Abstract

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 modelling, in a Bayesian framework, of settlement development. The site belongs to the Late Lengyel culture of the later fifth millennium cal BC, and represents the intake of new land following earlier initial colonisation. The formally estimated chronology for the settlement suggests spans for individual house biographies 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 modelled context of the later fifth millennium cal BC.

Keywords

Neolithic settlement development, Polish lowlands, houses, formal chronological modelling, 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 modelling 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 come better timings, and from those 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 selected themes important for a specific time and place, is one of a series which aims to encourage prehistorians more generally to embrace formal chronological modelling, for the resulting benefits of robustness and precision, which in turn can lead on 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 *c.* 5400 cal BC, 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 marks a complete disintegration of the preceding LBK arrangements and the discontinuous development of new forms of spatial organisation (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 fifth millennium cal BC can be labelled as the post-LBK cultures. The LBPC settlements are 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 comprise single pits and hearths associated with some kind of light dwelling structures. At the same time, the period marks the first spread of local groups beyond the early Neolithic enclaves. Local farming groups appear now right across the lowlands, from Kujavia in the east, to Lower Silesia in the south-west and Pyrzyce in the north-west.

The second half of the fifth millennium cal BC brings a completely different picture of lowland Neolithic communities, with the Lengyel culture. As the emergence of this tradition postdates

similar developments further 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 fifth millennium cal BC. It is particularly well manifested in 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, site 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 recognised at Osłonki, site 1 (Grygiel and Bogucki 1997; Grygiel 2008), the only settlement of this culture excavated to date that was surrounded by ditches. 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 have 'rich' grave goods. Burials of men and women are distinctively different. The presence of exotic goods, in addition to sex difference, implies the beginnings of social differentiation as well as being indicative of a new exchange network.

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 mostly 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. The houses were usually oriented NW–SE, like their rectangular LBK predecessors, and had a narrow north end and wide south end. Entrances were usually

located at the broader end, facing towards the east or south-east. Houses were normally 20–35 m long.

The house itself was now associated with a set of features including activity areas, ovens, storage pits, disposal pits/middens and burials. These 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 specialised 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 characterised 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. This kind of situation is widespread in the Polish lowlands.

The Racot settlement

Racot 18 and 25, belonging to the Late Lengyel culture, lay on either side of a small stream in the western Polish lowlands south of Poznań, an area whose first Neolithic settlements appear to belong to the later fifth millennium cal BC (FIGS. 1 and 2). They were excavated by Lech Czerniak in 1984–7. 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 *c.* 3 ha exposed in two sondages (2.5 by 50 m) and two small extensions. Both settlements arguably comprised one dwelling complex, but their function may have differed. Racot 18 was for residence, while Racot 25 was used for a

range of economic activities; a number of relatively small loam pits have been exposed here, which may be interpreted as 'sondages' used for searching for good-quality clay and stones.

Only about 10 per cent of both settlements has been excavated. Site 18 could extend over *c.* 3 ha and cover an area of *c.* 400 m by 75 m. An estimated 25–30 per cent of its houses have been exposed and studied, and the total number of houses could have been between 40–48 and 48–56.

Racot 18 was occupied in three, possibly four occupation phases, as indicated by its stratigraphy. The most complicated stratigraphic relations have been revealed in its north-east part where three superimposed structures were exposed. House 106 was earlier than House 211 and later than the pit-cellar F. 107. Close by, House 133, placed in a pair with House 134, is believed to be earlier than its counterpart, as indicated by its construction. At the same time, pottery from Pit F. 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 a 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), which makes them the longest constructions of this type in the Late Lengyel culture. Individual houses were of different length and alignment but similar in terms of form and construction. There were two major types: (1) with segmented and shallow bedding trenches (e.g. House 88; Houses 133 and 134) and (2) with continuous and deep (up to 1.0–1.5 m) bedding trenches (e.g. House 1, 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, placed in their central part

next to the eastern walls, and interpreted as small cellars (e.g. F. 80, 135 and 203). They were filled with refuse, in particular fragments of pottery, lithics and animal bones.

Longhouses, in particular from the early phase, 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 are characteristic of the late phase of the settlement occupation. The houses were more solidly constructed and have 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 standardised 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 (*c.* 40 m), its unique west–east alignment and the presence of a side room. The house was burnt and later reconstructed, as indicated by a *c.* 27 m-long bedding trench dug next to the original one. Consequently, the wall became significantly curvilinear. House 106 from the same phase was also of a different, NNE–SSW, alignment. In general, the final phase of use of the Racot settlement is marked by a significant departure from the previously dominant rules.

Of particular significance is House 1, which was burnt shortly after construction. This is indicated by an internal cellar (F. 49), which was full of clay debris, probably originating from the wall. One could argue that the fire that had destroyed that house was not linked to the fire that partly destroyed House 12 from Phase IIIB (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 most probably Houses 19 and 64. Only small fragments of the latter pair have been revealed. They have been

additionally destroyed by the later House 12. Another notable characteristic of this pair is their small size, which make them comparable to earlier houses from Brześć Kujawski 4 (Grygiel 2008). They were placed parallel to each other. It is unclear whether these houses 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 houses from each pair were occupied asynchronously. House 88, with its discontinuous and shallow bedding trenches, seems to be earlier that House 32 with continuous and more substantial wall trenches. This is further corroborated by different pottery in both houses. A distinctively trapezoidal shape and proportions imply that House 133 should be more probably regarded as earlier than House 134. Both Houses 19 and 64 have similar construction but their alignments differ. This difference may also point to asynchronous use.

A number of other features also flanked longhouses. These external pits are reminiscent of cellars located inside the house in terms of their size, shape and fill (F. 40, 53, 101, 107, 111, 220). They may have also been used for storage. Of these, Pit F. 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), as indicated by one burial found at the settlement (F. 82). That is located inside House 88, but was interred much later. 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 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 has 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).

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 fifth millennium cal BC. 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 fifth millennium cal BC.

Aims of this dating project

The initial objective of the dating programme 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 fifth millennium cal BC 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 programme 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 modelling

The new radiocarbon dating programme for Racot was conceived within the framework of Bayesian chronological modelling (Buck *et al.* 1996). This allows the combination of calibrated radiocarbon dates with archaeological prior 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 whilst 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 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 as Supplementary Material 2.

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

The Bayesian chronological modelling has been 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-hand side of FIGS. 6–7 and 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 modelling 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 modelling 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 BC* (*95% probability*; *Start Racot Late Lengyel settlement*; FIG. 6), probably in *4350–4310 cal BC* (*68% probability*). The Late Lengyel occupation ended in *4035–3995 cal BC* (*7% probability*) or *3990–3880 cal BC* (*88% probability*; *End Racot Late Lengyel settlement*; FIG. 6), probably in *3965–3915 cal BC* (*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 (Pit 80, Pit 135 and Pit 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 (Grygiel 1986) appear to have been workshops. 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 contain 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 is later than House 88 (which is associated with Pit 80, which contains Late Lengyel IIB pottery), which lies immediately to the east. House 32 has continuous and more substantial wall trenches than House 88, which has segmented and slight wall trenches. Three

lines of evidence, therefore — the ceramic phasing, the typology of house plans and radiocarbon dating — combine to suggest that this pair of houses are not contemporary, but rather that House 32 represents a re-building of House 88 slightly further west. The fourth dated feature is Pit 17, which appears to be associated with the fragmentary remains of another long house (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 has a plan (including an annexe) 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 contains a diagnostic assemblage of Late Lengyel IIIB pottery, and is 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 modelled 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 BC* (*95% probability*; *Start Racot Late Lengyel*; FIG. 7), probably in *4350–4310 cal BC* (*68% probability*). Late Lengyel phase IIB ended, and phase IIIA started in *4285–4200 cal BC* (*95% probability*; *Racot IIB/IIIA*; FIG. 7), probably in *4270–4230 cal BC* (*68% probability*). In turn, Late Lengyel phase IIIA ended and Late Lengyel phase IIIB started in *4145–4050 cal BC* (*95% probability*; *Racot IIIA/IIIB-1*; FIG. 7), probably in *4110–4060 cal BC* (*68% probability*). The later sub-phase of Late Lengyel IIIB identified on stratigraphic phase at Racot 18 began in *4095–3985 cal BC* (*95% probability*; *IIIB-1/IIIB-2*; FIG. 7), probably in *4075–4015 cal BC* (*68% probability*). Late Lengyel occupation at Racot 18 ended in *4035–3885 cal BC* (*95% probability*; *End Racot Late Lengyel*; FIG. 7), probably in *3970–3915 cal BC* (*68% probability*).

Grave 82 was interred in *4255–4145 cal BC* (*55% probability*) or *4135–4050 cal BC* (*40% probability*; *82 human burial*; FIG. 7), probably in *4245–4225 cal BC* (*10% probability*) or *4205–4160 cal BC* (*31% probability*) or *4130–4110 cal BC* (*10% probability*) or *4105–4070 cal BC* (*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 Phase 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 fifth millennium cal BC (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 (FIGS. 7–8) provides formal date estimates for the structural and ceramic phases of occupation that have been revealed through excavation. 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 south-east 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 modelling, thus allowing us to provide precise and robust chronologies even when we encounter plateaux on the radiocarbon calibration curve (such as the later-fifth millennium cal BC plateau that we face at Racot). In the absence of such relative sequence, 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 can be found from each building illustrated in FIG. 5, the calendrical band-width 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. 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 programme 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 modelling. This is obviously more hazardous than when circumstances combine to allow formal modelling of house durations.

Phase IIB at Racot 18 (FIG. 8) endured for *25–95 years* (*95% probability*; *Racot IIB*), probably for *40–80 years* (*68% probability*). The dated samples from this phase derive from pits associated with Houses 133 and Houses 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 (House 19 and House 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 (House 133 and 134), to an adult human lifetime (Houses 12, 106, perhaps House 88), to perhaps a century or so (House 211, and 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 modelling 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 that 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 these 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), where the phasing is different as this has been updated following the research presented here. Phase IIA is now labelled Phase IIB, Phase IIB now as Phase IIIA, and Phase IIIA now as Phase IIIB. The attribution of houses and features to subsequent phases has not been changed as compared with 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 have small rooms or annexes attached (Houses 12 and 106, and 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. It 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 characterised by the emergence of largely individualised autonomous households (Marciniak 2014).

Our modelled estimates encourage wider reflection on our understanding of the duration of houses. This, as noted at the start, 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: 189–90, 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 modelled 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 modelling of the kind discussed in this paper yet applies to the LBK itself. Clearly, many more formally modelled 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 individualisations of social arrangements.

The modelling also enables us to place the single burial found at Racot 18 within the sequence of dwelling structures. The burial pit (82) was dug inside House 88, and pottery analysis initially suggested that this happened *c.* 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 amongst 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 of 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, 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 modelled 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 when permanently occupied settlements existed both in the core area of the lowlands Neolithic 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 Neolithisation. While Racot 18 remains one of the very few Late Lengyel settlements in the western Polish lowlands, other settlements of 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 north-easterly 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 and the most north-eastern site in the area at Boguszewo: FIG. 1; Kirkowski and Kukawka 1990) and Żuławy (Dęby-Kaczynos), comprise the enclave located in the most north-eastern edge of the post-LBK 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 Late Band Pottery Culture and Late Lengyel ceramic types at Racot 18. TABLE 2 provide details of the radiocarbon measurements associated with these ceramics from sites other than Racot 18 in Poland. Details of the methods used for sample preparation and radiocarbon dating of these 83 measurements are provided as 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 *c.* 10 g of charcoal or *c.* 150 g of bone). Most samples (47/68 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 of 'clay raw material' (where the origin of the carbon dated is unclear) have also been modelled 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 Late Band Pottery Culture 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 Late Band Pottery Culture 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 BP). 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 on 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 towards slightly later date estimates than is realistic (Dee and Bronk Ramsey 2014).

LBPC I is estimated to have begun in *5585–4545 cal BC* (*95% probability*; *start LBPC I*; FIG. 9), probably in 4940*–4605 cal BC* (*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 BC* (*95% probability*; *LBPC I/LBPC IIA*; FIG. 9), probably in *4760–4565 cal BC* (*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 fifth millennium cal BC, and that LBPC IIA ceramics probably appear in the century or two before 4500 cal BC. 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 BC* (*95% probability*; *LBPC IIA/IIB*; FIG. 9), probably in *4335–4310 cal BC* (*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 (*4385–4285 cal BC at 95% probability*; *Start Racot Late Lengyel*;

FIG. 7), probably *4350–4310 cal BC* (*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 BC* (*91% probability*; *IIB/IIIA*; FIG. 9) or *4210–4185 cal BC (4% probability)*, probably in *4300–4265 cal BC* (*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 BC* (*95% probability*; *Racot IIB/IIIA*; FIG. 7), probably in *4270–4230 cal BC*. 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 BC* (*95% probability*; *IIIA–IIIB*; FIG. 9), probably in *4085–4000 cal BC* (*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 BC* (*95% probability*; *Racot IIIA/IIIB-1*; FIG. 7), probably in *4110–4060 cal BC*. 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 BC* (*95% probability*; *end IIIB*; FIG. 9), probably in *3805–3370 cal BC* (*68% probability*). This is rather later than the end of Late Lengyel activity at Racot 18, which occurred in *4035–3990 cal BC* (*95% probability*; *End Racot Late Lengyel*; FIG. 7), probably in *3970–3915 cal BC* (*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 BC. Late Lengyel IIIB ceramics may continue later into the fourth 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 modelling 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 fifth millennium cal BC, 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 Trichterband (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 neighbours. Thirdly, it was perhaps the longevity of sites like Racot, inhabited by individualised 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 modelling 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 emphasised 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 be done better still 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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Table 1. Radiocarbon and stable isotopic measurements from Racot 18.

Laboratory Number	Radiocarbon Age (BP)	Material and context	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N ratio
OxA-30500	5307±31	Disarticulated pig distal tibia from Pit 17, associated with the use of House 19	−21.3±0.2	+8.3±0.3	3.1
Poz-43969	5370±40	Replicate of OxA-30500			
T'=1.6; T'(5%)=3.8; ν=1; weighted mean 5331±25 BP					
SUERC-53975	5345±36	Articulating goat radius and ulna from Pit 17, associated with the use of House 19	−20.2±0.2	+5.8±0.3	3.2
SUERC-53973	5337±30	Roe deer mandible from pair (left and right), with similar wear stages, from Pit 31. Pit 31 cuts Pit 71 which cuts the trench of House 32. Probably associated with the use of House 12.	−20.7±0.2	+5.5±0.3	3.2
Poz-43970	5380±40	Disarticulated cattle distal radius from Pit 53, associated with the use of House 32.			
SUERC-53976	5368±32	Articulating sheep/goat proximal metatarsal and centroquartel from Pit 53, associated with the use of House 32.	−20.4±0.2	+5.6±0.3	3.2
OxA-30498	5353±32	Articulating roe deer phalanges 1 and 2, from Pit 53, associated with the use of House 32.	−20.8±0.2	+4.9±0.3	3.2
OxA-30536	5263±36	Carbonised residue from inner surface of pottery sherd from Pit 54, associated with the use of House 32.	−26.8±0.2		
Poz-43971	5360±40	Disarticulated sheep/goat distal humerus from Pit 54, associated with House 32.			
SUERC-53972	5384±30	Replicate of Poz-43971	−21.0±0.2	+6.3±0.3	3.2
T'=0.2; T'(5%)=3.8; ν=1; weighted mean 5375±25 BP					
Gd-2726	5380±80	Unidentified animal bone from Pit 80, associated with the use of House 88			
OxA-30537	5195±34	Carbonised residue from inner surface of potttery sherd from Pit 80, associated with the use of House 88	−27.1±0.2		
SUERC-53968	5367±32	Articulating roe deer phalanges I and II, from Pit 80, associated with the use of House 88	−21.1±0.2	+5.8±0.3	3.2
Gd-2729	5220±90	Human bone from an articulated flexed female skeleton in Grave 82, with a necklace of animal teeth and copper beads, 18 epaulets made from cattle rib, a shell belt, and two pots (Czerniak 2002, fig. 6). Later than House 88.			
OxA-30501	5366±32	Replicate of Gd-2729	−20.1±0.2	+9.1±0.3	3.1
T'=2.3; T'(5%)=3.8; ν=1; weighted mean 5350±31 BP					

OxA-30538	5330±40	Carbonised residue from inner surface of pottery sherd from Pit 101, thought to be associated with the use House 32.	−28.3±0.2		
Poz-43972	5370±40	Disarticulated sheep-sized (size 2) radius shaft from Pit 101, thought to be associated with the use of House 32.			
SUERC-53967	5363±30	Articulating sheep/goat unfused radius and ulna from Pit 101, thought to be associated with the use of House 32.	−20.7±0.2	+6.0±0.3	3.2
OxA-30497	5402±30	Articulating femur and ulna from neonate pig skeleton from Pit 107, earlier than annex 121 of House 106	−20.8±0.2	+6.3±0.3	3.2
Poz-43974	5390±50	Disarticulated sheep/goat pelvis (acetabulum and ilium) from from Pit 107, earlier than annex 121 of House 106			
SUERC-53966	5396±32	Replicate of Poz-43974	−20.3±0.2	+4.8±0.3	3.3
T'=0.0; T'(5%)=3.8; ν=1; weighted mean 5394±27 BP					
Poz-43975	5240±40	Disarticulated cattle distal metatarsal from Pit 129, probably associated with the use of House 106			
Poz-43976	5410±40	Disarticulated cattle distal humerus from Pit 135, associated with the use of House 134			
OxA-30499	5391±31	Articulating sheep/goat radius and ulna from Pit 135, associated with the use of House 134	−19.6±0.2	+4.2±0.3	3.1
SUERC-53974	5410±32	Pig right femur from what was probably a neonatal skeleton in Pit 135, associated with the use of House 134	−21.9±0.2	+7.8±0.3	3.3
OxA-30496	5394±30	Articulating sheep/goat radius and ulna from Pit 213, associated with the use of House 211	−19.6±0.2	+4.6±0.3	
SUERC-53965	5094±32	Articulating cattle proximal radius and ulna from Pit 213, associated with the use of House 211	−20.7	+5.2±0.3	3.5
Poz-43979	5430±40	Disarticulated sheep/goat phalanges (probably only one was sampled) from Pit 220, possibly associated with the use of House 133			
Gd-4177	5570±270	Unidentified animal bone from Pit 138A, with Late Band Pottery Culture IIA pottery			
Poz-43977	5820±40	Disarticulated cattle phalanx II from Pit 138A, with Late Band Pottery Culture IIA pottery			

Table 2. Radiocarbon measurements from the Late Band Pottery Culture and the Late Lengyel in the Polish lowlands.

Laboratory Number	Radiocarbon Age (BP)	Material and context	Ceramic phase
Białcz Stary 4 (Czerniak 1994)			
Gd-2054	5820±80	Unidentified charcoal from pit 108	Late Band Pottery Culture I
Gd-1753	5860±50	Unidentified charcoal from pit 109Bc	Late Band Pottery Culture I
Bodzia 1 (Czerniak unpublished)			
Poz-43553	5370±40	Animal bone from cellar pit A54 inside house	Late Lengyel IIB
Poz-43554	5335±35	Animal bone from cellar pit E225 inside house	Late Lengyel IIIA
Poz-43555	5220±40	Animal bone from pit B354	Late Lengyel IIIB
Boguszewo 43b (Kirkowski and Kukawka 1990)			
Gd-4451	5720±120	Hazelnut shells from pit 23 at a depth of 1.0m	Late Band Pottery Culture IIA (probably)
Gd-6060	5660±120	Hazelnut shells from pit 23 at a depth of 1.0m	Late Band Pottery Culture IIA (probably)
Gd-6047	5710±90	Unidentified charcoal from pit 23 at a depth of 1.0m	Late Band Pottery Culture IIA (probably)
T'=0.2; T'(5%)=6.0; ν=2; weighted mean: 5700±62 BP			
Gd-5545	5340±60	Unidentified charcoal from pit 23 at a depth of 0.4m	Late Lengyel IIB or IIIA
Gd-5463	5400±60	Unidentified charcoal from pit 11 (bottom layer)	Late Lengyel IIIA
Gd-2982	5310±60	Unidentified charcoal from pit 11 (upper layer)	Late Lengyel IIIA
Broniewice 1 (Czerniak 1994)			
Bln-1312	5060±60	Unidentified charcoal from pit	Late Lengyel IIIB
Brześć Kujawski 3 (Grygiel 2008)			
LOD-164	5210±180	Unidentified charcoal from a lens in pit 775, at a depth of 2.0m	Late Lengyel IIIA
GX-6369	5525±320	Unidentified charcoal from pit 775	Late Lengyel IIIA
T'=0.8; T'(5%)=3.8; ν=1; weighted mean: 5289±157 BP			
LOD-165	5370±180	Unidentified charcoal from a lens in pit 782, at a depth of 0.8m	Late Lengyel IIIA
LOD-173	5250±180	Unidentified charcoal from a lens in pit 834, at a depth of 0.7m	Late Lengyel IIIB
LOD-110	5160±180	Unidentified charcoal from pit 773 at a depth of 1.2m	Late Lengyel IIIB
LOD-162	4830±160	Unidentified charcoal from pit 773 at a depth of 1.2m	Late Lengyel IIIB
T'=1.9; T'(5%)=3.8; ν=1; weighted mean: 4981±120 BP			
LOD-163	5130±160	Unidentified charcoal from a lens in pit 774, at a depth of 2.0m	Late Lengyel IIIB (probably)
LOD-167	5410±340	Unidentified charcoal from a lens in pit 787 at a depth of 0.6m	Late Lengyel IIIA
LOD-170	4930±160	Unidentified charcoal from a lens in pit 816, at a depth of 0.7m	Late Lengyel IIIB
GX-6370	4515±210	Unidentified charcoal from pit 784	Late Lengyel IIIB
LOD-194	5280±190	Unidentified charcoal from a lens in a ditch of hut 56, at a depth of ca. 1.0m	Late Lengyel IIIA
LOD-187	5280±190	Unidentified charcoal from a lens in pit 899, at a depth of 1.2m	Late Lengyel IIIA
LOD-193	5400±190	Unidentified charcoal from a lens on the base of pit 892, at a depth of 0.6–0.8m.	Late Lengyel IIIA
LOD-195	5260±190	Unidentified charcoal from a lens at the base	Late Lengyel IIIB

		of pit 893, at a depth of 1.8m	
GrN-8869	5330±130	Unidentified charcoal from House 44	Late Lengyel IIIB
Firlus 8 (Kirkowski 1990)			
Gd-2429	6020±100	Unidentified charcoal from pit 4 (with basal hearth), at a depth of ca. 1.2m	Late Band Pottery Culture I
Inowrocław-Mątwy 5 (Czerniak 1994)			
Bln-1323	6000±120	Unidentified charcoal from pit 3	Late Band Pottery Culture I
Jankowo 4 (Czerniak 1980)			
GrN-14020	5450±60	Unidentified charcoal from pit 15	Late Band Pottery Culture IIA
Kościelec Kujawski 16 (Czerniak 1980)			
Gd-324	5400±180	Unidentified charcoal from pit	Late Lengyel IIB
Krusza Zamkowa 3 (Czerniak 1980)			
Bln-1810	5680±60	Unidentified charcoal from pit 311	Late Lengyel IIB
Bln-1809	5565±100	Unknown material from pit 576	Late Lengyel IIB
Bln-1811	5330±65	Human bone from grave 392	Late Lengyel IIIA
Kruszynek 6 (Czerniak and Siewiaryn unpublished)			
Poz-42022	5770±35	Animal bone from pit C69	Late Band Pottery Culture IIA
Poz-42010	5425±35	Animal bone from storage pit E109	Late Band Pottery Culture IIA
Poz-42012	5715±35	Animal bone from cellar pit B16 inside house	Late Lengyel IIB
Poz-42023	5440±35	Animal bone from cellar pit E23 inside house	Late Lengyel IIB
Poz-42013	5410±30	Animal bone from cellar pit B18 inside house	Late Lengyel IIIA
Poz-42014	5460±35	Animal bone from cellar pit B59 inside house	Late Lengyel IIIA
Poz-42015	5385±35	Animal bone from cellar pit B83 inside house	Late Lengyel IIIA
Poz-42016	5420±35	Animal bone from cellar pit B139 inside house	Late Lengyel IIIA?
Poz-42021	5420±35	Animal bone from pit C6	Late Lengyel III
Kuczyna 1 (Grygiel 2008)			
LOD-93	5530±220	Unidentified charcoal from loam pit, at a depth of 0.8–1.0m	Late Lengyel IIB
Łojewo 1 (Czerniak 1994)			
GrN-10771	5310±40	Animal bone from pit 11	Late Lengyel IIIA
Miechowice 4 (Grygiel 2008)			
LOD-1006	5640±60	Unidentified charcoal from pit 19	Late Lengyel IIB (probably)
LOD-1011	5610±60	Unidentified charcoal from pit 19a	Late Lengyel IIB (probably)
Miechowice 4a (Grygiel 2008)			
LOD-1017	5420±60	Unidentified charcoal from loam pit 3	Late Lengyel IIB
LOD-1016	5190±60	Unidentified charcoal from pit 4	Late Lengyel IIIA
Osłonki 1 (Grygiel 2008)			
LOD-434	5510±130	Unidentified charcoal from loam pit 7	Late Lengyel IIB
LOD-435	5570±150	Unidentified charcoal from loam pit 7, pit 75	Late Lengyel IIB
LOD-428	5600±130	Unidentified charcoal from loam pit 7, W niche	Late Lengyel IIB
T'=0.2; T'(5%)=6.0; ν=2; weighted mean: 5559±79 BP			
LOD-458	5560±150	Unidentified charcoal from loam pit 8, pit 109	Late Lengyel IIB
LOD-995	5580±60	Unidentified material from loam pit 10, A niche	Late Lengyel IIB
LOD-419	5690±140	Clay raw material from loam pit 2, X niche	Late Lengyel IIIA
LOD-426	5420±140	Clay raw material from loam pit 2, X niche	Late Lengyel IIIA

LOD-433	5400±150	Unidentified charcoal from loam pit 2, pit 71	Late Lengyel IIIA
T'=2.6; T'(5%)=6.0; ν=2; weighted mean: 5511±83 BP			
LOD-1002	5450±60	Unidentified charcoal from loam pit 3, part of A/93	Late Lengyel IIIA
LOD-1003	5300±60	Unidentified charcoal from loam pit 3, part of B/93	Late Lengyel IIIA
T'=3.1; T'(5%)=3.8; ν=1; weighted mean: 5376±43 BP			
LOD-540	5310±120	Unidentified charcoal from base of loam pit 9	Late Lengyel IIIA
LOD-539	5330±130	Unidentified charcoal from loam pit 9, A niche	Late Lengyel IIIA
LOD-538	5310±120	Unidentified charcoal from loam pit 9, G niche	Late Lengyel IIIA
T'=0.0; T'(5%)=6.0; ν=2; weighted mean: 5316±72 BP			
LOD-536	5250±120	Unidentified charcoal from pit 116, section 225	Late Lengyel IIIA
LOD-429	5330±120	Unknown material from house 5, pit 53	Late Lengyel IIIB
LOD-457	5410±150	Unidentified charcoal from pit 95	Late Lengyel IIIA
LOD-420	5480±150	Unidentified charcoal from loam pit 5, pit 45	Late Lengyel IIIB
LOD-418	5270±140	Unidentified charcoal from loam pit 5, section 12/15	Late Lengyel IIIB
LOD-424	5320±140	Unknown material from loam pit 5 (section 44)	Late Lengyel IIIB
LOD-423	5380±130	Unknown material from loam pit 5 (section 46)	Late Lengyel IIIB
LOD-425	5310±130	Unknown material from loam pit 5, pit 39	Late Lengyel IIIB
T'=1.3; T'(5%)=9.5; ν=4; weighted mean: 5349±62 BP			
LOD-454	5370±150	Unknown material from loam pit 6, D niche	Late Lengyel IIIB
LOD-455	5360±160	Unknown material from loam pit 6, M niche	Late Lengyel IIIB
LOD-453	5250±140	Unknown material from loam pit 6, N niche	Late Lengyel IIIB
LOD-427	5300±130	Unknown material from loam pit 6, P niche	Late Lengyel IIIB
LOD-456	5320±140	Unknown material from loam pit 6, P niche	Late Lengyel IIIB
T'=0.4; T'(5%)=9.5; ν=4; weighted mean: 5316±64 BP			
LOD-993	5480±60	Unknown material from pit 229	Late Lengyel IIIB
LOD-987	5280±60	Unknown material from section d earlier ditch	Late Lengyel IIIB
LOD-535	5310±120	Unknown material from section J later ditch	Late Lengyel IIIB
LOD-999	5610±60	Unknown material from pit 208	Late Lenygel IIIA
Węgierce 12 (Czerniak 1994)			
Gd-2509	5860±100	Animal bone from pit 1 at a depth of ca. 1.0m	Late Band Pottery Culture I
Zelgno (Czerniak unpublished)			
Poz-43965	5330±40	Animal bone from cellar pit A96 inside house	Late Lengyel IIB
Poz-43964	5310±40	Animal bone from pit A90, at a depth of 1.1m	Late Lengyel IIB
Poz-43962	5370±40	Animal bone from storage-pit A10, at a depth of 1.2m	Late Lengyel IIB

Figure captions

Figure 1 The Polish Lowlands 5400–4000 cal BC. 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; 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; 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; 3-6: grave goods; 3: part of hip belt *Unio* sp. Shells; 4: two pottery vessels; 5- necklace of animal teeth and copper beads, 6- 12 (from 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 BP. The hypothetical buildings were in use for a) 25 years, b) 50 years, and c) 100 years, and have simulated dates ranging from a building in use between 5000–4975 BC to one used between 3825–3725 BC.

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 and 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-hand 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-hand 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-hand 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.