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Narratives for Lengyel funerary practice

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Mots-clés:

In memoriam István Zalai-Gaál

Introduction: the scope of this paper

This paper, dedicated to the memory of István Zalai-Gaál, presents formally modelled date estimates for the sequence of Lengyel funerary pottery in western Hungary, eastern Austria and south-west Slovakia. It is an extension of the dating and modelling already carried out by the project, *The Times of Their Lives* (ToTL), on the major Lengyel aggregation, including burials, at Alsónyék-Bátaszék in south-east Transdanubia (OSZTÁS et al. 2016a; 2016b; BÁNFFY et al. 2016).

To put the aims of our paper in context, we first briefly introduce the history of research on the Lengyel culture and some of its key features. The many contributions of István Zalai-Gaál to this research and the recent work on Alsónyék form the background to the present study and help to define its aims. Three complementary chronologies for furnished Lengyel burials will emerge, which provide the basis for narratives of the origins, development and demise of furnished Lengyel burial.

Lengyel research history

There is of course a long research history for the Lengyel culture in general. This goes back to the first fieldwork by Mór WOSINSKY (1891) at the Transdanubian site of Lengyel itself and to early work by other pioneers on related phenomena, such as by Palliardi on what is now known as Moravian Painted Ware (KOVÁRNIK 2008; PAŽINOVÁ 2010; DONEUS / RAMMER 2017a). This is not the place to chronicle that story of investigations in detail, although it is worth noting that there was subsequent work on classification of this material in the 1920s and 1930s, and the culture-history label of 'the Lengyel culture' was probably first coined or at least in general currency by the 1920s (with references in the work of Oscar Menghin, Ferenc Tompa, R.R.

Schmidt and then Gordon Childe). From the 1960s, there was a step-change in the scope and intensity of fieldwork and discoveries on the one hand, and in the detail of chronological schemes on the other (see, for example, BOGNÁR-KUTZIÁN 1966). Eight international conferences on the Lengyel culture were held between 1967 and 2006 (KOZŁOWSKI / RACZKY 2007a), for example. A notable effort was made in the 1970s and 1980s by Juraj PAVÚK (1981; cf. PAŽINOVÁ 2010), as another individual example, to produce detailed relative chronologies for Lengyel development in Slovakia (as it became subsequently) and surrounding countries, based above all on the typological study of pottery.

Key features of the Lengyel culture

The Lengyel culture should figure prominently in any account of the development of the Neolithic way of life in the middle of Europe. It carries forward the story of early agricultural communities, after the Starčevo and *Linearbandkeramik* (LBK) beginnings, into the first half of the fifth millennium cal BC, involving parts of Hungary, Slovakia, Austria, Moravia (in the Czech Republic) and beyond, with closely related phenomena in Poland, south-east Germany, and Slovenia and Croatia to the south. Sarunas MILISAUSKAS and Janusz KRUK (2011b, 294) have preferred to call this an 'artifact style zone'. Whatever label is used for the people of the Lengyel phenomenon, their practices in the first half of the fifth millennium cal BC confront us with post-LBK developments which may be rather different compared to changes further north-west, associated with the *Stichbandkeramik* (SBK) pottery style (GLESER / BECKER 2012; ZÁPOTOCKÁ et al. 2015; LENNEIS 2017). There is also substantial diversity in contemporary material culture and lifeways in central Europe and the northern Balkans. This extends from the Lengyel orbit in western Hungary or Transdanubia and to the north (LENNEIS 2017), to the Tisza and Herpály groups on the Great Hungarian Plain (RACZKY et al. 2007) and the developed Vinča culture or network (WHITTLE et al. 2016) to their south. At the same time, literally, there is strong evidence for inter-regional connection; to cite just one recent witness, the sources of lithics used at the major site of Alsónyék-Bátaszék in south-east Transdanubia were extremely varied, from local resources to ones derived from as far afield as the western Carpathians and south-east Germany (SZILÁGYI 2017, fig. 7).

Prominent aspects of the Lengyel way of life included settlements with houses, which have been described as showing a 'melding of Danubian ideas with Balkan house concepts' (LAST 2015, 284), rondel and other ditched and palisaded enclosures, with opinion divided on their possible defensive or symbolic roles (PETRASCH 2015), and, at least for parts of its timespan and distribution, large burial grounds or cemeteries. In the eastern Lengyel area (mainly eastern Transdanubia and adjacent regions to the north), many burials are found, mostly in smaller or larger groupings, mixed in with or close to settlements. The western Lengyel area including Austria and Moravia must have had a burial custom that left no human remains behind, except some highly unusual, partial or multiple inhumations. Both these differences and overarching similarities raise issues of social relations at various scales, both within and between local and more distant communities. Many commentators have pointed to features of this kind, such as changing house architecture, more varied burial practices, including a greater range of grave goods, and enclosure construction, as signs of increasing social differentiation (e.g. PAŽINOVÁ 2009, 30; DEMJÁN 2015, 364; cf. KONČELOVA / KVĚTINA 2015, fig. 6, for the SBK; GLESER / BECKER 2012). Inter-connections are also important in the decline of the Lengyel, Vinča and other related phenomena from the 47th century cal BC onwards (BORIĆ 2015a; WHITTLE et al. 2016).

Lengyel questions: the many contributions of István Zalai-Gaál

István Zalai-Gaál died unexpectedly in March 2017. His name was synonymous with research on the Lengyel culture in Hungary. He had published a continuous flow of papers and monographs on Lengyel questions from the early 1980s onwards (ZALAI-GAÁL 1980; 1981; 1982), right up to the end of his life. Although he conducted important excavations of south-east Transdanubian Lengyel settlements himself, his research was notable above all for his working closely with the material, especially pottery and stone axes, applying typology, rigorous measurement and correspondence analysis (ZALAI-GAÁL 2010a; ZALAI-GAÁL et al. 2014a; 2014b; we do not attempt to cite his full bibliography). In the first place, that was a sustained effort — perhaps the outstanding contribution of its kind by any single Neolithic specialist — to determine sequence; this can be seen in many of his earlier papers (ZALAI-GAÁL 1993a; 1999; 2001a) and it remained of central interest and importance in his later work (ZALAI-GAÁL 2007a; 2007c; ZALAI-GAÁL et al. 2014b). Although often highly detailed and technical, this work on classification was allied to another prolonged search, for the overall character and subtle variations of Lengyel social relations. By the time of his 2010 monograph, his vision was of a degree of incipient social differentiation among Lengyel communities, discerned on the basis of variation in the character and abundance of grave goods with the burials of men, women and children. He compared his observations with analyses of the coeval east Hungarian Tisza culture and the subsequent

Tiszapolgár, Bodrogkeresztúr and Hunyadihalom cultures (ZALAI-GAÁL 2002; 2016), and reinforced them by reference to ethnographic situations and by comparison with Copper Age burial practice in Bulgaria. For him, the Lengyel culture of Transdanubia was not a context in which individuals operated on their own, but within family and clan groups (ZALAI-GAÁL 2010a, 255). Much of his work was based on analysis of the finds from older excavations of key Transdanubian sites such as Zengővárkony and Mórágy-Tűzkődomb (ZALAI-GAÁL 2002; 2010a), but that led him to his own fieldwork at the latter site. He also undertook excavations at the eponymous Lengyel itself (ZALAI-GAÁL 1983; 1984), and he was later centrally involved in the major rescue excavations of Alsónyék-Bátaszék in 2006–2009, detailed below (ZALAI-GAÁL / OSZTÁS 2009; ZALAI-GAÁL et al. 2012a; 2012b). Those led, among other things, to further refinement of his view of prominent individuals (ZALAI-GAÁL 2008; ZALAI-GAÁL et al. 2011a).

István's work was further distinguished by other strands of his approach to a social and wider contextual archaeology. Over many years, he published papers on the diverse topics, among others, of dogs and their significance in Lengyel burial practice (ZALAI-GAÁL 1994; ZALAI-GAÁL et al. 2011b); cattle cults (ZALAI-GAÁL 2005); skull cults (ZALAI-GAÁL 2009; 2010b: prompted by new discoveries at Alsónyék); pregnancy (ZALAI-GAÁL 2007b); figurines and cult objects (ZALAI-GAÁL 1993b; 1996; ZALAI-GAÁL et al. 2010) and copper (ZALAI-GAÁL 1996). By his own admission, this work can be related to a humanistic Hungarian tradition initiated by János Banner (ZALAI-GAÁL 2010a, 25). This recalls perhaps the general observation by Christopher CARR (1995) that it is not only social factors which condition the nature and form of mortuary practices. István was surely aware of this, citing in the introduction to one of his papers both 'die Angst' and 'der Charakter des Todes' as relevant possible factors in a list otherwise constituted by social dimensions, his own dominant theme and concern (ZALAI-GAÁL 2010b, 215).

Some of this work has had its critics. Zsuzsanna SIKLÓSI (2004, 6), for example, has argued that the fine social distinctions given by his close analysis of grave good assemblages are far too rigid to be plausible in a context such as that of the Lengyel culture, and that these anyway depend on unproven assumptions about exact contemporaneity (SIKLÓSI 2004, 50). We can add a further critique of our own, namely that no one, including István Zalai-Gaál himself, has so far fully and successfully linked chronological sequence and social analysis in Lengyel studies. In various of his papers, István (for example, ZALAI-GAÁL 2007a) identified an early Lengyel horizon represented by the respective grave assemblages of Svodín in Slovakia, Friebritz in Austria and some of those from Zengővárkony in Transdanubia, and declared his view that Svodín and Friebritz were earlier than the bulk of Lengyel mortuary practice in south-eastern Transdanubia. But there, despite his other analyses and insights, the matter rested, while he continued in what turned out to be his late papers to pick at the still nagging questions of Lengyel sequence (e.g. ZALAI-GAÁL et al. 2014b).

This study arose out of earlier work investigating the chronology of the Lengyel cemetery and settlement at Alsónyék-Bátaszék, in which István played a key part (ZALAI-GAÁL /OSZTÁS 2009; ZALAI-GAÁL et al. 2012a; 2012b; OSZTÁS et al. 2016b), which was subsequently extended to include grave-assemblages from similar sites in Transdanubia and beyond. The selection of new samples for radiocarbon dating as part of this study was directed by preliminary seriation of the grave-assemblages by István himself. In tribute to him, this paper can be seen as a contribution towards bringing the strands of chronological and mortuary analysis together to explore the social implications of Lengyel funerary practice. Research in this field has gained additional momentum and been enriched greatly by the latest results from investigations at Alsónyék-Bátaszék, which are also incorporated in this study.

Alsónyék-Bátaszék and its Lengyel setting

Recently, many of the important research questions raised by the Lengyel culture were put in the spotlight by the discovery, excavation and ongoing analysis of the remarkable, large site at Alsónyék-Bátaszék. As is now well known, here was a settlement estimated of as much as 80 ha, with hundreds of houses and attendant pits, and thousands of burials, in a series of grave groups (OSZTÁS et al. 2016a; 2016b; BÁNFFY et al. 2016). A major aggregation or coalescent community (OSZTÁS et al. 2016b; BÁNFFY et al. 2016), this complex proved to be at its largest extent for a surprisingly short period of time, in the decades around 4700 cal BC. Beginnings had probably been within the 48th century cal BC, and a long decline followed in the 47th and 46th centuries cal BC (OSZTÁS et al. 2016b; BÁNFFY et al. 2016). In turn, that history raises a series of further questions — about the geographical locations from which people may have moved; about the conditions under which such a gathering of people was achieved; about the social relations of the inhabitants or users of the site; about their place in the local and regional context; and about the circumstances in which the locale lost its lustre and attraction.

That chronological study of Alsónyék was based on over 200 new radiocarbon dates and formal modelling in a Bayesian statistical framework. It had earlier been claimed that Lengyel chronology had seen 'essential progress', on the basis of more radiocarbon dates, perfection of dating methods, and the introduction of AMS measurement (KOZŁOWSKI / RACZKY 2007b, 5). Such optimism was premature, but the results from Alsónyék and the present study which has led on from that site-based analysis do provide real hope that renewed interest in the Lengyel culture can be underpinned by robust chronology (see also PAŽINOVÁ 2010; GLESER 2012). In what follows, however, it is important to remember that the focus here is on pottery from graves, and the trajectory of Lengyel mortuary practice may not map precisely on to other trends. We come back to that in the final discussion.

Background to this study

As noted, the present study stemmed from the chronological modelling of the Lengyel settlement complex, including grave groups, at Alsónyék-Bátaszék (OSZTÁS et al. 2016a; 2016b). The original intention in that analysis was to use a site-specific seriation of the grave ceramics as prior information for the chronological modelling, and sampling was undertaken on this basis (BAYLISS et al. 2016, 51–3). For practical reasons relating to the post-excavation programme at Alsónyék, the seriation began by considering selected assemblages from subsites 10B and 11 (for various reasons, subsite 5603 was not included in our seriation). No chronological trend could be discerned in this material, and so the analysis of Alsónyék proceeded along different lines and the seriation study was expanded to include first other sites in Transdanubia and then sites in the wider distribution of Lengyel inhumation graves (Fig. 1).

The correspondence analysis undertaken for sites in southern Transdanubia was reported by ZALAI-GAÁL et al. (2014b, seriation table 1 and fig. 43). This analysis was subsequently extended to include selected sites in the northern part of the distribution of furnished Lengyel graves, although this work was still in progress at the time of István's death.

In order to complete this study within the timetable of the *Times of Their Lives* project, we did not attempt to extend the preliminary analysis undertaken by István Zalai-Gaál in March 2015, even though we are aware of assemblages from other sites that might have been included (such as Lengyel itself and Aszód: WOSINSKY 1891; SIKLÓSI 2007). Rather, we validated the working incidence matrix. The types had been optimised specifically for this analysis, and so the labelling does not relate to that of any previous published seriation of these finds. The pots assigned to each type were carefully checked for consistency against the original publication of the grave or, in the case of Alsónyék, against the pottery itself. A handful of discrepancies were identified and resolved by this process. This initial validated incidence matrix is provided as supplementary information (Supplementary Table 2: Incidence matrix 1).

Aims

The primary aim of this study is to establish a calendar chronology for furnished Lengyel graves across a significant part of the Lengyel distribution, in western Hungary, eastern Austria and Slovakia, thus revealing developments in Lengyel funerary ceramics through time. We aim to estimate the period during which Lengyel burials with grave goods occurred, and further to estimate the pace of their introduction and demise. We also aim to estimate the date when different cemeteries were in use, and to estimate the intensity of furnished burial through time.

To achieve these aims:

- we created a seriation using correspondence analysis of the incidence of ceramic types in grave assemblages;
- we obtained a large series of radiocarbon dates on skeletons buried with diagnostic grave assemblages;
- we combined the relative sequence of phases of grave assemblages derived from the seriation with the available radiocarbon dates using Bayesian chronological modelling;
- and we compared the results from this model with those for an analogous model based on the seriation suggested by DIACONESCU (2014a).

A secondary aim was to exploit the calendar dating of these sequences to produce more detailed narratives about the Lengyel phenomenon as a whole. That is largely a matter for future research, but the present study may indicate some of the directions that future work may explore. A final hope is to redress the balance of wider attention to Lengyel matters. While by no means ignored in broader narratives, the Lengyel culture tends to take a back seat compared to the LBK which preceded it, or other phenomena which overlapped or followed it, such as early and developed Copper Age groups or cultures like Tiszapolgár. Thus, two chapters in a survey of European prehistory contain numerous references to the Lengyel culture, but almost without exception these are brief and in passing, often with a more northerly perspective and with the main focus on other themes and subjects (MILISAUSKAS / KRUK 2011a; 2011b). Likewise, there are numerous mentions of the Lengyel culture throughout the recent Oxford handbook on Neolithic Europe (FOWLER et al. 2015), but again rarely with any detail; interestingly, given the focus of the present paper, the main exception is some depth of discussion of Lengyel mortuary practices by Dušan BORIĆ (2015b). We will come back to both these perspectives in the discussion.

Lengyel funerary ceramics

A characteristic feature of Lengyel burials is that they contain a substantial number of ceramic vessels. Usually between one and three pots were placed in the graves, although there may be up to 20. Compared to settlement ceramics, funerary pottery is limited to a smaller range of distinctive forms. Specific variations of the different forms make up the grave inventories. The number of pots and the variety of vessel types placed in graves were not random; chronological and social factors both played a role in the quantity and composition of the ceramic finds in Lengyel burials (ZALAI-GAÁL 2010a, 73). Similarities in the style of Lengyel pottery across its spatial distribution allow us to perform comparative cultural studies. Ceramics offer the best potential for detailed comparison, as they dominate Lengyel funerary finds and they are very sensitive to changes in burial practice. Study of the ceramics reveals characteristic traits that can be determined quantitatively.

István Zalai-Gaál had developed a form of typology based on quantitative attributes of Lengyel funerary ceramic finds (ZALAI-GAÁL 2002; 2007a; ZALAI-GAÁL et al. 2014b). As a first step, measurements of different parts of the pots were taken and, on the basis of metric descriptors, they were classified into a hierarchy (in German, from higher to lower, *Klassen*, *Gattungen*, *Serien*, *Formengruppen* and *Varianten*) of different categories. The two main metrically defined classes *(Klassen)* are high pots and wide pots. Their main forms (*Gattungen*) are designated as 1a–e and 2a–c. Thus, the 1a pots are pedestalled bowls, 1b are beakers or shouldered vessels (three-part vessels), 1c are beakers (bi-conical vessels), 1d are beakers (one-part vessels), 1e are cups, 2a Butmir vessels, 2b bowls, and 2c dishes. These are the basic forms of Lengyel funerary pottery, in which there are five and three generic groups or sub-classes (*Serien*) respectively (designated 1a1 and so on). The generic groups or sub-classes are further subdivided into 'form groups' (*Formengruppen*) or types according to the proportional shapes of the pottery (and are designated 1a1b, and so on). Those are further subdivided into variants (*Varianten*) according to their profiles (and labelled as 1a1b1 and so on), but that level of the hierarchy is not used in the present study.

The most characteristic Lengyel vessel form, the pedestalled bowl (1a), is classified on the basis of the bowl form and the pedestal form. Bowls, with profiles ranging from hemispherical to wide open conical shapes, stand on low or high pedestals in many variations. In our analysis we have four generic groups or sub-classes and 24 different types. Finely made beakers can be divided into three generic groups according to their profiles. Sharply shaped beakers (1b) are three-part vessels classified into four generic groups or sub-classes and 25 types. The 1c beakers are biconical vessels without the sharply profiled neck of the previous class, with four generic groups or sub-classes and four types. The 1d beakers are one-part vessels, globular in form, divided into two generic groups or sub-classes and three types. The larger, shouldered, three-part vessels constitute the fifth generic group or sub-class of 1b beakers (1b5) because of their similar profiles and the proportions, with ten types. The 1e cups are smaller, coarse, globular or slightly angular forms divided into four generic groups or sub-classes and 14 types. The Butmir vessel (2a) is a very typical Lengyel vessel form with its inwardly curved rim, high shoulder, and sharp carination. This sub-class comprises three generic groups or sub-classes and 14 types. The 2b bowls are extremely varied and have a wide range of characteristics. There are five generic groups or sub-classes and 19 types according to whether the pot is low or high, and the side is straight or profiled. The 2c dish forms are small vessels of mostly biconical body with two form groups and eight types.

The classification of pottery types used in the analysis presented here is defined in the catalogue of types provided as supplementary information (Supplementary Table 1; Supplementary Fig. 1), where each is described and a representative example is illustrated. We have standardised the format of the labelling of the graves in question. Acronyms are provided in the caption to Fig. 1.

Correspondence analysis

Correspondence analysis is a multivariate statistical technique for investigating the similarity or distance between entries in a table of categorical data. One of the major advantages of this method is that the results of the statistical calculations for both the columns and the rows can be jointly displayed in a two-dimensional graphic plot, which facilitates interpretation of the output.

A general description of the mathematical background of the method is given by GREENACRE (2013; 2016).

In archaeology, correspondence analysis is often employed to use the occurrence or abundance of variables to order units in sequence. This ordination represents underlying structure in the data, which can reflect a chronological trend or social, spatial, or functional differentiation. Information external to the analysis is needed to demonstrate whether the ordering in the data revealed by the analysis represents a temporal seriation. Correspondence analysis can be performed either on a matrix of the abundance of types in units, or on a matrix of the presence or absence (incidence) of types in units. Abundance seriation appears to be the preferred method with American scholars (BAXTER 1994; SMITH / NEIMAN 2007; PEEPLES / SCHACHNER 2012; PORČIĆ 2013), as it is particularly suitable for finds from open contexts such as settlement features which have high numbers of objects. In contrast, in Europe incidence seriation is more popular (JENSEN / NIELSEN 1997; BAYLISS et al. 2013), as it is particularly appropriate for investigating the relationships between closed archaeological contexts containing limited numbers of objects (such as grave assemblages). Discussion of seriation by correspondence analysis in archaeology can be found in SHENNAN (1997), BAYLISS et al. (2013, 60–73), BAXTER (2015, 16–18, 133–47) and SIEGMUND (2015).

Correspondence analysis of Lengyel graves

Some of the Lengyel funerary assemblages have already been subject to incidence seriation by correspondence analysis. ZALAI-GAÁL (2007a) considered pottery in graves from selected sites across the wider distribution of Lengyel furnished burials and, as mentioned above, ZALAI-GAÁL et al. (2014b) considered an extended dataset from southern Transdanubia. DIACONESCU (2014a) presented a correspondence analysis based on a different classification of pottery types, which unfortunately is not described in detail. He partitioned his sorted incidence matrix into successive non-overlapping phases which he suggests have chronological significance, and estimated calendar dates for the phase boundaries by combining the radiocarbon dates available to him with the suggested phasing scheme using Bayesian chronological modelling.

This study aims to determine whether there is a chronological order underlying the distribution of the Lengyel funerary data from different sites. Graves with two or more chronologically sensitive types were chosen for analysis, while a type had to occur in at least two graves in order to be included in the seriation. Another requirement for obtaining reliable seriation is that vessels must be in a closed context, with neither later re-opening of the grave introducing new finds nor curated items deposited. Graves where such issues were suspected were not included in the incidence matrix. It is generally assumed that the arrangement of the units and types in a horseshoe-shaped pattern in the bi-plot of the first and second principal axes of the correspondence analysis indicates a certain gradient and a degree of continuity in the data, which is often interpreted as a chronological signal (BAXTER 2015, 141; MADSEN 2016a; SIEGMUND 2015). The first and second principal axes are also known as the first and second eigenvectors, and are thought to account for the greatest amount of variability (or 'inertia') in the data, which means that they make the largest contribution towards explaining their structure or – in other words – the differences between assemblages (BAYLISS et al. 2013, 67; MADSEN 2016a).

Our correspondence analyses of Lengyel funerary ceramics

The initial validated incidence matrix comprised 275 graves and 121 types (Supplementary Table 2: Incidence matrix 1). The correspondence analyses were carried out using the CAPCA add-on for Microsoft Excel, version 3.03 (MADSEN 2016b).[1] Once correspondence analysis had been undertaken on the incidence matrix, the quality of the chronological trend in the data was examined by fitting a second-order polynomial function to the horseshoe of points plotted on the first two principal axes using regression. The goodness of fit of the polynomial was assessed using Pearson's R^2 statistic.

It became obvious from the result of the first run that the content of the matrix had to be modified. The Pearson correlation coefficient (R^2) for this analysis was only 0.2998 for graves, and 0.3229 for types, indicating that the data were probably either not continuous, or not unimodally distributed, or both (this value would be 1 for a perfectly ordered sequence and 0 for a set of unlinked graves; see Porčić 2013 for discussion of R^2 as a statistical indicator of goodness of fit for seriation solutions). The bi-plot of the first and second principal axes for graves and types identified several outliers: types 1b1d, 2a3b, 1e4c, 2a2f, 2a1d and 2c2f, and graves s88.79, zv79, s76.78 and az2028. These are generally rare types, each occurring in only two or three graves that are linked poorly to the other graves in the seriation. Graves az2028 and s88.79 exerted the greatest influence on data distribution and so were removed from the analysis,

[1] The algorithms employed in versions 3.03 and 3.1 are identical.

causing type 1b1d (an identified outlier) to be deleted from the matrix, because that type now only appeared in one grave.

The second run revealed that these measures slightly improved the R^2 values for graves (0.3239) and types (0.3522), but the bi-plot again indicated that there were further outlier graves — m50 and m48 in particular. Grave m50 contained a type (1e1a) that more frequently occurred close to the upper end of the seriation, whereas this grave appears almost at the bottom of it, thus masking a general gradient in the data otherwise visible in the bi-plot. Either this grave assemblage contained a vessel that was an heirloom, or the grave had been reopened again after the primary burial event and later types were added. This grave was removed from the analysis. Grave m48 had a unique combination of only two types, one of which was 2a1d (an identified outlier), and was only poorly linked to the other graves in the seriation. This grave was also removed from the analysis. Two other graves containing 2a1d (m25 and m40) were also outliers and similarly poorly connected with the remaining graves, and thus had to be removed from the matrix at this stage together with 2a1d.

After the third run, a further three outlier graves were detected containing type 1b5i which appeared at the lower end of the seriation, with weak links to the other graves. We chose to remove this type since its statistical weight would have caused the remaining graves in the correspondence analysis to coalesce, preventing possible phase boundaries from being visible in the bi-plot. Consequently, three further graves (an847, az724 and az190) which only included type 1b5i and one other type were deleted from the matrix. The R^2 values for the following seriation were 0.5518 for graves and 0.6450 for types, again representing a slight improvement compared to the previous run, but still indicating a degree of uncertainty as to whether the data were continuous. This required further steps to be taken, in order to obtain a clearer picture of the data structure.

The fourth run identified type 2a3b as occurring only twice, the two incidences appearing at either end of the seriation. Therefore, this type was deleted from the matrix, which in turn caused graves zv79 and zv135 each to have only one remaining type and so they, too, had to be removed from the matrix. The sorted incidence matrix from this run also revealed that there were other graves with types that were widely spaced in the seriation, at the very least indicating that these graves were of only very limited chronological significance and contained grave-goods of varying date. The graves concerned, s177.82, zv184, zv187, zv361, zv178, s121.80 and no1, were removed from the analysis. Following their removal from the incidence matrix, grave gy11 (now containing only one type) and type 2b2b (now occurring in only one grave) also had to be removed.

As a result, R^2 for the fifth run increased to 0.6392 for graves and 0.7070 for types. Another outlier grave with an apparently mixed assemblage could be identified from the bi-plot of the first and second principal axes and from the sorted incidence matrix (zv88), and was therefore removed from the analysis.

In the final steps, further outlier graves with rare combinations of types were detected and removed (s76.78, fr135, m58 and zv206), along with types 2b5c, 1a3j and 2a1a. Through this process we arrived at R^2 values of 0.7450 for graves and 0.7857 for types for the final run (see Supplementary Table 3: Incidence matrix 2, Figs 2a–b and Supplementary Fig. 2). Consequently, we are confident that the remaining graves (n=247) and types (n=113; note that Supplementary Figure 1 includes the full original 121 types) which were included in the final correspondence analysis reflect a clear gradient in the data, presumably a chronological one. This, however, remains to be verified by combining the radiocarbon dates from burials included in the correspondence analysis with the phased seriation, as we set out below.

Radiocarbon dating

A total of 91 radiocarbon measurements are now available from 57 Lengyel graves in western Hungary, eastern Austria, and south-western Slovakia (Fig. 1), all but 16 obtained by the ToTL Project (Tables 1 and 2).[2] Forty-eight of these graves are included in the correspondence analysis of the incidence of pottery types in Lengyel graves described above. In addition, 159 radiocarbon measurements from 143 Lengyel graves have been reported recently from Alsónyék-Bátaszék, Hungary (OSZTÁS et al. 2016b, tables 2–4). Twenty-nine of these graves are included in the same correspondence analysis.

[2] A further measurement has been obtained on human bone from grave 95 at Aszód (VERA-2073, 5901±57 BP, 4940–4610 cal BC (93% probability; STUIVER / REIMER 1993) or 4640–4610 cal BC (2% probability); STADLER / RUTTKAY 2007, 119), although this grave has no pottery and so is not included in the analyses presented here. We are also aware of further measurements that have been obtained on grave 1-718 from Pusztataskony and further graves from Aszód (DIACONESCU 2014a, 25), although these are not yet fully published.

The 27 samples of human bone dated at the Curt-Engelhorn-Zentrum Archäometrie, Mannheim (MAMS-), were prepared by gelatinisation and ultrafiltration (BROWN et al. 1988), combusted in an elemental analyser, graphitised and dated by Accelerator Mass Spectrometry (AMS) (KROMER et al. 2013). Of the samples dated at the Oxford Radiocarbon Accelerator Unit (OxA-), the seven samples of human bone from Esztergályhorváti were gelatinised and purified by ion-exchange (LAW / HEDGES 1989; HEDGES et al. 1989) before combustion and dating as carbon dioxide targets by AMS (HEDGES et al. 1992; BRONK RAMSEY / HEDGES 1997). OxA-6208 and OxA-6367 additionally underwent solvent extraction using acetone, methanol and chloroform, and OxA-6367 was graphitised and dated by AMS as described by BRONK RAMSEY et al. (2004). The other samples of human bone processed in Oxford were gelatinised and ultrafiltered (BROCK et al. 2010), and combusted, graphitised and dated by AMS as described by BRONK RAMSEY et al. (2004). The 31 samples of unburnt human bone dated at the Scottish Universities Environmental Research Centre (SUERC-), East Kilbride, were gelatinised, ultrafiltered and combusted; the two samples of calcined bone were pretreated as described by LANTING et al. (2001) and the carbon dioxide devolved using orthophosphoric acid and purified; all samples were then graphitised and dated by AMS. Methods used at SUERC are described in DUNBAR et al. (2016). The nine human bone samples dated at the Vienna Environmental Research Accelerator (VERA-) were gelatinised using a continuous-flow system (LAW / HEDGES 1989), graphitised and dated by AMS (WILD et al. 1998; ROM et al. 1998).

These measurements are conventional radiocarbon ages (STUIVER / POLACH 1977). At Mannheim, Oxford and Vienna they have been corrected for fractionation using $\delta^{13}C$ values measured by AMS. These values can include an element of fractionation introduced during the preparation and measurement of the samples in addition to the natural isotopic composition of the sample, and so they are not suitable for dietary analysis. For this reason, further stable isotopic values were obtained from most of the dated samples by Isotope Ratio Mass Spectrometry (IRMS). At Oxford $\delta^{13}C$ and $\delta^{15}N$ were measured by a mass spectrometer attached directly to the CN analyser used to combust the samples to carbon dioxide (BROCK et al. 2010, 110). At SUERC, $\delta^{13}C$ and $\delta^{15}N$ samples were prepared and analysed from sub-samples of the dated gelatin as described by SAYLE et al. (2014). It was these $\delta^{13}C$ values which were used for age calculation. Where sufficient material was available, sub-samples of the dated gelatin prepared at MAMS- were analysed for $\delta^{13}C$ and $\delta^{15}N$ at the Isotrace facility, University of Otago Chemistry Department, using methods outlined by BEAVAN ATHFIELD et al. (2008, 3).

All four laboratories maintain a continual programme of quality assurance procedures, in addition to participation in international inter-comparison exercises during the period when the measurements were made (SCOTT 2003; SCOTT et al. 2007; 2010a; 2010b).

Replicate radiocarbon measurements are available on 24 samples. Eighteen of these groups of replicate results are statistically consistent at 95% confidence, with a further two consistent at 99% confidence (WARD / WILSON 1978; Table 2). The other four groups (m66, zv108, s106.80 and ve2), however, are significantly divergent and it is not clear which of the results may be in error. This degree of replication arises from attempts to resolve some differences between replicate measurements reported in August 2014 by Mannheim (MAMS-21328–41) and East Kilbride (SUERC-54631–4, SUERC-54638–44 and SUERC-54648–9). Replicate $\delta^{13}C$ values are available for 22 samples. Twenty of these groups of measurements are statistically consistent at 95% confidence, with one more consistent at 99% confidence (Table 2). The other group (zv108) is widely divergent. Replicate $\delta^{15}N$ values are available for 21 samples. Fourteen of these groups of measurements are statistically consistent at 95% confidence, with two more consistent at 99% confidence (Table 2). Five groups, however, are divergent at more than 99% confidence (m53, zv91, zv108, s42.74 and s106.80).

The replicate radiocarbon measurements have been combined by taking a weighted mean before calibration (WARD / WILSON 1978; Table 2) and inclusion in the chronological models where they are statistically consistent at 99% confidence. The four divergent groups have been handled on a case-by-case basis during the modelling process as discussed below.

We also have two graves, those at Esztergályhorváti and Reichersdorf, where multiple corpses appear to have been interred at the same time. Samples from six individuals have been dated from Esztergályhorváti, producing measurements that are statistically consistent at 95% confidence ($T'=8.7$; $T'(5\%)=11.1$; $\nu=5$). But the two results from the double inhumation at Reichersdorf are statistically inconsistent at 95% confidence, but consistent at 99% confidence ($T'=4.5$; $T'(5\%)=3.8$; $\nu=1$).

Bayesian chronological modelling

The radiocarbon dating programme for Lengyel funerary ceramics was conceived within the framework of Bayesian chronological modelling (BUCK et al. 1996). Such an approach allows the combination of archaeological information from the ceramic seriations with calibrated radiocarbon dates using a formal statistical methodology. As the identification of closed assemblages and chronologically sensitive traits is key to successful seriation, the identification of samples for radiocarbon dating which are demonstrably not residual in the contexts from which they were recovered is essential if the sequence of those contexts provided by seriation is to be used to constrain the calibration of the radiocarbon dates. All potential samples must be of short-lived material, contemporary with their parent, closed context and derived from a well-understood carbon reservoir.

Human bone from articulated skeletons in graves or from discrete cremation deposits was clearly deposited at the same time as the accompanying grave assemblage. It is possible, however, for some of these artefacts to have been curated before deposition and so to have been older than the time when they were buried. Human bone also takes some time to incorporate carbon ingested through food, which can amount to an apparent age of one or two decades in the mid-shaft femoral bone of adult individuals (HEDGES et al. 2007, table 2; BAYLISS et al. 2013, fig. 2.23). Further offsets in radiocarbon age can arise if people ate foods that did not derive from the terrestrial biosphere, requiring estimates of the proportions of different diet-sources, the radiocarbon age of the relevant reservoirs, and mixed-source approaches for accurate calibration. Existing pairs of radiocarbon measurements on human and animal bone from Neolithic and Copper Age graves in this region, however, are statistically consistent, suggesting that consumption of non-terrestrial foods by the Lengyel population was probably negligible (BAYLISS et al. 2016, table 1; JAKUCS et al. 2016, table 1; RACZKY / SIKLÓSI 2013, table 1). This does not mean, however, that particular individuals might not have consumed a larger component of freshwater resources. For this reason, source-proportional dietary modelling was undertaken on the basis of carbon and nitrogen stable isotopic values, so that mixed-source calibration models could be constructed which would account for any potential reservoir effects in particular individuals. There can also be complications when dating calcined bone, as experimental evidence suggests that the carbon in calcined bone apatite may derive not only from the dated individual, but from the fuel used in the cremation process and the atmosphere during the time of cremation (ZAZZO et al. 2012; SNOECK et al. 2014). This can lead to offsets in dates on calcined bone (OLSEN et al. 2013). Anomalously recent ages can also be obtained from bone apatite if it is insufficiently calcined for reliable dating (cf. TASIĆ et al. 2015, 1076).

Dietary analysis of human remains

Forty-seven dated individuals from Lengyel sites have measured carbon and nitrogen stable isotope values that are suitable for dietary analysis (Table 2). These are from Mórágy-Tűzkődomb (n=16), including a 2–5-year-old infant (OxA-28913); Villánykövesd-Jakabfalusi út mente (n=3); Zengővárkony-Igaz-dűlő (n=11); Friebritz, in the form of a single 16–24-month-old baby (SUERC-54630; n=1); Svodín, Busahegy (n=11), including three children aged 1–5 years (SUERC-54633; MAMS-21332/MAMS-23165; MAMS-23166); and Veszprém-Jutasi út (n=5). The $\delta^{13}C$ and $\delta^{15}N$ values of each individual are plotted in Fig. 3.

The infants in these sites had notably enriched $\delta^{15}N$ values, and so a tailored FRUITS breastfeeding model constructed for them is set out separately below. An additional set of nine individuals from the sites of Veszprém-Jutasi út, Esztergályhorváti and Friebritz, who do not have measured stable carbon and nitrogen stable isotope values that are suitable for dietary analysis, are also considered (Table 2), using the estimates of potential diet proportions generated for adults by the FRUITS modelling for the same or nearby sites. Weighted means of the isotopic values for those individuals with replicate measurements have been used in the analysis (WARD / WILSON 1978; Table 2). Similar dietary modelling has already been undertaken for dated individuals from Alsónyék-Bátaszék (BAYLISS et al. 2016, 40–6).

We employed the Bayesian mixing model FRUITS v2.0β (Food Reconstruction Using Isotopic Transferred Signals; FERNANDES et al. 2014) for diet reconstruction for the Lengyel sites. FRUITS uses the isotopic averages of possible food sources and allows the user to define isotopic offsets between diet and consumer, the weighting and concentration of food sources, and prior information to constrain the calculations of the stable isotope mixing model. The FRUITS program then calculates estimates of the mean percentage and standard deviation of each food source for a given consumer.

The FRUITS proportional dietary estimates were modelled on two diet proxies ($\delta^{13}C$ and $\delta^{15}N$). The model for the adults and sub-adults was constructed by creating a baseline from the average isotopic data and its associated mean error for each of three general food sources: cereals, terrestrial herbivores and omnivores (cattle, sheep, and pigs), and freshwater fish (Table 3). The cereals baseline used carbon and nitrogen values for archaeobotanical samples of wheat (n=12) and barley (n=6) (OGRINC / BUDJA 2005) and emmer wheat (n=1) and barley (n=3) (BOGAARD et al. 2013), producing mean values and errors of −24.6±0.3‰ ($\delta^{13}C$) and 5.0±0.4‰ ($\delta^{15}N$). The food baseline data is particularly robust for animal protein sources, as the data are drawn from sites within approximately 1000 km of all the sites in this study. Baseline values for terrestrial animals (pig, sheep, cow, n=89; $\delta^{13}C$, −20.3±0.2‰ and $\delta^{15}N$, 6.9±0.2‰) are from faunal materials in the Starčevo, Sopot, and Lengyel sites at Alsónyék-Bátaszék (including 27 sets of analyses on terrestrial fauna provided by the Bioarchaeology Workgroup Mainz: MÖRSEBURG forthcoming). Isotopic values for archaeological freshwater fish ($\delta^{13}C$, −21.4±0.2‰ and $\delta^{15}N$, 8.7±0.2‰) were drawn from NEHLICH et al. (2010; n=3), BORIĆ et al. (2004; n=12), and BAYLISS et al. (2016; n=4). The freshwater fish baseline values were further supplemented with six sets of carbon and nitrogen values on fish from Alsónyék-Bátaszék, also provided by the Bioarchaeology Workgroup Mainz.

The FRUITS model incorporated an isotopic offset between diet and consumers of 4.8± 0.2‰ for $\delta^{13}C$ (FERNANDES et al. 2014), and for 6.0± 0.5‰ for $\delta^{15}N$ (O'CONNELL et al. 2012). The weight and concentration of each of the three diet sources was set at 100%. The FRUITS dietary model can also allow for further constraints on the calculations from a priori observations in the archaeological record and logical considerations. As we had observed in a previous dietary analysis of populations at Alsónyék-Bátaszék (BAYLISS et al. 2016, 40–6), there was a possibility for the consumption of freshwater resources from rivers associated with the Danube and its significant freshwater ^{14}C reservoir (COOK et al. 2001; 2002; BONSALL et al. 2015), although the proportion of fish in the diet was also likely to be quite small, given the radiocarbon results on contemporary pairs of human and faunal samples (see above). Our tests of the FRUITS model using no prior information and with prior information weighting terrestrial protein over fish, however, in each case produced unreasonably high proportions of cereals in individual diets. In particular, the use of prior weighting terrestrial protein over fish produced averages for cereals of 91.5±4.6%, and an equally unlikely depression of the percentage of terrestrial protein averaging 6.4±3.6%. These outcomes seemed unlikely given the number of domesticated and hunted terrestrial animals in the archaeological record. The final version of the FRUITS model was modified incorporating prior information that the proportion of terrestrial protein was greater than that of cereals, which added weight to the higher $\delta^{15}N$ contribution of terrestrial meat in the diet.

The results of the FRUITS proportional modelling for adult and subadult individuals aged above five years are provided in Table 4a.

The FRUITS model indicates that the adults and subadult consumers from all of the sites considered had diets that were made up almost entirely of cereals and terrestrial protein (mean and standard deviation for cereals, 48.3±1.2‰, and for terrestrial animals, 49.9±1.2‰). Several of the populations exhibit enriched average $\delta^{15}N$ values; the Svodín adult and subadult population has an average $\delta^{15}N$ value of 11.3±0.2‰, followed by Mórágy at 10.8±0.2‰, and Zengővárkony at 10.5±0.3‰. Individuals in these sites have the highest estimated percentages of fish of up to 2.9±2.8%. There are no appreciable differences in percentages of terrestrial protein in those diets, which average 49.8±1.2%.

There were nine individuals for whom no stable isotope analysis was obtained (Table 4b). To construct an individual radiocarbon calibration curve incorporating any proportional aquatic reservoir, a proxy for direct FRUITS-estimated percentage freshwater fish was required. In the case of Veszprém, the proportional diet estimates for burial Ve-4 (MAMS-14827) were derived from the mean FRUITS estimates for Veszprém burials for which there were stable isotope values (Table 4a). For Friebritz and Esztergályhorváti, sites for which no directly modelled FRUITS estimates had been obtained, the mean of proportional diet values over all sites was used.

There were also five infants from three sites (Svodín, Mórágy and Friebritz), with age estimates ranging between 16 months and five years, who exhibited $\delta^{15}N$ values that were enriched in relation to the average $\delta^{15}N$ values for older individuals from any of the sites. The median $\delta^{15}N$ value for infants (12.9±0.2‰) is significantly enriched by +1.6‰ (Mann-Whitney two-tailed, P=0.0042) over the highest adult and subadult $\delta^{15}N$ in any site, that for Svodín (mean $\delta^{15}N$, 11.3±0.2‰). The nitrogen enrichment for these infants under the age of five is not likely to come from higher proportions of terrestrial protein or freshwater fish, but rather, more probably reflects a nursing signal, as enriched $\delta^{15}N$ in infants is associated with breast feeding (JAY et al. 2008; FULLER et al. 2006) rather than consumption of fish or animal protein foods.

We have elsewhere examined the δ^{15}N enrichment in infants as a breast-feeding signal in Neolithic populations (DENAIRE et al. 2017; BAYLISS et al. 2016). Our modelling for the infants is based on studies of the difference in breastfeeding children's isotopic signature with their mothers' (FOGEL et al. 1989; RICHARDS et al. 2002; TSUTAYA / YONEDA 2013), wherein enriched δ^{15}N in infants reflects breastmilk as a step up on the dietary trophic level of the nursing mother (SONG 2004). The presence of an enriched δ^{15}N breastfeeding signal has been recorded from 31 weeks of age (TSUTAYA / YONEDA 2013); the waning of that enriched nitrogen signal from 18–20 months is interpreted as a weaning signal (FOGEL et al. 1989; RICHARDS et al. 2002) associated with the gradual introduction of solids such as cereal gruels (FILDES 1986).

The FRUITS breastfeeding model for Greater Lengyel sites is composed of two food sources, "breastmilk" and "cereal", the latter being a typical transitional weaning food (FILDES 1986). We created a proxy for "breastmilk" isotopic values from the weighted average and error for the δ^{13}C (−20.1±0.1‰) and δ^{15}N (10.9±0.2‰) isotopic values for women of reproductive age in Table 4a (15–38 years; n=8). The baseline values for cereals are those used in the FRUITS model for adults and subadults (δ^{13}C, −24.6±0.3‰; δ^{15}N, 5.0±0.4‰). For the FRUITS offsets (the consumer's trophic enrichment of the metabolised food) we compared the weighted average carbon and nitrogen of the five infants (δ^{13}C, −19.8‰±0.2‰ and δ^{15}N, 12.9‰±0.3‰) to that of the women of reproductive age. The calculated enrichment in infants (δ^{13}C by 0.3‰ and δ^{15}N by 2.0‰) was used for the FRUITS offset, with a ±0.5 error. The calculated offset also compares favorably with enrichment factors between mothers and nursing infants reported elsewhere (1‰ for δ^{13}C and 3‰ for δ^{15}N; FULLER et al. 2006; KATZENBERG et al. 1996; WHITE / SCHWARTZ 1994). The resulting baseline isotopic values for the FRUITS modelling are given in Table 5, and the results of the modeling in Table 6.

Model calculation and reporting

The Bayesian chronological modelling has been undertaken using the program OxCal v4.2 (BRONK RAMSEY 2009a; 2009b; BRONK RAMSEY / LEE 2013) 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 4–7, 11–12 and 14 and in the CQL2 code files provided in Supplementary Tables 4–6 (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. Calibrated date ranges of all the radiocarbon measurements included in any of the models reported here are provided in Table 7, along with the Highest Posterior Density intervals for each grave included in each of three models that are fully reported. In the text and tables, the Highest Posterior Density intervals of the posterior density estimates are given *in italics* to distinguish them from the simple calibrated radiocarbon dates (which are reported in normal type). The other distributions correspond to aspects of the model. For example, the distribution '*start Mórágy*' (Fig. 5) is the posterior density estimate for the time when the Lengyel cemetery at Mórágy-Tűzkődomb was established.

For the sensitivity analysis described below we have used a mixed-source calibration to allow for the potential consumption of freshwater fish from the Danube and its catchment. We have used the offset of 540±70 BP from the atmospheric calibration data-set calculated by COOK et al. (2002) for the Danube at the Iron Gates Gorge, and the Mix_Curves function of OxCal v4.2 (BRONK RAMSEY 2001, amended following JONES / NICHOLLS 2001). For each dated human, we have constructed an individual calibration curve, which incorporates the aquatic reservoir in the proportion suggested by the dietary estimates provided by the FRUITS model in that particular person (Tables 4 and 6), with the rest of the diet modelled as in equilibrium with the terrestrial biosphere (and calibrated using IntCal13; REIMER et al. 2013). The results of the mixed source models incorporating these individual-specific curves are described below.

The currency of furnished Lengyel burial

A model for the overall currency of furnished Lengyel burial is shown in Figs 4–7 (and defined in Supplementary Table 4: Greater_Lengyel_sites.oxcal). We have allowed for a gradual appearance and disappearance of furnished Lengyel burial (using flexible trapezium prior distributions; LEE /BRONK RAMSEY 2012), since we would like to estimate the duration of these processes. Sites that have only one dated grave (such as Esztergályhorváti) are simply included within the currency of the burial tradition, but the period of use of sites that have more dated burials (such as Mórágy-Tűzkődomb) has been calculated (using uniform prior distributions; BUCK et al. 1992). This means that such sites are not disproportionately weighted within the calculations for the overall currency of the burial tradition as they are in effect represented by only their estimated start and end dates. Key parameters for Lengyel graves at Alsónyék-Bátaszék are derived from the models shown in OSZTÁS et al. (2016b, figs 12–13, 15–16 and 18–19).

We have excluded eight radiocarbon measurements from the model as we believe them to be inaccurate. MAMS-21334 is significantly later than the replicate measurement from S-106/80 and much later than any other dated burial from Svodín. We therefore consider MAMS-23167 to provide a more accurate indication for the date of this burial. MAMS-14826 is much later than the other three measurements on grave Ve-2, which are statistically consistent at 99% confidence but not at 95% confidence (T'=7.6; T'(5%)=6.0; ν=2). This measurement has, therefore, also been excluded from the analysis and a weighted mean taken of the other three measurements on this skeleton. OxA-6274 is much later than the other measurements for the mass grave at Esztergályhorváti. It is possible that this sample comes from a later inhumation that was inserted into the mass grave which was not detected during excavation, but it is also possible that the ion-exchange protocol used to purify the protein in this sample failed to remove all exogenous contamination. For this reason, OxA-6274 is excluded from the analysis. Five further measurements all made in the first years of operation of the Vienna Environmental Research Accelerator have also been excluded from the analyses (VERA-226, -231, -410–11 and -413). These appear to be anomalously recent (Fig. 4). The two measurements on what appears to be a double grave at Reichersdorf 77 are not statistically consistent (T'=4.5; T'(5%)=3.8; ν=1), and both results are much more recent that would be expected from the position of this grave in Phase 2 in the seriation (Supplementary Fig. 2, and see below).[3] It should be noted, however, that the measurements on skeletons from Friebritz-Süd fall within the expected range of both Lengyel furnished burial and ceramic seriation (Fig. 4 and Supplementary Fig. 2), and so this technical issue at VERA appears to be confined to bone samples at the very start of the operation of the facility.

The model for the currency of Lengyel furnished burials (Figs 4–7) suggests that this tradition began in *5010–4825 cal BC* (*95% probability*; *start start Lengyel*; Fig. 4), probably in *4940–4850 cal BC* (*68% probability*). The end of the beginning occurred in *4965–4815 cal BC* (*95% probability*; *end*

[3] A further measurement made in Vienna at this time on a 25–35-year-old female skeleton from grave 5 at Antonshöhe, Austria (VERA-230; 5662±29 BP), is not included in the seriation presented in this paper, although it is included in that of DIACONESCU (2014a). This grave contained a single sherd of diagnostic late Lengyel pottery (RUTTKAY 1970, 78), which may have been redeposited in a later unfurnished inhumation rather than deliberately interred as part of the burial rite.

start Lengyel; Fig. 4), probably in *4915–4840 cal BC* (*68% probability*). The introduction of this form of burials thus occurred over a period of *1–85 years* (*95% probability*; *period of start Lengyel*; Fig. 8), probably over a period of *1–30 years* (*68% probability*). It should be noted, however, that the earliest Lengyel burials may not have been sampled for radiocarbon dating.

The end of the tradition began in *4550–4425 cal BC* (*95% probability*; *start end Lengyel*; Fig. 4), probably in *4525–4465 cal BC* (*68% probability*). It finally ended in *4525–4375 cal BC* (*95% probability*; *end end Lengyel*; Fig. 4), probably in *4505–4440 cal BC* (*68% probability*). This ending occurred over a period of *1–105 years* (*95% probability*; *period of end Lengyel*; Fig. 8), probably over a period of *1–35 years* (*68% probability*).

Overall, furnished Lengyel burials appear for a period *of 300–445 years* (*95% probability; use Lengyel*; Fig. 8), probably over a period of *330–405 years* (*68% probability*).

The dating of selected Lengyel cemeteries

The model defined in Figs 4–7 also provides estimates for the dates when selected Lengyel cemeteries were established and abandoned. We consider these sites from south-east to north-west. Highest Posterior Density intervals for each dated grave from this model are provided in Table 7.

Villánykövesd

The site of Villánykövesd, Jakabfalusi út mente, is situated on a gentle hillside in southern Transdanubia, north of the village of that name. A test excavation was undertaken in 1957 in order to check the results of surveys of the Lengyel sites Pécsvárad and Zengővárkony (DOMBAY 1959); more recent geophysical survey can also be noted (BERTÓK / GÁTI 2011). The two trenches excavated (23 by 4 m, and 19 by 11 m respectively) revealed intense settlement traces; a 3.75 m-wide ditch and 28 burials were recorded in the western part of the site. In addition to pottery, the 20 graves with grave good assemblages contained antler tools, copper and *Dentalium* beads, and a steatite bead. Most of the graves were found among settlement features in Trench II. The deceased were laid in contracted position, oriented mostly NW–SE or SE–NW, as well as E–W. Only three burials have been dated from Villánykövesd, and so estimates for the dates when this site was in use are imprecise. It was established in *4870–4705 cal BC* (*95% probability*; *start Villánykövesd*; Fig. 4), probably in *4810–4720 cal BC* (*68% probability*). Burial ended at this site in *4740–4505 cal BC* (*95% probability*; *end Villánykövesd*; Fig. 4), probably in *4715–4600 cal BC* (*68% probability*). This cemetery was in use for a period of *1–295 years* (*95% probability*; *use Villánykövesd*; Fig. 8), probably over a period of 25–*200 years* (*68% probability*).

Alsónyék-Bátaszék

Alsónyék-Bátaszék is located in the south-west part of the Tolna Sárköz region in southeast Transdanubia, where the Szekszárd Hills rise above the wide alluvial plains of the former Danube channels to the east (OSZTÁS et al. 2016a). The site was discovered in advance of road construction and extensive investigations followed in 2006–9. The excavated area is roughly cross-shaped (1.5 km N–S and 800 m E–W). Approximately 15,000 features were found over the *c*. 25 ha excavated, more than 70 percent of which could be assigned to the Neolithic: to the Starčevo culture, the LBK, the Sopot culture and Lengyel culture (OSZTÁS et al. 2016a). An unusually large Starčevo occupation (OROSS et al. 2016a), a substantial LBK longhouse settlement (OROSS et al. 2016b) and a Sopot site with ditches and burials (OROSS et al. 2016c) were notable features of the earlier history of this persistent place (BÁNFFY et al. 2016). Most striking of all was the Lengyel occupation, with an estimated extent of 80 ha, and consisting of some 120 post-framed houses, numerous pits, and some 2300 mainly individual burials from the excavated portions of the site (OSZTÁS et al. 2016b; BÁNFFY et al. 2016). The burials of men, women and children were characteristically found in smaller and larger grave groups, in amongst the settlement features. There were many variations in mortuary treatment but contracted, left-side, E–W positions were recurrent; there was likewise much variation in grave good assemblages, which could contain pottery, stone tools, ornaments, boar's tusks and copper (OSZTÁS et al. 2016b).

The chronologies for different areas of the extensive burial ground at Alsónyék-Bátaszék are presented in detail by OSZTÁS et al. (2016b, figs 12–13, 15–16 and 18–19). The key parameters from these models have been imported into the model defined in Figs 4–7 as prior distributions. Burial at subsite 10B started in *4740–4685 cal BC* (*95% probability*; *start: 10B – Cemetery*; Fig. 4), probably in *4715–4690 cal BC* (*68% probability*). It ended in *4705–4640 cal BC* (*95% probability*; *end: 10B – Cemetery*; Fig. 4), probably in *4695–4670 cal BC* (*68% probability*). The cemetery in this area was in use for a period of *1–95 years* (*95% probability*; *use: 10B – Cemetery*; Fig. 8), probably over a period of *1–40 years* (*68% probability*). Burial at subsite 11 started in *4820–4730 cal BC* (*95% probability*; *start: 11 – Cemetery*; Fig. 4), probably in *4795–4745 cal BC* (*68% probability*). It ended there in *4635–4490 cal BC* (*95% probability*; *end: 11 – Cemetery*; Fig. 4), probably in *4585–4520 cal BC* (*68% probability*). This area was in use for a period of *120–325 years* (*95% probability*; *use: 11 – Cemetery*; Fig. 8), probably for a period of *175–270 years* (*68% probability*). Burial at subsite 5603 started in *4815–4425 cal BC* (*95% probability*; *start: 5603 – Cemetery*; Fig. 4), probably in *4790–4740 cal BC* (*68% probability*). It ended in *4530–4440 cal BC* (*95% probability*; *end: 5603 – Cemetery*; Fig. 4), probably in *4510–4465 cal BC* (*68% probability*). This part of the cemetery was in use for a period of *215–355 years* (*95% probability*; *use: 5603 – Cemetery*; Fig. 8), probably for a period of *240–315 years* (*68% probability*).

Mórágy-Tűzkődomb

The site of Mórágy-Tűzkődomb in south-east Transdanubia lies in the upper reaches of the Lajvér stream, tributary of the Danube, and 20 km west of the great river (ZALAI-GAÁL 2007a, Abb. 3). Finds of Lengyel material were first made in 1896. Research excavations were carried out from 1978 to 1990 by István ZALAI-GAÁL (2001a; 2002). Three main areas were investigated by substantial trenching, two close together over a stretch of some 150 m, and the third over 100 m to the west (ZALAI-GAÁL 2007a, Abb. 2). Larger and smaller grave groups were found, with a total of 109 burials from 108 graves (ZALAI-GAÁL 2007a, 147). Settlement features were recorded, but have not yet been published; this was not a cemetery only. The deceased — men, women and some children — were in a variety of positions, but predominantly contracted and lying W–E on their right sides, with heads facing south. Grave assemblages varied, but contained pottery, stone tools and ornaments; a few lacked grave goods altogether (ZALAI-GAÁL 2010a, 72). The component of the model relating to the cemetery of Mórágy-Tűzkődomb is shown in Fig. 5. It was established in *4810–4705 cal BC* (*95% probability*; *start Mórágy*; Fig. 5), probably in *4770–4720 cal BC* (*68% probability*). It ended in *4585–4490 cal BC* (*95% probability*; *end Mórágy*; Fig. 5), probably in *4565–4515 cal BC* (*68% probability*). This cemetery was in use for a period of *140–295 years* (*95% probability*; *use Mórágy*; Fig. 8), probably for a period of *170–250 years* (*68% probability*).

Zengővárkony

Zengővárkony (Igaz-dűlő) lies in south-east Transdanubia, some 32 km west of the Danube, in the foothills of the Mecsek Mountains, in the upper reaches of the Fekete-víz. Finds of Lengyel material were first made in 1933. Research excavations led by János Dombay were carried over several seasons in the 1930s and 1940s, leading to the discovery of 379 Lengyel burials in 368 graves (DOMBAY 1939; 1960). These were in larger and smaller grave groups, covering a possible total area of some 40 ha (OSZTÁS et al. 2016b, 198), spread out over the fields that constitute the site; no single extensive surface was uncovered and the areas of the grave groups were largely investigated by strip trenches (ZALAI-GAÁL 2010a, Abb. 1, 3; ZOFFMANN 1972–1973). More recent geophysical survey is again also to be noted (BERTÓK / GÁTI 2011). The larger groups contained up to 70 graves, mainly of men and women, predominantly in contracted and E–W positions on their left sides, with their heads facing south (ZALAI-GAÁL 2007a; 2010a); there were some child burials. Many settlement features were found, including at least one post-framed house and numerous pits (DOMBAY 1960). Grave assemblages varied, but contained pottery, stone tools and ornaments; a few lacked grave goods altogether (ZALAI-GAÁL 2010a, 72). The component of the model relating to the cemetery of Zengővárkony is shown in Fig. 6. The cemetery was established in *4895–4765 cal BC* (*95% probability*; *start Zengővárkony*; Fig. 6), probably in *4860–4795 cal BC* (*68% probability*). Burial ended there in *4605–4475 cal BC* (*95% probability*; *end Zengővárkony*; Fig. 6), probably in *4575–4510 cal BC* (*68% probability*). This cemetery was in use for a period of *190–385 years* (*95% probability*; *use Zengővárkony*; Fig. 8), probably for a period of *240–335 years* (*68% probability*).

Györe

The Györe-Bocok site is in south-east Transdanubia, on the northern slopes of the Mecsek Mountains. Stray finds, an anthropomorphic vessel, and anthropomorphic and zoomorphic figurines were found south of the village during field surveys (ZALAI-GAÁL 1993b; 1996; 1998; 2000). Rescue excavations were undertaken in 1997 and 1999 after sewage and gas pipeline digging resulted in the discovery of 15 Lengyel burials, including eight cremation burials (ZALAI-GAÁL / ÓDOR 2008). This group of cremation burials was the first evidence that cremation was practised in southern Transdanubia (ZALAI-GAÁL 2001b). The distances between the graves indicated that there were six grave groups. Only a single grave has been radiocarbon dated from this cemetery. Calcined bones from two separate cremation burials interred in different pots have been dated from grave 13. This combined burial was made in *4790–4685 cal BC* (*95% probability; Gy-13;* Fig. 4), probably in *4770–4750 cal BC* (*15% probability*) or *4745–4690 cal BC* (*53% probability*).

Esztergályhorváti

The site of Esztergályhorváti is located in the Kis-Balaton region of western Transdanubia. It was excavated in 1994, in advance of house construction (BARNA 1996). A modest-sized pit, less than 2 by 2 m and up to 1.4 m deep, contained the incomplete and disturbed remains of 38 people, under an upper burnt fill. The people are judged to be predominantly younger males, in a variety of positions, prone and otherwise, with four apparently with their arms pinned behind their backs. Three skulls show blows to the head (BARNA 1996; BRONK RAMSEY et al. 1999, 202). These details and the age and sex of the deceased have led to speculation that this was some kind of massacre site (MAKKAY 2000), but other more ritualistic interpretations are possible, with some of the remains affected by burning. Esztergályhorváti represents the oldest, so-called formative phase of the culture, with close similarities between its finds of painted pottery and the ceramics from Sé and Lužianky (NOVOTNÝ 1962; BARNA 1996; PAVÚK 1981). The combined dating for this mass grave suggests that it was made in *4910–4785 cal BC* (*95% probability; Esztergályhorváti;* Fig. 4), probably in *4880–4865 cal BC* (*8% probability*) or *4855–4795 cal BC* (*60% probability*).

Veszprém

Veszprém-Jutasi út lies to the north of Lake Balaton in northern Hungary beside a stream on a dolomite plateau, within the town of the same name. This is a large Late Lengyel settlement, estimated as covering some 30 ha, and may well have owed its prominence to its proximity to Bakony radiolarite working areas. Finds were made at intervals during small-scale interventions over 80 years, beginning in the 1920s. The latest excavations took place in 2003 when a large area on the west of the site revealed hundreds of Lengyel features, as well as traces of Baden and Early Bronze Age settlement (REGENYE 2007). Several post-framed Lengyel houses and associated features were recorded; these were set in rows, and some had been reconstructed at least once (REGENYE 2007, fig. 2). Three fence lines of smaller and larger posts and slots were found. Graves were also recorded among the settlement features, with eight Lengyel burials, as well as four Balaton-Lasinja and four Baden graves. The Lengyel graves, of men and women, were found in open space beyond the houses; the deceased were mostly contracted and in E–W positions. The graves contained varying assemblages of pottery, stone tools, worked flint and obsidian, ornaments of bone and teeth, and boar's tusk (REGENYE 2007, 392). Only five graves containing diagnostic Lengyel pots have been dated[4] (although see REGENYE et al. (in prep.) for a

[4] A further measurement has been obtained from an unfurnished grave that was probably part of the Lengyel cemetery. A sample of the left femur of a 30–50 year-old male skeleton produced a radiocarbon date of 4825–4650

discussion of the chronology of the Balaton-Lasinja graves here). The cemetery was established in *4885–4725 cal BC* (*95% probability*; *start Lengyel Veszprém*; Fig. 4), probably in *4845–4745 cal BC* (*68% probability*). Burial ended there in *4695–4525 cal BC* (*95% probability*; *end Lengyel Veszprém*; Fig. 4), probably in *4680–4595 cal BC* (*68% probability*). The Lengyel cemetery was in use for a period of *45–325 years* (*95% probability*; *use Veszprém Lengyel*; Fig. 8), probably for a period of *100–255 years* (*68% probability*).

Svodín

The site of Svodín-Busahegy is located in south-west Slovakia, some 20 km north of the Danube, on the left terrace of the Dobra stream, a tributary of the river Hron. It was first detected in 1931 (NEUSTUPNÝ 1935). Following rescue excavations in 1959 (TOČIK / LICHARDUS 1966) and 1965 (ŠIŠKA / LICHARDUS 1970), a systematic excavation covering some 3 ha was undertaken between 1971 and 1983 (NĚMEJCOVÁ-PAVÚKOVÁ 1986a; 1986b; 1986c; 1991; 1995). Material ranging from the Palaeolithic to a Slavic settlement of the 9th–10th centuries AD was recovered, including assemblages of Lengyel pottery. There were two circular ditched and palisaded enclosures, so called rondels, in the area of the large Lengyel site (NĚMEJCOVÁ-PAVÚKOVÁ 1995). Viera NĚMEJCOVÁ-PAVÚKOVÁ (1986b, 137) recorded four early Lengyel settlement horizons with the help of house distribution analysis. Analysis of stratigraphic relationships has further increased this number to three pre-rondel phases, two rondel phases and at least one post-rondel phase (DEMJÁN 2016, fig. 21). Within the Lengyel settlement 111 burials were documented with rich inventories (DEMJÁN 2010; 2012). The component of the model relating to the cemetery at Svodín is shown in Fig. 7. The cemetery was established in *4890–4790 cal BC* (*95% probability*; *start Svodín*; Fig. 7), probably in *4855–4800 cal BC* (*68% probability*). Burial ended there in *4800–4700 cal BC* (*95% probability*; *end Svodín*; Fig. 7), probably in *4795–4735 cal BC* (*68% probability*). This cemetery was in use for a period of *1–165 years* (*95% probability*; *use Svodín*; Fig. 8), probably for a period of *25–120 years* (*68% probability*).

Friebritz

Friebritz-Süd is in the Weinviertel of Lower Austria, in the north-east of the country. At the south-east edge of the village there is a double concentric palisaded circular enclosure without

cal BC (92% probability; SUERC-54643; 5859±33 BP; STUIVER / REIMER 1993) or 4640–4610 cal BC (3% probability). The stable isotope measurements for this skeleton are: $\delta^{13}C$, −19.5±0.2‰; $\delta^{15}N$, 9.6±0.3‰; C:N ratio, 3.2.

any traces of settlement. The site was first detected in 1979, following aerial photographic survey. From 1981 to 1988 10,000 m² were excavated, out of a total estimated extent of 17,660 m². In the centre of the rondel, a group of ten graves were found in an area 6 by 4 m (NEUGEBAUER-MARESCH et al. 2002). Most of the graves were oriented to the south, but two were E–W. All the deceased were contracted and lying on their right sides; these comprised five children, four men and a probable fifth adult man (who was disturbed by Early Bronze Age activity). Grave assemblages contained abundant pots, microlithic tools, polished stone tools, *Spondylus* beads, boar's tusks and grindstones. In one grave there were pig and dog skeletons. Another grave, a double burial, was found 12 m from the first group. The deceased were deposited on top of each other in prone positions with arrowheads in their breasts and spines. That indicates violently killed individuals. The main grave group showed signs of violence too. Some graves had been opened; in one case the corpse was almost completely removed from the grave pit, and in two cases the bones were broken and dislocated. Three men had fatal skull injuries. All these details have led to ritualistic interpretation of the site. Based on pottery analysis, the graves can be dated to the beginning of the Lengyel culture. They appear to be contemporary with the use of the rondel ditch (NEUGEBAUER-MARESCH et al. 2002). Only four of these graves have been dated and so estimates for the dates when this site was in use are imprecise. The cemetery was established in *4925–4760 cal BC* (*95% probability*; *start Friebritz*; Fig. 4), probably in *4880–4805 cal BC* (*68% probability*). Burial ended there in *4775–4540 cal BC* (*95% probability*; *end Friebritz*; Fig. 4), probably in *4745–4625 cal BC* (*68% probability*). The cemetery was in use for a period of *10–330 years* (*95% probability*; *use Friebritz*; Fig. 8), probably for a period of *90–250 years* (*68% probability*).

A summary of the chronology for the Lengyel cemeteries included in this study, independent of any typological analyses, is shown in Fig. 9. From the second half of the 49th century cal BC sites were established across the entire spatial extent of the tradition, from Friebritz in the north-west to Zengővárkony in the south-east, and the mass burial from Esztergályhorváti in the south-west to Svodín in the north-east. Further cemeteries appear to have been established in south-eastern Transdanubia in the 48th century cal BC, such as Mórágy and Villánykövesd, although we know of no Lengyel cemeteries that were founded this late further north or west. Sites in the northern part of the distribution may also have ended rather earlier, perhaps by the first half of the 47th century cal BC (Fig. 9). In contrast, several sites in south-east Transdanubia, such as Zengővárkony, Mórágy and Alsónyék continued in use for burial into the later part of the 46th century cal BC. The duration of the Lengyel cemeteries varied in all areas, from well under a century, such as Alsónyék subsite 10B and Svodín, to several centuries, as seen at Zengővárkony and Friebritz (Fig. 8).

This analysis was recalculated using the approach to mixed-source calibration described above in order to explore the effect of any potential dietary offsets in the radiocarbon results on samples of human bone. This model produces date estimates for the start and end of Lengyel burial, and for the key parameters for specific sites just described, that are very similar to those provided by the model defined in Figs 4–7 (the medians of the equivalent parameters vary by an average of 13 years and a maximum of 32 years). Generally, the consumption of freshwater resources by the people buried with Lengyel ceramics was very slight, leading to a reservoir age of a decade or two at most.

A combined chronology for Lengyel funerary ceramics

The chronological models so far described do not include the relative dating for graves that is suggested by the clear gradient in the dataset visible in the bi-plot of the correspondence analysis (Fig. 2a and Supplementary Fig. 2). While the relative sequence of individual graves in the seriation probably does not entirely reflect their actual order in time, the overall trend is likely to be chronological and gaps in the horseshoe may indicate phase boundaries between groups of graves which do fall into a clear relative sequence. It is this sequence of phases derived from the correspondence analysis which we incorporate into our Bayesian models as prior information.

These models have been constructed using the general outlier model proposed by Bronk Ramsey (2009b, 1028), which weights each radiocarbon date in accordance with its probability of being an outlier. Each radiocarbon date has been given a prior probability of 5% of being an outlier; the posterior probability of its being an outlier is calculated by the model. So, for example, *Fr-131: SUERC-54630* has a prior outlier probability of 5% but a posterior outlier probability of 9% (Fig. 11), and so has been slightly down-weighted in the model accordingly. This approach allows us to identify misfits where either radiocarbon measurements are in error or the relative chronological sequence that we have inferred from the correspondence analysis is incorrect. It also weights radiocarbon dates in the model proportionately to their fit with the seriation, thus producing a holistic view of the chronology of the grave ceramics. Again, we have allowed for a gradual appearance and disappearance of furnished Lengyel burial (using flexible trapezium prior distributions; LEE / BRONK RAMSEY 2012), since we would like to estimate the duration of these processes. We have also modelled each phase of the seriation as a separate uniform phase, thus allowing the intensity of burial to vary between phases (BAYLISS et al. 2013, 300–1). This is important because some phases include far more dated burials than others, although the number of burials in each phase may not mirror this variability in sampling.

From the final correspondence analysis bi-plot it can be observed that there are several gaps in the distribution between clusters of graves, particularly between graves zv11 and s109.80, between zv314 and zv41, and between s143.81 and s113.80 (Fig. 2a). Such gaps in a horseshoe arrangement are commonly interpreted as phase boundaries, as the greater distance between grave clusters could point to the end of the currency of certain types or combinations of types, and the introduction of new types and combinations, marking a new phase. In order to investigate if the gaps in grave distribution do in fact represent phase boundaries, a chronological model was constructed combining the available radiocarbon dates with this proposed four-phase scheme. In this reading the third phase (bounded by the gaps between graves zv41 and zv314, as well as between zv11 and s109.80) is a transitional phase, with a small number of graves exhibiting a greater distance to those before and after, as well as weak links between one another (Supplementary Fig. 2).

This phasing, however, could not be confirmed by the radiocarbon data. Only two graves with radiocarbon dates are included in the transitional phase. One of these dates, *zv314: OxA-28925*, has the highest outlier probability (23%) of any date in this analysis. This suggests that the transitional phase is not a distinct chronological horizon and so should be merged with one of the neighbouring phases. The measurements from Reichersdorf have outlier probabilities of 100% and are clearly anomalously late for the accompanying grave assemblage (see above). One other date has a posterior outlier probability of more than 15% in this interim model. This is SUERC-48357, one of the measurements on calcined bone from *Gy-13*. We suspect that this bone fragment may have been insufficiently calcined for accurate dating as it had a slightly high carbon content of 0.6% by weight, and we have thus excluded it from further analysis.

A second model was constructed, which excluded SUERC-48357, and combined the radiocarbon dates with the three major phases shown on Fig. 10. The boundary between phases 1 and 2 is marked by the introduction and/or establishment of new types (e.g. 1b3b, 1b3a, 1e3b and 1b4a), while also indicating the falling out of use of others (1b1a, 1b5g and 1a2b). In the same way the boundary between phases 2 and 3 signifies, the introduction and acceptance of new types (e.g. 2b3a, 1c2b, 2a2e and 1a1a), and the disappearance of others (e.g. 1b3a, 1e3b and 2b2de). This bi-plot of graves classified by site shows that almost all of the graves from Lužianky, as well as some graves from Zengővárkony, the single mass grave from Esztergályhorváti and some graves from Svodín can be assigned to phase 1. The majority of graves from Svodín, as well as all graves from Györe, Friebritz, the double burial from Reichersdorf, many graves from Zengővárkony, two graves from Mórágy and one grave from Pári-Altacker cluster in phase 2. The remaining graves from Zengővárkony and Pári-Altacker, the vast majority of graves from Mórágy, as well as features from Veszprém, Lébény Objekt 350 (a well), Szekszárd-Ágostonpuszta, Brodzany, Pécsvárad, Nitra-Leningradska ulica, Szob and Lánycsók are in phase 3. All the graves from Villánykövesd and Alsónyék subsites 11 and 10B also fall into phase 3.

The chronological model of this phasing scheme is shown in Figs 11 and 12 (Supplementary Table 5: Lengyel_seriation_outlier_3_phase.oxcal). Highest Posterior Density intervals from this model for each dated grave are provided in Table 7. No measurement has an outlier probability of more than 10%. The model suggests that the very first Lengyel burial in phase 1 began in *5580–4805 cal BC* (*95% probability*; *start start Lengyel 1*; Fig. 11) probably in *5070–4830 cal BC* (*68% probability*). Lengyel burial became fully established by *5325–4790 cal BC* (*95% probability*; *end start Lengyel 1*; Fig. 11) probably by *4960–4810 cal BC* (*68% probability*). This introduction took place over a period of *1–365 years (95% probability*; *period of start Lengyel 1*; Fig. 13) probably *1–95 years* (*68% probability*). The imprecision of these estimates reflects the extreme paucity of dated burials in this phase. It is clear, however, from the shape of the distributions (Figs 11 and 13) that Lengyel burial was established relatively swiftly in the 50th or more probably in the 49th century cal BC. The boundary between phases 1 and 2 occurred in *4870–4790 cal BC* (*95% probability*; *Lengyel 1/2*; Fig. 11) probably in *4845–4800 cal BC* (*68% probability*). The boundary between phase 2 and 3 occurred in *4785–4740 cal BC* (*95% probability*; *Lengyel 2/3*; Fig. 11) probably in *4780–4750 cal BC* (*68% probability*). The decline of Lengyel burial began in *4770–4560 cal BC* (*95% probability*; *start end Lengyel 3*; Fig. 11) probably in *4760–4650 cal BC* (*63% probability*) or in *4595–4575 cal BC* (*5% probability*). The final Lengyel burials occurred in *4595–4460 cal BC* (*95% probability*; *end end Lengyel 3*; Fig. 11) probably in *4565–4495 cal BC* (*68% probability*). This slow decline occurred over a period of *1–265 years* (*95% probability*; *period of end Lengyel 3*; Fig. 13) probably over a period of *1–25 years* (*11% probability*) or *125–250 years* (*57% probability*).

Judging from the correspondence analysis bi-plot (Fig. 2a) and the arrangement of graves in the seriation table (Supplementary Fig. 2), there are additional breaks in the sequence of graves that may be significant. The distance between zv177 and lu4.56, and the disappearance of certain types after lu1.56, may divide phase 1 into an earlier sub-phase (phase 1a) and a later sub-phase (phase 1b comprising graves lu4.56, zv173, lu3.42, s48.76, s24.74 and s143.81). It is not possible to validate this, however, since there are currently no available radiocarbon dates for graves of the supposedly earliest phase 1a. Moreover, although not as pronounced as the gaps already identified, there appear to be three clusters of graves within phase 3. The "transitional" phase discussed above is one of them (3a). The boundary between the other two clusters (3b and 3c) is marked as a dotted line on Fig. 2a and Supplementary Fig. 2. Cluster 3a is distinguished from 3b because the pottery assemblages from graves of the former cluster seem to retain certain types from phase 2, whereas those graves from cluster 3b do not. In addition, all the graves from Villánykövesd and those from Alsónyék subsite 11 are grouped together tightly in cluster 3b, strongly suggesting contemporaneity of the two. However, we could not identify any chronological differentiation between the two clusters. This led us to suspect that there is another factor underlying the distribution of graves in phase 3, such as different social or ethnic groups. Testing such possibilities, however, would require a thorough analysis of burial contexts, which is not within the scope of this study.

This analysis was also recalculated using the approach to mixed-source calibration described above. This model produces date estimates for the phase boundaries in this seriation that are very similar to those provided by the model defined in Figs 11–12 (the medians of the equivalent parameters vary by an average of 19 years and a maximum of 37 years).

Another combined chronology for Lengyel funerary ceramics

Another seriation for Lengyel graves, based on the correspondence analysis of pottery types, has recently been proposed by Dragoş DIACONESCU (2014a, figs 10 and 12). This consists of 144 types from 265 graves excavated on 23 sites from across the spatial distribution of Lengyel burials (DIACONESCU 2014a, fig. 9). The typological scheme used to characterise the pottery is opaque. Although it is stated that the typological system used has already been discussed (DIACONESCU 2014a, 13), the references given refer to Tiszapolgár ceramics (DIACONESCU 2013; 2014b). We can only assume that some extension of this scheme has been used to define the types used in the Lengyel seriation. This certainly incorporates both form and decoration, as the 'most representative' of these are illustrated on the bi-plot of the correspondence analysis, although only the decorative motifs are labelled (DIACONESCU 2014a, 24, figs 17 and 18).

DIACONESCU (2014a, fig. 10) partitioned the bi-plot of his correspondence analysis into five successive phases (formative, Ia, Ib, IIa and IIb). Unfortunately the graves are not labelled on any of the bi-plots, and the phase boundaries are not shown on the seriation matrix (DIACONESCU 2014a, fig. 12). We have therefore reconstructed his proposed phasing using his list of the graves that fall into each phase and the published seriation matrix (DIACONESCU 2014a, 23–4 and fig. 12; Supplementary Fig. 3). There are a small number of discrepancies. Zengővárkony grave 178 is listed in both phase Ia and phase Ib. The seriation matrix, however, shows this grave to be in the liminal area where the formative and Ia phases overlap, and so we have allocated it to phase Ia. Zengővárkony graves 115 and 140 and Mórágy grave 66 are listed in both phase Ib and phase IIa. These lie adjacent in the seriation matrix in the liminal area between phases Ib and IIa (Supplementary Fig. 3). Fortunately, Mórágy grave 66 has radiocarbon measurements (Table 2), and so this grave has been included in the chronological model for this suggested partition of the seriation (see below), where it has an outlier probability of 33% when placed in phase IIa and an outlier probability of 2% when placed in phase Ib. For this reason, these three graves have all been placed in phase Ib. Twelve graves that are included in the seriation matrix are not listed by phase by DIACONESCU (2014a, 23–4). We have allocated these to the following phases based on their position in the seriation matrix and the phasing of surrounding graves: zv197 and asz170 to phase Ia; zv41b, zv203, zv232, zv265, m84, m86 and asz178 to phase Ib; and zv350,[5] m48 and pv8 to phase IIa.[6]

A model was constructed incorporating the five-phase scheme proposed by Diaconescu (2014a, fig. 10) with the radiocarbon dates that are now available from 41 of the graves that are included in his analysis. As described above five measurements have been excluded from this model: OxA-6274 from Esztergályhorváti, MAMS-14826 from Veszprém grave 2 and VERA-230, -410, and -411 from the early years of operation of the Vienna laboratory. Once more we have used

5 DIACONESCU (2014a, 23) lists zv250 in phase IIa, but this appears to be a typographic error for zv350, as zv250 contained only a stone tool and fragments of an unrecognisable vessel (DOMBAY 1960, 128).

6 It should also be noted that the double grave from Reichersdorf 177, which is treated as one assemblage in the seriation previously considered (Fig. 2a and Supplementary Fig. 2), is included in this analysis as two separate assemblages. This is discussed by DIACONESCU (2014a, fn 73).

flexible trapezium prior distributions (LEE / BRONK RAMSEY 2012) to allow for the gradual appearance and disappearance of furnished Lengyel graves. We have also modelled each phase of the seriation as a separate uniform phase to allow the intensity of burial to vary between phases. The form of this model is thus identical to that used to model the chronology of the previous seriation discussed (Figs 11–12).

Four graves have posterior outlier probabilities greater than 20% in this model. Graves m16 (O: 52%) and ve2 (O: 24%) lie in the liminal area where phases Ib and IIa overlap, grave vk23 (O: 48%) clearly lies within phase IIa according to this partition, and ve5 (O: 100%) lies in the liminal area between phases IIa and IIb (Supplementary Fig. 3). These results cause us to doubt the chronological significance of the boundary proposed by Diaconescu between his phases Ib and IIa.

This led us to consider the phasing of the seriation matrix in Supplementary Fig. 3 from first principles. We suggest three phases. The boundary between phases 1 and 2 lies between m5 and m30, although it not clear where the four graves that lie between these two (zv5, zv139, zv201 and zv279) fall as they are poorly connected to the rest of the incidence matrix, while also having identical inventories. This boundary is clearly marked by the introduction or establishment of new types and ornaments (e.g. B11toart, A4fund, A2buza and PB14orna), as well as the (gradual) disappearance of others (e.g. A2h, D1c and A2f). The boundary between phases 2 and 3 lies between graves m18 and m2 — again, a transition clearly marked by the introduction of new types (e.g. D8fund, F2e and A3h) and the phasing out of others (A2buza, D3buza and E10fund).

The chronological model which combines this proposed phasing with the available radiocarbon dates is shown in Fig. 14 (Supplementary Table 6: Greater_Lengyel_Diaconescu_outlier_3_phase.oxcal). Only three graves have posterior outlier probability above 10% in this model; m16 (O: 19%), ve2 (O: 17%) and ve5 (O: 14%). These values are within statistical expectations for a dataset of this size.

This three-phase partition effectively combines Diaconescu's formative and Ia phases into phase 1 and his phases Ib and IIa into phase 2 , and reproduces his phase IIb as phase 3 with only minor refinements of the placing of the phase boundaries. The initial analyses described above clearly highlighted the weaknesses of the division of phase 2. No such problems were identified, however, with the division between the formative and Ia phases, although this division is ill-defined in the seriation matrix (Supplementary Fig. 3). We ran a variant of the model shown in Fig.14 splitting phase 1 into an earlier part (dated by s-27/73, fr130, and gy13) and a later part (dated by fr134–5 and zv355). Only zv355 of these graves has a posterior outlier probability above 5% (O: 9%), and so there is clearly a chronological trend in this group of graves. We are unable, however, to identify a convincing partition within the seriation matrix and so we continue our analysis on the basis of the suggested three-phase partition illustrated in Supplementary Fig. 3.

This model suggests that furnished Lengyel burial began in *4970–4790 cal BC* (*95% probability*; *start start 1*; Fig. 14), probably in *4895–4805 cal BC* (*68% probability*). Lengyel burial became fully established by *4905–4745 cal BC* (*95% probability*; *end start 1*; Fig.14), probably by *4855–4770 cal BC* (*68% probability*). This introduction took place over a period of *1–150 years* (*95% probability*; *period of start 1*; Fig.15), probably over a period of *1–60 years* (*68% probability*). The boundary between phases 1 and 2 occurred in *4780–4725 cal BC* (*95% probability; 1/2*; Fig.14), probably in *4765–4735 cal BC* (*68% probability*). The boundary between phase 2 and 3 occurred in *4670–4600 cal BC* (*95% probability; 2/3*; Fig.14), probably in *4650–4625 cal BC* (*68% probability*). The beginning of the end of furnished Lengyel burial occurred in *4650–4535 cal BC* (*95% probability*; *start end 3*; Fig.14), probably in *4635–4575 cal BC* (*68% probability*), and the final Lengyel burial took place in *4635–4490 cal BC* (*95% probability*; *end end 3*; Fig.14), probably in *4610–4535 cal BC* (*68% probability*). This ending occurred over a period of *1–105 years* (*95% probability*; *period of end 3*; Fig.15), probably over a period of *1–40 years* (*68% probability*).

This analysis was also recalculated using the approach to mixed-source calibration described above. This model produces date estimates for the phase boundaries in this seriation that are very similar to those provided by the model defined in Fig. 14 (the medians of the equivalent parameters vary by an average of 15 years and a maximum of 25 years).

Discussion

Figure 16 summarises the three chronologies that we have proposed for furnished Lengyel graves: that based on the grouping of graves in cemeteries (Figs 4–7) and those based on the incidence of artefact types in closed assemblages (principally from graves) revealed through two correspondence analyses (Figs 11–12 and 14). These seriations included 390 features; 126 occur only in that illustrated in Supplementary Fig. 2, 143 occur only in that illustrated in Supplementary Fig. 3, and 121 occur in both.

The results appear to be complementary rather than contradictory.[7] Remarkably, of the 121 features that occur in both seriations, only one grave (m77) occurs in the two seriations in phases that do not overlap in time according to the chronological models.[8] Notwithstanding this single discrepancy, such agreement between the results of two seriations obtained on significantly different samples of Lengyel graves, and on different typological definitions of types, is clearly encouraging as it suggests that a consistent chronological trend is being revealed by both analyses.

The partitions that we have suggested in our analysis are conservative, but it is clear that the first correspondence analysis (Fig. 2; Supplementary Fig. 2) successfully divides phase 1 of the second correspondence analysis (Supplementary Fig. 3), and that the second correspondence analysis (Supplementary Fig. 3) successfully divides the Lengyel phase 3 derived from the first analysis (Fig. 2; Supplementary Fig. 2; Fig. 16). It seems probable that there are in fact five phases of Lengyel ceramics in these analyses, which neither of the seriations considered here has fully identified. Combining and optimising the chronological definition of types in these seriations, along with the addition of further graves from Alsónyék (including probably late graves from subsite 5603) must be a clear priority for future research. Further dating from the earliest Lengyel graves, such as those from Lužianky, is also clearly required. Nonetheless, these preliminary outcomes suggest a range of important implications, which we go on to discuss.

Beginnings

Despite the limited number of radiocarbon dates currently available for the earliest Lengyel burials, which leads to large uncertainties on some of the date estimates presented here, the

7 It should be noted that the calendar chronology proposed by DIACONESCU (2014a, 24–27), and the ensuing discussion of its implications (DIACONESCU 2014a, 28–36), are clearly erroneous. Further dating clearly shows that the majority of the radiocarbon dates on which this analysis was based are anomalous.

8 This grave occurs in phase Lengyel 2 (Fig. 2a; Supplementary Fig. 2) and phase 3 (Supplementary Fig. 3), which appear to be separated by at least a century in time (Fig. 16). The source of this discrepancy has been traced to typographic error in the original incidence matrix, which allocated pedestalled vessel 1a4b2 to m77, when this type actually appears in zv77. When this error is corrected, m77 has only one remaining type (1b4c) and so falls out of the analysis. The removal of this grave makes no substantive difference to the seriation derived from this analysis.

indications are that the practice arose swiftly, within the space of one or two human generations (Figs 8, 13 and 15). Cemeteries seem to have been established in some numbers from the 49th century cal BC (Fig. 9) across the whole area where Lengyel burials have been found, as represented by the locations of Friebritz, Svodín and Zengővárkony. So far, the only burial grounds known to be established in the 48th century cal BC or later, however, are in south-east Transdanubia.

This model has potentially significant implications for our understanding of both the beginnings of the Lengyel culture and its subsequent development. Though robust and precise chronologies remain to be established in virtually all regions of central Europe, one view can be of considerable continuity from the 'Danubian' tradition of the LBK. In various parts of Transdanubia, a continuity or sometimes overlap can be observed between the late Notenkopf, Zseliz and the formative Lengyel cultures, for example at the southern Transdanubian site of Sormás (KALICZ 1991; REGENYE 1991; BARNA 2011). If we follow the concept of ZÁPOTOCKÁ et al. (2015; note a different, multifocal model in LINK 2012) of beginnings for the *Stichbandkeramik* (here abbreviated as SBK) pottery style in central Europe, perhaps in Bohemia, there may have been a more seamless development in this broad region than further to the west, where possibilities of post-LBK hiatus have been raised recently (DENAIRE *et al.* 2017). Earliest Lengyel practices (as at Sé and coeval formative Lengyel sites: KÁROLYI 1984; 2004; KALICZ 1983-84; 1988; OROSS 2003), and also, for example, in the graves at Lužianky, could be equated with SBK III/IVa, and the horizon of Friebritz, Svodín and Zengővárkony (ZALAI-GAÁL 2007a) with SBK IVa1 (ZÁPOTOCKÁ et al. 2015, tab. 5). The implication of this study can be understood as a complementary southward spread of new practices and fashions, towards Moravia, Lower Austria and Transdanubia (ZÁPOTOCKÁ et al. 2015, obr. 14). We are not able yet to grasp in detail either the timing or the tempo of this overall trend, and so we cannot yet say whether the apparently rapid adoption of new mortuary practices in the area under consideration in this paper represents an acceleration in tempo, or a series of jumps. The geography of innovation also remains unclear, though it may be that, despite the presence of some early Lengyel graves at Zengővárkony in south-east Transdanubia, the bulk of new practices were to be found further north; the site of Aszód (SIKLÓSI 2007), just across the bend of the Danube, is also relevant.

There has been an understandable tendency to present chronologically quite generalised — though in themselves very welcome — models of Lengyel and other social differentiation, seen not only in the *oeuvre* of István Zalai-Gaál, noted at the start of this paper, but also in other syntheses and analyses (for example, SIKLÓSI 2004; BORIĆ 2015b). The results presented in this paper begin to allow us to propose a more nuanced narrative. Early Lengyel mortuary practice has been characterised as quite modest in character, with a relatively low frequency of burial. But by the time of Svodín, something more differentiated was happening (PAŽINOVÁ 2009, 30). One of us has recently reviewed the chronology and sociality of this site (DEMJÁN 2015; 2016; cf. NĚMEJCOVÁ-PAVÚKOVÁ 1995), and further dating and modelling are planned. In the current interpretation, burials are found in a series of concentrated groups (DEMJÁN 2015, 366), probably between the end of the 49th century cal BC and the start of the 48th century cal BC (Fig. 16). In the first three settlement phases, we see a separate funerary area existing alongside the usual burials in and around houses, and we see the highest intensity of residential activities (DEMJÁN 2016, 130–1). Through using the concept of exceptionality, more graves differentiated from the rest were identified over time, principally those of mature-aged men, with hypothetically the highest rank in the community. Amongst the most exceptional graves however, both sexes are represented equally (DEMJÁN 2015, 368–71). These people were provided at their funerals with 'prestige' indicators such as *Spondylus* pendants, boars' tusks and stone maceheads (DEMJÁN 2015, 371). It is also important to keep sight of the burial groups, possible indicators of more overt family or kin solidarity (DEMJÁN 2015, 370–1, fig. 6). Social differentiation is also visible in the concentration of exceptionally large houses in the area of the settlement, where the rondels would be built in later phases (DEMJÁN 2016, fig. 43, 116, 122).

This kind of development does not necessarily speak for all Lengyel mortuary practice at this time. Two of the three early burials at Zengővárkony, for example, do not appear to show the range or exceptionality proposed for Svodín burials of site phases 3 and 6, though zv214 does have a zoomorphic vessel and a boar's tusk; by the time of grave group 6c at Zengővárkony there are more examples of special graves (such as zv179). It is surely no coincidence that Svodín was also the locus for concentrated and increasing investment of labour, mobilised for the two phases of enclosure construction. Some of the more differentiated burials appear to belong to the phases just before building the first enclosure (two mature men, four children) and just after the building of the second, bigger enclosure (one adolescent woman and one elderly man; DEMJÁN 2016, fig. 47, 122). Two hypothetical scenarios might apply. Either there was an alternation between more communally and more individualising social tendencies, or particular individuals, potential 'aggrandisers' in the term of Brian HAYDEN (1995; 2001), could have taken advantage of the increasing renown of the place to attempt to bolster their own position. But with reference to some of the subsequent developments in south-east Transdanubia, it is useful to remember that for all the impressive elaboration of the second rondel at Svodín, the numbers of known houses and graves were relatively modest: some 40 of the former and a few more than 100 of the latter (DEMJÁN 2015, 365).

Further development

Whilst a new analysis which unites the two correspondence analyses presented here and produces a new chronological model which combines the new seriation with the available radiocarbon dates would clearly be optimal, some interesting trends can be discerned from the present study. Figure 17 shows the intensity of furnished Lengyel burial through time. This uses the most precise dating currently available for each grave. This may come from the site-based models (for example, at Alsónyék subsite 10B or Svodín). Alternatively, it may come from overlapping parts of the two seriations. For example, the four graves which fall into Lengyel phase 1 in the first seriation (Supplementary Fig. 2) and phase 1 in the second seriation (Supplementary Fig. 3) must date in the period after phase 1 had started and before Lengyel phase 1 had ended (Fig. 16). Dating may also come from phase allocations in a single seriation, for example Aszód grave 100, which appears only in phase 1 of the second seriation (Supplementary Fig. 3). Each grave is then spread proportionately across the period when it is likely to have been deposited.

Figure 18 shows the intensity of furnished Lengyel burial through time in the northern and southern parts of the area over which they are found (it should be noted that the gap between these areas shown in Fig. 1 is a result of the limited amount of research in this area, rather than a real gap in the distribution of Lengyel graves). It is clear that the number of furnished Lengyel graves in the northern part of their distribution declined markedly in the second half of the 47th century cal BC, and that this decline was mirrored by an increased intensity of furnished Lengyel burial at this time in southern Transdanubia. These changes were clearly synchronous with the formation of the coalescent community at Alsónyék (Fig. 19). This raises a series of important questions for both areas.

In the northern part of the distribution, this confronts us with the character of settlement and sociality in the latter part of the Lengyel, and more widely the MOG/MMK (*Mährisch-Ostösterreichische Gruppe der Bemaltkeramik/Moravská malovaná keramika* in Austria and Moravia), sequences: as defined by Zápotocká *et al.* (2015, tab. 5), say from LgK (Lengyel) II, MOG Ib1 and MMK Ib1–2 onwards (see also: KOŠTUŘIK 1972; NEUGEBAUER-MARESCH 1985; 1995; PAVÚK 2007; RUTTKAY 1985; LENNEIS 2017). This is probably after the main floruit of the rondel tradition in LgK I, when settlements spread into Upper Austria and southern Moravia (MOG/MBK Ia-b) and we see a shift of the settlements in Slovakia to higher elevations. In LgK II the expansion continued to middle Moravia and Upper Silesia (PAVÚK 2007, 23–4). Settlements appear to be of varied size, from quite extensive ones such as Michelstetten and Mitterretzbach in Lower Austria, for example, or Veszprém just north of Lake Balaton (REGENYE 2007), to small ones such as Münchendorf (RAMMER 2012; LENNEIS / RAMMER 2017); well defined buildings seem to become rarer through time, and more varied in character, as seen for example at Győr-Szabadrétdomb (assigned to Lengyel III: VIRÁG / FIGLER 2007). Late SBK buildings in the longhouse tradition, however, are still known further north, for example at Kolín in Bohemia (KONČELOVA / KVĚTINA 2015). Visible mortuary practice also becomes, or perhaps better, remains, quite rare; witness, for example, only a couple of burials within Michelstetten (Rammer 2012).

The detailed chronology of this period still remains to be established, and was beyond the scope of the present study. This horizon may be similar in many ways to that of the Grossgartach and Rössen phases further west; in the upper Rhine, the last visible longhouses belong to the Grossgartach phase, though they may well have been present also in the succeeding Rössen phase (DENAIRE et al. 2017). This is all part of the beginning of the ending of the Danubian tradition, and the start of a widespread shift to more dispersed settlement, the circumstances of which we still understand only very poorly. Speculatively, rondel enclosures may be one key clue to what was going on. If, whatever their symbolic or cultic dimensions (PETRASCH 2015; PÁSZTOR et al. 2015), rondels in some way reflected a series of social tensions which needed resolution and mediation, they may not ultimately have been successful, or not successful enough for long enough, before fission and ultimately dispersal set in, to end a very long established way of life. This raises all manner of so far unanswered questions, but that at least is valuable in putting the spotlight on pressing future research targets, including the detailed absolute chronology of rondels and of the demise of Danubian culture.

In the long run, the trend further south was the same: towards the dispersal of concentrations of Lengyel settlement by around the middle of the fifth millennium cal BC, and the emergence of the different conditions of the Early Copper Age (BORIĆ 2015a; BÁNFFY et al. 2016). As one well documented example of the biography of a single, major, locale, the rapid peak and then long, slow decline of the major aggregation at Alsónyék have been set out elsewhere (OSZTÁS et al. 2016b; BÁNFFY et al. 2016). We are still far, however, from understanding the wider context and setting. The apparent timelag in the intensity of mortuary practice between the area further north and south-east Transdanubia might be ascribed, at one level, merely to distance from the point or direction of origin of cultural trends; put simply, perhaps it just took longer for new fashions to travel southwards. But that does not explain the different circumstances in southern Transdanubia which produced a series of major aggregations of settlement, with accompanying concentrations of burial — both seen now at their most spectacular at Alsónyék. As explored in the papers on the chronology of Alsónyék (OSZTÁS et al. 2016b; BÁNFFY et al. 2016), the suspicion is that at its peak occupation the site could have been a coalescence of different communities drawn in from areas round about; that is an unfinished story, requiring the completion of mortuary analyses at Alsónyék itself. It is also worth remembering that burial may have begun before settlement in the Lengyel sequence at Alsónyék.

Clearly one key future requirement is a better and more integrated understanding of the settlement context and history around Alsónyék, and the same need exists for Zengővárkony, Mórágy, Villánykövesd and other major sites (see, for example, BERTÓK / GÁTI 2011). From the comparative literature (reviewed in detail in BÁNFFY et al. 2016), one might predict social tensions and open conflict as one likely push towards aggregation, but there are no clear signs from the corpus of southern Transdanubian human skeletal remains of either extensive or increasing signs of trauma, wounding or killing. That could lead us to posit once again a level of social competition which drew people together for variable periods of time, to interact and display individual and group positions and allegiances here not through collective labour tasks but principally in the mortuary domain, before tensions and fission took over. Clearly, from the results presented in this paper, this kind of putative process varied from site to site, given the fluctuating durations of individual cemeteries or concentrations of burial (Fig. 8).

This highlights another unfinished task — despite the prolonged efforts of István Zalai-Gaál — namely the correlation of mortuary variability with the passage of time. Generally speaking, the south-eastern Transdanubian burial sites, as well as being larger than those further north, show more signs of differentiation, in terms of both the quantities and the character of grave goods, as well as in the relative elaboration of graves themselves (ZALAI-GAÁL 2010a; SIKLÓSI 2004; BORIĆ 2015b). Figure 20, for example, shows the intensity of the deposition of copper artefacts in Lengyel burials through time. That process of differentiation may have built up gradually through the long use of Zengővárkony, for example, but came in much more accelerated fashion at Alsónyék. No universal or overarching hypothesis, such as 'Saxe-Goldstein no. 8', with its putative correlations between formal disposal areas, corporate descent groups and crucial or scarce resources, seems satisfactorily to stand up in particular circumstances, and the details of context and individual practice are potentially much more informative (MORRIS 1991; CARR 1995; PARKER PEARSON 1999; CHAPMAN 2000). The varying history of Lengyel mortuary practices to the north and the south, underlined in the present study, hardly gives credence to the idea of fluctuations in scarce or crucial resources; and Alsónyék, Zengővárkony, Mórágy and others were anyway surely both too big and too dispersed to represent single or unified corporate descent groups. The notion of corporate groups or descent groups of some kind, however, need not be set aside, and as already noted, was advocated in various ways by István ZALAI-GAÁL himself (2010a). We need now to break this kind of big concept down (cf. CARR 1995, 182), and examine constituent parts in close contextual detail. István ZALAI-GAÁL (2002) offered detailed analysis of one grave group, B_1, at Mórágy, suggesting both hierarchical differences among the adult and child burials and clusterings of biologically related people. Comparable analysis, supported by the battery of scientific analyses now available, remains a task for the many grave groups at Alsónyék, neighbourhood by neighbourhood across the site (OSZTÁS et al. 2016b). Whether future scientific investigation can show that these neighbourhood burial groups were principally formed of related people remains to be seen; we do not yet know whether incorporation in such mortuary groupings was a matter of descent, or residential affiliation, or both, but this looks the most promising scale at which to advance the next stage of research. There is also much potential for further investigation of spiritual and cosmological dimensions of Lengyel mortuary practice (cf. CARR 1995, 190).

In all these reflections, it is important not to overlook the pottery itself, often relatively neglected in comparison to identified 'prestige' objects. The ceramic material itself seems, according to both the seriations considered here, to develop steadily, whether three or perhaps more probably five phases can be discerned. With no radical jumps or abrupt transformations, tradition can be suggested as important, and this material may have projected shared communalities involved in the presentation and consumption of food and drink, for example, as much as hierarchy and differentiation. It is noteworthy that funerary ceramics have the same form variants all over the Lengyel distribution, whereas, by contrast, there are regional differences in the settlement ceramics (of which more briefly below). The man buried in grave 3060 at Alsónyék, distinguished by the form of his grave and the range of grave goods, and suggested as a *Häuptling* or chief or headman (ZALAI-GAÁL 2008), was also accompanied by six pots (ZALAI-GAÁL et al. 2011a). This assemblage contained a large bowl, a footed vessel and three beakers, as well as a Butmir-style bowl. The quantity of vessels is unusual, some three times the average number found in Lengyel graves (ZALAI-GAÁL et al. 2011a, 67), but apart from the Butmir bowl, the pottery in itself is hardly remarkable.

It is important also to underline the existing geographical imbalances in research into the Lengyel culture in Transdanubia. The south-east has long been studied, and intensively so, from the time of Wosinsky onwards (as noted at the start of this paper), while the west of Transdanubia has long been something of a blank spot. Northern Transdanubia, with the main exception of county Veszprém, has also been until now comparatively under-researched. The investigation of Alsónyék serves to deepen research on the south-east, while only Esztergályhorváti further west has provided samples for this study — and those from an unusual context. But even where sites further west have been investigated under rescue conditions, as at Balatonmagyaród-Hídvégpuszta (BARNA et al. forthcoming), no burials have been recorded. This puts the spotlight again on the character and tempo of change in south-east Transdanubia. Our discussion so far has looked mainly north, but the proximity of south-east Transdanubia to other long-lasting and significant cultural traditions, such as Sopot and Vinča (JAKUCS et al. 2016; OROSS et al. 2016c), should not be forgotten. By the time of grave 3060 at Alsónyék, with its Butmir vessel, the Butmir occupation of the Okolište tell was probably in decline or ending (HOFMANN 2013), and the Vinča network was characterised by Vinča D pottery (WHITTLE et al. 2016). These were times in the regions beyond Alsónyék of change and decline, and something of the character of what took place in south-east Transdanubia may be due to the disturbances in long-established networks to the south and east.

Finally, we should emphasise that Lengyel settlement pottery in Hungary (compare DONEUS / RAMMER 2017b, for Lower Austria) still needs investigation comparable to that long given to funerary pottery, with its selected, appealing finewares and often very good state of preservation in graves. For Alsónyék at least, the evaluation of the settlement pottery has now been started, but only when that has been completed will we obtain a more rounded overall chronology for Lengyel developments.

Endings

That last point is very relevant for our understanding of endings. Evidence about the pace of the abandonment of furnished Lengyel burial is currently mixed, with alternative models either suggesting a relatively swift abandonment (Figs 8 and 15) or a longer period of slow decline (Fig. 13). New, and currently only partially published, evidence from Alsónyék subsites 11 and 5603 will be key to understanding this better (OSZTÁS et al. 2016b; BÁNFFY et al. 2016). At Alsónyék, the provisional picture is of varied endings for burial and occupation. While the brief peak of intensive burial in subsite 10B was either side of 4700 cal BC, burial in subsite 11 lasted until the 46th century cal BC, and in subsite 5603 to around or just after 4500 cal BC (BÁNFFY et al. 2016, fig. 5); correspondingly, settlement activity in subsite 10B fell either side of 4700 cal BC, but lasted in subsite 11 perhaps till around 4600 cal BC, and in subsite 5603 to as late as a little before 4300 cal BC (BÁNFFY et al. 2016, fig. 5). We have modelled population numbers and house numbers, according to which there could have been a mere handful of late houses, around 4400 cal BC, occupied perhaps by fewer than a hundred people. There is so far no clear indication of formal burials accompanying this late settlement activity. It is as though the kind of mortuary rites typical of the floruit of Alsónyék required an audience of a certain size and kind, and the same may apply to other contexts. That even the sequence at Alsónyék requires further refinement, aside from the obvious other targets in south-east Transdanubia, indicates the scale of remaining research tasks.

Conclusions

In the spirit of István Zalai-Gaál, and in tribute to his memory, we have attempted to combine analysis of Lengyel funerary pottery from western Hungary, Slovakia and eastern Austria with new models for its development through time. We have done this through typology, correspondence analysis and formal chronological modelling of radiocarbon dates in a Bayesian statistical framework. Our models suggest that cemeteries were established in some numbers from the 49th century cal BC (Fig. 9) across the whole area where Lengyel burials have been found, as represented by the locations of Friebritz, Svodín and Zengővárkony. So far the only burial grounds known to be established in the 48th century cal BC or later, however, are in south-east Transdanubia. We have suggested a model of continuity from the LBK, perhaps mediated and influenced in part by the SBK ceramic tradition of central Europe. The pace and scale of this estimated SBK influence would be more precise, if we had a more detailed information on coeval Lengyel burials from northern Transdanubia. Some sites are known (e.g. Csabdi-Télizöldes: KÖHLER 2004; Felsőörs-Báróker: REGENYE 2011) but apart from preliminary reports, no details are available on these. For this reason, these graves could not be included in the programmes of radiocarbon dating and pottery seriation undertaken for the present study. Early Lengyel burial practice was modest in scale, though it already showed more signs of differentiation by the time of Friebritz, Svodín and Zengővárkony. Numbers of burials, however, remained relatively restrained, even at a clearly important locale such as Svodín. Thereafter, while burials became much rarer in the north-west, a rich burial tradition came to flourish in south-east Transdanubia, with relatively speaking plenty of signs of differentiation in terms of the style of graves and the character and range of grave goods, though the character of funerary pottery speaks to shared tradition and practice. Even the biggest concentrations of burials, however, as now seen most dramatically at Alsónyék-Bátaszék, can probably be broken down into smaller groupings, there at a probable neighbourhood scale. We still do not understand the circumstances in which major aggregations of occupation, with accompanying burials (or indeed major concentrations of burial with accompanying settlement), took place, though we can now grasp that the high point of the site biography for Alsónyék was brief. Other burial grounds in south-east Transdanubia were of varied durations, probably reflecting, we have suggested, local circumstances including themes of social competition and tensions rather than any universal relationship between putative corporate descent groups and crucial resources. We have also mooted the significance of connections to the south and east for the character of the mortuary tradition in south-east Transdanubia, at a time of change and the ending of tell and other settlement. The biography for Alsónyék is currently the best guide to the context of the ending of the Lengyel mortuary tradition in south-east Europe, with formal burial gradually petering out as the intensity of occupation declined. Our study, finally, has identified a long list of future research tasks and targets, from further dating of the earliest horizon of Lengyel furnished burial, perhaps back into the 50th century cal BC, and of Lengyel settlement in the north after the 48th century cal BC, to further investigation and synthesis of the context of major aggregations such as Alsónyék and Zengővárkony at the same time as continuing close analysis of the neighbourhood grave groups at Alsónyék and elsewhere; the detailed investigation of settlement pottery alongside funerary ceramics is also long overdue. While there is thus much still to do, what has been achieved in both recent fieldwork and post-excavation analyses should be sufficient to put the Lengyel culture more firmly into the mainstream of discussion of the development and history of Neolithic societies. That this can be so would perhaps be the best tribute we can pay to the work of István Zalai-Gaál.

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Summary · Zusammenfassung · Résumé

Summary

This paper, dedicated to the memory of István Zalai-Gaál, presents formally modelled date estimates for the sequence of Lengyel funerary pottery in western Hungary, eastern Austria and

south-west Slovakia. It is an extension of the dating and modelling already carried out by the project, *The Times of Their Lives* (ToTL), on the major Lengyel aggregation, including burials, at Alsónyék-Bátaszék in south-east Transdanubia.

Key aspects of the Lengyel culture and its research history are discussed, including the challenges of establishing its sequence with greater precision and of affirming its significance in wider Neolithic narratives. The many contributions of István Zalai-Gaál are noted. Results from Alsónyék are summarised.

The present study concentrates on furnished Lengyel graves, using the analysis of Lengyel funerary pottery from western Hungary, eastern Austria and south-west Slovakia. A full catalogue of the 121 pot types identified by István Zalai-Gaál is presented, and correspondence analysis of the occurrence of 113 of these types in 247 graves suggests a seriation for these grave-assemblages. The new radiocarbon dating programme for the sequence of Lengyel funerary pottery was designed within the framework of Bayesian chronological modelling. We aimed to provide formal date estimates for the use of different pot types and for their combinations in different phases of the seriation. We also aimed to estimate the period during which furnished Lengyel burial occurred, the pace of its introduction and demise, the date and duration of use of individual cemeteries, and the intensity of Lengyel funerary practice through time. In addition to the 159 radiocarbon measurements from 141 graves at Alsónyék (29 of which appear in the correspondence analyses presented here), 91 radiocarbon measurements are reported from 57 graves across the Lengyel distribution under discussion, all but 16 achieved by the ToTL project.

These provide three chronological models for the sequence of Lengyel furnished burials: one based on the chronology of individual cemeteries and other contexts; another combining the seriation based on István Zalai-Gaál's typology with the radiocarbon dates; and the third combining the seriation previously suggested by Diaconescu (2014a) with the radiocarbon dates. Details of the models, and of dietary analysis to investigate the possibility of offsets, are described. Lengyel furnished burial appears to have emerged rapidly, probably during the course of the 49th century cal BC, across the whole area in question (although the bulk of the earliest burials may have been in the north). Furnished burial increased in popularity in south-east Transdanubia during the 48th century cal BC, although there was a decline in the practice further north at this time. Furnished Lengyel burial appears to have become less frequent after *c.* 4600

cal BC, although the practice finally ended in the second half of the 46th century cal BC. Implications for the character of Lengyel communities and wider narratives of Lengyel development as a whole are discussed.

Zusammenfassung

Résumé

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Figure captions

Figure 1. Map showing the area over which Lengyel pottery is found and the locations of sites which produced graves that have been included in the correspondence analysis and/or sampled for radiocarbon dating. Abbreviations of the site names are given in brackets and in Table 2. Sites: 1: Lužianky (lu or lux); 2: Zengővárkony (Igaz-dűlő) (zv); 3: Svodín (Szőgyén), Busahegy (s); 4: Friebritz-Süd (fr); 5: Györe (Bocok-föld) (gy); 6: Pári-Altacker (pa); 7: Mórágy-Tűzkődomb (m); 8: Verőce (nograd); 9: Topoľčany; 10: Alsónyék-Bátaszék (an or az); 11: Lébény-Kaszás-domb (Le); 12: Szekszárd-Ágostonpuszta (ap); 13: Veszprém-Jutasi út (ve); 14: Pécsvárad (Aranyhegy) (pv); 15: Brodzany (br); 16: Villánykövesd (Jakabfalusi út mente) (vk); 17: Szob (szo); 18: Lánycsók (lcs); 19: Nitra-Leningradska ulica (ni); 20: Pusztataskony-Ledence 1 (pusz); 21: Aszód-Papi földek (asz); 22: Karancsság (kar); 23: Várdomb-Újberekpuszta (uj); 24: Kölesd-Lencsepuszta (kol); 25: Lengyel (len); 26: Felsőnyék (fel); 27: Reichersdorf (re); 28: Oberbergern (ober); 29: Ebelsberg (Ufer)(ebel); 30: Esztergályhorváti (es); 31: Wetzleinsdorf (wetz); 32: Antonshöhe bei Mauer (Wien 23) (ant).

Figure 2. Bi-plot of the first and second principal axes of the correspondence analysis of Lengyel funerary ceramics (a) graves and (b) types.

Figure 3. $\delta^{13}C$ and $\delta^{15}N$ values for adult, sub-adult and infant skeletons from Lengyel graves dated as part of this study.

Figure 4. Overall structure of the chronological model for the currency of Lengyel graves. Each probability 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 Villánykövesd*' is the estimated date when the cemetery at Villánykövesd was established. Distributions for Lengyel graves at Alsónyék-Bátaszék are derived from the models shown in OSZTÁS et al. (2016b, figs. 12–13, 15–16, and 18–19). The large square brackets down the left-hand side of Figs 4–7 along with the OxCal keywords define the overall model exactly.

Figure 5. Probability distributions of dates from Mórágy-Tűzkődomb. The format is identical to that of Fig. 4. The large square brackets down the left-hand side of Figs 4–7 along with the OxCal keywords define the overall model exactly.

Figure 6. Probability distributions of dates from Zengővárkony (Igaz-dűlő). The format is identical to that of Fig. 4. The large square brackets down the left-hand side of Figs 4–7 along with the OxCal keywords define the overall model exactly.

Figure 7. Probability distributions of dates from Svodín-Busahegy. The format is identical to that of Fig. 4. The large square brackets down the left-hand side of Figs 4–7 along with the OxCal keywords define the overall model exactly.

Figure 8. Probability distributions for the durations of Lengyel cemeteries, derived from the model defined in Figs 4–7.

Figure 9. Key parameters for the dates of Lengyel cemeteries, derived from the model defined in Figs 4–7.

Figure 10. Bi-plot of the first and second principal axes of the correspondence analysis of Lengyel funerary ceramics showing graves classified by site and suggested final phasing.

Figure 11. Overall structure of the chronological model for the sequence of typological phases of Lengyel graves suggested by the correspondence analysis illustrated in Fig. 2a and Supplementary Fig. 2. The format is identical to that of Fig. 4. The component relating to phase 3 of the seriation is shown in Fig. 12. The large square brackets down the left-hand side of Figs 11–12 along with the OxCal keywords define the overall model exactly.

Figure 12. Probability distributions of dates for Lengyel graves assigned to phase 3 by the correspondence analysis illustrated in Fig. 2a and Supplementary Fig. 2. The format is identical to that of Fig. 4. The large square brackets down the left-hand side of Figs 11–12 along with the OxCal keywords define the overall model exactly.

Figure 13. Probability distributions for the duration of the typological phases suggested by the correspondence analysis illustrated in Supplementary Fig. 2 (the tail of the distribution *period of start Lengyel 1* has been truncated for clarity and actually runs to more than 2800 years), derived from the model defined in Figs 11–12.

Figure 14. Probability distributions of dates from Lengyel graves following the typological phases suggested by the correspondence analysis illustrated in Supplementary Fig. 3. The format is identical to that of Fig. 4. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly.

Figure 15. Probability distributions for the duration of the typological phases suggested by the correspondence analysis illustrated in Supplementary Fig. 3, derived from the model defined in Fig. 14.

Figure 16. Schematic diagram showing the periods of use of various Lengyel cemeteries and ceramic phases, derived from the models defined in Figs 4–7, 11–12 and 14.

Figure 17. Number of furnished Lengyel burials per generation, derived as described in the text from the correspondence analyses shown in Supplementary Figs 2–3 and the chronological models shown in Figs 4–7, 11–12 and 14.

Figure 18. Number of furnished Lengyel burials per generation in the northern and southern areas (see Fig. 1), derived as described in the text from the correspondence analyses shown in Supplementary Figs 2–3 and the chronological models shown in Figs 4–7, 11–12 and 14.

Figure 19. Probability that a furnished Lengyel grave was made by generation in the northern and southern areas of furnished Lengyel burial (see Figs 1 and 18), and at Alsónyék (BÁNFFY et al. 2016, fig. 8).

Figure 20. Number of furnished Lengyel burials per generation with or without copper artefacts, derived as described in the text from the correspondence analyses shown in Supplementary Figs 2–3 and the chronological models shown in Figs 4–7, 11–12 and 14.

Table 1. Summary of available radiocarbon results and stable isotopic measurements from Lengyel-period graves.

Site	^{14}C ages	Graves	Reference
Ebelsberg, Austria	1	1	STROH 1954
Friebritz-Süd, Austria	4	4	NEUGEBAUER-MARESCH et al. 2002
Oberbergen, Austria	1	1	RUTTKAY 1978
Reichersdorf, Austria	2	1	NEUGEBAUER / NEUGEBAUER-MARESCH 2003
Wetzleinsdorf, Austria	1	1	RUTTKAY 1972
Alsónyék-Bátaszék, Hungary	159	143	OSZTÁS et al. 2016b, tables 2–4
Esztergályhorváti, Hungary	7	1	BRONK RAMSEY et al. 1999
Györe (Bocok-föld), Hungary	2	1	This study
Mórágy-Tűzkődomb, Hungary	23	16	This study
Veszprém-Jutasi út, Hungary	11	6	This study
Villánykövesd (Jakabfalusi út mente), Hungary	4	3	This study
Zengővárkony (Igaz-dűlő), Hungary	17	11	This study
Svodín (Szőgyén), Busahegy, Slovakia	18	11	This study

Table 2. Radiocarbon and stable isotopic measurements for Lengyel-period graves, except for those from Alsónyék-Bátaszék which are detailed in OSZTÁS et al. (2016b, tables 2–4). Replicate measurements have been tested for statistical consistency and combined by taking a weighted mean as described by WARD / WILSON (1978); values in bold are statistically inconsistent at the 5% significance level.

Laboratory number	**Grave/Sample number**	**Material and context**	**Radiocarbon Age (BP)**	**$\delta^{13}C$ (‰) [AMS]**	**$\delta^{13}C$ (‰) [IRMS]**	**$\delta^{15}N$ (‰)**	**C:N ratio**
	Györe (Bocok-föld)						
SUERC-48357	gy13/pot2	Calcined human bone, skull calvaria from cremation burial in pot 2 of grave 13 with 12 diagnostic pottery vessels	5795±34		−23.6±0.2		
SUERC-48358	gy13/pot12	Calcined human bone, skull calvaria from cremation burial in pot 12 of grave 13 with 12 diagnostic pottery vessels	5908±34		−25.1±0.2		
	Mórágy-Tűzkődomb						
SUERC-48359	m3	Human bone, right humerus from 13–14-year-old child inhumation in grave 3 in grave group B1 with three diagnostic pottery vessels	5812±34		−20.3±0.2	11.1±0.3	3.2
SUERC-48363	m10	Human bone, left humerus from 38–44-year-old male inhumation in grave 10 in grave group B1 with four diagnostic pottery vessels	5872±34		−20.0±0.2	11.5±0.3	3.2
OxA-28911	m15	Human bone, left humerus from 62–75-year-old female inhumation in grave 15 in grave group B1 with two diagnostic pottery vessels	5760±30		−19.8±0.2	9.6±0.3	3.3
SUERC-58095	m16(i)	Human bone, left femur from 41–45-year-old female inhumation in grave 16 in grave group B1 with two diagnostic pottery vessels	5709±30		−19.9±0.2	10.8±0.3	3.2
MAMS-23163	m16(ii)	Replicate of SUERC-58095	5707±26	−17.1			
	^{14}C age: 5708±20 BP, T'=0.0, T'(5%)=3.8, ν=1						
OxA-28912	m36	Human bone, left femur from 34–38-year-old female inhumation in grave 36 in grave group B1 with four diagnostic pottery vessels	5724±30		−20.1±0.2	10.8±0.3	3.3
SUERC-48364	m36	Replicate of OxA-28912	5716±34		−20.0±0.2	10.8±0.3	3.2
	^{14}C age: 5721±23 BP, T'=0.0, T'(5%)=3.8, ν=1; $\delta^{13}C$: −20.1±0.14‰, T'=0.1, T'(5%)=3.8, ν=1; $\delta^{15}N$: +10.8±0.21‰, T'=0.0, T'(5%)=3.8, ν=1						

OxA-28913	m37	Human bone, rib from 2–5-year-old child inhumation in grave 37 in group B1 with three diagnostic pottery vessels	5772±31		−19.9±0.2	12.8±0.3	3.3
OxA-28914	m39	Human bone, right femur from 13–15-year-old child inhumation in grave 39 in group B1 with four diagnostic pottery vessels	5767±29		−19.7±0.2	10.6±0.3	3.3
OxA-28915	m40	Human bone, right femur from 53–59-year-old female inhumation in grave 40 in group B1 with three diagnostic pottery vessels	5723±29		−20.0±0.2	10.9±0.3	3.3
MAMS-21328	m53	Human bone, right femur from 17–18-year-old female inhumation in grave 53 in group B1 with seven diagnostic pottery vessels	5729±25	−21.5	−19.8±0.11	9.2±0.13	3.3
MAMS-23161	m53	Replicate of MAMS-21328	5775±26	−15.3	−19.9±0.11	9.8±0.13	3.3
	^{14}C age: 5751±19 BP, T'=1.6, T'(5%)=3.8, ν=1; δ^{13}C: 19.9±0.08‰, T'=0.4, T'(5%)=3.8, ν=1; δ^{15}N: 9.5±0.09‰, **T'=10.7**, T'(5%)=3.8, ν=1						
SUERC-48365	m56	Human bone, left femur from 41–45-year-old female inhumation in grave 56 in group B1 with two diagnostic pottery vessels	5782±34		−20.2±0.2	11.0±0.3	3.2
OxA-28916	m59	Human bone, left femur from 19–21-year-old female inhumation in grave 59 in group B1 with two diagnostic pottery vessels	5809±32		−19.6±0.2	10.3±0.3	3.3
SUERC-48366	m59	Replicate of OxA-28916	5781±34		−19.8±0.2	10.5±0.3	3.2
	^{14}C age: 5796±24 BP, T'=0.4, T'(5%)=3.8, ν=1; δ^{13}C: −19.7±0.14‰, T'=0.5, T'(5%)=3.8, ν=1; δ^{15}N: +10.4±0.21‰, T'=0.2, T'(5%)=3.8, ν=1						
MAMS-21329	m60	Human bone, right femur from 5–6 year-old child inhumation in grave 60 in group B1 with three diagnostic pottery vessels	5729±24	−27.5	−20.3±0.11	10.6±0.13	3.2
MAMS-23162	m60	Replicate of MAMS-21329	5712±26	−13.9	−20.2±0.11	10.7±0.13	3.2
	^{14}C age: 5721±18 BP, T'=0.2, T'(5%)=3.8, ν=1; δ^{13}C: −20.3±0.08‰, T'=0.4, T'(5%)=3.8, ν=1; δ^{15}N: 10.7±0.09‰, T'=0.3, T'(5%)=3.8, ν=1						
OxA-28917	m62	Human bone, right femur from 4–5-year-old child inhumation in grave 62 in group B1 with three diagnostic pottery vessels	5778±29		−20.3±0.2	11.3±0.3	3.3

SUERC-54631	m66(i)	Human bone, right femur from 37–43-year-old male inhumation in grave 66 in group B1 with six diagnostic pottery vessels	5936±33		−20.1±0.2	10.6±0.3	3.2
MAMS-21330	m66(ii)	Replicate of SUERC-54631	5809±24	−17.4	−20.2±0.11	10.6±0.13	3.3
	^{14}C age: 5854±20 BP, T'=**9.7**, T'(5%)=3.8, ν=1; δ^{13}C: −20.2±0.1‰, T'=0.2, T'(5%)=3.8, ν=1; δ^{15}N: 10.6±0.12‰, T'=0.0, T'(5%)=3.8, ν=1						
SUERC-48367	m91	Human bone, right tibia from 9–11-year-old child inhumation in grave 91 in group B2 with four diagnostic pottery vessels	5838±34		−20.2±0.2	11.7±0.3	3.2
OxA-28918	m93	Human bone, left tibia from 23–28-year-old female inhumation in grave 93 in grave group B2 with five diagnostic pottery vessels	5901±29		−20.3±0.2	11.1±0.3	3.3
SUERC-48368	m93	Replicate of OxA-28918	5842±34		−20.4±0.2	11.7±0.3	3.2
	^{14}C age: 5876±23 BP, T'=1.7, T'(5%)=3.8, ν=1; δ^{13}C: −20.4±0.14‰, T'=0.1, T'(5%)=3.8, ν=1; δ^{15}N: +11.4±0.21‰, T'=2.0, T'(5%)=3.8, ν=1						
	Villánykövesd (Jakabfalusi út mente)						
SUERC-48369	vk12	Human bone, right radius from 12–13-year-old child inhumation in grave 12 with four diagnostic pottery vessels	5782±34		−20.3±0.2	10.0±0.3	3.3
SUERC-54644	vk20	Human bone, skull calvaria from 23–32-year-old female inhumation in grave 20 with two diagnostic pottery vessels	5879±30		−20.0±0.2	10.1±0.3	3.2
OxA-28919	vk23	Human bone, left tibia from 30–37-year-old male inhumation in grave 23 with five diagnostic pottery vessels	5856±29		−20.3±0.2	10.6±0.3	3.3
SUERC-48373	vk23	Replicate of OxA-28919	5875±34		−20.4±0.2	11.3±0.3	3.2
	^{14}C age: 5864±23 BP, T'=0.2, T'(5%)=3.8, ν=1; δ^{13}C: −20.4±0.14‰, T'=0.1, T'(5%)=3.8, ν=1; δ^{15}N: +11.0±0.21‰, T'=2.7, T'(5%)=3.8, ν=1						
	Zengővárkony (Igaz-dűlő)						
OxA-28920	zv13	Human bone, right femur from 46–55-year-old female inhumation in grave 13 in group 2b with two diagnostic pottery vessels	5735±30		−19.6±0.2	9.2±0.3	3.3
OxA-28921	zv13	Replicate of OxA-28920	5726±30		−19.8±0.2	9.1±0.3	3.3
	^{14}C age: 5731±22 BP, T'=0.0, T'(5%)=3.8, ν=1; δ^{13}C: −19.7±0.14‰, T'=0.5, T'(5%)=3.8, ν=1; δ^{15}N: +9.2±0.21‰, T'=0.1, T'(5%)=3.8, ν=1						

OxA-28922	zv14	Human bone, left femur from 50–75-year-old female inhumation in grave 14 in group 2b with five diagnostic pottery vessels	5856±29		−20.0±0.2	9.0±0.3	3.2
SUERC-48374	zv14	Replicate of OxA-28922	5857±34		−20.1±0.2	9.6±0.3	3.2
	^{14}C age: 5856±23 BP, T'=0.0, T'(5%)=3.8, ν=1; δ^{13}C: −20.1±0.14‰, T'=0.1, T'(5%)=3.8, ν=1; δ^{15}N: +9.3±0.21‰, T'=2.0, T'(5%)=3.8, ν=1						
SUERC-48375	zv90	Human bone, left femur from 50–56-year-old female inhumation in grave 90 in group 9 with four diagnostic pottery vessels	5939±34		−20.0±0.2	11.0±0.3	3.2
SUERC-54648	zv91(i)	Human bone, left tibia from 40–46-male inhumation in grave 91 in group 9 with two diagnostic pottery vessels	5815±33		−19.8±0.2	11.0±0.3	3.2
MAMS-21340-1	zv91(ii)	Replicate of SUERC-54648	5704±21	−20.6	−19.6±0.11	10.1±0.13	3.3
MAMS-21340-2	zv91	Replicate of SUERC-54648	5741±26				
	^{14}C age: 5738±15BP, T'=**8.1**, T'(5%)=6.0, ν=2; δ^{13}C: −19.6±0.1‰, T'=0.8, T'(5%)=3.8, ν=1; δ^{15}N: 10.2±0.12‰, T'=**7.6**, T'(5%)=3.8, ν=1						
OxA-28923	zv93	Human bone, left humerus from 28–38-year-old male inhumation in grave 93 in group 9 with six diagnostic pottery vessels	5864±30		−20.2±0.2	11.4±0.3	3.3
SUERC-54649	zv108(i)	Human bone, left femur from 36–46-year-old male inhumation in grave 108 in group 9 with three diagnostic pottery vessels	5981±31		−19.2±0.2	11.3±0.3	3.2
MAMS-21341	zv108(ii)	Replicate of SUERC-54649	5604±23	−17.6	−20.0±0.11	9.4±0.13	3.5
	^{14}C age: 5744±19 BP, T'=**96.6**, T'(5%)=3.8, ν=1; δ^{13}C: −19.8±0.1‰, T'=**12.3**, T'(5%)=3.8, ν=1; δ^{15}N: +9.7±0.12‰, T'=**33.8**, T'(5%)=3.8, ν=1						
OxA-28924	zv135	Human bone, skull calvaria from 40–80-year-old male inhumation in grave 135 in group 9 with five diagnostic pottery vessels	5868±30		−19.9±0.2	10.7±0.3	3.3
SUERC-48376	zv135	Replicate of OxA-28924	5908±34		−20.1±0.2	11.6±0.3	3.2
	^{14}C age: 5886±23 BP, T'=0.8, T'(5%)=3.8, ν=1; δ^{13}C: −20.0±0.14‰, T'=0.5, T'(5%)=3.8, ν=1; δ^{15}N: +11.2±0.21‰, T'=**4.5**, T'(5%)=3.8, ν=1						
SUERC-48377	zv272	Human bone, left femur from 54–66-year-old male inhumation in grave 272 in group 11 with four diagnostic pottery vessels	5898±35		−19.6±0.2	11.5±0.3	3.2

OxA-28925	zv314	Human bone left femur from 36–42-year-old male inhumation in grave 314 in group 14a with pot-types (six vessels)	5787±30		−20.4±0.2	9.8±0.3	3.2
SUERC-48378	zv326	Human bone, right femur from 40–80-year-old male inhumation in grave 326 in group 9 with two diagnostic pottery vessels	5700±34		−19.6±0.2	11.0±0.3	3.3
SUERC-48379	zv355	Human bone right femur from 30–59-year-old male inhumation in grave 355 in group 13 with six diagnostic pottery vessels	5976±34		−19.8±0.2	11.6±0.3	3.2
	Friebritz-Süd						
VERA-1976	fr130	Human bone from 20–25-year-old male inhumation in grave 130 with three diagnostic pottery vessels	5888±31				
SUERC-54630	fr131	Human bone, left femur from 16–24-month-old infant inhumation in grave 131 with five diagnostic pottery vessels	6012±31		−20.2±0.2	12.1±0.3	3.2
VERA-1977	fr134	Human bone from 50–60-year-old male inhumation in grave 134 with four diagnostic pottery vessels	5826±32				
VERA-1978	fr135	Human bone from 12–13-year-old child inhumation in grave 135 with two diagnostic pottery vessels	5847±30				
	Svodín-Busahegy						
MAMS-21331	s7.72	Human bone, left femur from 20–30-year-old ?female inhumation in grave 7/72 with two diagnostic pottery vessels	5921±24	−20.3	−20.1±0.11	11.5±0.13	3.2
MAMS-23164	s7.72	Replicate of MAMS-21331	5946±26	−15.6	−19.9±0.11	11.4±0.13	3.2
	^{14}C age: 5933±18 BP, T'=0.5, T'(5%)=3.8, ν=1; δ^{13}C: −20.0±0.08‰, T'=1.7, T'(5%)=3.8, ν=1; δ^{15}N: +11.5±0.09‰, T'=0.3, T'(5%)=3.8, ν=1						
SUERC-54632	s27.73	Human bone, right femur from 30–40-year-old male inhumation in grave 27/73 with four diagnostic pottery vessels	5985±31		−20.0±0.2	11.5±0.3	3.2
SUERC-58096	s29.73(i)	Human bone, left femur from 16–19-year-old female inhumation in grave 29/73 with four diagnostic pottery vessels	5838±31		−20.0±0.2	11.6±0.3	3.2

MAMS-23168	s29.73(ii)	Replicate of SUERC-58096	5933±26	−16.0	−20.1±0.11	12.1±0.13	3.2
	^{14}C age: 5894±20 BP, T'=**5.5**, T'(5%)=3.8, ν=1; δ^{13}C: −20.1±0.1‰, T'=0.2, T'(5%)=3.8, ν=1; δ^{15}N: +12.0±0.12‰, T'=2.3, T'(5%)=3.8, ν=1						
SUERC-54633	s37.74	Human bone, right femur from 3–4-year-old child inhumation in grave 37/74 with eight diagnostic pottery vessels	6012±34		−20.0±0.2	13.0±0.3	3.2
MAMS-21332	s42.74	Human bone, right femur from 3–5-year-old child inhumation in grave 42/74 with five diagnostic pottery vessels	5928±22	−24.7	−20.0±0.11	12.5±0.13	3.2
MAMS-23165	s42.74	Replicate of MAMS-21332	5904±26	−18.2	−20.0±0.11	11.9±0.13	3.2
	^{14}C age: 5918±17 BP, T'=0.5, T'(5%)=3.8, ν=1; δ^{13}C: −20.0±0.08‰, T'=0.0, T'(5%)=3.8, ν=1; δ^{15}N: +12.2±0.09‰, T'=**10.7**, T'(5%)=3.8, ν=1						
MAMS-21333	s45.74	Human bone, left femur from 1–2-year-old child inhumation in grave 45/74 with five diagnostic pottery vessels	5880±26	−30.7			
MAMS-23166	s45.74	Replicate of MAMS-21333	5870±26	−14.0	−19.0±0.11	14.2±0.13	3.2
	^{14}C age: 5875±19 BP, T'=0.1, T'(5%)=3.8, ν=1						
SUERC-54634	s76.78	Human bone, left femur from 40–50-year-old female inhumation in grave 76/78 with eight diagnostic pottery vessels	5968±33		−20.7±0.2	10.7±0.3	3.2
MAMS-23172	s105.80	Human bone, left femur from 30–40-year-old male inhumation in grave 105/80 with three diagnostic pottery vessels	5927±28	−9.7	−20.0±0.11	12.0±0.13	3.2
SUERC-58100	s105.80	Replicate of MAMS-23172	5858±33		−19.9±0.2	12.0±0.3	3.3
	^{14}C age: 5898±22 BP, T'=2.5, T'(5%)=3.8, ν=1; δ^{13}C: −20.0±0.1‰, T'=0.2, T'(5%)=3.8, ν=1; δ^{15}N: +12.0±0.12‰, T'=0.0, T'(5%)=3.8, ν=1						
MAMS-21334	s106.80	Human bone, right tibia from 15–18-year-old female (?) inhumation in grave 106/80 with six diagnostic pottery vessels	5729±28	−25.7	−20.5±0.11	11.0±0.13	3.3
MAMS-23167	s106.80	Replicate of MAMS-21334	5889±26	−18.1	−20.4±0.11	11.5±0.13	3.2

	^{14}C age: 5816±20 BP, T'=**17.5**, T'(5%)=3.8, ν=1; δ^{13}C: −20.5±0.08‰, T'=0.4, T'(5%)=3.8, ν=1; δ^{15}N: +11.3±0.09‰, T'=**7.4**, T'(5%)=3.8, ν=1						
SUERC-54638	s109.80	Human bone, left femur from 8–10-year-old child inhumation in grave 109/80 with two diagnostic pottery vessels	5960±34		−20.6±0.2	10.3±0.3	3.2
SUERC-58101	s130.80 (i)	Human bone, left femur from 40–60-year-old male inhumation in grave 130/80 with nine diagnostic pottery vessels	5958±33		−19.8±0.2	11.1±0.3	3.2
MAMS-23173	s130.80	Replicate of SUERC-58101	5918±28	−18.5	−20.3±0.11	11.0±0.13	3.2
	^{14}C age: 5935±22 BP, T'=0.9, T'(5%)=3.8, ν=1; δ^{13}C: −20.2±0.1‰, T'=**4.8**, T'(5%)=3.8, ν=1; δ^{15}N: +11.0±0.12‰, T'=0.1, T'(5%)=3.8, ν=1						
	Veszprém-Jutasi út						
SUERC-54639	ve2(i)	Human bone, (?) left femur from 50–70-year-old male inhumation in grave 2 with two diagnostic pottery vessels	5894±33		−19.7±0.2	9.6±0.3	3.2
MAMS-21335-1	ve2(ii)	Replicate of SUERC-54639	5854±21	−18.0	−19.5±0.11	8.9±0.13	3.3
MAMS-21335-2	ve2(ii)	Replicate of SUERC-54639	5785±26				
MAMS-14826	ve2	Replicate of SUERC-54639	5610±33	−34.1			
	^{14}C age: 5804±14 BP, T'=4**7.5**, T'(5%)=7.8, ν=3; δ^{13}C: −19.6±0.1‰, T'=0.8, T'(5%)=3.8, ν=1; δ^{15}N: +9.0±0.12‰, T'=**4.6**, T'(5%)=3.8, ν=1						
MAMS-21336	ve3	Human bone, left femur from 51–60-year-old (?) female inhumation in grave 3 with three diagnostic pottery vessels	5773±22	−21.0	−19.8±0.11	8.8±0.13	3.3
MAMS-23169	ve3	Replicate of MAMS-21336	5794±26	−18.3	−19.9±0.11	9.0±0.13	3.2
	^{14}C age: 5782±17 BP, T'=0.4, T'(5%)=3.8, ν=1; δ^{13}C: −19.9±0.08‰, T'=0.4, T'(5%)=3.8, ν=1; δ^{15}N: +8.9±0.09‰, T'=1.2, T'(5%)=3.8, ν=1						
MAMS-14827	ve4	Human bone from 17–19-year-old juvenile inhumation in grave 4 with one diagnostic pottery vessel	5861±26	−7.8			3.2
SUERC-54640	ve5	Human bone, right femur from 52–60-year-old male inhumation in grave 5 with four diagnostic pottery vessels	5958±31		−19.8±0.2	10.2±0.3	3.2
MAMS-21337	ve7	Human bone, right femur from 47–56-year-old female inhumation in grave 7 with seven diagnostic pottery vessels	5771±21	−21.6	−19.8±0.11	8.8±0.13	3.3

MAMS-23170	ve7	Replicate of MAMS-21337	5831±26	−13.9	−19.8±0.11	8.7±0.13	3.2
	^{14}C age: 5795±17 BP, T'=3.2, T'(5%)=3.8, ν=1; δ^{13}C: −19.8±0.08‰, T'=0.0, T'(5%)=3.8, ν=1; δ^{15}N: +8.8±0.09‰, T'=0.3, T'(5%)=3.8, ν=1						
SUERC-54643	ve15	Human bone, left femur 30–50-year-old male inhumation. No grave goods	5859±33		−19.5±0.2	9.6±0.3	3.2
	Esztergályhorváti						
OxA-6208	es19	Human bone from 38–44-year-old male inhumation in the common grave	5900±75		−19.8±0.3		
OxA-6367	es19	Replicate of OxA-6208	6040±55		−19.5±0.3		
	^{14}C age: 5992±45 BP, T'=2.3, T'(5%)=3.8, ν=1; δ^{13}C: –19.7±0.21‰, T'=0.5, T'(5%)=3.8, ν=1						
OxA-6271	es4A	Human bone from 17–18-year-old male inhumation in the common grave	5970±90		−17.5±0.3		
OxA-6272	es12A	Human bone from 34–40-year-old male inhumation in the common grave.	5990±80		−19.1±0.3		
OxA-6273	es11	Human bone from 40–48-year-old male inhumation in the common grave	5925±65		−19.3±0.3		
OxA-6274	es24C	Human bone from 22–23-year-old male inhumation in the common grave	5730±80		−21.5±0.3		
OxA-6275	es28	Human bone from a mature adult male inhumation in the common grave	5970±70		−20.7±0.3		
Ebelsberg							
VERA-413	ebel1	Human bone from one of two human skeletons (a ?girl of 17 years or an adult of unknown sex) in grave 1 with four pottery vessels	5344±33				
Oberbergern							
VERA-226	ober1	Human bone from inhumation in grave 1 with four pottery vessels	5676±32				
	Reichersdorf						
VERA-410	re1	Human bone from adult male inhumation in a double grave. This skeleton was directly above the female body, but in the opposite orientation. Grave goods: three vessels and fragments	5656±37				

VERA-411	re2	Human bone from adult female inhumation in a double grave. This skeleton was directly below the male body, but in the opposite orientation. Grave goods: four vessels and *Spondylus* beads	5546±36				
	Wetzleinsdorf						
VERA-231	wetz1	Human bone from inhumation in grave 1 with four pottery vessels	5381±31				

Table 3. Baseline isotopic values for food sources used in the FRUITS modelling.

Food source	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**
Cereals	−24.6±0.3	5.0±0.4
Terrestrial animals	−20.3±0.2	6.9±0.2
Freshwater fish	−21.4±0.2	8.7±0.2

Table 4a. FRUITS modelling results for individuals with measured stable isotope values suitable for dietary analysis older than five years of age.

Laboratory number	Grave	Sex	Age	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Cereals (%)	Terrestrial animal (%)	Freshwater fish (%)
Mórágy-Tűzkődomb								
SUERC-48359	m3	Unknown	13–14 years	−20.3±0.2	11.1±0.3	48.2±1.3	49.8±1.3	2.0±2.0
SUERC-48363	m10	Male	38–44 years	−20.0±0.2	11.5±0.3	47.9±1.5	49.7±1.5	2.5±2.4
OxA-28911	m15	Female	62–75 years	−19.8±0.2	9.6±0.3	48.1±1.3	50.0±1.3	1.9±1.8
SUERC-58095	m16	Female	41–45 years	−19.9±0.2	10.8±0.3	47.9±1.4	49.8±1.5	2.3±2.2
OxA-28912 & SUERC-48364	m36	Female	34–38 years	−20.1±0.14	10.8±0.21	48.5±1.0	49.9±1.0	1.6±1.5
OxA-28914	m39	Unknown	13–15 years	−19.7±0.2	10.6±0.3	47.8±1.6	49.8±1.6	2.5±2.4
OxA-28915	m40	Female	53–59 years	−20.0±0.2	10.9±0.3	48.0±1.3	49.8±1.4	2.2±2.0
MAMS-21328 & MAMS-23161	m53	Female	17–18 years	−19.9±0.08	9.5±0.09	48.8±0.8	50.0±0.9	1.2±1.2
SUERC-48365	m56	Female	41–45 years	−20.2±0.2	11.0±0.3	48.1±1.3	49.8±1.4	2.1±2.1
OxA-28916 & SUERC-48366	m59	Female	19–21 years	−19.7±0.14	10.4±0.21	48.3±1.1	49.9±1.2	1.8±1.7
MAMS-21329 & MAMS-23162	m60	Unknown	5–6 years	−20.3±0.08	10.7±0.09	48.9±0.8	50.0±0.8	1.2±1.2
OxA-28917	m62	Unknown	4–5 years	−20.3±0.2	11.3±0.3	48.2±1.3	49.8±1.4	2.1±2.1
SUERC-54631 & MAMS-21330	m66	Male	37–43 years	−20.2±0.1	11.4±0.21	48.7±0.9	49.9±0.9	1.4±1.4
SUERC-48367	m91	Unknown	9–11 years	−20.2±0.2	11.7±0.3	48.0±1.4	49.7±1.4	2.3±2.2
OxA-28918 & SUERC-48368	m93	Female	23–28 years	−20.4±0.14	11.4±0.21	48.6±1.0	49.9±1.0	1.6±1.5
Villánykövesd (Jakabfalusi út mente)								
SUERC-48369	vk12	Unknown	12–13 years	−20.3±0.2	10.0±0.3	48.4±1.1	49.9±1.2	1.8±1.8
SUERC-54644	vk20	Female	23–32 years	−20.0±0.2	10.1±0.3	48.1±1.3	49.9±1.3	2.0±2.0
OxA-28919 & SUERC-48373	vk23	Male	30–37 years	−20.4±0.14	9.3±0.21	48.0±0.8	50.0±0.8	1.2±1.2
Zengővárkony (Igaz-dűlő)								
OxA-289201	zv13	Female	46–55 years	−19.7±0.14	9.2±0.21	48.5±1.1	50.0±1.1	1.5±1.5
OxA-28922 & SUERC-48374	zv14	Female	50–75 years	−20.1±0.14	9.3±0.21	48.7±0.9	50.0±0.9	1.3±1.3
SUERC-48375	zv90	Female	50–56 years	−20.0±0.2	11.0±0.3	48.0±1.4	49.8±1.4	2.3±2.2
SUERC-54648, MAMS-213401 & MAMS-213402	zv91	Male	40–46 years	−19.6±0.1	10.2±0.21	48.4±1.1	49.9±1.1	1.6±1.6
OxA-28923	zv93	Male	28–38 years	−20.2±0.2	11.4±0.3	48.1±1.3	49.8±1.4	2.2±2.1
SUERC-54649 & MAMS-21341	zv108	Male	36–46 years	−19.8±0.1	9.7±0.21	48.6±1.0	50.0±1.0	1.4±1.4
OxA-28924 & SUERC-48376	zv135	Male	40–80 years	−20.0±0.14	11.2±0.21	48.4±1.1	49.9±1.1	1.8±1.7
SUERC-48377	zv272	Male	54–66 years	−19.6±0.2	11.5±0.3	47.4±1.7	49.6±1.8	2.9±2.8
OxA-28925	zv314	Male	36–42 years	−20.4±0.2	9.8±0.3	48.5±1.1	49.9±1.1	1.7±1.7

SUERC-48378	zv326	Male	40–80 years	−19.6±0.2	11.0±0.3	47.6±1.6	49.8±1.7	2.6±2.5
SUERC-48379	zv355	Male	30–59 years	−19.8±0.2	11.6±0.3	47.6±1.6	49.6±1.7	2.8±2.7
Svodín-Busahegy								
MAMS-23164 & MAMS-21331	s7.72	Female?	20–30 years	−20.0±0.08	11.5±0.09	48.6±1.0	49.9±1.0	1.6±1.6
SUERC-54632	s27.73	Male	30–40 years	−20.0±0.2	11.5±0.3	47.9±1.5	49.7±1.5	2.5±2.4
SUERC-58096 & MAMS-23168	s29.73	Female	16–19 years	−20.1±0.1	12.0±0.21	48.5±1.0	49.9±1.0	1.6±1.5
SUERC-54634	s76.78	Female	40–50 years	−20.7±0.2	10.7±0.3	48.5±1.0	49.9±1.1	1.6±1.5
SUERC-58100 & MAMS-23172	s105.80	Male	30–40 years	−20.0±0.1	12.0±0.21	48.5±1.1	49.8±1.1	1.7±1.7
MAMS-21334 & MAMS-23167	s106.80	Female?	15–18 years	−20.5±0.08	11.3±0.09	49.0±0.7	49.9±0.7	1.1±1.1
SUERC-54638	s109.80	Unknow n	8–10 years	−20.6±0.2	10.3±0.3	48.5±1.0	49.9±1.0	1.6±1.5
SUERC-58101 & MAMS-23173	s130.80	Male	40–60 years	−20.2±0.1	11.0±0.21	48.7±0.9	49.9±0.9	1.4±1.4
Veszprém-Jutasi út								
MAMS-213351, MAMS-213352, MAMS-14826 & SUERC-54639	ve2	Male	50–70 years	−19.6±0.1	9.0±0.21	48.6±1.0	50.0±1.0	1.4±1.3
MAMS-21336 & MAMS-23169	ve3	Female?	51–60 years	−19.9±0.08	8.9±0.09	48.9±0.8	50.0±0.8	1.1±1.1
SUERC-54640	ve5	Male	52–60 years	−19.8±0.2	10.2±0.3	48.0±1.4	49.9±1.5	2.2±2.1
MAMS-21337 & MAMS-23170	ve7	Female	47–56 years	−19.8±0.08	8.8±0.09	48.8±0.8	50.0±0.8	1.2±1.2
SUERC-54643	ve15	Male	30–50 years	−19.5±0.2	9.6±0.3	47.9±1.4	49.9±1.5	2.2±2.1

Table 4b. Estimates of proportional diet for the individuals without isotopic values. The proportional diet estimates provided for these burials are taken from the FRUITS estimates in Table 4a. For Veszprém-Jutasi út, Ve4, it is the average of the FRUITS results for the site. The proportional diet estimates for Friebritz and Esztergályhorváti are the mean of proportional diet estimates over all sites.

Site	**Grave**	**Laboratory number**	**Age**	**Sex**	**Cereals (%)**	**Terrestrial animal (%)**	**Freshwater fish (%)**
Veszprém-Jutasi út	ve4	MAMS-14827	17–19 years	Unknown	48.3±1.1	50.0±1.2	1.7±1.7
Friebritz	fr130	VERA−1976	20–25 years	Male	48.3±1.2	49.9±1.2	1.8±1.8
Friebritz	fr134	VERA−1977	50–60 years	Male	48.3±1.2	49.9±1.2	1.8±1.8
Friebritz	fr135	VERA−1978	12–13 years	Unknown	48.3±1.2	49.9±1.2	1.8±1.8
Esztergályhorváti	es4A	OxA−6271	17–18 years	Male	48.3±1.2	49.9±1.2	1.8±1.8
Esztergályhorváti	es11	OxA−6273	40–48 years	Male	48.3±1.2	49.9±1.2	1.8±1.8
Esztergályhorváti	es12A	OxA−6272	34–40 years	Male	48.3±1.2	49.9±1.2	1.8±1.8
Esztergályhorváti	es19	OxA-6208 & OxA-6367	38–44 years	Male	48.3±1.2	49.9±1.2	1.8±1.8

Esztergályhorváti	es28	OxA−6275	Mature adult	Male	48.3±1.2	49.9±1.2	1.8±1.8

Table 5. Baseline isotopic values for food sources used in the breastfeeding FRUITS modelling.

Food source	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**
Breastmilk proxy	−20.1±0.1	10.9±0.2
Cereals	−24.6±0.3	5.0±0.4

Table 6. FRUITS modelling results for infants with measured stable isotope values suitable for dietary analysis, who may have ingested a proportion of breastmilk in their diets.

Laboratory number	**Grave number**	**Age**	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**	**Breastmilk (%)**	**Cereals (%)**
Mórágy-Tűzkődomb						
OxA-28913	m37	2–5 years	−19.9±0.2	12.8±0.3	93.1±5.0	6.9±5.0
Friebritz						
SUERC-54630	fr131	16–24 months	−20.2±0.2	12.1±0.3	87.3±6.8	12.7±6.8
Svodín-Busahegy						
MAMS-21332 & MAMS-23165	s42.74	3–5 years	−20.0±0.08	12.2±0.09	89.6±6.1	10.4±6.1
SUERC-54633	s37.74	3–4 years	−20.0±0.2	13.0±0.3	93.3±5.0	6.7±5.0
MAMS-23166	s45.74	1–2 years	−19.0±0.11	14.2±0.21	97.8±2.0	2.2±2.0

Table 7. Highest Posterior Density intervals (at 95% probability unless otherwise stated) for each burial that has been sampled for radiocarbon dating, based on the alternative chronological models defined in Figs 4–7, 11–12 and 14. Those for Alsónyék subsites 10B and 11 are derived from the models defined by OSZTÁS et al. 2016b, figs 12–13 and 15–16. Unmodelled calibrated dates have been calculated using the probability method (STUIVER / REIMER 1993) and are given in normal type.

Parameter	**Figs 4–7 & OSZTÁS et al. (2016b, figs 12–13 and 15–16)**		**Figs 11–12**	**Fig. 14**	**Calibrated date**
	Alsónyék-Bátaszék: subsite 10B				
an398: OxA-27486	*4710–4665 cal BC*		*4685–4510 cal BC*	-	4615–4445 cal BC
an792: SUERC-53383	*4715–4675 cal BC*		*4765–4750 cal BC (1%)* or *4745–4585 cal BC (94%)*	-	4770–4755 cal BC (1%) or 4730–4550 cal BC (94%)
an796: OxA-27487	*4720–4680 cal BC*		*4780–4685 cal BC*	-	4830–4685 cal BC
an811: OxA-27640	*4715–4675 cal BC*		*4765–4605 cal BC*	-	4785–4590 cal BC
an813: OxA-27488	*4715–4680 cal BC*		*4780–4665 cal BC (93%)* or *4635–4620 cal BC (2%)*	-	4805–4665 cal BC (92%) or 4640–4615 cal BC (3%)
an818: OxA-27641	*4710–4675 cal BC*		-	*4765–4640 cal BC*	4795–4605 cal BC
an828: OxA-27485	*4710–4670 cal BC*		*4765–4600 cal BC*	-	4780–4580 cal BC
an853: SUERC-53322	*4725–4680 cal BC*		*4780–4715 cal BC*	-	4910–4725 cal BC
an1008: OxA-27481	*4715–4675 cal BC*		*4775–4650 cal BC (90%)* or *4640–4615 cal BC (5%)*	-	4795–4610 cal BC
an1473: SUERC-53323	*4730–4675 cal BC*		*4780–4665 cal BC (93%)* or *4640–4615 cal BC (2%)*	-	4800–4650 cal BC (92%) or 4640–4615 cal BC (3%)
an3020: OxA-29025	*4720–4665 cal BC*		*4765–4595 cal BC*	-	4780–4580 cal BC (94%) or 4565–4555 cal BC (1%)
an3089: OxA-X-2508-50	*4720–4665 cal BC*		*4765–4590 cal BC*	-	4770–4750 cal BC (3%) or 4745–4550 cal BC (92%)
an4027: SUERC-53382	*4710–4675 cal BC*		*4745–4580 cal BC*	-	4730–4550 cal BC
	Alsónyék-Bátaszék: subsite 11				
az1669: SUERC-53340	*4780–4610 cal BC*		*4770–4615 cal BC*	-	4790–4610 cal BC
az228: OxA-27460	*4780–4660 cal BC*		*4775–4615 cal BC*	-	4795–4605 cal BC
az263: OxA-27576	*4725–4600 cal BC*		*4730–4555 cal BC*	-	4730–4535 cal BC
az272: OxA-27461	*4720–4585 cal BC*		*4705–4535 cal BC*	-	4690–4485 cal BC (93%) or 4480–4460 cal BC (2%)
az319: OxA-27577	*4765–4650 cal BC (91%)* or *4640–4615 cal BC (4%)*		*4780–4650 cal BC (92%)* or *4640–4615 cal BC (3%)*	-	4830–4650 cal BC (91%) or 4640–4615 cal BC (4%)

az333	*4725–4585 cal BC*		*4725–4600 cal BC*	-	4725–4580 cal BC
az337: OxA-27528	*4730–4600 cal BC*		*4745–4565 cal BC*	-	4770–4750 cal BC (1%) or 4745–4735 cal BC (1%) or 4730–4540 cal BC (93%)
az673: OxA-27473	*4765–4675 cal BC*		*4780–4650 cal BC (92%)* or *4640–4615 cal BC (3%)*	-	4800–4650 cal BC (91%) or 4640–4615 cal BC (4%)
az699: SUERC-53326	*4765–4680 cal BC*		*4780–4670 cal BC (94%)* or *4635–4620 cal BC (1%)*	-	4825–4815 cal BC (1%) or 4800–4665 cal BC (92%) or 4640–4615 cal BC (2%)
az743: SUERC-53335	*4790–4655 cal BC (92%)* or *4640–4615 cal BC (3%)*		*4780–4665 cal BC (93%)* or *4635–4620 cal BC (2%)*	-	4800–4665 cal BC (92%) or 4640–4615 cal BC (3%)
az1190: SUERC-53331	*4765–4690 cal BC*		*4780–4700 cal BC*	-	4840–4705 cal BC
az1191: OxA-27475	*4765–4685 cal BC*		*4780–4675 cal BC (94%)* or *4635–4620 cal BC (1%)*	-	4830–4810 cal BC (1%) or 4805–4680 cal BC (92%) or 4635–4615 cal BC (2%)
az1235: OxA-27529	*4745–4550 cal BC*		*4765–4750 cal BC (1%)* or *4745–4575 cal BC (94%)*	-	4770–4750 cal BC (2%) or 4730–4545 cal BC (93%)
az1320: SUERC-53336	*4800–4705 cal BC*		*4775–4710 cal BC*	-	4850–4710 cal BC
az1391	*4790–4695 cal BC*		*4780–4700 cal BC*	-	4830–4705 cal BC
az1967: OxA-27531	*4770–4695 cal BC*		*4780–4710 cal BC*	-	4895–4865 cal BC (4%) or 4850–4715 cal BC (91%)
az2330: OxA-29049	*4785–4610 cal BC*		*4775–4650 cal BC (90%)* or *4640–4615 cal BC (5%)*	-	4795–4650 cal BC (88%) or 4645–4610 cal BC (7%)
	Ebelsberg				
ebel1: VERA-413	-		-	-	-
Esztergályhorvati					
Esztergályhorvati	*4910–4785 cal BC*		*4935–4805 cal BC*	*4895–4770 cal BC*	4935–4790 cal BC
	Friebritz-Süd				
fr130: VERA-1976	*4830–4705 cal BC*		*4830–4750 cal BC*	*4830–4740 cal BC*	4835–4700 cal BC
fr131: SUERC-54630	*4895–4765 cal BC (91%)* or *4760–4725 cal BC (4%)*		*4860–4780 cal BC*	-	4995–4825 cal BC (94%) or 4815–4805 cal BC (1%)
fr134: VERA-1977	*4795–4650 cal BC (93%)* or *4640–4620 cal BC (2%)*		*4800–4750 cal BC*	*4800–4735 cal BC*	4785–4590 cal BC
fr135: VERA-1978	*4800–4670 cal BC*		-	*4800–4735 cal BC*	4795–4650 cal BC (89%) or 4640–4615 cal BC (6%)
	Györe (Bocok-föld)				

gy13	4790–4685 cal BC		4835–4755 cal BC	4840–4740 cal BC	4880–4870 cal BC (1%) or 4850–4705 cal BC (94%)
	Mórágy-Tűzkődomb				
m3: SUERC-48359	4730–4555 cal BC		4765–4585 cal BC	4650–4560 cal BC	4770–4750 cal BC (2%) or 4745–4550 cal BC (93%)
m10: SUERC-48363	4785–4665 cal BC (92%) or 4640–4615 cal BC (3%)		4780–4680 cal BC	4775–4675 cal BC	4835–4680 cal BC
m15: OxA-28911	4695–4540 cal BC		4705–4555 cal BC	4710–4625 cal BC	4705–4530 cal BC
m16	4655–4640 cal BC (1%) or 4620–4510 cal BC (94%)		4685–4635 cal BC (12%) or 4620–4515 cal BC (83%)	4735–4625 cal BC (94%) or 4615–4595 cal BC (1%)	4610–4485 cal BC (94%) or 4480–4465 cal BC (1%)
m36	4680–4635 cal BC (11%) or 4620–4520 cal BC (84%)		4685–4630 cal BC (26%) or 4625–4530 cal BC (69%)	4695–4625 cal BC (94%) or 4615–4595 cal BC (1%)	4680–4635 cal BC (5%) or 4620–4490 cal BC (90%)
m37: OxA-28913	4705–4545 cal BC		4710–4560 cal BC	4650–4555 cal BC	4710–4540 cal BC
m39: OxA-28914	4695–4545 cal BC		4710–4560 cal BC	4650–4555 cal BC	4705–4540 cal BC
m40: OxA-28915	4685–4630 cal BC (19%) or 4625–4525 cal BC (76%)			4650–4545 cal BC	4685–4630 cal BC (12%) or 4625–4485 cal BC (83%)
m53	4685–4630 cal BC (29%) or 4625–4545 cal BC (66%)		4690–4550 cal BC	4695–4625 cal BC	4685–4540 cal BC
m56: SUERC-48365	4710–4550 cal BC		4720–4565 cal BC	4720–4625 cal BC	4715–4545 cal BC
m59: OxA-28916	4720–4555 cal BC		4720–4585 cal BC	4720–4625 cal BC	4715–4575 cal BC (93%) or 4570–4555 cal BC (2%)
m60	4670–4635 cal BC (4%) or 4620–4515 cal BC (91%)		4685–4635 cal BC (16%) or 4620–4525 cal BC (79%)	4650–4540 cal BC	4650–4640 cal BC (1%) or 4620–4490 cal BC (94%)
m62: OxA-28917	4705–4550 cal BC		4715–4565 cal BC	4650–4555 cal BC	4705–4545 cal BC
m66	4775–4680 cal BC		4770–4685 cal BC	4765–4685 cal BC	4785–4685 cal BC
m91: SUERC-48367	4770–4595 cal BC		4770–4615 cal BC	4760–4635 cal BC	4790–4600 cal BC
m93	4775–4685 cal BC		4775–4700 cal BC	4765–4690 cal BC	4800–4700 cal BC
	Oberbergen				
ober1: VERA-226	-		-	-	-
	Reichersdorf				
re1: VERA-410	-		-	-	-
re2: VERA-411	-		-	-	-
	Svodín-Busahegy				
s7.72	4845–4760 cal BC		4840–4765 cal BC		4845–4725 cal BC
s27.73: SUERC-54632	4870–4775 cal BC		4855–4775 cal BC	4900–4765 cal BC	4955–4785 cal BC

s29.73	*4830–4730 cal BC*		*4825–4750 cal BC*		4825–4815 cal BC (2%) or 4805–4715 cal BC (93%)
s37.74: SUERC-54633	*4870–4780 cal BC*		*4860–4775 cal BC*		5000–4825 cal BC (93%) or 4815–4800 cal BC (2%)
s42.74	*4835–4740 cal BC*		*4830–4760 cal BC*		4835–4725 cal BC
s45.74	*4805–4720 cal BC*		*4800–4750 cal BC*		4795–4705 cal BC
s76.78: SUERC-54634	*4870–4760 cal BC*				4945–4770 cal BC
s105.80	*4830–4730 cal BC*		*4830–4750 cal BC*		4830–4810 cal BC (5%) or 4805–4715 cal BC (90%)
MAMS-23167[9]	*4830–4730 cal BC*		*4825–4750 cal BC*		4830–4705 cal BC
s109.80: SUERC-54638	*4855–4745 cal BC*		*4780–4715 cal BC*		4940–4765 cal BC (93%) or 4760–4740 cal BC (2%)
s130.80	*4845–4760 cal BC (94%)* or *4755–4745 cal BC (1%)*		*4840–4765 cal BC*		4885–4865 cal BC (2%) or 4850–4725 cal BC (93%)
	Veszprém-Jutasi út				
ve2	*4780–4680 cal BC*		*4770–4680 cal BC*	*4645–4565 cal BC*	4780–4680 cal BC (94%) or 4630–4620 cal BC (1%)
ve3	*4710–4600 cal BC*		*4710–4585 cal BC*	*4705–4625 cal BC*	4700–4550 cal BC
ve4: MAMS-14827	*4790–4685 cal BC*				4795–4685 cal BC
ve5: SUERC-54640	*4845–4715 cal BC*		*4845–4765 cal BC*	*4780–4690 cal BC*	4940–4765 cal BC (93%) or 4755–4740 cal BC (2%)
ve7	*4715–4610 cal BC*		*4715–4600 cal BC*	*4655–4555 cal BC*	4715–4585 cal BC
	Villánykövesd (Jakabfalusi út mente)				
vk12: SUERC-48369	*4770–4750 cal BC (2%)* or *4745–4585 cal BC (93%)*		*4720–4565 cal BC*	*4720–4625 cal BC*	4715–4545 cal BC
vk20: SUERC-54644	*4790–4685 cal BC*		*4775–4690 cal BC*		4830–4810 cal BC (2%) or 4805–4690 cal BC (93%)
vk23	*4785–4690 cal BC*		*4770–4690 cal BC*	*4765–4685 cal BC*	4790–4690 cal BC
	Wetzleinsdorf				
wetz1: VERA-231	-		-	-	-
	Zengővárkony (Igaz-dűlő)				
zv13	*4685–4630 cal BC (19%)* or *4625–4530 cal BC (76%)*		*4685–4540 cal BC*	*4695–4625 cal BC (94%)* or *4615–4600 cal BC (1%)*	4680–4635 cal BC (10%) or 4620–4500 cal BC (85%)
zv14	*4790–4685 cal BC*		*4775–4685 cal BC*	*4765–4685 cal BC*	4790–4685 cal BC

[9] This parameter provides the most accurate date estimate for grave s106.80 at Svodín.

zv90: SUERC-48375	*4845–4720 cal BC*		*4845–4760 cal BC*	*4775–4705 cal BC*	4910–4720 cal BC
zv91	4680–*4635 cal BC (14%)* or *4620–4540 cal BC (81%)*		*4685–4630 cal BC (25%)* or *4620–4540 cal BC (70%)*		4680–4635 cal BC (9%) or 4620–4525 cal BC (86%)
zv93: OxA-28923	*4800–4680 cal BC (94%)* or *4635–4620 cal BC (1%)*		*4825–4815 cal BC (1%)* or *4810–4750 cal BC (94%)*	*4770–4675 cal BC*	4825–4815 cal BC (1%) or 4805–4680 cal BC (93%) or 4635–4620 cal BC (1%)
zv108	*4685–4630 cal BC (25%)* or *4625–4540 cal BC (70%)*		*4685–4545 cal BC*	*4695–4625 cal BC*	4685–4630 cal BC (20%) or 4625–4530 cal BC (75%)
zv135	*4800–4705 cal BC*		-	*4770–4700 cal BC*	4825–4815 cal BC (1%) or 4800–4705 cal BC (94%)
zv272: SUERC-48377	*4835–4705 cal BC*		*4780–4695 cal BC*	-	4845–4695 cal BC
zv314: OxA-28925	*4715–4555 cal BC*		*4720–4570 cal BC*	*4720–4625 cal BC*	4710–4550 cal BC
zv326: SUERC-48378	*4685–4630 cal BC (17%)* or *4625–4510 cal BC (78%)*		*4690–4520 cal BC*	*4710–4620 cal BC*	4670–4635 cal BC (3%) or 4620–4455 cal BC (92%)
zv355: SUERC-48379	*4855–4725 cal BC*		*4850–4770 cal BC*	*4895–4755 cal BC*	4960–4770 cal BC

Supplementary Figures

Supplementary Figure 1. The 121 Lengyel pot types identified by István Zalai-Gaál.

Supplementary Fig. 2. Seriated table of data from correspondence analysis of Lengyel funerary ceramics (Fig. 2a), showing phase boundaries (solid lines) and further tentative sub-divisions (dotted lines).

Supplementary Fig. 3. Seriated table of data from the revised partition suggested in this paper of the alternative correspondence analysis of Lengyel funerary ceramics (DIACONESCU 2014a, fig. 9). The original phasing proposed by DIACONESCU (2014a, 23–4 and figs 10 and 12) is shown in colour on the right-hand side of the diagram (pink, formative; yellow, Ia; mauve, Ib; red, IIa; green, IIb). The boundaries between the alternative phase partitions suggested here are indicated by the horizontal lines.

Supplementary Table captions

Supplementary Table 1. Descriptions of the 121 types illustrated in Supplementary Figure 1.

Supplementary Table 2. The original corrected incidence matrix based on data from István Zalai-Gaál, with Lengyel graves in rows and pottery vessel types in columns (Incidence matrix 1).

Supplementary Table 3. The amended incidence matrix, with Lengyel graves in rows and pottery vessel types in columns, which produces the seriation shown in Figure 2 and Supplementary Fig. 2 (Sorted Incidence matrix 2).

Supplementary Table 4. Greater_Lengyel_sites.oxcal.

Supplementary Table 5. Lengyel_seriation_outlier_3_phase.oxcal.

Supplementary Table 6. Greater_Lengyel_Diaconescu_outlier_3_phase.oxcal.