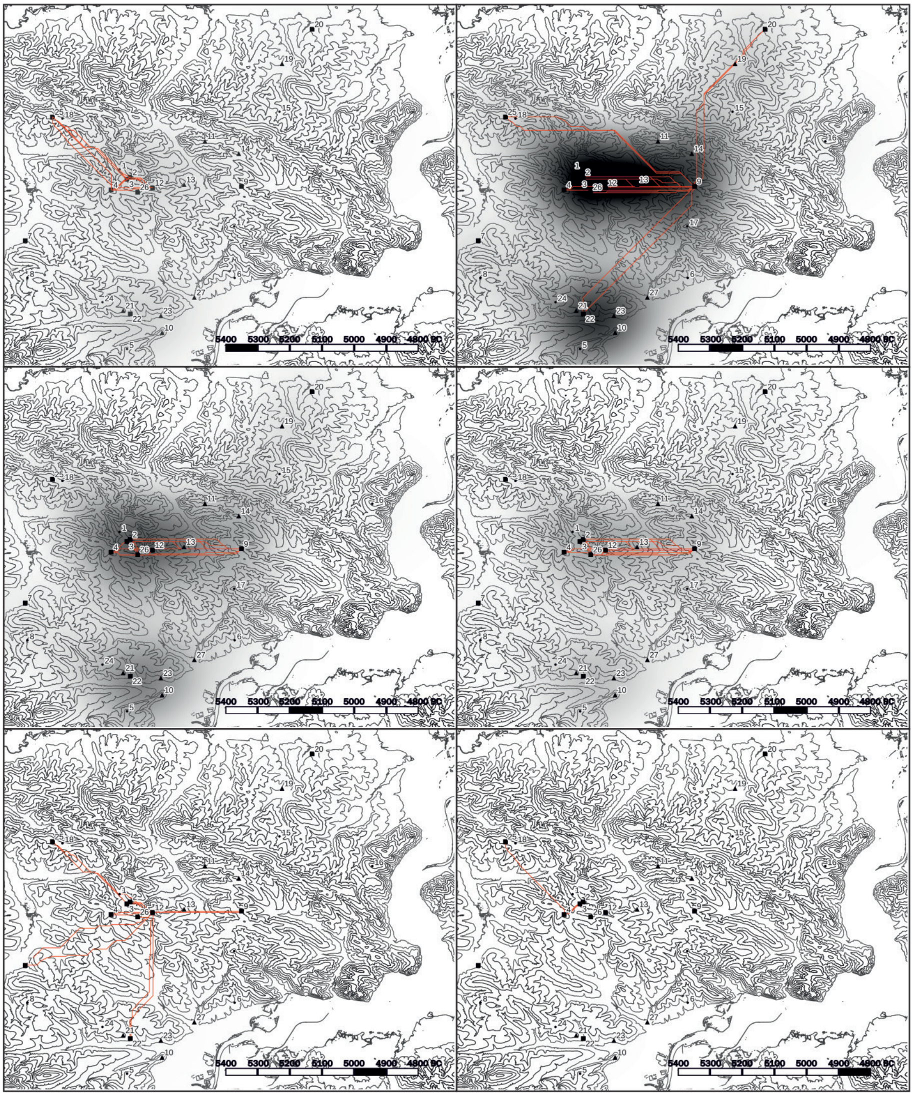

FIG. 5. An output of spatiotemporal simulation of LBK activity. The underlying heatmap shows the spatial density of potential activity (uniform white-black scale for each century BC). Overlying network shows 10 highest scores of connection between LBK settlements One frame represents one century between 5400 and 4800 BC; see text for detailed explanation and scores

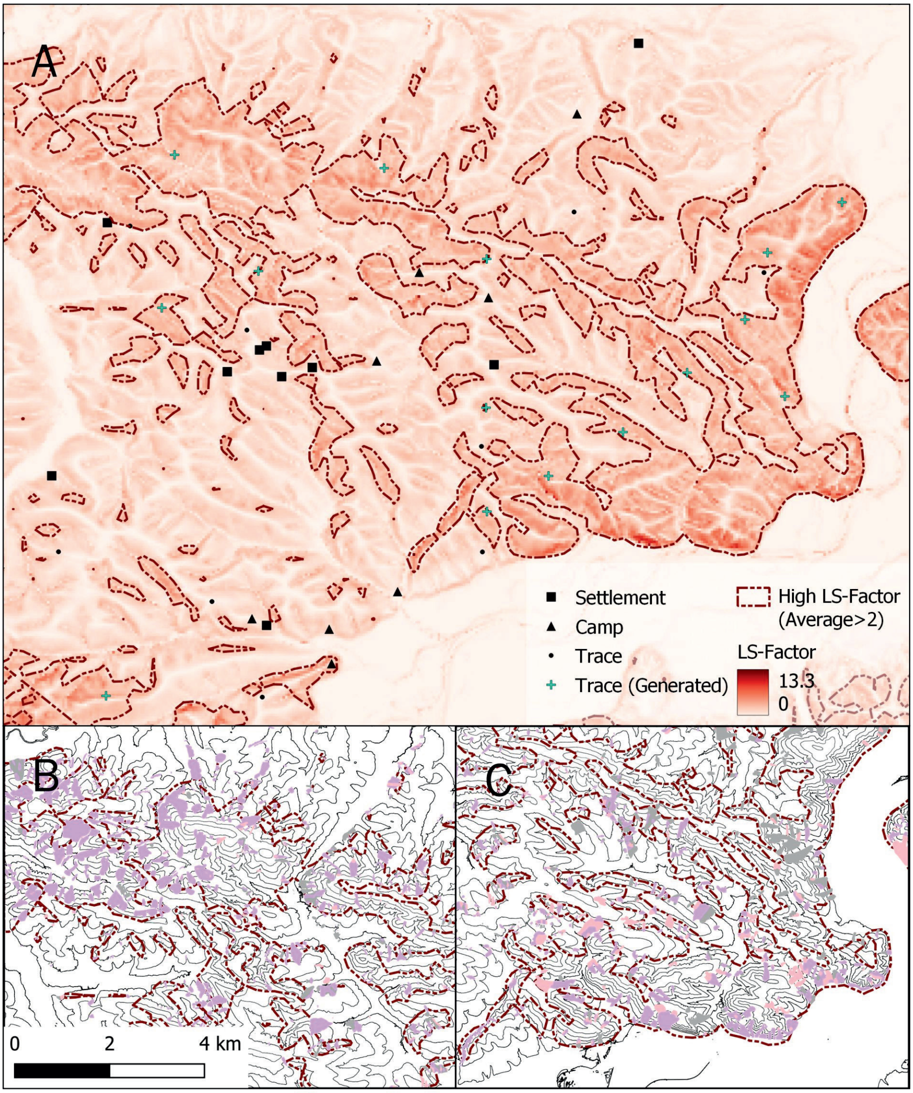

FIG. 6. A: the eastern part of the Wiśnicz Foothills with outlined regions of the high LS factor (A), localisation of archaeological sites and randomly generated potential sites (cyan crosses). B and C: north-western and the eastern part of the area of study with outlined regions of high LS factor and localisation of recorded landslides (source of data: Osuwiska I tereny zagrożone ruchami masowymi – WMS)

The cited study shows, that countries considered as "mountainous", are characterised by mean LS-factors value higher than 3. In the study with use of predictive modelling of archaeological traces in the upper Odra basin, sites of linear pottery cultures (there combined LBK and subsequent Stroke Ornamented Ware Culture) were mostly localised in the low (<1) LS-factor areas (Łuczak 2018: 247, Ryc. 17). These results were cited as significant for occupation in MaxEnt modelling (Łuczak 2018: 239, Tab. 5). The highest recorded value equals 3,3 in raster of 30 m x 30 m pixel size. In the case of Wiśnicz Foothills, in which values of LS-factor ranged locally up well above 10, the value of cut-off has been set to 2 for simulation process, as higher values occur only on the limited patches. Moreover, to generalise the picture, these values have been observed on the averaged LS-factor raster down sampled to the 50 m x 50 m mean cells. This generalisation is needed, as the raw values tend to show individual local slopes, that might be formed recently, such as outlines of plough fields and other recent changes. The exact used values of LS-factor and pixel size are therefore arbitrary, and they should be tested on the bigger sample of settlement microregions.

Noticeably, this boundary encloses only one of 27 known LBK sites. Conversely, it correlates closely with the recorded landslides (Fig. 6B and C). Unfortunately, as more sophisticated predictive modelling of archaeological sites relies heavily on data derived from the landform (slopes, aspects, relative altitudes, insolation, visibility or TWI used before), the environmental factors characterising known LBK sites do not provide an reliable comparison in this situation. Instead, a simple approach has been used to accommodate for potentially missing sites. Based on density and mean minimal distance between known LBK sites in low LS-Factor areas, sixteen new points were generated in semi-random locations within regions of high LS-Factor values. A second simulation of spatiotemporal density has been made, that included potential sites. In this case, the areas of the highest activity indicator have been outlined with the contour representing value 1 of the kernel density estimation (Fig. 7). The simulation ended in the year 5000 BC, due to diminished activity in the area after that date in the first simulation. It should be remembered that the scenario is based on the mean densities of known sites, and the actual distribution did not. Moreover, it did not account for an area of the Dunajec Valley, which, judging by the density of known sites in its vicinity, as well as good isolation and soil conditions, was likely to have been used at this time.

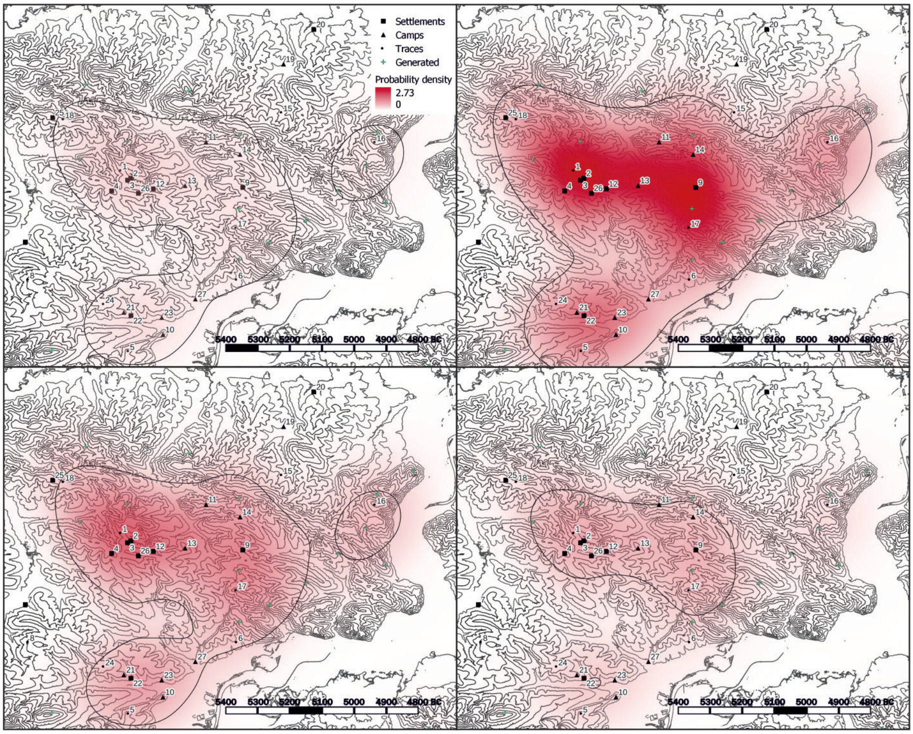

FIG. 7. An output of the spatiotemporal simulation of potential LBK activity between 5400 and 5000 BC, with included possible sites within high LS-factor areas (red scaled heatmap and an outline with uniform scale for each frame, an outline marks value 1)

II. GENERAL RESULTS

As both simulations have shown, in the present knowledge of the LBK settlement process in the eastern Wiśnicz Foothills, the central part of the area was likely settled first. This is represented by the early dates from Łoniowa and Gwoździec. Although in the view of the classical pottery stylistics development model, confirmation can be found only in the latter site (Czekaj-Zastawny, Oberc 2021).

Both simulations show the widest spread of the activity in 53rd century BC, concentrated in the central part and the southern part of analysed area. The results of the second simulation suggest, that at least similar intensity of settlement in the potential cluster of sites on the highly eroded, easternmost part of the Wiśnicz Foothills region, close to the site 12 in Milówka (Fig. 1B: 16).

At the same time, the Northern cluster, away from the dense activity centre, shows a similar degree of connectivity, as the other "peripheral" clusters. It suggests, that site 32 in Sufczyn (Fig. 1B: 20) might have been less isolated than it seems from the map overview. When the shifting of the weight of connections to the East – site 2 in Gwoździec and the other possible cluster mentioned – is considered, the existence of an active route to the Vistula Valley at this time seems even more likely. The 53rd century BC seems to be the peak of LBK activity in the area. The following century in both simulations shows lower overall activity but with a more homogenised settlement pattern. In the central cluster, the activity is still the highest, but the eastern and southern clusters seem to have a similar share. In the 51st century BC, all the clusters seem to be more isolated, and overall activity indicators are lower. According to the simulations, traces of activity of LBK settlers are most likely in this century to be found in the central part of the region and the southern cluster.

Unfortunately, data associated with other sites are not numerous. This absence is mostly visible in the case of sites Sufczyn 32 and Uszew 19 (Fig. 1B: 20 and 25), which seem to be positioned in the routes towards the central part of LBK ecumene in Lesser Poland. Given the lack of known LBK sites further to the south as far as the Poprad Valley, it seems likely that they played a major role in establishing LBK settlement network in this area. Furthermore a role in the system of the "cluster" of sites around Gnojnik 4 (Fig. 1B: 7) remains unknown.

III. SUMMARY

The LBK network in the analysed area was likely to have been dynamic one. As can be judged from the radiocarbon data, as well as archaeological material (e.g., composition of lithic raw materials with a high percentage of flints from Kraków-Czestochowa Upland and presence of obsidian and changes in pottery stylistics with the presence of ceramic imports/imitations; Kukułka 2001; Czekaj-Zastawny 2008; Valde-Nowak 2009; Wilczyński, Kufel-Diakowska 2021, Czekaj-Zastawny, Rauba-Bukowska, Kukułka 2021), communication between this and other settled regions was constantly maintained. The models presented, although they require further improvements, seem to add a new layer of understanding to this phenomenon. A process of organized (and perhaps rapid) colonization around 5300 BC, followed by gradual decentralisation over the following centuries, constitutes an intriguing hypothesis that should be tested on the wider sample of the regions. It would seem that the first colonisation of the new territory might have characteristics of mass movement, as has been pointed out by D. Hoffmann (2016). Furthermore, the later phases of occupation need more attention. The models presented, based on data from sites located closer to the centres of LBK ecumene, show a gradual dissapperance. This fact raises a question about the character of post-LBK occupation present in this area (Malice culture, Samborzec-Opatów and Pleszów-Modlnica groups). Unfortunately, more data from the area is needed to explore this problem.

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