Abhandlung

Arkadiusz Marciniak, Joanna Pyzel, Marta Krueger, Mikolaj Lisowski, Christopher Bronk Ramsey, Elaine Dunbar, Alistair Barclay, Alex Bayliss, Bisserka Gaydarska and Alasdair Whittle*

A history of the LBK in the central Polish lowlands

https://doi.org/10.1515/pz-2022-2041

Zusammenfassung: Eine neue chronologische Untersuchung der LBK in der zentralpolnischen Tiefebene zeigt, dass sie später entstand, kürzer dauerte und früher endete als bisher angenommen. LBK-Gemeinschaften entstanden wahrscheinlich Mitte des 53. Jahrhunderts cal BC in einer Enklave in der zentralpolnischen Tiefebene, wahrscheinlich als Ergebnis der Besiedlung von Lössgebieten im Süden Polens. Die Besiedlung intensivierte sich während des gesamten 52. Jahrhunderts v. Chr. und erreichte ihren Höhepunkt zu Beginn der Phase III. In der Mitte des 51. Jahrhunderts cal BC folgte ein abrupter Niedergang oder Zusammenbruch, die LBK-Besiedlung des Tieflandes war wahrscheinlich bis zum Ende dieses Jahrhunderts vollständig beendet. Es folgte eine nennenswerte Lücke bis zum Wiederaufleben der Besiedlung in Form der Late Band Pottery Culture (LBPC), die durch deutlich geringere Besiedlung, veränderte Wohnstrukturen und Kontakte zu Jäger-Sammler-Gruppen gekennzeichnet war. Ein Beginn der umfassenderen Aufgabe, die Situation im zentralpolnischen Tiefland mit anderen regionalen Sequenzen zu vergleichen, wird hauptsächlich durch die Überprüfung einer ähnlichen formalen Modellierung einer Post-LBK-Unterbrechung im Rheinland gemacht. Mögliche Faktoren, die den LBK-Rückgang verursachen, werden diskutiert, darunter ein Klimaumschwung, Bevölkerungswachstum und -rückgang, Kriegsführung, kulturelle Krisen, Krankheiten und interne soziale Konflikte.

Keine dieser Möglichkeiten ist für sich genommen vollkommen überzeugend, und eine der vielen Herausforderungen für die weitere Forschung im polnischen Tiefland und darüber hinaus wird darin bestehen, weitere spezifische Hinweise zu finden, um zu entscheiden, welche dieser Möglichkeiten in bestimmten Kontexten am plausibelsten ist.

Schlüsselwörter: Polnisches Tiefland, LBK-Gemeinschaften, formale chronologische Modellierung, Siedlungsentwicklung, Niedergang, Hiatus

Abstract: A new chronological study of the LBK in the central Polish lowlands shows that it emerged later, lasted for a shorter period, and ended sooner than has been supposed up till now. LBK communities emerged, probably in the middle of the 53rd century cal BC, to form an enclave in the central Polish lowlands, probably as a result of colonisation from loess areas in the south of Poland. Settlement steadily intensified throughout the 52nd century cal BC, reaching its peak at the beginning of Phase III. In the middle of the 51st century cal BC there followed an abrupt decline or collapse, and LBK occupation of the lowlands had probably ended completely by the end of that century.

***Corresponding author: Alasdair Whittle**, Department of Archaeology and Conservation, John Percival Building, Cardiff University, Colum Drive, Cardiff, CF10 3EU, United Kingdom.
E-Mail: whittle@cardiff.ac.uk
Arkadiusz Marciniak, Faculty of Archaeology, Adam Mickiewicz University, ul. Uniwersytetu Poznańskiego 7, 61–614 Poznań, Poland.
E-Mail: arekmar@amu.edu.pl
Joanna Pyzel, Institute of Archaeology and Ethnology, University of Gdańsk, ul. Bielańska 5, 80–851 Gdańsk, Poland.
E-Mail: joanna.pyzel@ug.edu.pl
Marta Krueger, Faculty of Archaeology, Adam Mickiewicz University, ul. Uniwersytetu Poznańskiego 7, 61–614 Poznań, Poland.
E-Mail: martabartkowiak86@wp.pl
Mikolaj Lisowski, Department of Archaeology, Environmental Building, Wentworth Way, University of York, York YO10 5NG, United Kingdom. E-Mail: mikloaj.lisowski@gmail.com
Christopher Bronk Ramsey, Oxford Radiocarbon Accelerator Unit, Research Laboratory for Archaeology and the History of Art, Dyson Perrins Building, University of Oxford, Oxford OX1 3QY, United Kingdom. E-Mail: christopher.ramsey@arch.ox.ac.uk
Elaine Dunbar, SUERC Radiocarbon Dating Laboratory, Scottish Enterprise Technology Park, Rankine Avenue, East Kilbride, G75 0QF, United Kingdom. E-Mail: Elaine.Dunbar@glasgow.ac.uk
Alistair Barclay, Cotswold Archaeology, Building 11, Cotswold Business Park, Cirencester, GL7 6BQ, United Kingdom.
E-Mail: Alistair.Barclay@cotswoldarchaeology.co.uk
Alex Bayliss, Historic England, Cannon Bridge House, 25 Dowgate Hill, London, EC4R 2YA, United Kingdom.
E-Mail: Alex.Bayliss@HistoricEngland.org.uk
Bisserka Gaydarska, Department of History, Politics and Philosophy, Manchester Metropolitan University, Geoffrey Manton Building, Rosamund Street West, Manchester M15 6EB, United Kingdom.
E-Mail: B.Gaydarska@mmu.ac.uk

There followed an appreciable gap before the re-emergence of settlement in the form of the Late Band Pottery culture (LBPC), characterised by significantly sparser settlement, changed dwelling structures and contacts with hunter-gatherer groups. A start to the wider task of comparing the situation in the central Polish lowlands with other regional sequences is made principally by reviewing similar formal modelling of a post-LBK hiatus in the Rhineland. Possible factors causing the LBK decline are discussed, including climatic downturn, population boom and bust, warfare, cultural malaise, disease and internal social conflict. None of these is overwhelmingly convincing on its own, and one of the many challenges for continuing research in the Polish lowlands and beyond will be to find further specific evidence to decide which of this range of possibilities is most plausible in specific contexts.

Keywords: Polish lowlands, LBK communities, formal chronological modelling, settlement development, decline, hiatus

The LBK and post-LBK in the central Polish lowlands

The character of LBK communities

The first Neolithic farmers in the Polish lowlands are represented by *Linearbandkeramik* (hereafter LBK) communities[1]. They occupied selected zones in the area, almost exclusively choosing fertile rich brown and black soils, such as found in Kujavia, Chełmno Land, the lower Vistula area and the Pyrzyce Land along the catchment of the lower Oder (Fig. 1). They tended to avoid areas occupied by Mesolithic hunter-gatherers[2], maintaining very limited contact with them.

Until very recently, the occupation of the Polish lowlands by LBK communities was often portrayed not only as distinctive but also largely unsuccessful in comparison with their counterparts in the loess areas in the south[3]. This was due to a lack of large and multi-generational settlements similar to those known from other LBK regions[4]. Now, however, thanks to recent rescue excavations relating to the construction of the A1 motorway in the western part of Kujavia, such big settlements have been recovered, for example at Ludwinowo 7[5], Smólsk 2/10[6] and Kruszyn 10[7]. Sufficient excavation has been carried out in this region to show that the early farmers here, just as across the LBK distribution as a whole, lived in stable settlements with typical large timber-framed houses[8]. As elsewhere, these LBK groups had a distinctive material culture including a diagnostic style of pottery and characteristic lithic artefacts.

Previous models of emergence, connections and development

The character of the movement of LBK communities into the lowlands and the rationale behind these developments have been intensively debated. Bogucki[9] argued that the insular character of the LBK occupation in the Polish lowlands may have been a result of environmental mapping, triggering some form of penetration and exploitation of hitherto unexplored areas. Pyzel[10] saw the spread of the Neolithic across central Europe as leapfrog colonisation. Earlier opinion was that LBK communities reached the Polish lowlands as early as 5500–5400 cal BC[11]. A more recent suggestion sets beginnings somewhat later, at around 5400–5300 cal BC[12]. Research in eastern Kujavia indicates that many settlements were inhabited from phase I/IIA of the local LBK ceramic typology (described below). The earliest settlements in the neighbouring Chełmno Land and the lower Vistula region also belong to this horizon[13]. These may indicate rapid colonisation of the lowlands during ceramic phase IIA[14], contradicting previous interpretations that postulate a long-lasting period of colonisation[15].

The specific place of origin for early LBK communities on the Lower Vistula River has been hard to pin down. A popular view has been that these groups originated from the uplands of Lesser Poland and probably also from Lower

1 Czerniak 1990; 1994; Grygiel 2004; Kirkowski 1990a; 1994; Kowalski 2003; Pyzel 2006; 2010.
2 Kukawka 1997, 78.
3 Grygiel 2004.
4 e.g. Grygiel 2004, 642.
5 Pyzel 2013; 2019.
6 Muzolf *et al.* 2012.
7 Płaza 2016.
8 Bickle/Whittle 2013, and references.
9 Bogucki 1988; 2000.
10 Pyzel 2010, 221–222.
11 Czerniak 1990; 1998; Milisauskas/Kruk 1989, 404; Pyzel 2006; 2010, 97.
12 Czerniak 2012.
13 Czerniak *et al.* 2016b.
14 Pyzel 2006, 37–40; 2010, 185–190.
15 e.g. Czerniak 1988; 1994.

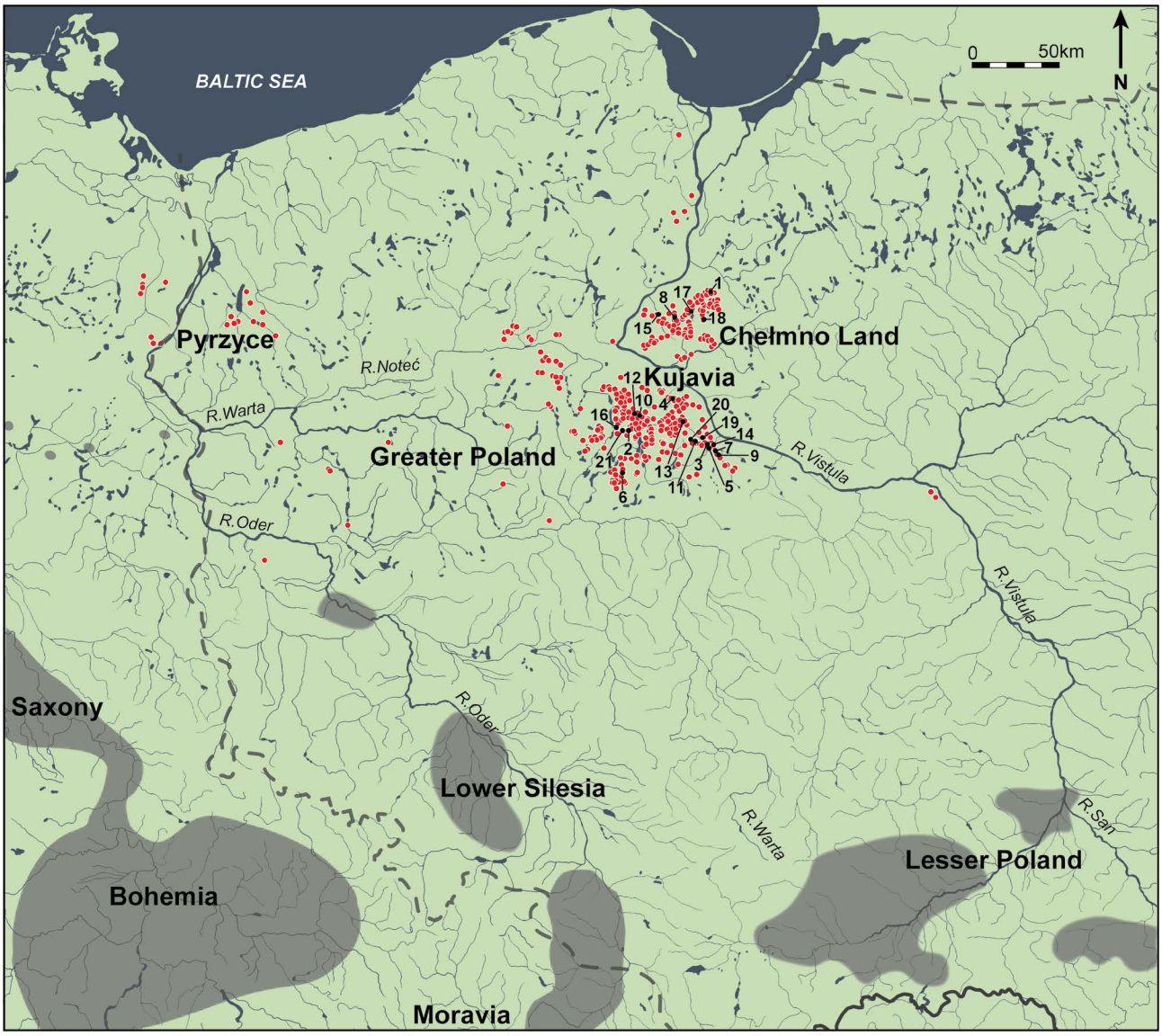

Fig. 1: LBK and post-LBK (LBPC) sites in the Polish lowlands (1. Boguszewo, site 41; 2. Bożejewice, site 22/23; 3. Brześć Kujawski, site 3; 4. Grabie, site 4; 5. Guźlin, site 2; 6 Kopydłowo, site 6; 7. Kruszyn, site 10; 8. Lisewo, site 31; 9. Ludwinowo, site 7; 10. Łojewo, site 1; 11. Miechowice, site 4 ; Miechowice, site 7; 13. Siniarzewo, site 1; 14. Smólsk, site 2/10 & 4; 15. Stolno, site 2; 16. Strzelce, site 2; 17. Wieldządz, site 31; 18. Wielkie Radowiska, site 24; 19. Wolica Nowa, site 1; 20. Zagajewice, site 1; 21. Żegotki site 2, 3 & 18).

Silesia[16]. They arguably reached selected enclaves of the Polish lowlands by moving northwards along the River Vistula, and a second route, established only slightly later, has been suggested either along the River Noteć or the River Warta[17]. While contacts with Lesser Poland seem to be dominant in earlier phases, these are seen as being slowly replaced by impacts or influences from the west and south-west. This is connected with the westwards movement of LBK groups, occupying different parts of western Kujavia and areas further to the west, as far as the lower Oder. As indicated by changes in material culture, it was argued that that process happened in the later part (in ceramic phases IIB and III) of LBK occupation in the lowlands[18].

The recognition of the place of origin of the incoming LBK groups into the lowlands and the location of their counterparts in the south, with whom they maintained active relations, has been thought to be traceable above all through the distinctive pottery and the procurement

16 Czerniak 1994, 117–118; Kozłowski 1988, 46; Kruk/Milisauskas 1999, 24–6; see also Czekaj-Zastawny *et al.* 2020.

17 Grygiel 2004, 641–642; Kabaciński 2010, 26.

18 Kowalski 2003; Pyzel 2006; 2010, 187.

of flint and stone implements. Various decorative motifs on Kujavian pots are seen as originating from southern Poland, Moravia or more generally from the eastern part of the LBK distribution[19]. Pottery from various Kujavian settlements exhibits Alföld and Bükk motifs of the eastern Linear Pottery tradition[20], in some cases accompanied by finds of obsidian artefacts[21]. It is unclear to what extent these motifs indicate the movement of people between these two zones of LBK occupation, and to what extent they reflect imitation or indeed other processes. In any scenario, however, they clearly indicate contacts between farming groups in the lowlands and in the uplands of Lesser Poland, which in turn facilitated contacts with communities further to the south and east.

The LBK communities in the central Polish lowlands mainly used high-quality flint originating from deposits in southern Poland. In the first period, they heavily relied upon the Cracow Jurassic flint, whose outcrops are located in the direct vicinity of large LBK settlements in Lesser Poland. During ceramic phases IIA and IIB the importance of the so-called chocolate flint increased, reaching almost 100 per cent in some assemblages in phase III[22]. This originates from the northern edges of the Holy Cross Mountains about 300 km south of Kujavia. The importance of Cracow Jurassic flint slightly increased in the final phase, though probably serving some kind of ceremonial rather than economic purpose. Its presence is indicative of the re-emergence of contacts with groups from Lesser Poland, which did not, however, translate into changes in pottery technology or style[23].

Intense contacts with the south are also documented by the importation of stone artefacts. Stone adzes found at numerous sites in Kujavia and in the lower valley of the river Oder are made of amphibolite, including actinolite-hornblende-schist, a raw material that originates in the Jizerské hory mountains in northern Bohemia, some 400 km south-west of Kujavia[24]. This type of stone adze is omnipresent across the entire LBK distribution[25], indicating the existence of vast communication networks.

The early LBK communities in the Polish lowlands have been seen as very homogeneous, and their subsequent development as steady and uninterrupted[26]. A large number of LBK settlements in Kujavia appeared in ceramic phase IIA. Their development has not been seen to accelerate through time and has been thought to have remained at the same level for a long time. A decreased dynamism of local groups is reported from ceramic phase III. It needs to be reiterated, however, that some potentially inhabitable areas in Kujavia and Chełmno Land remained unoccupied until the end of the LBK[27].

The current state of research on the end of the LBK and post-LBK communities in the Polish lowlands

LBK communities have been believed to have been present in the Polish lowlands until around 4900–4800 cal BC[28]. The period between 5000 and 4800–4700 cal BC has been defined as a transformation from LBK to post-LBK[29]. However, it now seems from detailed ceramic and other studies that the occupation of some large settlements in eastern Kujavia was coming to an end around the transition between ceramic phases IIB/III or at the beginning of phase III[30]. This had been supported by previous analysis of regional settlement density, which indicated a decline in the number of sites during ceramic phase III[31], although a different picture can now be presented for the density of features in this phase (Fig. 12), with decline coming only at the end of the period.

The wider question has been posed whether the ending of the LBK may be indicative of some kind of crisis, potentially caused by climatic changes from around 5100 cal BC[32] or triggered by other social and cultural factors[33]. By the end of the sixth millennium cal BC, LBK communities in Kujavia had a couple of centuries of existence behind them. They formed a relatively intensively occupied enclave consisting of settlements with longhouses and had a social organisation and subsistence economy not significantly different from their counterparts in the loess zone. LBK farmers were arguably organised at some kind of communal level. The basic social groupings might have comprised associations of neighbours, while individual houses were probably owned by individual families. Various productive, everyday and ceremonial activities

19 Pyzel 2006; 2010, 221–226.
20 Pyzel 2009.
21 Kabaciński *et al.* 2015.
22 Domańska 1988; 1995; Małecka-Kukawka 1992.
23 Pyzel/Wąs 2018.
24 Krystek *et al.* 2011; Szydłowski 2015.
25 Přichystal 2015.
26 Pyzel 2010.
27 Kirkowski 1994, 68; Pyzel 2006; 2010, 173.
28 Grygiel 2004, 523; Pyzel 2006; 2010, 97.
29 Czerniak 2012.
30 Muzolf *et al.* 2012.
31 Pyzel 2010, 185.
32 Gronenborn 2012; Grygiel 2004; Strien/Gronenborn 2005.
33 Boulestin/Coupey 2015; Spatz 2003; Zeeb-Lanz 2009.

may have taken place in and around multiple houses. These groups were strongly embedded in a traditional mode of life with what has been thought to have been a poor understanding of their newly inhabited areas[34].

The end of the LBK marks a period of disintegration of existing networks and relationships, reflecting significant changes in all domains of life across central Europe. The previously large settlements with solidly built rectangular longhouses were abandoned and replaced by smaller ones with small and unelaborated dwelling structures. Different parts of the Polish lowlands and uplands have been seen to have developed in diverse ways and at significantly different tempos. This has been particularly well manifested in distinct traditions of pottery manufacture, which have served as the foundation for distinguishing various cultural groups. Accordingly, the Late Band Pottery culture (LBPC) has been proposed for Kujavia and Greater Poland, the Stroked Band Pottery culture for western Pomerania and Lower Silesia, and the Malice culture for Lesser Poland. All these entities from the first half of the fifth millennium cal BC can be labelled as post-LBK cultures[35]. These correspond with the development of different post-LBK cultures across other parts of central Europe, such as *Stichbandkeramik* (SBK), Lengyel, Tisza-Herpály, Grossgartach and Rössen. One view for the Polish lowlands has been that such changes began around 4800 cal BC, immediately following the demise of the LBK[36].

Given the established character of the LBK occupation of the Polish lowlands, it has been thought hardly possible that LBK communities suddenly disappeared and were replaced by new groups. Czerniak[37] argued that it is impossible that they could have vanished without leaving any surviving groups who may have contributed to the development of successive communities. Hence, he has advocated continuity between the LBK and LBPC groups, supported, in his view, by a new wave of immigrants[38]. It does seem to be the case, however, that the earliest LBPC, which arguably corresponds to phases III/IVa–IVa of the SBK, definitely did not develop in Kujavia[39]. A different migration model has been proposed by Grygiel[40], who argued that the entire Kujavian LBK population migrated to the Saale basin towards the end of the sixth millennium cal BC because of unfavourable climatic changes. This includes the view that Kujavia was re-occupied only some 100–200 years later by new groups from Lower Silesia representing the Late SBK. The first half of the fifth millennium cal BC also marked the development of contacts with local hunter-gatherer groups and the establishment of new kinds of pan-regional contacts among post-LBK groups, as manifested by rondel enclosures for example[41].

Aims and approach of this study

The aim of this paper, part of the project *The Times of Their Lives* (see Acknowledgements), is to examine critically and refine these previous scenarios for the development of the LBK in the Polish lowlands and its aftermath, through a combination of formal chronological modelling and current knowledge of the relevant material culture. This is another example of how we can attempt to weave a strong cable from constituent strands of evidence[42]. In tandem with the objective of dating the trajectory of LBK and immediate post-LBK development in the Polish lowlands, our further, ultimate, aim is to relate our results from this region to the wider picture of the start, development and end of the LBK well beyond the Polish lowlands[43].

The Polish lowlands region is defined here as a set of enclaves occupied by the LBK farmers, namely Kujavia, Chełmno Land, the lower Vistula area and the Pyrzyce Land along the catchment of the lower Oder. Our initial objective had been to use the large-scale excavations of the site of Ludwinowo 7 as a case-study to explore alternative models of settlement organisation (that is, the *Hofplatzmodell* and the row model). It soon became clear, however, that, given the limited vertical stratigraphy, the poor preservation of bone collagen on the site, and the radiocarbon calibration curve in the expected age range, the large numbers of samples that would be needed to provide sufficient precision to be useful for resolving this debate were simply not available[44]. We therefore decided to focus on the seriation of LBK pottery from Kujavia[45] rather than undertaking a site-based study. Correspondence analysis of decorative traits found on closed assemblages of LBK ceramics from these features could be combined with a series of radiocarbon dates on samples that were freshly deposited in the same features in formal Bayesian statistical models. The

34 Bogucki 1995; Marciniak 2008; 2013.
35 further described in Czerniak *et al.* 2016a; Czerniak/Pyzel 2016.
36 Czerniak 2012, 154.
37 Czerniak 1994, 60.
38 Czerniak 1988, 67.
39 Czerniak 2012, 155–156.
40 Grygiel 2004, 631.
41 Czerniak/Pyzel 2016.
42 Bayliss *et al.* 2016; Bayliss/Whittle 2015; Wylie 2002.
43 Denaire *et al.* 2017; Jakucs *et al.* 2016.
44 cf. Czerniak *et al.* 2016a, fig. 5.
45 Pyzel 2006; 2010.

relative sequence provided by the correspondence analysis-based seriation would offer constraints in the model, thus producing date estimates of a useful precision even where suitable datable samples were scarce[46].

Typology and seriation of LBK pottery in the Polish lowlands

The internal chronology of the LBK in Kujavia is based on the pottery, which is very distinctive due to the high percentage of decorated vessels and the relative abundance and variability of the decorative motifs and schemes employed. Traditionally, a very general division into three main phases (early, middle and late), proposed originally for the whole LBK in Poland[47] has been adopted in the Polish lowlands[48]. Additionally, the middle phase has been divided into two stages: IIA and IIB[49]. The definition of phases is very general and based mainly on description, rather than on quantitative analysis.

Phase I (Fig. 2)

The existence of this phase in the lowlands is controversial[50]. In theory, it should correspond to the *älteste* LBK, and so by definition, this must be a pure pre-Music Note phase, distinguished mainly by the absence of music note imprints or impressions on the fine ware, which instead is decorated only with wide incised lines. In the Kujavian material, there are in fact no pure pre-Music Note assemblages, but there are very few features or sites assigned traditionally to this phase, in which the percentage of vessels without music note impressions as well as wide lines is quite high. Decorative motifs are mainly curvilinear, loosely arranged and made of a single line, but often covering most of the vessel surface without separate rim decoration. Coarse pottery is usually ornamented with large vertical cuts, finger impressions and pinched decorations covering the whole body or its upper part. The boundary between coarse and fine pottery is often indistinct. In both types, organic temper is liberally used; grit is also found in coarse pottery.

Phase II is the classical Music Note phase, which has been subdivided into two stages (IIA and IIB).

Phase IIA (Fig. 3)

From this stage on, the division between fine and coarse pottery is very distinct. Fine wares become more and more thin-walled over time and show no traces of intentional inclusions. Coarse ware has mainly a coarse organic temper.

In the decoration, there are still some echoes of the previous phase in the form of wide incised lines, but these are less common and are more often associated with music notes (in large motifs as well as smaller ones). Fine incised lines with such imprints, especially on their curves, are very common. Motifs are often formed of a restricted number of lines, mainly one or two. There are more curvilinear motifs, although the straight linear motif of rhombuses used both in fine and coarse pottery is also frequent. Characteristics of coarse ware are mainly finger impressions and pinched decoration, arranged in lines but also as plain ornaments covering most of the vessel bodies. Rim decoration, to a large extent made up of a single line, is more common as well.

Phase IIB (Fig. 4)

In the coarse pottery organic temper ware still prevails, but mineral-tempered vessels become gradually more important. Generally, this phase is characterised by a certain stylistic poverty in comparison to phases IIA and III. Old traditions and general tendencies are continued, without many new elements.

The fine incised line is dominant, although the broad line can still occasionally be found. The line is usually double or triple, with medium-sized, rounded music notes. Decorative motifs are more often curvilinear than straight, and among the latter, plain triangle motifs are especially popular.

Phase III (Fig. 5)

In this phase mineral-tempered coarse pottery becomes predominant and this trend is also visible in the fine ware, in which sand is added to some vessels as well. The wall thickness of the coarse ware diminishes so in general the technological boundaries between the two basic categories of vessels are gradually becoming eroded.

It is not so in the decoration. In the fine ware, the fine incised line prevails, more often tripled or even more. It is accompanied by impressions usually placed densely on the lines. The imprints are quite often smaller than clas-

46 cf. Denaire *et al.* 2017.
47 Kulczycka-Leciejewiczowa 1979.
48 Czerniak 1994; Grygiel 2004; Pyzel 2006; 2010.
49 Czerniak 2004.
50 Pyzel 2014.

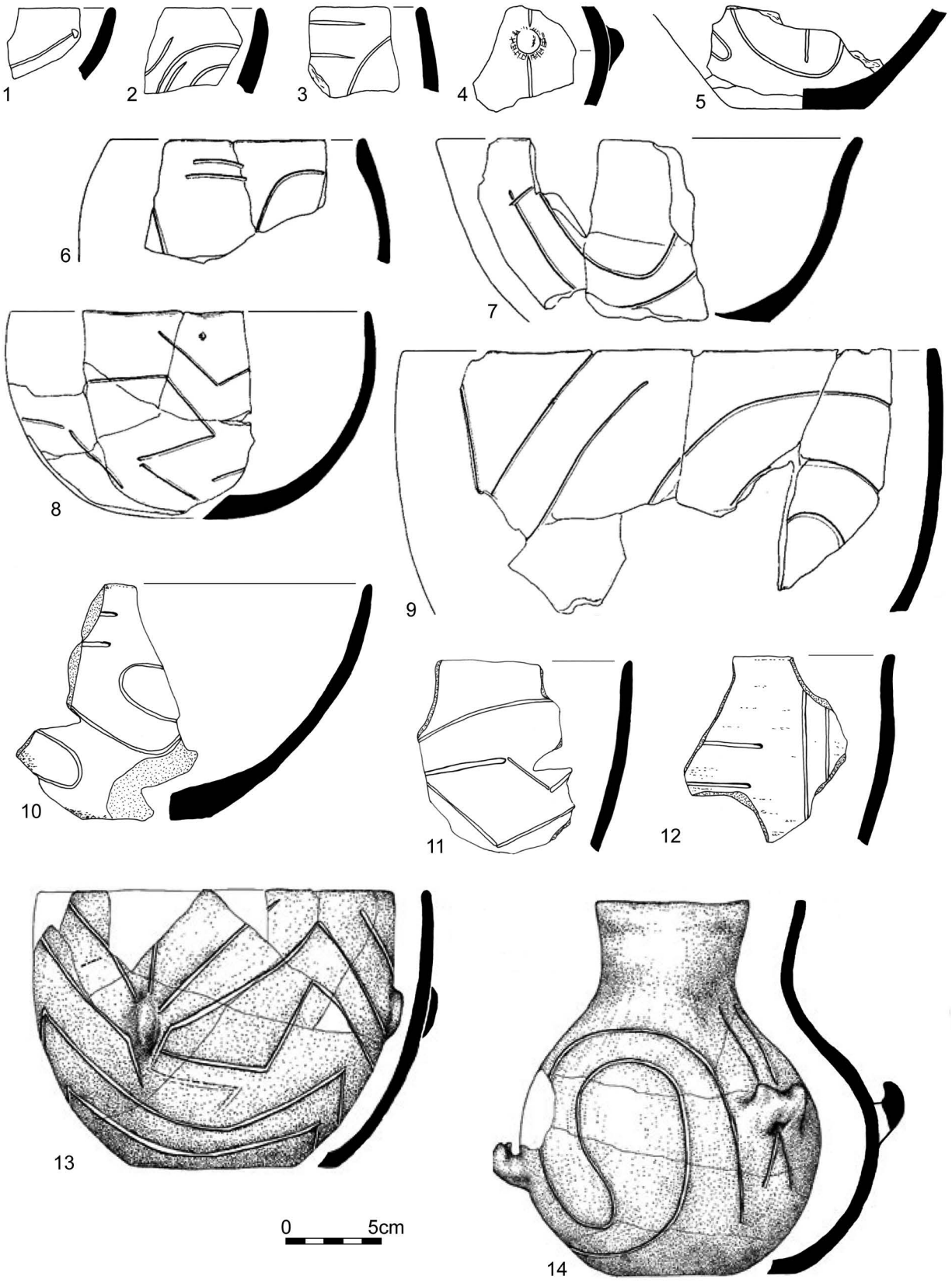

Fig. 2: Typical decorative motifs for LBK pottery belonging to Phase I of the LBK seriation for Kujavia. 1–3: Ludwinowo 7, feature G42; 4: Ludwinowo 7, feature S6; 5: Ludwinowo 7, feature S13; 6–9: Grabie 4, feature 1 (after Czerniak 1990, 54, fig. 3, j, 56, fig.4, a, e, i); 10–12: Boguszewo 43a (after Werra 2010, 127, fig. 5, c–e); 13–14: Smólsk 2/10, well 1709 (after Muzolf *et al.* 2012, 50, fig. 7, 2–4).

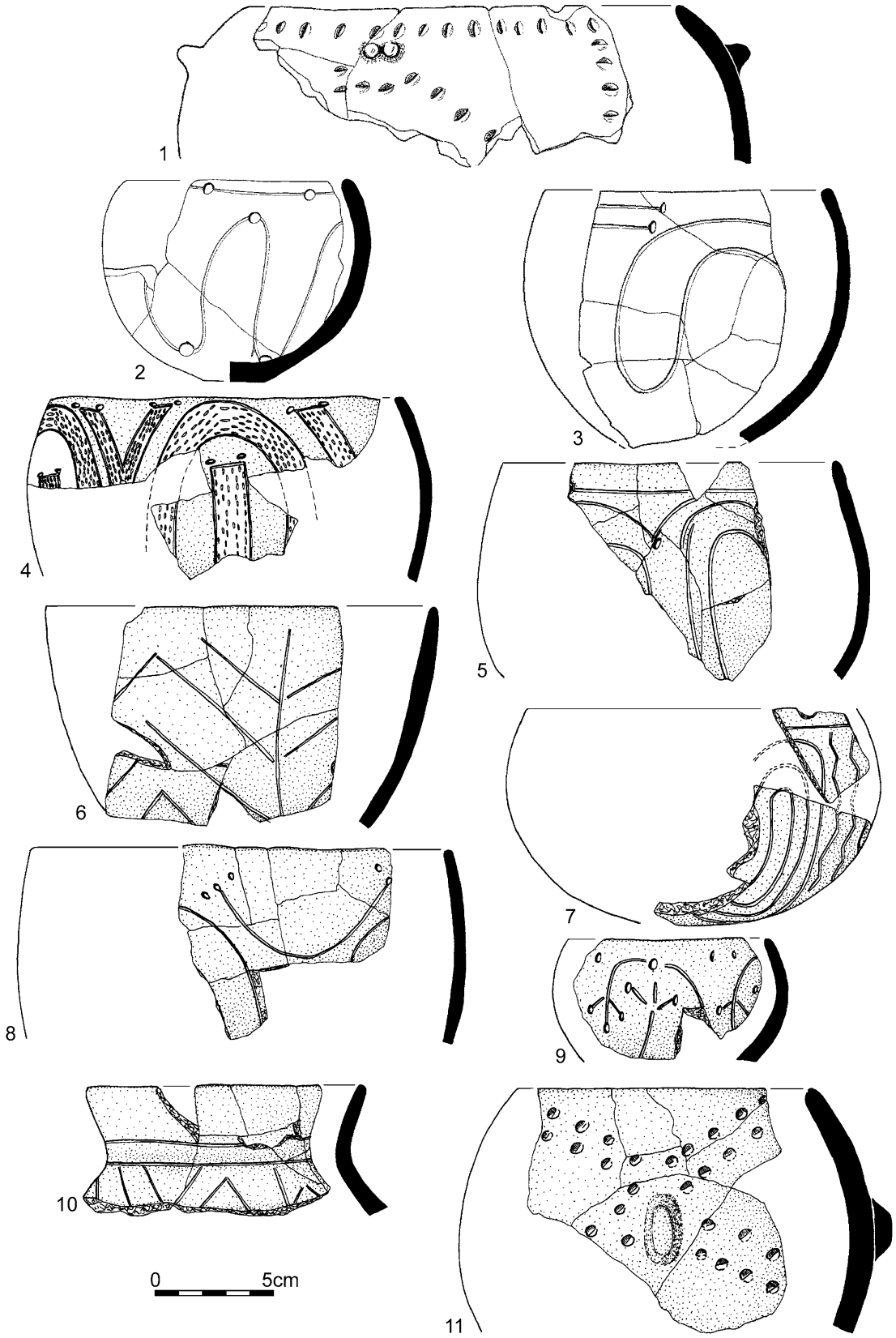

Fig. 3: Typical decorative motifs for LBK pottery belonging to Phase IIA of the LBK seriation for Kujavia. 1–3: Ludwinowo 7, feature B30; 4, 5: Bożejewice 22/23, feature A5; 6: Bożejewice 22/23, feature F2; 7: Bożejewice 22/23, feature A4; 8, 10: Żegotki 2, feature A31; 9: Łojewo 35, feature B75; 11: Bożejewice 22/23, feature A13.

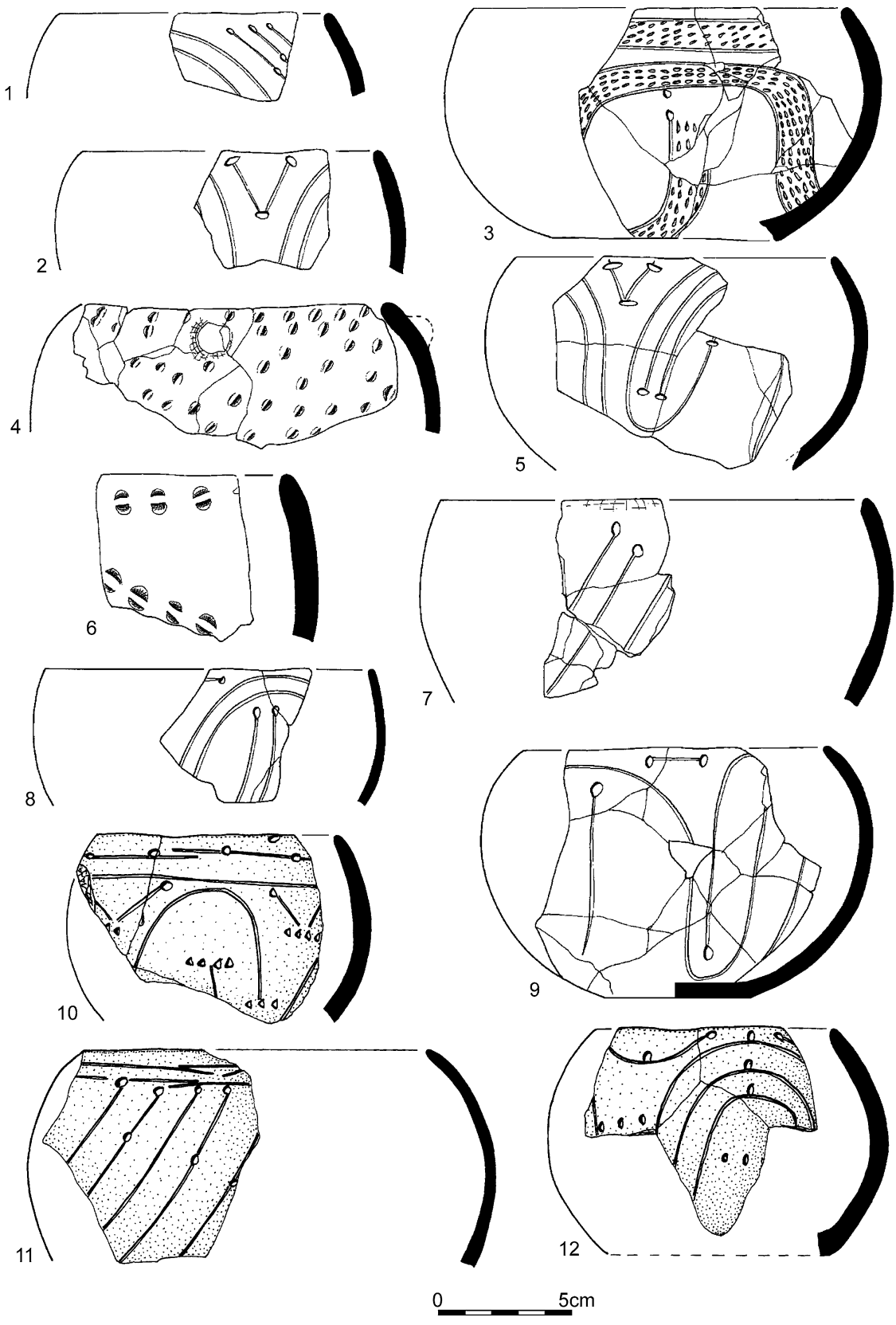

Fig. 4: Typical decorative motifs for LBK pottery belonging to Phase IIB of the LBK seriation for Kujavia. 1–7: Ludwinowo 7, feature A49; 8–9: Ludwinowo 7, feature O23; 10, 12: Żegotki 2, feature B71; 11: Żegotki 2, feature B40.

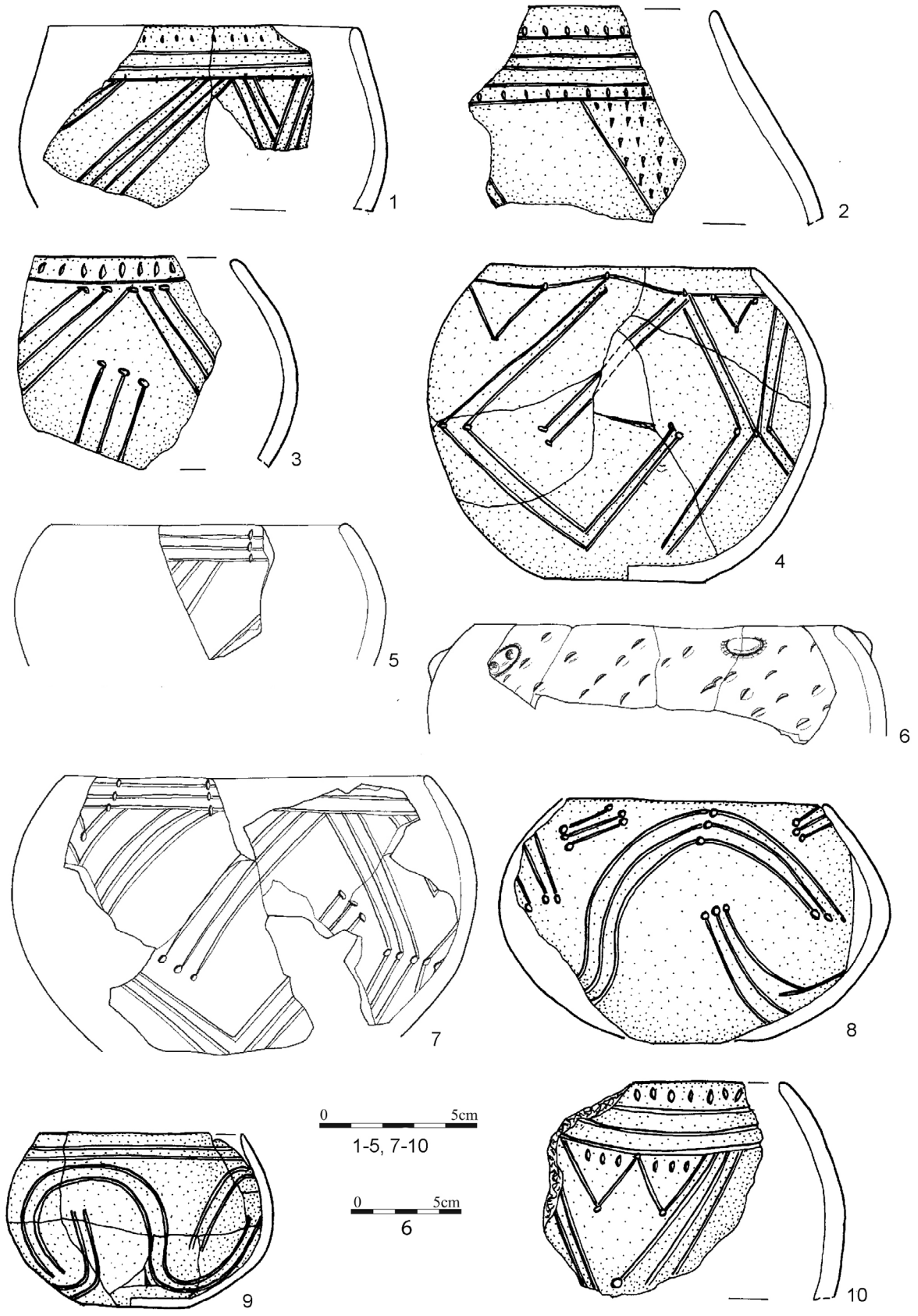

Fig. 5: Typical decorative motifs for LBK pottery belonging to Phase III of the LBK seriation for Kujavia. 1: Żegotki 18, feature A10; 2: Żegotki 18, feature A42; 3–4, 8: Żegotki 3, feature A54; 5–7: Ludwinowo 7, feature K66; 9: Ludwinowo 7, feature B46; 10: Chabsko 40, feature A6.

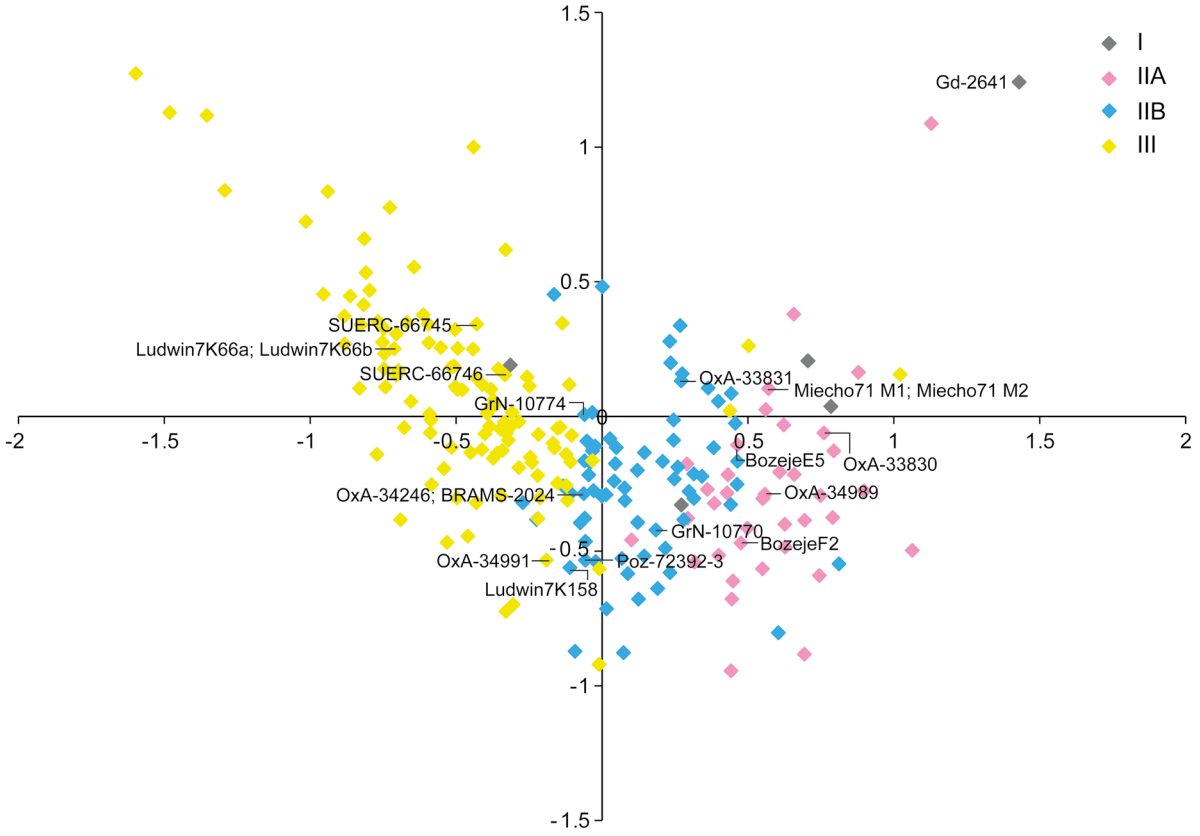

Fig. 6: Correspondence analysis of frequency of decorative motifs on LBK ceramics occurring in features in the Polish lowlands, showing the positions of features which have radiocarbon dates and the ceramic phase assigned to each assemblage on typological grounds (see Fig. S1 for the sorted seriation matrix).

sical music notes and take the form of triangles or rhombuses. In coarse pottery, nail impressions are dominant. There is great variability of rim decorations and so-called secondary motifs (*Zwickel*) in this phase compared with previous ones.

This description demonstrates some general temporal trends in the development of the LBK pottery in Kujavia, especially in its decoration, but this is a gradual, piecemeal process which makes it difficult to draw sharp boundaries between different phases and to date small assemblages especially very accurately. The way to get around this problem is the application of a more precise statistical analysis of the material. Correspondence analysis-based seriation especially has proved very successful in the study of the LBK of the Rhineland[51] and it has served as an inspiration for the Kujavian material as well. The Rhineland classification system of the main motifs (*Bandtypen*) is not very useful for the Polish lowlands pottery, so a new classification system was created combining other, partly quantitative, information on the main motifs such as the technique of the decorative motifs, the combination of motifs, and their arrangement on vessels. Altogether 221 types were distinguished[52], which initially allowed the correspondence analysis of the frequency of at least two different types from 128 features found at 21 sites in Kujavia[53].

This analysis was later extended[54], and now includes details of 13,230 decorated pieces from 224 features. More than half of them (113 features) are from just one site: Ludwinowo 7. This large LBK settlement in eastern Kujavia, on the line of the A1 motorway, was excavated in 2000–2010 by various teams. Over an area of 119 020 m^2, 871 LBK features were revealed: a part of a village consisting of at least 31 houses[55]. The majority of them were excavated by *Zespół ds. Ratownictwa Archeologicznego* of the Institute of Archaeology and Ethnology of the Polish Academy of

51 Kerig 2005, and references.

52 Pyzel 2006, Anhang 3: the so-called ez/wz system or *Mustersystem*.

53 Pyzel 2006; 2010.

54 see Pyzel 2013; 2014.

55 Pyzel 2019.

Sciences, Poznań Branch and these features were analysed in this study.

The seriation is based on the map of the correspondence analysis with features and motif types located according to the 1st and 2nd dimensions (Fig. 6 and Supplementary Information 1). Assemblages have been assigned to ceramic phases on typological grounds. The features form a parabola of fairly dispersed points. This may be due to the relatively low variability of the assemblages, or to the presence of assemblages from some features that were filled over a period of time. In these circumstances, the interpretation of the positions of features on this plot, and the typological divisions just described, as an indication of relative age has to be undertaken with caution.

Nevertheless, there is clearly a general trend from ceramic phase IIA (pink), to ceramic phase IIB (blue), to ceramic phase III (yellow) from right to left across Figure 6. Only five features have been assigned typologically to ceramic phase I (grey) and, although three of these lie towards the upper right-hand side of the plot, Ludwinowo 7, feature H123 lies in the liminal area between ceramic phases IIA and IIB, and Ludwinowo 7, feature S4 lies in an area of the plot otherwise inhabited only by features of ceramic phase III. In these circumstances, the doubts about the presence of this ceramic phase in Kujavia expressed on typological grounds appear to be valid.

Eighty of the 112 features assigned to ceramic phase III (72 %) lie in a block on the left-hand side of Figure 6, with another 26 features (23 %) lying at the boundary between ceramic phases IIB and III (Fig. 6 and Supplementary Information 1). Thus only 6 features (5 %) lie outside this region of the analysis, and the vast majority of features assigned to ceramic phase III appear to be later than those assigned to ceramic phases IIA and IIB. None of the features with radiocarbon dates from ceramic phase III appear before those with radiocarbon dates assigned to ceramic phases IIA or IIB.

The succession of ceramic phases IIA and IIB is much more problematic. There is a block of 29 features assigned to ceramic phase IIB (41 % of the 71 features assigned to this typological group), before the liminal area between ceramic phases IIB and III, which accounts for a further 22 features (31 %). But the other 20 features assigned to ceramic phase IIB (28 %) are inter-mingled with those assigned to ceramic phase IIA. This typological group is much less clearly defined in the correspondence analysis, with the largest block of features assigned to ceramic phase IIA falling together being only eight in number (22 % of the 36 features assigned to this group). It is, perhaps, that more highly decorated assemblages in ceramic phase II (here termed ceramic phase IIA) tend to be earlier, but less highly decorated assemblages (here termed ceramic phase IIB) can occur anywhere within ceramic phase II.

Radiocarbon dating and chronological modelling

The radiocarbon dating programme for the sequence of LBK ceramics in Kujavia was conceived within the framework of Bayesian chronological modelling[56]. Such an approach allows the combination of archaeological information from the ceramic seriations with calibrated radiocarbon dates using a formal statistical methodology.

Sampling

As the identification of closed assemblages and chronologically sensitive traits is vital for successful seriation, the identification of samples for radiocarbon dating which are demonstrably not residual in the contexts from which they were recovered is essential if the sequence of assemblages provided by seriation is to be used to constrain the calibration of the radiocarbon dates. First, all potential samples must be of short-lived material. Secondly, they must be contemporary with their parent contexts. Assessing whether material is residual is the most hazardous step in sample selection since the taphonomic relationship between a sample and its context is always a matter of interpretative judgment rather than certain knowledge. We employed the hierarchy of criteria for assessing sample taphonomy outlined by Bayliss *et al.*[57], selecting samples of: bones found in articulation, which would have been still connected by soft tissue when buried and hence from recently dead individuals; bones identified as articulating during analysis, which may have been articulated in the ground or have only been slightly disturbed before burial; bones with refitting unfused epiphyses identified during analysis, for the reasons given above; and carbonised food residues relating to the final use of pottery sherds.

Selecting samples on this basis minimises the archaeological risk that the dated sample may not have a direct association with the time when the ceramic assemblage included in the correspondence analysis was deposited. Bone and residues on pottery are not, however, the easiest

56 Buck *et al.* 1996.
57 Bayliss *et al.* 2011, 38–42.

materials to date accurately using radiocarbon[58], and so concentrating on these materials adds scientific risk to the dating programme. This risk was managed by obtaining replicate measurements from two laboratories on a significant number of samples (see below), and through statistical approaches which measure the compatibility of the radiocarbon dates with the sequences produced by the correspondence analyses.

The samples all derive from a range of features included in the correspondence analysis-based seriation of Kujavian LBK pottery (Fig. 6 and Supplementary Information 1). Animal bones and pottery from all the available features were screened for suitable samples. Unfortunately, the finds from a number of sites and features could not be located and many are thought to be lost. We were able to gain access and select samples in the following facilities: *Instytut Archeologii i Etnologii Polskiej Akademii Nauk* (IAiE PAN) in Poznań; *Fundacja Uniwersytetu im. Adama Mickiewicza* (F UAM) in Poznań; *Instytut Archeologii Uniwersytetu im. Adama Mickiewicza* (IA UAM) in Poznań; *Muzeum Archeologii Gazociągu Tranzytowego* (MAGT) in Szamotuły; and *Kujawskie Centrum Kultury* (KCK) in Inowrocław. A full list of features screened for possible samples and those whose location is currently unknown is provided in Supplementary Information 2.

Altogether 31 groups of articulating bone were identified in the archives, although %N analysis of whole bone prior to sampling for radiocarbon dating demonstrated that sufficient protein for dating only survived in 60 % of the bones[59]. Almost three quarters of samples of carbonised residue on pottery sherds that were submitted for dating failed to produce sufficient carbon.

Radiocarbon dating

A total of 69 radiocarbon measurements are now available from features containing LBK pottery in Kujavia. The 38 measurements obtained as part of the *Times of Their Lives* project (Table 1), however, have been obtained on only 16 samples, and more than half the measurements obtained outside this project (Table 2) were on samples of unidentified charcoal which might have a significant old-wood offset.

The radiocarbon results are all conventional radiocarbon ages[60]. Technical details of the methods used for sample preparation and dating are provided as Supplementary Information 3.

Replicate measurements are available on eight animal bone samples that were divided and submitted for dating in more than one laboratory. This degree of replication arises from a laboratory problem with one batch of samples at the Oxford Radiocarbon Accelerator Unit. The results from this batch have been withdrawn but, in the process of identifying and rectifying the problem, a number of repeat measurements were undertaken at both SUERC and Oxford. The radiocarbon results on five of these replicate groups are statistically consistent at 2σ, with the other three statistically consistent at 3σ (Table 1[61]). This scatter is rather more than would be expected on purely statistical grounds, although as none of the results is clearly erroneous, we have taken weighted means of all groups of replicate results before inclusion in the modelling.

Seven of the groups of $\delta^{13}C$ values are statistically consistent at 2σ, with the other group, on an articulating medium-sized mammal lumbar vertebra from feature K158 at Ludwinowo 7, very significantly different (Table 1). Some of the $\delta^{13}C$ values quoted for this bone are clearly inaccurate. Seven of the groups of $\delta^{15}N$ values are statistically consistent at 2σ, with the other group statistically consistent at 3σ (Table 1[62]). This scatter is in line with statistical expectations.

Bayesian modelling

The chronological modelling has been undertaken using OxCal 4.4[63], and the internationally agreed calibration curve of the northern hemisphere[64]. The models are defined by the OxCal CQL2 keywords and by the brackets on the left-hand side of Figures 7–8. In the diagrams, calibrated radiocarbon dates are shown in outline and the posterior density estimates produced by the chronological modelling are shown in solid black. The Highest Posterior Density intervals which describe the posterior distributions are given in italics.

58 Bayliss/Marshall 2019.
59 Brock *et al.* 2010a.
60 Stuiver/Polach 1977.
61 Ward/Wilson 1978.
62 Ibid.
63 Bronk Ramsey 1995; 2009a; 2009b.
64 IntCal20; Reimer *et al.* 2020.

Tab. 1: Radiocarbon and stable isotopic measurements obtained by *The Times of Their Lives* (replicate measurements have been compared using the method of Ward and Wilson (1978) and weighted means calculated.

Laboratory number	Site	Material and stratigraphic details	Radiocarbon Age (BP)	$\delta^{13}C_{IRMS}$ (‰)	$\delta^{15}N$ (‰)	C:N	Publication/notes
Phase IIA							
OxA-33830	Siniarzewo 1	S82 internal carbonised residue on pottery	6309±35	−28.73			Acid only pretreatment (RR; Brock *et al.* 2010b, table 1)
SUERC-69451	Miechowice 7	(M1) articulating cattle 2nd and 3rd phalanges from feature 1	6179±29	−20.4±0.2	5.9±0.3	3.2	
SUERC-70916	Miechowice 7	Replicate of SUERC-69451	6211±32	−21.0±0.2	5.8±0.3	3.3	
SUERC-70732	Miechowice 7	Replicate of SUERC-69451	6176±30	−20.7±0.2	5.8±0.3	3.3	
OxA-34797	Miechowice 7	Replicate of SUERC-69451	6137±31	−20.5±0.2	6.0±0.3	3.2	
OxA-35131	Miechowice 7	Replicate of SUERC-69451	6195±34	−20.5±0.2	6.1±0.3	3.2	
^{14}C: mean 6179±14 BP, T′= 3.1; $\delta^{13}C$: −20.6±0.09‰, T′=5.7; $\delta^{15}N$: 5.9±0.13 ‰, T′=0.8;T′ (5 %)=9.5, *v*= 4 for all							
SUERC-66750	Miechowice 7	(M2) articulating cattle distal radius and carpal from feature 1	6130±31	−20.8±0.2	6.0±0.3	3.4	
SUERC-69450	Miechowice 7	Replicate of SUERC-66750	6266±29	−20.7±0.2	6.2±0.3	3.2	
OxA-34798	Miechowice 7	Replicate of SUERC-66750	6223±31	−20.8±0.2	6.0±0.3	3.2	
SUERC-70915	Miechowice 7	Replicate of SUERC-66750	6187±32	−20.9±0.2	6.3±0.3	3.3	
SUERC-70731	Miechowice 7	Replicate of SUERC-66750	6252±30	−21.0±0.2	6.3±0.3	3.3	
^{14}C: mean 6214±14 BP, T′= **12.9**; $\delta^{13}C$: −20.8±0.09‰, T′=1.3; $\delta^{15}N$: 6.2±0.13 ‰, T′=1.0;T′ (5 %)=9.5, *v*= 4 for all							
SUERC-66748	Bożejewice 22/23	(BOZ5) articulating cattle radius and two carpals from feature E5	6072±33	−20.5±0.2	5.5±0.3	3.3	
SUERC-69448	Bożejewice 22/23	Replicate of SUERC-66748	6085±28	−20.6±0.2	5.9±0.3	3.3	
OxA-34791	Bożejewice 22/23	Replicate of SUERC-66748	6157±31	−20.6±0.2	6.1±0.3	3.2	
OxA-34792	Bożejewice 22/23	Replicate of SUERC-66748	6166±30	−20.7±0.2	5.9±0.3	3.2	
^{14}C: mean 6121±16 BP, T′= 7.5; $\delta^{13}C$: −20.6±0.01‰, T′=0.5; $\delta^{15}N$: 5.9±0.15 ‰, T′=2.1;T′ (5 %)=7.8, *v*= 3 for all							
SUERC-66749	Bożejewice 22/23	(BOZ2) articulating cattle atlas and axis vertebrae from feature 2	6178±31	−20.6±0.2	4.9±0.3	3.3	
SUERC-69449	Bożejewice 22/23	Replicate of SUERC-66749	6109±28	−20.7±0.2	5.1±0.3	3.2	
OxA-34793	Bożejewice 22/23	Replicate of SUERC-66749	6160±30	−20.7±0.2	5.1±0.3	3.2	
^{14}C: mean 6147±18 BP, T′= 3.0; $\delta^{13}C$: −20.7±0.12‰, T′=0.2; $\delta^{15}N$: 5.0±0.17 ‰, T′=0.3;T′ (5 %)=6.0, *v*= 2 for all							
OxA-34989	Bożejewice 22/23	BOZ012 Pottery internal surface carbonised residue from feature A13	6280±40	−29.0±0.2			

Tab. 1 (continued)

Laboratory number	Site	Material and stratigraphic details	Radiocarbon Age (BP)	$\delta^{13}C_{IRMS}$ (‰)	$\delta^{15}N$ (‰)	C:N	Publication/notes
Phase IIB							
OxA-33831	Żegotki 2	Pottery internal surface carbonised residue from feature A34	6172±34	−27.0± 0.2			Acid only pretreatment (RR; Brock *et al*. 2010b, table 1)
OxA-34990	Żegotki 2	020 pottery internal surface carbonised residue from feature B92 (which is part of feature B40)	6635±45	−29.5±0.2			Anomalously old, so excluded from the model
SUERC-66741	Ludwinowo 7	(a) articulating medium-sized mammal lumbar vertebrae from feature K158	6101±33	−21.0± 0.2	4.0±0.3	3.3	
OxA-35132	Ludwinowo 7	Replicate of SUERC-66741	6114±40	−20.3± 0.2	3.9±0.3	3.2	
SUERC-69446	Ludwinowo 7	Replicate of SUERC-66741	6063±29	−23.7±0.2	4.9±0.3	3.3	
OxA-34794	Ludwinowo 7	Replicate of SUERC-66741	6186±29	−23.8±0.2	4.7±0.3	3.2	
^{14}C: mean 6118±16 BP, T′= **9.4**; $\delta^{13}C$: −22.2±0.1‰, T′=**246.5**; $\delta^{15}N$: 4.4±0.15 ‰, T′=**8.3**;T′ (5 %)=7.8, v= 3 for all							
OxA-34246	Ludwinowo 7	A49 (a) pottery internal surface carbonised residue from feature A49	6265±45	−28.3±0.2			40 % C. High in organics. Possible contamination
Phase IIB/III							
SUERC-70197	Kopydłowo 6	Disarticulated cattle tibia from Feature 25B K6/205/1559	6179±32	−20.5±0.2	5.5±0.3	3.5	
SUERC-72037	Kopydłowo 6	Replicate of SUERC-70197	6127±27	−20.6±0.2	5.5±0.3	3.2	
Poz-66705	Kopydłowo 6	Replicate of SUERC-70197	6060±40				
^{14}C: mean 6130±19 BP, T′= 5.4, T′ (5 %)=6.0, v= 2; $\delta^{13}C$: −20.6±0.14‰, T′=0.1; $\delta^{15}N$: 5.2±0.21 ‰, T′=0.0;T′ (5 %)=3.8, v= 1 for both							
Phase III							
SUERC-66746	Żegotki 3	Pottery internal surface carbonised residue from feature A54	6171±27	−27.3±0.2			
SUERC-66745	Żegotki 18	(ZEG1) articulating cattle metapodial and phalanx from feature A10	6163±30	−20.6±0.2	6.7±0.3	3.2	
SUERC-66747	Ludwinowo 7	(a) articulating cattle carpals (LUD 7 bone 104) from clay pit K66	6071±31	−20.9±0.2	7.3±0.3	3.3	
SUERC-69447	Ludwinowo 7	Replicate of SUERC-66747	6072±32	−21.2±0.2	7.5±0.3	3.3	
OxA-34796	Ludwinowo 7	Replicate of SUERC-66747	6170±30	−21.2±0.2	7.4±0.3	3.2	
^{14}C: mean 6107±18 BP, T′= **7.0**; $\delta^{13}C$: −21.1±0.12‰, T′=1.5; $\delta^{15}N$: 7.4±0.17 ‰, T′=0.2;T′ (5 %)=6.0, v= 2 for all							
OxA-35133	Ludwinowo 7	LUD 13, articulating cattle phalanges 2 & 3 from clay pit K66	6206±35	−21.0±0.2	7.5±0.3	3.2	
SUERC-69452	Ludwinowo 7	Replicate of OxA-35133	6132±29	−20.6±0.2	7.4±0.3	3.2	
OxA-34795	Ludwinowo 7	Replicate of OxA-35133	6148±30	−20.9±0.2	7.6±0.3	3.2	
^{14}C: mean 6157±18 BP, T′= 2.8; $\delta^{13}C$: −20.8±0.12‰, T′=2.2; $\delta^{15}N$: 7.5±0.17 ‰, T′=0.2;T′ (5 %)=6.0, v= 2 for all							
OxA-34991	Siniarzewo 1	SIN005 internal carbonised residue from feature R33 R14 R3A	6195± 45	−29.1±0.2			

Tab. 2. Existing radiocarbon and stable isotopic measurements for the LBK in the Polish lowlands.

Laboratory number	Site	Material and stratigraphic details	Radiocarbon Age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$(‰)	C:N	Publication/notes
Phase I							
Gd-4427	Boguszewo 41	Unidentified charcoal from feature 3 which was not cut by any other feature	6420±100	–25.0 (assumed)			Kirkowski 1990a; possibly includes old wood and therefore treated as a *terminus post quem*
Gd-6046	Boguszewo 41	Unidentified charcoal from feature 5 which was not cut by any other feature	6440±120	–25.0 (assumed)			Kirkowski 1990a; possibly includes old wood and therefore treated as a *terminus post quem*
Gd-2641	Grabie 4	Unidentified animal bone from feature 1	6240±90	–25.0 (assumed)			Czerniak 1994, 36 and fig. 3
Phase IIA							
OxA-19807	Guźlin 2	Charred cereal grain (indeterminate) from pit 1	6224±32	–24.4			
Poz-24735	Lisewo 31	Unidentified charcoal from pit 3	6240±40				Werra 2010, table 2; could have old-wood offset and so treated as a *terminus post quem*
Poz-24734	Lisewo 31	Unidentified charcoal from pit 181, which cuts or is part of LBK feature 180. However, both features belong to the same phase of activity.	6180±40				Werra 2010, table 2; could have old-wood offset and so treated as a *terminus post quem*
GrN-10770	Łojewo 1	Unidentified charcoal from feature 22	6180±100	–25.7			Possibly includes old wood and therefore treated as a *terminus post quem*
LOD-1007	Miechowice 4	Unidentified charcoal from clay-extraction pit 7 and cut by a wall of house 6 from the early phase of the Brześć Kujawski culture (Grygiel 2004, 362, fig. 275; 2008, fig. 860)	5990±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later settlement and so excluded from model
LOD-1012	Miechowice 4	Unidentified charcoal from clay-extraction pit 7 and cut by a wall of house 6 from the early phase of the Brześć Kujawski culture (Grygiel 2004, 362, fig. 275; 2008, fig. 860)	5960±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later settlement and so excluded from model
Gd-5465	Stolno 2	Unidentified charcoal from feature 2, a large pit with a hearth on its base at the southern end from which the charcoal sample was taken	6440±70	–25.0 (assumed)			Sosnowski 1990; possibly includes old wood and therefore treated as a *terminus post quem*
GrN-5087	Strzelce 2	Unidentified charcoal from feature 1, rubbish pit of developed Linear pottery settlement, with 'music note' ornament, under Tumulus II	6260±60	–24.3			Vogel and Waterbolk 1972, 69; possibly includes old wood and therefore treated as a *terminus post quem*

Tab. 2 (continued)

Laboratory number	Site	Material and stratigraphic details	Radiocarbon Age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$(‰)	C:N	Publication/notes
LOD-1170	Wolica Nowa 1	Unidentified charcoal from clay pit 2	6240±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes old wood and therefore treated as a *terminus post quem*
Phase IIB							
GrN-9255	Brześć Kujawski 3	Unidentified charcoal from feature 769	6180±35	–24.8			Grygiel 2004, 517 and tab. XVIII; possibly includes old wood and therefore treated as a *terminus post quem*
KN-2996	Brześć Kujawski 3	Unidentified charcoal from feature 825	6170±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes old wood and therefore treated as a *terminus post quem*
Poz-66971	Kopydłowo 6	Cattle radius from feature 25C	6120±50	8.0	2.3		Marciniak *et al.* 2015, 19 and tab. 1; see Table 1
Poz-72392	Ludwinowo 7	Charred *Chenopodium* seeds (x60) from feature B104	6210±40				Unpublished data Research project NCN: UMO-2013/10/M/HS3/00537
Poz-72393	Ludwinowo 7	Charred wheat chaff from feature B104	6180±40				Unpublished data Research project NCN: UMO-2013/10/M/HS3/00537
BRAMS-2024	Ludwinowo 7	LDW-C-2267: $C_{16:0}$ and $C_{18:0}$ fatty acids from a single coarse sherd (A/484) from pit A49	6177±26				Casanova *et al.* 2020, extended data table 1
LOD-1006	Miechowice 4	Unidentified charcoal from pit 19, which was cut by house 6 of the Brześć Kujawski culture (Grygiel 2004, p. 362, fig. 275; 2008, fig. 860)	5640±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later settlement and so excluded from model
OxA-19746	Miechowice 4	Charred cereal grain (indeterminate) from pit 19, which was cut by house 6 of the Brześć Kujawski culture (Grygiel 2004, 362, fig. 275; 2008, fig. 860)	6197±37	–23.0			
GrN-10774	Miechowice 7	Unidentified charcoal from feature 2	6175±50	–24.5			Possibly includes old wood and therefore treated as a *terminus post quem*
LOD-1521	Smólsk 2/10	Unidentified charcoal from layer in single pit 1391	6110±50	–25.0 (assumed)			Possibly includes old wood and therefore treated as a *terminus post quem*
Phase III							
BRAMS-2028	Karwowo 1	KAR-C-3636: $C_{16:0}$ and $C_{18:0}$ fatty acids from single coarse, thin-walled sherd with incised decoration from pit 47	6204±25				Casanova *et al.* 2020, extended data table 1

Tab. 2 (continued)

Laboratory number	Site	Material and stratigraphic details	Radiocarbon Age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$(‰)	C:N	Publication/notes
BRAMS-2025	Karwowo 1	KAR-C-3677: $C_{16:0}$ and $C_{18:0}$ fatty acids from two refitting coarse, thin-walled sherds with incised decoration from pit 43	6236±26				Casanova *et al*. 2020, extended data table 1
LOD-1011	Miechowice 4	Unidentified charcoal from pit 19a, which was cut by pit 2 of the Brześć Kujawski culture (Grygiel 2004, 362, fig. 275; 2008, fig. 860)	5610±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later activity and so excluded from model
LOD-1165	Smólsk 4	Unidentified charcoal from clay extraction pit 1, which lies along the eastern side of the probable plan of a house (unnumbered) and near clay pits 5 and 7 of the Brześć Kujawski culture (Grygiel 2004, 263, fig. 181; 2008, 326, fig. 275)	5960±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later settlement and so excluded from model
LOD-1166	Smólsk 4	Unidentified charcoal from clay pit 2a, which lies along the western side of a house (unnumbered) of the Brześć Kujawski culture (Grygiel 2004, 263, fig. 181; 2008, 326, fig. 275)	5750±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later settlement and so excluded from model
Gd-4023	Wieldządz 31	Unidentified charcoal found with hearth stones from the base of a 40cm deep pit, feature 2 which was probably the remains of a hearth; this feature was not cut by any other feature	6150±100	–25.0 (assumed)			Kirkowski 1990b, 20–21 and fig. 5; possibly includes old wood and therefore treated as a *terminus post quem*
Gd-7221	Wielkie Radowiska 24	Unidentified charcoal from the upper part of feature 2, a large pit house, c. 1.2m deep, which was reoccupied and reconstructed many times.	5930±60				Kirkowski 1993; possibly includes intrusive material from later activity and so excluded from model
Gd-7222	Wielkie Radowiska 24	Unidentified charcoal from a hearth located in the central part of feature 4, an irregular pit house c. 1.8m deep	6040±50				Kirkowski 1993; possibly includes intrusive material from later activity and so excluded from model
LOD-1174	Zagajewice 1	Unidentified charcoal from clay pit 1; there is no indication that this pit was cut by later features although the site was occupied in later periods and the ceramic assemblage was mixed.	6080±60	–25.0 (assumed)			Grygiel 2004, 517 and tab. XVIII; possibly includes intrusive material from later occupation and so excluded from model

Results: the LBK sequence in the Polish lowlands

Considerable difficulties have been encountered in combining the radiocarbon dates (Tables 1 and 2) with the typological sequence illustrated by the correspondence analysis (Fig. 6 and Supplementary Information 1). Models were calculated incorporating all the samples of unidentified charcoal as *termini post quos* for the context from which they were recovered (barring those bulk samples that were omitted on taphonomic grounds described below), and the agreement indices provided by OxCal[65] were used to assess the compatibility of the typological sequence included in a model with the radiocarbon dates.

All the models which included a chronological succession between stages IIA and IIB had very poor model agreement (some so poor that the models would not calculate). Generally, these models also had poor convergence[66], and we note that improvements to our understanding of the shape of the radiocarbon calibration curve in this period are probably needed[67]. The model presented in Figures 7–8 simply includes the information that ceramic phase III is later than ceramic phases IIA and IIB. The dates assigned to ceramic phase I are simply included as part of the period of LBK occupation of the Polish lowlands, as are the dates from Kopydłowo 6, feature 25B, which on typological grounds can only be assigned to either ceramic phase IIB or ceramic phase III. We have calculated the first and last dated events in each ceramic phase to estimate the currency of each typological stage.

Of the 38 measurements obtained by the *Times of Their Lives* project (Table 1), only those from Kopydłowo 6 are from a feature that is not included in the correspondence analysis. Of the 31 measurements obtained previously (Table 2), only six (Gd-2641, GrN-10770, Poz-72392, Poz-72393, BRAMS-2024, GrN-10774,) are from features included in the correspondence analysis. All measurements have been incorporated in the model based on the typological assessment of their associated ceramic assemblage, although this is frequently supported by the position of the feature in the seriation.

Only three features have been dated associated with what is here called LBK I (see description of the pottery above). All three radiocarbon measurements have been inherited from previous research. Gd-4427 and Gd-6046 were made on unidentified charcoal that may have included an old-wood offset, and so are included as *termini post quos*.

Twelve features have been dated which contain pottery assemblages of ceramic phase IIA, although half of these only have measurements on unidentified charcoal and so are included as *termini post quos*. Furthermore, the two bulk charcoal samples from Miechowice 4, clay extraction pit 7 (LOD-1007 and LOD-1012), are anomalously late for the associated ceramics and appear to have contained a component of intrusive charcoal from a later building of the Late Lengyel culture[68]. These results have therefore been excluded from the analysis.

Eleven features have also been dated which contain pottery assemblages of ceramic phase IIB, and again half of these have measurements on unidentified charcoal and so are modelled as *termini post quos*. Miechowice 4, pit 19, was also cut by a later building of the Late Lengyel culture. The bulk charcoal sample from this feature (LOD-1006) is anomalously late and appears to have contained a component of intrusive charcoal, although the measurement on a cereal grain from the same feature (OxA-19746) has a good individual agreement in the model (A: 112) and appears to be contemporary with the ceramic assemblage included in the seriation. LOD-1006 has been excluded from the model. The measurement on a carbonised residue from a vessel in feature B92 at Żegotki 2 is anomalously old, and probably contained endogenous carbon which was not removed by the pre-treatment protocol used. This result (OxA-34990) has also been excluded from the analysis. OxA-34246, a measurement on a carbonised residue from a pottery sherd from feature A49 at Ludwinowo 7, has been retained in the analysis. Although this sample was noted as high in organic contaminants, the date has a good individual agreement in the model (A: 74) and appears to be accurate.

The ceramic assemblage from Kopydłowo 6, feature 25B, can only be assigned to either phase IIB or phase III. The radiocarbon dates are thus modelled simply as belonging to the period of LBK occupation in the Polish lowlands.

Thirteen features have been dated which contain pottery assemblages of ceramic phase III. Seven of these only have results from samples of unidentified charcoal, although several of these are much later than the results on articulating bone and carbonised residues on ceramic. Samples from Miechowice 4, pit 19a, and Smólsk 4, clay extraction pits 1 and 2a, appear to have contained components of later charcoal from overlying occupation of the Late Lengyel culture and so all have been excluded from the analysis. The two samples of unidentified charcoal

65 Bronk Ramsey 1995, 429; 2009a, 356–357.
66 Bronk Ramsey 1995, 429.
67 Bayliss *et al.* 2020.
68 see Czerniak *et al.* 2016a.

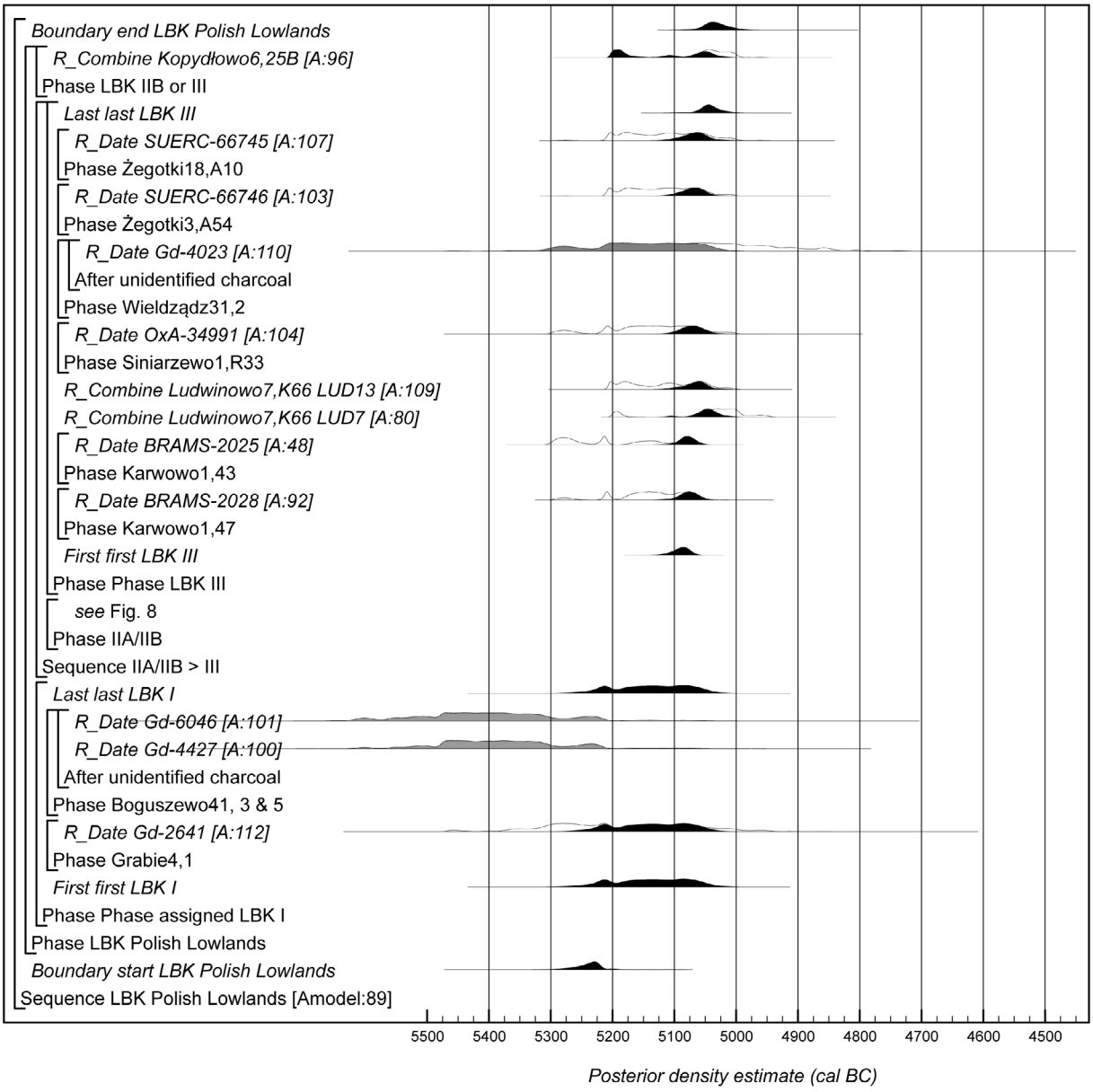

Fig. 7: Probability distributions of radiocarbon dates from the sequence of LBK pottery in the Polish lowlands. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the result of simple radiocarbon calibration, and a solid one, based on the chronological model used. Distributions other than those relating to particular samples correspond to aspects of the model. For example, the distribution '*start LBK Polish Lowlands'* is the estimated date when LBK settlement was established in the Polish lowlands. Distributions in grey have been modelled as *termini post quos*. The large square brackets down the left-hand side of Figs 7 and 8, along with the OxCal keywords, define the overall model exactly.

from Wielkie Radowiska 24, features 2 and 4, are from features described as 'large pit houses'. Gd-7221 was from the upper part of feature 2 and Gd-7222 was from a feature of irregular shape which may have been an unrecognised complex of intercutting pits. In both cases, the perforce bulked charcoal samples necessary for conventional dating may have contained an element of intrusive material. These measurements have also been excluded from the analysis. There is no indication that clay pit 1 from Zagajewice 1 was cut by later features, although the site was occupied in later periods and the ceramic assemblage was mixed. Therefore, on a precautionary principle, this measurement has also been excluded from the model.

The model illustrated in Figures 7–8 thus contains 59 radiocarbon measurements, produced on 37 samples from 33 features. Nine measurements on samples of bulk unidentified charcoal, which may have contained a component of intrusive material, and one measurement on a

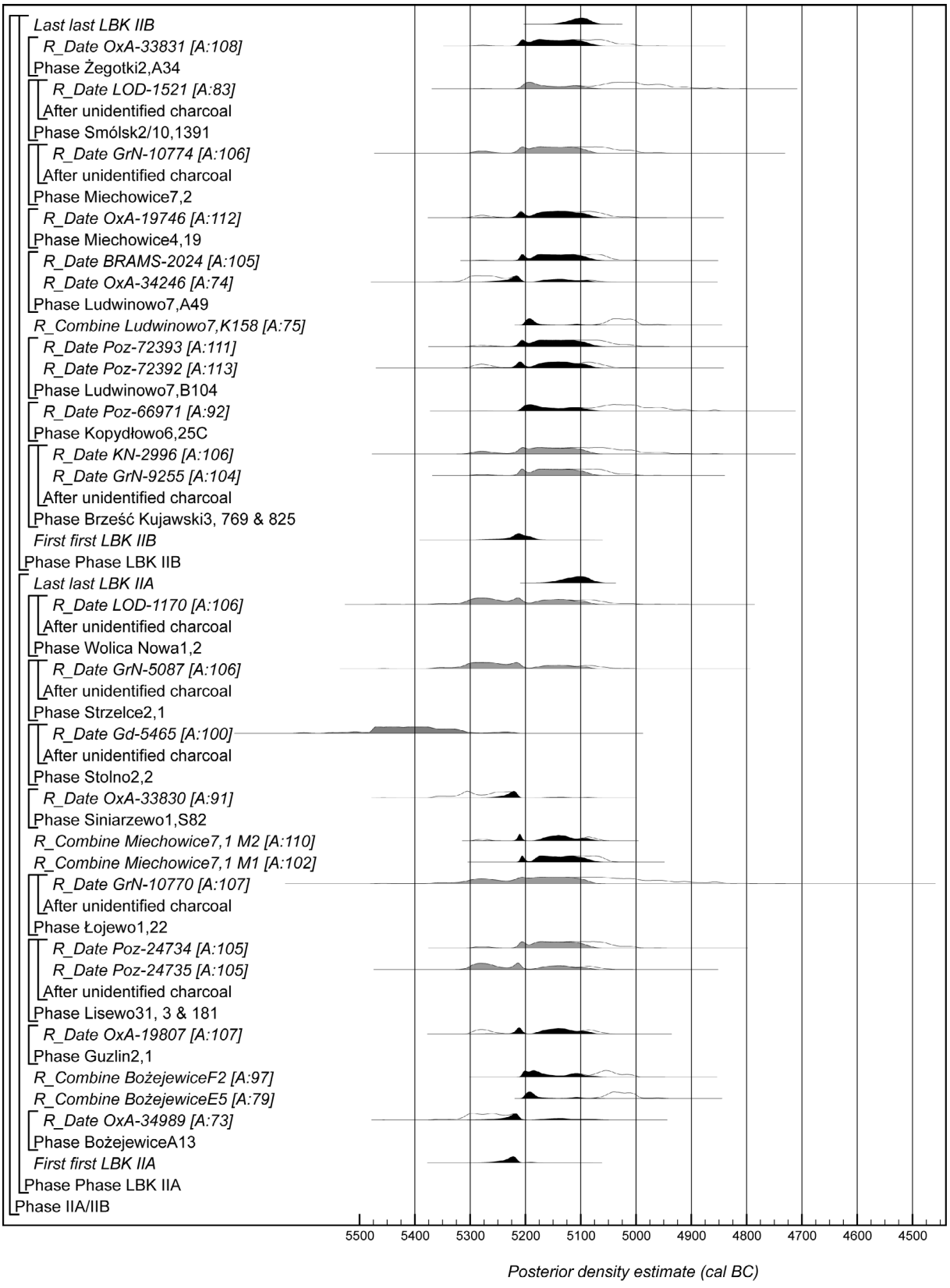

Fig. 8: Probability distributions of radiocarbon dates from the sequence of LBK pottery in the Polish lowlands. The format is identical to that of Fig. 7. The large square brackets down the left-hand side of Figs 7 and 8, along with the OxCal keywords, define the overall model exactly.

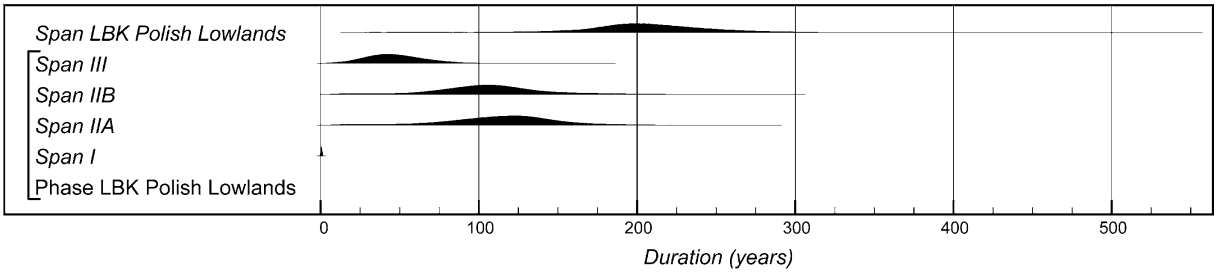

Fig. 9. Probability distributions for the number of years during which the typological phases of LBK pottery were used in the Polish lowlands, derived from the model defined in Figs 7 and 8.

carbonised residue which appears to have been contaminated, have been omitted from the analysis. This model has good overall agreement (Amodel: 89), which suggests that the reading of the radiocarbon dates outlined above is compatible with the succession of ceramic phase IIA/IIB by ceramic phase III.

This model suggests that the first LBK settlement in the Polish lowlands began in *5320–5175 cal BC* (*93 % probability*; *start LBK Polish Lowlands*; Fig. 7) or *5120–5080 cal BC* (*2 % probability*), probably in *5265–5215 cal BC* (*68 % probability*). The use of LBK pottery in the Polish lowlands ended in *5080–4980 cal BC* (*95 % probability*; *end LBK Polish Lowlands*; Fig. 7), probably in *5055–5015 cal BC* (*68 % probability*). It was used over a period of *50–70 years* (*1 % probability*; *span LBK Polish Lowlands*; Fig. 9) or *105–310 years* (*94 % probability*), probably for a period of *165–245 years* (*68 % probability*).

Only Gd-2641, from Grabie 4, provides meaningful evidence for the potential date of LBK I in the Polish lowlands, since the two samples of unidentified charcoal from Boguszewo 41 seem to have contained appreciable components of old wood (Fig. 7). This single sample suggests that this ceramic phase was present in *5255–5030 cal BC* (*95 % probability*; *first LBK I*; *last LBK I*; Fig. 7), probably in *5220–5205 cal BC* (*7 % probability*) or *5175–5060 cal BC* (*61 % probability*). The calculated duration (Fig. 9) is not meaningful as it is effectively based on a single date. It is *98 % probable* that Grabie 4, feature 1, dates to the time when ceramic phase II was in use in the Polish lowlands.

Ceramic phase IIA began in *5300–5155 cal BC* (*94 % probability*; *first LBK IIA*; Fig. 8) or *5110–5085 cal BC* (*1 % probability*), probably in *5250–5210 cal BC* (*68 % probability*); and ceramic phase IIB began in *5295–5155 cal BC* (*94 % probability*; *first LBK IIB*; Fig. 8) or *5115–5090 cal BC* (*1 % probability*), probably in *5230–5185 cal BC* (*68 % probability*). It is *70 % probable* that ceramic phase IIA began slightly before ceramic phase IIB, although the gap between the earliest assemblages in each stage (if such a gap existed) is unlikely to amount to more than a decade or two (*gap first IIA/IIB*; distribution not shown). Ceramic phase IIA ended in *5155–5065 cal BC* (*95 % probability*; *last LBK IIA*; Fig. 8), probably in *5130–5080 cal BC* (*68 % probability*); and ceramic phase IIB ended in *5145–5155 cal BC* (*95 % probability*; *last LBK IIB*; Fig. 8), probably in *5120–5080 cal BC* (*68 % probability*). The relative order of these distributions demonstrates that these stages effectively ended at the same time. Pottery assigned to stage IIA was used for *25–35 years* (*1 % probability*; *IIA*; Fig. 9) or for *40–185 years* (*94 % probability*), probably for a period of *85–150 years* (*68 % probability*). Stage IIB ceramics were used for a period of *30–180 years* (*95 % probability*; *IIB*; Fig. 9), probably for *75–135 years* (*68 % probability*).

Ceramic phase III began in *5125–5060 cal BC* (*95 % probability*; *first LBK III*; Fig. 7), probably in *5105–5070 cal BC* (*68 % probability*), and ended in *5080–5000 cal BC* (*95 % probability*; *last LBK III*; Fig. 7), probably in *5060–5025 cal BC* (*68 % probability*). Ceramics of this type were therefore in use for a period of *10–90 years* (*95 % probability*; *III*; Fig. 9), probably for a period of *25–65 years* (*68 % probability*).

Discussion

The timing and tempo of the LBK trajectory in the Polish lowlands

The timing of the first LBK presence in the central Polish lowlands can now be compared with recent formal chronological modelling of the earliest LBK in central Europe[69]. It is clearly later than both the formative phase of the LBK and the start of the earliest phase of the LBK according to all three alternative models presented in that study (Fig. 10). It is, for example, *97 % probable* that the first LBK

69 Jakucs *et al.* 2016, figs 18–23.

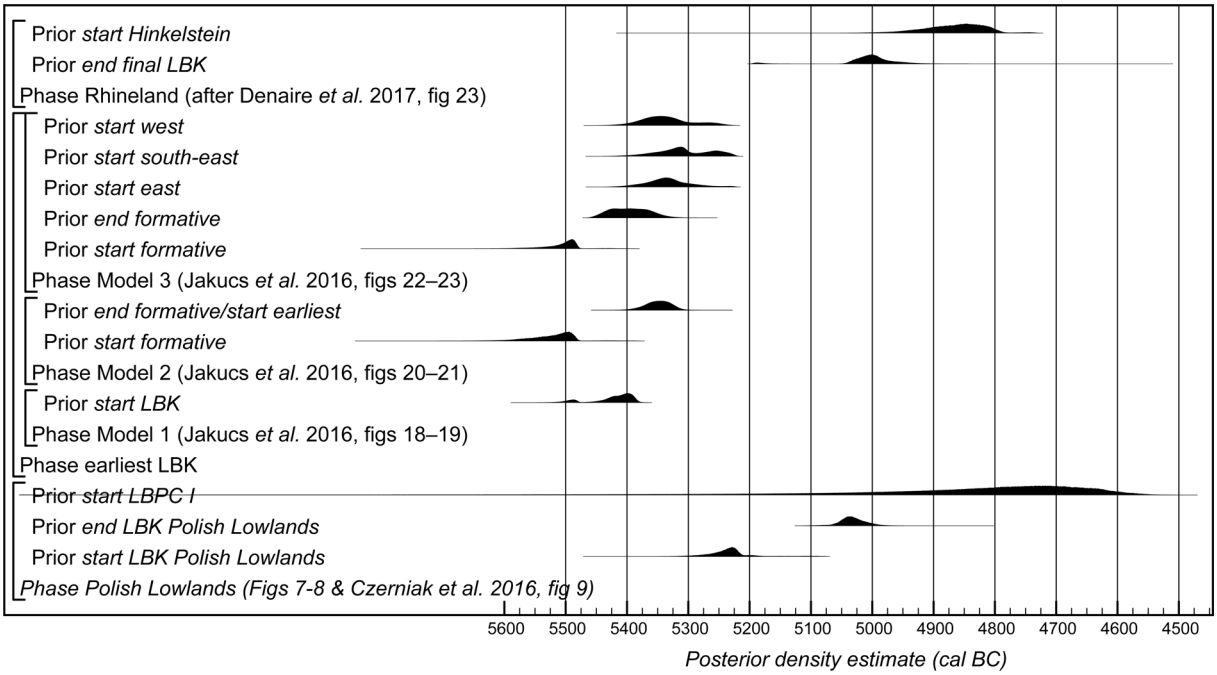

Fig. 10. Key parameters for the occurrence of phases of LBK ceramics and the succeeding ceramic phase in (a) the Polish lowlands (Figs 7–8; Czerniak *et al.* 2016, fig. 9), (b) the Formative and *älteste* phase of the LBK in central Europe (Jakucs *et al.* 2016, figs 18–23), (c) in the Rhineland (Supplementary Information 4). All models have been (re)calculated using IntCal20 (Reimer *et al*. 2020) and OxCal v4.4.

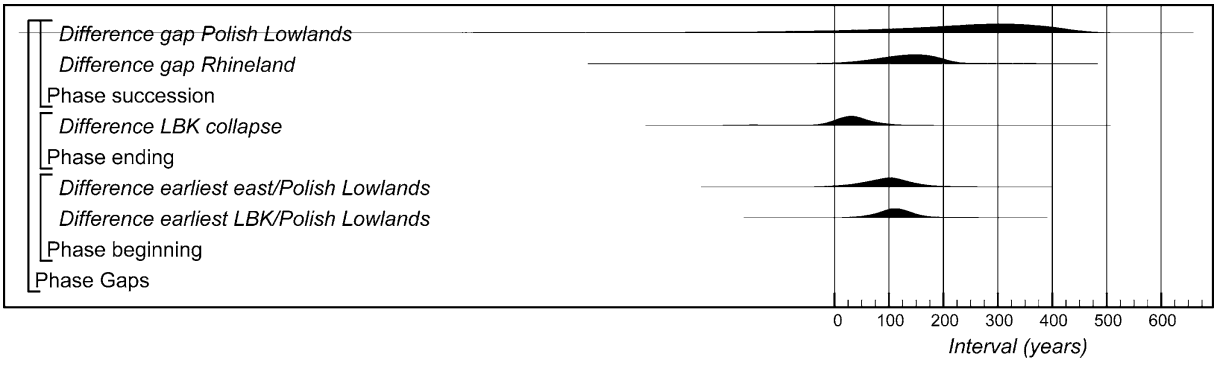

Fig. 11: Probability distributions for the delay in the introduction of LBK ceramics to the Polish lowlands in comparison with elsewhere in the LBK oecumene, the duration of the collapse of LBK lifeways, and the gaps between the last LBK and the earliest post-LBK ceramics in the Polish lowlands and the Rhineland, derived from selected parameters illustrated on Fig. 10.

in the Polish lowlands is later than the start of the LBK in the eastern area defined by Jakucs *et al.*[70]. Indeed, we can calculate that the LBK in the Polish lowlands appeared *–25–220 years* (*95% probability*; *earliest east/Polish Lowlands*; Fig. 11) after it did elsewhere in this eastern area, probably *45–145 years* (*68% probability*) afterwards[71]. This is also *c*. 150–250 years later than previous estimates[72], but also *c*. 50–150 years later than more recent calculations[73]. Informal estimates of LBK chronology appear consistently to have misinterpreted probable start dates, setting them too early.

Our analysis casts doubt on the identification of features associated only with pottery of ceramic phase LBK I in the Polish lowlands. If they existed at all, the appear-

70 Ibid. fig. 1.

71 Note that the negative part of this range reflects the *3% probability* that the earliest LBK in this eastern region was actually in the Polish lowlands.

72 Czerniak 1990; 1998; Milisauskas/Kruk 1989, 404; Pyzel 2006; 2010.

73 Czerniak 2012.

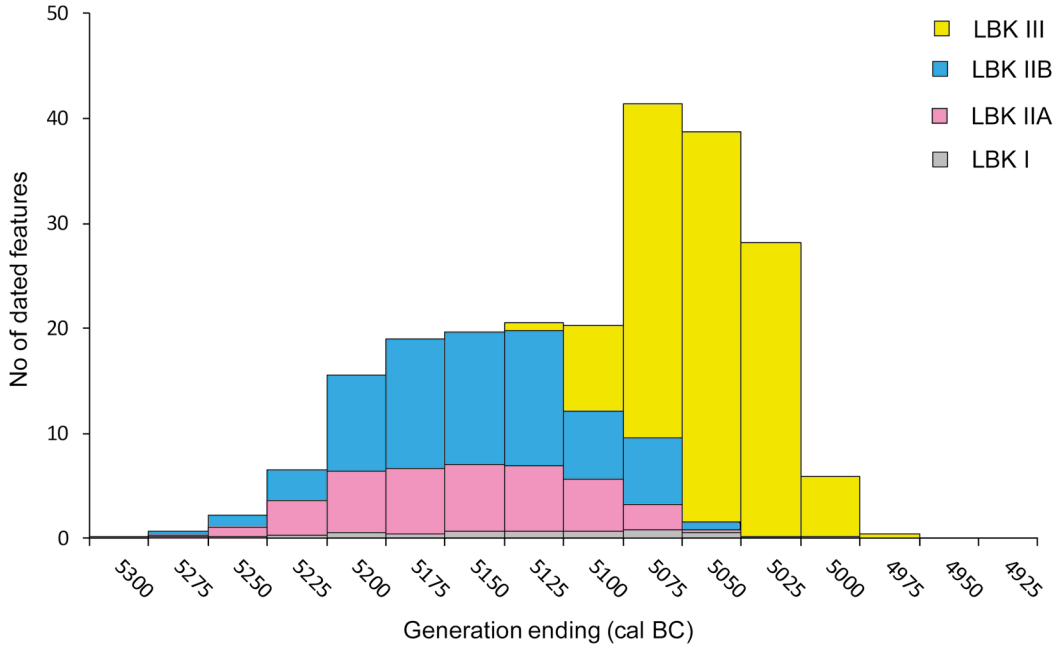

Fig. 12: Estimated intensity of LBK activity in the Polish lowlands over time (calculated by apportioning the number of features in a ceramic phase evenly over the period of its use in 25-year bins, and then summing these estimates).

ance of the earliest LBK communities in this region was only on a small scale. A more extensive establishment of settlement was only achieved in Phase II, probably through continuing migration. The timescale and probable scale of any LBK I presence in lower Poland were so limited that previous suggestions that this extension of settlement might result from local growth and infill or part of a second, distinct wave of migration[74] can probably be discounted. Overall, the pattern observed in the Polish lowlands may be repeated widely elsewhere within the LBK distribution, with initial rapid diaspora, starting at a later date than envisaged through informal inspection of simple calibrated radiocarbon dates, followed by infill and consolidation. The lag of perhaps two to four human generations between the first appearance of the earliest LBK in a region and further expansion into adjacent lands has also recently been observed in the upper Rhine valley[75]. The 53rd century cal BC is beginning to emerge in many regions as a key horizon of growth and change[76].

An indication of the intensity of LBK occupation in the Polish lowlands can be obtained by apportioning the number of features in each phase of the seriation evenly across the period when ceramics of that type were in use. First, we calculate the probability that each ceramic phase was in use in each 25-year bin (approximating to one human generation), then we normalise the values for each ceramic phase. This gives us the proportion of features from each ceramic phase that date to a particular 25-year period (for example, 7.3 % of the 112 features allocated to ceramic phase III in the seriation probably date to 5125–5100 cal BC). The intensity of activity in each 25-year period is then simply the total number of features in all the phases that probably date to that time period (Fig. 12).

Phase II clearly marks the major step in the establishment of LBK communities in the Polish lowlands. It will be for future research to unpick the processes involved, perhaps a combination of movement from the south (as explored earlier in the paper) and then subsequent local growth. Occupation intensified over a period of a few generations, but soon became established and stable. Large settlements were founded that were inhabited for a number of generations, particularly well documented in eastern Kujavia. As indicated by the pottery seriation model developed for Ludwinowo 7[77], the settlement there was occupied for six house generations, each consisting of about four houses. At this time LBK groups spread into the western edges of the Polish lowlands (the Pyrzyce region on the lower Oder), and contacts within these newly es-

74 Pyzel 2010; 2014.
75 Denaire *et al.* 2017, fig. 8.
76 see also Cladders/Stäuble 2003.
77 Pyzel 2013.

tablished communities soon became more important than with those inhabiting the areas of origin in the south[78].

LBK occupation intensified rapidly, and markedly, in the first half of the 51st century cal BC during the early years of ceramic phase III. The peak of LBK occupation in Kujavia was reached at this time. The following part of the phase, however, is marked by a sudden decline in the number of houses and their ultimate replacement by single pits. This is particularly discernible in the character of the occupation at Ludwinowo 7 towards the end of Phase III[79], and this pattern is readily recognisable across the region as a whole, particularly clearly at Kruszyn 10 and Smólsk 2/10, two other large LBK settlements in eastern Kujavia. Phase III at these sites is represented by only a few features and is devoid of typologically very late pottery[80].

This decline in the intensity of occupation in the later part of ceramic phase III was almost as dramatic as the increase of a few decades before. There was a dramatic collapse – certainly within the lifetime experience of an elderly member of the community, and even perhaps within a much shorter timescale in the middle of the 51st century cal BC. This collapse saw the number of closed contexts containing diagnostic LBK ceramics – and by extension the number of occupied houses (many of those features are long pits) and the population that lived in them – decline from its peak to nothing over, at most, just a few decades. The character of this demise remains, however, to be established in more detail, and that is discussed further below.

Ending and aftermath: late LBK and the early post-LBK horizon in the Polish lowlands and regions beyond

The timing of the final LBK presence in the Polish lowlands can also now be compared with recent formal chronological modelling of the latest LBK in the Rhineland[81]. As described in Supplementary Information 4, we have updated this model to include additional radiocarbon dates from Herxheim[82]. From this, it is *96 % probable* that the end of LBK III in the Polish lowlands occurred before the final LBK pottery was deposited in the Rhineland. Whereas LBK ceramics appear to have gone out of use in the Polish lowlands by the end of the 51st century cal BC, they may have continued in use in the Rhineland until the earliest decades of the 50th century cal BC (Fig. 10). The speed of this ending can be assessed by comparing the date estimates for the final use of LBK ceramics in the Polish lowlands and the Rhineland. This suggests that their disuse occurred over a period of *–35–165 years* (*95 % probability*; *LBK collapse*; Fig. 11), probably over a period of *1–95 years* (*68 % probability*)[83].

According to the model presented here, the end of ceramic phase III in *5080–4980 cal BC* (*95 % probability*; *end LBK Polish lowlands*; Fig. 7), probably in *5055–5015 cal BC* (*68 % probability*), is much earlier than previously assumed[84]. This contradicts the commonly held opinion that Kujavia was a region occupied by LBK communities as late as the beginnings of post-LBK groups in other regions, such as the SBK in Bohemia, Saxony and Lower Silesia, Lengyel in the west Carpathian basin, west Slovakia and Moravia, or Hinkelstein in Rhine-Hesse[85].

On the basis of existing evidence and according to the formal models used here, there appears to be an appreciable gap in the Polish lowlands between the last communities using LBK ceramics in this region and the first from the Late Band Pottery culture (Fig. 10). This hiatus lasted for *–580–505 years* (*95 % probability*; *gap Polish Lowlands*; Fig. 11), probably for *85–430 years* (*68 % probability*)[86].

This hiatus in occupation within the Danubian tradition at the end of the LBK may appear unexpected to some – after all, in other regions such as Bohemia or Saxony, continuity between the LBK and post-LBK cultures is postulated, largely on the basis of pottery typology[87] – but it is a phenomenon that extends beyond the Polish lowlands. A similar break in the sequence, in this case between the final LBK and Hinkelstein groups, has recently been suggested in Lower Alsace (although radiocarbon dates are lacking from the final phase of the ceramic seriation there), and it is possible[88] that such a break extends more widely across the lower Rhine valley (*end final LBK, start Hinkelstein*; Fig. 10; *gap Rhineland*;

78 cf. Kirkowski 1994; Pyzel 2006; Czekaj-Zastawny *et al.* 2020.
79 Pyzel 2013.
80 Muzolf *et al.* 2012; Płaza 2016.
81 cf. Denaire *et al.* 2017, 23.
82 Zeeb-Lanz 2019.
83 Again, the negative part of these ranges reflects the *(10 %)* probability that the LBK in the Rhineland ended before that in the Polish lowlands.
84 cf. Czerniak 2012; Grygiel 2004, 523; Pyzel 2006; 2010, 97.
85 Kirkowski 1994; Czerniak 1994, 60.
86 The negative part of this range reflects the *(20 %)* probability that LBPC I began before the end of the LBK in the Polish lowlands. These probabilities arise from the extreme uncertainty of the date estimate for the start of the LBPC – it is, for example, 10 % probable that it began before the LBK in the Polish lowlands!
87 Link 2014a.
88 see also Riedhammer 2019; Zeeb-Lanz 2019.

Fig. 11), although this appears to have been of shorter duration and there may have been patchy continuity there[89].

The fact that gaps appeared elsewhere helps to underpin the hiatus which we propose[90] for the Polish lowlands. The estimate presented above (Fig. 11), which is extremely imprecise due to the paucity of radiocarbon dates for the LBPC, allows for this to be either just a few generations or a yawning gap of several centuries. Clearly, it must be a goal of future research to locate and date more samples from LBPC contexts. We go on here briefly to consider, first, the conditions in which established LBK communities could have foundered, and secondly, the implications of the proposed hiatus for our view of the emergent transformations of the post-LBK scene in the Polish lowlands in the first half of the fifth millennium cal BC.

Overall, the picture in the Polish lowlands appears to be of a later start to LBK settlement than previously envisaged, followed by two to three centuries of occupation which intensified markedly and then collapsed dramatically during the second half of the 51st century cal BC. At this point there appears to have been a hiatus of considerable duration, and the succeeding LBPC presence, when it does emerge, is sparse. It is plausible to see this as part of a connected narrative, rather than as a series of separate episodes. This sequence might be considered as a purely regional phenomenon, but because it resonates so strongly with patterns observed elsewhere in the LBK trajectory, it may form part of a wider LBK and post-LBK history. Different kinds of explanations, some overlapping, have been marshalled to explain this disruption to established settlement, from climatic downturn, population boom and bust, and communal conflict and warfare, to conceptual malaise and disease. No single one is yet entirely convincing on its own, and one of the many challenges for continuing research in the Polish lowlands and beyond will be to find further specific evidence to decide which of this range of possibilities is most plausible in specific contexts.

Models of unfavourable climatic conditions towards the end of the LBK have been suggested many times[91]. They are faced with several problems. One is that it is so far difficult to time the suggested episodes of increased rainfall and shorter growing seasons with any precision, so that it is not clear that they need to coincide neatly with the ending of LBK settlement in many regions in the late 51st or early 50th centuries cal BC. Another is that is hard to evaluate the scale of potentially harmful effect on the LBK subsistence economy; given the varied resources and staples in use, there must have been considerable buffering built into the system. There is also now the need to reconcile a period of deteriorating climate with the speed and scale of the LBK collapse in the Polish lowlands. A climatic explanation might perhaps predict a more gradual decline, or at least some kind of decline and struggle before a decision was made to abandon the region. A similar pace and date of collapse may be inferred in Alsace[92]. This means that a climate model potentially also has to explain collapse in regions as far apart as the Polish lowlands and the upper Rhine valley, whilst accounting for stability in regions where LBK lifeways and succession continued apparently uninterrupted, such as in western Hungary[93].

Another generalising model is of population boom and bust, which could have afflicted not only the LBK but also a series of other situations in succeeding millennia[94]. Now it is entirely plausible that population could increase through time, and also that the balance between fertility and mortality could vary. Whether it is likely that population growth reached the scale envisaged in such a short period – definable now in the case of the Polish lowlands as around two centuries (Fig. 9) – is another matter, and the specific indications in this context are that there was literally room to spare. But the evidence does clearly point to a rapid and dramatic decline in the number of closed contexts of LBK ceramics deposited in the Polish lowlands in the second half of the 51st century cal BC (Fig. 12) and, since most of these contexts are long pits associated with houses, it is probably reasonable to infer a similar collapse in the LBK population[95]. It is only fair to note, however, that climatic downturn and population excess can be considered together. In one scenario, it has been modelled that a single episode of famine in a time of poor climate could have had very serious consequences for an LBK population grown rapidly large[96]. Could such a putative famine have led to the migration of surviving LBK communities out of the Polish lowlands? There is, however, no clear evidence yet of such migration in any region visible from connections between pottery styles, apart perhaps from the vaguely defined Elster-Saale regional pottery

89 Denaire *et al.* 2017, 59–66.

90 cf. Grygiel 2004.

91 e.g. Gronenborn 2012; Strien/Gronenborn 2005; Pechtl/Land 2019.

92 although with less confidence, given the absence of radiocarbon dates for the final, LBK V, phase there: Denaire *et al.* 2017.

93 see, for example, Regenye *et al.* 2020.

94 Shennan 2013; 2018; Shennan *et al.* 2013.

95 note this estimate does not rest on using radiocarbon dates themselves as a proxy for population, the reliability of which is open to serious doubt: see Downey *et al.* 2014; Timpson *et al.* 2015; Torfing 2015a; 2015b.

96 Bocquet-Appel *et al.* 2014.

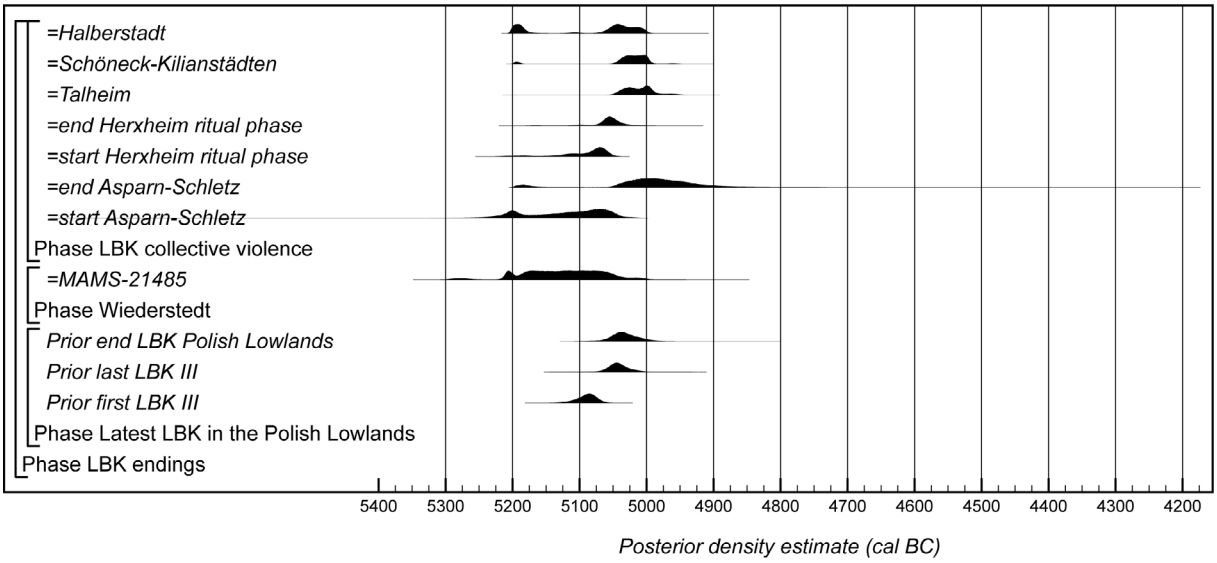

Fig. 13: Probability distributions of dates for LBK mass graves and the latest LBK ceramics in the Polish lowlands (derived from the models defined in Supplementary Information 4 and 5, and in Figs 7–8).

style in central Germany. Grygiel[97] interprets its emergence as an indication of incomers from Kujavia, while German researchers see it more generally as an influence from the south-eastern part of the LBK oecumene[98].

Warfare has been another candidate for the cause of the perceived late LBK crisis[99], and the number of instances of collective violence has risen over the past decades of research. To add to the well-known (and varying) examples of Talheim and Asparn-Schletz, there are also now the mass graves at Schöneck-Kilianstädten and Halberstadt[100]. Herxheim, of course, continues to provoke debate about the extent to which its disassembled human remains may reflect killings before processes of dismemberment and possible cannibalism, with rival hypotheses now of ritual destruction and sacrifice[101]. A collective burial at Wiederstedt contains a group of ten skeletons apparently buried at the same time but without any clear evidence for violence[102]. So without question the late LBK world saw episodes of inter-group violence, some potentially on a considerable scale. Here, again, our new timings perhaps shed light on whether inter-group violence was in some way responsible in its own right for the end of the LBK, or was rather a symptom of other underlying causes.

Figure 13 shows a summary of the dating of these mass graves (derived from chronological modelling described fully in Supplementary Information 4 and 5) in relation to our date estimates for the final phase of LBK ceramics in the Polish lowlands. The end of the LBK in the Polish lowlands probably came just before the episodes of collective violence in the Rhineland, at Talheim (*77 % probable)* and Schöneck-Kilianstädten (*69 % probable*) and before deposits within the enclosure at Asparn-Schletz had ended (*84 % probable*), but after the 'ritual phase' at Herxheim (*81 % probable)* and the massacre at Halberstadt (*67 % probable)*. So its demise was within a period of troubled times within the wider LBK oecumene and *could* have resulted from it. But we note that, so far, at least, there is no specific evidence either from the lowlands or the uplands in Poland for conflict of the kind seen to their west and south.

Another explanation, of some kind of conceptual or spiritual malaise afflicting late LBK communities, has also been mooted[103], but not only is this rather poorly defined but it is again unclear why it should have resulted in such a scale of early post-LBK hiatus as is now beginning to emerge in various areas. Given the difficulties with all these interpretations, an alternative of some form of widespread disease has also been suggested[104]. The reality of diseases as a factor of early farming life has been underlined by cases of tuberculosis in the LBK and the Lengyel

97 Grygiel 2004, 631.
98 Kaufmann/York 1985.
99 for a critical view, see Link 2014b.
100 Meyer *et al.* 2014; 2015; 2018.
101 Boulestin/Coupey 2015; Orschiedt/Haidle 2012; Hajdas 2019; Riedhammer 2019; Zeeb-Lanz 2016; 2019.
102 Meyer *et al.* 2004.
103 Boulestin/Coupey 2015; Zeeb-Lanz 2009; 2019.
104 Jakucs *et al.* 2016; cf. Shennan *et al.* 2013, 4.

cultures[105], and the presence of the carrier of later plagues has now been documented through aDNA analysis as far back as the third millennium cal BC in eastern Europe and Eurasia[106]. The mass grave at Wiederstedt, which included ten skeletons but only two adults and no evidence of trauma[107], may be an indication of the presence of epidemic disease in LBK communities. But this episode is clearly earlier than the LBK endings in regions that have so far been formally modelled (the lower Rhineland and the Polish lowlands; Fig. 10), and it is also unclear why such a putative epidemic would strike some LBK communities but not others. In western Hungary, for example, undiminished continuity between LBK and later communities is demonstrable[108].

A less extreme but nonetheless potent scenario has been suggested recently in the biography of the Slovakian site of Vráble[109]. Here it is suggested that there were contradictions between particular farmstead and collective village and neighbourhood interests, which resulted in the construction of an enclosure around one portion of the settlement in the mid-51st century cal BC. Putative rising levels of internal social conflict and emerging social inequality were seen as leading to the abandonment of the site in the 50th century cal BC[110]. This resonates with the history of many other LBK settlements across central and western Europe too numerous to list here individually and offers another way of thinking how the end of the LBK world may have unfolded.

If debate on the circumstances of LBK endings in the Polish lowlands and elsewhere can now be informed by our formally modelled chronologies, what do they imply for our understanding of the post-LBK scenario in the Polish lowlands? That there was extensive change, compared to the LBK context, has already been emphasised above; sparse settlement, changed structures, contacts with hunter-gatherer groups and the emergence of the rondel phenomenon (though the precise date of that has yet to be formally modelled) all speak to that. These alterations seem compatible with major disruptions to the previous way of doing things, if not also with a more or less complete break; indeed, these possibilities are now a convenient way of explaining the series of observed shifts. How sparse post-LBK settlement really was, how such a scenario could have been compatible with the emergence of rondel constructions[111], and whether a prolonged gap of the order of centuries must also be entertained are all important, unresolved questions for future research.

Conclusions

Formal chronological modelling – using a phased sequence of pottery types as prior information combined with a substantial suite of radiocarbon dates on samples from the same features – indicates that the LBK in the Polish lowlands probably lasted from the late 53rd to the late 51st centuries cal BC; within that span, the most intense occupation lay in the first half of the 51st century cal BC. This more compressed history than given by previous accounts is in line with the results of many other formal chronological studies, which have shown that informal date estimates can be importantly wrong, falsely suggesting that phenomena started earlier, lasted longer and ended later than was the case in reality. Not only did the intensity of LBK settlement decline markedly in the second half of the 51st century cal BC, in ceramic phase III, but there was subsequently a gap in occupation, probably to be measured in centuries, before the resumption of sparse settlement of the Late Band Pottery culture. There is as yet no specific evidence from the Polish lowlands to explain this trajectory of growth, collapse, abandonment and very gradual re-establishment. The sequence does, however, match the temporal patterns suggested by other formal chronological modelling of the LBK, and suspected causes have included population boom and bust, climatic downturn, inter-group conflict, conceptual malaise, and epidemic or pandemic disease of some kind. Key challenges for future research are therefore not only to locate more datable samples (including residues on decorated, diagnostic pottery), in order to refine the picture presented here, but also to interrogate the record for specific indications of the possible causes of decline and hiatus. Whatever the outcomes of that search, the study presented here is one more example[112] of a more dynamic and punctuated Neolithic history than has commonly been envisaged.

Acknowledgements: We would like to thank Natalia Piotrowska from the Department of Radioisotopes, Institute of Physics, Silesian University of Technology, for additional information on the radiocarbon dates undertaken in Gliwice, Johannes van der Plicht for similarly resolving

105 Bickle/Whittle 2013; Osztás *et al.* 2016; and references.
106 Rasmussen *et al.* 2015.
107 Meyer *et al.* 2004.
108 e.g. at Alsónyék-Bátaszék; Bánffy *et al.* 2016, fig. 7.
109 Furholt *et al.* 2020.
110 Furholt *et al.* 2020.
111 see Czerniak *et al.* submitted.
112 see also Whittle 2018.

queries relating to the measurements made in Groningen, Paweł Trzeciak for providing additional information on the samples dated in Łódź, and Aldona Mueller-Bieniek for access to then unpublished dates from Ludwinowo 7 obtained within the NCN project (UMO-2013/10/M/HS3/00537[113]). Antony Denaire kindly checked contextual details for some of the dated samples from Herxheim. Jessica Smyth helped with sample selection. Kirsty Harding helped to prepare the figures. We are grateful to Eszter Bánffy, Agnieszka Czekay-Zastawny, Daniela Hofmann and Marek Nowak for critical readings of an earlier draft of the paper. *The Times of Their Lives* was funded by an Advanced Investigator Grant (295412; 2012–17) from the European Research Council, and led by Alasdair Whittle and Alex Bayliss.

References cited in the text

Bánffy *et al.* 2016: E. Bánffy/A. Osztás/K. Oross/I. Zalai-Gaál/T. Marton/É. Á. Nyerges/K. Köhler/A. Bayliss/D. Hamilton/A. Whittle, The Alsónyék story: towards the history of a persistent place. Bericht der Römisch-Germanischen Kommission 94, 2016, 283–318.

Bayliss *et al.* 2016: A. Bayliss /N. Beavan/D. Hamilton/K. Köhler/É. Á. Nyerges/C. Bronk Ramsey/E. Dunbar/M. Fecher/T. Goslar/B. Kromer/P. Reimer/E. Bánffy/T. Marton/K. Oross/A. Osztás/I. Zalai-Gaál/A. Whittle, Peopling the past: creating a site biography in the Hungarian Neolithic. Bericht der Römisch-Germanischen Kommission 94, 2016, 23–91.

– *et al.* 2011: –/J. van der Plicht/C. Bronk Ramsey/G. McCormac/F. Healy/A. Whittle, Towards generational timescales: the quantitative interpretation of archaeological chronologies. In: A. Whittle/F. Healy/A. Bayliss (eds), Gathering time: dating the early Neolithic enclosures of southern Britain and Ireland (Oxford 2011) 17–59.

– *et al.* 2020: –/P. Marshall/M. W. Dee/M. Friedrich/T. J. Heaton/L. Wacker, IntCal20 tree-rings: an archaeological SWOT analysis. Radiocarbon 62, 2020, 1045–1078 (https://doi.org/10.1017/RDC.2020.77)

–/– 2019: –/–, Confessions of a serial polygamist: the reality of radiocarbon reproducibility in archaeological samples. Radiocarbon 61, 2019, 1143–1158 (https://doi.org/10.1017/RDC.2019.55)

–/Whittle 2015: –/A. Whittle, Uncertain on principle: combining lines of archaeological evidence to create chronologies. In: A. Wylie/R. Chapman (eds), Material culture as evidence: learning from archaeological practice (Abingdon 2015) 213–242.

Bickle/Whittle 2013: P. Bickle/A. Whittle: The first farmers of central Europe: diversity in LBK lifeways (Oxford 2013).

Bocquet-Appel *et al.* 2014: J.-P. Bocquet-Appel/J. Dubouloz/R. Moussa/J.-F. Berger/A. Tresset/E. Ortu/J.-D. Vigne/R. Bendrey/S. Bréhard/D. Schwartz/A. Salavert/M. F. Sanchez-Goñi/D. Ertlen/Y. Gauvry/G. Davtian/M. Vander Linden/E. Lenneis/L. Noiret/A. Guillaumont/M. O'Connor, Multi-agent modelling of the trajectory of the LBK Neolithic: a study in progress. In: A. Whittle/P. Bickle (eds), Early farmers: the view from archaeology and science (Oxford 2014) 53–69.

Bogucki 1988: P. Bogucki, Forest farmers and stockherders: early agriculture and its consequences in north-central Europe (Cambridge 1988).

– 1995: –, The Linear Pottery culture of Central Europe: conservative colonists? In: W. K. Barnett/J. W. Hoopes (eds), The emergence of pottery. technology and innovation in ancient societies (Washington 1995) 89–97.

– 2000: –, How agriculture came to north-central Europe. In: T. D. Price (ed.), Europe's first farmers (Cambridge 2000) 197–218.

Boulestin/Coupey 2015: B. Boulestin/A.-S. Coupey, Cannibalism in the Linear Pottery culture: the human remains from Herxheim (Oxford 2015).

Brock/Higham/Bronk Ramsey 2010a: F. Brock/T. Higham/C. Bronk Ramsey, Pre-screening techniques for identification of samples suitable for radiocarbon dating of poorly preserved bones. Journal of Archaeological Science 37, 2010, 855–865.

–/–/Ditchfield/Bronk Ramsey 2010b: –/–/P. Ditchfield/C. Bronk Ramsey, Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 52, 2010, 103–112.

Bronk Ramsey 1995: C. Bronk Ramsey, C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. Radiocarbon 36, 1995, 425–430.

– 2009a: –, Bayesian analysis of radiocarbon dates. Radiocarbon 51, 2009, 37–60.

– 2009b: –, Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51, 2009, 1023–1045.

Buck/Cavanagh/Litton 1996: C. E. Buck/W. G. Cavanagh/C. D. Litton, Bayesian approach to interpreting archaeological data (Chichester 1996).

Casanova *et al.* 2020: E. Casanova/T. D. J. Knowles/A. Bayliss/J. Dunne/M. Z. Barański/A. Denaire/P. Lefranc/S. di Lernia/M. Roffet-Salque/J. Smyth/A. Barclay/T. Gillard/E. Claβen/B. Coles/M. Ilett/C. Jeunesse/M. Krueger/A. Marciniak/S. Minnitt/R. Rotunoo/P. van de Velde/I. van Wijk/J. Cotton/A. Daykin/R. P. Evershed, Accurate compound-specific ^{14}C dating of archaeological pottery vessels. Nature 580, 2020, 506–510 (https://doi.org/10.1038/s41586-020-2178-z)

Cladders/Stäuble 2003: M. Cladders/H. Stäuble, Das 53. Jahrhundert v. Chr.: Aufbruch und Wandel. In: J. Eckert/U. Eisenhauer/A. Zimmermann (eds), Archäologische Perspektiven: Analysen und Interpretationen im Wandel. Festschrift für Jens Lüning zum 65. Geburtstag (Rahden 2003) 491–503.

Czekaj-Zastawny *et al.* 2020: A. Czekaj-Zastawny/A. Rauba-Bukowska/A. Kukułka/B. Kufel-Diakowska/M. Lityńska-Zając/M. Moskal-del Hoyo/J. Wilczyński, The earliest farming communities north of the Carpathians: the settlement at Gwoździec site 2. PLOS One January 15, 2020 (doi.org/10.1371/journal.pone.0227008)

Czerniak 1988: L. Czerniak, The neolithisation of the Kuyavian communities. Archaeologia Polona 28, 1988, 49–69.

113 Nowak *et al.* 2017.

– 1990: –, First settlement of the oldest phase of the Linear Pottery culture on the Polish lowland: Grabie 4, Włocławek voivodeship. Archaeologia Interregionalis 11, 1990, 49–62.
– 1994: –, Wczesny i środkowy okres neolitu na Kujawach 5400–3650 p.n.e. (Poznań 1994).
– 1998: –, The first farmers. In: M. Chłodnicki/L. Krzyżaniak (eds), Pipeline of archaeological treasures (Poznań 1998) 23–36.
– 2004: –, Kultury z cyklu ceramiki wstęgowej. In: J. Bednarczyk/A. Kośko (eds), Od długiego domu najstarszych rolników do dworu staropolskiego. Wyniki badań archeologicznych na trasach gazociągów Mogilno-Włocławek i Mogilno-Wydartowo (Poznań 2004) 195–233.
– 2012: –, After the LBK. Communities of the 5th millennium BC in north-central Europe. In: R. Gleser/V. Becker (eds), Mitteleuropa im 5. Jahrtausend vor Christus. Beiträge zur Internationalen Konferenz in Münster 2010 (Berlin 2012) 151–174.
– *et al.* 2016a: –/A. Marciniak/C. Bronk Ramsey/E. Dunbar/T. Goslar/A. Barclay/A. Bayliss/A. Whittle, House time: Neolithic settlement development at Racot during the fifth millennium cal BC in the Polish lowlands. Journal of Field Archaeology. Online (August 2016) http://www.tandfonline.com/doi/full/10.1080/00934690.2016.1215723
– *et al.* submitted: –/A. Matuszewska/M. Dziewanowski/M. Jakubczak/A. Marciniak/K. Michalak/L. Połczyński/L. Pospieszny/K. Pyżewicz/R. Ryndziewicz, Neolityczny rondel w Nowym Objezierzu i jego kontekst osadniczy. Wstępne wyniki badań w latach 2017–2020. Materiały Zachodniopomorskie submitted.
–/Pyzel 2016: –/J. Pyzel, Being at home in the Early Chalcolithic. The longhouse phenomenon in the Brześć Kujawski culture in the Polish Lowlands. Open Archaeology 2, 2016, 97–114.
–/–/Wąs 2016b: –/–/M. Wąs, The beginnings of the Neolithic in eastern Pomerania: a Linear Pottery culture settlement at site 13, Kościelna Jania, Smętowo graniczne commune. Sprawozdania Archeologiczne 68, 2016, 193–222.
Denaire *et al.* 2017: A. Denaire/P. Lefranc/J. Wahl/C. Bronk Ramsey/E. Dunbar/T. Goslar/A. Bayliss/N. Beavan/P. Bickle/A. Whittle, The cultural project: formal chronological modelling of the Early and Middle Neolithic sequence in Lower Alsace. Journal of Archaeological Method and Theory 2017 (doi: 10.1007/s10816-016-9307-x).
Domańska 1988: L. Domańska, Recepcja małopolskich surowców krzemiennych wśród kujawskich społeczeństw cyklu wstęgowego. In: A. Cofta-Broniewska (ed.), Kontakty pradziejowych społeczeństw Kujaw z innymi ludami Europy Studia i materialy do dziejów Kujaw (Inowrocław 1988) 281–291.
– 1995: –, Geneza krzemieniarstwa kultury pucharów lejkowatych na Kujawach (Łódź 1995).
Downey *et al.* 2014: S. S. Downey/E. Bocaege/T. Kerig/K. Edinborough/S. Shennan, The Neolithic demographic transition in Europe: correlation with juvenility index supports interpretation of the summed calibrated radiocarbon date probability distribution (SCDPD) as a valid demographic proxy. PLOS One 9/8, 2014, 1–10.
Furholt *et al.* 2020: M. Furholt/N. Müller-Scheeßel/M. Wunderlich/I. Cheben/J. Müller, Communality and discord in an Early Neolithic settlement agglomeration: the LBK site of Vráble, southwest Slovakia. Cambridge Archaeological Journal 30, 2020, 469–489.
Gronenborn 2012: D. Gronenborn, Das Ende von IRD 5b: Abrupte Klimafluktuationen um 5100 cal BC und der Übergang vom Alt- zum Mittelneolithikum im westlichen Mitteleuropa. In: R. Smolnik (ed.), Siedlungsstruktur und Kulturwandel in der Bandkeramik (Dresden 2012) 241–250.
Grygiel 2004: R. Grygiel, Neolit i początki epoki brązu w rejonie Brześcia Kujawskiego i Osłonek I. Wczesny neolit. Kultura ceramiki wstęgowej rytej (Łódź 2004).
Hajdas 2019: I. Hajdas, Radiocarbon dating of human bones from Herxheim. In: A. Zeeb-Lanz (ed.), Ritual destruction in the Early Neolithic – the exceptional site of Herxheim (Palatinate, Germany). Forschungen zur Pfälzischen Archäologie 8,2 (Speyer 2019) 279–283.
Jakucs *et al.* 2016: J. Jakucs/E. Bánffy/K. Oross/V. Voicsek/C. Bronk Ramsey/E. Dunbar/B. Kromer/A. Bayliss/D. Hofmann/P. Marshall/A. Whittle, Between the Vinča and Linearbandkeramik worlds: the diversity of practices and identities in the 54th–53rd centuries cal BC in southwest Hungary and beyond. Journal of World Prehistory 29, 2016, 267–336.
Kabaciński 2010: J. Kabaciński, Przemiany wytwórczości krzemieniarskiej społeczności kultur wstęgowych strefy wielkodolinnej Niżu Polskiego (Poznań 2010).
– *et al.* 2015: –/I. Sobkowiak-Tabaka/Z. Kasztovszky/S. Pietrzak/J. J. Langer/K. Biró/B. Maróti, Transcarpathian influences in the Early Neolithic of Poland. A case study of Kowalewko and Rudna Wielka sites. Acta Archaeologica Carpathica 50, 2015, 5–32.
Kaufmann/York 1985: D. Kaufmann/K.-H. York, Zur Verbreitung des Elster-Saale-Verzierungsstiles der jüngeren Linienbandkeramik. Jahresschrift für mitteldeutsche Vorgeschichte 68, 1985, 75–91.
Kerig 2005: T. Kerig, Zur relativen Chronologie der westdeutschen Bandkeramik. In: J. Lüning/C. Frirdich/A. Zimmermann (eds), Die Bandkeramik im 21. Jahrhundert. Symposium in der Abtei Brauweiler bei Köln vom 16.9.–19.9.2002 (Rahden 2005) 125–138.
Kirkowski 1990a: R. Kirkowski, Boguszewo, gmina Gruta, województwo toruńskie, stanowisko 43b, obiekty 11 i 23. In: D. Jankowska (ed.), Z badań nad chronologią absolutną stanowisk neolitycznych z ziemi chełmińskiej (Toruń 1990) 26–31.
– 1990b: –, Wieldządz, gmina Płużnica, województwo toruńskie, stanowisko 31, obiekt 2. In: D. Jankowska (ed.), Z badań nad chronologią absolutną stanowisk neolitycznych z ziemi chełmińskiej (Toruń 1990) 20–22.
– 1993: –, Wielkie Radowiska, gm. Dębowa Łąka, stan. 22 i 24 – Osada kultury ceramiki wstęgowej rytej. Ze studiów nad kurkocińskim mikroregionem osadniczym kultury ceramiki wstęgowej rytej. In: J. Chudziakowa (ed.), Badania archeologiczne Ośrodka Toruńskiego w latach 1989–1992 (Toruń 1993) 15–21.
– 1994: –, Kultura ceramiki wstęgowej rytej na ziemi chełmińskiej. Zarys systematyki chronologiczno-genetycznej. In: L. Czerniak (ed.), Neolit i początki epoki brązu na ziemi chełmińskiej (Grudziądz 1994) 57–99.
Kowalski 2003: K. Kowalski, Przyczynek do poznania kultury ceramiki wstęgowej rytej w przyodrzańskiej części Pomorza Zachodniego. In: T. Galiński/E. Wilgocki (eds), Res et fontes. Ksiega jubileuszowa Eugeniusza Cnotliwego (Szczecin 2003) 57–68.

Kozłowski 1988: J. K. Kozłowski, Z problematyki interregionalnych powiązań Kujaw w młodszej epoce kamienia. In: A. Cofta-Broniewska (ed.), Kontakty pradziejowych społeczeństw Kujaw z innymi ludami Europy (Inowrocław 1988) 45–54.

Kruk/Milisauskas 1999: J. Kruk/S. Milisauskas, Rozkwit i upadek społeczeństw rolniczych neolitu (Warszawa 1999).

Krystek *et al.* 2011: M. Krystek/H. Młodecka/K. Polański/M. Szydłowski, Neolityczne narzędzia z metabazytów typu Jizerské hory (Masyw Czeski) na obszarze Polski. Biuletyn Państwowego Instytutu Geologicznego 444, 2011, 113–123.

Kukawka 1997: S. Kukawka, a rubieży środkowoeuropejskiego świata wczesnorolniczego, Uniwersytet Mikołaja Kopernika (Toruń 1997).

Kulczycka-Leciejewiczowa 1979: A. Kulczycka-Leciejewiczowa, Pierwsze społeczeństwa rolnicze na ziemiach polskich. Kultury kręgu naddunajskiego. In: W. Hensel (ed.), Prahistoria ziem polskich, t. II. Neolit (Wrocław, Warszawa, Kraków, Gdańsk 1979) 19–164.

Link 2014a: T. Link, Welche Krise? Das Ende der Linienbandkeramik aus östlicher Perspektive. In: T. Link/D. Schimmelpfennig (eds), No future? Brüche und Ende kultureller Erscheinungen. Fallbeispiele aus dem 6.–2. Jahrtausend v. Chr. (Kerpen-Loogh 2014) 95–111.

– 2014b: –, Gewaltphantasien? Kritische Bemerkungen zur Diskussion über Krieg und Krise am Ende der Bandkeramik. In: T. Link/H. Peter-Röcher (eds), Gewalt und Gesellschaft. Dimensionen der Gewalt in ur- und frühgeschichtlicher Zeit/Violence and society. Dimensions of violence in pre- and protohistoric times (Bonn 2014) 271–286.

Małecka-Kukawka 1992: J. Małecka-Kukawka, Krzemieniarstwo społeczności wczesnorolniczych ziemi chełmińskiej (2 połowa VI–V tysiąclecie p.n.e.) (Toruń 1992).

Marciniak 2008: A. Marciniak, Communities, households and animals: convergent developments in central Anatolian and central European Neolithic. Documenta Praehistorica 35, 2008, 93–109.

– 2013: –, The society in the making: the house and the household in the Danubian Neolithic of the central European lowlands. In: T. Kerig/A. Zimmermann (eds), Economic archaeology: from structure to performance in European archaeology (Bonn 2013) 47–63.

– *et al.* 2015: –/I. Sobkowiak-Tabaka/M. Bartkowiak/M. Lisowski, Kopydłowo, stanowisko 6. Osady neolityczne z pogranicza Kujaw i Wielkopolski (Pękowice, Poznań 2015).

Meyer/Kürbis/Alt 2004: C. Meyer/O. Kürbis/K. W. Alt, Das Massengrab von Wiederstedt, Ldkr. Mansfelder Land. Auswertung und Gedanken zur Deutung im Kontext der Linienbandkeramik. Jahresschrift für Mitteldeutsche Vorgeschichte 88, 2004, 31–66.

– *et al.* 2015: –/C. Lohr/D. Gronenborn/K. W. Alt, The massacre mass grave of Schöneck-Kilianstädten reveals new insights into collective violence in Early Neolithic central Europe. Proceedings of the National Academy of Sciences 2015 (doi/10.1073/pnas.1504365112)

– *et al.* 2014: –/–/O. Kürbis/V. Dresely/W. Haak/C. J. Adler/D. Gronenborn, Mass graves of the LBK: patterns and peculiarities. In: A. Whittle/P. Bickle (eds), Early farmers: the view from archaeology and science (Oxford 2014) 307–325.

– *et al.* 2018: –/C. Knipper/N. Nicklisch/A. Münster/O. Kürbis/V. Dreseley/H. Meller/K. W. Alt, Early Neolithic executions indicated by clustered cranial trauma in the mass grave of Halberstadt, Nature Communications 9, 2018, 2472 (doi 10.1038/x41467-018-04773-w)

Milisauskas/Kruk 1989: S. Milisauskas/J. Kruk, Neolithic economy in central Europe. Journal of World Prehistory 3, 1989, 403–446.

Muzolf/Kittel/Muzolf 2012: B. Muzolf/P. Kittel/P. Muzolf, Sprawozdanie z prac badawczych na wielokulturowym kompleksie osadniczym w miejscowości Smólsk, stanowisko 2/10, gm. Włocławek, woj. kujawsko-pomorskie. In: S. Kadrow (ed.), Raport 2007–2008. Tom I (Warszawa 2012) 43–64.

Nowak *et al.* 2017: M. Nowak/M. Moskal-Del Hoyo/A. Mueller-Bieniek/M. Lityńska-Zając/K. Kotynia, Benefits and weaknesses of radiocarbon dating of plant material as reflected by Neolithic archaeological sites from Poland, Slovakia and Hungary. Geochronometria 44, 2017, 188–201.

Orschiedt/Haidle 2012: J. Orschiedt/M. N. Haidle, Violence against the living, violence against the dead on the human remains from Herxheim, Germany. Evidence of a crisis and mass cannibalism? In: R. Schulting/L. Fibiger (ed.), Sticks, stones, and broken bones: Neolithic violence in a European perspective (Oxford 2012) 121–137.

Osztás *et al.* 2016: A. Osztás/I. Zalai-Gaál/E. Bánffy/T. Marton/É. Á. Nyerges/K. Köhler/K. Somogyi/Z. Gallina/C. Bronk Ramsey/E. Dunbar/B. Kromer/A. Bayliss/D. Hamilton/P. Marshall/A. Whittle, Coalescent community at Alsónyék: the timings and duration of Lengyel burials and settlement. Bericht der Römisch-Germanischen Kommission 94, 2016, 179–282.

Pechtl/Land 2019: J. Pechtl/A. Land, Tree rings as a proxy for seasonal precipitation variability and Early Neolithic settlement dynamics in Bavaria, Germany. PLoS ONE 14/1, 2019: e0210438. https://doi.org/10.1371/journal.pone.0210438

Płaza 2016: D. Płaza, Osadnictwo młodszej epoki kamienia i wczesnej epoki brązu. In: W. Siciński/D. Płaza/P. Papiernik (eds), Ratownicze badania archeologiczne na stanowisku 10 w Kruszynie, pow. Włocławek, woj. kujawsko-pomorskie (trasa autostrady A1) (Łódź 2016) 21–136.

Přichystal 2015: A. Přichystal, Key raw materials for Neolithic shoe-last celts and axes in Central Europe: their sources and distribution. In: T. Kerig/S. Shennan (eds), Connecting networks: characterising contact by measuring lithic exchange in the European Neolithic (Oxford 2015) 1–7.

Pyzel 2006: J. Pyzel, Die Besiedlungsgeschichte der Bandkeramik in Kujawien. Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz 53, 2006, 1–57.

– 2009: –, Migration und Kontakte in der Bandkeramik Kujawiens. In: A. Krenn-Leeb/H.-J. Beier/E. Claßen,/F. Falkenstein/S. Schwenzer (eds), Mobilität, Migration und Kommunikation in Europa während des Neolithikums und der Bronzezeit (Langenweißbach 2009) 49–52.

– 2010: –, Historia osadnictwa społeczności kultury ceramiki wstęgowej rytej na Kujawach (Gdańsk 2010).

– 2013: –, Different models of settlement organisation in the Linear Band Pottery Culture – an example from Ludwinowo 7 in eastern Kuyavia. In: S. Kadrow/P. Włodarczak (eds), Environment and subsistence – forty years after Janusz Kruk's "Settlement studies …" (Rzeszów, Bonn 2013) 85–93.

– 2014: –, Findet sich im Norden Polens die älteste Bandkeramik? Probleme der Periodisierung der polnischen Linearbandkeramik. In: T. Link/D. Schimmelpfennig (eds), No future?

Brüche und Ende kultureller Erscheinungen. Fallbeispiele aus dem 6.–2. Jahrtausend v. Chr. (Kerpen, Loogh 2014) 83–93.
– 2019: –(ed.), Ludwinowo, stanowisko 7. Osada neolityczna na Kujawach. Ludwinowo, site 7. Neolithic settlement in Kuyavia. Ocalone Dziedzictwo Archeologiczne 8 (Pękowice, Gdańsk 2019).
–/Wąs 2018: J. Pyzel/M. Wąs, Jurassic-Cracow flint in the LBK in Kuyavia, Chełmno Land and the Lower Vistula region. In: D. Werra/M. Woźny (eds), Between history and archaeology: papers in honor of Jacek Lech (Oxford 2018) 181–194.
Rasmussen *et al.* 2015: S. Rasmussen/M. K Allentoft/K. Nielsen/ L. Orlando/M. Sikora/K.-G. Sjogren/A. G. Pedersen/ M. Schubert/A. Van Dam/C. M. O. Kapel/H. B. Nielsen/S. Søren Brunak/P. Pavel Avetisyan/A. Epimakhov/M. K. Khalyapin/ A. Gnuni/A. Kriiska/I. Lasak/M. Metspalu/V. Moiseyev/ A. Gromov/D. Pokutta/L. Saag/L. Varul/L. Yepiskoposyan/ T. Sicheritz-Ponten/R. A. Foley/M. M. Lahr/R. Nielsen/ K. Kristiansen/E. Willerslev, Early divergent strains of Yersinia pestis in Eurasia 5,000 years ago. Cell 163, 2015, 571–582.
Regenye *et al.* 2020: ´J. Regenye/E. Bánffy/P. Demján/J. Ebert/ A. Osztás/C. Bronk Ramsey/E. Dunbar/R. Friedrich/A. Bayliss/ N. Beavan/B. Gaydarska/A. Whittle, Narratives for Lengyel funerary practice. Bericht der Römisch-Germanischen Kommission 97, 2020, 5–80.
Reimer *et al.* 2020: P. J. Reimer/W. E. N. Austin/E. Bard/A. Bayliss/ P. Blackwell/C. Bronk Ramsey/M. Butzin/H. Cheng/R. I. Edwards/M. Friedrich/P. M. Grootes/T. P. Guilderson/I. Hajdas/ T. J. Heaton/A. G. Hogg/K. A. Hughen/B. Kromer/ S. W. Manning/R. Muscheler/J-. G. Palmer/C. Pearson/ J. van der Plicht/R. W. Reimer/D. A. Richards/E. M. Scott/ J. R. Southon/C. S. M. Turney/L. Wacker/F. Adolphi/ U. Büntgen/C. Capano/S. Fahrni/A. Fogtmann-Schultz/ R. Friedrich/S. Kudsk/F. Miyake/J. Olsen/F. Reinig/ M. Sakamoto/A. Sookdeo/S. Talamo, The IntCal20 Northern Hemispheric radiocarbon calibration curve (0–55 kcal BP). Radiocarbon 62, 2020, 725–757 (doi.org/10.1017/RDC.2020.41)
Riedhammer 2019: K. Riedhammer, The radiocarbon dates from Herxheim and their archaeological interpretation. In: A. Zeeb-Lanz (ed.), Ritual destruction in the Early Neolithic – the exceptional site of Herxheim (Palatinate, Germany). Forschungen zur Pfälzischen Archäologie 8,2 (Speyer 2019) 285–303.
Shennan 2013: S. Shennan, Demographic continuities and discontinuities in Neolithic Europe: evidence, methods and implications. Journal of Archaeological Method and Theory 20, 2013, 300–311.
– 2018: –, The first farmers of Europe: an evolutionary perspective (Cambridge 2018).
– *et al.* 2013: –/S. S. Downey/A. Timpson/K. Edinborough/ S. Colledge/T. Kerig/K. Manning/M. G. Thomas, Regional population collapse followed initial agriculture booms in mid-Holocene Europe. Nature Communications 4, 2013 (doi: 10.1038, www.nature.com/ncomms/2013/131001/ ncomms3486/full/ncomms3486.html)
Sosnowski 1990: W. Sosnowski, Stolno, gmina Stolno, województow toruńskie, stanowisko 2, jama 2. In: D. Jankowska (ed.), Z badań nad chronologią absolutną stanowisk neolitycznych z ziemi chełmińskiej (Toruń 1990) 15–19.
Spatz 2003: H. Spatz, Hinkelstein: eine Sekte als Initiator des Mittelneolithikums? In: J. Eckert/U. Eisenhauer/A. Zimmermann (eds), Archäologische Perspektiven. Analysen und Interpretationen im Wandel. Festschrift für Jens Lüning zum 65. Geburtstag (Rahden 2003) 574–587.
Strien/Gronenborn 2005: H.-C. Strien/D. Gronenborn, Klima- und Kulturwandel während des mitteleuropäischen Altneolithikums (58./57.–51./50. Jahrhundert v. Chr.). In: D. Gronenborn (ed.), Klimaveränderung und Kulturwandel in neolithischen Gesellschaften Mitteleuropas, 6700–2200 v. Chr. (Mainz 2005) 131–149.
Stuiver/Polach 1977: M. Stuiver/H. A. Polach,Reporting of ^{14}C data. Radiocarbon 19, 1977, 355–363.
Szydłowski 2015: M. Szydłowski, Surowce skalne użytkowane przez społeczności młodszej epoki kamienia na Niżu Polskim. Uwagi o statystykach w świetle ostatnich badań. Śląskie Sprawozdania Archeologiczne 57, 2015, 65–80.
Timpson/Manning/Shennan 2015: A. Timpson/K. Manning/ S. Shennan, Inferential mistakes in population proxies: a response to Torfing's "Neolithic population and summed probability distribution of ^{14}C-dates". Journal of Archaeological Science 63, 2015, 199–202.
Torfing 2015a: T. Torfing, Neolithic population and summed probability distribution of ^{14}C-dates Journal of Archaeological Science 63, 2015, 193–198.
– 2015b: –, Layers of assumptions: a reply to Timpson, Manning and Shennan. Journal of Archaeological Science 63, 2015, 203–205.
Vogel/Waterbolk. 1972: J. C. Vogel/H. T Waterbolk, Groningen radiocarbon dates X. Radiocarbon 14, 1972, 6–110.
Ward/Wilson 1978: G. K. Ward/S. R. Wilson, Procedures for comparing and combining radiocarbon age determinations: a critique. Archaeometry 20, 1978, 19–31.
Werra 2010: D. Werra, Longhouses and long-distance contacts in the Linearbandkeramik communities on the north-east border of the oecumene: "à parois doubles" in Chełmno Land (Poland). Anthropologia et Praehistorica 121, 2010, 121–142.
Whittle 2018: A. Whittle, The times of their lives: hunting history in the archaeology of Neolithic Europe (Oxford 2018).
Wylie 2002: A. Wylie, Thinking with things: essays in the philosophy of archaeology (Berkeley 2002).
Zeeb-Lanz 2009: A. Zeeb-Lanz, Gewaltszenarien oder Sinnkrise? Die Grubenanlage von Herxheim und das Ende der Bandkeramik. In: A. Zeeb-Lanz (ed.), Krisen – Kulturwandel – Kontinuitäten: zum Ende der Bandkeramik in Mitteleuropa (Rahden 2009) 87–101.
–2016: – (ed.), In: A. Zeeb-Lanz (ed.), Ritual destruction in the Early Neolithic – the exceptional site of Herxheim (Palatinate, Germany). Forschungen zur Pfälzischen Archäologie 8,1 (Speyer 2016).
– 2019: –, The Herxheim ritual enclosure: a synthesis of results and interpretative approaches. In: A. Zeeb-Lanz (ed.), Ritual destruction in the Early Neolithic – the exceptional site of Herxheim (Palatinate, Germany). Forschungen zur Pfälzischen Archäologie 8,2 (Speyer 2019) 423–482.

Supplemental Material: The online version of this article offers supplementary material (https://doi.org/10.1515/pz-2022-2041).