UDK 903'12/'15(4/5)"633/634":575.17; 903'12/'15(4/5)"633/634":574.91
Documenta Praehistorica XXXI

Modelling the Neolithic dispersal in northern Eurasia

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ABSTRACT – *Comprehensive lists of radiocarbon dates from key Early Neolithic sites in Central Europe belonging to the Linear Pottery Ceramic Culture (LBK) and early pottery-bearing cultures in the East European Plain were analysed with the use of the χ^2 test. The dates from the LBK sites form a statistically homogeneous set, with a probability distribution similar to a single-date Gaussian curve. This implies the rate of expansion of the LBK in Central Europe being in excess of 4 km/yr. Early pottery-bearing sites on the East European Plain exhibit a much broader probability distribution of dates, with a spatio-temporal trend directed from the south-east to the north-west. The rate of spread of pottery-making is in the order of 1 km/yr, i.e., comparable to the average expansion rate of the Neolithic in Western and Central Europe.*

IZVLEČEK – *S testom χ^2 smo analizirali obsežen seznam radiokarbonskih datacij iz ključnih zgodnjeneolitskih najdišč srednje Evrope, ki pripadajo kulturi linearnotrakaste keramike (LTK), in iz najdišč z zgodnjo keramiko iz vzhodnoevropskih nižin. Datacije z najdišč LTK so statistično homogene z verjetnostno distribucijo, ki je podobna Gaussovi krivulji. To kaže, da je bila stopnja ekspanzije LTK v srednji Evropi več kot 4 kilometre na leto. Najdišča z zgodnjo keramiko iz vzhodnoevropskih nižin kažejo veliko daljšo verjetnostno distribucijo datacij, pri čemer je prostorsko-časovni trend usmerjen od jugovzhoda k severozahodu. Hitrost širjenja izdelovanja keramike je reda velikosti 1 kilometer na leto, se pravi da je primerljiv s povprečno stopnjo ekspanzije neolitika v zahodni in srednji Evropi.*

KEY WORDS – *Neolithic; LBK; pottery-making; expansion rate; radiocarbon; statistical analysis*

INTRODUCTION

Since Childe (*Childe 1925*) the concept of 'agricultural revolution' has been focused on the introduction of agriculture. Neolithisation was viewed as the spread of colonists bearing ceramic containers, domesticated plants and animals, new architecture, long-distance trade, burial rituals, and eventually overwhelming indigenous hunter-gatherers to the cultivation of domesticated cereals and rearing the animal stock (*Price 2000*). New criteria included sedentary settlements, social hierarchy and symbolic expressions (*Tringham 2000*). Yet to this day the shift to *agro-pastoral* farming is deemed to be the most important single signature of Neolithic (*Zvelebil 1996.323*).

However, recent archaeobotanic studies (*Hather and Mason 2002.4, 5*) show that it is often impossible to draw a clear distinction between agriculture and hunter-gathering, as hunter-gatherers may undertake agricultural practices and vice versa. This evidence shows that wild plant species were extensively gathered in most areas in Neolithic Britain (*Robinson 2000*). The appearance of ceramic vessels at shell-midden sites in the coastal areas of Europe (the Algarve in Portugal, Ertebølle in southern Scandinavia) apparently failed to modify subsistence based on marine shellfish resources and wild plants (*Stiner et al. 2003; Andersen and Johansen 1987; Robinson and Harild 2002*). On the other hand, pottery-making hunter-gatherers in the boreal forests of Eurasia display the attributes of complex societies, such as sedentism, high population density, intense food procurement, technological elaboration, development of exchange networks (that may include their agriculturalist neighbours), social differentiation, and territorial control (*Zvelebil 1996. 331*). It becomes increasingly clear that the distinction between agricultural and non-agricultural Neolithic is rather loose, and the dominant manifestations of the Neolithic are different in different parts of the world and even Europe (*Sériadès 1993; Trigham 2000*). Thomas (*Thomas 1996; 2003*) argues against the concept of a fixed and universal 'Neolithic package', and views the Neolithic as a range of various processes, generating considerable variability in subsidence practices. Similar views were popular amongst scholars in the former USSR, who identified 'Neolithic culture' with hunter-gathering communities manifesting a sedentary way of life, large-scale production, and the use of ceramic ware, polished stone and bone tools (*Oshibkina 1996a*).

The mechanism of spread of the Neolithic in Europe remains a subject of debate. A model of Neolithisation as a result of direct migration is omnipresent in the works of Childe (*1958*). More recently, this idea took the form of demic expansion or 'wave of advance' (*Ammerman and Cavalli-Sforza 1973*). This model was further substantiated by genetic markers (*Menozzi et al. 1978; Cavalli-Sforza et al. 1994*), which have been interpreted as an indication of the diffusion of a farming population from Anatolia into Europe. Renfrew (*Renfrew 1987; 1996*) linked the dispersal of farming with the proliferation of Indo-European languages.

There are several varieties of migrationist concept. These range from the direct colonisation of hitherto unpopulated areas or the annihilation of previous Mesolithic groups (*Childe 1958; Ammerman and Cavalli-Sforza 1973*), to a model of elite dominance (*Renfrew 1987*). Zilhão (*Zilhão 1993; 2001*) views Neolithisation as 'leap-frogging colonisation' by small sea-faring groups along the Mediterranean coast. An alternative approach views the process as an adoption of agriculture by indigenous hunter-gatherers through the diffusion of cultural and economic novelties by means of intermarriage, assimilation, and borrowing (*Whittle 1996; Tilley 1994; Thomas 1996*).

A unifying position advocated by Zvelebil (*Zvelebil 1986; 1996*) distinguishes three phases in the transition to agriculture: availability, substitution, and colonisation, each operating in the broader context of an 'agricultural frontier' (see also *Zvelebil and Lillie 2000*). The 'individual frontier mobility' concept relates Neolithisation to 'small-scale' contacts between hunter-gatherers and farmers at the level of individuals and small groups linked by kinship. Several writers (*Gronenborn 1999; Price et al. 2001*) argue that Neolithisation involved small groups of immigrant farmers who came into contact with 'local forager-herder/horticulturalists'.

The advent of radiocarbon dating has provided a new instrument for testing the various models of Neolithisation. The first series of radiocarbon measurements seemed to confirm the Childean concept of *Ex Oriente lux*, indicating that the 'Neolithic way of life penetrated Europe from the south-east spreading from Greece and the south Balkans...' (*Clark 1965.67*). Later publications based on comprehensive radiocarbon data for Neolithic sites suggested a more balanced view. Tringham (*Tringham 1971. 216–7*) discussed the spread of new techniques, and their adoption (or rejection) by local groups, resulting from an expansion of population. Dolukhanov and Timofeev (*Dolukhanov and Timofeev 1972. 29–30*) considered this process as a combination of diffusion and local inventions.

A recent analysis of a large dataset of Neolithic radiocarbon measurements (*Gkiasta et al. 2003*) has basically confirmed the earlier results (*Clark 1965; Ammerman and Cavalli-Sforza 1973*), showing a correlation of the earliest occurrence of the Neolithic with the distance from an assumed source in the Near East.

The earlier Russian writers (*Gorodtsov 1923*) attached a significant importance to human migrations. The Soviet archaeology in the 1930–50s totally rejected these views, stressing the 'autochthonous development' of archaeological entities. Migrationist concepts were revitalised in more recent Russian studies (*Klejn 2000*).

Over the past two decades, extensive series of radiocarbon dates were obtained for Mesolithic and Neolithic sites in broad areas of the former USSR (*Timofeev 2000*). This evidence has considerably changed the hitherto held views on the chronology of Late Prehistory in the area, with the new dates of pottery-bearing sites on the East European Plain being significantly older than previously thought (*Bryusov 1952*).

The present article addresses these and related issues from the viewpoint of the radiocarbon chronology with the use of the novel methods discussed below.

THE DATABASE

This work is based on two major databases of radiocarbon dates recently developed for Neolithic sites in Europe. All dates for the former USSR (the Russian Federation, the Baltic States, Byelorussia, Ukraine, and Moldova) have been included in the database developed at the Institute for the History of Material Culture in St. Petersburg (*Timofeev and Zaitseva 1996*). The date list for LBK sites in Central Europe was compiled mainly from the Radon (*Furholt et al. 2002*). We have also included radiocarbon dates from sites in Austria and Germany (*Lenneis et al. 1996; Stäuble 1995*). The latter dates appear to span relatively short time ranges and are relatively homogeneous archaeologically; we use them to estimate the typical empirical uncertainty of radiocarbon dates.

In all cases, data referred to as 'dubious' were omitted. Since our aim is to assess the early stages of Neolithisation, only dates from the lowest strata of multistratified sites were included. All the data were calibrated using OxCal 3.2.

STATISTICAL ANALYSIS

In order to quantify the spread of Neolithisation, we tested the hypothesis that the dates in each individual subset (namely, the LBK in the West and the Neolithic sites in the East European Plain) are coeval. In other words, we verified whether or not the radiocarbon dates in a subset can represent a single date contaminated by Gaussian random noise. If the data are compatible with this hypothesis, one can conclude that the Neolithisation proceeded rapidly (in the sense of radiocarbon dating); if this is not the case, the spread of Neolithisation was gradual.

Our analysis is based on the χ^2 test, and so requires a knowledge of the total errors of the date measurements, rather than just the instrumental ones that only characterize the accuracy of the radiocarbon age measurement in the laboratory (*Dolukhanov et al. 2001*). Therefore, we derive the lower limit of total uncertainty from statistically significant data sets belonging to archaeologically and culturally homogeneous sites. For several sites, we have been able to isolate a date subset that can be considered coeval in the statistical sense. It is important to ensure that the dates in this set are also archaeologically homogeneous.

The errors published together with radiocarbon dates, refer to the uncertainty of the laboratory measurement of the sample radioactivity alone, whereas the total uncertainty undoubtedly includes errors arising from archaeological context, from contamination by young and old radiocarbon, and from other effects (*Aitken 1990*). The relation of so-called instrumental errors to the total uncertainty of radiocarbon age estimates has been recently discussed (*Dolukhanov et al. 2001*). In order to estimate the total uncertainty of the radiocarbon dates in a sample we use a statistically representative set of dates belonging to a single archaeological object whose lifetime is negligible in comparison with the other time scales involved.

For the 20 calibrated dates from Brunn am Gebirge (*Lenneis et al. 1996*), the standard deviation is 99 years, which is useful to compare with the average published instrumental error of $\langle\sigma_i\rangle = 69$ years (after calibration, with individual errors σ_i ranging from 45 to 92 years).

Rosenburg is another site for which a statistically significant set of data has been published (*Lenneis et al. 1996*). There are seven dates plausibly belonging to the same Phase I of LBK. The standard deviation of these dates is 127 years, which is significantly larger than their average published error and rather close to the standard deviation of the Brunn am Gebirge dates.

The difference between the two error estimates, 100–130 years (the standard deviation in a coeval subsample) and 40–70 years (the mean instrumental error), is significant. Following our previous arguments (*Dolukhanov et al. 2001*), we accept 100 years as the lower limit for the total error of the LBK radiocarbon dates. This error is assumed to include several components, e.g., the instrumental uncertainty, the real life-span of an archaeological object, and various uncertainties arising from the archaeological context (inflow of old or young carbon, etc.). Of course, some archaeological objects can have smaller uncertainty (e.g., because of their shorter lifetime), but such cases have to be considered individually, and the corresponding uncertainty has to be estimated from independent evidence.

An estimate of the total uncertainty Σ_i for each date in each sample considered below was chosen as the maximum of the published instrumental error σ_i, as obtained after calibration and the corresponding lower limit discussed above. The lower limits are 100 and 127 years for the LBK and East European data, respectively, except for the Rosenburg LBK site, where 127 years was adopted.

The most probable common date T_0 of the coeval subsample is obtained using the weighted least squares method, and the quality of the fit is assessed using the χ^2 test,

$$\sum_{i=1}^{n} \frac{(t_i - T_0)^2}{\Sigma_i^2} \le \chi_{n-1}^2$$

where n is the number of measurements in the subsample, t_i , i = 1, ..., n are the dates belonging to the subsample, and Σ_i are their errors obtained as described above. If the χ^2 test is not satisfied, the dates deviating most strongly from the current value of T_0 are discarded one by one until the test is satisfied. This procedure results in a 'coeval subsample'.

The confidence interval Δ of T_0 has been calculated as (see *Dolukhanov et al. 2001* for details)

$$\Delta = \frac{\sigma}{n}\sqrt{\chi_{n-1}^2 - X^2(T_0)}$$

where

$$\frac{1}{\sigma} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{\Sigma_i^2}$$

and

$$X^2(T_0) = \sum_{i=1}^{n}\frac{(t_i - T_0)^2}{\Sigma_i^2}$$

The results of our calculations are presented in the form T = $T_0 \pm \Delta$; another important quantity is the standard deviation of the dates in the coeval subsample, σ_c. The quantity T_0 is the most probable age at which the cultural entity studied was at its peak. The confidence interval of T_0, denoted as Δ, characterizes the reliability of our knowledge (rather than the object itself). For example, small values of Δ can indicate that a slight improvement in the data can resolve a temporal heterogeneity in the subsample. The standard deviation in the coeval subsample, σ_c, is a measure of the duration of the cultural phenomenon considered. For example, it can be reasonably expected that the early signatures of the cultural entity under consideration appear by (2–3)σ_c earlier than T_0, while the total lifetime of the entity is of the order (4–6)σ_c (with a probability of 95–99.5%). In many cases, the significance of σ_c is similar to the total error of an individual radiocarbon date.

Our results are based on statistically significant samples; the number of individual dates in a sample cannot be smaller than, say, 5–10. Since a random element is present in any data, it is reasonable to expect that the spread of the data will grow with the size of the sample (even if the sample is drawn from statistically homogeneous data). The histogram of a coeval sample will fit a Gaussian shape. The Gaussian distribution admits data that deviate strongly from the mean value, and a pair of dates arbitrarily extracted from the widely separated wings of the Gaussian can be very different. The conclusion that they do belong to a coeval subsample can only be obtained from a simultaneous analysis of all the dates in the sample.

LINEAR POTTERY FROM CENTRAL EUROPE

The general LBK date list presented in Table 1 is taken from the *Radon* database, with the addition of dates obtained for several individual sites (Brunn am Gebirge, Rosenberg and others, for which numerous measurements were available). The final subset includes 47 measurements; 40 of them can be combined into a coeval subsample, with the most probable age of

$$T_0 = 5154 \pm 62 \text{ BC},$$

and the standard deviation

$$\sigma_c = 183 \text{ years}.$$

Both the general sample and its coeval part are further illustrated in Figure 1 in the form of date probability distributions.

THE NEOLITHIC OF THE EAST EUROPEAN PLAIN

This group consists of samples from the Neolithic sites of the East European Plain. These sites feature the large-scale production of pottery, but in most cases with limited or no evidence of either agriculture or stockbreeding. The sites are found in all parts of the East European Plain, and include the Lower Volga and the Lower Don areas, Ukraine, Moldova, Byelorussia, the Baltic States, Central and Northern Russia. They include several chronological stages and a considerable number of local 'archaeological cultures'.

Site	Index	Age bp	σ_i, yr	Age BC	Σ_i, yr
Les Longrais	Ly-150	5290	150	4100	167
Montbelliard	Gif-5165	5320	120	4125	142
Chichery	Gif-3354	5600	120	4450	150
Frankenau	VRI-207	5660	100	4525	125
Horné Lefantovce	**Bln-304**	**5775**	**140**	**4700**	**200**
Kaster	KN-2130	5840	55	4700	100
Schwanfeld 14				**4786**	**458**
Guttenbrunn	Bln-2227	5935	50	4830	100
Ulm-Eggingen				**4831**	**261**
Cuiry-les-Chaudardes				**4841**	**321**
Dresden-Nickern	**Bln-73/73A**	**5945**	**100**	**4850**	**133**
Hallertau	**HAM-197**	**5990**	**90**	**4875**	**125**
Menneville	**Ly-2322**	**6030**	**130**	**4900**	**225**
Mold	**Bln-58**	**5990**	**160**	**4900**	**300**
Chabarovice	**Bln-437**	**6070**	**200**	**4950**	**217**
Kirschnaumen-Evendorff	**Ly-1181**	**6050**	**200**	**4975**	**263**
Kecovo	**GrN-2435**	**6080**	**75**	**5000**	**100**
Dachstein	**Ly-1295**	**6280**	**320**	**5050**	**350**
Hienheim	**GrN-5870**	**6125**	**35**	**5065**	**100**
Friedberg	**Bln-56**	**6120**	**100**	**5075**	**125**
Niedermerz 3	**KN-2286**	**6180**	**120**	**5075**	**188**
Niedermerz 1	**KN-I.594**	**6180**	**50**	**5100**	**100**
Eilsleben	**OxA-1627**	**6190**	**90**	**5100**	**117**
Langweiler 2	**KN-I.885**	**6210**	**125**	**5100**	**133**
Lautereck	**GrN-4750**	**6140**	**45**	**5100**	**200**
Northeim-Imbshausen	**H-1573/1126**	**6192**	**140**	**5100**	**250**
Müddersheim	**KN-I.6**	**6210**	**50**	**5110**	**100**
Mohelnice	**MOC-70**	**6220**	**80**	**5125**	**163**
Niemcza	**Bln-1319**	**6210**	**80**	**5125**	**163**
Dnoboh-Hrada	**LJ-2040**	**6300**	**300**	**5150**	**317**
Bylany Stage II a-c	**GrN-4754**	**6270**	**65**	**5190**	**100**
Rosenburg				**5187**	**138**
Langweiler 9	**KN-2697**	**6370**	**210**	**5200**	**233**
Elsloo	**GrN-5733**	**6300**	**65**	**5215**	**100**
Köln-Mengenich	**KN-I.369**	**6320**	**70**	**5220**	**100**
Gerlingen	**KN-2295**	**6390**	**160**	**5225**	**158**
Langweiler 1	**KN-2301**	**6340**	**70**	**5245**	**100**
Brunn				**5252**	**99**
Geleen	**GrN-995**	**6370**	**60**	**5260**	**100**
Duderstadt	**H-919/889**	**6422**	**100**	**5300**	**100**
Blicquy				**5302**	**255**
Lamersdorf	**KN-I.367**	**6410**	**45**	**5340**	**100**
Langweiler 8	**KN-2989**	**6540**	**155**	**5375**	**158**
Eitzum	**Bln-51**	**6530**	**100**	**5400**	**100**
Göttingen	**H-1534/1027**	**6530**	**180**	**5400**	**200**
Schwanfeld 11				**5467**	**514**
Bylany Stage IV	BM-569	6754	96	5625	108
	$X^2(T_0) = 46.3$, $\chi_{39}{}^2(0.95) = 54.6$				

Tab. 1. Radiocarbon dates for the Linear Pottery (LBK) sites in Central Europe: the site name, laboratory index, the uncalibrated age and its instrumental error, the calibrated age and an estimate of its total error. Dates belonging to the coeval subsample are shown in bold face.

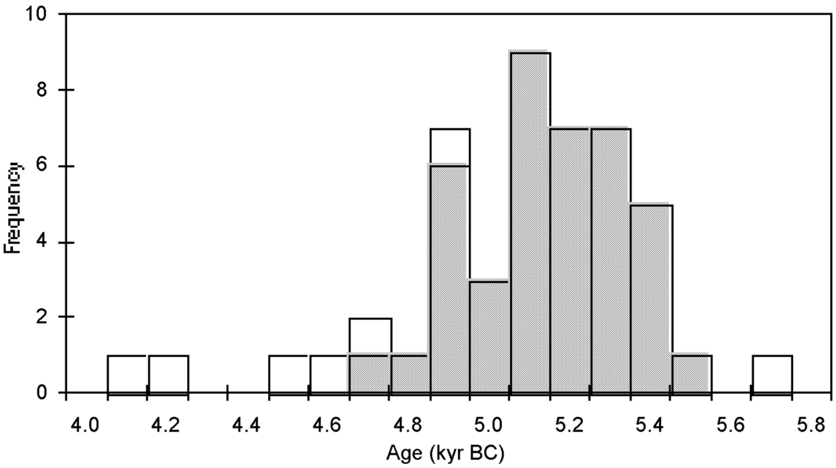

Fig. 1. The rate of occurrence of radiocarbon dated sites for LBK sites in Central Europe, according to Table 1. The coeval subsample is shown shaded, the remaining dates, unshaded.

In the case of the Serteya 2 Neolithic lake dwelling site in the Smolensk District (*Dolukhanov and Miklyaev 1986; Miklyaev 1995*) we have obtained a unique opportunity to assess the minimum statistical error of the radiocarbon age of Neolithic dwelling structures. The excavated area lies below the water level in the drainage canal and consists of rows of piles forming six distinct clusters. Each of these clusters allegedly formed a foundation for a platform on which a house was erected. The platform is well preserved in the case of Structure 1. Thus, the samples from each structure apparently belong to a single house constructed during a single season. Hence, the dates from each structure characterise a momentary event in the sense of radiocarbon dating. Botanical analysis shows that all the piles are made of spruce, which could not sustain prolonged stocking. Several samples were taken from different sets of annual rings in a single pile. We calculated the empirical error for four sets from Structures 1, 2, 3 and 6. In the case of Structure 1 all dates form a Gaussian-like distribution with one date obviously falling out. The mean age of the remaining dates is 2304 BC, with a standard deviation of 113 years. The corresponding values for the other structures are: 2372 ± 83 BC for Structure 2; 2295 ± 129 BC for Structure 3 (with one outlier), and 2219 ± 184 BC for Structure 6 (with one outlier). The average age of all four structures is 2298 ± 127 BC. The latter standard deviation, 127 years, is adopted as the minimum error in the statistical analysis of the dates for the entire East European Plain.

Yelshanian

The sites of the Yelshanian Culture (*Mamonov 2000*) have been identified in a vast area of the steppe stretching between the Lower Volga and the Ural Rivers. Small, presumably seasonal occupations are found close to water channels. Subsistence was based on hunting a wide range of animals (wild horse, aurochs, elk, brown bear, red deer, fallow deer, saiga antelope, marten, beaver), food collecting (tortoise, and edible molluscs, mostly *Unio*), and fishing. The remains of domestic animals (horse, cattle sheep and goat) were found at several sites, yet penetration from the later levels cannot be excluded. The stone inventory, which comes from mixed assemblages, includes single- and (rarely) double-platform cores, end scrapers (both from blades and flakes), burins, numerous axes, gouges and chisels (rarely polished), with the common occurrence of arrowheads made from blades, and tanged points. The archaic-looking pottery is made from silty clay tempered with organic matter, fish scales, and bone. The early vessels are small, with straight or S-shaped rims, flat or conic bottom. They are ornamented with imprints of pits, notches, incised and lines forming rows, rhombi, triangles, and zigzags. More complicated patterns appeared at later stages.

The sample contains eight dates, five of which can be assumed to be coeval, since they group within a narrow age interval, with a mean age and standard deviation of

$$T_0 = 6910 \pm 58 \text{ BC}.$$

The remaining dates are older (8025–7475 BC).

Rakushechnyi Yar

Rakushechnyi Yar is a clearly stratified Neolithic settlement located on a small island in the lower stretches of the River Don, ca 100 km upstream from the city of Rostov, which has 23 archaeological layers (*Belanovskaya 1995*). The deepest levels (23–6) belong to the Early Neolithic. The levels are 5–15 cm thick and separated by sterile sand or silt. The archaeological deposits, which are not identical in each layer, allegedly resulted from seasonal occupations. Fireplaces and the remains of surface dwelling structures occur in several levels. Animal remains consist of both wild (red deer, roe deer, fox, hare, numerous birds) and domesticated species (sheep, goat, cattle, dog and horse – either wild or domestic). Numerous shells of edible molluscs (mostly *Viviparus*) indicate the importance of food gathering. The flint industry includes end scrapers made from blades and flakes, retouched blades, and borers. Arrowheads and geometrics (symmetrical trapezes) occur only in the upper levels. The pottery is often tempered with organic matter and includes both flat- and pointed-bottom varieties. Their ornamentation is usually restricted to the upper part of the vessel and consists of triangular notches forming horizontal rows, small pits, and incised lines. The developed character of the material culture and the apparent absence of Mesolithic elements imply that Rakushechnyi Yar is not the oldest Neolithic site in the area; its preceding stage remains to be found.

Two Early Neolithic sites, Matveyev Kurgan 1 and 2, are located in the valley of the Miuss River, on the littoral of the Azov Sea (*Krizhevskaya 1992*). Site 1 includes the remains of a surface dwelling with hearths and post-holes, as well as an open, allegedly ritual fireplace. At Site 2, open fireplaces and large stone and clay inlays were found. The animal remains from both sites are dominated by wild species: aurochs, red deer, roe deer, beaver, wolf, wild boar, kulan, and wild ass (the latter two were more typical of the Mesolithic age). The domesticates, which formed 18–20% of the total assemblage, include horse, cattle, sheep/goat, pig, and dog.

Both sites contain rich lithic industries, with no less than 600 cores (both single- and double-platformed); elongated broad blades and less numerous flakes dominate the assemblage. End scrapers, made from large flakes, and retouched blades, were found, with various blade tools. There are about 90 geometric microliths, mostly trapezes, both symmetric and asymmetric. Several 'bifacial' flint axes were reported, yet the number of slate polished axes is much larger. The diverse bone-and-antler industry found at the both sites includes spear- and arrowheads, awls and their fragments. Both sites yielded slate sinkers for fishing nets. Only a handful of pottery items were found at each site: 6 fragments at Site 1, and 21, at Site 2. The pottery fragments were unornamented and manufactured from silty clay with no apparent artificial tempering.

The sample contains 10 dates from the lower layers (the Early Neolithic), of which six dates satisfy the criterion for contemporaneity, yielding

$$T_0 = 5863 \pm 130 \text{ BC}, \quad \sigma_c = 247 \text{ years}.$$

The remaining dates include one younger date (5000 BC) and three older (6550–6850 BC).

Bug-Dniestrian

The Early Neolithic in the western Ukraine and Moldova is usually associated with the sites of the Bug-Dniestrian Culture (*Danilenko 1969; Markevich 1974*). About 40 sites belonging to this culture are located on the lower terraces of the River Dniestr (Nistru) and its tributaries, and on the River Pyvdenyi Buh, in their middle courses. Thin archaeological deposits are found in the matrix of silty loam, often interbedded with alluvial sediments. The remains of an oval-shaped semi-subterranean dwelling and a rectangular surface dwelling were identified at the Soroki 1 site on the Dniestr. At early sites, about 80% of animal remains belong to wild species, mostly roe deer and red deer. Among the domestic animals, pig, cattle and (on later sites) sheep/goat have been identified. The archaeological deposits contain huge amounts of *Unio* molluscs and tortoise shells. Roach (the most common), wells and pike were found among numerous fish bones. Birds such as sparrow hawk, honey buzzard and wood pigeon have been recorded. Remarkably, impressions of three varieties of wheat were found on the pottery: emmer, einkorn, and spelt.

The flint industry was based on the prismatic core technique, with the common occurrence of retouched blades, backed blades, and small-size circular end scrapers. The numerous shapes include trapezes and triangles. Several blades at Soroki 1 show a sickle gloss. The Bug-Dniestrian sites include bone and antler implements: points, awls, mattocks, chisels, and 'hoe-like' tools. Polished stone axes, pestles, and querns were found at a number of sites.

The pottery corpus for the early Bug-Dniestrian sites includes deep bowls, with an S-like profile, and hemispherical flat-bottomed beakers made of clay tempered with organic matter and crushed shells. Ornamental patterns consist of rows of shell-rim impressions, finger impressions, and incised lines forming zigzags and volutes. Remarkably, several patterns find direct analogies in the 'monochrome' pottery of the Balkan Early Neolithic (Starčevo-Cris Culture). Imported potsherds of Linear Pottery (with 'music-note' patterns) were found at several sites on the Pyvdenyi Buh River belonging to later stages of Bug-Dniestrian Culture.

The sample contains a total of 7 date measurements from the sites on the Pyvdenyi Buh. All seven dates satisfy the statistical test for contemporaneity, with

$$T_0 = 6121 \pm 143 \text{ BC}, \sigma_c = 101 \text{ years.}$$

Early Neolithic Cultures in Forested Central and Northern Russia

The early Neolithic in the central part of the East European Plain exhibits several stylistic varieties of 'notch-and-comb decorated pottery', including the Upper Volga and Valdai cultures. The Upper Volga Culture consists of small-size sites usually found along the rivers of the Upper Volga basin, on lake shores, and in bogs and mires (*Krainov 1996*). The subsistence of Upper Volga groups was based on hunting (elk, red deer, roe deer aurochs, wild boar, and other wild forest animals), supplemented by fishing and food-collecting. The flint industry was based on blade blanks (rarely flakes); the occurrence of the 'Post-Sviderian' points indicates its genetic relationship to the Late Mesolithic (Butovian) tradition. The early types of pottery consist of small vessels (15–30 cm in diameter) that are either conical or flat bottomed, and made of chamotte-tempered clay. They are ornamented with impressions of notches, combs, cords and incised lines that form simple geometric motifs. Starting with the culture's middle stage, small round-bottomed cups appear, and mineral tempering becomes more frequent. Flat-bottomed vessels disappeared at a later stage.

The temporal division of the Upper Volga Culture is based on the sequences of stratified bog and mire sites (Ivanovskoe 3, Sakhtysh 1, Yazykovo, etc.). In these sequences, the Upper Volga deposits are found beneath the strata of the Lyalovo Culture that feature the pit-and-comb pottery. Previously, this culture was considered to be the oldest Neolithic entity in Central Russia.

The sites of the Valdai Culture are located along water channels and lakes in the upper stretches of the Volga, Lovat, Western Dvina and Dniepr rivers, within the Valdai Hills in Central Russia (*Gurina 1996*). This area is rich in outcrops of high-quality flint. The original flint industry includes circular end scrapers manufactured from elongated flakes, and large-size axes and chisels. It also includes Post-Swiderian points. The technology, forms, and ornamentation of the Valdai pottery are fairly similar to those of the early Upper Volga.

The sites of Sperrings Culture (or the Style I:1 according to Finnish writers) are located on ancient sea and lake shore-lines in a vast territory encompassing southern and central Finland and Ladoga and the Onega Lake basins in Russian Karelia (*Oshibkina 1996b*). The pottery corpus consists of large conical vessels, with straight rims decorated with impressions of cord, incised lines, and pits forming a simple zoned ornament. The lithic industry manufactured from quartz, schist, and rarely, flint, (presumably imported from the Upper Volga) retains a Mesolithic character. Earlier age assessments based on the gradients of the shore-line displacements (*Siiriäinen 1970*) have placed the I:1 Style in Finland into a time range of 4100–3000 BC.

Several Neolithic in the extreme north-east of European Russia, on the Pechora and Northern Dvina Rivers form the Chernoborskaya Culture (*Luzgin 1972; Vereshchagina 1989*). The stone inventory of these sites has a Mesolithic character, while the pottery reflects Upper Volga and Valdai influences.

The sample used here contains 55 radiocarbon date measurements. They include a series of dates from the stratified wetland sites of the Upper Volga Culture: Ivanovskoe 2, 2a, 3 and 7, Berendeevo 1 and 2a, and Yazykovo. The sample also includes dates

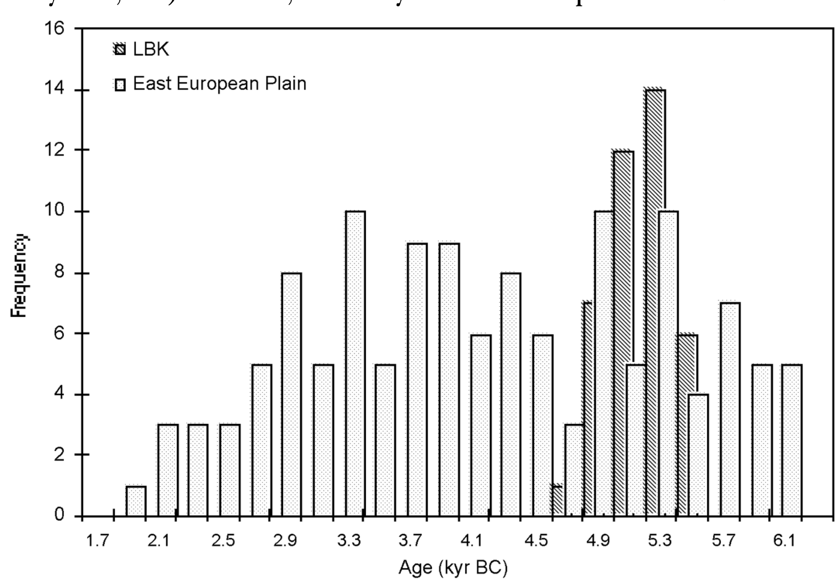

Fig. 2. The rate of occurrence of Neolithic radiocarbon dated sites on the East European Plain (light grey) and the coeval subsample of the LBK dates, as in Fig. 1 (dark grey).

for the Valdai Culture sites, which several writers consider to be related to the Upper Volga. We also include several dates from the Sperrings sites (located in Karelia), as well as two dates from Chernoborskaya-type sites in the Russian North-east.

Thirty-two dates satisfy the statistical test for contemporaneity and yield

$$T_0 = 5417 \pm 30 \text{ BC}, \sigma_c = 160 \text{ years}.$$

The remaining dates include those which are older (5800–6200 BC) and younger (4200–5200 BC) than the coeval sample.

The Neolithic of the East European Plain: the total sample

Our selection of Neolithic dates for the East European Plain as a whole contains 129 measurements presented in Table 1 and Figure 2. The data set exhibits a temporal structure with several broad maxima. One of them, at 5300–4900 BC, is remarkably close to the coeval LBK subsample discussed above, in both mean age and width.

DISCUSSION

According to Childe (*Childe 1958.110*), the LBK was 'made by ... farmers spreading from the southern cradle of cereals'. This view was corroborated with the use of the model of 'advance of advantageous gene', which asserted that early agriculture was brought to Europe by the descendants of Middle Eastern farmers who completely overran the indigenous Mesolithic population (*Ammerman and Cavalli-Sforza 1973*). An alternative hypothesis (well known to, but rejected by Childe) viewed Neolithization as the result of the adoption of farming by local hunter-gatherers (*Wittle 1996*). This has been substantiated by the finds of Late Mesolithic Danubian points found at LBK sites (*Street et al. 2002*). Another scenario has been suggested, where the spread of the LBK involved small groups of immigrant farmers who encountered 'local forager-herder-horticulturalists' (*Gronenborn 1999; Price et al. 2001*). The latter view is strengthened by the discovery of a distinct 'La Hoguette' pottery at several LBK sites in its north-western area. It is represented by pots of clay tempered with crushed shells and bone that have a conical, round-bottomed shape and are decorated with garlands of comb-like impressions (*Van Berg and Hauzeur 2001*). At the site of Place Saint Lambert in Belgium, La Hoguette pottery has been found in a Late Mesolithic context, yet with predominantly domesticated animal remains (*Van Berg and Hauzeur 2001.70*). Another cultural variety, the Limburg Group in the area of the Maas River, also supposedly belonged to a culturally distinct population. Being familiar with agriculture, this group coexisted, interacted and outlasted the LBK (*Modderman 1964*).

The emergence of numerous radiocarbon dates has sufficiently modified the earlier chronological schemes for the LBK. It is argued (*Price et al. 2001*) that the 'initial' LBK appeared in Hungary at around 5700 BC and spread further west. Using 'traditional' radiocarbon dates, it has been suggested (*Gronenborn 1999.156*) that the earliest LBK sites appeared in Transdanubia at around 5700–5660 BC, and reached Franconia around 5500 BC. However, our analysis does not reveal any temporal structure in the entire sample of LBK dates for Central Europe. Forty out of 47 LBK dates in our sample satisfy the criterion of contemporaneity, forming a Gaussian distribution spread from 5600–4800 BC (2σ range), with the most probable age of 5154 ± 62 BC. Our analysis indicates that the LBK propagated as a single-phase process that cannot be subdivided into distinct events (using radiocarbon dating alone); this is the reason most of the LBK sample can be characterized in terms of a single date (corresponding to the culture peak) with a relatively small error. In this sense, the spread of the LBK culture across the loessic plateaux of Central Europe had the character of a single event. Our results do not rule out the possibility that local Mesolithic groups participated in the process.

The resulting lower estimate of the rate of spread can be obtained from the width of the above probability distribution. With the largest dimension of the LBK region of about 1500 km (from Transdanubia to Franconia) and the time taken to spread over that area of about 360 years (twice the standard deviation of the dates in the coeval LBK sub-sample), the lower limit for the propagation rate of the LBK is obtained as about 4 km/yr. This value is consistent with the earlier estimates of about 6 km/yr (*Ammerman and Cavalli-Sforza 1973; Gikasta et al. 2003*) for a significantly larger region. The LBK propagation rate is in striking contrast to other European Neolithic spread rates of 1 km/s.

The probability distribution of radiocarbon dates for individual Neolithic entities on the East European Plain reveals a different spatio-temporal structure

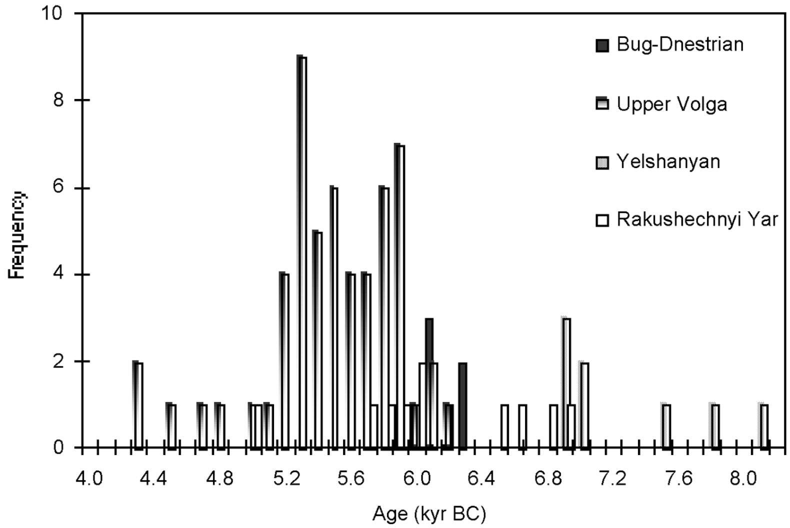

Fig. 3. The rate of occurrence of radiocarbon dates for distinct cultural entities on East European Plain.

emanating from the Eastern steppe area.

Recent evidence shows a very early appearance of pottery making in an area further east, stretching along the southern edge of the boreal forest in Eurasia (*Van Berg and Cauwe 2000*). This includes Jomon Culture in Japan, with the earliest 'incipient' stage at ca 11 000 BC (*Aitkens and Higuchi 1982*). An early centre of pottery making of an even earlier age (13 200–12 900 BP) has been identified in the lower stretches of the Amur River (*Derevyanko and Medvedev 1997; Kuzmin and Orlova 2000*). A group of early pottery sites in the Trans-Baikal province in southern Siberia (Ust-Karenga, Ust-Kyakhta and Studenoye) has yielded a similar age (*Kuzmin and Orlova 2000*). At these sites, subsistence was based on hunting-gathering and the intense procurement of aquatic resources. These pottery assemblages are stylistically unrelated and are believed to be local inventions (*Khlobystin 1996*). One may only speculate that pottery making developed independently in the context of broad-spectrum hunter-gathering economies with reliance on aquatic resources. This technical novelty initially emerged in the forest-steppe belt of northern Eurasia

extended over a long time interval. Our statistical age estimates for key cultural entities indicate that they form a clear temporal sequence from Yelshanian (6910 ± 58 BC), through Bug-Dniestrian (6121 ± 101 BC) and Rakushechnyi Yar (5846 ± 128 BC), to the Upper Volga and other 'Forest Neolithic' cultures (5317 ± 30 BC) (Fig. 4). The rate of spread of the pottery bearing cultures in East European Plain, estimated from the extent of the region involved (ca 2500 km for the distance from Yelshanian via Bug-Dniestrian to Upper Volga) and the time of spread (ca 1600 years, the time lag between the Yelshanian and Upper Volga cultures as estimated above), is about 1.6 km/yr. This is significantly smaller than the rate of spread of the LBK and yet comparable to other European Neolithic rates. This fact stresses again the unusual nature of the LBK. On the other hand, the comparable magnitudes of the rates of spread of farming in Western Europe and ceramics production in Eastern Europe are compatible with – although do not prove – their common Neolithic nature.

Our results reveal a clear spatio-temporal trend indicating that the Yelshanian–Rakushechnyi Yar temporal sequence (perhaps including the earlier Bug-Dniestrian) exhibits systematic propagation from the east, and so can be a manifestation of an impulse

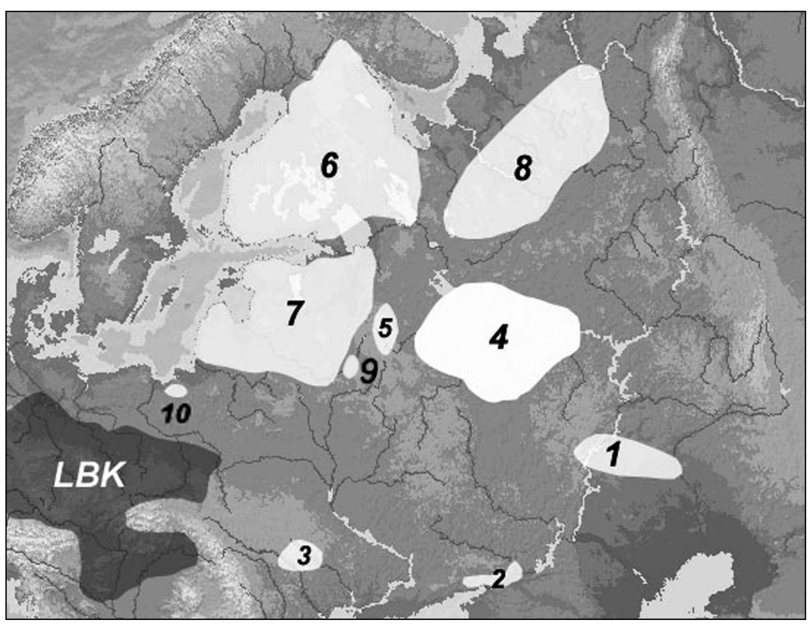

Fig. 4. Early Neolithic cultures in central and eastern Europe: Linear Pottery Culture (LBK); Yelshanian (1); Rakushechnyi Yar (2); Bug-Dniestrian (3); Upper Volga (4); Valdai (5); Sperrings (6); Narva (7); Chernoborskaya (8); Serteya (9); and Zedmar (10).

starting at 11 000–10 000 BC, and spread to the west to reach the south-eastern confines of the East European Plain by 7000–6000 BC.

The group of dates at 5300–4900 BC apparent in Figure 2, largely belongs to the Upper Volga and other early pottery-bearing cultures in boreal central and northern Russia. This is also the epoch of the LBK in Europe. Significantly, this period corresponds to the Holocene climatic optimum, characterized by a maximum rise in temperature and biological productivity in the landscapes of both Central and Eastern Europe (*Peterson 1993*).

A currently advanced model (*Aoki et al. 1996*) can be relevant in explaining these phenomena. These writers model the advance of expanding farmers accompanied by the partial conversion of the indigenous population into farming. The intruding farmers can spread either as a wave front or as an isolated, solitary wave. However, either intruding or converted farmers remain behind the propagating wave (front) in both cases. There are no definite signs of widespread farming in the East European Neolithic sites, even though there is clear evidence of the interaction of hunter-gathering and farming communities. This suggests a distinct scenario where an advancing wave of farming is not accepted by the local hunter-gatherers, but still results in demographic and cultural shifts. This approach can be further developed to incorporate the advantages of the wave of advance, adoption and other models in a single mathematical framework. A reliable assessment of these possibilities requires further analysis, including detailed numerical simulations.

ACKNOWLEDGEMENTS

This work was partially supported by INTAS Grant 00-0016.

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