House time: Neolithic settlement development at Racot during the 5th millennium CAL B.C. in the Polish lowlands

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The settlement of Racot 18 in the western Polish lowlands is used as a case study in the investigation of continued development and expansion following initial Neolithic beginnings, and in the formal chronological modeling, in a Bayesian framework, of settlement development. The site belongs to the Late Lengyel Culture of the later 5th millennium CAL B.C., and represents the intake of new land following earlier initial colonization. The formally estimated chronology for the settlement suggests individual house biographies spanned from as little as a generation to over a century; distinctive substantial buildings from late in the sequence may have lasted longest. Racot 18 is compared to its formally modeled context of the later 5th millennium CAL B.C.

Keywords: Neolithic settlement development, Polish lowlands, houses, formal chronological modeling, house duration

Introduction

Much ink continues to be spilled on debate about Neolithic beginnings, in Europe as elsewhere, but often there is less intensive debate about subsequent developments, perhaps because they are perceived as somehow less significant than initial transformations and as likely to follow more or less the same course everywhere. Neolithic settlement is often thought to have been sedentary, witnessed in the construction of substantial houses, but the specific durations of houses are often taken for granted. This paper is about these two themes, through the lens of a case study in the lowlands of Poland, which uses formal chronological modeling in a Bayesian framework.

For both themes, time is of the essence. For virtually all archaeologies dependent on radiocarbon dating, the default procedure has been an uneasy and varying combination of stratigraphy, associations, and material typology (and less frequently seriation based on correspondence analysis), combined with the visual inspection of calibrated radiocarbon dates, on samples which often have an uncertain relationship to their contexts. We should no longer be content with this "fuzzy prehistory". From more precise chronological resolution comes better dating, and from this in turn a better sense of duration and the tempo of change (Bayliss *et al*. 2007, 2011; Bayliss and Whittle 2015). This paper, about two themes important to a specific time and place, is one of a series which aims to encourage prehistorians more generally to embrace formal chronological modeling for the resulting benefits of robustness and precision, which in turn can lead to more detailed understandings of agency and change.

The development of houses and households in the Polish lowlands

The Danubian Neolithic of the Polish lowlands: Context

The first Neolithic communities in the lowlands of central Europe, of the *Linearbandkeramik* Culture or LBK, probably appeared ca. 5400 CAL B.C., shortly after they emerged in the loess

uplands (Czerniak 1998: 23; Milisauskas and Kruk 1989: 404). LBK sites were scattered throughout the Polish lowlands—in Kujavia, Chełmno Land and Pyrzyce along the lower Oder—almost exclusively on fertile rich brown and black soils, similar in quality to the loess soil of the uplands (FIG. 1). The period following the demise of the LBK in this region brought about significant developments of local communities.

The post-LBK period—the first 400–500 years after the end of the LBK—in all the main regions of the Polish lowlands marked a complete disintegration of the preceding LBK arrangements and the discontinuous development of new forms of spatial organization (FIG. 1). This is seen in different and diverse traditions of pottery manufacture, which have served as a foundation for distinguishing different cultural groups. Accordingly, the Late Band Pottery Culture (LBPC) was proposed for Kujavia and Greater Poland, the Stroked Band Pottery Culture for Western Pomerania and Lower Silesia, and the Malice Culture for Little Poland. All these entities from the first half of the 5th millennium CAL B.C. can be labeled as the post-LBK cultures. The LBPC settlements were largely dispersed and appeared only in the form of individual farmsteads. Only two houses from this period (Białcz Stary in Wielkopolska and Konary in Kujavia) have been found. Other sites comprised single pits and hearths associated with some kind of light dwelling structures. At the same time, the period marked the first spread of local groups beyond the early Neolithic enclaves. Local farming groups now appeared across the lowlands, from Kujavia in the east to Lower Silesia in the southwest and Pyrzyce in the northwest.

The second half of the 5th millennium CAL B.C. brought a completely different picture of lowland Neolithic communities with the Lengyel Culture. As the emergence of this tradition postdated similar developments farther to the south (in Slovakia and Hungary, for example), it is appropriate to refer to this period in the Polish lowlands as the Late Lengyel. The beginning of this period brought a dramatic turn from the network of small sites in the

first part of the 5th millennium CAL B.C. to the appearance of large (some up to 6–7 ha) and densely occupied settlements. Numerous settlements of this kind have been identified in the Polish lowlands. Prominent examples in Kujavia include Brześć Kujawski, Osłonki, Krusza Zamkowa, Kościelec Kujawski and Dobre (Czerniak 2002; Grygiel 2008; Grygiel and Bogucki 1997). Brześć Kujawski 4 consisted of over 50 trapezoidal longhouses from a few phases of occupation, along with outbuildings, different kinds of pits, and human graves. The houses were 13–40 m long, with interiors divided into three parts (Bogucki and Grygiel 1981, 1993). Thirty-one longhouses were recognized at Osłonki 1, the only settlement of this culture excavated to date that was surrounded by ditches (Grygiel and Bogucki 1997; Grygiel 2008). Burials appeared at many large settlements and were highly differentiated in terms of body position and grave goods (Czerniak and Pyzel 2013). A majority of these mainly single burials had "rich" grave goods. Burials of men and women were distinctively different. The presence of exotic goods, in addition to sex differences, implies the beginnings of social differentiation as well as new exchange networks.

The Late Lengyel house and household

LBK houses had been solid rectangular constructions, 7–45 m long and 5–7 m wide (Marciniak 2013). Late Lengyel longhouses were normally 20–35 m long and trapezoidal in shape, although some rectangular structures remained. Their walls were made of oak posts, closely set in substantial bedding trenches up to 1.5 m deep (Grygiel 2008). This eliminated the large number of interior posts characteristic of the LBK house. Late Lengyel houses were usually oriented northwest-southeast, like their rectangular LBK predecessors, with a narrow northern end and wide southern end. Entrances were usually located at the broader end, facing east or southeast.

The house itself was now associated with a set of features, including activity areas, ovens, storage pits, disposal pits/middens, and burials, which have been used to imply the presence of the autonomous household. Accordingly, the basic social entity has been seen as the extended family with strong kinship identities residing in discrete buildings with most domestic and some craft activities performed within the residence (Bogucki and Grygiel 1981; Grygiel 1986; Marciniak 2000, 2005, 2008, 2014). The inhabitants of individual households are believed to have specialized in some craft production (Grygiel 1986). They were the primary unit of decision-making but they were not completely independent (Bogucki 2000). These developments may imply that Late Lengyel communities in the lowlands were no longer characterized by a communal self-identity, as in the LBK. For the first time, individual and kinship identities became strongly articulated, with extended families forming various different alliances. These patterns are widespread in the Polish lowlands.

The Racot settlement

Racot 18 and 25, belonging to the Late Lengyel Culture, lay on opposite sides of a small stream in the western Polish lowlands south of Poznań, an area whose first Neolithic settlements appear to belong to the later 5th millennium CAL B.C. (FIGS. 1, 2). They were excavated by Lech Czerniak from 1984–1987. Racot 18 was investigated over 0.33 ha, revealing 12–14 longhouses, numerous external and internal pits, and one burial (FIG. 2). Racot 25 had only one longhouse, and possibly the remains of two others, located in an area of ca. 3 ha exposed in two sondages (2.5 × 50 m) and two small extensions. Both settlements arguably comprised one dwelling complex each, but their functions may have differed. Racot 18 was residential, while Racot 25 was used for a range of economic activities, as a number of relatively small loam pits have been exposed here, which may be interpreted as “sondages” to search for good-quality clay and stones.

Only about 10% of either settlement has been excavated. Racot 18 may extend over ca. 3 ha, and cover an area of ca. 400 × 75 m. An estimated 25–30% of its houses have been exposed and studied, and the total number of houses could have been between 40–56. Racot 18 was occupied over three, possibly four occupation phases, as indicated by its stratigraphy. The most complicated stratigraphic relations have been revealed in the northeastern part of the site, where three superimposed structures were exposed. House 106 was earlier than House 211, yet later than the pit-cellar Feature 107. Close by, House 133, paired with House 134, is believed to be earlier than its counterpart, as indicated by its construction. At the same time, pottery from Feature 107 indicates that it was in use at the same time as Houses 133 and/or 134. Analysis of this part of the settlement seems to imply the presence of four phases of occupation: (1) House 133, (2) House 134 (3) House 106, and (4) House 211 (FIG. 2).

Racot 18 houses were more than 30 m long (House 12: 39.7 m; House 32: 36.0 m; Houses 1 and 88: more than 30 m), making them the longest constructions of this type in the Late Lengyel Culture. Individual houses were of different lengths and alignment but similar in terms of form and construction. There were two major types: (1) houses with segmented and shallow bedding trenches (e.g., House 88; Houses 133 and 134) and (2) houses with continuous and deep (up to 1–1.5 m) bedding trenches (e.g., Houses 1 and 12; Houses 106 and 211). The former group is earlier in date, as indicated by the distinctive house shape and size, as well as diagnostic pottery (FIG. 3). This is further corroborated by similar structures in Kujavia (Czerniak 1980; Grygiel 2008). The oldest construction at Racot 18 was House 133, as indicated by its proportions and clearly trapezoidal shape. Some houses from this phase had oval/rectangular internal pits in their centers next to the eastern walls, and interpreted as small cellars (e.g., Features 80, 135, and 203). They were filled with refuse, particularly fragments of pottery, lithics, and animal bones.

Longhouses, from the early phase in particular, were flanked by clusters of loam pits. These contained residues of ceremonial consumption, a pattern known from the Early Neolithic (Marciniak 2005, 2014). Continuous, deep bedding trenches were characteristic of the late phase of the settlement occupation. The houses were more solidly constructed and had small rooms/annexes attached to them (Houses 12 and 106, and probably House 211). It is unclear whether these annexes were constructed at the same time as the houses or were added later. In any case, they indicate a departure from the standardized mode of construction and maintenance. Similar houses have also been identified at Brześć Kujawski 4 (Grygiel 2008). Out of the early constructions, House 12 is of particular significance due to its length (ca. 40 m), its unique west-east alignment, and the presence of a side room. The house was burned and later reconstructed, as indicated by a ca. 27 m-long bedding trench dug next to the original one. Consequently, the wall became significantly curvilinear. House 106 from the same phase also had a different, NNE-SSW, alignment. In general, the final phase of use of the Racot settlement was marked by a significant departure from the previously dominant rules.

Of particular significance is House 1, which was burned shortly after construction. This is indicated by an internal cellar (Feature 49), which was full of clay debris, probably originating from the burned wall. One could argue that the fire that had destroyed House 1 was not linked to the fire that partly destroyed House 12 (see above). It is also difficult to decide whether this was an accidental or deliberate incident.

Paired longhouses are represented by Houses 32 and 88, Houses 133 and 134, and probably Houses 19 and 64. Placed parallel to each other, it is unclear whether these house pairs were built and used at the same time or represent two superimposed dwelling structures built by subsequent generations. However, a combination of pottery typology and formal house characteristics implies that each house pair was occupied asynchronously. House 88,

with its discontinuous and shallow bedding trenches, seems to be earlier than House 32, with continuous and more substantial wall trenches, and is further corroborated by different pottery in both houses. A distinctively trapezoidal shape and proportions imply that House 133 was probably earlier than House 134. Both Houses 19 and 64 were constructed similarly but their alignments differed, which may also point to asynchronous use. Only small fragments of this pair have been revealed, as they were destroyed by the later House 12. This pair was notably small in size, making them comparable to earlier houses from Brześć Kujawski 4 (Grygiel 2008).

A number of other features also flanked the longhouses. These external pits are reminiscent of cellars located inside the house in terms of their size, shape, and fill (Features 40, 53, 101, 107, 111, and 220). They may have also been used for storage. Of these, pit Feature 107 was surrounded by postholes indicating some kind of light construction. No hearths have been found at the Racot settlement.

Significant social changes at Racot are also manifested in burial practices (Marciniak 2014). One burial was found at the settlement inside House 88 (Grave 82) but was interred much later, after the house itself was abandoned. A 30–35-year-old woman was buried in a crouched position on her right side with her head facing south, in accordance with general rules from the preceding period, though the right-side position typically had been reserved for men both in the Early Neolithic and the Late Lengyel in the lowlands (Czerniak and Pyzel 2013). In contrast to LBK burials, the Racot burial had a number of grave goods, including a necklace of animal teeth, copper beads, 18 richly ornamented armlets made of cow ribs, a hip belt of *Unio* shells, and two pots (FIG. 4).

Modeling house time at Racot

Previous dating

Bone samples from Racot 18 were submitted in 1987 for conventional radiocarbon dating to the Gliwice Radiocarbon Laboratory. Most of these results, when calibrated, fall in the second half of the 5th millennium CAL B.C. To refine the chronology for the settlement, a further series of animal bone samples were dated by the Poznań Radiocarbon Laboratory in 2011. When calibrated, most of these results fall in the last third of the 5th millennium CAL B.C.

Aims of this dating project

The initial objective of the dating program was to estimate formally the duration of use of a Lengyel longhouse. Such a chronology would contribute to discussion of changes in social relations through the 5th millennium CAL B.C. in the Polish Neolithic and to wider discussion of the duration and place of the house in Neolithic societies as a whole. Assessment of the site archive and a series of simulation models soon demonstrated that insufficient samples would be available from Racot 18 to allow this objective to be achieved by dating a single longhouse or series of longhouses (FIG. 5). So the dating program was designed to determine the dates and duration of use of the settlement itself, and furthermore to estimate the dates of the Late Lengyel ceramic phases. From this information we aimed to provide minimum and maximum estimates of the likely duration of Late Lengyel longhouses.

Radiocarbon dating and Bayesian chronological modeling

The new radiocarbon dating program for Racot was conceived within the framework of Bayesian chronological modeling (Buck *et al*. 1996). This allows the combination of calibrated radiocarbon dates with prior archaeological information using a formal statistical methodology.

Sampling concentrated on articulated or articulating groups of animal bone (and in one case a human grave), since this material was deposited while tendons were still attached and

so is very likely to be contemporary with the deposit from which the sample was recovered. This means that the relative order of the dated samples should be the same as that of the parent contexts, which is vital when using the relative dating provided by stratigraphy or ceramic phasing to refine the calibration of a series of radiocarbon dates. In addition, a small number of charred food crusts were found adhering to the interior surfaces of pottery sherds. On the basis that this material is relatively fragile, these sherds are assumed not to have been reworked.

Thirty radiocarbon measurements are now available from Racot 18, including 18 commissioned by The Times of Their Lives (ToTL) project (TABLE 1). Those dated in Gliwice are not corrected for fractionation; the others are all conventional radiocarbon ages (Stuiver and Polach 1977). Details of seven measurements not used in the models presented here are given in Supplementary Material 1. Technical details of the methods used for sample preparation and dating are provided in Supplementary Material 2.

Four pairs of replicate measurements are available, all of which are statistically consistent (TABLE 1). Weighted means of these results were taken before calibration and inclusion in the statistical modeling (Ward and Wilson 1978).

The Bayesian chronological modeling was undertaken using the program OxCal v4.2 (Bronk Ramsey 2009) and the atmospheric calibration curve for the northern hemisphere published by Reimer *et al*. (2013). The algorithms used are defined exactly by the brackets and OxCal keywords on the left side of FIGS. 6–9 (http://c14.arch.ox.ac.uk/). The posterior density estimates output by the model are shown in black, with the unconstrained calibrated radiocarbon dates shown in outline. The other distributions correspond to aspects of the model. For example, the distribution *Start Racot Late Lengyel settlement* (FIG. 6) is the posterior density estimate for the time when the Late Lengyel settlement was established. In

the text and tables, the Highest Posterior Density intervals of the posterior density estimates are given *in italics*.

At its most simple, Bayesian statistical modeling allows us to account for the fact that all the radiocarbon dates from Racot 18 are related. They come from the same site and randomly sample the period of occupation of that site. We incorporate into the model the information that the site was established, continued to be used for a period of time, and was then abandoned (Buck *et al*. 1992). It is necessary to include this basic prior information in a model because estimating radiocarbon ages is a probabilistic process, and calibrated radiocarbon dates scatter around the actual calendar dates of the samples. In practice, this means that if no modeling is undertaken and tables or graphs of calibrated radiocarbon dates are inspected visually, there is a very significant risk that past activity will be interpreted as starting earlier, ending later, and enduring for longer than was actually the case (Bayliss *et al*. 2007).

The first model is shown in FIG. 6. The samples from Pit 138A, which contained LBPC IIA pottery (FIG. 3: 1–4), are not included in the period of Late Lengyel occupation at Racot 18. This period is estimated to have begun in *4385–4285 CAL B.C.* (*95% probability*; *Start Racot Late Lengyel settlement*) (FIG. 6), probably in *4350–4310 CAL B.C.* (*68% probability*). The Late Lengyel occupation ended in *4035–3995 CAL B.C.* (*7% probability*) or *3990–3880 CAL B.C.* (*88% probability*; *End Racot Late Lengyel settlement*) (FIG. 6), probably in *3965–3915 CAL B.C.* (*68% probability*). By taking the difference between these dates, we can estimate that the Late Lengyel occupation at Racot 18 continued for *275–410 years* (*95% probability*; distribution not shown), probably for *340–390 years* (*68% probability*).

Model 1 represents the most cautious interpretation of the radiocarbon dates from Racot 18, since no relative dating information is incorporated. There were a limited number of inter-cutting features on the site, so relative dating has to be inferred from the spatial layout of

the features and their functional relationships. Sequence can also be suggested on the basis of changes in the form and decoration of the Late Lengyel ceramics over time (FIG. 3).

Model 2 includes the interpreted sequence based on stratigraphy and associated pottery and is shown in FIG. 7. It has good overall agreement (Amodel: 123; Bronk Ramsey 2009: 356–7), which suggests that the radiocarbon dates are compatible with the archaeological interpretation included in the model.

Four features can be assigned to the earliest phase, on the basis of diagnostic assemblages of Late Lengyel IIB pottery. Three of the features (Pits 80, 135, and 220) are associated with longhouses which have segmented foundation trenches (FIG. 2). These are known to date to the earlier part of the Late Lengyel (Czerniak 1980). The fourth feature, Pit 107, appears to be an ancillary structure with a sunken floor surrounded by posts that supported the roof. Similar structures excavated in Brześć Kujawski appear to have been workshops (Grygiel 1986). One radiocarbon result, on a charred food crust on a pottery sherd from Pit 80 (OxA-30537), has extremely poor individual agreement with this position in the model. It is significantly later than the other results from Pit 80 ($T' = 25.6$; $T'(5\%) = 3.8$; $\nu = 1$), and appears to contain an anomalously late contaminant that was not fully removed during pretreatment (Bayliss *et al*. 2011: 56).

Four features can also be assigned to the succeeding phase because they contained Late Lengyel IIIA pottery. On spatial grounds, three of these features appear to be associated with the use of House 32 (Pits 53, 54, and 101) (FIG. 2). The radiocarbon dates are compatible with the suggestion that this house was later than House 88 immediately to the east (which was associated with Pit 80, containing Late Lengyel IIB pottery). House 32 had continuous and more substantial wall trenches than House 88, which had segmented and slight wall trenches. Therefore three lines of evidence—the ceramic phasing, the typology of house plans, and radiocarbon dating—combine to suggest that this pair of houses were not

contemporary, but rather that House 32 represented a re-building of House 88 slightly farther west. The fourth dated feature is Pit 17, which appears to be associated with the fragmentary remains of another longhouse (House 19). It contained Late Lengyel IIB or (more probably) IIIA ceramics. Unfortunately, due to a dearth of diagnostic sherds its chronology cannot be established more precisely.

The last phase at Racot 18 is defined by stratigraphy, architectural form, and ceramic associations. Three dated features have been assigned to this phase. Pit 31 contained few sherds, but is stratigraphically later than House 32 which contained Late Lengyel IIIA ceramics. It appears to be associated with House 12, which had a floor plan (including an annex) similar to that of House 106. We have therefore assigned both these longhouses to the earlier sub-phase of Late Lengyel IIIB. Pit 213 also contained few sherds, but is associated with House 211, which overlies House 106. On that basis, we have assigned Pit 213 and House 211 to the later sub-phase of Late Lengyel IIIB. Pit 129 contained a diagnostic assemblage of Late Lengyel IIIB pottery, and was part of a group of clay-extraction pits that on spatial grounds appear to be older than House 211. OxA-30496, a measurement on an articulating animal bone group from Pit 213, has poor agreement with its position in the model. Pit 213 seems to be contemporaneous with House 211. This is surprising, since the sampled bones refit, but this result is significantly earlier than a measurement on a second articulating bone group from the same feature (SUERC-53965; T' = 46.6; T'(5%) = 3.8; ν = 1) and so the sample was probably reworked. It has been modeled on this basis as a terminus post quem for Pit 213.

Grave 82 contained two pots that can be assigned to Late Lengyel IIIA or IIIB (FIG. 4). This burial has therefore been placed in the model after phase IIB, and before the end of the Late Lengyel settlement at Racot 18.

Model 2 suggests that Late Lengyel occupation at Racot 18 began in *4385–4285 CAL B.C.* (*95% probability*; *Start Racot Late Lengyel*) (FIG. 7), probably in *4350–4310 CAL B.C.* (*68% probability*). Late Lengyel phase IIB ended, and phase IIIA started in *4285–4200 CAL B.C.* (*95% probability*; *Racot IIB/IIIA*) (FIG. 7), probably in *4270–4230 CAL B.C.* (*68% probability*). In turn, Late Lengyel phase IIIA ended and Late Lengyel phase IIIB started in *4145–4050 CAL B.C.* (*95% probability*; *Racot IIIA/IIIB-1*) (FIG. 7), probably in *4110–4060 CAL B.C.* (*68% probability*). The later sub-phase of Late Lengyel IIIB at Racot, identified through stratigraphic relationships, began in *4095–3985 CAL B.C.* (*95% probability*; *IIIB-1/IIIB-2*), probably in *4075–4015 CAL B.C.* (*68% probability*). Late Lengyel occupation at Racot 18 ended in *4035–3885 CAL B.C.* (*95% probability*; *End Racot Late Lengyel*) (FIG. 7), probably in *3970–3915 CAL B.C.* (*68% probability*).

Grave 82 was interred in *4255–4145 CAL B.C.* (*55% probability*) or *4135–4050 CAL B.C.* (*40% probability*; *82 human burial*) (FIG. 7), probably in *4245–4225 CAL B.C.* (*10% probability*) or *4205–4160 CAL B.C.* (*31% probability*), or *4130–4110 CAL B.C.* (*10% probability*) or *4105–4070 CAL B.C.* (*17% probability*). It is *83% probable* that Grave 82 belongs to Late Lengyel IIIA, *15% probable* that it belongs to IIIB-1, and only *2% probable* that it belongs to IIIB-2. It is therefore probably associated with the use of House 32. Pit 138A, which contained LBPC IIA pottery, probably dates to the second quarter of the 5th millennium CAL B.C. (FIG. 7).

Overall, the Late Lengyel occupation at Racot 18 endured for *275–410 years* (*95% probability*; *Late Lengyel settlement*) (FIG. 8), probably for *335–390 years* (*68% probability*). Late Lengyel IIB occupation at Racot lasted for *25–95 years* (*95% probability*; *Racot IIB*) (FIG. 8), probably for *40–80 years* (*68% probability*); Late Lengyel IIIA occupation lasted for *65–185 years* (*95% probability*; *Racot IIIA*) (FIG. 8), probably for *100–165 years* (*68% probability)*; and Late Lengyel IIIB occupation lasted for *45–225 years* (*95% probability*;

Racot IIIB) (FIG. 8), probably for *105–185 years* (*68% probability*). There was probably a gap of *205–445 years* (*95% probability*; *LBPC IIA/Late Lengyel*) (FIG. 8), probably of *265–390 years* (*68% probability*), between the LBPC IIA Pit 138A and the start of Late Lengyel settlement on the site.

Discussion

The duration of Late Lengyel longhouses

The model for the chronology of the Late Lengyel settlement at Racot 18 provides formal date estimates for the structural and ceramic phases of occupation that have been revealed through excavation (FIGS. 7, 8). It does not provide direct dating for the duration of use of particular houses. This is because we have neither the depth of stratigraphic sequence available, for example, in the Neolithic tells of southeastern Europe, nor the detailed ceramic phasing available, for example, for parts of the LBK. Such detailed relative sequences can be used as strongly informative prior information in chronological modeling, thus allowing us to provide precise and robust chronologies even when we encounter plateaux on the radiocarbon calibration curve (such as the later 5th millennium CAL B.C. plateau that we face at Racot). In the absence of such relative sequences, large numbers of samples are required to provide precise and accurate dating for particular houses (FIG. 5). For example, even in the unrealistic situation where 50 suitable samples could be found from each building illustrated in FIG. 5, the calendrical bandwidth of the start estimate is more than 100 years at 95% probability in around a quarter of simulations, and over 50 years at 68% probability in around half of them. To put this in perspective, at Racot 18 it is a struggle to find more than a handful of short-lived samples that are clearly associated with the use of any structure. This does not mean, however, that the dating program presented here has provided no information at all on house times in the Polish Late Lengyel, just that we have to infer this from our site and ceramic

phasing rather than estimate it directly through formal modeling. This is obviously more hazardous than when circumstances combine to allow formal modeling of house durations.

Phase IIB at Racot 18 endured for *25–95 years* (*95% probability*; *Racot IIB*), probably for *40–80 years* (*68% probability*) (FIG. 8). The dated samples from this phase derive from pits associated with Houses 133 and 134 (which are argued above to be successive), and a pit associated with House 88. We can thus say that houses of Phase IIB at Racot could have endured for a period up to *25–95 years* (*95% probability*; *Racot IIB*), probably for up to *40–80 years* (*68% probability*). But some certainly endured for less time. If Houses 133 and 134 were occupied for similar periods, then each could have been in use for a few decades, and if only one of the four structures sampled for dating from Phase IIB was standing at any one time, each could have endured for little more than a human generation (say 25 years).

Phase IIIA provides firmer evidence for an extended period of use of at least some Late Lengyel houses. This period lasted for *65–185 years* (*95% probability*; *Racot IIIA*) (FIG. 8), probably for *100–165 years* (*68% probability)*, and material associated with only two houses (Houses 19 and 32) was sampled for dating. If both houses were standing for the entire period, then they probably endured for well over a century. If, however, they were successive then each was probably used for between 50 and 100 years.

On stratigraphic grounds, ceramic Phase IIIB can be divided into an earlier period comprising Houses 106 and 12 (Phase IIIB-1) and a later period comprising House 211 (Phase IIIB-2). Samples associated with Houses 12 and 211 have been dated. Model 2 estimates that Phase IIIB-1, and thus House 12, was in use for *1–105 years* (*95% probability*; *Racot IIIB-1*) (FIG. 8), probably for *10–65 years* (*68% probability*). Phase IIIB-2, and thus House 211, was in use for *15–170 years* (*95% probability*; *Racot IIIB-2*) (FIG. 8), probably for *50–135 years* (*68% probability*).

If we can make some inference about the duration of use of eight houses from the Late Lengyel settlement at Racot 18, there remains much uncertainty. But there is some evidence that house times may have varied, from a few decades (Houses 133 and 134), to an adult human's lifetime (Houses 12 and 106; perhaps House 88), to perhaps a century or so (House 211; perhaps Houses 19 and 32). It may be no coincidence that the houses for which we have inferred the shortest durations are those with slight, segmented bedding trenches.

House and settlement dynamics

The results of Bayesian modeling of the Racot settlement establish much more robust estimates for house times in the Lengyel settlement of the Polish lowlands. They suggest that houses in the first phase of the occupation of Racot 18 may have been used for a shorter period of time than those in its second phase. In the first phase, in Late Lengyel IIB, each house appears to have existed for a few decades and then to have been rebuilt in close proximity to its predecessor, which has made them look like paired houses. Connections with the LBK world are more pronounced at the beginning of the Racot settlement. These are particularly evident in the realm of animal exploitation. Cattle remained reserved for "special" and public consumption events in this period. The practice of cattle marrow consumption outside the longhouse in the form of communal feasting, known from LBK settlements, was continued. Similarly, the debris from these activities was deposited in loam pits not directly associated with the house (see Marciniak 2014). The phasing of these loam pits has been updated following the research presented here (Phase IIA is now labelled Phase IIB, Phase IIB is now Phase IIIA, and Phase IIIA is now Phase IIIB). The attribution of houses and features to subsequent phases has not been changed from the original publication (see Czerniak 1989).

House time in the second part of the Racot 18 occupation was significantly longer. The last phase probably endured for more than a century (*Racot IIIB-2*) (FIG. 8). The period also marked a departure from hitherto dominant architectural practices, as manifested by abandoning the NW-SE alignments of longhouses, thereby creating more random orientations. Subsequent houses were no longer built next to one another. They were also more solidly constructed and had small rooms or annexes attached (Houses 12 and 106; probably House 211). These significant spatial changes are indicative of the emergence of activity areas outside the house. Similarly pronounced changes occurred in human-animal relations. Consumption of sheep/goats began to dominate at this time, which served both small groups of people inhabiting successive buildings and larger groupings in the form of ceremonial consumption of their marrow. The latter was performed in a manner similar to that of cattle in earlier phases, but certainly on a smaller scale. Interestingly, the remains of sheep/goat marrow consumption were dumped in domestic pits, rather than in loam pits. This may indicate that the practice of marrow consumption was moved from the communal domain into the domestic sphere, arguably reflecting a significant shift in social arrangements at the settlement characterized by the emergence of largely individualized autonomous households (Marciniak 2014).

Our modeled estimates encourage wider reflection on our understanding of the duration of houses. This, as noted in the introduction, has often been taken for granted. Various estimates exist in the literature for the duration of Late Lengyel houses. In earlier research, houses in the Brześć Kujawski region were argued to have been used for between 20 (Gabałówna 1960) and 50 years (Jażdżewski 1938). Later, broad phases of only 200 years were proposed (Grygiel 2008: 311). But it has been noted how sequences of houses must fit within such phases, and it has been speculated that Late Lengyel house durations and replacement rules could have varied to a much greater extent than in the LBK (Pyzel 2013:

189–190, 193), with some reference, though unquantified, to the concept of longer lasting "history houses" and "origin houses" (Pyzel 2013: 194). More widely, we can make comparisons with informal estimates of house durations in various settings, and with much more precise estimates based on dendrochronology. In the Vinča Culture, it has been suggested that houses could have lasted for up to 50 years (Chapman 1981), though shorter (if unspecified) durations were mooted for Opovo (Tringham *et al*. 1985). Formally modeled estimates from the top of the great tell at Vinča-Belo Brdo allow house duration to have been probably as little as 15 years (Tasić *et al*. 2015). The once-dominant *Hofpltzmodell* for LBK houses promoted a duration of 25–30 years (Zimmermann 2012), though that model is under increasing general challenge and house lives of up to 70 or more years have been suggested (Rück 2007). No formal modeling of the kind discussed in this paper yet applies to the LBK itself. Clearly, many more formally modeled estimates are needed, but one possibility could be that many house lives were shorter rather than longer, and if so, the development of more enduring structures and households, as suggested here for the later stages of the occupation of Racot, could have resulted from significant changes triggered by individualizations of social arrangements.

The modeling also enables us to place the single burial found at Racot 18 within the sequence of dwelling structures. The burial pit (Grave 82) was dug inside House 88, and pottery analysis initially suggested that this happened ca. 200 years after this building was abandoned (Czerniak 1989). The results of the current project make it possible to suggest that Grave 82 belongs to Late Lengyel IIIA (*83% probable*), and so may have been contemporary with the adjacent House 32.

The size and dynamics of the Late Lengyel settlement at Racot 18 can also be considered. From the number of houses partially revealed over the area of investigation, estimates for the number of longhouses present on the site vary from 40–48 to 48–56 (see

above). Assuming that our sample of dated houses is representative of the whole, we can divide these proportionately among the site phases. We would thus expect between 15 and 21 houses in Phase IIB, although not all of these may have been standing at once (since Houses 133 and 134 in this phase seem to have been successive). If, on the basis of our dated sample, we infer that around two-thirds of these houses were standing at any one time over this period, we can estimate that the settlement consisted of 10–14 longhouses at this time. Similar numbers can be inferred for Phases IIIA and IIIB-1. In Phase IIIB-2, however, it is possible that the settlement reduced in size to between five and seven longhouses (although any inference based on one dated house must be extremely tentative). This could in turn have implications for demography, though it remains classically difficult to infer numbers of inhabitants from floor plans alone.

Overall, however, it seems that in the Late Lengyel period Racot 18 was some kind of small settlement, consisting of a dozen or so houses. The settlement was stable, enduring in this form for over 300 years (*Late Lengyel settlement*) (FIG. 8).

Continuity and stability of settlement

The increasingly well-established community referred to the past and its significantly less pronounced predecessors. This is indicated by the fact that the earliest dwelling structures at Racot 18 were created on a spot previously occupied by an as-yet-unspecified LBPC hamlet or camp. The first part of the settlement was built *205–445 years* (*95% probability*), probably *265–390 years* (*68% probability*), after the use of the LBPC Pit 138A (*LBPC IIA/Late Lengyel*) (FIG. 8). The probable first structures at Racot 18—Houses 133 and 134, and Pits 135, 203, and 220—were placed close to the earlier LBPC occupation, as though the first inhabitants of the Late Lengyel site actively sought out traces of what the estimate given

above suggests was a significantly older settlement. Such reference to the LBK world is also reported at other later sites, such as Bożejewice 22/23 (Czerniak 1998).

The overall span of the Racot 18 settlement represents considerably greater stability of occupation compared to the LBPC settlement pattern. While we cannot be certain that there were no gaps in the sequence at Racot 18, the layout of the site, the modeled estimates for site phases, and the character of the associated material, all combine to suggest that this was not a punctuated occupation. This and the probably greater number of houses in use at any one moment at Racot 18 contrast strongly with the apparently single houses found in LBPC settlements, such as Białcz Stary in Greater Poland and Konary in Kujavia (Czerniak 1994). This can be seen as a distinctive feature of the intake of the western Polish lowlands and probably as identical to the developments taking places in Kujavia. Hence, for the first time we have a situation in which permanently occupied settlements existed both in the core area of the Neolithic lowlands and in the regions that were occupied for the first time following the demise of the LBK.

On the last note, the stable longhouse occupied by discrete groups, most likely kin-based, can be seen as a key part of the process of regional Neolithization. While Racot 18 remains one of the very few Late Lengyel settlements in the western Polish lowlands, other settlements of a similar type have been reported outside Kujavia, including in Chełmno Land and East Pomerania. The Kociewie region from the Starogard Lake District is a relatively small area in the Lower Vistula region, distinguishable by fertile black soils. A few post-LBK sites were excavated there, including two Late Lengyel settlements with longhouses at Barłożno, Site 15, Skórcz Commune, and at Bielawki, Site 5, Pelplin Commune. The most northeasterly post-LBK site is Równina Dolna, Site III, Korsze Commune, on the Sępopol Plateau in Masuria. The Równina Dolna site (Rybicka and Wysocki 2004) along with a few dozen sites from Chełmno Land—including a Late Lengyel settlement with longhouses at

Zelgno, the most northeasterly site in the area at Boguszewo (Kirkowski and Kukawka 1990) (FIG. 1), and Żuławy (Dęby-Kaczynos)—comprise the enclave located in the most northeasterly edge of the post-LBK settlement in close proximity to the Niemen-Zedmar-Narva complex, making it a unique and peculiar setting (Czerniak 2007). These dynamically developing individual farmsteads began to control production activities and manage their own resources and inter-relations, and Neolithic groups transformed into strong and autonomous communities, capable of living independently and dispersing over the previously unoccupied areas of the lowlands.

Racot 18 in the Late Lengyel Culture of the Polish lowlands

The model defined in FIG. 7 provides a chronology for the occurrence of LBPC and Late Lengyel ceramic types at Racot 18. TABLE 2 provide details of the radiocarbon measurements associated with these ceramics from sites in Poland other than Racot 18. Details of the methods used for sample preparation and radiocarbon dating of these 83 measurements are provided in Supplementary Material 3.

Replicate groups of determinations are available on nine samples, in all cases being statistically consistent at 95% confidence (TABLE 2). This impressive evidence of the reproducibility of the conventional measurements strongly suggests that these data should be regarded as accurate radiocarbon determinations on the samples submitted for dating. Their utility is, however, limited by the character of the material that had to be selected for dating to make up the required sample weight for a conventional measurement (usually ca. 10 g of charcoal or ca. 150 g of bone). Most samples (47 of the 68 conventional samples) were of charcoal. Generally, these samples derived from coherent deposits of charred material that were probably deliberately deposited in the features from which they were recovered. The archaeological association between the radiocarbon sample and the dated context was thus

usually reasonably good. But this material was not identified to age and species before submission for dating. This means that the radiocarbon date could be older than the feature from which the sample came if a component of "old wood" was included in the dated sample. Sample size requirements also means that multiple fragments, probably derived from different branches and trees, had to be bulked together for dating. These were not single-entity samples (Ashmore 1999). This increases the risk that the dated material was of diverse ages, and so the resultant radiocarbon date is an average of the date of all the fragments and a true reflection of the age of none. All these samples should, however, provide termini post quos for the deposits from which they derived. They have all been included in the model on this basis (with the exception of Gd-6047 from pit 23 at Boguszewo 43b, which is statistically consistent with two measurements on hazelnut shell from the same pit and so probably does not have an appreciable old wood offset). Samples where the material was not recorded (which were probably also of charcoal, based on the other materials dated at this time) and samples of "clay raw material" (where the origin of the dated carbon is unclear) have also been modeled as potentially older than their parent contexts.

Overall, we have 18 dates on samples of short-lived material (including one replicate group), and 46 dates on samples that might have contained a component of long-lived material (including eight replicate groups). These dates come from 17 sites. The pottery from each dated feature has been assigned to one of the LBPC or Late Lengyel ceramic phases (TABLE 2).

The model combining this ceramic phasing with the radiocarbon dates listed in TABLE 2 is shown in FIG. 9. Weighted means have been taken of all replicate groups before their inclusion in the model. With only two minor adjustments, these dates are in good agreement with the suggested ceramic sequence (Amodel: 73) (FIG. 9). The first adjustment relates to samples from Kruszynek 6, where post-excavation analysis is still progressing. Poz-42012, an

animal bone from cellar pit B16 inside House VI (a feature clearly associated with Late Lengyel IIB ceramics) seems to be residual from a nearby pit, B17, which is associated with LBPC IIA ceramics. The second adjustment is the exclusion of GX-6370, a sample of unidentified charcoal from pit 784 at Brześć Kujawski 3. Statistically, this date is clearly anomalously late (there is only a 23% probability that it falls within the currency of Late Lengyel ceramics at all, despite the large quoted error term of ± 210 B.P.). Given the excellent reproducibility of the conventional measurements, it seems most likely that the dated sample included a component of intrusive, later charcoal. This is certainly possible for this multi-phase site.

The outputs of the model shown in FIG. 9 must be interpreted with a degree of caution that is appropriate to the quality and quantity of the data that are available for various ceramic phases. In particular, it is not ideal that currently over 70% of the data can only be incorporated in the model as termini post quos. We must be aware that in this circumstance some estimates may be biased toward slightly later date estimates than is realistic (Dee and Bronk Ramsey 2014).

LBPC I is estimated to have begun in *5585–4545 CAL B.C.* (*95% probability*; *Start LBPC I*) (FIG. 9), probably in *4940–4605 CAL B.C.* (*68% probability*). The imprecision of this estimate accurately reflects that we have a single dated sample on short-life material from this phase (Gd-2509 on animal bone from pit 1 at Węgierce 12). The transition from LBPC I to LBPC IIA is estimated to have occurred in *4725–4530 CAL B.C.* (*95% probability*; *LBPC I/LBPC IIA*) (FIG. 9), probably in *4760–4565 CAL B.C.* (*68% probability).* On current evidence, we can thus say little more than that LBPC I ceramics in Poland probably date to some time within the first half of the 5th millennium CAL B.C., and that LBPC IIA ceramics probably appear in the century or two before 4500 CAL B.C. Further radiocarbon dates on short-lived

material securely associated with relevant ceramic assemblages are essential to further understanding of the chronology of this material.

The transition from LBPC IIA to Late Lengyel IIB occurred in *4345–4270 CAL B.C.* (*95% probability*; *LBPC IIA/IIB*) (FIG. 9), probably in *4335–4310 CAL B.C.* (*68% probability*). There are three assemblages of LBPC IIA ceramics associated with dates on short-lived material. These dates are rather disparate, so it is not clear that they are entirely representative of this ceramic phase. The date for the beginning of Late Lengyel IIB is, however, compatible with the estimate for the start of Late Lengyel activity at Racot 18, in *4385–4285 CAL B.C.* (*95% probability*; *Start Racot Late Lengyel*) (FIG. 7), probably *4350–4310 CAL B.C.* (*68% probability*). The start of this ceramic phase and the foundation of the settlement at Racot may have been close in time.

The transition from Late Lengyel IIB to Late Lengyel IIIA occurred in *4310–4240 CAL B.C.* (*91% probability*; *IIB/IIIA*) (FIG. 9) or *4210–4185 CAL B.C. (4% probability)*, probably in *4300–4265 CAL B.C.* (*68% probability*). Again, this date estimate is compatible with the estimate for the equivalent transition at Racot 18, where it occurred in *4285–4200 CAL B.C.* (*95% probability*; *Racot IIB/IIIA*) (FIG. 7), probably in *4270–4230 CAL B.C.*. Both models agree in suggesting that Late Lengyel IIB was a short phase, lasting perhaps only two or three generations. We have five assemblages associated with short-life samples (plus one residual short-life sample) from Late Lengyel IIB.

Late Lengyel IIIA ended and Late Lengyel IIIB began in *4140–3975 CAL B.C.* (*95% probability*; *IIIA–IIIB*) (FIG. 9), probably in *4085–4000 CAL B.C.* (*68% probability*). Once more, this date estimate is compatible with the estimate for the equivalent transition at Racot 18, where it occurred in *4145–4050 CAL B.C.* (*95% probability*; *Racot IIIA/IIIB-1*) (FIG. 7), probably in *4110–4060 CAL B.C.*. The dating of Late Lengyel IIIA is relatively robust, with seven assemblages associated with dates on short-life materials.

The date when Late Lengyel IIIB ended is more uncertain, since we have only one assemblage associated with a short-life sample. The model suggests that Late Lengyel IIIB ended in *3905–2715 CAL B.C.* (*95% probability*; *End IIIB*) (FIG. 9), probably in *3805–3370 CAL B.C.* (*68% probability*). This is rather later than the end of Late Lengyel activity at Racot 18, which occurred in *4035–3990 CAL B.C.* (*95% probability*; *End Racot Late Lengyel*) (FIG. 7), probably in *3970–3915 CAL B.C.* (*68% probability*). It is currently not clear, however, whether Racot 18 ended before the demise of Late Lengyel IIIB ceramics elsewhere. Neither the animal bone from pit B354 at Bodzia 1 (Poz-43555) nor any of the dates on unidentified charcoal from this phase (FIG. 9) need be any later than the 40th century CAL B.C. Late Lengyel IIIB ceramics may continue later into the 4th millennium but, on present evidence, they need not have done so and, again, only further radiocarbon dates on short-life material associated with diagnostic cultural material will demonstrate this unequivocally.

That aside, the tempo of material change now established by the combination of typology and formal chronological modeling seems sedate. Other practices within the Late Lengyel Culture, especially in Kujavia, also seem relatively uniform and stable, including burials (e.g., Grygiel 2008), suggesting that continuity and stability were actively valued. This pattern has interesting wider implications. First, at a time in the second half of the 5th millennium CAL B.C. when settlement in many other parts of central and western Europe had reverted to a much more dispersed and possibly less sedentary pattern—with the demise of tells and major settlement aggregations in the Carpathian basin (Tasić *et al*. 2015; Osztas *et al*. 2012) and the end of longhouses in many other parts of the "Danubian world" (Milisauskas and Kruk 2011)—an established way of life persisted in western Poland for a significant period. There was no inevitable path to the development of Neolithic settlement, though a case can be made for repeated trajectories of development, since in turn what succeeded the Late Lengyel in western Poland, in the form of the Funnel Beaker Culture

(TRB), was again a more dispersed and perhaps more mobile lifestyle (Milisauskas and Kruk 2011). Secondly, it can be noted that during the Late Lengyel period in western Poland, Mesolithic communities on the Baltic coasts to the north were seemingly unaffected, though in contact with their farmer neighbors. Thirdly, it was perhaps the longevity of sites like Racot, inhabited by individualized social groupings, that produced the conditions in which long-lived houses could emerge. In turn, that depth of history may have been a powerful factor in the subsequent appearance of long barrows in Kujavia and elsewhere (Milisauskas and Kruk 2011).

Conclusion and future research

While this study has been carried out in far from perfect conditions, the gains from formal chronological modeling are considerable. We have provided much more robust estimates of the timing and duration of the Racot 18 settlement as a whole. We can now discuss the implications for the development of Neolithic settlement in the region and beyond, and the possibilities for interpreting house durations and accompanying developments at Racot 18, on a more secure basis than previously. We have provided insights into a number of contemporaneously occupied houses, durations of longhouse use, and shifts in house building through time across Racot 18, and more generally into the biography of the Neolithic settlement. Above all, perhaps, given the now evident variations through time in terms of longhouse architecture, site layout, house durations, and settlement durations, this study shows clearly that the Neolithic house cannot be taken for granted; it had particular, contingent histories, which must be investigated in detail and in context, case by case. This paper has also emphasized the context of continued Neolithic development and settlement expansion; better timings allow us to see more clearly the contingent histories of Neolithic change.

Our study also serves to indicate what can still be done better in the future through careful on-site recording of potential short-life samples, the preservation of organic residues on pottery by very careful post-excavation cleaning of finds, the maintenance of archives of finds, the continued study of the material by detailed typological analysis and correspondence analysis, and even the development of a Bayesian approach to correspondence analysis itself.

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Figure captions

Figure 1 The Polish Lowlands 5400–4000 CAL B.C. 1) LBK sites; 2) Areas of LBPC and Late Lengyel settlement; 3) Brześć Kujawski-type sites included in the text (BS: Białcz Stary, R18: Racot 18 and 25, KZ: Krusza Zamkowa, Os: Osłonki, BK: Brześć Kujawski, Kr: XXX, Zg: Zelgno, Br: Barłożno, Bl: Bielawki); 4) Other post-LBK sites mentioned in the text (Bg: Boguszewo, DK: Dęby Kolonia, RD: Równina Dolna); 5) Ertebølle Culture sites (D: XXX); 6) Zedmar Culture sites.

Figure 2 Plan of Racot 18 showing site phasing and house plans, with (inset) schematic plan of Racot 18 and Racot 25.

Figure 3 Pottery forms and decoration from Racot 18. LBPC IIA: 1–4) Feature 138A. Late Lengyel phase IIB: 5–7) Feature 135; 8, 9) Feature 220; 10, 11) Feature 80; 16, 20, 21) Feature 107. Late Lengyel phase IIIA: 12, 13) Feature 54; 14, 15) Feature 67; 17–19) Feature 101.

Figure 4 Grave 82 from Racot 18. 1, 2) General view of grave. Grave goods: 3) Part of hip belt, *Unio* sp. shells; 4) Two pottery vessels; 5) Necklace of animal teeth and copper beads; 6) 12 (of 18) richly ornamented armlets made of cow ribs.

Figure 5 Highest Posterior Density intervals for the *start* parameter for a series of simulations for the chronology of a hypothetical longhouse. Each model incorporates two short sequences of stratigraphically related samples from associated long pits, and 50 simulated measurements with error terms of ± 30 B.P. The hypothetical buildings were in use for A) 25 years; B) 50

years; C) 100 years, and have simulated dates ranging from a building in use between 5000–4975 B.C. to one used between 3825–3725 B.C..

Figure 6 Probability distributions of radiocarbon dates from Racot 18 (Model 1). 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 Racot Late Lengyel settlement"* is the estimated date when Late Lengyel activity on the site began. Measurements followed by a question mark or shown in outline have been excluded from the model for reasons explained in the text, and are simple calibrated dates (Stuiver and Reimer 1993). The large square brackets down the left side along with the OxCal keywords define the overall model exactly.

Figure 7 Probability distributions of dates from Racot 18, derived from a chronological model incorporating the site phasing based on the Late Lengyel ceramic forms (Model 2). The format is identical to that of FIG. 6. The large square brackets down the left side of the diagram along with the OxCal keywords define the overall model exactly (http://c14.arch.ox.ac.uk/).

Figure 8 Probability distributions for the number of years during which various activities occurred at Racot 18, derived from the model defined in FIG. 7.

Figure 9 Probability distributions of dates from Late Band Pottery Culture and Late Lengyel ceramic assemblages from other sites in Poland, incorporating the proposed typological

sequence of ceramic forms. The format is identical to that of FIG. 6. The large square brackets down the left side of the diagram along with the OxCal keywords define the overall model exactly (http://c14.arch.ox.ac.uk/).

Figure 10 Probability distribution of key parameters for Late Lengyel ceramics in Poland, derived from the models defined in FIGS. 7 and 9.