The uncertain frontier: risks, reversals and interactions in the initial establishment of Neolithic settlement

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ABSTRACT – *Long archaeological debate on the process of Neolithisation across Europe has been resolved at a broad level, thanks to aDNA and other scientific investigations, in favour of significant migrations virtually everywhere. This development has coincided with the establishment of more robust and generally more precise chronologies, and in the long run the historical process of change brought by Neolithic migrants was irreversible. However, the emergent big picture can and should still be examined in much further detail. Some significant implications for the understanding of mobility and migration have been explored, but there is plenty of scope for better integration of archaeological and scientific, especially archaeogenetic, investigations. This can reveal important dimensions of the process of colonisation and the initial establishment of Neolithic settlement, which appears often to have been small-scale at the outset; prone to adjustment, experiment, reversal and even failure; and open to contacts with indigenous people. We support these claims with a series of brief case studies principally from the northern Balkans, the Carpathian basin and northern central Europe to build a simple model of frontier conditions which could have implications for the study of initial Neolithisation across Europe as a whole.*

KEY WORDS – *Neolithisation; aDNA; migration; initial establishment; scale; risk; reversal; failure*

Negotova meja: tveganja, preobrati in interakcije ob ustanavljanju prvih neolitskih neselbin

IZVLEČEK – *Dolga arheološka razprava o procesu neolitizacije Evrope se je, zahvaljujoč raziskavam stare DNK in drugim znanstvenim raziskavam, končala v korist velikih migracij. Vzporedno so bile vzpostavljene bolj robustne in na splošno bolj natančne kronologije. Dolgoročno gledano, je zgodovinski proces sprememb, ki so jih prinesli neolitski migranti, nepovraten. Kljub vsemu se lahko in mora nastajajoča 'velika slika' podrobneje preučiti. Nekatere ključne implikacije za razumevanje mobilnosti in migracij so bile sicer raziskane, vendar pa je še veliko možnosti za boljšo povezavo arheoloških in znanstvenih, predvsem arheogenetskih raziskav. Te lahko razkrijejo nove vidike procesa kolonizacije in ustanavljanja neolitskih naselbin, za katero se zdi, da je bila na začetku majhna; nagnjena k prilagajanju, eksperimentiranju, preobratu in celo propadu; in odprta za stike z domorodnimi skupnostmi. Te možnosti dokazujemo z nizom kratkih študijskih primerov s severnega Balkana, Karpatskega bazena in severne Srednje Evrope. Z njimi želimo oblikovati preprost model 'mejnih razmer', ki bi jih lahko uporabljali pri preučevanju začetkov neolitizacije Evrope.*

KLJUČNE BESEDE – *neolitizacija; stara DNK; migracija; prve ustanovitve; velikost; tveganje; preobrat; propad*

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Neolithisation across Europe: the current big picture

The long archaeological debate about the process of Neolithisation across Europe, which goes back to the later nineteenth century and even earlier, appears now at one level finally to have been settled. The big question has been whether migrants and colonisers were responsible for the introduction into Europe of a new way of life involving agriculture and a more settled existence than practised by hunter-gatherers, or whether this transition was in the hands of indigenous European hunter-gatherers themselves, using knowledge of new techniques and practices diffused from centres of innovation in the Near East. Numerous aDNA studies particularly over the last nine or ten years (froma a much longer list, see *Brandt* et al*. 2014; Szécsényi-Nagy* et al*. 2014; 2015; in press; Lipson* et al. *2017; Reich 2018; Brace* et al. *2019; Nikitin* et al. *2019; Rivollat* et al. *2020; Marchi* et al. *2022; Koptekin* et al. *2024*), supported by even earlier isotopic investigations (for example, *Price* et al. *2001; Schulting, Richards 2002; Schulting 2008*), have at last settled the major outlines of Neolithisation process. Virtually everywhere across Europe, including in regions such as southern Scandinavia (*Allentoft 2024a; 2024b;* and see the references cited above) where previously there were very respectable archaeological arguments in favour of a significant involvement for indigenous people if not indeed a leading role, it now appears that incomers ultimately of Near Eastern genetic ancestry were principally responsible for the introduction of the new way of life.

This decisive shift has broadly coincided with the establishment of a more robust and often more precise chronological framework for early Neolithic sequences than previously available. Many more radiocarbon dates have been achieved, to be interrogated now in many regions in a Bayesian chronological framework, with much more precise regional sequences emerging (*e.g., Jakucs* et al. *2016; Whittle* et al. *2011; Porčić 2024*). That has served to lower some previous informal date estimates for the start of Neolithic activity in given regions, such as the coasts of the west Mediterranean (*Cruz-Berrocal 2012; Szécsényi-Nagy* et al. *2017; Revelles* et al. *2018; Alt* et al. *2020; Leppard 2021*) or central Europe at the time of the earliest LBK (*Jakucs* et al. *2016; Bánffy* et al. *2018;* for a differing view, see *Strien 2017; 2018*), and to unravel and extend a potentially lengthy process in the cases of Britain and Ireland, where debate had previously assumed a single point of change (*Whittle* et al. *2011; McClatchie, Potito 2020; Smyth* et al. *2020*). While there is still plenty of regional detail to be sorted, one can now fairly claim a generally solid and plausible timeframe for the narratives of migration and change (*e.g., Shennan 2018; Whittle 2018; Hofmann* et al. *2024*).

These key twin developments also sit well generally with the previous assertion made by John Robb (*2013*) that the process of Neolithisation across Europe was irreversible; region by region, once Neolithic practices had been introduced, there was in the long run no going back to earlier ways.

By all these means, our understanding of the beginnings of the Neolithic period across Europe has been transformed within the last generation of research, or at an even tighter timescale within the last decade or so. This has served to reset debate in many fundamental ways but the rapidity with which data and interpretations have changed may also explain why, so far, there has been comparatively little further detailed discussion about the implications of these many shifts of perspective. On the one hand, there is a tendency to assume a single, broad or major initial migration in any given region. In contrast, it is clear from wider, comparative discussion of concepts of frontiers, borders and boundaries (see for example, *Green, Perlman 1985; Kopytoff 1987; Parker 2006; Feuer 2016*), that frontiers can often be fluid, unstable and porous. On the other hand, there has been so far rather limited – though very welcome – discussion of how the archaeogenetic data contribute to new understandings of migration and mobility in general and in particular cultural contexts such as the LBK and elsewhere (*Hofmann 2016; 2020; Hofmann* et al. *2022; 2024; Porčić 2024*). We assert that, by contrast, there is still considerable scope for further and better integration of archaeological and archaeogenetic results and for the continuing interrogation of the specific fine detail, region by region, of the emergent big picture described above. We argue that alongside or complementing this big picture this may reveal much about the nature of colonisation and the varying conditions of the initial establishment of Neolithic settlement across Europe. We offer selected brief case studies from the frontiers, principally from the north Balkans and central Europe, and cover further comparative examples from other regions of Europe in our discussion. These may variously illustrate themes of local adjustment, experiment, reversal and even failure, as well as contacts with indigenous people, and they may all help, in our view, to

show something of the character and scale of initial Neolithic activity (Fig. 1).

The debate reset: some case studies from the frontiers

Impermanent Körös settlement on the east bank of the Danube

There is reasonable information now about the spread of Neolithic people, things and practices through the Balkans though of course more excavation and more, robust dating would continue to be welcome. A plausible model is the establishment of settlement in the central Balkans by the later seventh millennium cal BC, represented principally by the Starčevo culture, and then in the northern Balkans and into the Carpathian basin, including on to the Great Hungarian Plain and Transdanubia, by the turn of the millennium and into the early sixth millennium cal BC (*Whittle* et al. *2002; Whittle 2007; Oross, Siklósi 2012; Blagojević* et al. *2017; Shennan 2018; Porčić* et al. *2020; 2021*). The settlement at Alsónyék in southernmost Transdanubia represents a Starčevo strand (*Oross* et al. *2016*), while Körös culture sites dominate the Alföld, with Criş sites in Romania (*Kutzián 1944; Kalicz*, *Raczky 1980-1981; Raczky 1980; Comşa 1959*). While the data are far from perfect, the evidence we have is generally compatible with a picture of steady spread from south to north: in Transdanubia up to Lake Balaton (*Kalicz 1990; Bánffy 2004*), and on the Great Hungarian Plain, as far as up to near its northern limits (*Domboróczki 2010.Fig. 11; Mester, Rácz 2010*). Overall, many of the landscapes with Körös culture sites appear busy and even populous, though well-dated individual sites such as Ecsegfalva 23 are still few and far between (*Whittle 2007;* see *Oross, Siklósi 2012* for a wider summary of the dating of Körös sites), and individual locations may have seen plenty of coming and going; but it remains hard to pin down a sense of settlement density at any one particular time. In Transdanubia, current research suggests that Alsónyék and a few settlements in its immediate vicinity on the south-east edge of the region

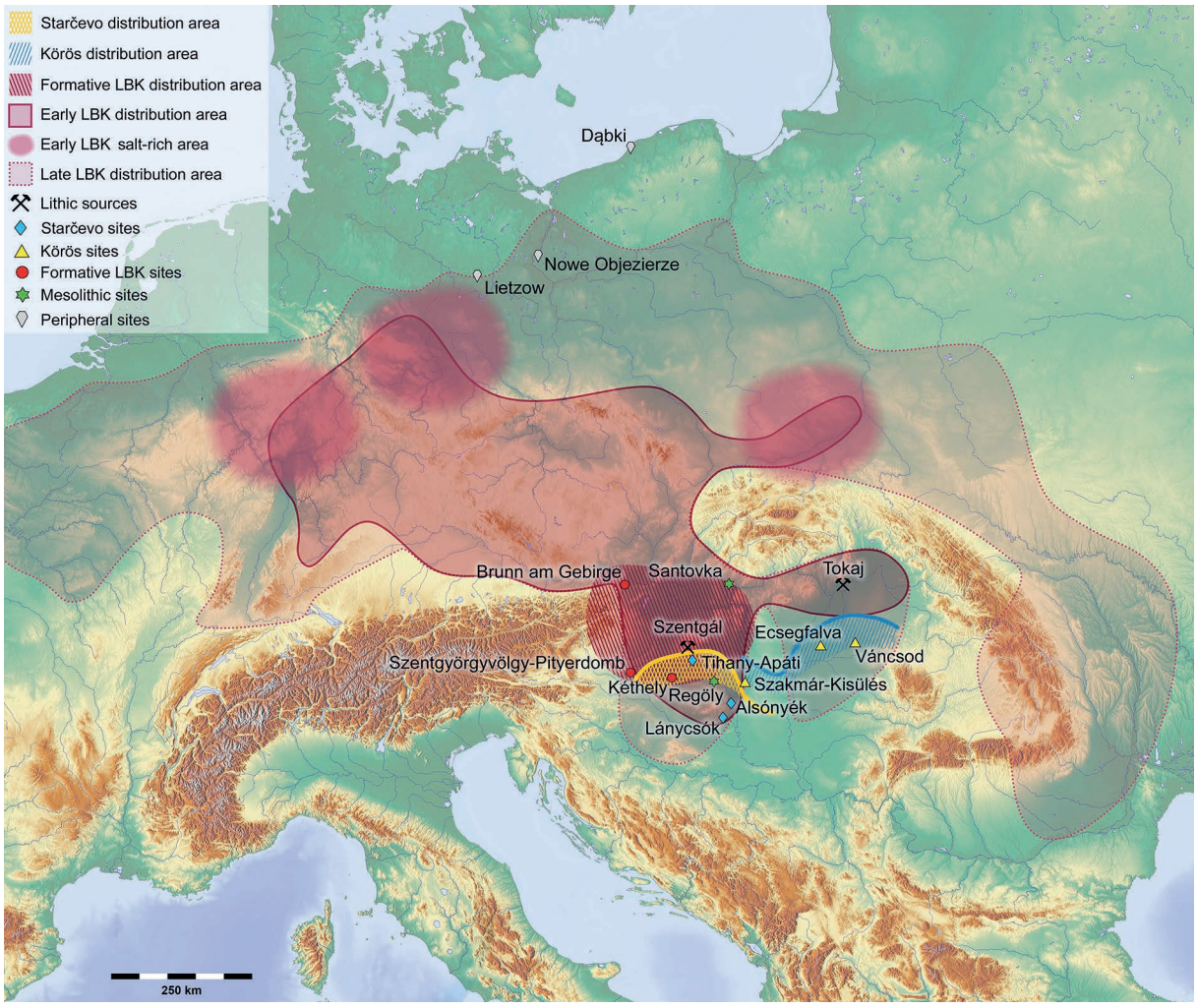

Fig. 1. Map of the core case study areas and key sites discussed in the paper.

stood out for their size and comparative longevity, while other sites further north may have been more scattered, smaller and with less abundant remains, and of short duration (*Kalicz* et al. *1998; Bánffy 2004*).

In this broader context, the example of Körös settlement on the east bank of the Danube can be particularly informative. Research on Körös settlement on the Great Hungarian Plain, east of the Tisza, had started in earnest in the 1930s (*Banner 1937; Kutzián 1944*), though the investigation of a Starčevo presence in south-west Hungary took much longer to get going (*Kalicz 1990*). The subsequent emergence of a notable Körös settlement niche close to the Starčevo sites along the east bank of the Danube came as an absolute surprise that suddenly filled a large blank spot in the Neolithic landscape (*Bánffy 2013.157*). After some sporadic mentions of Körös potsherds in field walking reports, a small excavation at Szakmár took place in 1975, led by Ida Kutzián. Apart from a short report (*Kutzián 1977*), the site and its finds remained unpublished until a later synthesis and two further books dedicated to one of the most distinctive finds (*Bánffy 2013; 2019*). A single, conventional date is available from the excavated site (*Bognár-Kutzián, Csongor 1987; Oross, Siklósi 2012.150*). Precise dating for these settlements remains to be established. Based on the finds compared with well-dated parallels (*Whittle* et al. *2002; Oross, Siklósi 2012*), however, the settlement niche could fall between 5800–5700 and 5650 cal BC (*Bánffy 2012*). Crucially for our wider argument, by the time of the late Körös period, none of the settlements seems to have been inhabited, and there was a gap in settlement approximately four centuries long until Transdanubian LBK groups occupied some of the small elevations in the alluvial area (*Kustár 2013*).

The niche in question, with some 50 known sites, is located where palaeochannels of the Danube led from the Tisza to the Danube: a green corridor for movement north-westwards. In the presumably periodically inundated floodplain, with potentially favourable conditions for garden or other cultivation, the inhabitants probably moved around seeking the drier spots and avoiding temporarily submerged areas; such local instability may explain the high number of sites found within a small area of some 25km^2. A plausible scenario of the outcome is the return of this Danubian Körös group to where it came from: back again to the core distribution region on the Tisza. Overall, the emergence and decline of Körös settlement along the banks of the Danube could be seen as a story of trial and error or failure at the onset of the Neolithic. We do not know the detailed conditions of such a trajectory, but they could be to do with scale and connectivity, neither being sufficient for settlement to be maintained on a sustained basis.

The evidence also highlights an intriguing lack of interaction between the Körös and Starčevo communities in the Sárköz region, despite their close proximity, not more than 15–18km apart in the Danube wetlands. This lack of connection between the Körös and Starčevo communities in the Sárköz region is unexpected (*Bánffy 2013*). While both groups shared similar cultural and economic backgrounds, the differences between the Körös and Starčevo populations may have been expressed more through different practices (*cf. Anthony 2007.104–105*) than in their rather similar material culture. Whatever the reason that the Körös and Starčevo groups avoided contact and cooperation, this circumstance may have contributed to the Sárköz Körös group falling back to the southern Alföld.

Possible long-range but impermanent pioneering in north-west Poland

An early analysis of frontier conditions and the spread of the Neolithic phenomenon across Europe, suggested a 'wave of advance', progressing outward overall but consisting of local movement in all directions (*Ammerman, Cavalli-Sforza 1971; 1973; 1984; cf. Clark 1965; Porčić 2024.3–4*). Subsequently, better dating indicated a less even process, amongst which targeted or leapfrog colonisation was suggested (*van Andel, Runnels 1995*). That helps to give a more nuanced view of some frontier conditions, though it has to stay within the range of chronological and geographical probabilities. It has been invoked in the interpretation of the occupation of Brunn in eastern Austria, where the authors have proposed a leapfrog jump from Starčevo communities some 300km to the south, avoiding Transdanubia (*Stadler, Kotova 2019;* but see *Bánffy 2021*). Leapfrog colonisation could also help to make sense of some of the distribution of earliest LBK communities across central and western Europe, often with considerable gaps between known sites (*Stäuble 2005; Strien 2018*).

Recently, a possible extreme case of long-range pioneering has been proposed (*Czerniak* et al. *2023*), which raises both further questions about frontier conditions and interpretive challenges in equal measure. The scene is north-west Poland in the lower Oder valley, at the very edge of the overall LBK distribution area, and

some 90km from the Baltic. The authors present the results of a purely environmental investigation, from a pollen study of a lake core near Nowe Objezierze, focusing on an estimated 140-year-long episode of clearance, cultivation and claimed animal husbandry (their Phase II), from the early 57th century to the mid-56th century cal BC. There follows a hiatus of some 200 years, preceded by signs of climatic downturn at the end of Phase II, and then a second phase (their Phase IV), some 300 years in length, of established clearance and cultivation, starting in the later 54th century cal BC. Although there is a cluster of known LBK sites on either side of the lower Oder (*Czerniak* et al. *2023. Fig. 2*), and in the vicinity one established, late LBK longhouse has been excavated, no archaeological sites contemporary with the Phase II episode have yet been found.

The Phase II episode is defined by increased visibility of Chenopodiaceae, *Artemisia*, *Urtica* and *Plantago major, Rumex acetellum* and *Viola arvensis*; the presence of *Triticum*- and *Hordeum*-type cereal pollen; and an initial decline in the values of oak, hazel and alder and subsequently a marked decrease in pine. There are also signs of burning. This is all taken to represent clearance, cultivation of cereals and perhaps animal husbandry.

Lech Czerniak *et al.* (*2023*) propose that this episode was the result of long-range migration by Neolithic people, not in circumstances of demographic pressure in their area of origin (*cf. Shennan* et al. *2013; Silva, Vander Linden 2017*) – the available evidence for Formative LBK and earliest LBK settlement hardly speaks to crowded landscapes (*Jakucs* et al. *2016*) – but, in their view, perhaps as an outcome of ethnic diversity or of competition for prestige and access to resources among pioneering colonisers. The episode played out some fully 700km north of the area of the Formative LBK, and ignoring the spaces in between.

At face value, there do not seem to be interruptions to or anomalies in the accumulation of lake sediment. The documented sequence has a coherent trajectory, with Phase IV corresponding broadly with our understanding of the chronology of established LBK settlement in the north of Poland (*cf. Marciniak* et al. *2022*). There are of course problems in the identification of cereal pollen (*Behre 2007*), so that the claim for cereal cultivation in a context of probably limited interference with local woodlands might be challenged, but a uniform method was applied to both Phases II and IV, and the presence of cereal cultivation in Phase IV is hardly controversial.

The authors ascribe this 'infiltration phase' to the activity of Neolithic people, without quite specifying their possible identity. They refer to what has been claimed by the excavator of Brunn (*Stadler, Kotova 2019*) as a 300km 'flying' jump or leapfrog from Starčevo communities in northern Croatia to found Brunn. One might also support the general argument of Czerniak *et al.* (*2023*) by reference to more general models of the prevalence and importance of movement in the LBK tradition as a whole (*Hofmann 2020*), although Daniela Hofmann speaks about micro-mobility, back and forth, rather than on wider scales. There is the specific difficulty here that the activity in question begins before the emergence of the Formative LBK as represented by Szentgyörgyvölgy-Pityerdomb in western Hungary and Brunn in eastern Austria, if we follow the formal date estimates of János Jakucs *et al.* (*2016*) and reject the 'high' start date for Brunn proposed by the authors (*Stadler, Kotova 2019*). The appeals to ethnic diversity and competition are rather vague, though preeminent clans or lineages have been envisaged as a powerful force in the spread of earliest LBK communities (*Frirdich 2005*).

Another possibility to be thought about, though rejected by Czerniak *et al.* (*2023*), is of an episode of experimentation by local hunter-gatherers. We know of the long-distance movement of materials and objects in Mesolithic Europe as a whole (*Gronenborn 2010a*). Putting this activity in the hands of far-ranging Mesolithic people might make it easier to explain the impermanence of the episode. In the end, time will tell whether similar instances can be documented beyond the frontier or leading edge of Neolithic settlement in the first half of the 6th millennium cal BC, and whether matching local archaeology can be located and documented.

Whichever interpretation is preferred, this episode can be seen as an important further clue to unstable frontier conditions in the very early stages of the Neolithic, and we note other possible comparisons in the discussion below. Once again – especially in the version promoted by Czerniak *et al.* (*2023*) – not only is there the possibility of fission and long-range movement, but failure was the end result, as the activity described came to an end after probably some 140 years. Czerniak *et al.* (*O.c.14*) refer to probable indications of climatic downturn at the very end of their Phase II,

strongly implying that that was the cause of abandonment. As with the Körös example discussed above, speculatively the limited scale of settlement, isolation and poor connectivity might also have been responsible for abandonment.

Other impermanent settlement and interaction close to the Baltic

Following the probably 54th-century cal BC rapid expansion of the earliest LBK (*Jakucs* et al. *2016; Bánffy* et al. *2018; Bánffy, Whittle 2022*) that took agricultural colonisers far west and north, there was further infill of the loess-dominated river basins in the established LBK. There are also signs of further spread beyond the fertile loess areas. LBK groups have been found farther down the Vistula and Oder rivers on the north European Plain, some fairly close to the Baltic (*Bogucki 1979; 1982; cf. Czerniak* et al. *2017; Marciniak* et al. *2022; Czerniak* et al*. 2023.Fig. 2*).

Such LBK groups faced the challenge of creating a subsistence strategy in a post-glacial landscape without obviously fertile soils. Possible advantages included large empty spaces for settling and herding, rich wild game and plant resources, and perhaps good communication routes (probably also with hunters and fishers living in the coastal area: *Kabaciński, Terberger 2009*). The earliest, arguably temporary settlements known so far are small, consisting of a few pits with potsherds and food remnants (*Grygiel 1976*). Demographic pressures may not have played a crucial role in this move since many of the loess-covered regions to the south remained unoccupied. One characterisation of these numerous, scattered early sites has been as a group of tactical pioneers in search of finding and developing resources other than arable land (*Bogucki 1979.242*).

The Baltic coastal and palaeo-lakeside settlement of Dąbki, Sławno County, West Pomerania, initially a forager (Ertebølle) site, offers an important case study with a long tradition of cultural exchange and adaptation. Its inhabitants are believed to have encountered LBK farmers and subsequently incorporated some elements of the Neolithic lifestyle (*Zvelebil 1998*). Since 2004, extensive fieldwork and analysis have been carried out, providing numerous details about the mixed foraging and sedentary lifestyle. There are a large amount of final Mesolithic material finds, including locally made pointed-bottom vessels, animal bones and plant remains indicating a coastal hunting and fishing lifestyle (*Czekaj-Zastawny* et al. *2013; Kabaciński, Terberger 2009; Kabaciński* et al. *2015*). The earliest evidence for agriculture gained from cereal pollen grains is dated to no earlier than the final phase of the settlement, *c*. 3700–3600 cal BC. Its earliest dates (though not entirely unproblematic) appear to underline the dynamic nature of this cultural transition (*Kotula* et al. *2015.119,133*).

In the neighbouring area to the west, in north-east Germany, similar dates have been published for the earliest Neolithic sites in northern Brandenburg and in western Pomerania (*Cziesla 2008.409*). Several publications have investigated the appearance and disappearance of LBK groups in this northern periphery (*Cziesla 2008*). A new summary of the site of Lietzow 10, Havelland, Brandenburg, located on a ground moraine plateau, covers enclaves of agricultural life amidst the settlement zone of forager groups (*Kirleis* et al. *2024*). The site yielded features containing late LBK pottery fragments, from which a settlement site with two farmsteads could be reconstructed, which was inhabited for two or three generations, around 5100 to 5000 cal BC. Despite its peripheral location, the pottery finds, and raw material provenance for tools attest to long-distance contacts. Domesticated cattle and emmer are well documented, with pigs and small ruminants also present, as well as evidence for extensive gathering. A wide range of game species is represented but hunting was probably not very important overall.

These sites did not have abundant material remains and probably disappeared by the early 5th millennium cal BC. In these northerly areas, to which the later Neolithic Lengyel orbit did not extend, the following culture group to occupy the northerly margins was the Funnel Beaker culture (*Midgley 1992;* see also *Marciniak* et al. *2020; Czerniak* et al. *2017*). The one-and-a-half millennia-long hiatus between the two settlement periods is telling and meaningful; the LBK attempt to settle in northern post-glacial landscapes appears to have been unsuccessful. Speculatively again, perhaps scale and connectivity were insurmountable challenges, apart from the difficulties set for the LBK subsistence system by the surroundings. Plausibly, these groups in the Polish and German cases that failed to thrive probably moved back to their core areas of settlement, as we suggested above was probably the case in the Danube-bank Körös case, to the regular LBK zones to the south.

Another facet of the frontier: contact with indigenous groups

Interbreeding at Brunn and pre-Neolithic pottery in Slovakia

Recent aDNA results right across Europe (see, for example, the references cited above) have tended to suggest a rather modest contribution at best from indigenous hunter-gatherers to Neolithic genetic signatures. The picture is varied region by region and we do not have the space here to go into all the detail. The great majority of LBK samples come from established phases of that culture. The example of Brunn near Vienna (*Nikitin* et al. *2019*), however, can remind us of the potential variability in frontier contexts. Here in the Formative LBK at Brunn am Gebirge site 2, one of three analysed individuals had a genetic ancestry descended from Anatolian Neolithic farmers. The other two, however, had a mixture of Western Hunter-Gatherer-related and Anatolian Neolithic Farmer-related ancestry, one of them with approximately 50% of each. Strontium isotope analysis also showed that the latter individual with mixed, balanced ancestry was non-local to the Brunn 2 area (*Nikitin* et al. *2019*). Stable carbon and nitrogen isotope ratios for all three individuals indicated a broadly Neolithic diet. Though the sample is very small, the report on the autosomal analysis reveals descent from a potentially large number of ancestors (*cf. Mathieson* et al. *2015; Booth 2019*) and highlights interbreeding between incoming farmers and indigenous hunter-gatherers, and the 'integrative nature and composition of the early LBK communities' (*Nikitin* et al. *2019.1*).

Whether or not LBK lithic production was strongly influenced by Mesolithic traditions (*Mateiciucová 2008; Kozłowski 2004*), we know that raw materials from areas occupied by hunter-gatherers were coming down into early Neolithic settlements, obsidian from north-east Hungary to Körös settlements on the Great Hungarian Plain (*e.g., Szeverényi, Priskin 2021*), and radiolarite from north of Lake Balaton into Starčevo and Formative LBK contexts (*Biró 2005; Mateiciucová 2008*).

Further evidence of possible contact across a fluid frontier between early farmers and hunter-gatherers, thus providing more information about the conditions of early Neolithic settlement, comes from a recent study in Slovakia (*Tóth* et al. *2023*). During palaeoecological research in calcareous lake sediments at Santovka, in the Slovakian Danube basin, so far without corresponding settlement traces, sherds of grass-tempered vessels were found. Stylistically these sherds do not match LBK styles, normally considered as the first Neolithic pottery north of Lake Balaton. The study faced considerable challenges in attempting the radiocarbon dating of this Santovka pottery. A novel method of bulk separation of organic content from the grass-tempered pottery was used, producing a coherent series of dates, from the 58th to 55th centuries cal BC, and in line with the chronostratigraphic Bayesian model for the coring site. However, dates on lipids extracted from the same sherds were divergent by up to 400–600 years.

If the dating of the organic content of the grass-tempered pottery is robust, reliable and correct, ceramics predating the Formative LBK phase have been found, and the authors conclude that Mesolithic groups must have experimented with pottery-making prior to the arrival of farming in the region (*Tóth* et al. *2023*). Santovka, just north of the Danube, is under 200km from known concentrations of early Neolithic, Starčevo settlement to the south, making a contact and connections plausible.

Local copies of Starčevo and Formative LBK objects

People who experimented with tempered pottery-making probably also tried their hand at other facets of Neolithic things and practices, further informing us of frontier conditions. Given an overlap between the end of the late Mesolithic and the start of early farming settlement in Transdanubia, this may have been the case among the many sites found near each other between the Regöly Mesolithic settlement (*Marton* et al. *2021*) and the large oldest, Starčevo phase of Alsónyék. In the first half of the 6th millennium cal BC, the Starčevo culture occupied the region involving the whole of Lake Balaton, at least sporadically including its northern side (for example at Tihany-Apáti: *Regenye 2010*). As already noted, there is proven contact between the Transdanubian Starčevo and the hunter-gatherers inhabiting the forested upland north of them since the Starčevo groups were also users of the north Transdanubian red radiolarite. Accessing the sources was presumably only possible via forager contacts. Speculatively, some domesticates and pottery know-how may have gone in the other direction. A synchronicity between the latest phase of the Starčevo and the Formative LBK has also been documented by radiocarbon dates (*Kalicz* et al. *2002; Jakucs* et al. *2016; Oross* et al. *2023*) as well as by archaeological

analyses, with the ubiquitous use of the red radiolarite raw material by Formative LBK communities (*Bánffy 2004; Biró 2005; Bánffy, Whittle 2022*). This evidence implies that the forager groups must have been in contact with people from both major Neolithic cultural formations. During these long-standing encounters, there are further signs of the foragers' intention to adapt to the Neolithic lifestyle and perhaps also adopt some of the farmers' material practices.

Among the figural finds from the Formative LBK site of Szentgyörgyvölgy-Pityerdomb, in westernmost Transdanubia (*Bánffy 2004*), a fragment of a carefully modelled vessel, resting on a human foot, indicates a direct south-east European Starčevo origin. Another fragment found at the nearby site of Balatonszentgyörgy comes from a similar vessel, although it was less carefully made and is of vastly inferior quality (*Bánffy 2004*). This footed vessel is a fragment of a pot which is arguably a copy of late Starčevo and Formative LBK representations. Speculatively, and setting out from the Mesolithic traces in the region (*Duffy* et al. *2023*), the copy was made by local foragers.

The well-known animal (or human)-headed Starčevo altar from Lánycsók, in southern Transdanubia (*Kalicz 1990*), with a hint of its female character, may have been the model for a similar object of which only a fragment remains. This is the head from Kéthely, also not so far away in southern Transdanubia (*Sági, Törőcsik 1991*) (Fig. 1). This looks like an imitation – a local copy – of the same type as Lánycsók, albeit it is a vastly inferior, poorly fired variant of the 'original'. The Kéthely fragment has a further interesting detail. Its eyes were formed by cereal grains (*Triticum dicoccum*), a phenomenon that can perhaps be taken as a symbol indicating that the indigenous groups related positively to Neolithic innovations and made efforts to adopt cereal cultivation.

Thus, arguably, some Balkan early Neolithic cult paraphernalia like clay figural representations were adopted and used by the Formative LBK communities, while others (like pintaderas and small clay house models) were discarded. We could posit that certain elements of the Balkan cult inventory were adopted or copied for prestige reasons, as in the case of other Neolithic innovations such as some domesticated plants, perhaps reflecting some kind of incipient, modest social ranking among these indigenous communities, in the 56th–55th centuries cal BC.

However, this kind of motivation seems to decrease at the time of the LBK spread in the 54th century cal BC. There is a very high number of clay figural images from late Starčevo sites from the southern Carpathian basin, part of the north Balkan abundance of clay objects in general, while just a few years ago the total number of LBK figurines was 267 over its entire occupation area across Europe, and through its entire duration (*Becker 2011*). Moreover, this fading away matches the spatial and temporal distribution process of LBK spread, since most of the relatively low number of LBK clay images concentrate in the regions closest to the original zone of the Formative LBK. Bottlenecks, with features or objects fading away during the spread of Neolithic lifestyle from its Anatolian source, occur several times. While the reasons are not fully understood, the decline in clay figurine making is potentially connected to two main factors. One might be a scarcity of suitable clay raw material due to environmental factors, and the other would be the increasing influence of a different ontology of cult and ritual of local, forager population groups (*Bánffy 2019*).

Discussion: implications for our detailed understanding of colonisation and initial establishment

We have given examples of varied situations and processes at what we have called the frontier of Neolithisation in central Europe. An important general examination of frontiers and borderland processes has called for "*cross-disciplinary supra-regional comparison of frontier dynamics*" (*Parker 2006.77*) but our principal aim has been the examination of specific contexts in central Europe. Two examples, from the margins of the Körös and LBK cultures, on the east bank of the Danube and in Pomerania respectively, the latter including the site of Lietzow 10, show settlement established for a while – or in the case of Lietzow just for a generation or two – but then being abandoned. A recent, controversial claim for early, long-range pioneering into northern Poland in the earlier sixth millennium cal BC has been discussed. Some of the evidence for contact and interaction between incoming farmers and indigenous hunter-gatherers has been reviewed, including aDNA evidence from Brunn 2 for interbreeding in the Formative LBK phase, adoption of new practices at Dąbki, and material evidence from Transdanubia in the form of figural representations in the Formative LBK phase, suggestive of potential local copying and the adoption of Neolithic things and practices by indigenous people, seen also in the experiment

at Santovka in Slovakia with the making of grass-tempered pottery probably before the arrival of Neolithic people and other new practices. These varied case studies suggest to us that we need to make more allowance for fluid, unstable, frontier conditions in the initial stages of Neolithisation than has normally been the case in the recent archaeological literature, though we note the 'continuum of boundary dynamics' proposed by Bradley J. Parker (*2006*). We can profitably think more about instability, risk, reversals and even failures, paying attention to specific contexts and relying less on generalising or universalising models. Further reference to the development of the archaeological literature underlines this claim.

The difficult conditions for pioneers of the initial establishment of Neolithic settlement were perhaps first imagined in detail long ago by Humphrey Case (*1969*), in a far-sighted essay about the beginning of the Neolithic in Britain and Ireland. In the era of processualism and post-processualism, at least in what we can call the Anglo-American literature, there was a subsequent shift in favour of indigenous explanations, and it took two essays by David Anthony (*1990*; *1997*) among others (note, for example, *Gronenborn 1999; 2007; Sheridan 2003; Rowley-Conwy 2004; 2011*) to remind the discipline of the realities and practicalities of migration and colonisation. As noted in our introduction, that perspective has been dramatically underscored for studies of Neolithisation by the results of aDNA analysis, particularly over the last decade or so. So far, so good: but we argue that an over-generalising approach has been employed in ongoing modelling of the processes of Neolithisation. Targeted or leapfrog colonisation has usefully been recognised (*van Andel, Runnels 1995*), as noted in our introduction, and is regularly included in continuing discussions (for example, *Porčić* et al. *2020; LaPolice 2024*), but the evident favourite frame of reference remains the wave of advance model (*Ammerman, Cavalli-Sforza 1971; 1973; 1984*). That in turn encourages a general model of population growth and demographic pressure as the generative motor of Neolithisation across Europe (*Shennan 2013; 2024; Blagojević* et al. *2017; Silva, Vander Linden 2017; Porčić* et al. *2020; Porčić 2024. 3–4*). Refinements of this approach are to be found in the literature, such as a study of the central Balkans, based on summing of radiocarbon dates which suggests, plausibly enough, high fertility and 'scalar stress',or the tendency for communities to fission and disperse further before reaching sizes of 50–100 people, to avoid social tensions (*Porčić* et al. *2021;* with slight revisions in *Porčić 2024*). Predominantly within-group mating has been proposed, and fresh calculations have been made about the 'front speed' of the wave of advance (*LaPolice* et al. *2024*). Reference has also been made to competition (*Czerniak* et al. *2023; cf. Frirdich 2005; Shennan 2018; Porčić 2024.12*).

Though many of the details and methods used can be debated – the summing of radiocarbon dates, for example, remains a flawed method, on the open admission of one of its exponents (*Crema 2022*) – the emphasis on a wave of advance and on demographic growth and pressure seems to fit well the big-picture narrative of Neolithisation provided now by aDNA analysis. What we want to emphasise, however, is the over-general character of this perspective, especially for the early stages of Neolithisation in Europe. Admittedly in the era immediately preceding the aDNA revolution, a strong reminder was given of the potential variability and complexity of frontier conditions (*Barker 2006.378–379*), and in his many publications the late Marek Zvelebil patiently explored the possibilities for fusion models involving both incomers and indigenous people (*Zvelebil 1996; 1998; 2004; Zvelebil, Rowley-Conwy 2004; Zvelebil* et al. *2010;* see also *Porčić 2024.8*). These ideas seem largely to have been forgotten in the recent literature, though they seem still relevant to us. Even if the contribution of indigenous hunter-gatherers to Neolithic genetic signatures was generally low – and there is no space here to go into all the regional detail – that still leaves open the possibility that indigenous knowledge of landscapes and resources was of major importance in the colonisation process (*Bánffy 2004; Whittle forthcoming a; forthcoming b*). And hunter-gatherers did not all go away, as pockets of survival and the later re-emergence of U-haplotypes testify (*Bollongino* et al. *2013; Szécsényi-Nagy et al. 2015; in press; Lipson* et al. *2017; Bánffy 2023)*. Much of the aDNA sampling for early Neolithic populations has been within established phases of settlement, and as we have emphasised above in relation to Brunn 2, where a demonstrably very early situation has been investigated (in an admittedly tiny sample), interbreeding has been demonstrated.

Thus, without wishing to subvert the big picture which we have sketched earlier, we think we should be refining elements of a model for frontier conditions in the initial stages of Neolithisation. These appear to us to have been often fluid and unstable. There seem to have been variations in the rate of the spread of Neolithic people, things and practices across mainland Eu-

rope (for reasons of space, we here leave the Mediterranean aside (see *Leppard 2021*), though the same claim may well apply). It has been argued that the rate of spread in the central Balkans was faster than the continental average (*Porčić* et al. *2020)*, with a detectable slowing down north of the Sava and Drava (*Porčić 2024.7*): significant differences in the context of our discussion, since they bring variability. Moreover, summing of radiocarbon dates offers a possible bust or decline at the very end of the 6th millennium cal BC (*O.c.4*): yet another instance of possible reversal. What we further need to understand better are whether faster spread equated to greater or lesser density of settlement, and the duration of individual occupations, few of which have been precisely dated and modelled. We have suggested above that the scale of initial, pioneering settlement may regularly have been small and the gaps between pioneer occupations potentially considerable, even though wave of advance modelling, of for example a kilometre of advance or more per year (*LaPolice* et al. *2024; cf. Porčić 2024.6*), implies a much more regular setting up of the Neolithic presence. There may have been all manner of reasons for the abandonment, indeed failure, of settlement in given circumstances. Unfavourable climatic conditions are often summoned, for example at the end of the LBK in general (*e.g., Gronenborn 2010b*) and have been used in the interpretation of the end of the Phase II episode at Nowe Objezierze (*Czerniak* et al. *2023*); social tensions and disease are other main suspects, as discussed briefly above. We have also suggested, however, that low social connectivity, related in turn to small scale, is another potential suspect in processes of abandonment, especially in marginal situations. We should also fully incorporate leapfrog moves into a more nuanced model of frontier conditions, and not see these as just sporadic (*Porčić* et al. *2020.10*). These may have had varied motivations: to create space, to build prestige (*cf. Frirdich 2005*), or to avoid social tensions (*Porčić* et al. *2021*). And we could make allowance too for genuinely targeted colonisation. During their initial spread across central into western Europe, probably in the 54th century cal BC, farming groups of the earliest LBK reached out to three regions which were specifically rich in desirable salt water: the salt region of the Wetterau in north-west Germany, the Middle Elbe-Saale region in central Germany and the Cracow-Wieliczka salt region in south-east (Lesser) Poland (*Bánffy 2015*). A final element of a nuanced model for frontier conditions is interaction with indigenous population. Even though the contribution of local hunter-gatherers to genetic signatures is now shown by aDNA analysis to have been modest in the early stages of the Neolithic, nonetheless the people already there should still be accorded agency and influence. In the long term, we can note further changes. Whereas in the early Neolithic Starčevo and Körös culture-associated samples the U haplogroups were much rarer than in the hunter-gatherer populations, the frequencies of subvariants of U in Neolithic populations gradually increased in the LBK, and reached some 10–12% (especially of U5b) by the late LBK and in the succeeding Tisza and Lengyel phases of the earlier fifth millennium cal BC (*Szécsényi-Nagy* et al. *in press*).

Our aim in sketching a simple model of this kind is to reinforce the importance of local circumstance, and to make full allowance for variability from context to context. And while the wider literature can be seen as often too prone to over-generalisation if not universalising (*cf. Whittle 2023*), we can also reflect that risk, reversal and even failure have regularly been underplayed. Risk has often been seen as lying principally in unfavourable environmental or climatic conditions (*e.g.*, for the LBK, *Bogucki 1988; Gronenborn 2010b*), but social risk, for example in undertaking feats of construction under the gaze of a watching, critical public (*Richards 2004*), should also be kept in mind; pioneering as much as monument building can be thought of as risky. Likewise, when risk leads to bad outcomes, failure results, but probably too much attention has been given to major failures and collapses, like the fall of great empires (*Morrison 2006*), and not enough to ones on a smaller scale (*Price, Yaffe 2023*).

Finally, we believe that our call for a more nuanced view of the Neolithic frontier and the conditions of initial settlement could be useful in the detailed region-by-region interpretation of the spread of the Neolithic. Clearly this requires longer treatment than we have space for here, but an indication of its potential can be seen by brief, initial reference to some other situations across mainland Europe. Around the Aegean, including in Greece, for example, there seem to have been multiple strands in the process of initial Neolithisation (*e.g., Furholt 2016; Douka* et al. *2017; Özdoğan 2024; cf. Koptekin* et al. *2024*). Perhaps that set the tone, as it were, for the continuing colonisation of the Balkans. We have already noted the significant claim for a faster wave of advance in the central Balkans (*Porčić* et al. *2020*). There is still much to understand better about the timing and tempo of the spread of the earliest LBK (*cf. Lenneis, Lüning 2001; Jakucs* et al. *2016*) but the rapid nature of its spread, the patchy nature of its di-

stribution and the often sizeable gaps between sites or clusters of settlement are striking. It is plausible that at least some of the spread was conditioned by existing connections created by the movement of raw materials by indigenous hunter-gatherers (*Mateiciucová 2008*). Seriation of pottery decoration in the west allows for finer phase estimates (*Strien 2017; 2018*), compatible in our view with continuing migration streams (*cf. Anthony 1990; 1997*). Jumping further west to the lower river valleys, coastal wetlands and estuaries of the Netherlands, a recent review of Neolithisation in the later fifth millennium cal BC stresses that "*there is no reason to assume that early farming appeared in the same way at the same time everywhere in northern Europe*" (*Brusgaard* et al. *2024.666*) and "*sweeping narratives should be reassessed to focus more on local trajectories and regional processes*" (*Brusgaard* et al. *2024. 667; cf. Whittle, Cummings 2007*). The appearance of the first sedentary settlements post-dates the initial appearance of domestic resources in the context of a mobile wetland economy, by around a millennium (*Amkreutz 2013; Dusseldorp, Amkreutz 2020. 124*). Lastly, there are several competing models for the start of the Neolithic in Britain and Ireland (full references in *Whittle forthcoming a; forthcoming b*). The wave of advance model has never been formally applied to Britain and Ireland, though informal representation of possible, time-transgressive processes of spread have been speculatively mapped on the basis of formal chronological modelling (*Whittle* et al. *2011. Figs. 14.177, 15.8*); those are now in need of revision. The possibility of successive migration events or streams has been suggested (*Thomas 2022; Whittle forthcoming a*), compatible with the aDNA evidence as it stands (*Brace, Booth 2023; Booth forthcoming*). Small-scale and low-key beginnings have been mooted (*Thomas 2022*), perhaps from the 41st to 39th centuries cal BC, but whether those excluded cereal cultivation in the initial stages (*Griffiths 2018*) remains debateable. There are controversial claims, on the basis of pollen analysis, for local experimentation with cereal cultivation in northern England, in the later fifth millennium cal BC (*Albert, Innes 2020; Innes* et al. *2024*). In Ireland, Neolithic settlement is much better documented from ENII, probably from the 38th century cal BC onwards, with earlier activity in ENI (back to *c.* 4000 cal BC) minimal (*Smyth* et al. *2020*). The aDNA evidence suggests the dominant presence of incoming farmers, though with some local interbreeding, for example in western Scotland (*Brace, Booth 2023; Booth forthcoming; Cassidy 2023*).

Conclusion

Ancient DNA analyses and robust chronological modelling have had a profound impact in recent years on wider narratives for the Neolithisation of Europe. There is, however, still considerable scope for the further integration of archaeogenetic and archaeological evidence and for working at varied scales. Our paper has suggested that a more nuanced approach to frontier conditions, early settlement and initial contacts with indigenous people is one important way ahead, making allowance in thinking about pioneering conditions and initial Neolithisation for fluidity, instability, variations in scale, duration and connectivity, and some interaction between incoming farmers and indigenous population. Risk and even failure should be taken into account. A simple model incorporating these kinds of factors serves to unpick some of the familiar generalisations of the dominant conceptualisations of an irresistible wave of advance, unrelenting demographic pressure and ubiquitous Neolithic success. Though generated by selected examples principally from the northern Balkans, the Carpathian basin and northern central Europe, such a model could have wider usefulness.

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