Impacts of the Neolithic Demographic Transition on Linear Pottery Culture Settlement

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Abstract This study aims to look for a new signal of the demographic transition linked in time to the installation and development of an agro-pastoral lifestyle. Demographic growth has always been a component of models for the spread, during the second half of the sixth millenium BC, of the Linear Pottery Culture (LBK), and the analysis of the space–time distribution of sites appears to confirm the hypothesis. Now a different signal is used here to examine in terms of quantitative trends the strength and rate of supposed growth: household size, measured by house groundplan surface-area. This criterion is particularly suitable because the data for houses are more accurate and manageable on a large scale than the data for the sites themselves. Thus the research issue can be addressed with a representative and uniform sample.

While the demographic transition is a phenomenon in itself, its coherence can best be gauged by measuring the time passing (dt) after the start of the process in each locality (time zero: $t0$). The intention here is to look for intrinsic trends in the strength and rate of the process.

Using time-spans of 100 or 50 years, changes in the ground surface-areas of 505 houses (433 for the shorter time-span) from the different regions of LBK Europe show a curve with a sharp increase in the first two centuries of a Neolithic economy, with values falling back over the following one or two centuries. A possible rise occurs again up to 450–500 years after the start of the process, but the evidence for this needs completing. So it seems that the average size of the "family" living under the same roof (household) increases considerably for two centuries after $t0$ and then decreases, before rising again at roughly $d\text{t} = 500$.

This growth and decline is visible at a continental scale, as well as at local (Bylany, Merzbachtal) and subregional scale (Aisne, Meuse/lower Rhine), in the same rate and proportions. The trend thus appears universally valid for the LBK.

The local data (Merzbachtal) suggest two correlated phenomena: a population density threshold per village and community fission once this was crossed. Further evidence suggests that the process involved the largest households rather than the

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village itself, although this must remain a working hypothesis for the moment. These phenomena may well explain the rapid and widespread nature of LBK dispersal.

Finally, a broad overview of the historical and environmental context reveals a good match between the "universal" demographic trend proposed here and the main climatic and culture-historical changes affecting the LBK. Rather than evoking simple ecological determinism, quite contradictory to the data assembled in this study, this highlights the ability and adaptability of the first farming communities in central and western Europe.

Keywords Climate · demographic pattern · ground surface-areas · household · linear pottery culture (LbK) · local dating · neolithic · population · settlement

In Search of New Demographic Signals in Archaeological Data: LBK Settlement

The hypothesis of population growth has existed since the beginning of research on the emergence and development of an agro-pastoral economy. As an integral part of the demic diffusion model (Ammerman and Cavalli-Sforza 1971, 1973, 1979; Ammerman 2003), this hypothesis naturally underlies interpretation of the spread of the Linear Pottery Culture (LBK) as a colonization process. Of particular interest to us here, the LBK phenomenon has been the object of a general demographic overview (Lüning 1998), based on an estimation of numbers of sites and houses to reconstruct population density. The suggested population level (1 to 2.5 million people at the height of the LBK) gives a fair indication of the size and scale of the historic phenomenon under consideration. The question of demography has also been addressed in various ongoing regional projects examining settlement (Hesse, Souabe), even though this aspect is not always the main goal of research.

Thus the information we are currently able to use comes basically from the distribution of sites in space. Yet, in the opinion of many researchers, our large-scale knowledge still remains superficial and imprecise, limiting our capacity to construct reliable models of general value.

Recent paleo-demographic work (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006) has produced an original interpretation of the Neolithic transition, broadly applicable to a variety of spatio-temporal situations. Having been marginally involved in this research (Bocquet-Appel and Dubouloz 2003, 2004), I soon realized the interest and usefulness of looking for new demographic signals in archaeological data. The idea pursued here is that once signals of population growth in various categories of archaeological information have been identified, and the reality, strength and rhythm of these signals measured, one can then go on to examine the range of socio-cultural responses.

At first glance, settlement seems one of the areas most concerned by this issue, and in western Europe it is clearly the LBK that offers the best possibilities for this kind of study.

Now, to examine in terms of quantitative trends the strength and rate of the supposed growth, I shall use here a new signal: household size, measured by house groundplan surface-area. This criterion is particularly suitable because the data for houses are more accurate and manageable on a large scale than the data for the sites themselves. Thus the research issue can be addressed with a probably more representative and uniform sample. By initial assumption, house groundplan surface-area is supposed to be linked, at least partially, to the number of people living under the same roof. And, at the same time, these people are supposed to represent a basic and coherent socio-parental segment within the community. At this point, we can believe that the LBK household and its size variation through time are related in some way with broad demographic evolution.

Background on the LBK

The LBK constitutes the first major manifestation of a Neolithic, agro-pastoral way of life in central, west-central and western Europe (Lichardus and Lichardus-Itten 1985; Lüning 1988). It developed through the entire second half of the sixth millennium BC and is characterized by a surprising abundance of remains, with particularly good evidence for settlement organization. A large proportion of the LBK can be considered as a 'demic' phenomenon (Bogucki 2003), even if some acculturation may have taken place, involving particular aspects which will not be developed further here (Whittle 1996; Gronenborn 1999).

– Variability of the LBK house: size and function

The LBK house is known for its standardization (Coudart 1987; 1998). Indeed, one same architectural conception seems to structure the vast majority of houseplans, recovered at least partially by thousands on hundreds of sites. We can recall here the long, rectangular shape of the groundplan, the large numbers of posts set deeply into the ground, the longitudinally arranged beams, the non-load-bearing walls, the presence of external lateral pits and the proportionately stable tripartite division of internal space.

The internal organization of the LBK houses, however standardized it may be, also includes a certain variability. Besides the predominant tripartite groundplans, there are also bipartite and monopartite variants. The front part of a house (identifiable only with the tripartite groundplans), includes the one recognizable entrance and can include posts supporting an extra floor, termed "granary". The front part is generally assumed to be non-residential. The central and back parts of each house, either connected or separate, are considered as areas for receiving visitors or for sleeping. The question of an area reserved for animals has often been debated, but so far there are no decisive arguments in favor of such an area. The arguments against are in fact more convincing: the absence of a specific entrance, the unsuitability of the internal space for large-horned animals and the lack of traces of stalling on the animal bones. On this subject, I share the opinion that these buildings were constructed for people, although it seems likely at this time that certain young, fragile, or small animals may occasionally have been kept indoors in a non-specific part of the house.

The standardization also includes great variability in size: the length of the buildings varies a great deal (from ≈ 7 to ≈ 40 m), while the width is relatively constant (≈ 4.5 to ≈ 8m). This variation, in terms of floor surface-area, is of particular interest to our study.

– Variability of the LBK village: duration and hierarchy

As with the house-plans, the LBK village shows a certain standardization, with variability notably involving village duration and position in the settlement system. Some sites lasted continuously for several centuries and seem to play an important role in the local organization of settlement (Zimmermann 1995), especially with regard to long-distance exchange. Other short-lived and more peripheral sites were only a generation long: they must reflect the economic and demographic respiration of the LBK system. The average number of contemporary houses revolves generally around 5–7, with a few peaks at over 10 and a some minima at 2–3. In almost all cases, we are dealing with a hamlet rather than a village in the strict sense of the word.

When the evidence is complete, the duration of occupation on these sites and the relative and absolute dating of the houses which make up the different phases in development can be precisely estimated. Several case studies are available (Bylany, Langweiler, Cuiry-lès-Chaudardes, for example) where the temporal resolution of the data is about a generation (17–18 to 25 years); in other cases we must content ourselves with a resolution to the century. Unfortunately too often, the evidence only permits a broad dating of all or part of a site; in this case the individual houses belonging to the occupation cannot be placed in chronological order with certitude.

– Variability in the LBK settlement pattern: density and duration

A third level of variability should be rapidly evoked in order to circumscribe the conditions of our study. The LBK population zones, spread out over $700,000\,\text{km}^2$, show differences of duration and site density between themselves and between the sectors of actual settlement within these zones. The rate and intensity of occupation was thus variable, involving both short-distance and long-distance expansion (Bogucki 2003). These different impacts are interesting in terms of the variability in population density.

Hypothesis

Given the variability of the house, village and settlement pattern, it is not easy to assess the demographic developments suggested only by the study of the geographic distribution of LBK sites during the half-millennium in question (Lüning 1998). Admittedly, the increasingly widespread dispersal of the LBK cultural and economic system, as well as the dense settlement of the most favorable geographic sectors, cannot have taken place without population growth. However, it is not possible to accurately evaluate the strength and rate of this growth. Indeed, we are far from knowing how many houses are hidden beneath each site marked on a map, how many houses are contemporary, how many villages coexisted at different moments in time, or the duration of each house and village. Detailed evidence currently available at various spatial scales (Bylany, Merzbachtal, Aldenhovener Platte, the Aisne valley) is still too sparce and uneven to support a reliable and precise understanding. New micro-regional and regional projects, in Hesse (Ebersbach and Schade 2004; Schade 2004) and on the Danube (Knipper et al. 2005), based on systematic survey around a few extensive excavations, will surely contribute to improving precision and reliability.

Therefore, population growth during the LBK is a reasonable hypothesis, though difficult to elaborate solely from these quantitative data currently available. In order to bypass this difficulty, I propose to use a criterion related to demographic factors which is more easily definable and measurable than the sites themselves: the household size, measured by house groundplan surface-area. It is therefore necessary to establish a sample of houses which is the most representative possible of the spatial, temporal and functional variability of the LBK.

– House surface-area representative of the number of occupants

The initial hypothesis supporting such a selection of samples is, as we noted before, simple and almost trivial: surface-area is proportional to the number of occupants. This equation has already been tested in ethnography by different authors (Narrol 1962; Casselberry 1974; Cook 1972) and the results used in archeological research on the LBK (Soudsky 1969; Milisauskas 1972; Bakels 1978; Coudart 1998). Beyond a few practical formulas, these ethnographic studies underlined the importance of the socio-cultural context in looking for the rules of correlation between surface-area and the number of occupants. Thus, what emerges from this approach is that there are probably no general rules in this matter, but only select rules.

The small exercise summarized in Table 1 perfectly illustrates the illusory character of a precise evaluation of the numbers of occupants in a LBK house: the estimations can vary by a factor of three and their application to parts considered as truly residential sometimes produces unlikely results (2–3, 5–4).

But the exact figures here matter less than the correlation occupant/surface-area itself, and we shall thus consider that a large house corresponded to a larger population than a small house.

– Which surface-area? total vs. back-central

In their hypotheses on the tripartition of the LBK house-plan, specialists of the central European early Neolithic only consider the central and/or back parts of the

Table 1 Estimation of the number of occupants of an 80m² LBK house, using three ethnographic formulas

$80\,m^2$ house	Naroll (1964)	Casselberry (1974)	Cook (1972)
Back part	2	3,5	6,5
Central part	4	6,5	9
Back + central parts	6	10	11
Total	8	13	13

houses as having a truly residential function (Soudsky 1969; Coudart 1998). The analysis of the surface-area of these two parts alone would thus seem well adapted to our problem, especially since the uninhabited front part varies to a great extent; it can be absent, include a simple hallway or support a vast raised granary. On the other hand, the total surface-area of the house is easier to estimate, in a larger number of cases, and with a more reliable margin of error: when the groundplan of a house is not completely preserved, the possible error in calculating its total surface-area is proportionally less than for one of its parts.

Detailed research already undertaken on LBK architecture (Brandt 1988; Coudart 1998) shows that it is possible to use the criterion of total surface-area. Indeed the number of distinct internal spaces varies with the length of houses, jointly increasing or decreasing the number of available "rooms"; the number of rooms also varies with the length of each of the 'residential' parts.

Based on a credible sample stemming from the database of the present study (Langweiler 8 and Cuiry-lès-Chaudardes), it can be shown that variations in the total surface-area perfectly match those of the surface of the back part and the central part ($r = 0.92$ and 0.97). Hence, when the total surface-area of the house increases, the surface-area of the parts considered as truly inhabited also increases. The analysis even shows that this increase is broadly proportional, the share of each of the considered parts remaining stable. The statistics allow us to assess the proportions in relation to total surface-area, centering on 25% for the back part and 50% for the central part, with a sound concentration around these values.

Thus, it is through the architectural rules of the LBK house and the cultural standards underlying its conception that we find the best validation for choosing the total surface-area as a relevant criterion for our argument.

The Database

Gathering data on a vast sample of LBK houses for which surface-areas could be estimated seems a relatively easy task: are there not thousands of houses on hundreds of sites? Nevertheless, the hypothesis underlying this study and its examination of the rate and strength of the supposed phenomenon imposes considerable constraints which greatly restrict the number of potential examples that can be used. Thus, in order to be analyzed with this conception and methodology, an LBK house has to meet several requirements in terms of preservation, representativity and datation.

Constraints

– Preservation of houses and contemporary groups

The first constraint lies, as can be expected, in the preservation of the house-plans. To estimate the total surface-area of a given house implies that we have reliable knowledge of its total length and average width. Only a small proportion of the available data completely fulfills this requirement. Fortunately, the well-known and previously evoked unchanging architectural rules allow us to add less well-preserved houses to the initial database. For example, thanks to stability in the proportions of the various parts of the houses, it is possible to complete a poorly preserved back part with acceptable reliability; or, thanks to the extent of the lateral pits, we can often define with good precision the position of a missing front gable and thus reconstruct the dimensions of the house with a low margin of error.

The second constraint constitutes the second important filter for our sample. Excavations of a certain scale and certain spatial coherence are necessary, but not sufficient, so that the variability in dimensions of contemporary houses can be identified: in fact, each building belonged to a variably sized group of contemporary houses, and this size variation is particularly relevant for our study. Single houses with insufficient evidence for their surroundings risk being unrepresentative of the occupation to which they belong. For this reason they are generally excluded from the sample.

– Temporal representativeness of the houses

As it involves measuring the chronological development of a criterion, the question of dating constitutes the third major constraint. In order to be integrated into the analysis, houses must be dated in relationship to one another. This rules out a number of sites for which the evidence is incomplete. The level of precision in dating varies from house to house and from site to site, depending on the quantity and the quality of finds. Thus there are series of houses dated to within a generation, and others dated more approximately to within a century. It is this last level of precision that has been retained as a filter of selection.

The Houses Sample

Five hundred and fifty house groundplans, from 44 different sites, went through this long and harsh sampling procedure. Among them, from 39 different sites, 478 houses belong to the true LBK and 27 to its immediate successor in the Paris basin (VSG: Villeneuve-Saint-Germain group). The latter increase the spatial and chronological range of observation in this peripheral region, without affecting the overall coherence of the study (Table 2). The LBK I houses of Schwanfeld, Bruchenbrücken and Mohelnice were retained in spite of their imprecise dating within this initial period of at least two centuries, and in spite of the incomplete evidence from these sites. They are included in the sample because they provide information on the earliest LBK. Other houses are also approximately dated: Hienheim, Orconte and Ecriennes in particular. The first doubtless belongs to the end of LBK IV; the others are broadly attributed to the main periods of occupation found on each site (LBK III or IV). Together with additional houses which will be mentioned later, these imprecisely dated buildings have not been used in a second level of more finer analyses.

Forty-five other post-LBK houses from the main area of the western LBK (from Slovakia to Dutch Limburg), and which only partially meet our requirements in the selection of the LBK sample, have been added to this main sample: they are not very numerous and concentrated in a single region, the German Lower Rhine (Table 3). In these two respects, their representativeness for the purposes of our study does not offer the same level of confidence as the LBK houses. While post-LBK architecture and hamlets recall the LBK, probable changes in the arrangement of domestic space,

Table 2 Distribution in time and space of the LBK houses analyzed

Areas	Sites	N sites	N houses	Periods
Slovakia	Sturovo *(Pavuk 1994)*	1	17	LBK III à IV
Bohemia	Mohelnice *(Tichy 1962)*, Bylany *(Pavlu et al. 1986)*	2	83	LBK I à IV
Little Poland	Olszanica *(Milisauskas 1976)*	1	12	LBK II à III/IV
Lower-Bavaria	Alteglofsheim-Köfering, Straubing Lerchenhaid, Landshut-Salmannsberg *(Brink-Kloke 1992)*, Hienheim *(Modderman 1986)*	4	37	LBK II/III à IV
Hessen-Main	Schwanfeld *(Lüning 1986)*, Bruchenbrücken *(Stäuble 1989)*	2	10	LBK I
Neckar	Gerlingen *(Neth 1999)*	1	24	LBK I à IV
Souabe	Ulm Eggingen *(Kind 1989)*	1	25	LBK III à IV
Lower-Rhine	Merzbachtal-LW2, 8, 9, 16, LB7, NM4- *(Boelicke et al. 1994; Brandt 1988; Farruggia et al. 1973; Kuper et al. 1977)*	6	79	LBK II à IV
Meuse	Elsioo, Stein *(Modderman 1970)*, Geleen JKV *(Louwe-Kooijmans 2003)*	3	87	LBK II à V
Alsace	Sierentz *(Lefranc 2001)*	1	9	LBK IV à V
Champagne	Orconte *(Tappret et al. 1988, 1991)*, Ecriennes *(Bonnabel et al. 2003)*	2	23	LBK III à IV
Seine	Aisne *(Allard 2005; Allard et al. 1997; Constantin et al. 2003; llett and Hachem 2001; llett and Plateaux 1995)*, Oise *(Bostyn et al. 2003)*, Seine *(Mordant 1991; Prestreau 1992)*, Yonne *(Delor 1991)*	15	99	LBK IV à V

Table 3 Distribution in time and space of the post-LBK houses analyzed

Areas	Sites	N sites	N houses	Periods
Lower-Rhine	Hambach 260 et 471 *(Dohrn-lhmig 1983), Inden 1 (Kuper et al. 1966; 1975), Aldenhoven 1 (Jürgens 1979)*	4	45	Grossgartach, Rössen

in the duration of use and in overall settlement pattern possibly limit the relevance of these houses for the present study (Kuper and Piepers 1966; Kuper and Lüning 1975). We shall thus use them as simple heuristic tools, potentially offering a wider scope to the hypothesis constructed for the LBK period.

Data Processing

Methodology

– Local dating: *d*t

Following the hypothesis that the demographic phenomenon is a process in itself, independent of geography and absolute chronology, I used the method of local dating initiated by J.-P. Boquet-Appel to highlight what he called the 'Neolithic Demographic Transition' (Boquet-Appel 2002; Boquet-Appel and Naji 2006). Because, at first, the actual time in which the phenomenon took place matters little, each element is thus dated by its temporal distance (*d*t) to the local starting date of the beginning of an agricultural way of life ($t = 0$). In this manner we can build a profile common to all the data directly connected to the temporal depth at every location and track down an 'absolute' signal of the effect of the new way of life on demography. This approach was also applied by the present author in a previous study on enclosed sites in the central-western European Neolithic (Boquet-Appel and Dubouloz 2003; 2004). Here, an LBK I house of Bohemia or Slovakia is dated in the same way as a house of the beginning of the Flomborn (LBK II) on the Rhine, and in the same way as a house at the beginning of the RRBP (LBK IV) in the Aisne valley.

– Simple statistics

In analyzing the duration of moderate values, the field of calculation is vast and sophisticated. We nevertheless contented ourselves with simple statistics: scatter plots, fitting curves, distribution histograms and correlation coefficients.

Scatter plots were used to distribute the values of surface-areas on the distance *d*t, first to within a century, then to that of a half-century for the houses best dated. These scatter plots were subjected to an adaptation by calculation through the Lowess smoothing procedure (similar to a moving average) and which allows us to define an average profile-trajectory of the data in time. This trajectory, which can be adjusted by the size of the windows allowing calculation of the successive averages (α), defines the general trends of point dispersal in the plot analyzed. Some frequency histograms served to describe certain distributions of relevant values and, from the initial stages of the analysis, the calculation of the correlation coefficient allowed to ensure on one point in particular the validity of a criterion in the selection.

First Level of Analysis: The 'Continental' Profile

LBK Houses on dt, Dated to Within a Century

The first researched profile was supposed to establish a comprehensive reference of our sample from the point of view of the surface-area variation of the houses in the local chronology; it was thus necessary to take into account the maximum amount of data in space and time. The dispersal of the values of the 505 LBK houses was analyzed according to the time-span of a century in order to take into account the

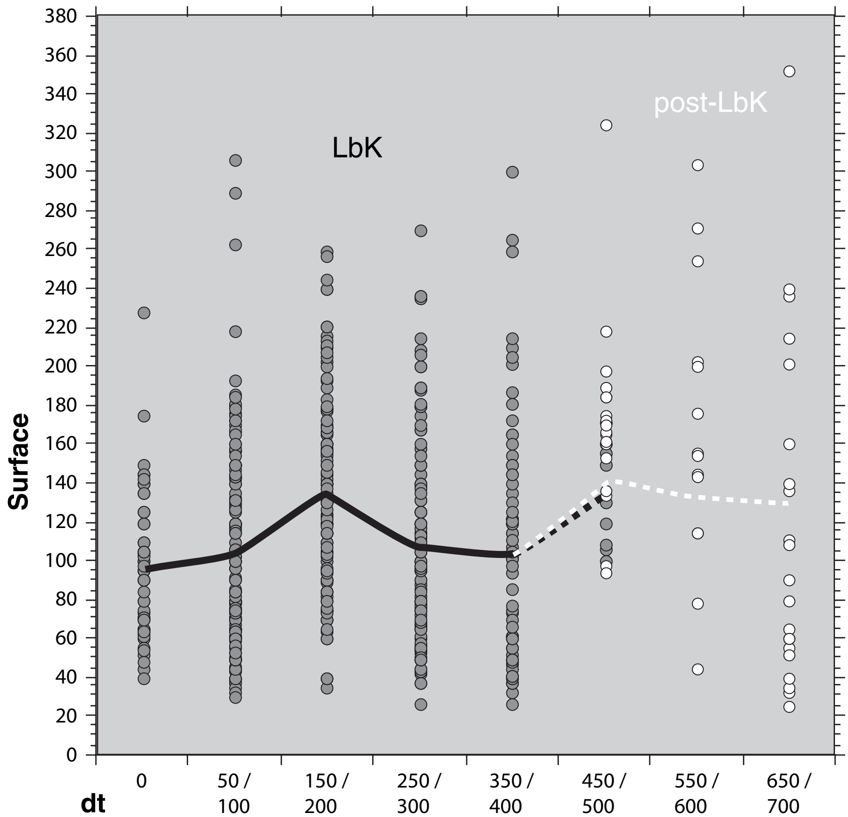

Fig. 1 Surface-area of 505 LBK houses by dt to the century with a Lowess smoothing of 25%

variable precision of the dating of each house (Fig. 1); the scatter plot was summarized by Lowess smoothing ($\alpha = .25$).

This profile, which I will call 'continental', shows a peak around dt = 200, followed by a decline before a possible increase around dt = 450–500. The first peak indicates, at each point of the area studied, a growth of more that 40% in the average surface-area of the houses for the first two centuries of the agro-pastoral economy. The decrease which follows seems statistically viable, though the final increase is only based on a restricted amount of data.

For general heuristic purposes, it is tempting to include data which allow us to follow the curve beyond 500 years (Fig. 1). There, we reach the post-LBK period, for which there are fewer and more diverse documents, probably less viable for the methodology of this project.

The projection of the surface-areas of these houses onto dt and the calculation of the Lowess curve seem to confirm an expected increase on the LBK houses themselves; it defines a new peak at dt = 450–500 years, before a period of possible stability lasting two centuries. With this latter observation, conjectural because based on sparce and poorly distributed data, we can establish a tentative 'continental' profile of about seven centuries; it shows a bi-modal evolution of the average surface-area of the houses and, by extension, of their number of occupants. Over two centuries, there was a 40–50% increase, followed by a decrease over the next two centuries; a century of new rapid growth then occurred reaching a stable level during two centuries.

LBK Houses on dt, Dated to Within the Half-Century

The wealth and the quality of the work on LBK data by several generations of European researchers enable us to employ a much finer chronology than the century-long units used above. Sometimes, local and regional analyses propose a dating to within ±20 years. For example, 14 successive settlement phases over about two and a half centuries (5300–5050 BC) for the LBK occupation of Merzbach valley – Lower-Rhine, Germany – (Stehli 1989); 25 settlement phases over about 450 years (5550–5100 BC) for the LBK occupation of Bylany – Bohemia, Czech Republic – (Pavlu et al. 1986); 5 settlement phases over about 100 years (5050–4950 BC) for the LBK occupation of Cuiry-lès-Chaudardes – Aisne, France – (Ilett and Hachem 2001). In other cases, the houses were only attributed to particular moments in cultural chronology: for example, the end of Flomborn, middle of LBK III, beginning of LBK IV, etc. and it is possible to transcribe this dating to within 50 years. This half-century dating span (2–3 settlement phases) was chosen to establish the most precise 'continental' profile in our selection (Fig. 2). The respective surface-areas of 433 LBK houses[1] are thus included here and summarized by Lowess smoothing ($\alpha = 0.27$).

[1] Houses dated at best to within a century are eliminated from this calculation: the others are from the Seine Basin, the Dutch Limbourg, the German lower Rhine, Bavaria (except Hienheim), Bohemia and Slovakia.

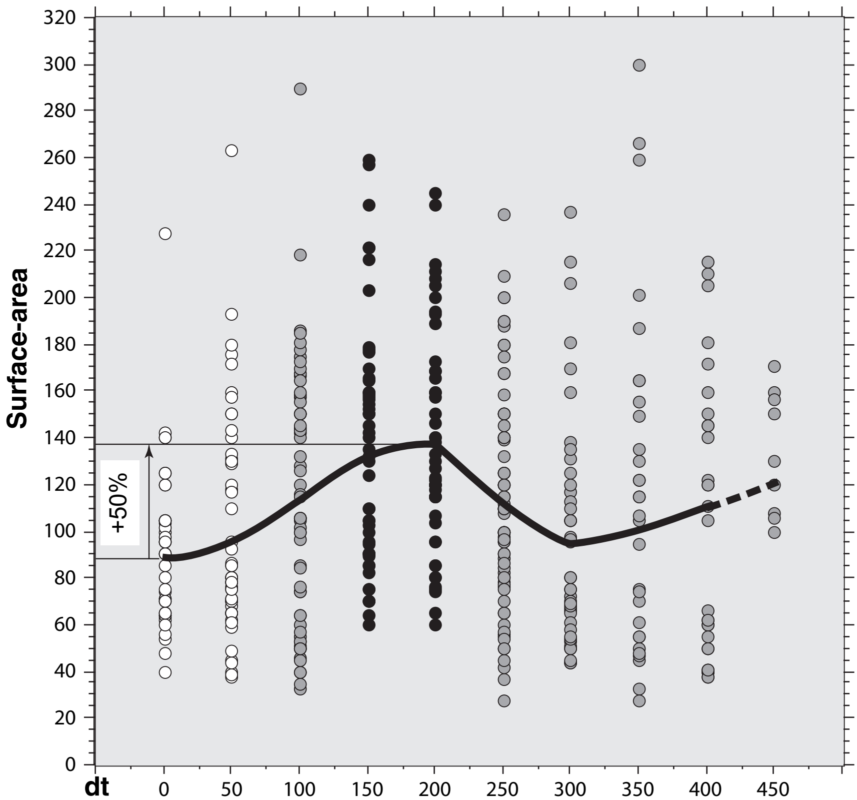

Fig. 2 Surface-area of 433 LBK houses on dt, to within a half-century, with a Lowess smoothing of 27%

A peak appears at $d\mathrm{t} = 200$, illustrating a 50% increase in the average surface-area area, followed by a decrease up to $d\mathrm{t} = 300$, then a probable rise by at least $d\mathrm{t} = 450$. The comparison through histograms of these surface-areas at $d\mathrm{t} = 0$–50 (86 houses) and $d\mathrm{t} = 150$–200 (91 houses) shows a very clear redistribution of values between comparable extremes (Fig. 3): the maximum peak of 55% of the houses between 50 and 100 m^2 at the beginning of the curve is followed by a maximum peak of 35% of the houses between 100 and 150 m^2 at the apex of the curve. One notes that the classes of larger surface-areas (150–200 m^2 and 200–250 m^2) are also reinforced according to the situation at the beginning of the curve – *40% (for larger surfaces) as opposed to a previous 12%* – confirming that there was an overall increase in the number of middle and large-sized houses over the first two centuries. This suggests that the domestic units and the families composing them had themselves increased in size. At $d\mathrm{t} = 300$–350, surface-area value distribution returns to what it was at the beginning of the process studied here, with a peak of about 50% of the surface-areas included between 50 and 100 m^2.

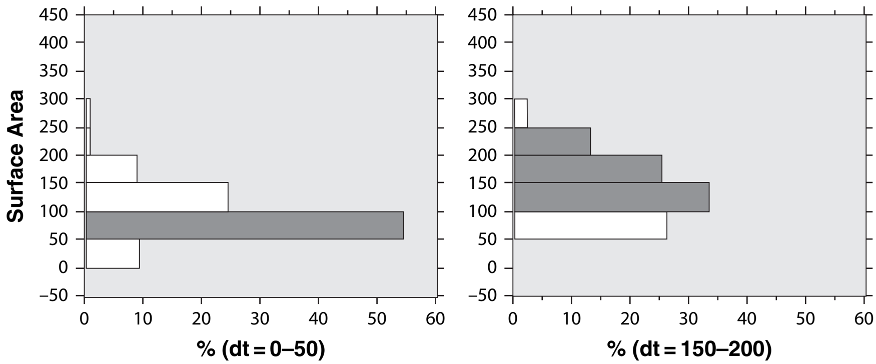

Fig. 3 Surfacce-area distribution at dt = 0-50 (86 houses, 14 sites) and dt = 150-200 (91 houses, 12 sites)

General Validation: Particular Profiles at Local, Micro-regional and Regional Level

As an evaluation of the validity and precision of the conclusions taken from a general profile of the data, one can now tie in the particular profiles from the three main spatio-temporal subsets in our sample (Fig. 4): the local subset of Bylany in

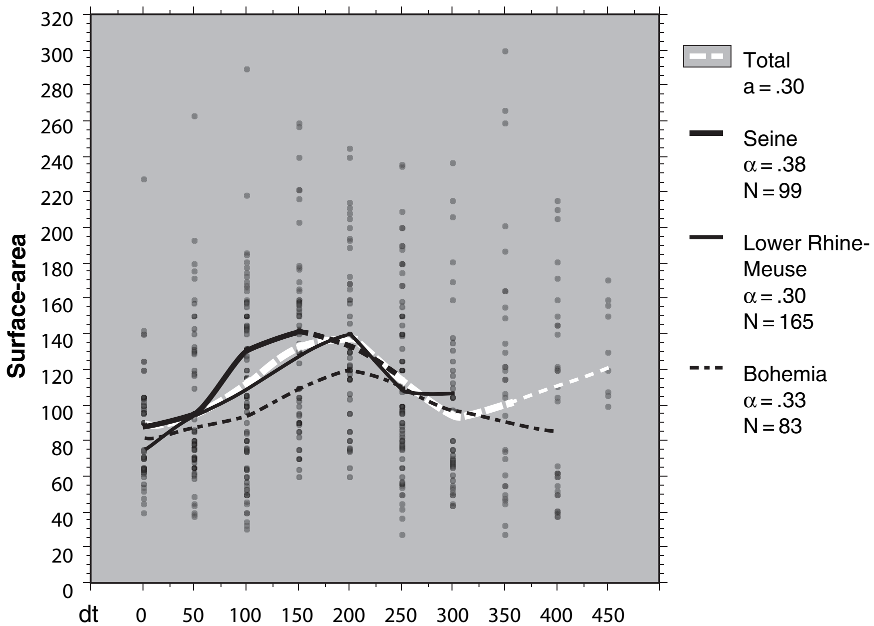

Fig. 4 Surface-area of 433 LBK houses on dt with Lowess smoothing for three principal selections

Bohemia (83 houses); the micro-regional subset of the Maastricht-Aachen region (165 houses) and the regional subset of the Seine Basin (99 houses).

As with the 'continental' profile, these three profiles, established respectively at $\alpha = .33$, .30 and .38, diverge little between each other; one peak takes shape at $d\text{t} = 150–200$ followed by a pronounced decrease in each case. One notes that the growth at the local level of Bylany is a little weaker than that of the sub-regional, regional and continental averages; and that growth occurs at a more rapid pace in the Seine basin, at the western edge of LBK dispersal. Beyond these differences which can be accounted for by several factors of variability – *quality of documentation, observable duration of occupation, size of the social integration area involved, dynamic of cultural dispersal* – the group shows an interesting coherence which validates the general curve as representative of the same observable phenomenon at different scales.

Regional Validation: Analyses of Local Examples (Aisne Valley, Merzbach Valley)

We shall now try to show how this broad and sound pattern appears at lower scales and how it matches with other characteristics of settlement data. As we will emphasize later, the amount of information available for the Merzbach valley is to date still exceptional. But extensive research initiated by B. Soudsky in the Aisne valley (Soudsky et al. 1982) and then undertaken for more than 30 years (Dubouloz et al. 2005), offers detailed evidence at a level spatially above that of the Merzbach: the micro-region.

Analysis of a Sub-regional Example: The Aisne Valley

– Surface-areas – Number of houses – Number of sites

The scope of research in this area is sufficient to affirm that the occupation and population density were lower than that of the classic settlement zones of the more eastern regions. Of course, the extent of our knowledge here is probably still partial and concerns a short duration – the last century of the LBK phenomenon (RRBP). However, the space concerned allows us to envisage the demographic question at the scale of a network of several micro-areas. Here, the archeological remains are still better preserved – more than 75% of the located houses can be studied with our criteria – and their dating is easier thanks to the less dense occupation (Ilett and Hachem 2001; Ilett and Plateaux 1995).

This information, very homogeneous in constitution – same team, same protocol – was analyzed within a supra-local perspective, the only spatio-temporal dimension really accessible.

The evolution of the physical and sociological sizes of the domestic units reveals itself well in the chronological phasing of this region (Fig. 5). Lowess fitting curve of the surface-areas of the houses (72 in number) shows an explosive growth in

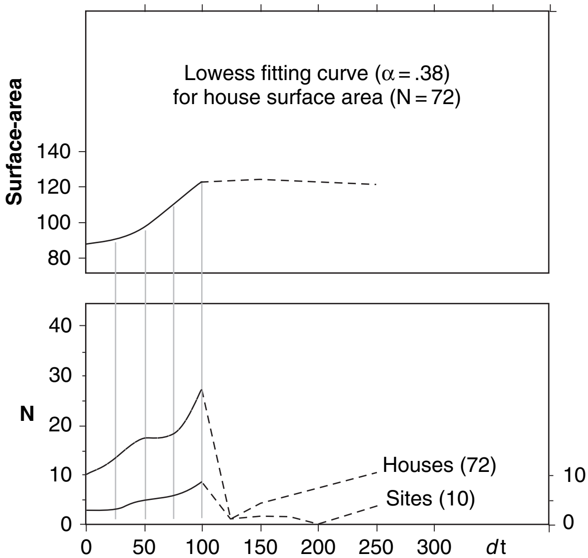

Fig. 5 Demographic signs at a regional level: synchronicity of the variations of three criteria in the Aisne Valley during the LBK

one century; the following of which is too poorly understood to be commented on. Curves of the number of sites and houses show an unequivocal synchronism with this figure: a rapid growth culminated around $d\text{t} = 100$. This would suggest that the local development of the Neolithic lifestyle brought first a rapid population growth, identifiable at the scale of the domestic unit, and a spatial expansion and densification of the LBK occupation (>40% increase in the size of the domestic unit, 300% increase in the number of houses, 300% increase in the number of sites, in one century). Thus, the data at this spatial scale reinforce the hypothesis of a general phenomenon connecting population growth and development of an agro-pastoral lifestyle.

Analyses of a Local Example: The Merzbach Valley

By their extent and precision of results, excavations and research on the Merzbach valley (Lüning and Stehli 1994) have remained a model study at the local level, in an area a hundred times smaller than the previous example. It remains today an essential reference for the economic and cultural phenomenon of the LBK. The hypothesis defended in the preceding analyses must therefore be challenged here, within a heuristic approach, by the best local data available.

– Surface-areas – Number of houses – Number of sites

The proportion of houses possible to study in the different sites of Langweiler, Niedermerz and Laurenzberg only reaches 50% of the total recorded number and certain phases are better allotted than others. To even out this quantitative weakness and neutralize the heterogeneity of the data, a re-elaboration of the chronological data was undertaken by regrouping phases into half-century units. The same procedure was used for the number of contemporary sites and the number of houses in order to construct again three comparable curves on the same timescale.

The evolution of the physical and sociological sizes of the domestic units can be seen rather well in the chronological sequence of this micro-area (Fig. 6). Lowess fitting curve of the surface-areas of the houses and the curves of the number of sites and houses show again an unequivocal synchronism: after a steady growth culminating around $d\mathrm{t} = 200$, the three curves collapse rapidly until an abandonment of the micro-area as a settlement zone. The situation appears to begin in a similar way to the Aisne valley: with the local development of Neolithic lifestyle, the population growth seen at the level of domestic unit first led to spatial expansion and densification of the LBK occupation, and therefore an increase in the number of sites and houses (>20% increase in the size of the domestic unit, 250% increase in the number of houses and a 500% increase in the number of sites, over two centuries). But secondly, the curves suggest a continuously rapid abandonment (an important decrease in the number of sites and houses) under the impact of a sort of local demographic crisis (an important decrease in the average size of the domestic units).

– Demographic evolution

An attempt will now be made to obtain additional information, by transcribing this evolution in terms of population numbers. For this, we need to balance

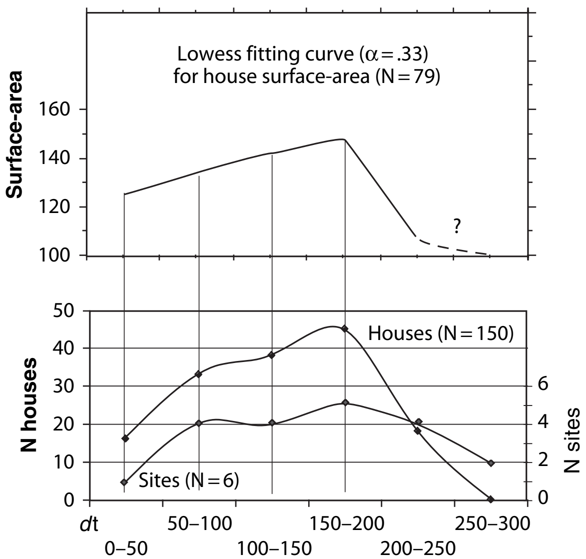

Fig. 6 Demographic signs at a local level: synchronicity of the variations of three criteria in the Merzbach Valley during the LBK

an average population base per household (p) with the evolution coefficient of the average surface-area (ΔS). The result is then applied to the houses 'contemporary' within a half-century time-span. The hypothetical population of each stage (P) is then calculated according to the simple formula: $P = N(p^*\Delta S)$.

A doubt remains, however, in the precision of the Lowess profile for the Merzbach, which we have attempted to reduce. This curve for the single values of the Merzbach differs a little from that of the Lower-Rhine-Meuse region as a whole (Fig. 5 and 4). This difference doubtless reflects, at least partially, a quantitative problem: the number of Merzbach houses used in our approach is twice as less than the actual number of houses recorded in this micro-area, which possibly makes the results of the analysis less reliable at this local scale. However, the great geographic (30–40 km) and chrono-cultural proximity of the houses studied in Dutch Limburg (Elsloo, Stein, Geleen 'JKV') allows us to consider the group 'Lower-Rhine-Meuse' as a relevant analytical unit. As such, and to reduce the quantitative problem which has just been underlined, the fitting curve of this main area will be used as a valid model for the Merzbach itself.

The number of houses by settlement phase (N) being known (Stehli 1989), the surface-area averages (S) and its evolution (ΔS) being given by the Lowess curve for the Lower-Rhine-Meuse, the basic average number of people per house now remains to be determined. As we saw previously, this is a difficult question to answer. But as it is, one must first evaluate a trend, and the exact number matters little. I chose the option of at least six individuals per house, a number often upheld by specialists of this period (Lüning 1988; Ebersbach and Schade 2004). One can note that this value, even if it seems too low, is not incompatible with the results of the three estimations (Narrol; Casselberry and Cook) noted earlier.

We can now construct the evolution curve of the population (P) of the Merzbach as a whole and that of its main site, Langweiler 8, the founding and only permanent village of the micro-area (Fig. 7).

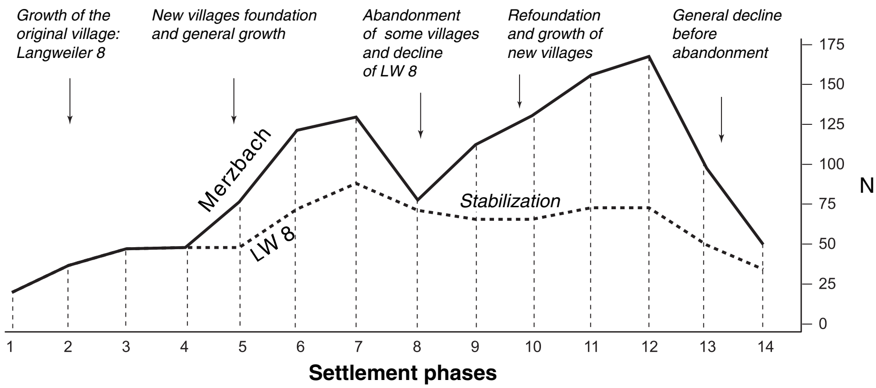

Fig. 7 Estimation of the population of the Merzbach Valley and of Langweiler 8 during the LBK

Here, we observe a continuous growth of the entire occupation over 12 phases of settlement (approximately 200–250 years), supported (tenfold increase of the local population) and marked by a temporary fall-back at the end of 125–150 years. After the culminating point, the abandonment of the micro-area within a half-century is particularly clear. The specific curve of the main site, Langweiler 8, shows two phases of disjunction with this general curve:

- The first disjunction takes place from the fourth settlement phase (approximately 70 years after the beginning of the occupation of the Merzbach valley) and corresponds to the creation of 2–3 new hamlets, whereas Langweiler 8 seems to stagnate for one generation. This short stagnation before a new rapid growth, while the population of the Merzbach as a whole grows continuously, can be interpreted as the result of a 'fissioning event' of the main village, to the advantage of new settlements in close proximity. Even if we envisage the arrival of new settlers from the outside (Zimmermann 1995), it is likely that part of the growth of the new hamlets is connected to the momentary congestion of Langweiler 8; as if part of the surplus population in this main village left to form new local settlements.
- The second disjunction, more pronounced and probably complex, occurs after the recession phase 8 which could represent either a very localized demographic accident (sanitary, ecological or political?), or a voluntary departure by one part of the population for a non-local destination. The strong and rapid return in population growth, of the peripheral hamlets only, evokes the arrival of new extra-local people, while the long stagnation of the main village suggests a voluntary control in its demography, as if a population threshold in this settlement had been reached. Indeed, from this point and during roughly one century, the population growth of the Merzbach valley involves exclusively the creation and development of new hamlets. This difference in the management of local population density may refer again, at least partially, to a repeated fissioning process at the main village level toward the neighboring hamlets.

This hypothesis of a population threshold and of fissioning events as a means of population dispersal is such a general idea that it has rarely been used for the analysis and interpretation of variations in population density and spatial expansion. It was recently the subject of new research (Bandy 2004) where the author recalls the particular documentary conditions that must be brought together in order to recognize such a process. It appears that the LBK data allow us to develop this issue with a certain precision and to detail the implied process from such an analysis (Fig. 8).

Here, in the Merzbach Valley, one notes that between occupation phases 3 and 6, or, in other words, before and after the first supposed fissioning event, the number of contemporary houses of the main village remained more or less stable (7–9), but the number of large and middle-sized houses steadily increased (from 1 to 4 in each phase), with a set-back at phase 5 (a return to one single unit). This rhythm is corroborated by the curve of the surface-areas of the largest houses, whose slight

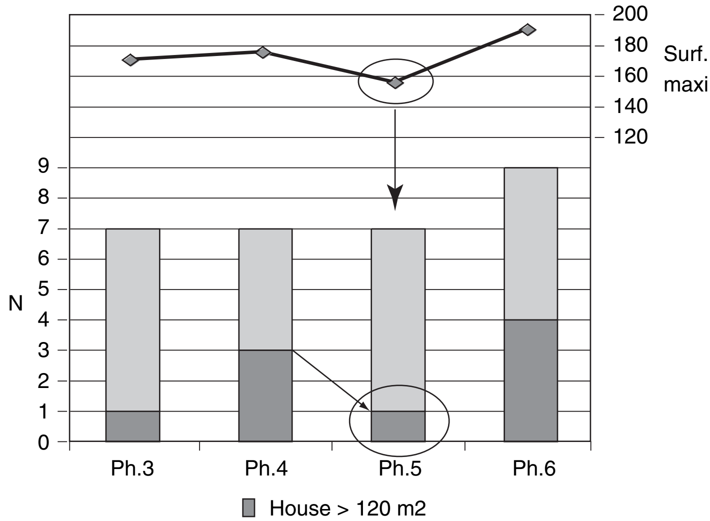

Fig. 8 Average-sized and large houses of Langweiler 8 during the supposed fissioning event of the village

but regular increase (from 170 to 190 m^2) also deviates in phase 5 (a fall to 155 m^2 maximum). One deduces from this episode that the fissioning event phase (4–5) of Langweiler 8, to the benefit of new neighboring hamlets, seen in the provisional lowering in size and number of the biggest houses, involved the largest domestic units rather than the village itself. A big house, sheltering a larger population than the others, may therefore split once it reaches a certain local population threshold, whose significance remains undefined. As well as an explanation of overpopulation, with its negative economic, sociologic and sanitary consequences, one can envisage another reading of the data, stressing the attainment of a population level which allowed a successful expansion. Such a dimension of interpretation was not explored in this study.

Therefore, one can only formulate the following hypothesis: a fissioning event is a process more at a domestic level than at a village level, set in motion once the population density of a domestic unit is sufficiently strong to enable the foundation of a new unit, in a new residential location and all the while preserving the viability of the pre-existing mother-unit.

Conclusions and Perspectives

Conclusions of the Study

Up to this point, the analysis has shown that a general, underlying pattern indeed exists in the data brought together in this representative sample of LBK settlements.

Following the hypothesis of a direct relationship between the surface-area of the houses and the number of occupants, the analysis leads to coherent results:

1. First, a cycle can be found in the variation of the physical and sociological size of the LBK domestic units;

   – the first two centuries following the local establishment of the LBK farming system show a pronounced growth in the size of the domestic unit, followed by a rapid contraction, possibly corresponding to a relocation of the populations toward other less densely settled zones or toward new land;
   – a rapid secondary growth, culminating at about $d\mathrm{t} = 500$, remains more a suggestion than a real hypothesis.

2. Secondly, this trend covaries with the local and supra-local density of occupation;

   – at the local and micro-regional levels, this trend in the physical and sociological size of the domestic units goes hand in hand with the overall numbers of houses and villages. It thus appears that with the local development of a neolithic lifestyle, population growth recordable at the scale of the domestic unit brings with it spatial expansion of the occupation and, therefore, a growth in the number of sites and houses;
   – perceived breaks at about $d\mathrm{t} = 100$ (Aisne) and 200 (Merzbach) would illustrate two different historical situations relating to threshhold in socio-cultural viability: the first corresponds to a more explosive population growth than the second. The reasons for such a difference have not been explored further in this study. Whatever the answers may be, the broad phenomenon identified in the data provides a strong argument to link population growth, at least temporally, with the establishment of a neolithic way of life in this part of Europe.

3. Thirdly, in the absence of specialized political institutions, low threshold of population density and fissionning process at the largest household units level may have played a major role in managing population density;

   – detailed study of the particularly favorable situation offered by LBK settlement of the Merzbach valley suggests that, under certain conditions of occupation density and duration, the fissioning of large domestic units reaching a certain threshold of inhabitants played a major role in territorial expansion;
   – this process, relating to household rather than village decision level (Bogucki 2000), could only be identified locally. It is possible that such a process of fission was also a fundamental driving force in the overall territorial expansion of the LBK.

Thus the Neolithic demographic transition is reflected in the settlement system of west-central Europe by archaeological evidence for quite explosive population growth, and specific ‘sociological’ adaptations to it. Growth seems to have been managed by the first farmers, so that population density could be maintained at a level compatible with the sociological values on which these communities were founded. This may be the main reason why, along with the wide availability of unoccupied, favorable landscape, the maximum population density seems to have remained low. But this may not be the reason why the first phase of population growth seems to have been short, two centuries, with regard to the general NDT model (Bocquet-Appel and Naji 2006).

Perspectives: A Return to Prehistory

The demographic pattern observed in settlement data is specific to the development of the LBK way of life and is independent of time and space. Yet the phenomenon actually happened in various times and places. Let us recall that five to six centuries separate the beginning of the LBK in Hungary and Slovakia from the appearance of the LBK in the central Seine basin, and that quite varied territories scattered over more than 700, 000 km^2 served as receptacles for the diffusion of this agro-pastoral culture. The variations of the natural environment and its evolution certainly had an influence on the choices and cultural adaptations of the first farmers. It is therefore interesting to set the demographic phenomenon identified in this study into a broad geo-environmental context.

Current interest in climatology, with its series of quite frightening forecasts, follows on much previous work by historians and prehistorians. In France, P. Pétrequin was the first Neolithic specialist to have elaborated an environmental database, enabling him to analyze and interpret the development of lake-side settlement in the peri-Alpine regions (Pétrequin and Pétrequin 1988). As with other authors (Strien and Gronenborn 2005), I too have been tempted, in my study on the demography of the first farmers of central-western Europe, to investigate the possible role of ecological factors.

The work of numerous specialists, notably in France M. Magny (1995; 2004) and more recently J.-F. Berger (2005) has convincingly shown that environmental proxy-data constitute very effective aids for constructing a general framework of analysis and interpretation. For example, the curve of residual ^{14}C in the atmosphere can be considered in an empirical manner as a reflection of the history of late glacial and Holocene climate (Magny 1995). The data that have recently become available ($\Delta^{14}C$, $\Delta^{18}O$) thus offer the possibility of establishing a broad picture of the sixth millennium BC in terms of humidity ($\Delta^{14}C$) and temperature ($\Delta^{18}O$).

The LBK: A Cultural Adaptation to Cold-Humid Conditions

The decadal curve of residual atmospheric ^{14}C (1998 residual $\Delta^{14}C$ data set, QIL Washington) reveals a long period of climatic deterioration between roughly 5600 and 5100 BC (Fig. 9), principally characterized (Magny 1995) by the abundance and rate of precipitation (cold, wet summers and long winters). This period of

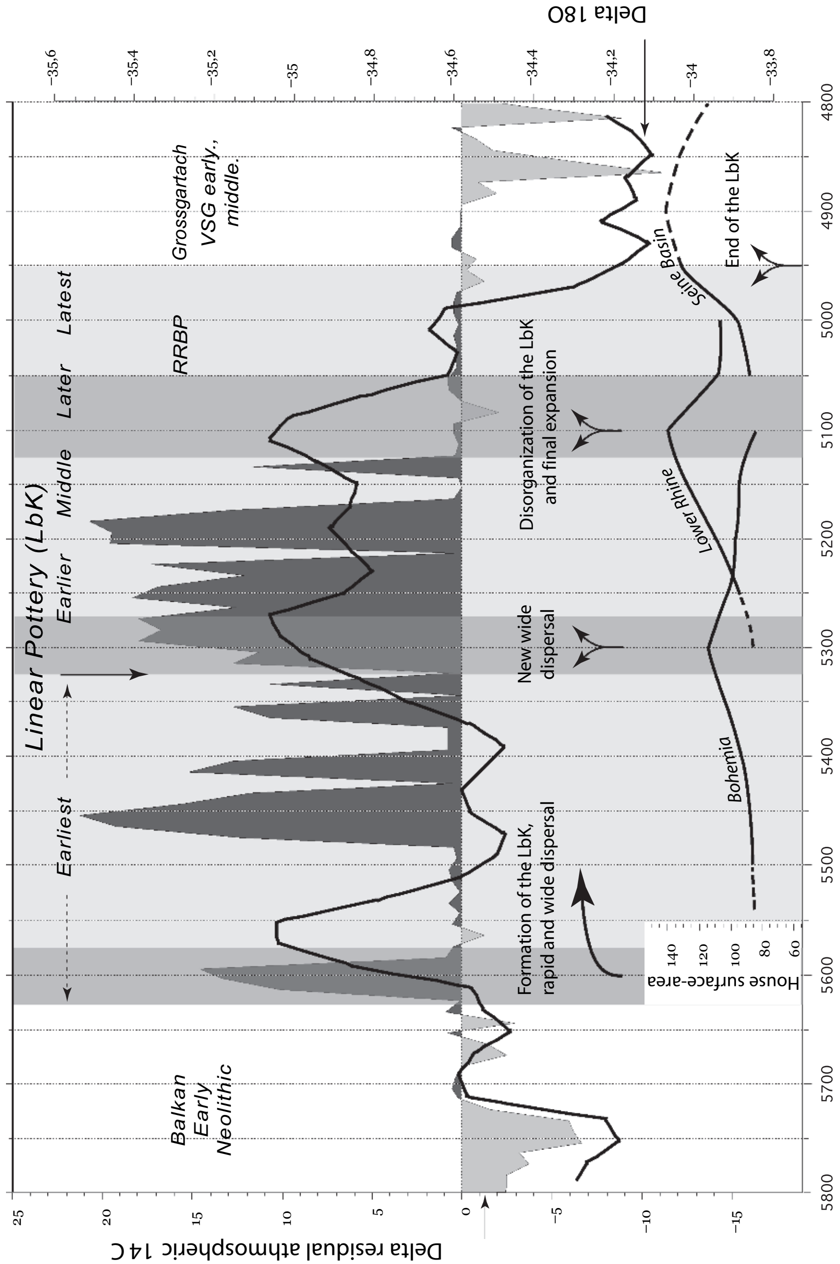

Fig. 9 Climatic, cultural and demographic trends during the LBK

harsh climatic conditions corresponds well to the duration of the LBK. It follows a much milder phase, after c.6000 BC, during which the cultures of the Balkan early Neolithic flourished. A new phase of climatic improvement starts at the end of the sixth millennium BC. The formation of the LBK therefore broadly corresponds to a time of deteriorating climate, and the disappearance of the LBK broadly coincides with the onset of warmer and drier conditions.

Well characterized in the circum-Alpine region, where it is known as the Cerin phase (Magny 1995), the period from 5600 to 5100 BC can be considered as a Little Ice Age, probably comparable to the better known one which lasted from the end of the Middle Ages to the 19th century (Leroy-Ladurie 1967; Lamb 1977; Groove 1988; Magny 1995; Berger 2005). The shortening of the growing season is one of its main characteristics.

Together with the bidecadal curve of the ratio $^{18}O/^{16}O$ (GISP2 bidecadal Oxygen isotope data set, QIL Washington), which focuses on the broad evolution of temperatures during the period (Fig. 9), we can recognize five interesting climatic variations: (1) first cold and humid around 5600 BC, (2) the climate improves rather clearly until just after 5500 BC; (3) it becomes more humid but remains mild until just after 5400 BC; (4) then it turns humid and cold until c.5150 BC, before (5) becoming clearly warmer and less humid or dry from 5100 BC until shortly after 4500 BC.

Thus, humid conditions characterize the start of the LBK and the three centuries between 5475 and 5175 BC; cold conditions also predominate the initial stage, as well as the period 5350–5075 BC. The cold-humid combination, the most unfavorable for an agro-pastoral system due to shorter germination times, thus concerns not only the beginning of the LBK but also the second half of its duration. One has to ask how the LBK system succeeded in developing so well under these conditions, to the point of spreading throughout west-central Europe.

A number of signs of adaptation to these difficult climatic conditions can doubtless be found. In relation to the present study, one can note the massive, robust nature of the buildings (Brandt 1988; Coudart 1998), the frequent location of villages on secondary or tertiary drainage networks, well away from the large rivers and their flood-plains (Kneipp 1995), the importance of cattle-herding (Hachem 1995; 2000; Tresset and Vigne 2001), a marked reduction of the Balkan early Neolithic range of cultivated plants (Kreuz et al. 2005) and the practice of autumn sowing in intensively cultivated plots, according to a recent study (Bogaard 2004). With the help of these adjustments, some of which must have been adopted during the climatic shift at around 5600 BC, the LBK farmers came through the bad times of the second half of the sixth millennium with no apparent difficulty.

A Climatic-Cultural Rhythm?

On closer examination, however, one is under the impression that cultural developments broadly correspond to climatic changes. The important stages in LBK expansion indeed coincide quite well with the main thresholds of climatic change, following a cycle of 150–200 years (Fig. 9):

1. the initial climatic deterioration corresponds to the formation of the LBK at around 5600 BC;
2. the relative improvement of climatic conditions which followed, at around 5450 BC, coincides with the rapid, widespread dispersal of the earliest LBK, probably up to the banks of the middle Rhine;
3. a serious decline sets in to reach a maximum at around 5300 BC, at the moment where one clearly sees considerable LBK expansion both east and west, the westward movement, for example, crossing the Rhine into Alsace and Dutch Limburg. This corresponds to the early LBK (LBK II), which then initiates a long cycle of three continuous centuries of LBK history in the same sectors of occupation;
4. at about 5100 BC, when a new climatic cycle begins, characterized by steady temperature increase and drier conditions, the LBK starts to be rapidly affected by a cultural break-down, notably involving the disappearance of vast circulation networks of raw materials which had characterized the preceding periods (Burnez-Lanotte 2003). With the end of the bad weather, the bell thus tolled for a system specifically adapted to such weather, and this would have triggered the adaptations necessary for ultimate expansion to territories ecologically and culturally very different, as far as the Normandy coast, reached at the beginning of the fifth millennium.

A Demography in Cycles, in Phase with Climatic-Cultural Change?

The various episodes of rapid and fairly massive cultural expansion mentioned above evoke of course a demographic issue, and the possible existence of a two-century cycle brings these two analytical dimensions closer together. Following the same heuristic approach which has guided this study from the onset, and also as a means of opening up research perspectives, the specific LBK demographic pattern revealed by settlement data can be matched against the time in which the phenomena which interest us actually happened (Fig. 9). Only the curves of Bohemia, the Lower-Rhine-Meuse and the Seine basin, representative of the initial hypothesis of a demographic trend, are consistent enough to face the yardstick of a historical chronometer; their reinsertion in absolute chronology shows a good fit with the climatic-cultural trends evoked earlier:

- The curve of the average surface-area of the houses in Bohemia first increases throughout the period of temporary climatic improvement which characterizes this moment of fast, widespread distribution of the earliest LBK. The trend continues up to 5300 BC, the time of the second great territorial expansion in the LBK, and highest point of the climatic deterioration, and then changes in the opposite direction up to around 5100 BC.
- The curve for the Lower-Rhine-Meuse, corresponding to the beginning of the early LBK in the newly occupied territories, starts around 5300 BC and rises sharply until about 5100 BC, during what seems to be the worst period of this Little Ice Age. The reversal of the demographic trend at 5100 BC coincides with

the climatic reversal, which sees the onset of the LBK cultural break-down and its ultimate expansions, notably toward the west.
– It is thus during this period of probable major upheavals that the Seine basin ‘demographic’ curve begins. This shows a very subtle increase, chronologically linked to the climatic improvement which brings a close to the LBK cycle.

One can note several observations of interest both to the general issue of demography and to the specific historical and cultural question of the LBK. If a two-century growth cycle constitutes the overall demographic and ‘universal’ pattern of this prehistoric culture, this also matches quite well the cycle of its main socio-cultural adaptations and phases of geographical expansion. One can even imagine, given the analyzed data, that this demographic cycle accelerates and is amplified in time and space; this remains a hypothesis to develop. We may be dealing here with a signal of the steady improvement of the adequacy of the LBK system to its natural environment, as if the time-depth of agro-pastoral experience enabled a greater ability to react to necessities. The demographic success shown by the curve of the Lower Rhine-Meuse, with the harsh climatic period in full swing and hardly favorable to farming way of life, could thus be explained by perfecting the Neolithic socio-economic ‘software’, after several centuries of experiment. The dismantling of this system during the climatic shift at the end of the sixth millennium would have certainly led to adaptations necessitated by the new environmental order, adaptations which could in turn have contributed to the success of the final expansion into new territories further west.

This brief return to absolute chronology, and the interpretative doors that it opens, underlines the overall interest of the approach followed in this study. Without initial reference to a local chronology, independent of historic time and geography, it is not easy to detect the intrinsic trends of the Neolithic demographic process, as far as its strength and rate are concerned: without this local chronology, the ‘universal’ demographic pattern would in fact have remained undetected. Ultimately, this pattern enlightens the investigation of the historic and environmental circumstances which certainly interacted and contributed to its form. This repositioning of the demographic question in the center of research on the Neolithic transition was in fact the basic ambition of the study presented here.

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