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Titel | Title

Subsistence and animal husbandry practices in Lower Alsace in the Middle Neolithic – studied using stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) in faunal remains from the excavation of Oberschaeffolsheim.

verfasst von | submitted by

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“Learning lacks the quality of finality. There is always more to know.”
(Wurcraft & White, 2023)

This master-paper is dedicated to
Richard Pittioni and Georg Grabner,
the two outstanding personalities
that shaped my academic thinking and all my life,
in gratitude and love.

I also wish to most cordially thank
my loved wife Gabriele
and all my family that has always supported
my (too) many hobbies
with enduring patience, understanding and interest,
much more than I could have hoped for.

Vienna, May 2024.

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Introduction

The Research Questions

Subsistence of Neolithic farmers, based on their domesticated animals and plants and complemented by wild game to a greater or lesser extent, demonstrated significant changes on their long way from the origins in Southwest Asia (the "Fertile Crescent") via the Aegean, Thessaly and the Balkans towards Central and Western Europe (Bickle & Whittle, 2013). This strategy of adaptation must also have correlated with significantly changing climatic and environmental conditions as the early settlers moved from southeastern Europe via southern Germany into the Rhine valley to populate the Upper and Lower Alsace, the latter being the area of this study.

This ***laboratory investigation*** focuses on domestic *animal husbandry*, with a special interest in the farming of livestock, specifically pigs, but also cattle, sheep and goats - and comparing the data to the ones of wild animals (boars, aurochs and deer) that were hunted on a local scale - at the newly excavated study site of ***Oberschaeffolsheim***, which is situated on a loess plateau north of the rivulet Bruche to the west of Strasbourg and east of the Vosges.

How the husbandry of these farmers was organized in detail is studied by using specific stable isotopes (SI), both carbon $\delta^{13}C$ and nitrogen $\delta^{15}N$, in bone collagen of the different animal species uncovered in large pits that could precisely be dated by ceramics (Denaire et al., 2017):

First looking at data from domesticated versus wild animals in general, and thereafter comparing wild versus domesticated species (e.g. wild boars versus the pigs kept by the villagers, either extensively or intensively) will help to understand under which conditions the latter were kept as compared to those hunted. The feeding of domesticated pigs, as omnivores, will specifically be addressed also. Additional information will be gathered regarding the potential browsing areas (e.g. closed forest versus open landscape using $\delta^{13}C$) and the possible amount of manuring in the fields surrounding the village that might have been used for feeding the livestock following harvest (using $\delta^{15}N$).

In addition, these will be compared with selected published SI data from early to late Neolithic sites from Upper and Lower Alsace, the Paris basin and beyond as well as some excavations that are located within central Europe to place the findings into a regional and supra-regional framework. In addition, more *faunal baseline data* for Lower Alsace and the Middle Neolithic will also be provided.

This village has been quite precisely dated to the *Grossgartach* period in the early *Middle Neolithic*, starting 4765–4705 cal BC and ending 4690–4610 cal BC (both with 95% probability) that followed the very brief *Hinkelstein* time period. The initially clearly distinguished five Grossgartach sub-phases are

probably just contemporary variations of the ceramic style, which is succeeded by the *Planig-Friedberg* typology, which has been confirmed as a transition period to the following *Rössen* phase.

Interestingly, there appears to be a clear ***settlement interruption*** and a ***re-population*** following a gap of about 100 – 150 years between the end of the *Linearband-Keramik* (LBK), and the rapid introduction of the short-lasting *Hinkelstein* style. The latter appeared within 20 years, coming in from the middle Rhine, with only five known sites located close to the Rhine River. It lasted less than two generations, just prior to the onset of the *Grossgartach* phase that is important for this study. These pioneer "re-settlers" started a mortuary tradition to be maintained until the end of the Planig-Friedberg period (Denaire, 2009; Levoprost & Queyras, 2011) with the tombs, specifically at Ertein and Entzheim showing the connecting links between the Hinkelstein and Grossgartach styles.

Different models for the *"LBK crisis"* preceding this gap, but also more generally for climate-induced stress and socio-cultural changes have been discussed. They must consider not only apparent regional variations but the resilience of the settlers as well (Denaire et al., 2017, Fig. 24, p.1139 - 1142).

It is astounding that within a short time of three generations the total of the LBK territory was re-inhabited (Denaire, 2009; 2012) with the same density as in the LBK, albeit *smaller villages* than e.g. Bischoffsheim were the rule (Levoprost, 2012). People in the Grossgartach phase might also have come in from the more southern Neckar valley region (Denaire, 2009, 338 - 340; 2012).

It seems that for at least a century or more a large swathe of the Rhine valley under consideration in this study was poorly if at all inhabited (!), so that the settlers of Oberschaeffolsheim newly entering the area in the Grossgartach phase would have found a *"clean slate"* for raising their domesticated animals, hunting the wild ones, and growing their crops, making it altogether quite a "new start".

This new finding of a settlement gap that was recently published by Denaire et al. (2017), will have to be considered in the discussion regarding our SI data when looking at husbandry of domestic animals and wild fauna hunted for additional subsistence.

Stable Isotopes in Archaeological Research

Studies of husbandry practices in prehistory were long based on analogies with early 20th century and contemporary traditional herding procedures that are very helpful to analyze the variety of options of subsistence available in the specific geographical areas to be covered. Over the last few decades huge advances in stable isotope studies have complemented these concepts with *direct* evidence gathered from bones, teeth, as well as the local faunal and geological environment and have shown how ingeniously the early herders were able to adapt their strategies to new climatic and environmental challenges (for review see Balasse, 2014).

It was already in the late 1970s that Vogel and van der Merwe started this new concept of research by chemically analyzing human bone material in order to clearly demonstrate a change in diet of the early cultivators of maize (a "C_4-plant") starting around 1000 AD in New York State, USA, as compared to the previous hunter-gatherers of the same region (Vogel & van der Merwe, 1977). Early studies about human meat consumption using these techniques, comparing ancient and medieval times, already appeared in the nineties (Bocherens et al., 1991).

A wide range of applications for stable and radiogenic isotope studies (mostly using carbon, $\delta^{13}C$, nitrogen, $\delta^{15}N$, oxygen, $\delta^{18}O$ and strontium, $^{87}Sr/^{86}Sr$) has since been published, ranging from the age of dinosaurs up to modern times (see Table 1 for an exemplary overview of topics).

Bocherens, H., et al., 1988.	Dinosaurs (Anatosaurus), terrestrial plant diet, arid environment, USA.
Domingo, L., et al., 2020.	Fossil mammals, pampas, Argentine.
Anczkiewicz, R. et al., 2023.	Spatial resolution, woolly mammoth tooth, for paleoecology, Poland.
Bocherens, H., Drucker, D.,2021.	Ecological interaction between humans and woolly mammoths, Europe.
Ecker, M. et al., 2023.	Neanderthal and Hominin habitats in Zagros mountains, wild goats, Iran.
Makarewicz, C.A., 2017.	Vertical transhumance in caprine, in early Neolithic, Jordan.
Vaiglova, P., et al., 2023.	Diversity in Neolithic agropastoral management, mainland Greece.
Isaakidou, V. et al., 2022.	Faunal bone collagen, grains, Neolithic, Bronze Age, Knossos, Greece.
Lösch, S., et al., 2014.	Diets, gladiators vs. contemp. Romans, 2^{nd}- 3^{rd} c. CE, Ephesus, Turkey.
Dotsika, E., Michael, D.E., 2018.	Dietary habits of Romans, 2^{nd}- 4^{th} c. CE, Macedonia, Greece.
Aguraiuja-Lätti, Ü., et al., 2022.	Food webs and regions, faunal collagen, ca. 200 – 1800 CE, Estonia.
Salmi, A.-K., et al., 2020.	Sámi reindeer offerings, 1200 – 1700 CE, Finnland, Sweden.
Britton, K. et al., 2018.	U.K. breastfeeding practices, 12^{th} – 15^{th} and 15^{th}- 18^{th} century AD, UK.

Table 1. Selected examples of stable isotope use from the terminal Cretaceous to modern times.

The fact that stable isotopic studies can also elicit quite emotional scientific debates is clearly shown by the controversy on insinuated "chauvinism of prehistory" having arisen after great media attention following a report on pig movements to neolithic British henge monuments with the first rebuttal and its critical appraisal (Barclay & Brophy, 2021 versus Magdwick et al., 2021).

Animal husbandry, diet and management and its study with the use of Stable Isotopes (SI)

Selection of the fodder of domesticated animals, from pasture, forage, and transhumance practices, and breeding techniques, e.g. choice of mates, time of weaning, and age of slaughter, are the means how husbandry practices all have been exercised in prehistorical and early historical time periods, long before any written information on herding and stock management was available. Models of Neolithic farming in Europe have been extensively discussed (for review see Bogaard, 2004).

Bone and teeth sampled at archaeological sites, and duly classified by the specialist, can be used to address these parameters (mostly using the elements mentioned above) *in the laboratory* as their isotopic compositions are related to the physiology of the animal studied, the specific animal feed used and the environment present during their lifetime, such as soil history, climate, seasonal cycle, and vegetation cover (Katzenberg & Waters-Rist, 2019).

On an *intra-annual scale*, the study of serial teeth samples has helped to understand many consequences of the seasonal climatic cycle which is clearly of great importance in the middle and higher latitudes. Water and fodder availability as well as the yearly biological cycles of the domesticates themselves are strongly influencing both husbandry and related tasks (Bocherens et al., 2001; Balasse & Tresset, 2002; Balasse & Tresset, 2007; Balasse et al., 2017; Balasse et al., 2019).

The stable isotope (SI) composition of any food consumed will be reflected - after a known isotope fractionation - in the body tissues that can be used for analysis (De Niro & Epstein, 1978, 1981; Schoeller, 1999). SI ratios that were present during life will therefore be available for study in cases where archaeological findings are preserved well enough, and in most cases SI analysis will focus on well-preserved bone, dentine, and enamel, although many types of tissues are suitable. The former two are composed of organic (ca. 20–25% of dry weight, mostly collagen) and inorganic (ca. 75–80% of dry weight, mostly hydroxyapatite) matter. Enamel is typically composed of more than 98% inorganic hydroxyapatite (Hare, 1980). Their chemical origin and formation are reflected by their specific stable isotope values: the inorganic mineral has its origin from the carbon SI ratios of the whole diet, while the organic matter (collagen) stems mostly from amino acids which correlate mainly with protein consumption (Ambrose & Norr, 1993). To study diet bulk collagen from bone or dentine is usually the preferred material, as it is the major nitrogen source in skeletal remains, and its biochemistry is well known since a long time. To measure its quality the atomic ratio of C to N is a robust indicator, even for very old samples (De Niro, 1985; Van Klinken, 1999). Collagen has a slow turnover. Therefore data from adult human bone collagen will reflect the averaged protein diet over several years prior to death and is dependent on the collagen turnover rate of the specific bone sampled (Hedges et al., 2007).

Dentine collagen, in contrast, primarily reflects the protein sources consumed during the short time in which the dentine of each tooth was formed, basically in childhood (Beaumont et al., 2012).

Other major elements and trace elements as well as individual amino acids and fatty acids, in a compound-specific analysis, that is complex and costly, may be used more frequently in the future to address additional questions arising. A summary on the factors influencing SI composition of the human and animal body alike, by Jaouen & Pons, 2017, is given in the graph (Fig. 1).

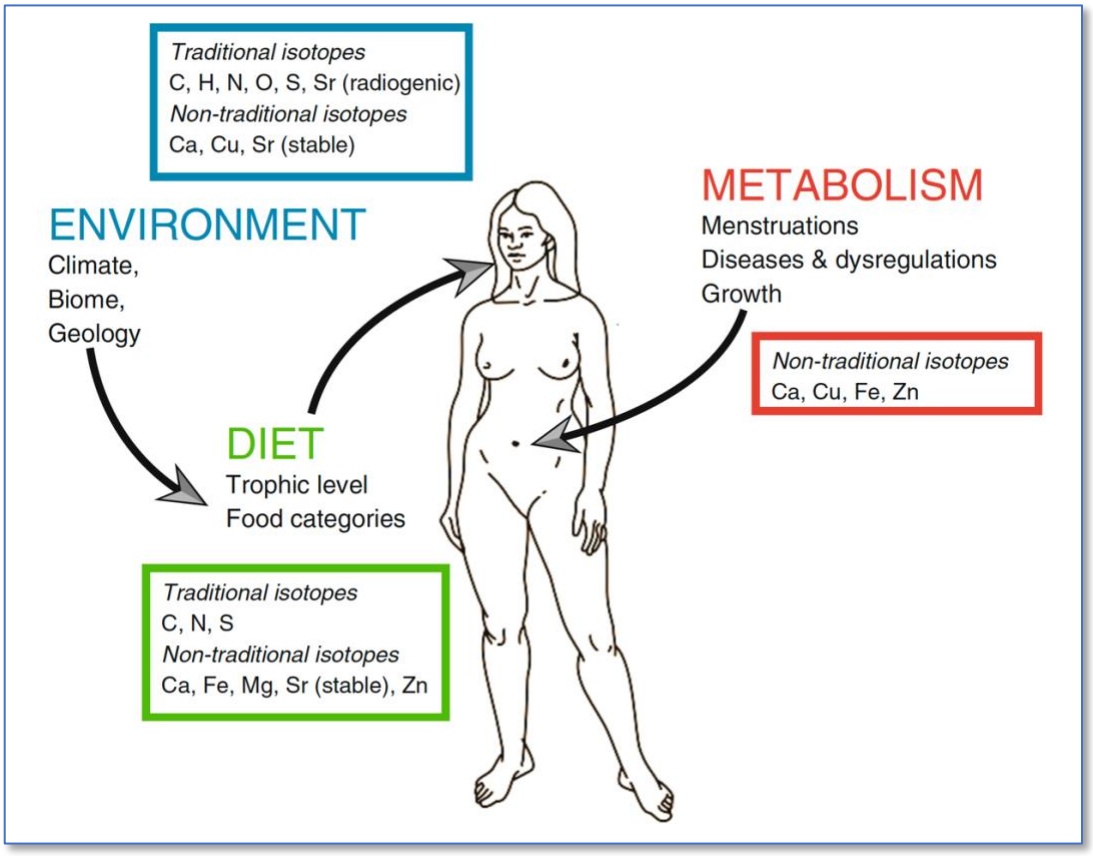


Fig. 1. Factors influencing traditional and non-traditional isotope compositions of different elements of the human (and certainly faunal) body (from Jaouen & Pons, 2017, Fig.2. (The woman template originates from the pioneer plaque – NASA, no copyright).

Carbon SI values of bone collagen ($\delta^{13}C$) can be used to study the uptake of plants that are performing the C_4 photosynthesis versus those that use the C_3 photosynthesis pathways (O'Leary, 1981), with all C_3 plants (all trees, shrubs, grasses, and herbs) being "^{13}C depleted", while C_4 plants, e.g. maize, sugar cane and millet are relatively speaking "^{13}C enriched" (Fig. 2).

As examples this effect, namely a substantial contribution of a C_4 plant (e.g. millet?) to the diet of domestic pigs in the early Neolithic in China and of maize in the Peruvian highlands in the first millennium CE to a camelid species (probably llama?) diet has been described (Pechenkina et al., 2005; Finucane et al., 2006).

Inorganic *apatite* from bone or enamel can be used for carbon SI analysis as well, without yielding information for $\delta^{15}N$, however. As bone apatite is more vulnerable to post-depositional diagenesis than the one from enamel, when studying enamel apatite $\delta^{13}C$, one must bear in mind that its composition reflects the *overall* diet, whereas collagen mostly reflects the *protein fraction* of the diet (Lee-Thorp & Sponheimer, 2006; Lee-Thorp, 2008).

Forest leaf foddering and SI analysis

The amount of labor which must be committed to feed the different domesticated animals within a pastoral Neolithic community depends on the varying proximity of the herds to the settlement (e.g. in case of transhumance) or on the requirement to compensate for a restricted grass availability in winter times and during dry summers. Forests were used to feed domestic stock since prehistory until historical times (Rasmussen P., 1989; Haas et al., 1998).

In one of the earliest specific studies that were published looking at Neolithic time and the effect of human activity on the environment in Denmark, the decrease of some tree pollen data (e.g. of *Ulmus*, the elm tree) was taken as evidence for the arrival of farmers in a region with their animals grazing on samplings and undergrowth following forest clearing, thereby increasing the initially deforested settlement areas (Iversen, 1949). For southern Alsace similar data have recently been published studying the palynological diagram, magnetic susceptibility, and radiocarbon data in a paleochannel in the foothills of the northern Jura mountains (the Sundgau area): starting around 9,400 – 9,300 cal. years BC a long period was dominated by pine until around 3,600 – 3,500 cal. BC (Richard et al., 2016). Only from 4,400 – 4,300 cal. BC the sediments disclosed weak evidence of possible human impact with some cereal pollen grains together with *Rubiaceae* and *Artemisia* pollen, which was more recent than the oldest Neolithic occupations detected in an area of 15 km around the sampling site at the Hagenthal-le Bas village: the early Neolithic sites (Stetten, Haut-Rhin, to the north and Bale-Bottmingen to the east) and the Middle Neolithic (confirmed by Grossgartach type ceramics) rock shelter of Lutter at a distance of 8 km to the south-west (Jeunesse et al., 2014). These weak signs of human impact – cereal grain pollen - seem to disappear in the late Neolithic around 2,700 cal. BC and only to reappear in the 5th century BC (Richard et al., 2016).

This has also been studied with methods for the examination of cattle, sheep, and goat dung in prehistoric wetland settlements when conditions are favorable for preservation of plant macro- and micro-remains, micromorphology, and paleoparasitology (Kühn et al., 2013; Jakobitsch et al., 2023).

However, in habitats where long-term dung preservation is not possible, other proxies must be used: In these circumstances the practice of leaf foddering can be studied by the analysis of $\delta^{13}C$, since plants that grow in a closed forest exhibit a *"canopy effect"* that results in a lowering of $\delta^{13}C$ values (Balasse et al., 2012). This is a term used for the reduction of ^{13}C stable isotope values in forest ecosystems with

lowered light intensity originally thought to be caused by the recycling of depleted carbon from decomposed organic material on the forest floor. Others have proposed a change in processes at the leaf level caused by increased shade. Indeed, a study looking at ^{13}C SI depletion in grass grown in open and closed locations has found a shift of up to 5 ‰, and of up to 2‰ between individual grass species and even of ± 0.3. to ± 0.4‰ within species, at the very basis of the food chain. This difference did not appear when comparing sheep fed in open grassland and fallow deer living within the woodlands, which might have been related to their respective feeding strategies that seems to modulate these effects (Bonafini et al., 2013).

A recent study examining a large set of SI data from domesticated and wild ruminants (N = 451) to *investigate the use of forests by the first herders* collected from archaeological sites reaching from the Paris basin to the eastern parts of Hungarian steppe and dating to the 6th millennium BC revealed that $\delta^{13}C$ values of *cattle* are significantly affected by longitude and to a lesser extent by latitude as well. The same held true for *sheep and goats*, although within a narrower range and with a significantly higher mean $\delta^{13}C$ value. In contrast, *deer* species*,* although the sample number was smaller, had a significantly lower mean $\delta^{13}C$ value than all three domesticated species studied, and these were not correlated with either longitude or latitude, albeit not different from those of modern samples collected in the dense deciduous forests from France and Poland after correction for the fossil fuel effect (Gillis & Zanon, 2021; Gillis et al., 2022).

Using ***Nitrogen SI ratios*** in bone collagen, trophic levels, which lead to an increase of up to 3 - 5‰ with each step up the food-chain (Fig. 2), can be estimated starting with the C_3 terrestrial plants at the lowest level (these being determined by local soil parameters and plant physiology), albeit some inherent variations among these values must be considered (De Niro & Epstein, 1981; Hedges & Reynard, 2007; O'Connell et al., 2012). Nitrogen isotope biogeochemistry in plant-soil-systems is very complex and still holds complex questions for the study of ancient animal management practices, e.g. the type of agricultural practices (use of animal fertilizers, burning of vegetation or shifting cultivation, tillage, grazing intensity, stocking rate, and foddering with cultigens (for a detailed review see: Szpak, 2014)).

Briefly, herbivorous animals will show *lower* $\delta^{15}N$ values than omnivores and top carnivores (Petzke et al., 2005). In contrast consumption of freshwater and marine fish – with the higher number of intermediate trophic levels as compared to terrestrial food chains – will demonstrate *increased* $\delta^{15}N$ levels. To avoid equifinality, combining $\delta^{15}N$ data with $\delta^{13}C$ levels allows to distinguish between a terrestrial C_4-plant and a mainly aquatic nutrition (Schoeninger et al., 1983; Schoeninger & De Niro, 1984; Outram & Bogaard, 2019).

The type of fodder used and the diverse schemes for herding strategies will also indirectly be reflected by the animal's place within the above mentioned "trophic chain", with the *equifinality* of the

biological systems investigated using the SI in bones retrieved by the zoo-archaeologists at excavations leading to a *significant complexity for interpretation* (Balasse et al., 2014).

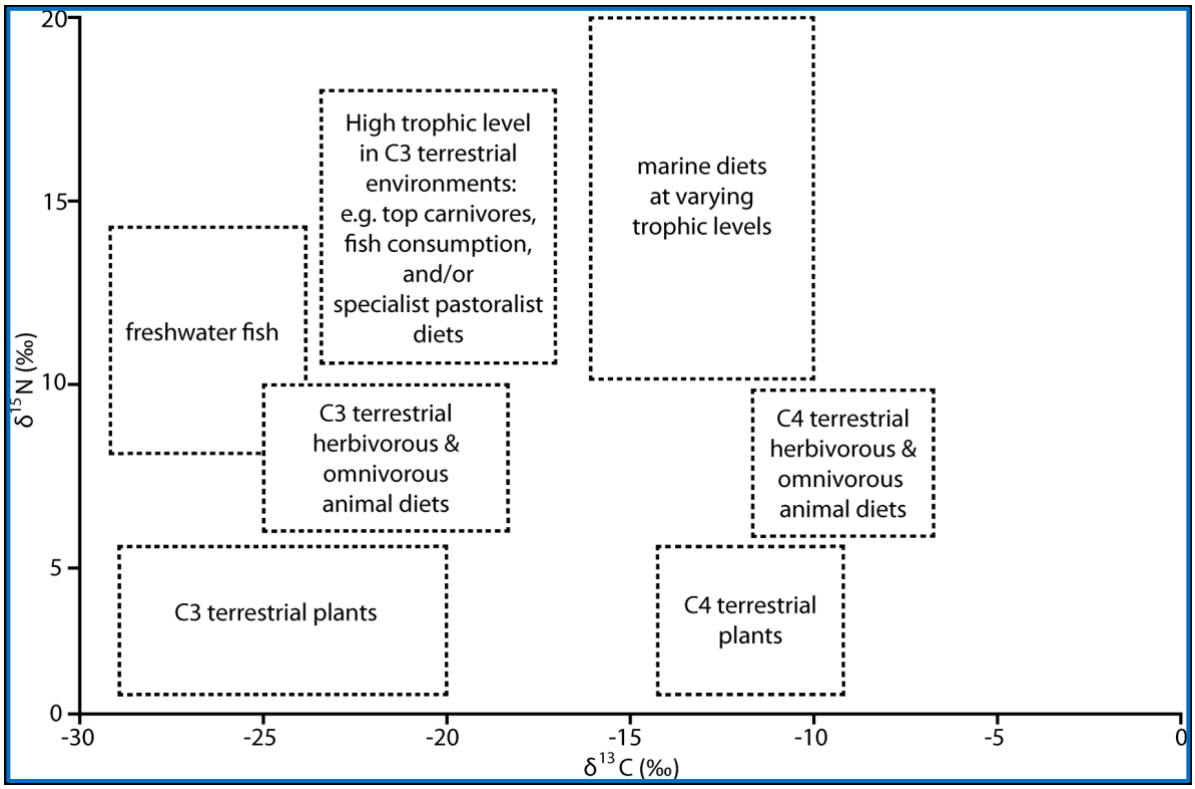


Fig. 2. An approximate and generalized representation of the relationship between $\delta^{13}C$ and $\delta^{15}N$ values in organisms with different diets, as measured in collagen. From: Outram and Bogaard, 2019; Figure 3.1., page 54.

The *domestic pigs* seem to possess the greatest plasticity as to their feeding behavior: herded in woodland, as an additional or main fodder resource, their diet would be quite similar to that of wild boars, which are mainly herbivorous, with plants and roots being their first level in the trophic chain. When living within the settlements, however, fattened from human refuse, this closed environment would raise their stable isotope values to a higher omnivore level in the trophic chain, reflected by the enrichment in $\delta^{15}N$. Although the intention and behavior of the human – animal living relationship is irremediably lost at the archeological site as zooarchaeology can work with the remains of dead animals only, the analysis of their skeletons provides a plethora of information about this relationship, such as slaughter age, meat consumption, and also their different husbandry practices having been reconstructed with the use of stable isotopes (Balasse et al., 2016, 2018).

These values, however, must *necessarily be compared to other domesticated and wild animals within the same ecosystem*, as they do not speak for themselves, depending on plant physiology and local soil composition (Ervynck et al., 2007; Dobney et al., 2007; Katzenberg and Waters-Rist, 2019).

The Study Site of Oberschaeffolsheim in Lower Alsace, France

The Time Frame of the Site

In Alsace, both in its upper (southern) and lower (northern) part – with its border set approximately between Colmar and Sélestat – many Neolithic sites on the loess-covered terraces of the valley were excavated and studied in great detail in the last hundred years, Fig. 3, a, b (Forrer, 1911, 1922; Jeunesse 1995 a, b; Jeunesse & Arbogast, 1997; Lefranc et al., 1998, 1999, 2006, 2021; Denaire, 2011; Lefranc, 2013, 2014; Bickle et al., 2013; Lefranc & Denaire, 2018; Denaire et al., 2017).

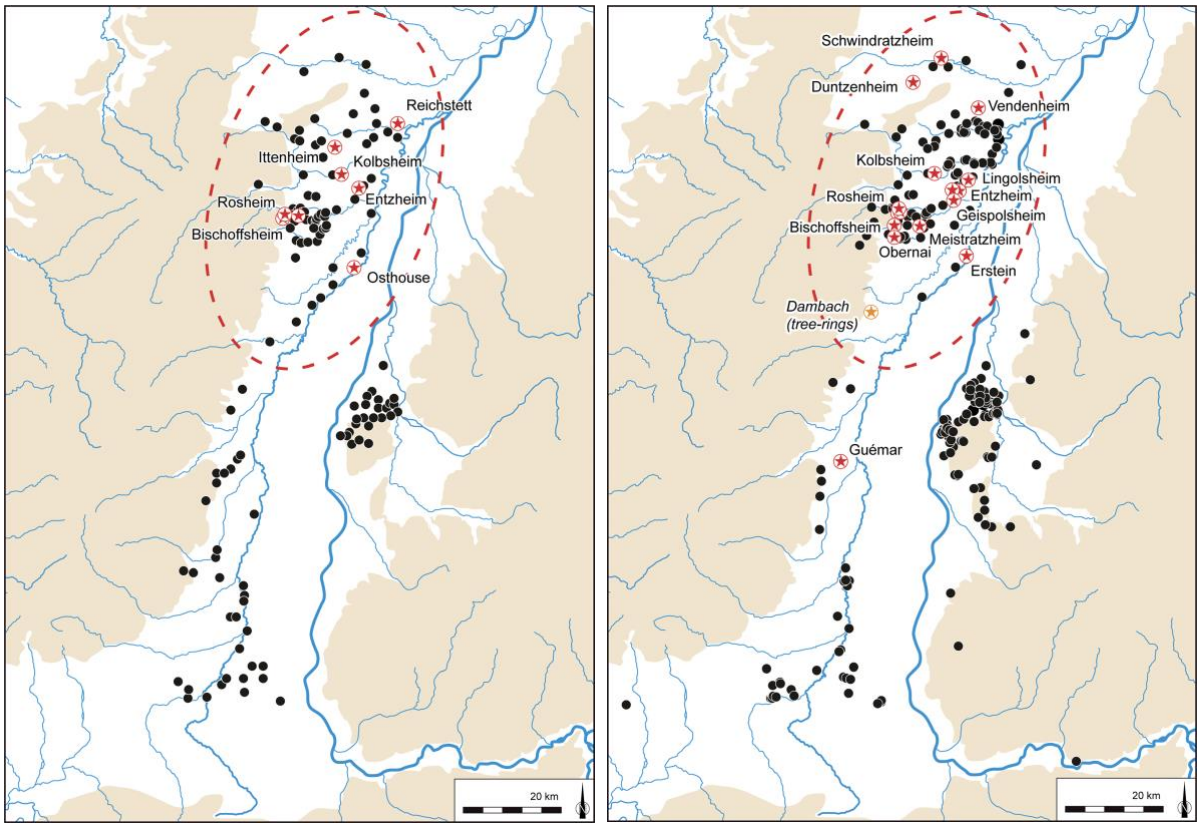


Fig. 3.a (left). Map of the upper Rhine valley, showing the distribution of *LBK settlements* and 3.b (right) showing the distribution of *Middle Neolithic settlements.* Lower Alsace is circled by the red dotted line and sites which provided radiocarbon samples are shown by red stars. From: Denaire et al., 2017, p. 1076 and 1078.

This last seminal paper mentioned, looking at a region west of the upper Rhine with about 25 km width from the river to the uplands of the Vosges and approximately 55 km in length, has resulted both in the uncovering of a complex settlement pattern as well as a detailed timescale based not only on pottery styles (seriation and typology) but also on detailed radiocarbon dating and modelling within a Bayesian statistical framework, starting from the late 6th to the end of the 5th millennium cal BC, Fig. 3.

This revealed *"A Neolithic world in Lower Alsace busy with comings and goings, tinkerings and adjustments, and relocations and realignments"*. In addition, *"A significant hiatus is identified between the end of the LBK and the start of the Hinkelstein group, in the early part of the fifth millennium cal*

BC", a finding *"appearing to be a wider phenomenon"*, with probable relevance for the bio-archaeological findings of the current study, as will be discussed later (Denaire et al., 2017).

Within the space of two generations the LBK appearing in Lower Alsace densely settled all the loess areas, explained by an influx of a new population, possibly via two routes: one stream from the Neckar valley, the other from the Danube valley (Lefranc, 2006), with a cultural divide in the area of Colmar towards the southern Upper Alsace, with differences in architecture, funerary rites, ceramics and animal management (Jeunesse 1995 a, b; Casanova et al., 2020).

Denaire et al. (2017) have included four of the seven Middle Neolithic sequences, beginning with Hinkelstein, followed by **Grossgartach**, Planig-Friedberg and Rössen into a *single* correspondence analysis, due to the links existing between the decorations and forms (Fig. 4), with the following three typological stages (Bischheim, Bruebach-Oberbergen and BORS – Bischheim Occidental du Rhin Supérieur) showing more differentiation in order to finally end the long Danubian cultural tradition with Michelsberg in the Lower Alsace (Jeunesse et al., 2003). In this new seriation the *Grossgartach (GG)* style can be divided into five sub-groups *not* representing a chronological sequence, as suspected by Denaire (2009, 174 – 257). These comprise the majority (154) of ^{14}C dated (37) and undated graves and pits. This permitted Denaire et al. to establish a fine chronological model, with a *swift* appearance of *Hinkelstein* ceramics within less than 40 years and a start between 4,835 – 4,745 cal BC (a quite late dating and with "*NO continuity with the LBK style in this region"*!) to be replaced by the succeeding *Grossgartach* in 4,745 – 4,720 cal BC (at a 68% probability), therefore Hinkelstein being in use in this area for one or two generations in the middle of the 48th century BC only (Denaire et al., 2017, 1114).

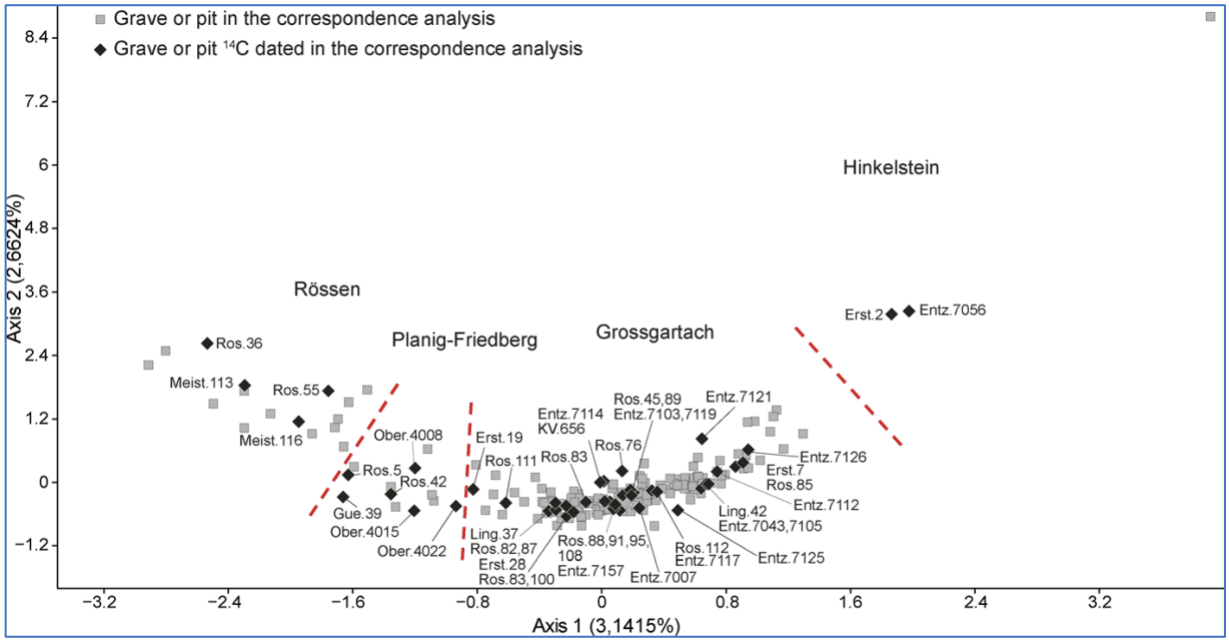


Fig. 4. Correspondence analysis of Middle Neolithic ceramics (190 assemblages, predominantly Grossgartach) in Lower Alsace. From: Denaire et al., 2017, p. 1107.

Grossgartach showed a highly increased activity from the preceding Hinkelstein period, with a significantly larger number of cemeteries and settlements, such as the current study site of ***Oberschaeffolsheim***, lasting about three generations (40 – 95 years, with 68% probability) to be replaced by Planig-Friedberg (around 4,680 – 4,640 cal BC, 68% probability), the latter being a transition phase from typical GG to the typical Rössen assemblages. The chronological details are given in Figure 5. The durations of the LBK and Middle Neolithic ceramic phases are given in Figure 6.

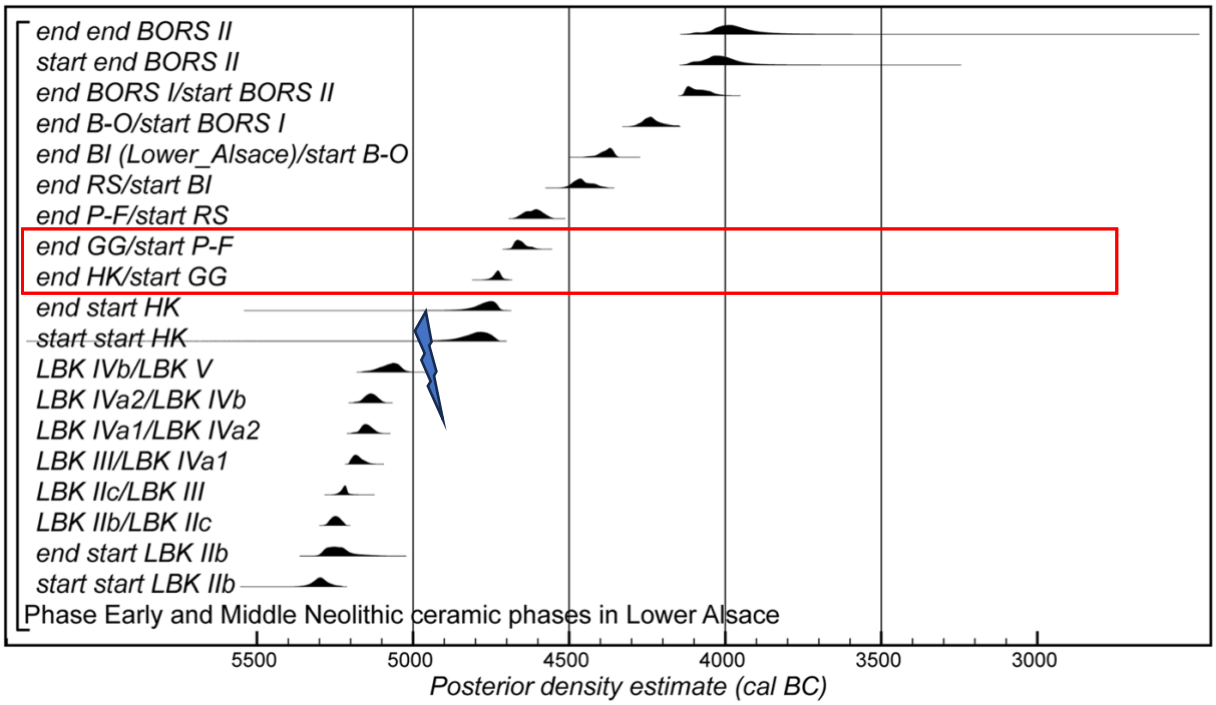


Fig. 5. Key parameters for the chronology of LBK and Middle Neolithic ceramics in Lower Alsace as suggested by the correspondence analyses of LBK to BORS phases, with a major gap between the end of the LBK and the start of Middle Neolithic (blue sign). From: Denaire et al., 2017, p.1128, defined from the models in Figs. 8, 15 and 16.

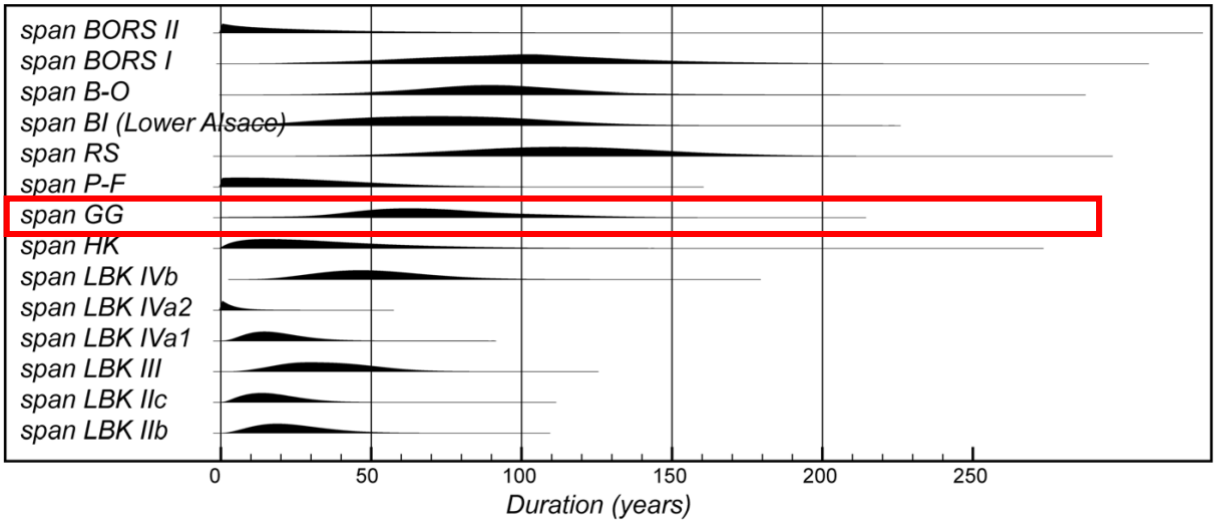


Fig. 6. Posterior density estimates for the durations of the LBK and Middle Neolithic ceramic phases in Lower Alsace. From: Denaire et al., 2017, p.1128, defined from the models in Figs. 8, 15 and 16.

In this important study diet-induced radiocarbon offsets were unlikely to affect the chronologies by *more than a few decades at most*, as studied by dietary analysis of human remains (30 adult plus sub-adult humans) of the Middle Neolithic Rhineland population using FRUITS modelling of dated individuals, with a newly postulated start of the Grossgartach period from *4,735 – 4,700 cal BC* (68%) and an end from *4,635 – 4,590 cal BC* (52%). From the 96 measurements included in the study there were no misfits identified in the Middle Neolithic model (Denaire et al., 2017, 1127 - 1129).

This formal modelling approach, together with serial material analysis, has clearly revealed a **major gap** between the late LBK (IVb/V) in Lower Alsace probably in *5,105 – 5,040 cal BC* (with a 68% probability) and the early, brief Hinkelstein period (Fig. 7. a and b), appearing in 4,835 – 4,745 cal BC (68% prob.) which must be discussed in detail to explain this hiatus at the start of the Middle Neolithic.

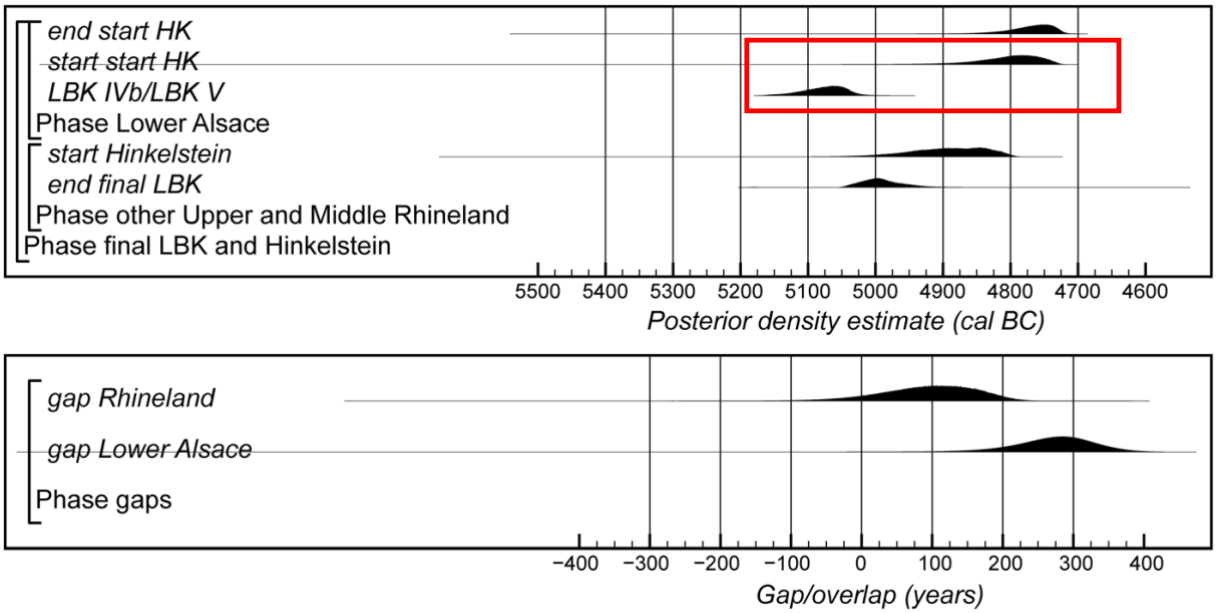


Fig. 7. a (top). Posterior density estimates for the end of use of LBK ceramics and the start of the use of Hinkelstein ceramics in Lower Alsace (above) and elsewhere in the Upper Rhineland, Hessen, and the Neckar valley (below). Fig. 7. b (bottom). Posterior density estimates for the gap between the last LBK and the first Hinkelstein ceramics. Both from: Denaire et al., 2017, p. 1136 and 1137.

These might have been Hinkelstein pioneer settlers coming in from the middle Rhine, appearing rapidly within 20 years and with only five sites known without houses close to the river, and a mortuary style that lasted until the end of the Planig-Friedberg phase (Denaire, 2011; Levoprost & Queyras, 2011).

Only *during the Grossgartach phase all the LBK territory was re-inhabited*, with the density of sites and a duration of the amazing recolonization of about *only three generations*. The size of the known sites, however, was smaller with hamlets of a few contemporary farmsteads probably a better suited model, and the people might also have come in from the Neckar valley (Leprovost 2012; Denaire 2009, 2012, Denaire at al., 2014). “Considerable *contemporary* variation in the decorative motifs used on pottery is now seen quite compatible with an intense *local differentiation* in this phase” (Denaire et al.,2017).

The Rössen phase, with over four to five generations, lasted longer than Grossgartach, but changed the nature of its features, so that e.g. big pits, common in the Grossgartach, (and at the study site of Oberschaeffolsheim) were no longer dug. The area inhabited, however, expanded to the other side of the Rhine, the north of Franche-Comté and even into central Germany (Denaire, 2009; Spatz 1996).

The Time Gap

The time gap between the late LBK in lower Alsace (but also in other regions north and south in the Rhine valley and its catchments) and the start of the Middle Neolithic raises the question *what conditions* provoked the end of the former, challenging the notion of continuity between periods.

The "crisis at the end of LBK" resulting in its disappearance has led to several models: after the discovery of violence at famous sites such as Thalheim, Asparn/Schletz or Herxheim, the possibility of high population growth has been put forward, combined with short-term climate variations causing famine, "social dislocation", and collapse (Wahl & König, 1987; Teschler-Nicola et al., 1997; Boulestin et al., 2009; Zimmermann et al., 2009; Boquet-Appel et al., 2014; Meyer et al., 2014). A mental or moral crisis has also been advocated (Zeeb-Lanz, 2009), as have been complex models linking climatically highly volatile periods with phases of population growth and periods of warfare (Gronenborn et al., 2014). This "crisis of the LBK" has been questioned altogether due to resilience and adaptive options available, with life of the populations somehow subsequently, slowly, and continuously returning to normal (Stäuble, 2014).

It is clear, however, that in the *Lower Alsace region* a rapid decline was followed by a significant hiatus before a fairly rapid re-settlement took place, even if arguments and archaeological stratigraphies supporting a *continuity in the eastern LBK´s regions* as in eastern Germany and Hungary have been discussed (Link, 2014; Banffy et al., 2016; Denaire et al., 2017).

The collapse process is certainly a complex one, with supposedly many factors interacting, which are difficult to prove at the archaeological level: population 'overshoot', epidemics, environmental change and degradation, agricultural failure, hostile neighborhoods, and internal social conditions (Tainter, 2006). Cultures have been shown to collapse within a few decades following drought, competition for resources and violence (Schwindt et al., 2016).

Newer aDNA techniques evolving might offer new information whether densely inhabited areas such as the Lower Alsace at the end of LBK were harbinger to deadly infectious diseases, which is another line of thought to be followed, such as tuberculosis, *initiating nearly 200 years of a population gap in this very fertile swath of land* (Tainter, 1988; Hedges et al., 2013; Spyrou et al., 2019).

The Location and Spatial Details of the Site in the Early and Middle Neolithic time frame

The maximal **spatial distribution** of the different styles of Early and *Middle Neolithic* ceramics are shown in Figure 8, with the small extent of the 1 - 2 generation Hinkelstein style well in contrast with the longer lasting **Grossgartach** to Planig-Friedberg to Rössen types (Denaire et al., 2017). The Middle Neolithic ended in Lower Alsace with the BORS II pottery style around 4,045 – 3,920 cal BC (68% prob.) after having lasted about two generations and was replaced by Michelsberg II (Jeunesse et al., 2003).

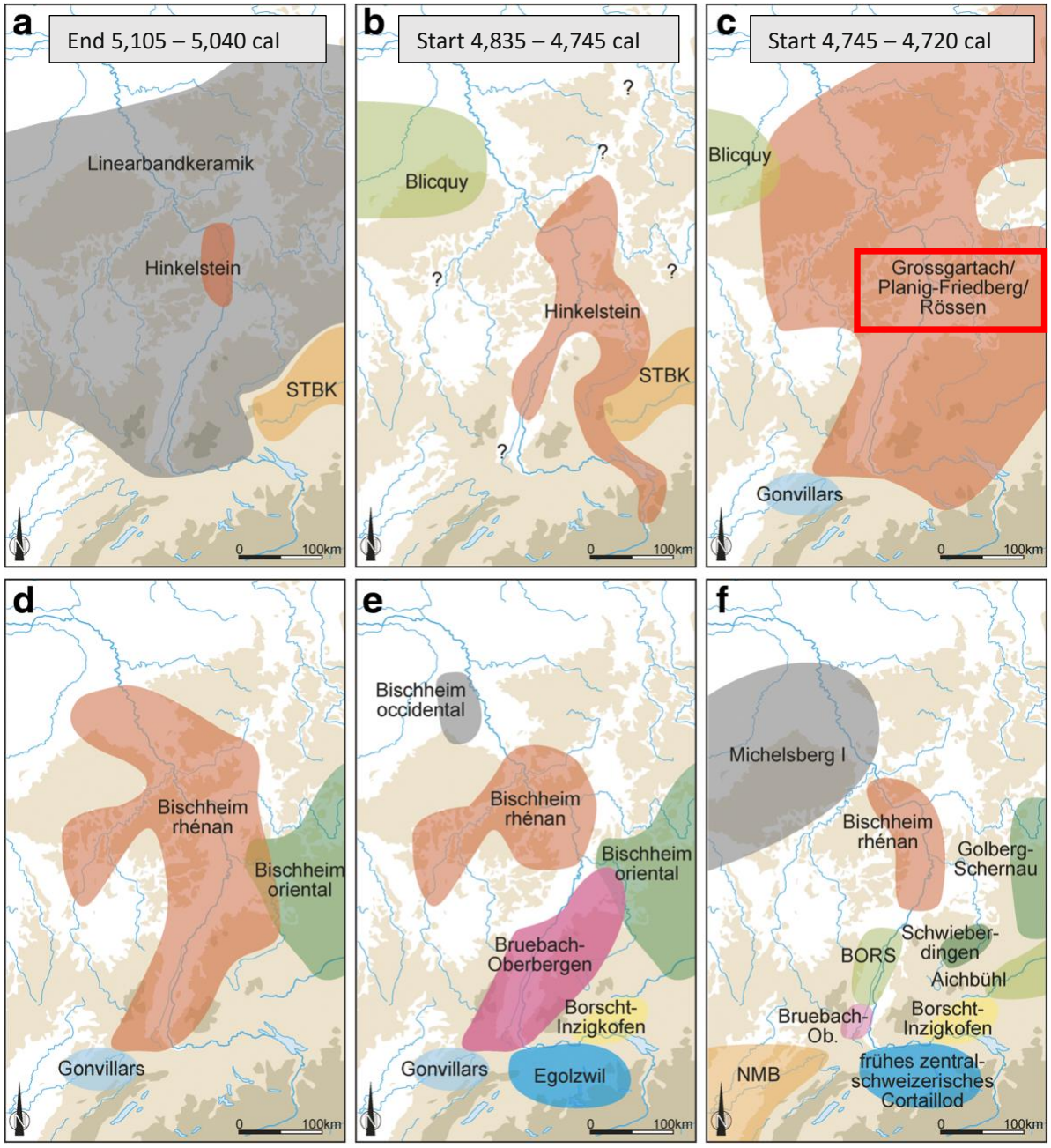


Fig. 8. Maps of the upper Rhine valley and surrounding regions, showing the maximum spatial extent of different styles of Early and Middle Neolithic ceramics: **a** LBK, **b** Hinkelstein, **c Grossgartach,** Planig-Friedberg and Rössen, **d** Bischeim, **e** Bruebach-Oberbergen and **f** BORS (NMB: Néolithique moyen Bourguignon). Modified from: Denaire et al., 2017, p. 1077.

Relevant Climate and Environmental Data of Lower Alsace in the Neolithic

General aspects of climate and vegetation

The middle Holocene with its warmer winters, milder summers, and increased rainfall has precipitated the appearance of deciduous forests that dominated the central and northern Europe landscapes during Neolithic times, but the actual extent of the Neolithic woodland stands is difficult to estimate, as today's landscapes might significantly differ from their earlier appearances (Dambeck & Thiemeyer, 2002; Abdulkarim et al., 2022).

The shading canopy of these woods, specifically its extent and structure, determines the undergrowth possible (because it cannot regenerate under a dense shadow) and thereby also the presence and quantity of herbs and grasses (Härdtle et al., 2004, as cited by Kreuz 2008, 60).

The kind of undergrowth in turn is essential because it defines the plenty of fodder available to both wild and domesticated animals and thereby forms an essential part of the agricultural potential of a landscape. Based on archaeobotanical results, these early woods, of a mixed structure with trees of various ages, are thought to have had regularly *natural* clearings in them, created both by large herbivores (e.g., aurochs, red deer, elk and also domestic cattle), but also beavers, and in addition to natural phenomena such as the breaking down of trees by lightning and fire, snow, wind and storm and flooding (Bunzel-Drüke et al., 2001; Kreuz, 2008, 2012).

They would also have been partly – and in some areas probably completely - cleared by the LBK farmers to build their homesteads, fences, and to use the space for fields, as has been postulated by a study of proxy records (mostly pollen) from the pre-Bronze Age human impact on the landscape in the Aegean, the Balkan and Carpathian regions (Chapman, 2018). Therefore, woods in the areas surrounding the settlements would have been considerably thinned and widely opened due to these human activities, coppicing especially in the *river valleys*, both for crop growing and animal breeding, favoring the increase of undergrowth and thereby also supporting wild and domesticated grazing animals feeding upon it (Fig. 9, for a discussion of wild and domestic animal feeding types, tree growth and an effect of a closed canopy on woodland structure, see Kreuz, 2008).

In any case, even in the Middle Neolithic, the farmers that were re-populating the soft hills on the left bank of the Rhine in Lower Alsace after a time gap of several generations were using the *fertile soils of the loess plateau* east of Strasbourg for livestock and for growing their crops, as recent paleoenvironmental reconstructions have shown on a large scale (Lehmkuhl et al., 2021).

In a radiocarbon-dated study of peat profiles of the *Northern Vosges* in the middle of the Atlantic period (around 4500 BC) an oak-forest, rich in pine, covered this area at a short distance (about 25 km) *south-west of the study site*, with *no land use detectable in the pollen diagram before 4000 BC* and

larger charcoal particles, barley grain and beech pollen (considered a sign of woodland pasture and first agriculture) detected thereafter (Sudhaus & Friedmann, 2015).

Fig. 9. a. (left) The favorite habitats of grazers like aurochs, horse, domestic cattle, and sheep probably were the floodplains with their rich undergrowth.
Here are depicted two contemporary examples from loess landscapes in Hessen, Germany a floodplain of the brook called Darmbach near Darmstadt (left) and 9.b. (right) of the river Rhine in the Kühkopf nature reserve in the upper Rhine valley near Stockstadt. From: Kreuz, 2008, Fig. 2, p. 60.

There is consensus that during the Neolithic - from the inhabited parts of northern Europe to the Mediterranean regions - these woods of a mixed structure with trees of various ages and sufficient clearings have provided an important space for land use and a complementary source of fodder (such as underwood, leaves and branches) to be exploited during periods of scarcity, mostly in the wintertime and also to avoid overgrazing (Kreuz, 2008; Halstead, 2018).

This technique of feeding livestock has directly been confirmed by studying well-preserved dung of domestic animals (stemming from cattle, goat, and sheep) in wetland settlements in Germany and Switzerland (Rasmussen, 1993: Kühn et al., 2013).

Introduction of domestic animals into Alsace and Middle European sites

Livestock was introduced into Alsace possibly following two routes, Fig. 10, a, and b (Bickle et al., 2007; Lefranc, 2007; Casanova et al., 2020). In addition, in the Paris basin recent aDNA research has demonstrated a genetic contribution of farmers descendent both from the Danubian and Mediterranean Neolithization waves and with a *large pedigree of the Middle Neolithic human group from Gurgy 'les Noisats'* (dated 4,850 – 4,500 BC, also providing important SI data, see below) this has significantly forwarded the understanding of their social organization (Rivollat et al., 2015, 2020, 2023).

How this domestic stock was raised and fed by Neolithic people in this area can be studied in more detail using faunal and - as a comparison - also botanical and human stable isotope values of carbon and nitrogen as discussed above, to reconstruct paleodiet and land use (Fraser et al., 2013; Doppler, et al., 2015; Gillis et al., 2022).

Of special interest in this upper Rhine River valley is the possible canopy effect in a dense forest as postulated for this period (Bakels, 1978; Van der Merve & Medina, 1991; Zoller & Haas, 1995; Litt, 2000; Whitehouse & Smith, 2004) possibly leading to quite low values of the $\delta^{13}C$ isotope in the bones of the animals kept under these conditions, or alternatively living in humid environments.

The values of stable $\delta^{15}N$ isotope can, in addition, confirm the effect of field manuring and possible foddering with tree leaves and branches (Oelze et al., 2011; Kendall et al., 2018).

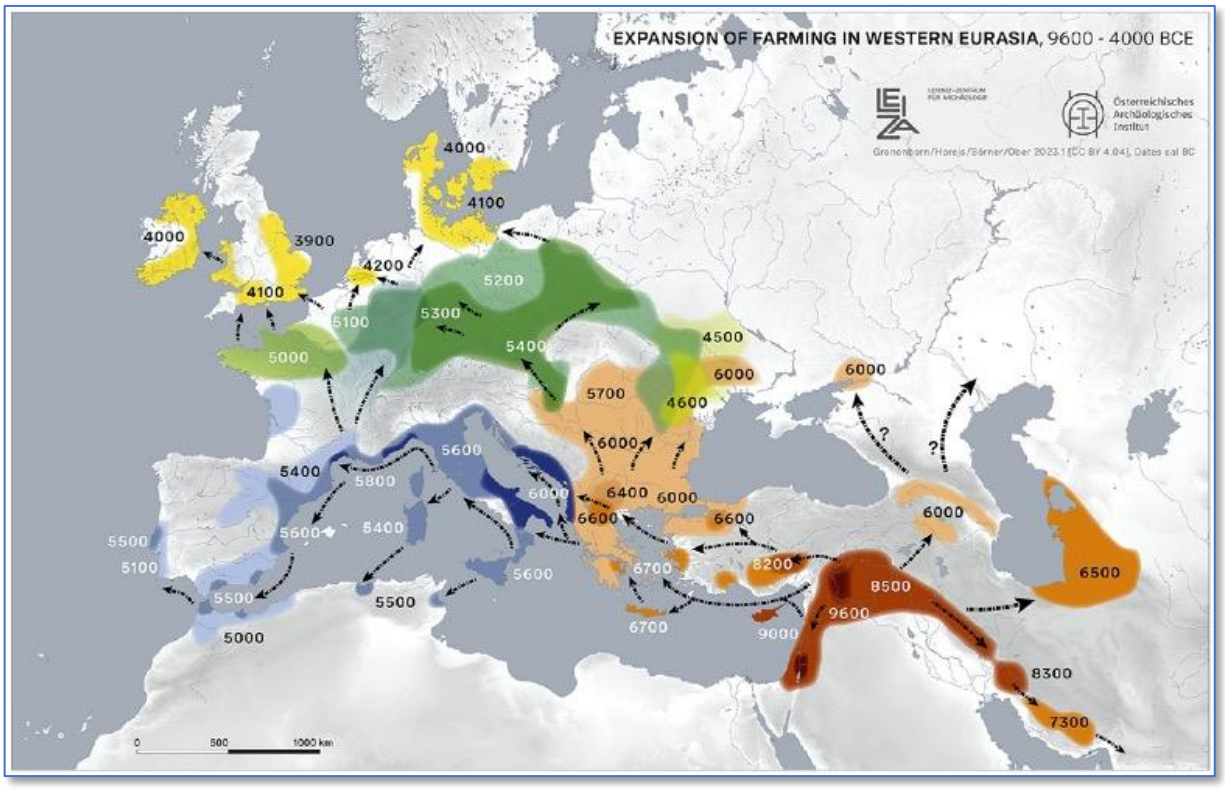


Fig. 10.a. Condensed and simplified map of the spread of farming in western Eurasia. Cit.: Gronenborn/Horejs/Börner/Ober (LEIZA/ÖAI) 2023.1.

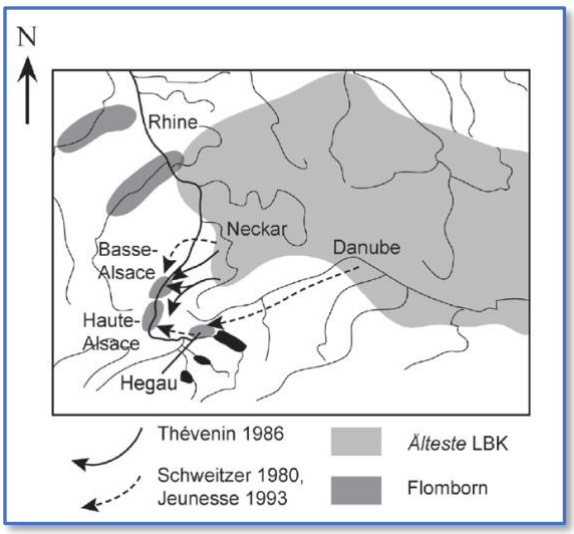


Fig. 10. b. The suggested colonization routes along which the LBK reached the Lower (Basse-) and Upper (Haute-) Alsace.

From: Bickle et al., 2013, Fig.8.2, detailed discussion: pp. 291 – 302. After: Lefranc, 2007, 33.

A series of ***stable isotope data,*** combined with zoo-archaeological information, stemming from ***LBK sites*** in Lower and Upper Alsace dealing with questions of animal farming, hunting practices and subsistence, are available (Fig. 11). They will be discussed in the following paragraphs to present a sketchy overview – evolving over the last decades - of the early keeping of domestic animals, and the observed proportion and browsing of the wild game, that was made use of by the farming societies.

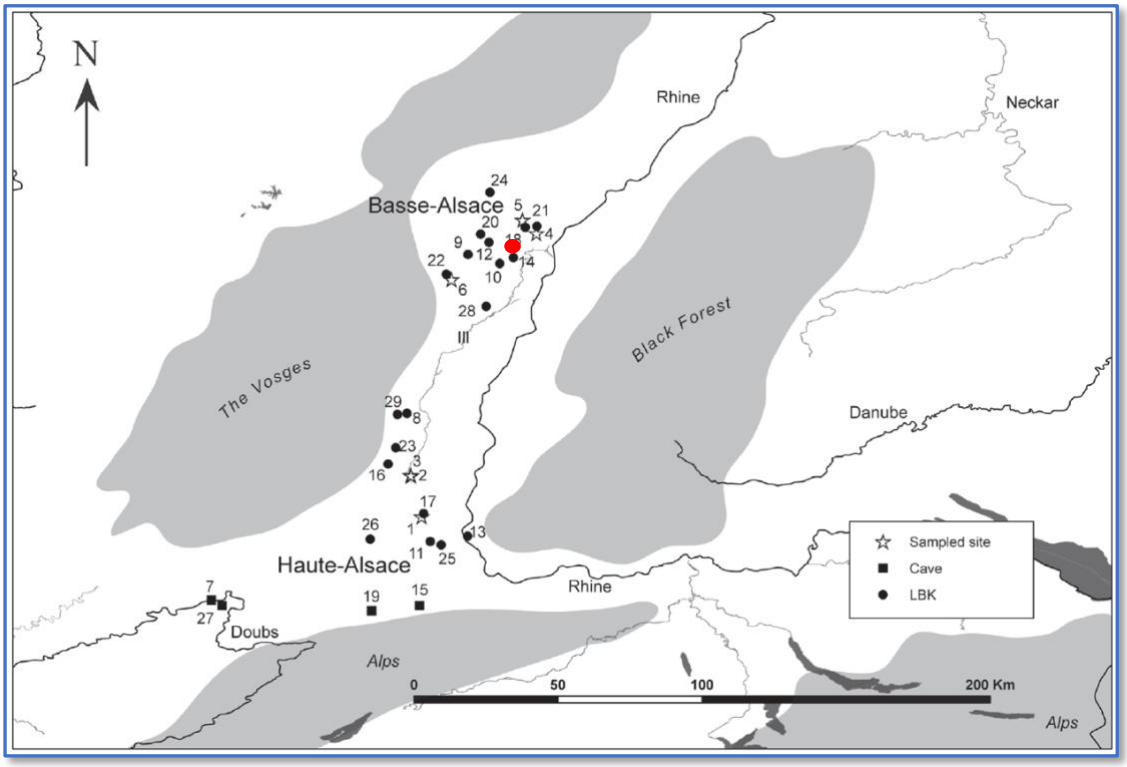


Fig. 11. Map of sites sampled for ***stable isotopes*** (animal and human):

- in **Upper** (Haute-) Alsace*: 1) Moulhouse-Est, 2) Ensisheim Ratfeld, and Ensisheim les Octrois,* and
- in **Lower** (Basse-) Alsace: *4) Souffelweyersheim, 5) Vendenheim, 6) Bischoffsheim (2 studies).*

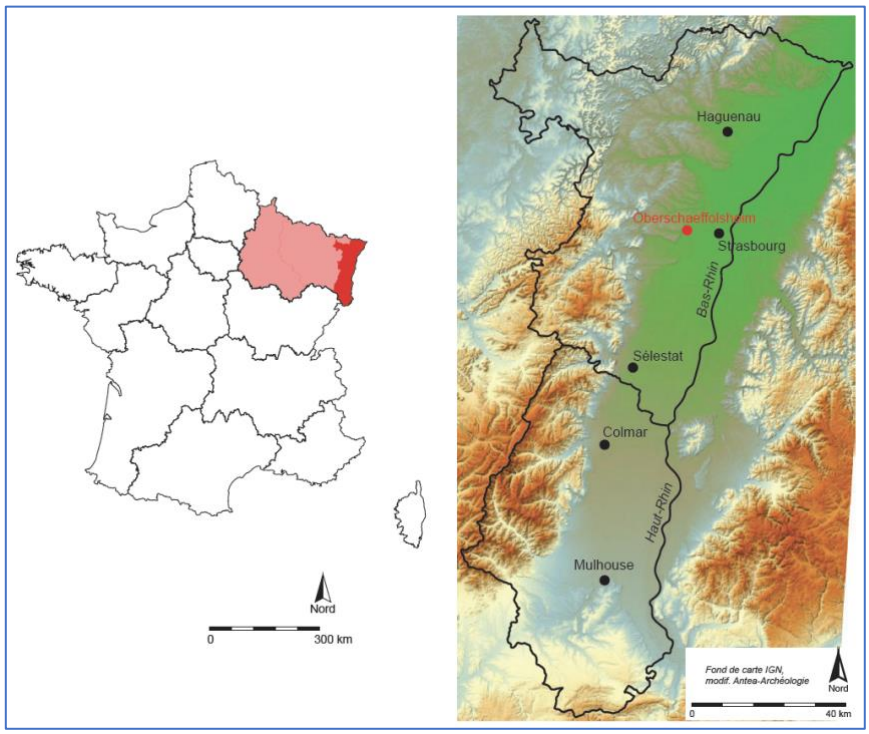
The red dot shows the location of the study site, *Oberschaeffolsheim*. From: Bickle et al., 2013, Fig.8.1.

To add a slightly larger overview selected sites from France and the southwestern and central areas of Germany that fit into the timeframe will also be considered in the discussion section.

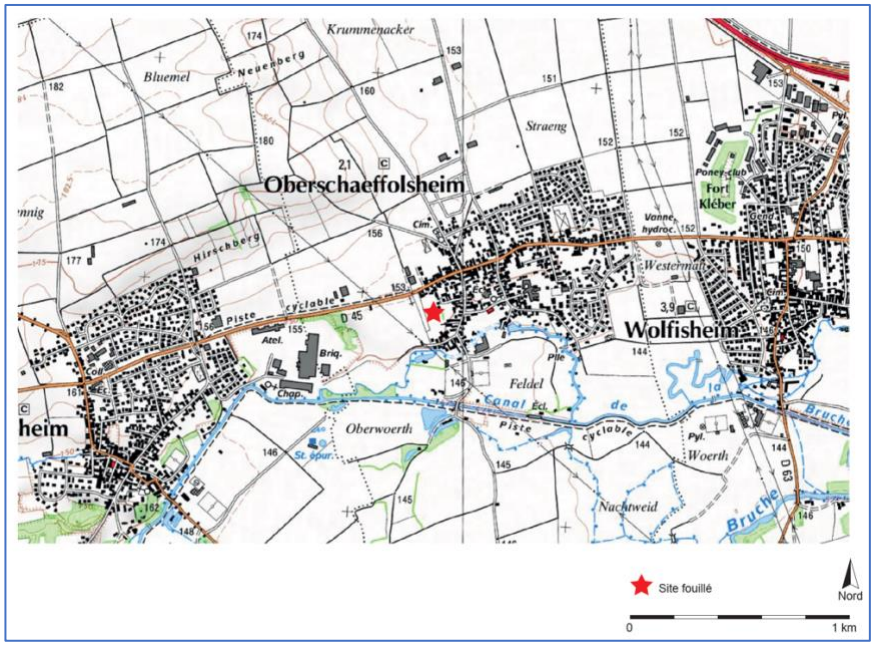
Details of the Study Site of Oberschaeffolsheim in Lower Alsace, France

The Location and Spatial Details of the Site in the Early and Middle Neolithic Time Frame

The community *Oberschaeffolsheim* is located about 7 km to the west of the city of Strasbourg, France, Fig. 12.a., on the southern ledge of the plain of Kochersberg on the loess terrace of Schiltingheim. The excavation itself is situated at the western exit of the village about 4 m above the little river "Bruche", which flows about 60 m south of the location (Fig.12.b) and it comprises a total area of 17.455 m^2.

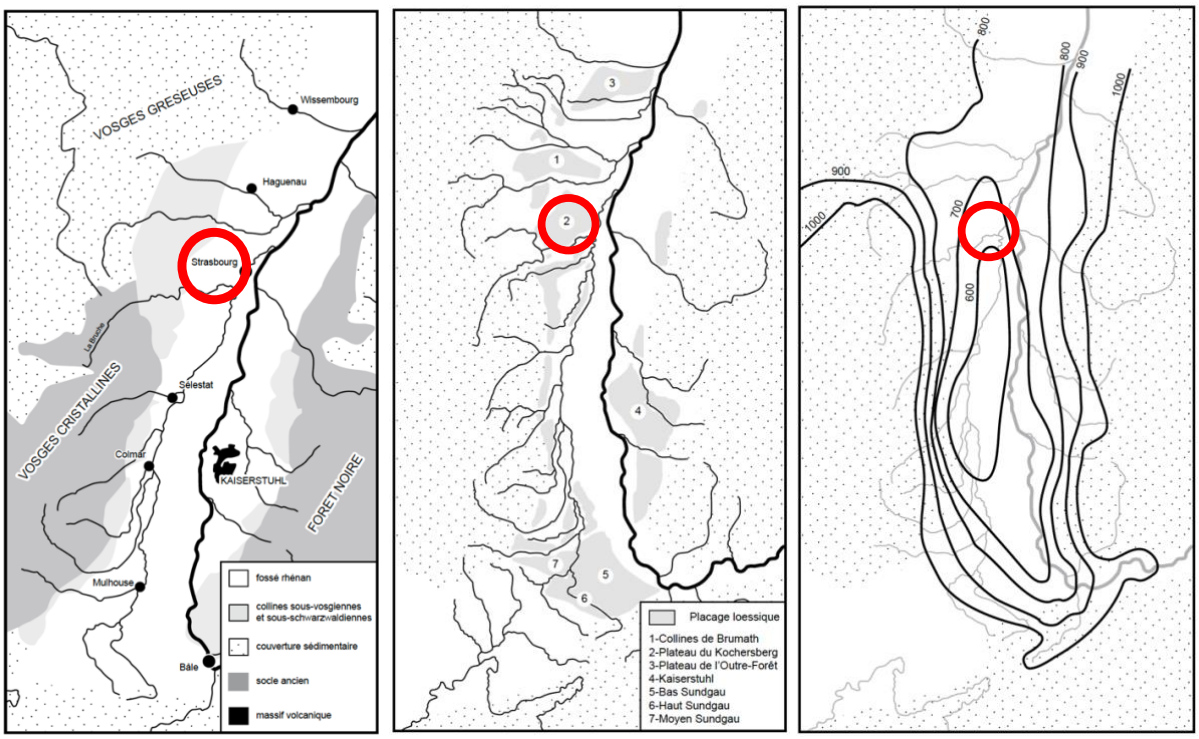


12.a.



12.b.

Fig. 12. a. Location of the study site in Lower Alsace (Basse Alsace) west of Strasbourg. Fig. 12. b. Location of the excavation site west of the village. From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d ´operation d´archéologie preventive. Volume 1 – Texte. ALTEA. Fig. 1, p. 68.



a. b. c.

Fig. 13. (left to right) a. Geological units, west of the Rhine valley the **Vosges** mountains and in the east the **Black Forest** hills are located. b. Principal *loess fields*, # 2: Kochersberg, and c. *Isohyetal map* of average annual rainfall in the southern part of the Rhine valley (mm/year). From: Lefranc 2007, Fig.1.; From: Denaire 2009, Fig. 6 and 7, after Jeunesse 1993, Fig. 29; Fig. 28.

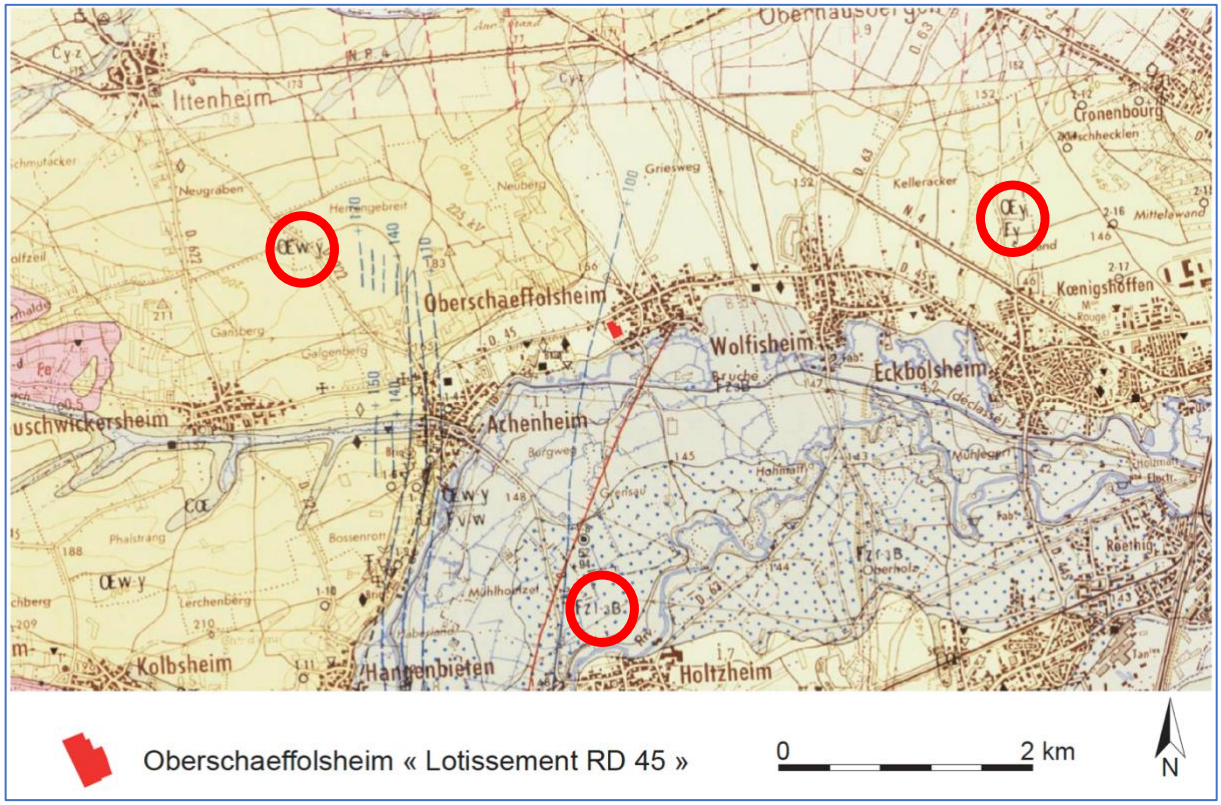


Fig. 14. Geological context of the landscape around the site: *OE w-y*: loess from Mindel to Würm, *Oe y/Fy* loess of the Würm period covering the gravel from the Rhine and Bruche rivers, Fz 1-3B: gravel of the Bruche covered by a fine overflow of silt from the Würm until historical times.
Modified from: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d ´operation d´archéologie preventive. Volume 1 – Texte. ALTEA. Fig. 2, p. 70.

The overall geological context is shown in Fig. 13. a, the principal loess fields in Fig. 13.b., the annual rainfall in Fig. 13.c. The detailed geological context of the landscape around the site (with the thickness of the loess cover varying between 8 and 12 m according to the geological sounding) is shown in Fig.14.

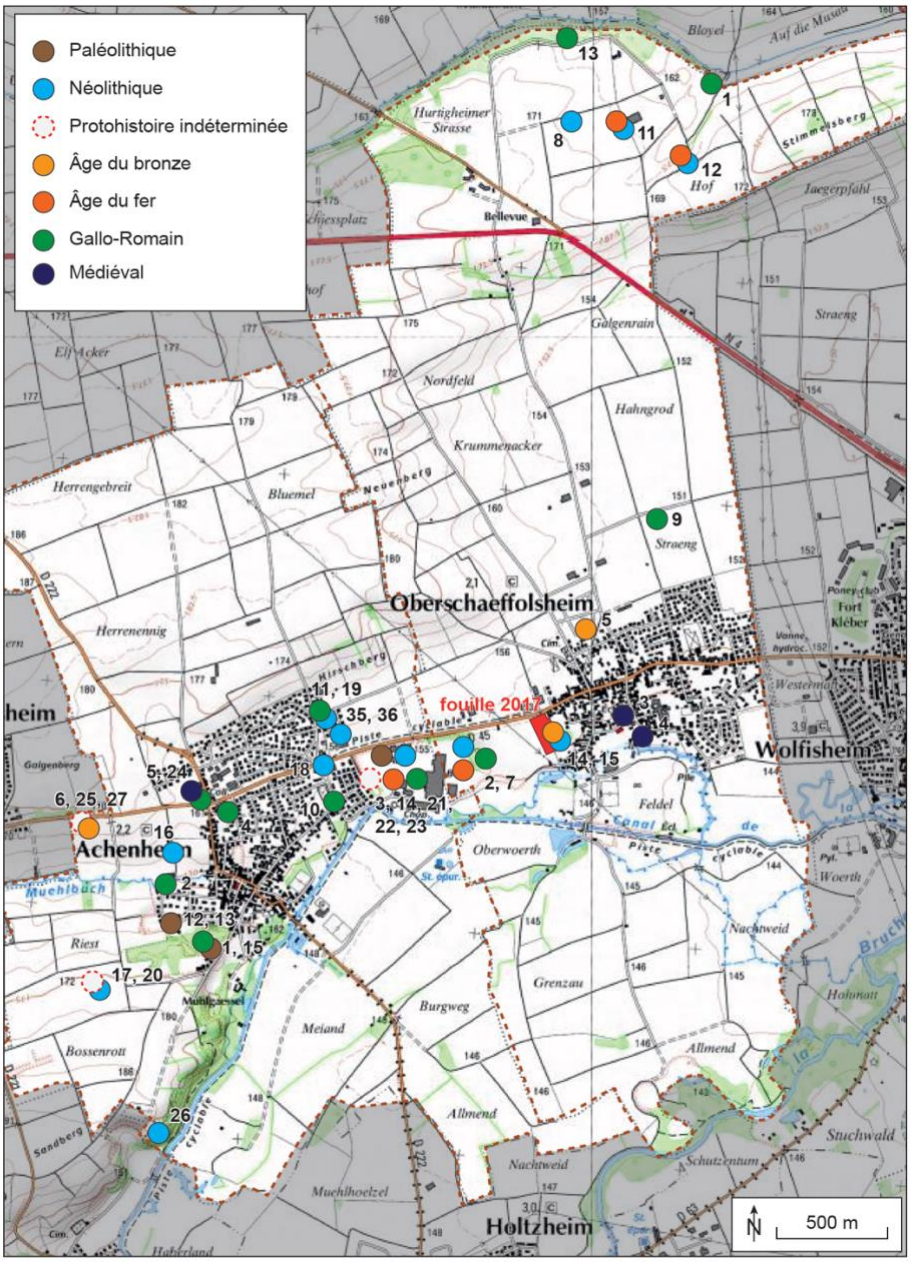


Fig. 15. Archaeological map of the communities of *Achenheim* and *Oberschaeffolsheim* showing the find spots from the paleolithic to medieval times. From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1 – Texte. ALTEA. Fig. 4, p. 72.

Although the Neolithic findings (12 locations) seem to comprise the majority in the area (Perrin et al., 2019., Fig. 15, 16) many other sites have been identified in the surroundings from the Lower and Upper Paleolithic including a cemetery, dating to medieval times, and a local castle, destroyed in 1679.

The amount of Middle Neolithic sites, specifically the Grossgartach (GG) culture (4750 – 4660 BC) is astounding (Fig. 16), probably related to the exploitation of the very fertile soils of the Kochersberg,

the resources offered by gallery-forest along the river Bruche and its tributaries, the mineral resources provided by the nearby Vosges and the connection to the Lorraine plateau via the col du Donon.

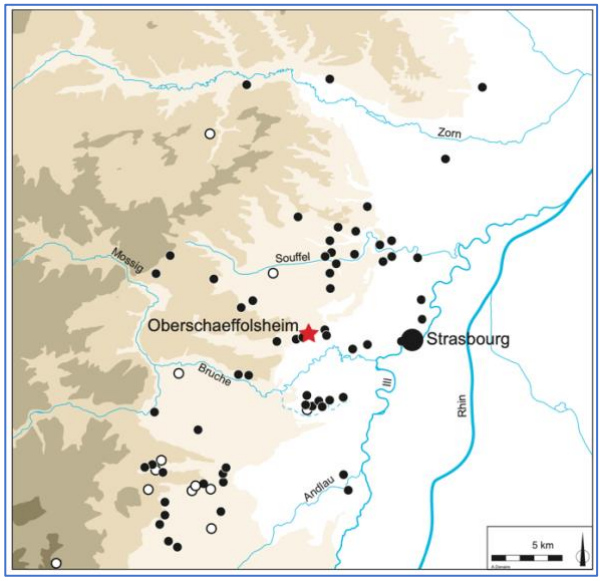


Fig. 16. Grossgartach sites on the Kochersberg plateau and the surroundings.
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1 – Texte. ALTEA. Fig. 19, p. 97.

In spite of the many sites from this period discovered in the area, only very few were of a large size, and particular reference should be made to Kolbsheim "Vogeseblick", with an area of nearly 3 ha, large ditches and abundant numbers of findings, located only a few km from Oberschaeffolsheim (Denaire, 2010; Denaire et al., 2013).

At the site of Oberschaeffolsheim « Lotissement RD 45 » that was studied in detail, the majority of the Middle Neolithic structures were large poly-lobulated ditches, mostly ***Grossgartach*** (represented by 68 structures and additional 15 shards), but also a few older and younger Neolithic ones, but none that could clearly be attributed to Planig-Friedberg or Roessen.

That number might seem low at first, but some complexes covered large areas, e.g. ditch # 177 with 43 m x 16 m and ditch # 446 with 34 m x 23 m. The structures were found all over the excavated area, with no limit of the Neolithic settlement reached, the findings getting slightly rarer towards the north side, however. No trace of buildings could be uncovered, a fairly constant of the Alsace sites, except for Bernoldsheim (Leprovost, 2012), probably caused by the spatial organization of the villages in the Grossgartach period, when the extraction of loess did not happen around the buildings themselves, but in small collective ditches at some distance from the houses (Denaire et al., 2013).

Additional structures uncovered on the site fitted well into the final Bronze age and the final Latène and Roman time periods (cf. Fig. 17 for spatial and Fig. 18 for temporal distribution).

An old valley ("paléo-vallon"), most probably present during the Grossgartach occupation period, seems to have divided the structures and was subjected to a palaeo-geomorphological study by S. Goudissard (Fig. 19). It ran from east to west through the excavation area and from the detailed analysis

it was postulated that the Grossgartach settlement developed intentionally on the banks of this old depression (in: Perrin et al., 2019, Fig. 14 – 18, p. 86 – 94).

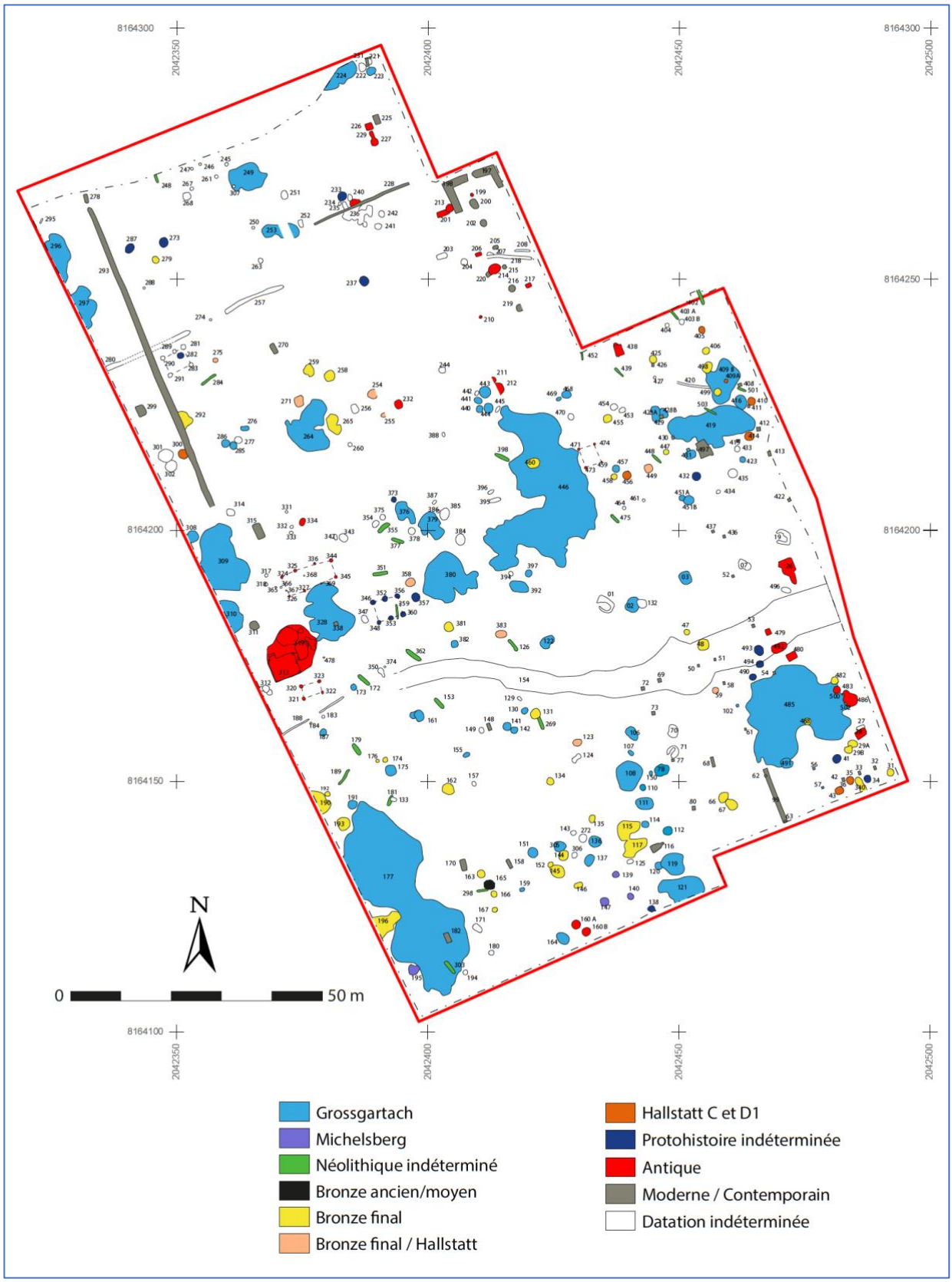


Fig. 17. Phase plan of *Oberschaeffolsheim* showing the find spots from the Neolithic to modern times. From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d ´operation d´archéologie preventive. Volume 1 – Texte. ALTEA. Fig. 11, p. 83.

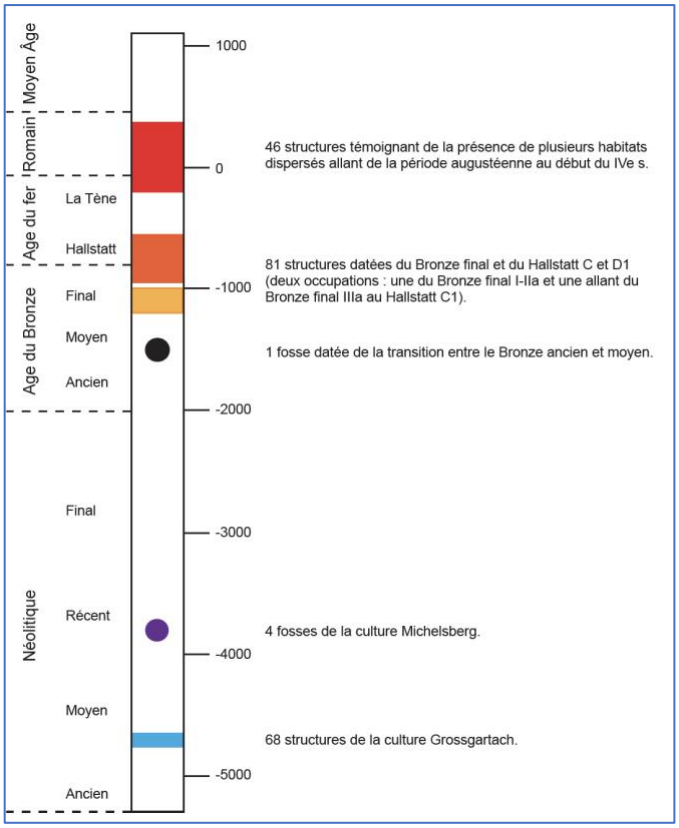


Fig. 18. (left). Chronology with number of identified structures of *Oberschaeffolsheim.*
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1. Fig. 12, p. 84.

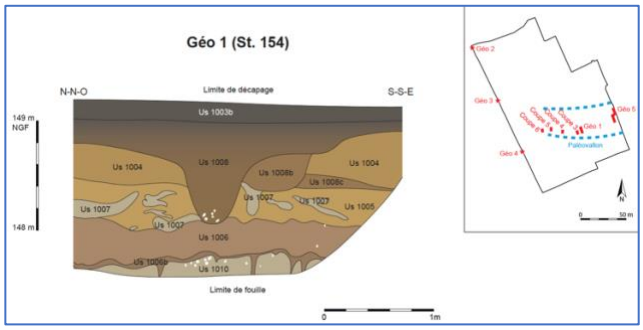


Fig. 19. (above). Cross section of the "paléo-vallon" crossing the excavation of *Oberschaeffolsheim.*
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1. Fig. 16, p. 91.

Of the 68 Grossgartach structures, 21 were classified as ditches with irregular profiles, testimony of several episodes of deepening, with three (# 177, 446 and 485) very large in size. The first and biggest one, with a maximum depth of 1,75 m from the surface and 49 lobes detected at the basement, with one of them serving as a hearth, contained a total of 4368 shards (GG phase 2 to 4), two human inhumations and a total of 4331 faunal bones. Similar characteristics of the deposits were found for the ditches 446 and 485 with the latter one providing human remains and a partial bovine skeleton. The other 18 smaller complexes, also containing several human inhumations and bone collections were detailed in the excavation report (see Fig. 26).

The placement of the **houses** on the site is highly speculative (Fig. 20) and postulated to follow the data known from Brumath concerning their size, shape, and orientation (which at the later site is around 16 – 30 m by 6 – 8 m, with an orientation from northwest to southeast), (Levoprost, 2012). Another theory, based on the excavation of Kolbsheim "Vogeseblick", has proposed that the location of the habitations would be expected to be at a distance from the ditches, in this case, based on the number of deposits and the mudbricks in the ditch # 177, to the west of the site (Denaire, 2010, 2013).

The few **human remains** were reported by A. Mauduit in detail (p. 108 – 124), with four inhumations in structures 177 (2), 121 and 485, as well as a deposit of human bones. These findings are exceptional, as funerals *within habitations* had not been described for the Grossgartach period in Alsace and two of the individuals had been deposited in a position that has been described as "brutally constrained". The collection of human bones in ditch 409B (Fig. 21) with the fractures performed in fresh bones that were thereafter exposed to fire, reminds one of the LBK findings at Herxheim (Boulestin et al., 2009).

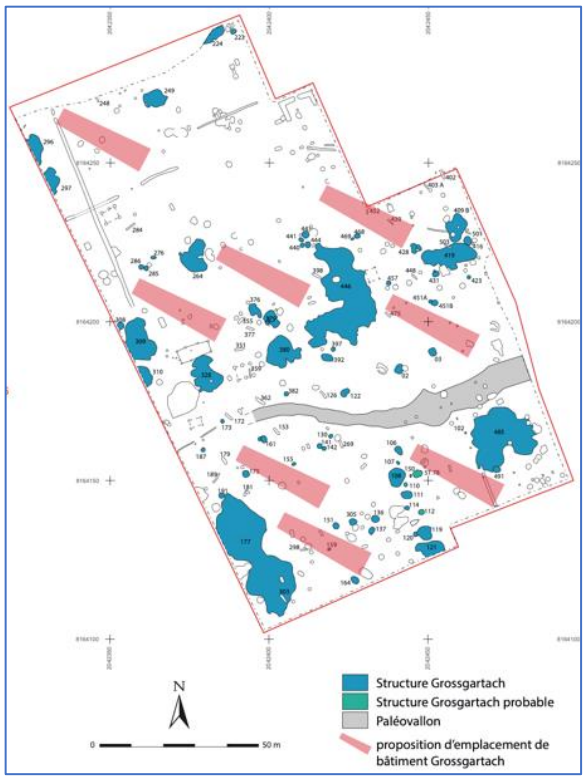


Fig. 20. Right. Proposed plan of GG structures with GG buildings and the location of the "paléo-vallon" in the excavation area of *Oberschaeffolsheim.*
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1. Fig. 27, p. 106.

Fig. 21. Above. Overview of the bone deposit in ditch 409B.
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1. Fig. 38, p. 118.

The **ceramics** consisted of nearly 14.000 fragments, all dated to the Grossgartach period, beginning in Lower Alsace between 4,765 and 4,705 BC (95% confidence interval, 4,745 – 4,720 BC, 68%) and ending with Planig-Friedberg, as the final phase between 4,690 – 4,610 BC (95%) or 4,680 – 4,660 BC (68%), see above (Denaire et al., 2017). Many of the shards still retain their white incrustations (Fig. 22). The relevant details were presented by Perrin and Denaire (p. 124 - 159).

Fig. 22. Example of the white incrustations on the Grossgartach ceramics.
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1. Fig. 41, p. 125.

Faunal Remains

These were reported in detail by M. Fabre (p. 161 – 176) and out of the 160 structures of different periods comprised a total of over 11.000 pieces with a weight of nearly 505 kg. Of these the GG period included 85% of the number of pieces (NP) and 91% of the total weight, the structure # 177 alone accounting for one third (NP= 4331), the structures # 446 and # 485 for another 1000, whereas more than half of the other structures contained less than 10 pieces each (as an example for NP, Table 2). Of the pieces determined by species, 13% showed a manducation by carnivores or pigs and about 8% traces of human activity, with only 2% showing signs of having been burnt.

Table 2. Summary of the number of faunal pieces (NP) as sampled, per structure. From: Perrin et al., 2019. Oberschaeffolsheim, “Lotissement RD 45”. Rapport final d ´operation d´archéologie preventive. Volume 1. Fig. 72, p. 163.

Structure	177	309	310	328	419	446	485	autres	Total
Bœuf : *Bos taurus*	1372	176	135	155	147	777	497	837	**4096**
Suinés	721	146	111	106	51	318	140	216	**1809**
Caprinés	149	41	13	21	37	63	26	56	**406**
chèvre : *Capra hircus*	10	5	3	5	9	11	1	3	**47**
mouton : *Ovis aries*	10	1	6	4	8	20	10	14	**73**
chien : *Canis familiaris*		1				1		3	**5**
TOTAL domestique	**2262**	**370**	**268**	**291**	**252**	**1190**	**675**	**1128**	**6436**
Aurochs : *Bos primigenius*	5	6	7	2	3	13	28	16	**80**
Sanglier : *Sus scrofa*	1	5	11	4	6	21	6	14	**68**
Chevreuil : *Capreolus capreolus*	8 (1)	1				4 (1)	3	0	**16 (2)**
Cerf : *Cervus elaphus*	123(17)	24 (12)	24 (1)	6 (1)	15	46 (3)	8 (4)	60 (9)	**306 (47)**
Equidés : *Equus sp.*	1	1					1	1	**4**
Lièvre: *Lepus sp.*		4							**4**
Mustélidé	1								**1**
Blaireau : *Meles meles*							1		**1**
Ours : *Ursus arctos*		1							**1**
Castor : *Castor fiber*								2	**2**
Hamster								1	**1**
oiseau	1						1	1	**3**
TOTAL sauvage	**158**	**54**	**43**	**13**	**24**	**87**	**51**	**58**	**488**
Bovinés	31	5	2	2		9	4	13	**66**
Suinés	37	4	7	2		4	2	18	**74**
grand mam	714	72	25	20	40	123	75	294	**1363**
moyen mam	86	18	6	1	12	23	20	45	**211**
petit mam	270	35	27	15	21	90	8	70	**536**
très petit mamm			1						**1**
ind.	773	142	96	55	85	356	278	400	**2185**
Coquillage				2	1	4			**7**
TOTAL général	**4331**	**700**	**475**	**401**	**435**	**1887**	**1113**	**2073**	**11415**

Bovines

These comprised the majority of the number of pieces determined (NPD, corresponding to NISP = number of identified specimens) with over 50% and 75% of the weight of pieces (WP), with all large skeletal parts present, the axial parts of the skeleton, however, being under-represented, according to the method of Oueslati, 2006 (Fig. 23). There were 3 infantile, 12 juveniles and 41 adults, with males and females equally distributed. Compared with the GG site of *Kolbsheim* these animals appeared to be larger (Guthman, in Denaire, 2013).

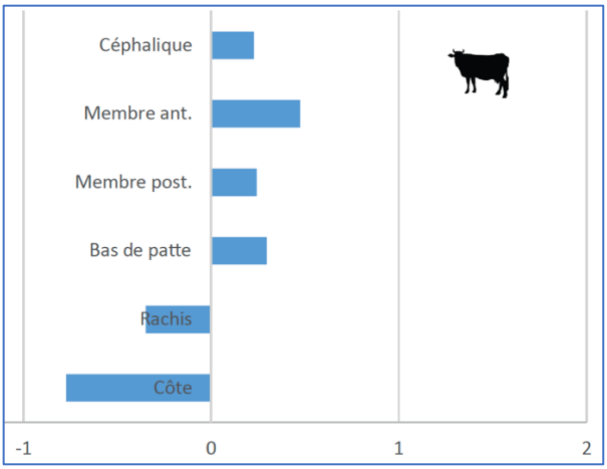


Fig. 23. Proportion of the weights of the bovine body parts excavated as compared to a reference animal.

Céphalique = head parts
Membre ant. = forelimbs
Membre pos. = hindlimbs
Bas de patte = forefoot
Rachis = backbone
Cote = rib

From: Perrin et al., 2019. Oberschaeffolsheim, “Lotissement RD 45”. Rapport final d ´operation d´archéologie preventive. Volume 1. Fig. 75, p. 165.

Their slaughter age shows a first peak before 6 months of age and another one from 4 to 9 years, (Fig. 24), which can be interpreted as an exploitation of the majority of the animals for milk. The most aged might also have been used for their traction power (as shown by a case of bone deformation) and their meat. In contrast, at Kolbsheim a significantly younger slaughter age of 2 – 4 years was apparent.

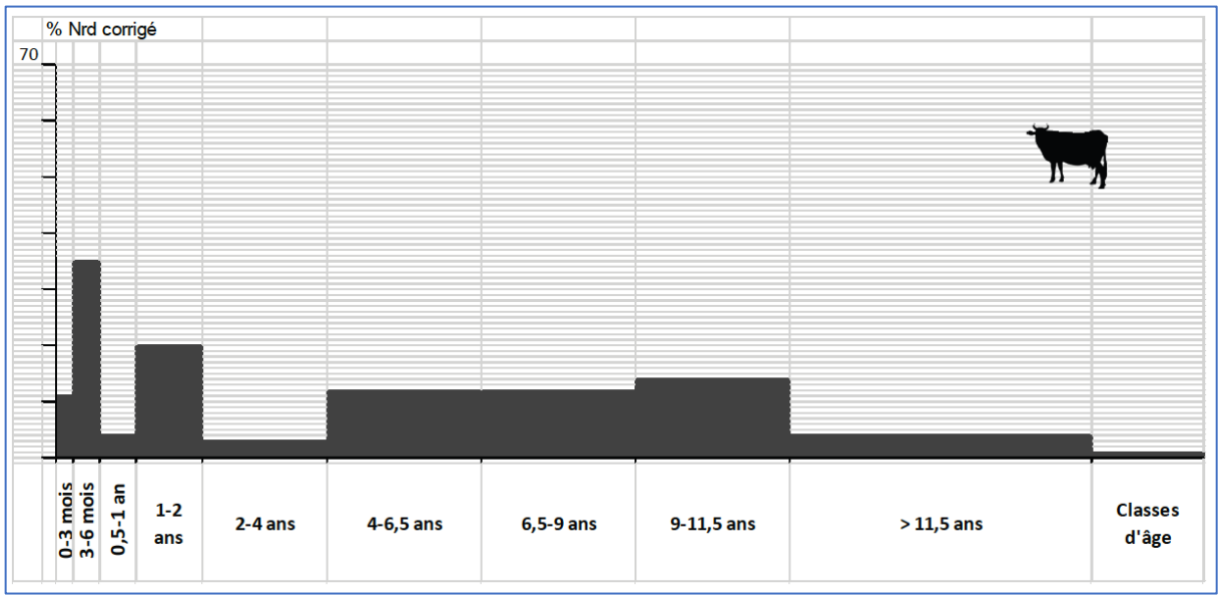


Fig. 24. Bovine slaughter age (mois = months, an(s) = year(s), classes d´age = age groups, Nrd corrigé = corrected percentage). From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d ´operation d´archéologie preventive. Volume 1. Fig. 95, p. 176.

Pigs

They comprise about one fourth of the NPD and one third in some structures (# 309, 310, and 328). Head parts are overrepresented as compared to the forefeet and the body parts of a reference animal (Fig. 25). There were 4 infantile with less than 6 months, 12 juveniles and 22 adults, with 5 males and 8 females minimum. Again, they seem to be slightly larger than the ones found at Kolbsheim. 29 pieces showed signs of light burning, 70 had signs of fractures or cut marks. Most animals (50%) were slaughtered between the age of 6 months and one year (Fig. 26).

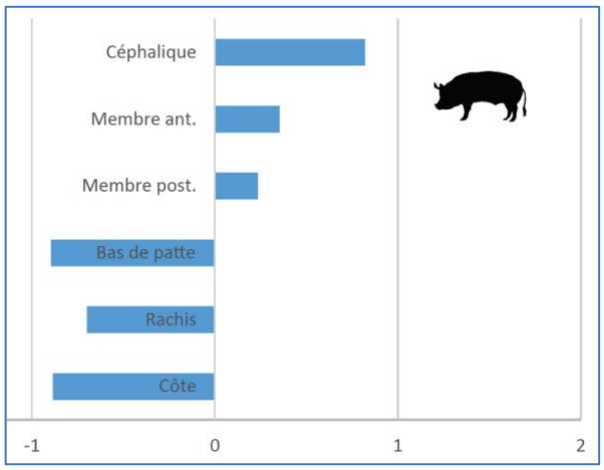


Fig. 25. Proportion of the weights of the suid body parts excavated as compared to a reference animal.
Céphalique = head parts
Membre ant. = forelimbs
Membre pos. = hindlimbs
Bas de patte = forefoot
Rachis = backbone
Cote = rib
From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d ´operation d´archéologie preventive. Volume 1. Fig. 84, p. 168.

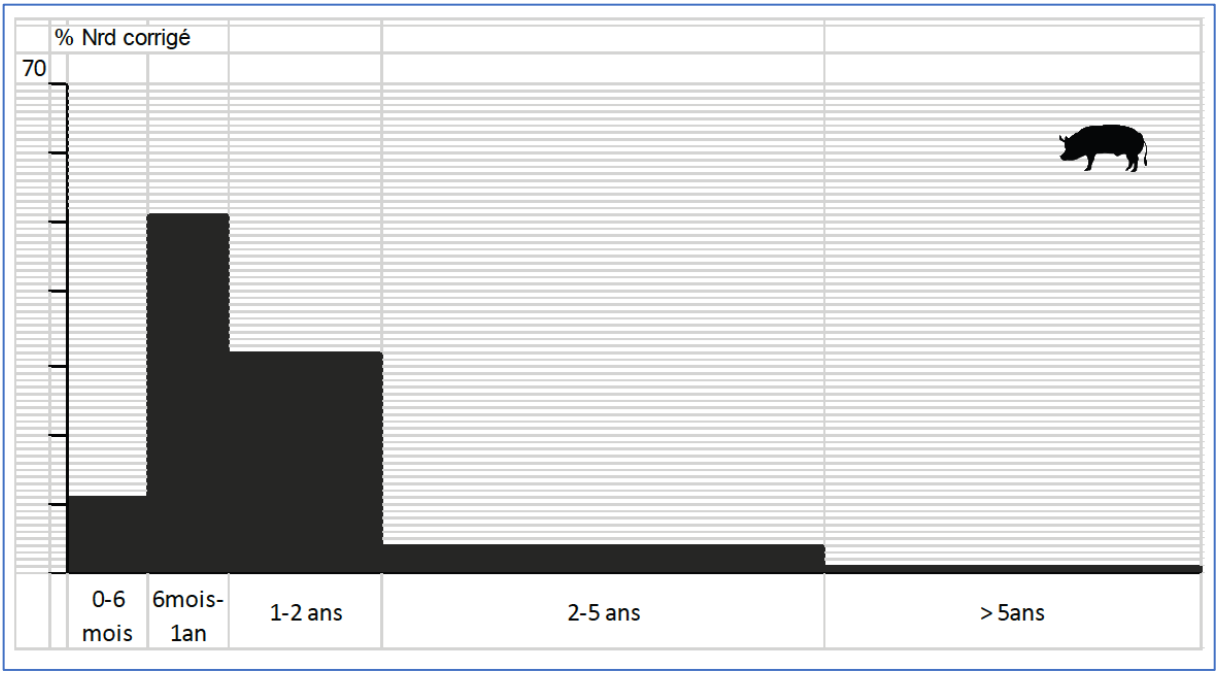


Fig. 26. Suid slaughter age. (mois = months, an(s) = year(s), Nrd corrigé = corrected percentage). From: Perrin et al., 2019. Oberschaeffolsheim, "Lotissement RD 45". Rapport final d´operation d´archéologie preventive. Volume 1. Fig. 95, p. 176.

Caprines

They comprise about 8% of the NPD with two species, *Ovis aries* (60% and 120 identified pieces) and *Capra hircus* being present, whereas in Kolbsheim about 75% were classified as sheep.

Here too head parts and fore- and hindlimbs are overrepresented as compared to the forefeet and the body parts of a reference animal. There was a minimum of 32 individual animals identified, 12 goats (one infantile, two juveniles and nine adults) and 13 sheep (three juveniles and ten adults), the majority older than 4 years. 11 were heavily burnt, and 14 showing cut marks.

Other animals identified.

- The *aurochs'* taxon was 1 % of the NPD, with a minimum of 12 individuals, all adult, from less than 4 to over 4 years of age, as the missing juveniles might have been difficult to separate from the bovines of smaller size. One piece was burnt, a dozen showed cut marks.
- The *wild boar*, like the aurochs, was identified by his larger size as compared to the domestic pig, with 74 pieces confirmed, making this 1 – 2 % of identified pieces. All were older than the domestic pigs, mature adults, four identified males, one female, the skeletal distribution was found to be like the domestic one.
- The *red deer* was the best documented wild species, 4 % of NPD, 11 individuals, including two juveniles, six mature (over 3 - 4 years) and one young specimen, one identified male, two females. Two pieces slightly burnt, ten with cut marks for disarticulation and meat recuperation.

- The *roe deer* was only represented in 0.2% of the NPD, in four structures, the 18 pieces without axial skeleton parts, stemming from three individuals, one juvenile, two adults.

These wild species constitute 7% of the meat providers, with the red deer dominating, followed by aurochs and wild boar, corresponding well with the regional expectation: at Kolbsheim with 6% (red deer and aurochs dominating) and Lingolsheim 7 %, again with a preponderance of the red deer (Guthmann, in Denaire, 2013; Hachem, 1995).

- Five pieces, without signs of human activity, such as burn or cut marks, belonged to one adult *dog*.
- Few parts of other animals were recovered, e.g. one hare, isolated horse pieces and few bird bones.

Overall, the bone preservation was very good, so that the findings can be considered to correspond to the initial deposits. The cut marks present attest to the fact that *remains of consummation*, both of domestic and wild animals were recovered, as mentioned above.

Whatever the classification method (number of pieces, weight of the pieces, or number of individuals identified) the ***bovines dominate consumption*** with 74% of the meat and slaughter weight (poids de viandes et abats, PVA), followed by suids with 22% and caprines with 4% PVA. Most of the bones recovered were systematically fractured to recuperate the bone marrow in many cases, like the observations at Kolbsheim show (Guthmann, in Denaire, 2013).

The skeletal representations of all domestic species that were recovered speak for a *secondary* slaughtering with the bulkier elements being deposited at other sectors, certainly outside the habitation, again similar to Kolbsheim.

The bovine slaughter ages speak for an exploitation of the animals mainly for milk production, but clearly also for meat consumption as evidenced by the numerous cut marks. The oldest animals might have been used for traction work as attested by some pathological bone changes observed. This contrasts with the slaughter age at the site of Kolbsheim which was between 2 and 4 years.

Organic residue analysis at Rosheim, a site close to Oberschaeffolsheim, using potsherds spanning a time frame from *late/final LBK* through the *Grossgartach* to *Rössen* periods has demonstrated a significant shift in dietary practices in Lower Alsace: with no ***dairy fats*** present in the earlier time, a low admixture of those in the Grossgartach and high percentage in the Rössen periods. These lipid chromatography data do not fully mirror the cattle vs. pig vs. caprine meat weight distribution which shows a decrease of the percentage of pig from 30% to 12%, however (Casanova et al., 2020).

With this shift to more use of dairy products will there be a change of livestock farming observable at Oberschaeffolsheim?

Domestic pigs are slaughtered between the age of one and two years, having attained the maximum weight. Due to the lower numbers, slaughter age for the caprines could not be determined.

With over 11000 pieces recovered **Oberschaeffolheim** is incontestably one of the principal Grossgartach culture sites, next to Kolbsheim and Lingolsheim providing several additional pieces of information about meat consumption, being mostly centered on bovines.

Materials and Methods

All faunal bone samples (Table 3) were evaluated and categorized at the Oberschaeffolsheim study site by M. Fabre (Perrin et al., 2018/19, Excavation reports, Vol.1, 161 – 176) then selected and initially prepared for analysis by M. Blanz in cooperation with M. Balasse and M. Fabre at the *Centre de conservation et d'étude d'Alsace,* CCE, 11 rue Champollion, 67600 Sélestat, Alsace, France (Figs. 27, 28).

Table 3. List of all faunal samples studied (Σ = 71)

Species	**Common name**	**n**
Bos taurus	cattle	16
Bos primigenius	aurochs	9
Caprinae	sheep / goat	10
Sus domesticus	domestic pig	19
Sus scrofa	wild boar	8
Cervus elaphus	red deer	8
Capreolus capreolus	roe deer	1

Fig. 27. The "Centre de Conservation et d' Étude d'Alsace". https://www.archeologie.alsace/fr/collections/le-centre-de-conservation-et-detude-alsace

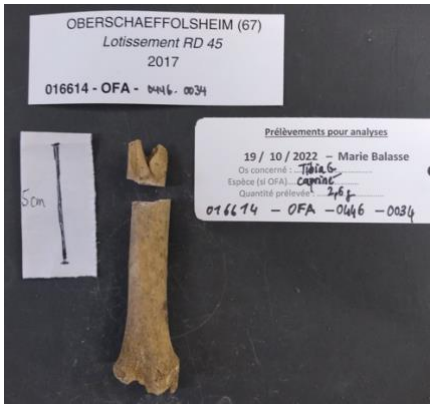


Fig. 28. Example of preparation and documentation at the CCE.

For the mammals, the same part of the bone from the same side of the body within each species group was sampled, to prevent studying identical individuals twice (pers. comm. M. Blanz). Care was taken to collect well-preserved thick pieces of cortical bone avoiding trabecular meshwork parts as much as possibly using a circular dental saw and all bone samples were photographed for documentation.

Fig. 29. Mechanical grinder used at HEBA.

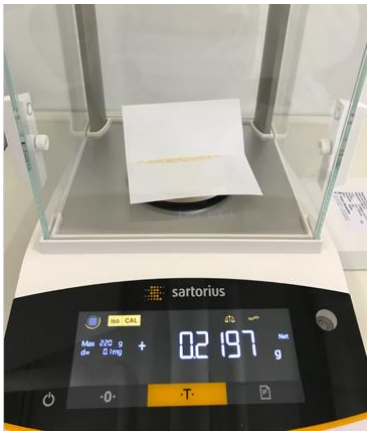


Fig. 30. Weighing after grinding

Sample preparation

was thereafter performed at the former *HEBA-Laboratory of the* Vienna Institute for Archaeological Science (VIAS) at the University of Vienna (UZAII, Josef-Holaubek-Platz 2, A-1090 Vienna, Austria) according to directions given by M. Balasse and written up as standard laboratory protocol by M. Blanz, October 2022, following largely Bocherens (et al., 1988, 1991 a, b) and Guiry and Szpak (2021):

All samples were ***weighed*** before further ***bone cleaning*** using a tungsten drill bit to remove the outer layer of the bone that usually comes off easily, taking care to also detach all trabecular bone when cleaning the inside of the samples.

Thereafter ***grinding*** the respective bone in a mechanical grinder (IKA A 11 Basic, Analyse-Mühle) was performed in multiple steps (Fig. 29) before each time sequentially collecting the 0.710 – 0.355 mm size fraction which again was ***weighed*** *and* ***collected*** in a 2 ml Eppendorf vial (Fig. 30).

Collagen extraction

of each sample was performed in several consecutive steps:

- after weighing in approx. 200 - 230 mg ground bone sample (recording the exact weight),
- *demineralization was* started with 20 ml of 1M HCl for 20 minutes (Fig. 31) and,
- after filtration with a nitrocellulose membrane (50 µm MCE membrane, 47 mm, Fig. 32),
- *humic acids and lipids* were removed with 20 ml of 0.125 M NaOH for 20 hours at room temperature (Bocherens et al., 1988).
- All samples were *diluted with MilliQ water,* when appropriate.

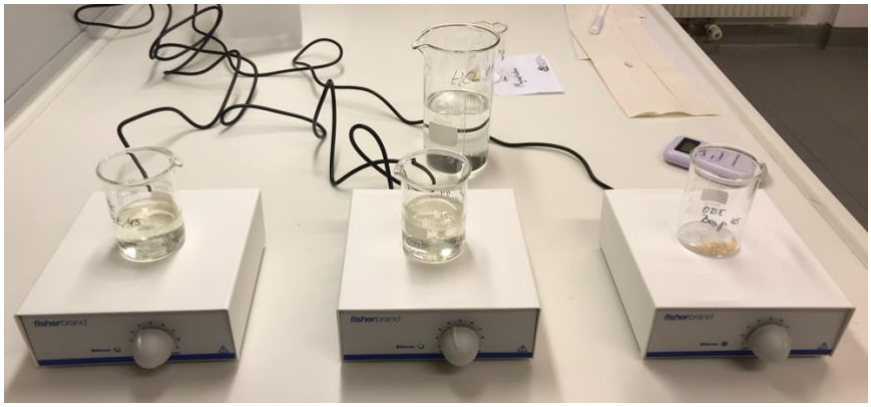


Fig. 31. Simultaneous demineralization.

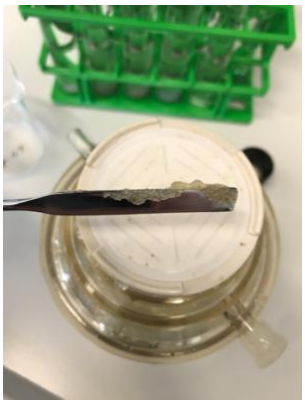


Fig. 32. Filtration of collagen.

Gelatinization of collagen

was performed following filtration of each 0.125 M NaOH solution with a nitrocellulose membrane (50 µm MCE membrane, 47 mm diameter) and placing the collected extract into approx. 12 ml 0.01 M HCl and keeping it at 70 °C for an additional 17 hours. The next step involved

Freezing the gelatinized collagen

in labelled 20 mL glass vials with sample names (after weighing each empty vial covered with the *final* lid) following an additional filtration step and replacing each lid with one that featured small perforations. The vials with their frozen content (< - 30^{o} C) were then transferred for

Freeze-drying the collagen solutions

by following the freeze-dryer protocol for at least 48 hours (Figs. 33 and 34).

Fig. 33. Freeze-drying the samples.

Fig. 34. Storage of samples after freeze-drying.

The freeze-dried collagen

was then weighed for collagen yield after putting the initially marked lids back on the vials. Thereafter

Weighing-in the samples

in specific, minuscule tin cups for analysis (320 – 380 µg bone collagen into each) was performed with a micro-balance Mettler Toledo UMT2, (Mettler-Toledo GmbH, Im Langacher 44,8606 Greifensee, Schweiz), Fig. 35. When correct weight was reached the tin-capsule was crimped, stored in a labelled 96-well microplate, and thereafter again stored in a drying cabinet (Fig. 36).

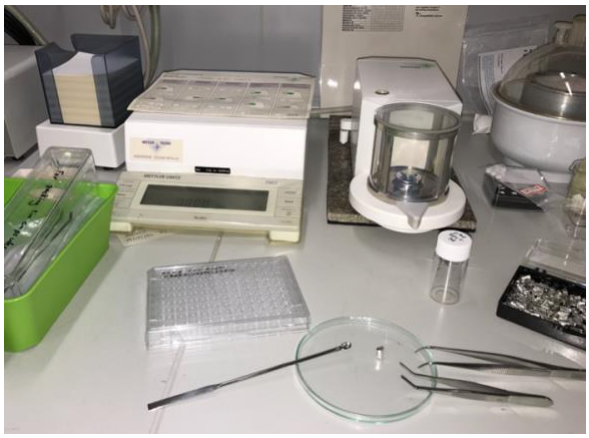


Fig. 35. Micro-balance Mettler Toledo UMT2.

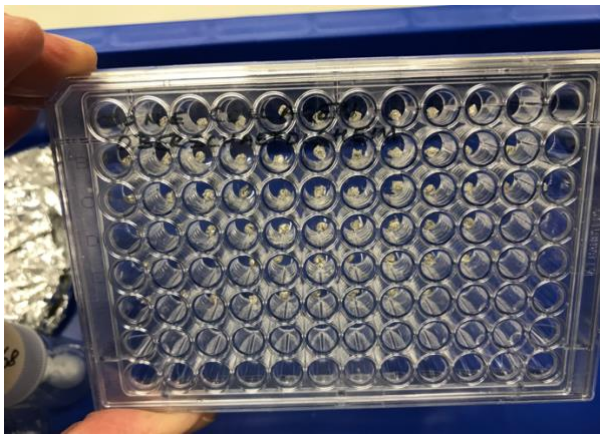


Fig. 36. Samples prepared for IRMS.

Coupled Measurement of $\delta^{13}C$ and $\delta^{15}N$

of the bone collagen samples prepared as described above were conducted using an elemental analyzer (EA; Thermo Flash 2000) interfaced with an isotope ratio mass spectrometer (IRMS, Thermo DeltaVAdvantage, at the Service de Spectrometrie de Masse Isotopique du Musée National d `Histoire Naturelle, SSMIM, Paris). Multiple replicates of a secondary alanine standard were included within each run (calibrated to primary standards IAEA-600 for $\delta^{13}C$, and IAEA-USGS25, IAEA-N-1 and IAEA-N-2 for $\delta^{15}N$).

The alanine standards gave mean values of −22.05 ± 0.27 ‰ for $\delta^{13}C$ (mean ± σ; expected value: −22.16 ‰ with reference to VPDB) and 0.29 ± 0.12 ‰ for $\delta^{15}N$ (expected value: +0.59 ‰ with reference to AIR), and 40.68 ± 0.31 % for C content (expected value: 40.44 %) and 15.92 ± 0.15 % for N content (expected value: 15.72 %) over the course of all measurements (n = 13), and were used to correct the measured data.

Quality criteria

to ensure data robustness were chosen in a way that results were rejected if the bone collagen yield was less than 1 %, or if the collagen had a C/N (molar) ratio outside of 2.9 - 3.45, or the C content less than 13 %, or the N content less than 4.8 % (following suggestions in Guiry & Szpak, 2021).

The data of *all samples analyzed* from Oberschaeffolsheim are given in **Supplement Table 1** on the final pages.

Statistics

Statistical analysis was performed using the *Microsoft® Excel for Mac program*, version 16.53 (21091200) with a Microsoft license 2021 for the author. For all groups median as well as mean and standard deviations were calculated. For the comparisons between all groups Student´s t-tests were used with the Bonferroni corrections that are required. This program was also partly used for the graphics presentations, with the whisker boundaries in the boxplots set at the 1.5 x interquartile range.

In addition, the *PAleontological STatistics Version 4.13* program developed by the Natural History Museum, University of Oslo, and updated 2023, was used both for calculations and graphics as appropriate, as well as the

DATAtab-program (DATAtab Team, 2023. DATAtab: Online Statistics Calculator. DATAtab e.U. Graz, Austria. URL https://datatab.de) was employed for the one-way analysis-of-variance (ANOVA) test (following a Kolmogorov-Smirnov with Lilliefors-correction) and Bonferroni post-hoc-tests.

Results

Of the 71 samples prepared in two cases (both *Cervus elaphus, OBE_Cerv.57 and OBE_Cerv.59*) no collagen could be weighed in after the lyophilization step from the vials. In two additional cases (one *Cervus elaphus, OBE_Cerv.60* and one *Bos taurus, OBE_Bost.31*) the collagen yield and C- and N-content respectively and in one *Sus domesticus (OBE_Susd.06)* the C/N atomic ratio did not meet the quality criteria (see Table 4, where the complete set of data is listed) resulting in a total number of 66 bone samples analyzed that yielded excellent data.

Table 4. Bone collagen $\delta^{13}C$ and $\delta^{15}N$ stable isotope ratios **(n = 66)**.

Species	**common name**	**n**	**Min.**	**Median**	**Max.**	**Mean**	**St.-Dev.**
				$\delta^{13}C$ (‰)			
Sus domesticus	domestic pig	18	−22.14	−21.52	−20.56	-21,46	0.45
Sus scrofa	wild boar	8	−22.11	−21.38	−21.09	-21.52	0.41
Bos taurus	cattle	15	−23.18	−22.12	−19.46	-21.97	0.95
Bos primigenius	aurochs	9	−23.75	−21.54	−21.18	-21.95	0.85
Caprinae	sheep/goat	10	−23.48	−21.76	−20.08	-21.68	1.0
Cervus elaphus	red deer	5	−22.73	−22.30	−21.86	-22.22	0.36
Capreolus capreolus	roe deer	1		−21.15			
Species	**common name**	**n**	**Min.**	**Median**	**Max.**	**Mean**	**St.-Dev.**
				$\delta^{15}N$ (‰)			
Sus domesticus	domestic pig	18	5.83	7.50	8.42	7.23	0.86
Sus scrofa	wild boar	8	6.41	6.90	8.23	7.19	0.67
Bos taurus	cattle	15	4.54	7.09	8.25	7.03	0.91
Bos primigenius	aurochs	9	4.06	6.95	8.00	6.93	1.05
Caprinae	sheep/goat	10	6.22	7.63	8.77	7.55	0.74
Cervus elaphus	red deer	5	4.06	5.17	7.99	5.37	1.56
Capreolus capreolus	roe deer	1		4.29			

As shown in Table 4 and Fig. 37 – 39, the results both for $\delta^{13}C$ and $\delta^{15}N$ for most species ***overlap to a large extent*** and only small differences between groups (specifically in the small samples of red deer and roe deer) can be appreciated.

Few outliers must be discussed, statistical analysis using the Student´s t-test (unequal variance and sample size) with the Bonferroni correction detected no statistically significant differences at the $p < 0.05$ level.

One aurochs, one sheep and two cattle yielded the lowest $\delta^{13}C$ values, all below – 23.0 ‰, which can indicate that forest resources might have significantly contributed to their fodder.

A subsequent one-way analysis-of-variance (ANOVA) test (following a prior Kolmogorov-Smirnov test with Lilliefors-correction that revealed a normal distribution for all groups studied, p = 0.184) and the Bonferroni post-hoc-tests showed **no statistically significant differences between all groups** for the **$\delta^{13}C$** values (Fig. 38). The standard deviation of the suids, both domesticated and wild ones, appears to be smaller than the one of the herbivores, with the exception of the group of red deer.

For the **$\delta^{15}N$** values, however, the small sample of *red deer* showed a **significant difference** to the aurochs (p= 0.013), the cattle and the wild boar (p= 0.007) groups as well as the samples of the domestic pigs (p= 0.001) and the sheep/goat group (p < 0.001), Fig. 39.

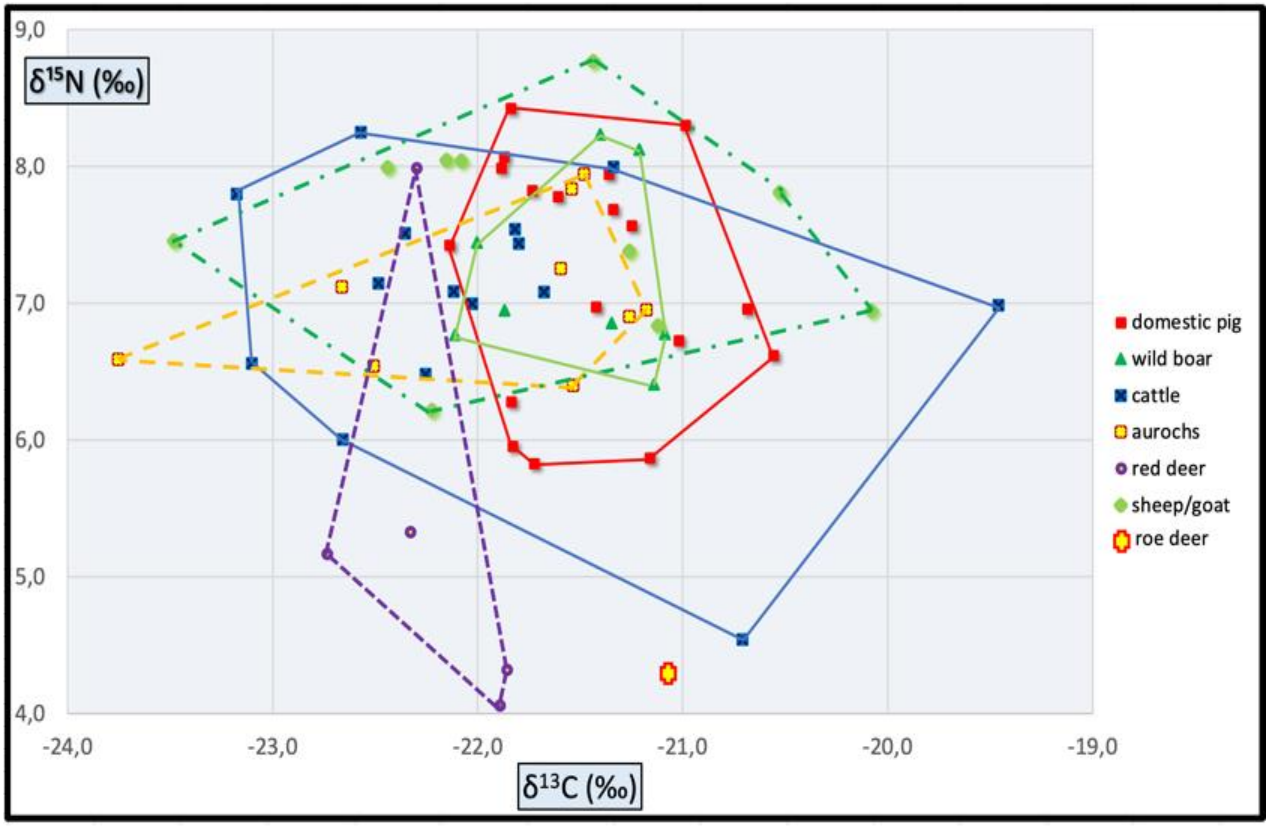


Fig. 37. Shows the stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios for **all bone collagen** samples from the *Oberschaeffolsheim* study site.

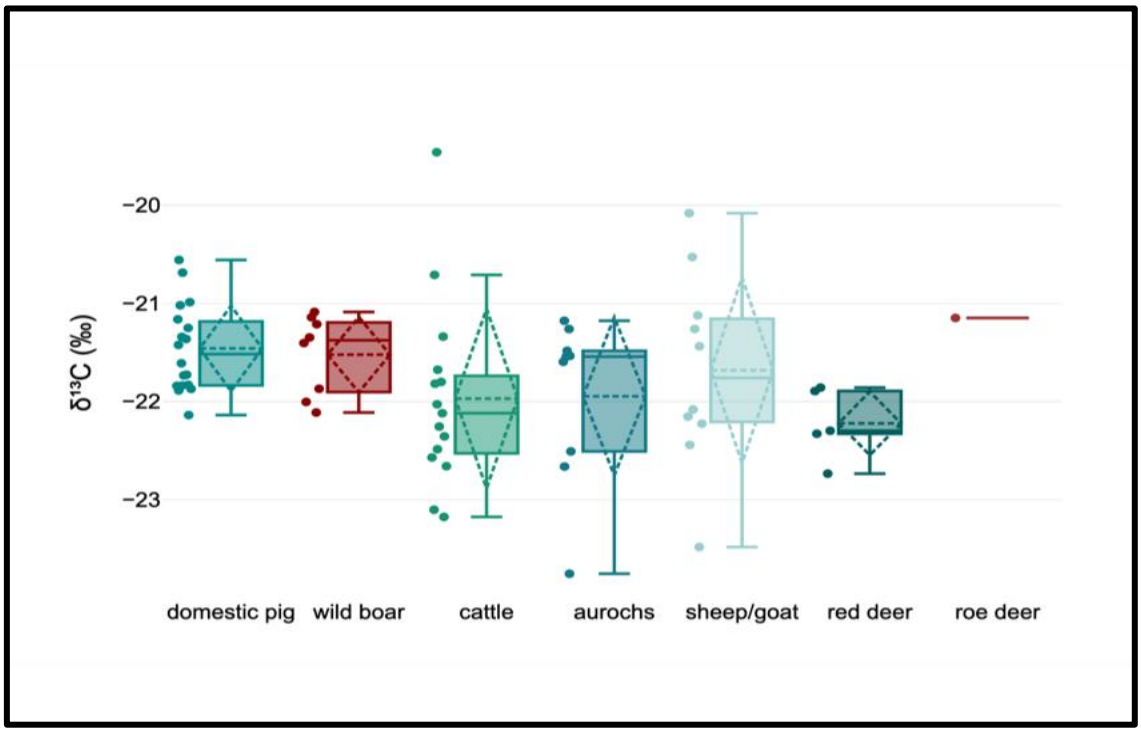


Fig. 38. shows the identical data as shown in Fig. 1. using boxplots with a median (line) and mean +/-SD (doted lines), and all data points, with the whisker boundaries chosen at the 1.5 x interquartile range for $\delta^{13}C$ (‰), *DATAtab graphics.*

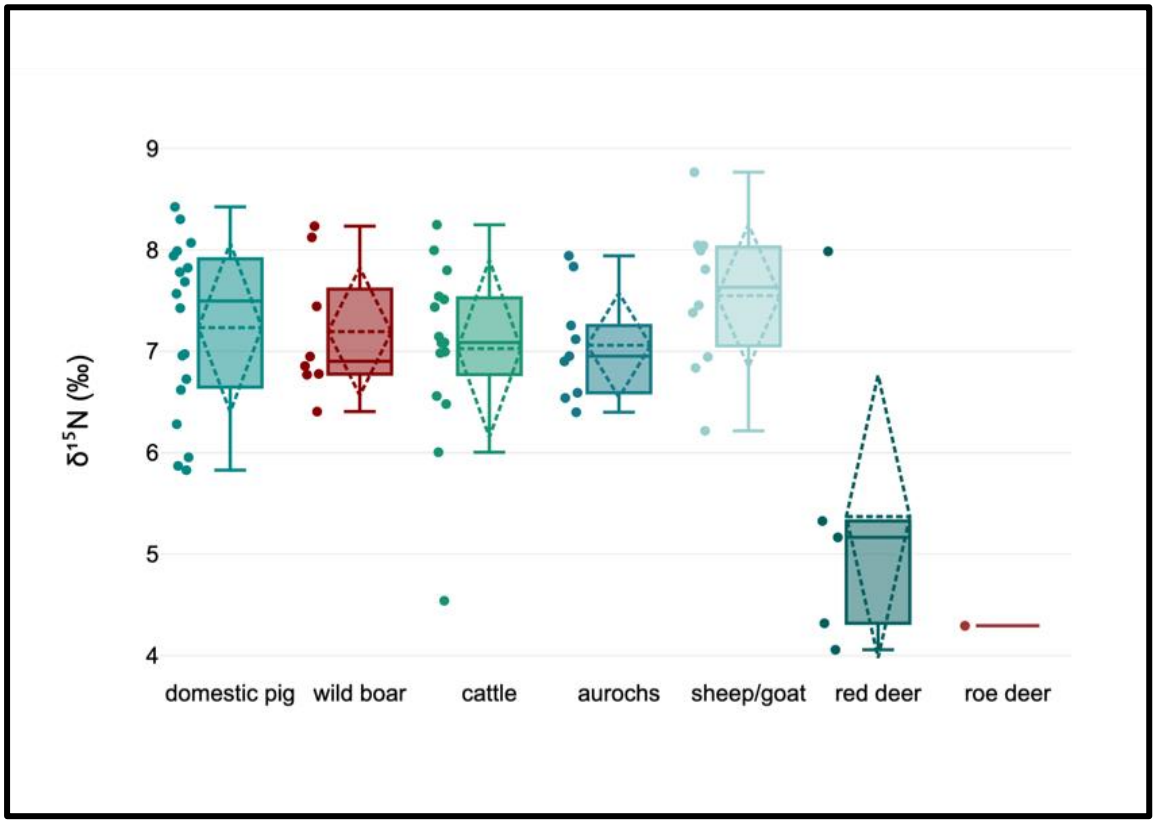


Fig. 39. shows the identical data as shown in Fig. 1. using boxplots with a median (line) and mean +/-SD (doted lines), and all data points, with the whisker boundaries chosen at the 1.5 x interquartile range for $\delta^{15}N$ (‰), *DATAtab graphics.*

Discussion

Oberschaeffolsheim

In the *Grossgartach period*, the second phase of the Middle Neolithic studied at the site of *Oberschaeffolsheim* in Lower Alsace, a ***large overlap*** *in bone collage* $\delta^{13}C$ *and* $\delta^{15}N$ *values for domesticated (cattle, sheep, goat and pig) and wild herbivores and omnivores (aurochs, boar, red and roe deer) is clearly apparent*, with the one exception of *significantly lower* $\delta^{15}N$ *values in the small group of deer.*

This seems to clearly suggest that, except for the latter group of animals hunted, they may possibly have shared identical browsing/grazing grounds in the area considered, for at least part of the year.

In the *domesticated* faunal assemblage from the *Grossgartach* period of the site, bovines comprised a large majority of the number of identified species (NISP) with over 50 %, dominating the findings by far and also by weight, followed by pigs with about one fourth of NISP (and up to one third in some structures) and the caprines with about 8 % NISP (divided between about 60 % sheep and 40 % goats).

By contrast wild species corresponded to only 7 % of the meat providers (red deer with 4 %, wild boar with 1-2 %, aurochs with 1 % and roe deer with only 0.2 % of the samples), so that hunting, apparently, was not a prominent activity for human subsistence out of sheer necessity, possibly also hinting at a rather wide-open landscape with manured fields used for crop growing around the village.

Placed on the southern edge of the large Kochersberg plateau, on the large loess terrace of Schiltingheim, the site lies only at a short distance to the north of the small river Bruche that meanders down from the Vosges into the Rhine alluvial valley. The gravel from both rivers is covered by a fine overflow of silt - dating from the Würm until historical times – and has an average annual rainfall of 600 – 700 mm (Denaire, 2009 d ´après Jeunesse 1993; Perrin et al., 2019, 70). This *very fertile landscape* east of Strasbourg certainly offered plenty of advantages for the Neolithic farmers as to the variety of options available to raise crops and livestock:

it would not only provide the forested hills to the west as food sources for their animals, but also the waterlogged marshes and gallery woods around creeks and rivers as well as fertile meadows to the south and east. The feeding options would be supplemented – on a seasonal basis, depending on their availability – by leafed branches from forest resources or additional summer hay collected (currently studied in more detail by Marie Balasse, using sequential analysis of tooth enamel of the animals sampled).

Pigs and wild boars

The nearly perfect SI data overlap between domestic pigs (n= 18) and wild boars (n= 8), lying within a narrow range of about 1.0 (boars) to a maximum 1.6 ‰ (pigs) for $\delta^{13}C$ and of 1.8 (boars) to a maximum

2.6 ‰ (pigs) for δ^{15}N values points to a *very similar "food habitat"* for both related species surrounding the site investigated (Table 4 and Fig. 37). None of the suids tested had a bone collagen value of δ^{13}C *lower than -22.14 ‰* (mean -21.46 ‰, and -21.52 ‰, respectively), and their standard deviation of δ^{13}C being smaller than the one of our herbivores possibly hints at a *more restricted browsing area (basically only reflecting fodder isotope composition) than our herbivores*. The first parameter mentioned is in clear contrast with the data reported from *modern* forest-dwelling herbivores, red and roe dear, living in *dense deciduous forests*, with all values observed being below -22.5 ‰, with an average of -23.7 ‰ (Drucker et al., 2008). This observation could also be explained by their wider range of scavenging in a more open habitat or feeding on fruits, such as acorns (Frémondeau et al., 2012).

Most pigs (60 %) were slaughtered before the age of one year. Out of more than 1800 pieces only 29 had signs of light burning, 70 showed signs of fractures or cut marks. The wild boars (with 1 – 2 % of the total bone assemblage) were identified by their larger size, with 74 pieces confirmed, and all were older than the domestic pigs, namely mature adults (4 identified males, 1 female), with the *skeletal distribution in the pits identical to their domestic relatives*: a higher proportion of head parts, fore- and hind-limbs as compared to backbone, forefeet and ribs. The latter observation speaks for a *secondary* slaughtering with the bulkier elements being deposited at other sectors, for both, domestic and wild species (in the areas of raising/hunting the animals, respectively?), but certainly outside of the village.

Cattle and aurochs

Except for three outliers (two cattle and one aurochs) the SI again show a nearly perfect data overlap between cattle (n= 15) and aurochs (n= 9), lying within a range of about 2.0 (cattle) to 1.5 ‰ (aurochs) for δ^{13}C and of 2.2 (cattle) to a maximum of 1.5 ‰ (aurochs) for δ^{15}N values respectively. The outlier cattle might have been kept close to the habitation, the one aurochs dwelling in the dense forest (with a δ^{13}C of less than -23.5 ‰). This again points to a *very similar "food habitat"* of these large ruminants, possibly occupying a slightly more densely shaded/wooded area, at least by some animals of this group. The minimal dairy production in the Grossgartach period seems to have had no effect on livestock farming (Casanova et al., 2020). They represented the bulk of bone specimens identified at the site, with over 50% (and 75 % of the weight of pieces, WP), with all large skeletal parts being present, the axial parts of the skeleton (heavier to carry?), however, again being *under-represented*. Their slaughter age shows a first peak before 6 months of life and another one from four to nine years, as most of the cattle might have been exploited for milk, meat and/or traction power, an observation which come up significantly later than at the LBK site of Kolbsheim (with the slaughter age from 2 – 4 years), possibly a sign of more dairy practice. The aurochs´ taxon represented only 1% of the number of pieces detected, with a minimum of 12 adults, with an age of less than 4 to over 4 years, the juveniles conspicuously missing (or under-diagnosed?), a dozen bones with cut marks, one burnt.

Wild boar and aurochs have slightly lower mean $\delta^{15}N$ values than domesticated pig and cattle, but as these are not nearly statistically significant, no valid conclusions as to feeding patterns can be drawn.

Sheep and goats

have – except for one lower outlier – $\delta^{13}C$ values nearly identical to domestic pigs and the highest $\delta^{15}N$ values on average, but again not significantly different as regards statistics. They comprise about 8% of the NPD in the sample within the two species, 120 identified pieces being present, there was a minimum of 32 individual animals identified, 12 goats and 13 sheep, the majority older than 4 years.

Red and roe deer

were the best documented wild species at Oberschaeffolsheim, the former with 4 % of NPD, a total of eleven individuals, six of them mature. The latter species was only represented in 0.2% of the total NPD, one animal in our sample. With only one high outlier, they had, as a group, *significantly lower* $\delta^{15}N$ *values* compared with all the other 60 samples, be it domesticated or wild animals. They might have thrived on *less manured environments* as compared to the domesticated animals (with fields after harvest used by the farmers for the latter?). The $\delta^{13}C$ of our small group of red deer (n=5), with a mean of -22.3‰, was closer to the above mentioned modern values reported than the mean of the other species in our sample and certainly can point to most of them browsing in a more *closed habitat*.

Alsace, the Paris, and Loire basins and Southern to Central Germany

- *How do the SI data from Oberschaeffolsheim compare to the ones reported from sites of an area immediately adjacent to the study site and to those reported from northwestern parts of France and southern to middle Germany?*

Stable Isotope values from *dietary components* (especially plants) arise from many factors: soil components, climate, location, elevation and ecology for $\delta^{15}N$ and from several physiological processes within the plants and the distribution in their single parts as well (see chapter above and Szpak, 2014).

As *bone collagen SI ratios* are a reflection mostly of *dietary protein* (and few other dietary ingredients) consumed in the last years of the individual´s life cycle with a *systematic diet to collagen offset* (about 5 – 6 ‰ for $\delta^{13}C$ and 3 – 5 ‰ for $\delta^{15}N$), they can be used as indicators for the food groups consumed by both livestock and wild animals and can be compared to data gathered from human bone samples as well (Froehle et al., 2012). One must keep in mind, however, that faunal samples typically show at least twice the variance in their SI values (!) when compared to humans, that the three species regularly found (cattle, suids and cervidae) cannot be meaningfully substituted for each other, and that many *local* effects mentioned above are themselves “entangled” (Hedges et al., 2013).

You are what you eat: One should expect humans to be enriched in $\delta^{15}N$ when compared to data from their fauna and crops they consumed. This holds true for $\delta^{13}C$ as well, albeit in a smaller proportion. Both, *protein* as well as *carbohydrate carbon* contribute to the $\delta^{13}C$ ratio, whereas the latter do not contribute to $\delta^{15}N$). The difference between animal $\delta^{15}N$ and human $\delta^{15}N$ is given the designation $\Delta^{15}N$, the term $\Delta^{13}C$ rarely being used (Hedges et al., 2013). A measurement of this difference is a reflection of the proportion of animal protein in the total human diet protein. *This makes an inclusion of sites with data from human burials useful for comparison, although the interpretation is quite challenging.*

Alsace, the Departement of Indre-et-Loire, and the Paris basin

Bischoffsheim *(LBK),* animal SI data, Lower Alsace

In the paper by Gillis et al. (available as a preprint in 2022/3 for the author), the published values for $\delta^{13}C$ and $\delta^{15}N$ closely resemble the ones from the earlier work by Bickle et al., 2013 (Table 5). In the former one, the $\delta^{13}C$ values are significantly higher in the pigs and sheep herds than in the cattle and red deer. Therefore, they suggest that these respective groups of species had frequented "identical" pastures. The $\delta^{15}N$ values in the domesticated animals were always higher than those measured in the red deer (with p-values ranging from p= 0.03 to p=0.003), leading to the additional conclusion that the former had access to manured plants on cultivated soils (Bogaard et al., 2013; Fraser et al., 2013). The $\delta^{13}C$ values between the two studies did not differ for cattle, pigs, and sheep (Mann Whitney, p= 0.4).

The $\delta^{15}N$ values of the earlier study showed a greater spread for cattle, pigs and sheep and are significantly lower than the ones from the cattle in the later one (Mann Whitney, p= 0.01). The *newer $\delta^{15}N$ values* for the red deer are significantly lower than the ones for pigs and sheep, both at p= 0.008, but not different from the earlier cattle values, possibly because of the low sample numbers.

Table 5. Stable isotope data combined from: Bickle et al., 2013 and Gillis et al., 2022/3, as shown by the authors, including the statistical significances given for the comparisons. Data from this paper are shown in the last line.

Site Bischoffsheim	**Cattle**	**Cattle**	**Pig**	**Pig**	**Sheep/Goat**	**Sheep/Goat**	**Red deer**	**Red deer**
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
Bickle et al., 2013	-22.9±1.0‰ n= 14	6.2±0.83‰ n= 14	-20.8±0.38‰ n= 6	7.7±0.97‰ n= 6	-20.7±0.16‰ n=6	7.8±0.82‰ n= 6	n.d.	n.d.
Gillis et al., 2022/3	-22.7±0.7‰ n= 4	7.4±0.5‰ n= 4	-21.1±0.2‰ n= 6	7.4±0.3‰ n= 6	-20.6±0.6‰ n= 7	7.8±0.6‰ n= 7	-22.4±0.5‰ n= 6 (Without value – 19.6 ‰)	5.6±0.4‰ n= 6 (Without value – 7.4 ‰)
Mann Whitney (comparison of the two upper reports)	***n.s.***	***p = 0.01***	***n.s.***	***n.s.***	***n.s.***	***n.s.***		*Sign. lower than all dom. animals except for cattle of the first study*
Data from this study	**-22.0±0.95‰ n= 15**	**7.0±0.9‰ n= 15**	**-21.46±0.45‰ n= 18**	**7.23±0.86‰ n= 18**	**-21.68±0.99‰ n=10**	**7.55±0.74‰ n= 10**	**-22.22±0.36‰ n=5**	**5.37±1.56‰ n= 5**

For the plants of the area that were collected near Bischenberg (located at about 12 to 14 km from the Oberschaeffolsheim site) and measured as to their $\delta^{13}C$ by Gillis et al., 2022/3 (with similar data cited according to the study performed by Vogel in southern Germany in 1978), and with the values corrected for the fuel fossil (^{13}C Suess-) effect (Suess, 1955; Francey et al., 1999; Cerling & Harris, 1999) were -30.0 to -29.2 ‰ for the undergrowth and -29.7 to -25.6 ‰ for the trees (Vogel, 1978).

The ***combined*** *data* (!) for the *two Bischoffsheim studies* (only published in the graph Fig. 301, from Gillis et al., 2022/3, Fig. 40 below) for $\delta^{13}C$ are approximately: *cattle –22.9 ± 0.8 ‰, pigs –20.9 ± 0.6 ‰, sheep/goat –20.7 ± 0.6 ‰, and deer –22.0 ± 0.6 ‰*, excluding one higher outlier. For $\delta^{15}N$ the values are (again approximately): *cattle 6.5 ± 0.9 ‰, pigs 7.5 ± 0.25 ‰, sheep/goat 7.7 ± 0.4 ‰*, and *deer 5.5 ± 1.1 ‰*, excluding one higher outlier again. In this case the cattle differ significantly from both pigs (p= 0.002) and sheep (p= 0.003), suggesting to the authors a different strategy of foddering, possibly the use of forest foliage. The SI values published for Bischoffsheim in these two studies (single data *and* combined) for cattle, pigs, sheep, and goats und red deer ***closely parallel the ones from Oberschaeffolsheim***, including the *significantly reduced values for $\delta^{15}N$ in the red deer group*.

The fact that these $\delta^{15}N$ deer values reported by the latter study are not significantly different from the ones of the cattle of the first study (5.6 ± 0.4 ‰ versus 6.2 ± 0.8 ‰) is explained by the authors by their low sample number. They also conclude that domestic animals "had access to plants enriched with ^{15}N via manuring combined with pasturing on tilled soils" (Gillis et al., 2022/23).

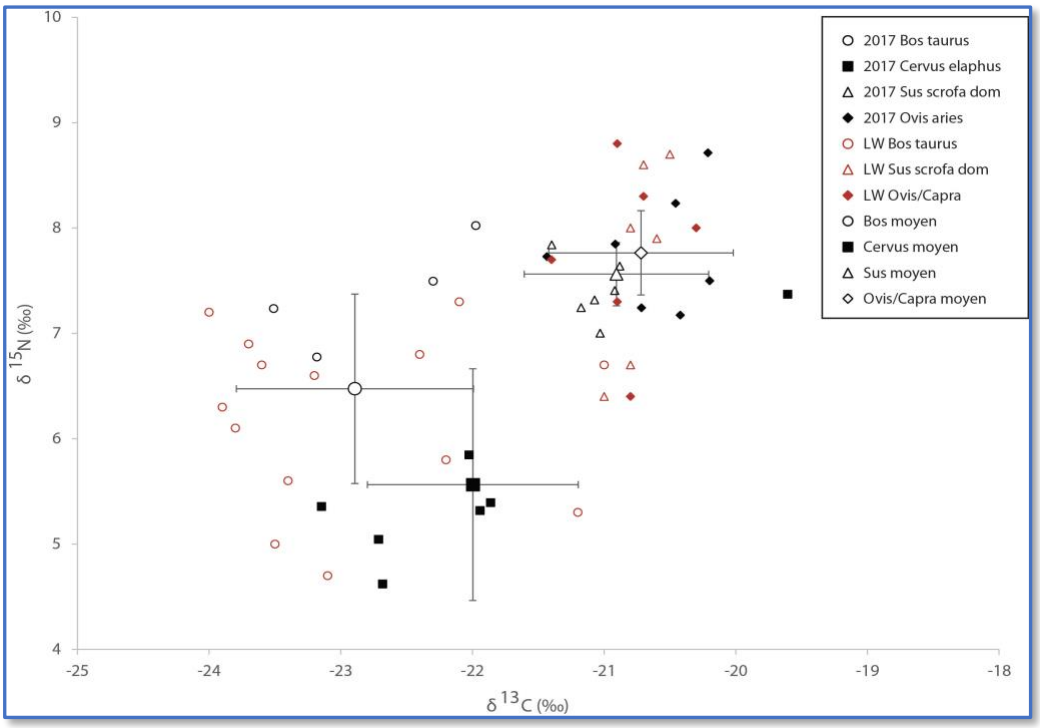


Fig. 40. Data ($\delta^{13}C$ and $\delta^{15}N$) from the *study by Gillis et al.* (in black) and from the *Lifeways project* (in red). The signs on the upper right show in order from above: cattle, red deer, domestic pig, sheep, then the three Lifeways animal groups sampled (cattle, domestic pig, and sheep/goat) and from ***both studies*** the mean values and SD (*lower four symbols in the list*, excluding the high $\delta^{15}N$ value of the red deer). From: Gillis et al., 2022/3. Fig. 301).

Ensisheim Ratfeld, *(LBK, La Hoguette),* animal SI data, Upper Alsace

This settlement, excavated in 1987 (Lefranc, 2007), featured pottery from all the different LBK phases reported in Alsace, including sherds of La Hoguette ware. It abundantly produced wild and domestic (over 95%) animal remains, 2300 of which could be identified, cattle being more frequent than pigs, sheep, and goats. In the later phase of the site, the *recent* LBK, the importance of "secondary animals" increased with the role of cattle much reduced (were these reserved for feasting events?), and the wild animal bone assemblage growing more varied in this phase also (Arbogast & Jeunesse, 1990).

The authors suggest, as the variance of $\delta^{13}C$ values of cattle was significantly higher and the mean significantly lower than the values of the sheep, goats, and pigs, that these *large herbivores were grazing in the forest or foddered from forest areas* (Balasse et al., 2012). As the $\delta^{15}N$ values are not significantly lower, they might have had additional access to manured areas or crop wastes (Table 6).

Although located in Upper Alsace, at a distance of about 100 km in the south of Oberschaeffolsheim and set in an earlier time frame, $\delta^{13}C$ data for cattle closely resemble the ones from our study, including the large spread. Our pig and sheep $\delta^{13}C$ data are lower than the ones observed in the southern region of Alsace, possibly another sign of added leaf fodder and/or grazing in the woods of these smaller domesticates. The slightly higher $\delta^{15}N$ values in all our samples, but specifically of sheep and goats, as compared to the earlier data of all three species would support the notion that in our study these species might have had access to manured areas or crop wastes also.

Table 6. Stable isotope data of the animal specimens tested at Ensisheim Ratfeld (From: Bickle et al., 2013, Table 8.14 and Fig. 8.24). Data from this paper are shown in the last line.

Site Ensisheim Ratfeld	**Cattle**	**Cattle**	**Pig**	**Pig**	**Sheep/Goat**	**Sheep/Goat**
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
Bickle et al., 2013 316 - 317	-21.7±0.99‰ n= 14	6.4±1.13‰ n= 14	-20.5±0.19‰ n= 6	7.0±0.90‰ n= 6	-20.6±0.41‰ n=5	6.0±0.61‰ n= 5
Data from this study	**-22.0±0.95‰ n= 15**	**7.0±0.9‰ n= 15**	**-21.46±0.45‰ n= 18**	**7.23±0.86‰ n= 18**	**-21.68±0.99‰ n=10**	**7.55±0.74‰ n= 10**

Considerations regarding ***human data*** *from Alsace*

In this seminal "Cultural Project" Denaire and co-workers have used *"FRUITS Modelling"* of dietary proportions in diets of *human individuals* that were dated to the Middle Neolithic. Above we described this outstanding project and its importance for *precise* and quite novel dating the LBK and the Middle Neolithic phases, especially the Grossgartach phase at Oberschaeffolsheim (Denaire et al., 2017).

To the best of my knowledge, the "$\delta^{13}C$ and $\delta^{15}N$ values for the *Middle Neolithic Rhineland population* that are from 30 adult and sub-adult humans (plus four children aged 4 years and under) are the *only*

ones available in publication at present (Fig. 41). Mean isotopic values for all unsexed and sexed adults (n= 25) are −20.6 ‰ ± 0.2 ‰ for $\delta^{13}C$ and +9.6 ‰ ± 0.3 ‰ for $\delta^{15}N$. Mean isotopic values for older children and sub-adults (ranging from 3 to 6 years to 15 – 19 years; n = 5) are −20.3 ‰ ± 0.2 ‰ for $\delta^{13}C$ and +9.4 ‰ ± 0.3 ‰ for $\delta^{15}N$. The $\delta^{15}N$ value of +11.6 ‰ ± 1.7 ‰ of the four children 4 years or less was significantly enriched over that of adult females (+9.6 ‰ ± 0.7 ‰; P= 0.0152)" (Citing: Denaire !).

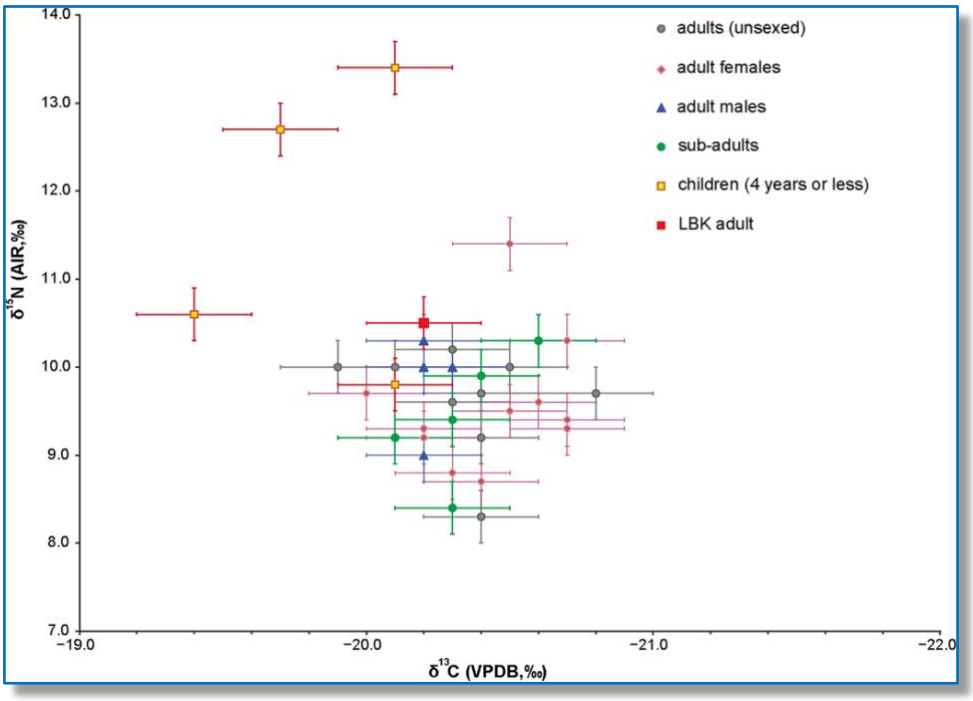


Fig. 41. $\delta^{13}C$ and $\delta^{15}N$ values for human skeletons (n= 34) from Lower Alsace (error bars at 1σ). From: Denaire et al., 2017. Fig. 18).

"This FRUITS model employs the isotopic averages of possible food sources and allows the user to define isotopic offsets between diet and consumer as well as the expected weighting and concentration of food sources. Prior information to constrain the calculations of the stable isotope mixing model can also be added (Fernandes et al., 2014). The modelling then produces *estimates* of the mean percentage (and standard deviation) for *each of the possible food sources* making up the diet for each individual consumer which is analysed. The diet-to-consumer offsets used by the authors were 4.8 ‰ ± 0.2 ‰ for $\delta^{13}C$ (Fernandes et al., 2014) and 6.0 ‰ ± 0.5 ‰ for $\delta^{15}N$ (O'Connell et al., 2012). They used crop values from archaeo-botanical samples of emmer, naked wheat, einkorn, barley, and peas (Styring et al. in 2016). They included *pig* samples in their terrestrial "herbivore" values (together with red deer, goat, and cattle for a total of n = 60) that were used for this project from both, the LBK and Middle Neolithic sites. In the absence of obvious fish remains it was assumed that terrestrial herbivores provided the bulk of dietary protein consumed by the humans, together with crops. The mean values for the food sources used in the FRUITS diet proportion modelling are given in Table 7."

Adults have a *substantial reliance on crops with a mean 79.8 ‰ ± 13.8%* (from 68.7% to 89.1%), according to the employed model. "*Terrestrial herbivores were estimated to have contributed a far*

smaller part of overall diets, with mean diet proportions of *15.9 ‰ ± 12.5%,* and a minimum of 8.5% to a maximum of 23.9%. Sub-adults are not significantly different and the estimation of fish in the adult and sub-adult diets indicates *very little reliance* on riverine or lake-derived food sources (4.2 ‰ ± 3.8%, and 3.7 ‰ ± 3.4% respectively) being like other Grossgartach and Rössen sites" (Denaire et al., 2017).

Table 7. "The Cultural Project". Mean isotopic values for food sources used for the FRUITS modelling of adults and sub-adults (for terrestrial herbivores and freshwater fish), and crops (including children under 4 years of age). Errors are the standard deviation of the mean for each food source. From: Denaire et al., 2017, Table 3.

Food source	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Terrestrial herbivores (adults and sub-adults)	−21.2 ± 0.9	8.2 ± 1.3
Freshwater fish (adults and sub-adults)	−21.8 ± 0.9	8.9 ± 1.1
Crops (adults and sub-adults and children under 4 years of age)	−26.1 ± 0.9	5.2 ± 0.8
Breast milk (children under 4 years of age)	−20.4 ± 0.2	9.5 ± 0.7

The values for the identical terrestrial "herbivores" species (n = 48) at our site of ***Oberschaeffolsheim*** are ***-21.74 ‰ ± 0.76 ‰ for $\delta^{13}C$*** (with min: - 23.48 ‰ to max. - 19.46 ‰) and ***7.04 ‰ ± 1.08 ‰ for $\delta^{15}N$*** (with min: 4.06 ‰ to max. 8.77 ‰). Both values are somewhat lower than the ones reported in the large study published by Denaire et al., 2017, albeit not significantly so.

As for a lack of human SI data for the *Oberschaeffolsheim* excavation the human SI data from surrounding sites (although only very few feature concomitant animal data) will have to be considered:

Souffelweyersheim and ***Vendenheim*** *(Late LBK),* Human SI data, Lower Alsace

The cemetery of *Souffelweyersheim* was dated to the recent phase of the LBK and the poor preservation allowed a sampling of 11 humans only (Table 8).

The values were compared by the authors to the "*Bischoffsheim* animal data (cf above, Table 5), which were considered to *exhibit larger differences (human versus cattle) as compared to the ones of the sites east of the Rhine*, and this result was thought to *reflect low cattle values* rather than a "larger gap" between human and faunal values overall" (Bickle et al. 2013, Chapter 9.2.5-6, p.3 58). This gap is only marginally smaller when comparing these human data with the cattle data from Oberschaeffolsheim ($\Delta^{15}N$ = 4.2‰ (Bis) versus $\Delta^{15}N$ = 3.4‰ (Obe) and $\Delta^{13}C$ = 2.5‰ (Bis) versus $\Delta^{13}C$ = 1.6‰ (Obe) and well within the range reported for all the sites ($\Delta^{15}N$ from 1.9 to 4.3 ‰ and $\Delta^{13}C$ from 0.4 to 2.8 ‰).

Interestingly, when considering the whole dataset, this $\Delta^{15}N$ gap, human versus all the species tested (cattle, sheep/goat, pig), is smaller in the *eastern* sites (in the Danube catchment) than the ones measured in the Rhine area - with much variation due to *inherent higher faunal variation*. For $\Delta^{13}C$ the difference between cattle (higher) and the other fauna is clearly apparent in the western (Alsatian)

region, possibly a reflection of a different environmental situation for which a potential canopy effect has been put forward. Even when overall climatic or geographic trends are accounted for, several sites are still found to exhibit unusual SI values both in humans as well as in cattle and sheep in all the range of excavations from east to west (Balasse et al., 2012; Hedges et al., 2013, Table 9.4, p. 355).

At *Vendenheim* the preservation again was rather poor (29/99 burials sampled), with the $\delta^{13}C$ values tightly clustered and the $\delta^{15}N$ showing a greater range than usual (cf Table 8, lower half). It is speculated that, although "the community shares a very similar diet and similar origins", this could reflect a *dietary difference* in terms of protein source: animal versus plant protein or consumption of plants from manured versus un-manured areas (Bickle et al., 2013, 336 – 339). All in all, the data of both sites look very homogeneous.

Table 8. Stable isotope data of the 11 humans sampled at Souffelweyersheim and the 29 humans sampled at Vendenheim (From: Bickle et al., 2013, Table 8.18 and 8.22). Below:
Table 9. $\delta^{15}N$ data of domestic animals and red deer at Oberschaeffolsheim.

	Juvenile	**Juvenile**	**All adults**	**All adults**	**Unknown**	**Unknown**
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
Site Souffelweyersheim Bickle et al., 2013, 325 - 328	-20,2 ± 0,39 ‰ n= 2	10,0 ± 0,45 ‰ n= 2	-20,4 ± 0,46 ‰ n= 7	**10,4 ± 0,66 ‰ n= 7**	-20,4 ± 0,05 ‰ n=2	11,1 ± 0,04 ‰ n= 2
Site Vendenheim Bickle et al., 2013, 328 - 334	-20,2 ± 0,16‰ n= 12	10,3 ± 0,59‰ n= 12	-20,2 ± 0,24‰ n= 17	**10,6 ± 0,80‰ n= 17**	_	_

This study	**Cattle**	**Pig**	**Sheep/Goat**	**Red deer**
	$\delta^{15}N$			
	7.0 ± 0.9 ‰ n= 15	**7.23 ± 0.86 ‰ n= 18**	**7.55 ± 0.74 ‰ n= 10**	**5.37 ± 1.56 ‰ n= 5**

If one compares these *adult human $\delta^{15}N$* data of the two sites with the domestic *animal* data from our investigation (***Mean ± SD = 7.2 ‰ ± 0.9 ‰***, Table 9), one could surmise a *higher proportion of domesticated animals in their overall diets* as they reached *a higher $\Delta^{15}N$ (3.46 ‰) with higher human $\delta^{15}N$ and lower animal $\delta^{15}N$ than in the "The Cultural Project" study ($\Delta^{15}N$ = 1.4 ‰)* assuming a *systematic diet-collagen offset* of 6.0 ‰ ± 0.5 ‰ for $\delta^{15}N$ as was used in the *"FRUITS Modelling"* of dietary proportions (O'Connell et al. 2012; Denaire et al., 2017). If one uses 3 – 5 ‰ for the $\delta^{15}N$ offset the proportion of meat in the diet might even be substantially higher (Froehle et al., 2012).

Other assemblages to be considered are:

Gougenheim *(Late Neolithic) and* ***Mittelhausen*** *(Iron Age),* Human and animal SI data, Lower Alsace

This diachronic study was performed on 23 human adults, 18 infants and children, and 25 animal remains from the Late Neolithic (Michelsberg) and 4 human and 5 animal samples from the Iron Age

(Goude et al., 2015). The LN animals SI values for $\delta^{13}C$ were – 21.2 ‰ ± 0,6 ‰ (range -23.4 ‰ to -19.8 ‰) and 7.6 ‰ ± 1.1 ‰ (range 5.3 ‰ to 11.1 ‰) for $\delta^{15}N$. This *wide range is considered to reflect the variability of animal diets*, with the values differing according to species (the one dog with a high $\delta^{15}N$ value in the human range, higher than herbivores and pigs) and the respective age within their species (suckling calves have more elevated $\delta^{15}N$ values than cattle). Except for cattle $\delta^{13}C$ which is significantly depleted compared to the one of caprines and pigs (at the $p < 0.05$ level), these variations are not statistically different (Fig. 42). *They closely resemble the cattle, caprines and pig $\delta^{13}C$ data from the Middle Neolithic Oberschaeffolsheim site, which is only around 15 km away to the south-east* (Mean ± SD for $\delta^{13}C$: – 21.7 ‰ ± 0,8 ‰, range -23.5 ‰ to -19.5 ‰) and the slightly higher $\delta^{15}N$ values (Oberschaeffolsheim: 7.2 ‰ ± 0.9 ‰, range 4.5 ‰ to 8.8 ‰) of the later dated close-by LN site.

The LN human SI values (n = 34, infants below 4 years excluded) were for $\delta^{13}C$: – 20,7 ‰ ± 0,3 ‰ and 11,2 ‰ ± 0,7 ‰ for $\delta^{15}N$ (Fig. 43). The comparison between animal and human values from the LN ($\Delta^{13}C$ human – fauna = 0.6‰; $\Delta^{15}N$ human – fauna = 3.4‰) would primarily indicate for the authors, that *a large quantity of the protein consumed came from faunal resources* (meat and dairy products), when using the prey-predator collagen enrichment values for C and N stable isotopes previously published for modern and palaeolithic (Solutrean and Middle Magdalenien) animal specimens (Bocherens & Drucker, 2003, cited by Goude et al., 2015 for these assumption), possibly mirroring our earlier MN site.

Another possibility to be considered might be the use of manuring that can significantly increase $\delta^{15}N$ values to the level of trophic effects, again with a small rise from the MN site (Treasure et al., 2016).

Secondly, they conclude that *resources from cattle and calves were clearly preferred compared with those from caprine and pigs*, as suggested by the number of remains detected, which is supported by a zoo-archaeological study at the site (cattle 62.6 %, raised as both meat and milk providers, sheep, and goat 24.9 %, pig 9.4 %, the remainder being aurochs, deer, hare).

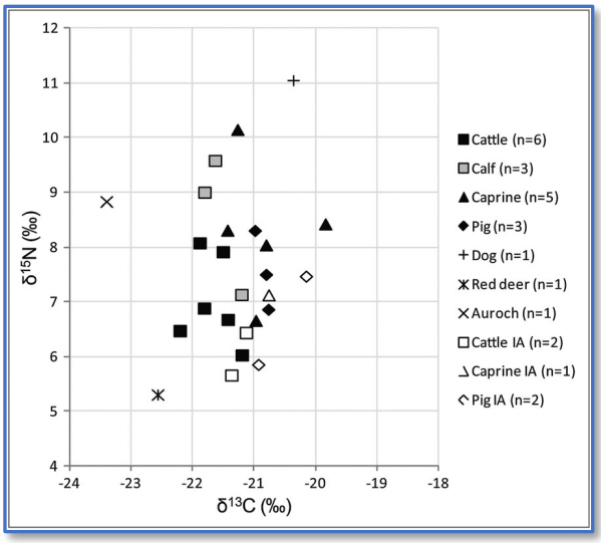


Fig. 42. Carbon and nitrogen isotopic distribution for the different animal species studied from Late Neolithic (filled symbols) and Iron Age (empty symbols) layers.

From: Goude et al., 2015. Fig. 2.

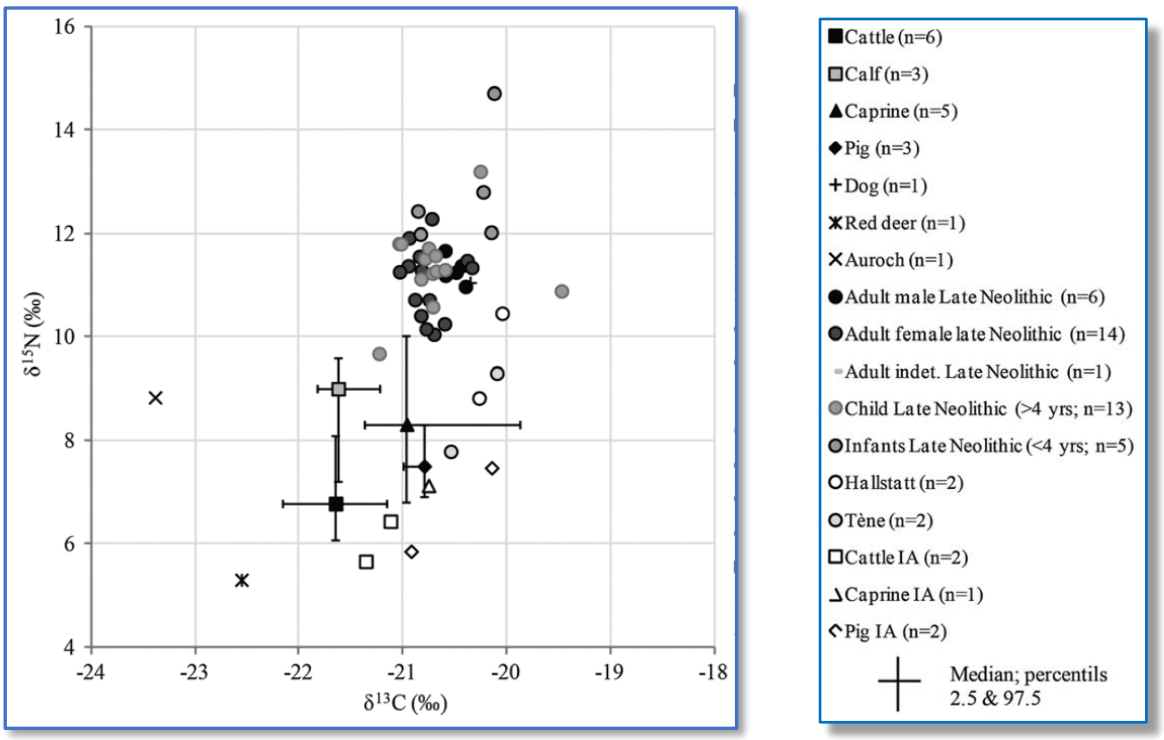


Fig. 43. Carbon and nitrogen isotopic distribution of humans and animals (*all the iron age samples shown with open symbols*). Median and percentiles 2.5 – 97.5 of *Late Neolithic animal* values are also included. From: Goude et al., 2015. Fig. 2.

Mulhouse-Est (Rixheim) and ***Ensisheim les Octroi***, *(LBK),* Human SI data, Upper Alsace

For the sites of ***Upper*** Alsace a total of 46 human SI data are available (Table 10). Again, the values of *Ensisheim les Octrois* human data were compared to the *Ensisheim Ratfeld* animal data (given above, Tab.6), which were considered to exhibit larger $\Delta^{13}C$ differences (human versus cattle, 1.5 ± 0.26 ‰) as compared to the ones of the sites *east of the Rhine,* but $\Delta^{15}N$ values for all the species considered (cattle, sheep/goat, pig) were nearly identical to the ones in the eastern part of the study area (Bickle et al. 2013, Chapter 9.2.5-6). The *Upper Alsace* human $\delta^{13}C$ and $\delta^{15}N$ values were almost parallel to the ones from several sites from *Lower Alsace*, $\delta^{13}C$: −20.6 ± 0.2 ‰ and $\delta^{15}N$: +9.6 ± 0.3 ‰, n= 25 (MN Lower Rhineland, Denaire et al., 2017, 1117), Souffelweyersheim ($\delta^{13}C$: −20.4 ± 0.46 ‰, $\delta^{15}N$: +10.4 ± 0.66 ‰, n= 7) and Vendenheim ($\delta^{13}C$:−20.2 ± 0.24 ‰, $\delta^{15}N$:+10.6 ± 0.8 ‰, n= 17, Bickle et al., 2013).

Table 10. Stable isotope data of the 8 humans sampled at Mulhouse-Est (From: Bickle et al., 2013, Table 8.8 and Fig. 8.12) and 38 humans sampled at Ensisheim les Octrois (From: Bickle et al., 2013, Table 8.15 and Fig. 8.25).

	Juvenile	Juvenile	All adults	All adults
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Site **Mulhouse-Est (Rixheim)** **Bickle et al.,** 2013, 302 - 310	-20.5 ‰ n= 1	11.6 ‰ n= 1	-20.3 ± 0.14‰ n= 7	10.6 ± 0.62‰ n= 7
Site **Ensisheim les Octrois** **Bickle et al.,** 2013, 317 - 321	-20.1 ± 0.25‰ n= 6	9.3 ± 0.40 ‰ n= 6	-20.2 ± 0.19‰ n= 32	9.3 ± 0.52‰ n= 32

Le Vigneau 2, Human and animal SI data, Pussigny, Centre Val de Loire region, Dep. of Indre-et-Loire

belongs to the *Middle Neolithic*, at this site dated to 4720 – 4350 cal BC, with 102 tombs (a total of 112 individuals). The site was interpreted as a cemetery of shepherds that were buried with their domestic animals and is located at about 500 km from Oberschaeffolsheim, (Fig. 44, from Goude et al., 2019).

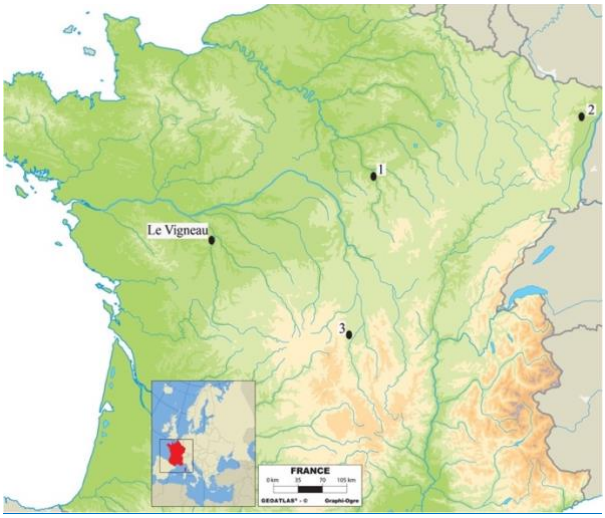


Fig. 44. Location of the sites:

Le Vigneau, Pussigny, Centre Val de Loire region, Dep. of Indre-et-Loire.

1 *Gurgy,* Paris basin area (Rey et al., 2017),

2 *Gougenheim,* Alsace area (Goude et al.,2015), (about 15 km as the crow flies to the north-west of ***Oberschaeffolsheim***)

3 *Pontcharaud*, Auvergne area (Goude et al., 2013).

From: Goude at al., 2019, Fig.1.

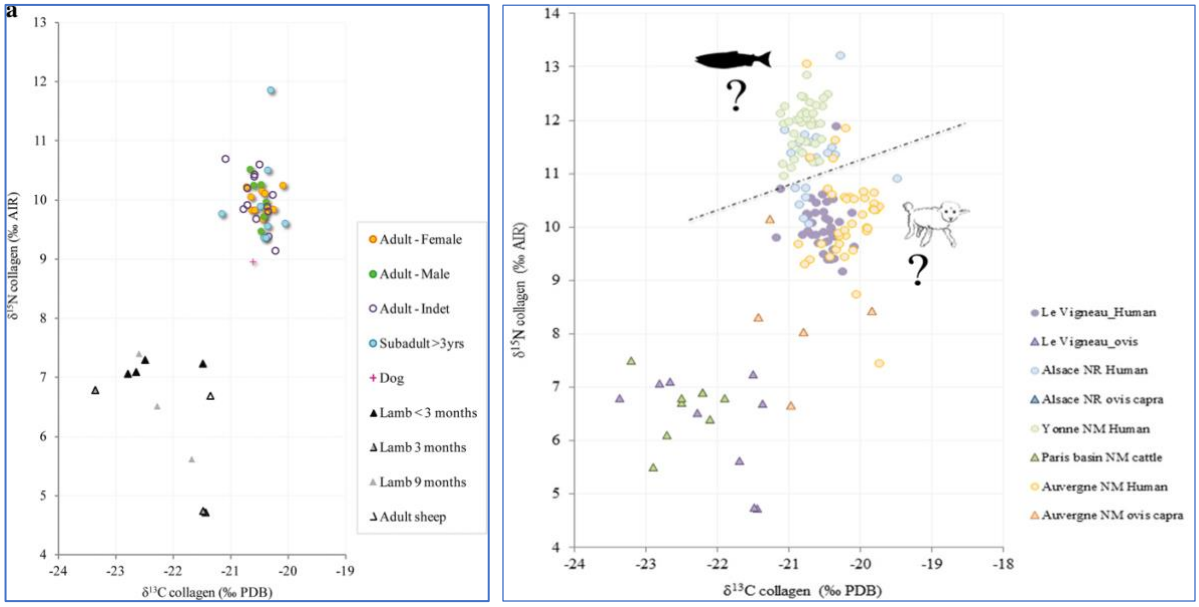


Fig. 45 a. Left. Bone collagen SI ratios at Le Vigneau 2, from human, dog, lamb, and sheep samples.

Fig. 45 b. Right. Comparison of Le Vigneau 2 carbon and nitrogen ratios with those from other *Middle Neolithic* (NM= Néolithique Moyen) and *Late Neolithic* (NR= Néolithique Recent) sites in Northern France (from Goude et al., 2013; Goude et al., 2015; Rey et al., 2017). Yonne = Gurgy "Les Noisats". The dotted line represents a *hypothetical* delineation between individuals consuming mainly terrestrial resources with various amounts of animal protein intake (below the line) and individuals with additional resources such as freshwater fish / young animal proteins in their diet (above the line). From: Goude et al., 2019, Fig. 2 a, and 5.

At *Le Vigneau* very comprehensive studies (including bone collagen SI for C, N, and S, teeth enamel Sr isotope ratio, palaeo-parasitological, dental calculus, aDNA) were combined. The preservation at the site allowed sampling of 40 humans (11 females, 6 males, 13 non-sexed adults, and 6 juveniles > 4 y of

age) and 12 animals (ten lambs, one adult sheep, one dog) for C and N SI ratio analysis (Fig. 45 a). The faunal group data from the most symbolically deposited 4 newborn lambs ($\delta^{13}C$: −22.8 to −21.5‰; $\delta^{15}N$: 7.1 to 7.3‰) are consistent with the one adult sheep data (18 months; $\delta^{13}C$: −21.4‰; $\delta^{15}N$: 6.7‰) and consistent with herbivore data from northern France for C_3 terrestrial landscapes (Goude and Fontugne, 2016). For the 3 to 9 months old lambs the spread is wider ($\delta^{13}C$: −23.4 to −21.4‰; $\delta^{15}N$: 4.7 to 7.4‰; n = 6) and the lower nitrogen values are difficult to explain. *When comparing these MN Le Vigneau values with the MN Oberschaeffolsheim sheep data the former are only slightly lower than the latter* ($\delta^{13}C$: −21.68 ± 0.99 ‰; $\delta^{15}N$: 7.55 ± 0.74 ‰; n = 10), possibly from browsing in more densely vegetated habitat. The human data had a limited isotopic variability (independent of sex, age, or biological and archaeological criteria): $\delta^{13}C$: −21.2 to −20.1 ‰; $\delta^{15}N$: 9.1 to 11.9 ‰; n = 40 and closely resemble the ones from both Upper and Lower Alsace (with means ranging from $\delta^{13}C$: −20.6 to -20.2 ‰ and $\delta^{15}N$: +9.3 ‰ to +10.6). These SI values show that humans from the Loire region based their diet on terrestrial resources also, with a higher trophic position than that of the fauna studied ($\Delta^{13}C$: 1.8‰; $\Delta^{13}N$: 3.1‰), indicating a *significant consumption of animal protein* (Fig. 45 b), *again well within the range reported for all the more easterly sites* ($\Delta^{15}N$ from 1.9 to 4.3 ‰ and $\Delta^{13}C$ from 0.4 to 2.8 ‰). These data agree with preliminary observations proposed by a zoo-archaeological study, *highlighting an economy turned toward pastoralism and sheep herding instead of agriculture* (Goude et al., 2017).

Gurgy "Les Noisats" *and other sites of the Yonne valley (Neolithic)* with human and animal SI data

are located in the Paris basin, at a distance of 320 km from Oberschaeffolsheim. They were occupied for more than one millennium (from 5200 to 3800 BC) with a great diversity of grave goods and burial practices attesting to multiple influences (Rivollat et al., 2015; Rey et al., 2017, 2019).

Table 11 a. Distribution of isotopic values for all the samples, *all sites*, for $\delta^{13}C$ and $\delta^{15}N$ (155 humans and 56 animals). From: Rey et al., 2019, Table 3, partly shown. Table 11 b. Data from this study.

Species	N	$\delta^{13}C$ (‰)				$\delta^{15}N$ (‰)			
		min	**mean**	*SD*	max	min	**mean**	*SD*	max
TOTAL human	155	-21.3	**-20.7**	*0.2*	-19.8	8.7	**11.3**	*0.8*	13.4
TOTAL pig	20	-21.7	**-20.2**	*0.7*	-19.3	5.3	**8.0**	*1.2*	11.0
cattle	18	-23.7	**-22.1**	*0.7*	-20.7	4.5	**6.3**	*0.7*	7.3
sheep/goat	12	-22.7	**-21.8**	*0.8*	-19.5	5.0	**6.3**	*0.9*	8.3
TOTAL herbiv	30	-23.7	**-22.0**	*0.8*	-19.5	4.5	**6.3**	*0.8*	8.3
deer	5	-23.5	**-22.4**	*0.9*	-21.4	3.3	**5.0**	*1.2*	6.5
aurochs	1	-23.3	**-23.3**		-23.3	4.5	**4.5**		4.5
TOTAL wild	6	-23.5	**-22.5**	*0.9*	-21.4	3.3	**4.9**	*1.1*	6.5

This study	Cattle	Cattle	Pig	Pig	Sheep/Goat	Sheep/Goat	Red deer	Red deer
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
	-22.0±0.95‰ n= 15	7.0±0.9‰ n= 15	-21.46±0.45‰ n= 18	7.23±0.86‰ n= 18	-21.68±0.99‰ n=10	7.55±0.74‰ n= 10	-22.22±0.36‰ n=5	5.37±1.56‰ n= 5

There are no *straightforward* conclusions to be drawn when comparing data sets from areas more than 300 km apart that were settled for such different periods of time (about 1400 versus a maximum of three generations, up to 90 years). The fact that the twenty pigs from this study clearly have higher $\delta^{13}C$ and $\delta^{15}N$ values than the cattle, sheep and goats might point to added fodder (dairy products or manured cereals) and being kept in less wooded areas (closer to the settlements), both assumptions contrasting with findings at Oberschaeffolsheim.

For the domestic herbivores the $\delta^{13}C$ very closely resembles the data from the Paris basin, our $\delta^{15}N$ values being a little higher in both cases, but not significantly so. Red deer are practically identical again, our group of aurochs (n= 9) showing significantly higher values ($\delta^{13}C$: −21.95 ± 0.85 ‰, $\delta^{15}N$: 6.93 ± 1.05 ‰) than the one animal in the Gurgy "Les Noisats" sample (Tables 11 a, and b).

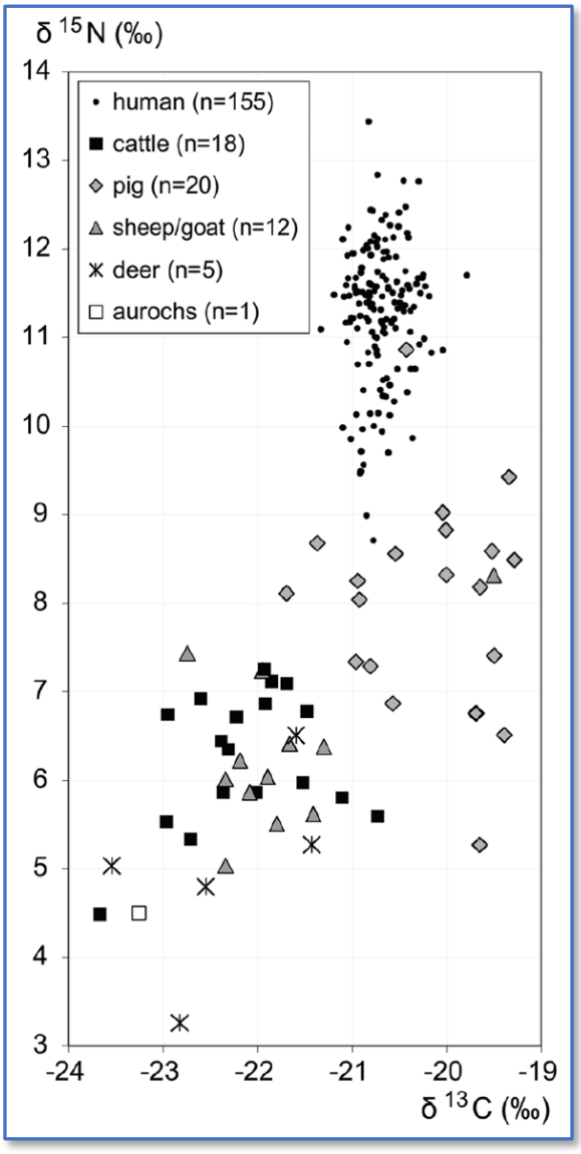


Fig. 46. Distribution of isotopic values for *all the samples, all sites*, for $\delta^{13}C$ and $\delta^{15}N$ (155 humansand 56 animals). From: Rey et al., 2019, Fig. 2.

This spread of $\delta^{15}N$ of about 5‰ (8.7‰ to 13.4‰) points to great differences of the meat/dairy ratios in the diets of the population (personal consideration for Fig.ure46).

The very low ranges for $\delta^{13}C$ (Δ= 0.7‰) and $\delta^{15}N$ (Δ= 1.4‰) in the population at Gurgy "Les Noisats" (n= 40) show a *considerable homogeneity for the Middle Neolithic*, which renders the conclusion of the authors for that specific site highly probable that the individuals consumed identical categories of food (meat, cereals) coming from the same environment (*see Fig.2, from Rey et al,* ***2017***). The large isotopic trophic spacing levels observed between domestic fauna and humans is remarkable and several explanations have been proposed: consumption of either very young animals, specifically pork for tenderness and sheep meat, possibly shortly after the end of weaning, or of specific body parts such as brain, or freshwater fish (Rey et al., 2017, 2019). Intense manuring of cereals might be considered as an additional option (Treasure et al., 2016).

Germany

Vaihingen an der Enz, *(Baden-Württemberg),* with Human and animal SI data,

is a well-preserved LBK site on loess sediment, its 6 ha size completely excavated, located in a tributary valley of the Neckar, slightly over 100 km from Oberschaeffolsheim, as the crow flies. At its maximum extent the occupation spanning the LBK period (about 400 years duration) had around 40 to 50 longhouses with an estimated population of 300 to 400 people (Krause, 2003; Fraser et al., 2013; Bogaard et al., 2016).

As the detailed species data for humans, fauna and crops give an excellent example of LBK stable isotope values in the medium vicinity of the site Oberschaeffolsheim that is studied in my research paper, these are shown as published in Figures 47 a and b and in Table 12.

Thousands of archaeo-botanical samples point to an intensive cultivation of the probably small individual plots with long-term strategies of weeding, tillage and possibly manuring. The $\delta^{13}C$ and $\delta^{15}N$ values of the 16 cereal and pulse samples are like the modern experimental ones, well preserved and typical of C_3 plants in central Europe (Table 12, bottom). They have $\delta^{15}N$ values (+2.7‰ to + 5.7‰) that are quite consistent within those of cereals growing on long-term manured plots, whereas un-manured ones show values from -0.3‰ to + 1.9‰ (Bogaard et al., 2007).

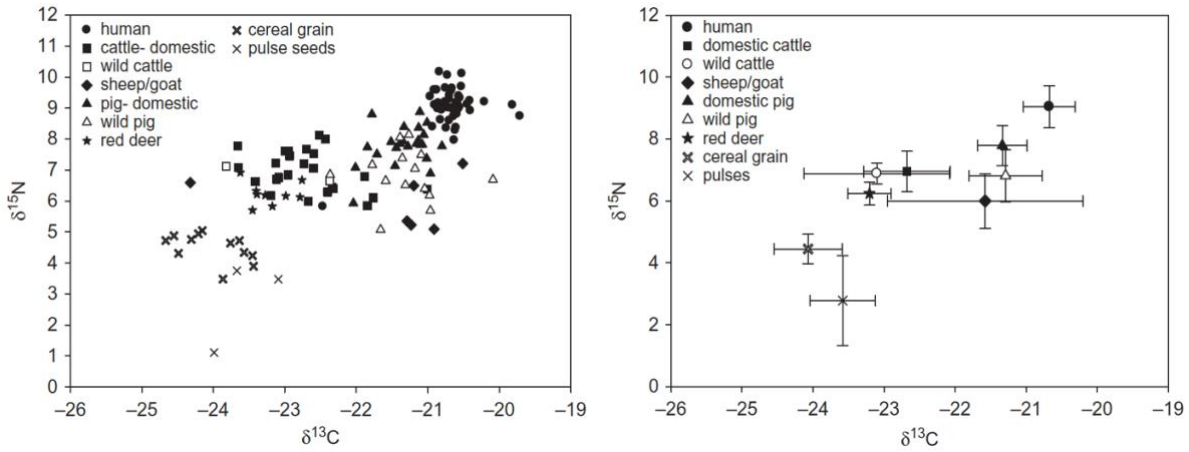


Fig. 47 a. Left. Plot of human and animal bone collagen and archaeo-botanical cereal grain and pulse seed $\delta^{13}C$ and $\delta^{15}N$ values. And Fig. 47 b. Right. Mean $\delta^{13}C$ and $\delta^{15}N$ values (with 1σ SD). Charred crop $\delta^{15}N$ values are adjusted for charring effects. From: Fraser et al., 2013, Figures 5 and 6.

The very large number of *faunal samples* (over 39000 specimens) shows that the *wild taxa* remained constant at about 15 % (25% by weight) of total, while the *domestic* ones changed over time: the oldest LBK featured about 66 % cattle, decreasing to 44 % in younger LBK, whereas pigs climbed to 37 % and sheep and goats reached 19 % of total. The mortality data suggest that cattle were primarily used for meat, *excluding* them largely for dairying or traction, sheep and goat were mainly exploited for hair and meat, and male pigs usually killed before the age of one year after intensive small-scale

management, suggested by metrical contrast (Schäfer, 2017). Interbreeding between domestic and wild pigs, which is quite difficult to prohibit by the farmers, was detected by archaeological mtDNA analysis (Kraus-Kyora, 2011, Halstead & Isaakidou, 2011).

Table 12. Mean stable isotope values (1σ SD) for humans and animals and the isotopic offsets (Δ) for $\delta^{13}C$ and $\delta^{15}N$ among fauna, and humans and crops for Vaihingen an der Enz; * charring effect of 1‰ subtracted. † = mean of cereals and pulses 50:50% mix. From: Fraser et al., 2013, Table 4.

						Δ fauna - human	
Taxon	*N*	$\delta^{13}C$	*SD*	$\delta^{15}N$*	*SD*	$\Delta^{13}C$‰	$\Delta^{15}N$‰
Human	45	−20.7	0.4	9.1	0.5		
Domestic fauna							
Bos taurus	25	−22.7	0.6	6.9	0.7	−2.0	−2.2
Ovis aries	4	−21.8	1.7	6.4	0.8	−1.1	−2.7
Capra hircus	2	−21.1	0.3	5.2	0.2	−0.4	−3.9
Sus domesticus	23	−21.3	0.3	7.8	0.6	−0.6	−1.3
Wild fauna							
Bos primigenius	2	−23.1	1.0	6.9	0.3	−2.4	−2.2
Sus scrofa	14	−21.3	0.5	6.8	0.8	−0.6	−2.3
Cervus elaphus	9	−23.2	0.3	6.2	0.4	−2.5	−2.9
All domestic fauna $\bar{x}$	54	−22.0	0.9	7.2	0.9	−1.3	−1.9
All wild fauna $\bar{x}$	25	−22.1	1.1	6.6	0.7	−1.4	−2.5
All fauna $\bar{x}$	79	−22.0	1.0	7.0	0.9	−1.3	−2.1
All domestic herbivores $\bar{x}$	31	−22.5	0.9	6.8	0.8	−1.8	−2.3
All wild herbivores $\bar{x}$	11	−23.2	0.4	6.4	0.4	−2.5	−2.7
All herbivores $\bar{x}$	42	−22.7	0.9	6.7	0.7	−2.0	−2.4
						Δ crop plant − human	
Cereals	13	−24.1	0.5	4.5	0.5	−3.4	−4.6
Pulses	3	−23.6	0.5	2.8	1.5	−2.9	−6.3
All crops†	16	−23.8	0.3	3.6	1.2	−3.1	−5.5
						Δ crop plant − domestic fauna	
Cereals						−2.1	−2.8
Pulses						−1.6	−4.4
All crops†						−1.8	−3.6
						Δ crop plant − domestic herbivores	
Cereals						−1.4	−2.3
Pulses						−1.1	−4.0
All crops†						−1.4	−3.1

"In terms of consumption evidence, the faunal remains tended to be heavily fragmented, cut marks are well documented and are especially frequent on the wild taxa, such that domestic and wild animals probably were processed and consumed in distinctly different ways" (Schäfer, 2017). Faunal $\delta^{13}C$ and $\delta^{15}N$ values are shown in Table 12 with evidence of feeding of the fauna on C_3 plants with admixture

of C_4 consumption. Cattle, aurochs, and deer show significantly lower $\delta^{13}C$ values than pigs, sheep, and goats, with domestic herbivores on average statistically higher by 0.7 ‰ than wild ones. The boars stand out higher than the other wild fauna, very similar to the domestic pig. The $\delta^{15}N$ values of domestic and wild herbivores are not statistically significantly different, but domestic pigs have a significantly higher value (7.8 ‰ ± 0.6) than the other fauna, with boars and cattle in the intermediate range (6.9 ‰ ± 0.7) while sheep, goat, and red deer show the lowest values (6.1 ‰ ±0.6).

For a comparison with Oberschaeffolsheim this is a *very important site*, mainly because of the relative vicinity, the completeness of its excavation and the large number of faunal and botanical samples studied. Comparing the sites can allow a glimpse on the changes that took place between the LBK (in this case with a 400-year duration) and the MN with less than 90 years.

A close comparison of data (Table 13) shows *very homogeneous SI $\delta^{13}C$ data in all species from Oberschaeffolsheim*, whereas in Vaihingen cattle, aurochs and deer values are lower. This could reflect the so-called "canopy effect" - the reduction of $\delta^{13}C$ in these herbivores - which is caused by their browsing of in dense forests.

Domestic pigs and caprines have a similar range of $\delta^{13}C$ values. The latter species, however, has a markedly lower $\delta^{15}N$ in Vaihingen, as has the cohort of deer in Oberschaeffolsheim. Whether sheep and goats were kept in different browsing areas far from habitation as compared to domestic pigs, that were possibly raised near the farmsteads on human refuse, remains open for discussion.

All other species again show similar data.

Table 13. Comparison of the mean SI values (1σ SD) for humans and animals and the isotopic offsets (Δ) for $\delta^{13}C$ and $\delta^{15}N$ among fauna from Vaihingen an der Enz versus the mean SI values (1σ SD) from Oberschaeffolsheim (own data). From: Fraser et al., 2013, Table 4.

Data Vaihingen an der Enz						***Data Oberschaeffolsheim***		
Taxon	***N***	$\delta^{13}C$	$\delta^{15}N$	Δ Fauna – Human		***N***	$\delta^{13}C$	$\delta^{15}N$
Human	45	-20.7±0.4	9.1±0.5					
Domestic fauna				$\Delta^{13}C$	$\Delta^{15}N$			
Bos taurus	25	-22.7±0.6	6.9±0.7	-2.0	-2.2	15	-21.97±0.95	7.03±0.91
Ovis aries	4	-21.8±1.7	6.4±0.8	-1.1	-2.7	10	-21.68±1.0	7.55±0.74
Capra hircus	2	-21.1±0.3	5.2±0.2	-0.4	-3.9			
Sus domesticus	23	-21.3±0.3	7.8±0.6	-0.6	-1.3	18	-21.46±0.45	7.23±0.86
Wild fauna								
Bos primigenius	2	-23.1±1.0	6.9±0.3	-2.4	-2.2	9	-21.95±0.85	6.93±1.05
Sus scrofa	14	-21.3±0.5	6.8±0.8	-0.6	-2.3	8	-21.52±0.41	7.19±0.67
Cervus elaphus	9	-23.2±0.3	6.2±0.4	-2.5	-2.9	5	-22.22±0.36	5.37±1.56

Herxheim** and **Trebur,

are located at about 90 km and 200 km distance from Oberschaeffolsheim respectively, and studies there have added SI data to the LBK, but also the Hinkelstein and *Grossgartach* periods in the Middle Rhine/Main area, with the later periods both dated to between 5000 – 4500 cal BC (Raetzel-Fabian, 1986; as cited by Dürrwächter et al., 2006). SI data for the faunal samples studied are given below with all $\delta^{13}C$ values ranging within a narrow band from –22.5 ‰ to –19.0 ‰ which are expected for a temperate terrestrial C_3 ecosystem, and again close to the data from Oberschaeffolsheim (Table 14).

Species	$\delta^{13}C_{VPDB}$ (‰)	$\delta^{15}N_{AIR}$ (‰)
Herxheim		
Bos taurus	−21.2	7.0
Sus scrofa	−20.9	7.8
Sus scrofa (w; $n = 2$)	−20.9 (0.8)	5.7 (2.0)
Cervus elaphus ($n = 4$)	−21.5 (0.9)	5.7 (0.6)
Canis familaris	−19.0	11.5
Canis familaris	−19.9	5.8
Esox lucius	−22.1	9.2
Esox lucius	−22.5	8.5
Cyprinus spp.	−20.4	10.2
Cyprinus spp.	−22.1	7.5
Trebur		
Bos taurus ($n = 5$)	−21.3 (0.7)	5.7 (0.7)
Bos taurus (j; $n = 2$)	−21.2 (0.9)	7.8 (0.1)
Sus scrofa ($n = 5$)	−21.1 (0.8)	5.9 (1.1)
Sus scrofa (j)	−21.0	8.0
Sus scrofa (w; $n = 5$)	−20.6 (0.4)	6.7 (0.9)
Cervus elaphus ($n = 2$)	−21.6 (0.0)	5.2 (0.3)
Ovis aries ($n = 5$)	−20.6 (0.3)	6.2 (0.5)

Table 14. Average isotope values for faunal samples obtained from two Neolithic sites in Southern Germany, Herxheim and Trebur.
Standard deviations are shown in parenthesis.

j = Juvenile.
w = *Sus scrofa* identified as wild.

From: Dürrwächter et al., 2006, Tab.1.

There were *no significant differences in the mean $\delta^{13}C$ and $\delta^{15}N$ values between the two human Middle Neolithic groups,* with the nitrogen SI ratios consistently being c. 3.5 ‰ higher than the ones of the herbivore samples (Mean: + 6.0 ‰ ± 0. 8), which amounts to around one trophic level, suggesting that both groups consumed the *dietary proteins from herbivore meat* (Fig. 48).

As cereals consist of around 10 % proteins and meat to about 25 %, it is likely that *manured* plants were consumed in addition, as completely herbivore diet seems unlikely (Mann, 2018). Here too *no significant difference to the earlier LBK was observed*, although the later culture showed a greater $\delta^{15}N$ variance, possibly because of a usage of the Herxheim site for *secondary internment by Neolithic communities dispersed over a wide geographical area with a range of resources* (Dürrwächter et al., 2006).

Assuming a *similar $\delta^{15}N$ mean for the MN population at Oberschaeffolsheim* and considering the *higher $\delta^{15}N$ values for domestic and wild species* (except for deer) leading to lower $\Delta^{15}N$ values, one could postulate a higher percentage of crop proteins added to the daily staple of the later farmers.

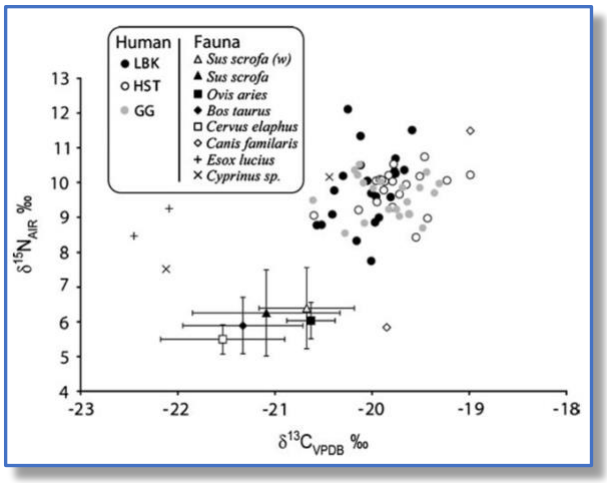


Fig. 48. Plot of human and faunal bone collagen $\delta^{13}C$ versus $\delta^{15}N$ values from Neolithic Sites in Southern Germany.

LBK - Linienbandkeramik burials at ***Herxheim.***

GG - Grossgartach and
HST - Hinkelstein burials at ***Trebur.***

Values for juvenile fauna are not shown.

From: Dürrwächter et al., 2006, Fig.3.

Nieder-Mörlen,

at a distance a little bit further north, in the Wetterau between Taunus and Vogelsberg, has yielded 12 human samples from the early Flomborn and LBK periods with the human $\delta^{13}C$ and $\delta^{15}N$ values around a mean of –20.3 ‰ ± 0.5 and 10.4‰ ± 1.1 respectively, with a slight decrease from the Flomborn to the LBK samples (Fig. 49), albeit with very small numbers only (Nehlich et al., 2009).

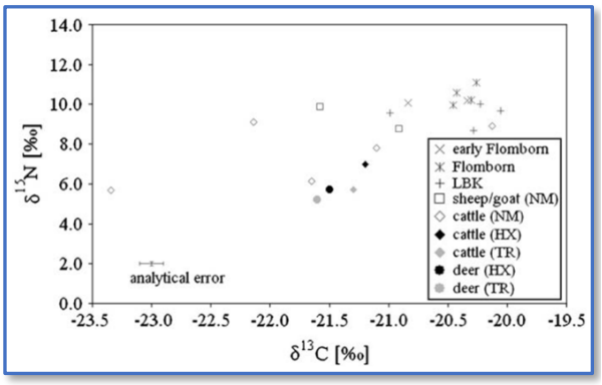


Fig. 49. Plot of stable carbon and nitrogen isotope values in human and animal bones from ***Nieder-Mörlen*** and animals from ***Herxheim*** and ***Trebur***, taken from Dürrwächter et al. (2006).

From: Nehlich et al., 2009, Fig.3

Bavaria

with 92 human samples dating from 5500 BC (Dillingen) to 2000 BC (Weichhering) and collected from 32 burial sites quite evenly covering most parts of the Bavarian Freistaat make an interpretation *challenging at best*. LBK and Middle Neolithic cultures (5500 – 3000 BC) seem to overlap markedly (Fig. 50), whereas in the *Younger* Neolithic cultures the $\delta^{13}C$ values show a higher variability between different sites. As the males show a tendency towards higher $\delta^{15}N$ levels as compared to females the authors assume the data to be caused by a higher percentage of meat in their diet (Asam et al., 2006). The MN Bavarian data (male and female combined) for $\delta^{13}C$ range from about -22.1 ‰ to – 20.8 ‰ and for $\delta^{15}N$ from 7.0 ‰ to about 10.6 ‰ (no mean ± SD given) which appears, in both cases, to be *lower* than the data published for the MN Rhineland population with their mean isotopic values for all adults (n= 25) which are −20.6 ‰ ± 0.2 ‰ for $\delta^{13}C$ and +9.6 ‰ ± 0.3 ‰ for $\delta^{15}N$ (no ranges given).

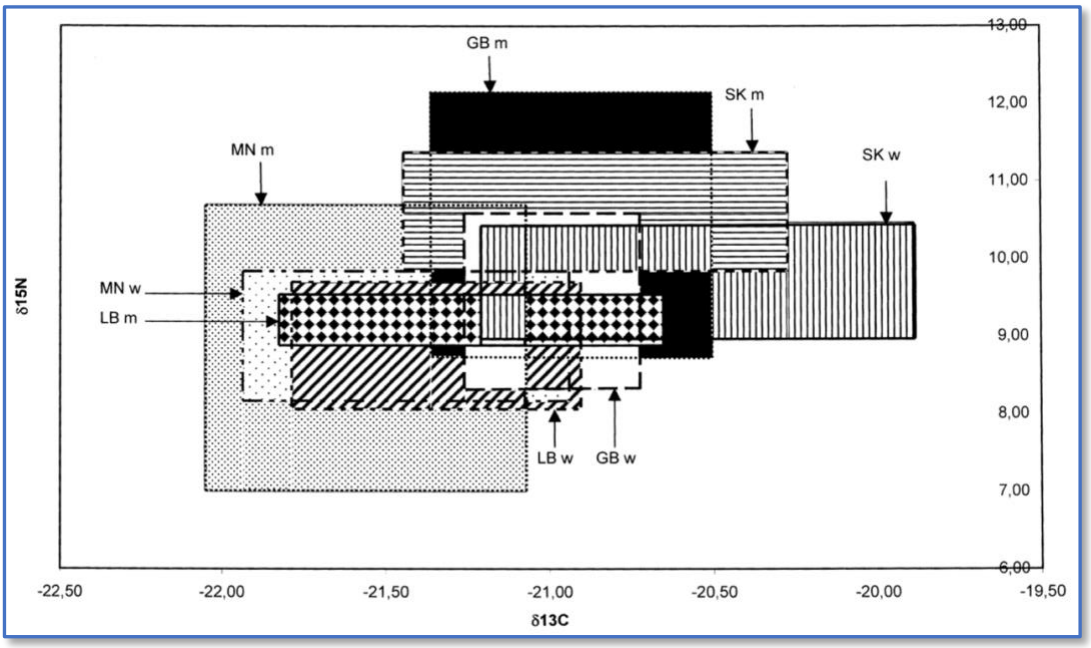


Fig. 50. Distribution of all human $\delta^{13}C$ and $\delta^{15}N$ values from all 32 sites sampled shown in a composite graph, LBK (Linearbandkultur), MN (Middle Neolithic), SK (Corded Ware culture), GB (Bell Beaker culture); m= male, w= female. From: Asam et al., 2006, Fig.4.

Derenburg, Heberstein *and* ***Karsdorf,***

are located in Saxony-Anhalt, in the middle Elbe-Saale region, at a distance of about 500 km from Alsace and have provided detailed data, both from 95 human and 49 faunal samples of earlier to later LBK burials. Domestic animals raised at farms uniformly were cattle, pigs, sheep, and goat, whereas wild species appear in the refuse of these sites with a frequency of less than 5% only (Oelze et al., 2011). Cultivable acreage was apparently scarce and furthered a small-scale intensively manured agriculture (Bogaard, 2004) as reflected in the offset of about 2 – 3 ‰ $\delta^{15}N$ between wild and domestic ruminants at the site of Karsdorf (Fig. 51). As Karsdorf domestic cattle values (n= 12, $\delta^{13}C$: –21,6 ‰ ± 0.8 ‰ and $\delta^{15}N$: 7.1 ‰ ± 1.2 ‰) are significantly different from the three aurochs´ ones (with very low numbers) it is postulated that they might have grazed on different pastures, being kept separate on purpose. These *cattle data are nearly identical to the ones from Oberschaeffolsheim* (n= 15, $\delta^{13}C$: –21.97 ‰ ± 0.95 ‰ and $\delta^{15}N$: 7.03 ‰ ± 0.91‰). Local sheep and goats (n= 8) cluster around the mean of –20,4 ‰ ± 0,3 ‰ for $\delta^{13}C$ and between 6,4 and 7,9 ‰ for $\delta^{15}N$ again suggesting a similar diet. According to the authors their less negative $\delta^{13}C$ values, like the aurochs´ ones, could indicate their pastures to be in the open landscapes rather than shaded forests, whereas the *Oberschaeffolsheim data* (n= 10) with $\delta^{13}C$: –21.68 ‰ ± 1.0 ‰ and $\delta^{15}N$: 7.55 ‰ ± 0.74‰, seem to suggest a more closed environment. Pigs (n= 8), being omnivorous, had a slightly higher $\delta^{15}N$ level of 7.8‰ ± 0.4 ‰ (Benecke, 1994), their $\delta^{13}C$ values: –21.0 ‰ ± 1.0 ‰ (Fig. 51), both similar to the Oberschaeffolsheim data (n= 10) with $\delta^{13}C$: –21.46 ‰ ± 0.45 ‰ and $\delta^{15}N$: 7.23 ‰ ± 0.86 ‰.

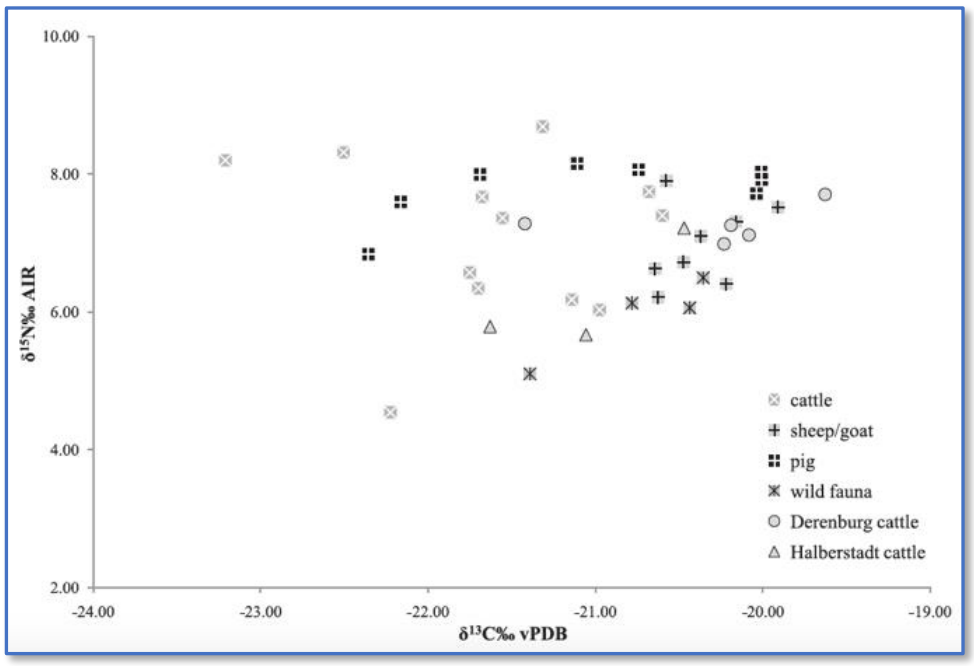


Figure 51. Karsdorf faunal sample; scatter blot of $\delta^{13}C$ and $\delta^{15}N$ data for all domestic and wild animals from the site Karsdorf. By means of comparison the cattle samples from Derenburg and Halberstadt are included. From: Oelze et al., 2011, Fig. 1

"For all three sites the mean human bone collagen isotope ratios are for $\delta^{13}C$: –19.9 ‰ ± 0.4 and 8.7 ‰ ± 0.8 for $\delta^{15}N$, when subadults are excluded, the spectrum of $\delta^{13}C$ reflecting a *C_3 based diet.*

The *intensive* cultivation of C_4 plants, specifically millet, can therefore be excluded, although there is archaeo-botanical evidence for its introduction in the earliest LBK in the study area (Beug, 1992).

All adult human $\delta^{15}N$ values (ranging from 6.3 ‰ to 11.7 ‰) are *within the expected range for farming societies with a mixed omnivore diet relying on the products of domestic animals and on field crops.* The values for the isotope fractionation between the domestic herbivores (only cattle, sheep, and goat) and the adult humans ($\Delta_{herbivore\text{-}human}$) are shown in Table 15." (Oelze et al., 2011).

For Halberstadt and Karsdorf the Δ represent one trophic level in $\delta^{13}C$ and between 1⁄2 and one trophic level in $\delta^{15}N$, so that these farmers probably had significant amounts of domestic herbivore protein in their daily diet (following Ambrose & Norr, 1993; Robbins et al., 2005). At Derenburg, however, the lower $\Delta_{herbivore\text{-}human}$ points to a higher contribution of cultivated crops in their nutrition.

Table 15. Total sample size of each site, mean isotopic values of adult human individuals and animal samples, and isotopic fractionation of $\delta^{13}C$ and $\delta^{15}N$ between domestic herbivores (pigs and wild fauna excluded) and humans ($\Delta_{herbivore\text{-}human}$). From: Oelze et al., 2011, Table 3.

Site	Total human samples	Adult human means				Total animal samples	Animal means				$\Delta_{herbivore-human}$	
		$\delta^{13}C‰$	1σ	$\delta^{15}N‰$	1σ		$\delta^{13}C‰$	1σ	$\delta^{15}N‰$	1σ	$\Delta^{13}C‰$	$\Delta^{15}N‰$
Derenburg	39	−19.8	±0.4	8.8	±0.5	7	−20.4	±0.5	7.2	±0.2	0.5	1.6
Halberstadt	36	−19.8	±0.3	8.4	±0.5	6	−21.0	±0.4	6.4	±0.9	1.1	2.3
Karsdorf	22	−20.0	±0.3	9.0	±0.4	32	−21.0	±0.8	7.1	±1.0	1.1	2.0

Conclusions

Trying an interpretation of the collagen $\delta^{13}C$ and $\delta^{15}N$ stable isotope patterns of our study site in Lower Alsace additionally requires a comparative "synoptic" overview of faunal and human SI data from recent reports not only in the close vicinity of Oberschaeffolsheim, but also from a medium distance, as attempted above, in order to place them into an appropriate context as done in the comprehensive analysis "Diversity in LBK Lifeways", edited by Bickle and Whittle, in 2013.

It can be assumed that the basic trends for both domestic as well as wild fauna stable isotope ratios mirror both the mixture of plants they eat, as well as the variety of landscapes and climate (mostly continental in this case) and habitats they might occupy (meadow, marshland, forest, or manured fields) and that those also follow a variety of types of human control and husbandry. Stark differences – caused by high variations of these factors and therefore diets of markedly different isotopic composition of the species under consideration - would work against strong inter-species correlations.

It is apparent in our series that ***both elements*** analysed for stable isotope ratios show a ***very homogenous distribution for all species****, both domestic and wild* (with the only exception of the deer group comprising about 10% of the overall sample with significantly lower $\delta^{15}N$ values).

This would imply that all species had *very similar feeding habits* (e.g. on regularly manured – necessarily large - fields after the harvest for about half of the year) except for the red and roe deer being shyer animals grazing in areas distant from human habitats *only*. Sheep and goats with their slightly elevated $\delta^{15}N$ values - as compared to all other ruminants – might have been reared differently, possibly closer to the human habitats.

As the domestic pig $\delta^{15}N$ values are close to the ones of boars and all the ruminants in this study, this speaks against the "village pig model of feeding" that has been proposed for the LBK pigs (Hedges et al., 2013, 361).

The mean of all the $\delta^{13}C$ values (–21.78 ‰ ± 0.75‰; maximum: –19.46 ‰, minimum: –23.75 ‰) is well compatible with *feeding strategies in rather open environments for both domestic and wild species alike*.

How can this *uniformity* at the Middle Neolithic site of Oberschaeffolsheim best be explained?

Independent of whatever cause(s) that resulted in the "crisis at the end of LBK", a *clear time gap* of around 150 to 200 years (!) has been demonstrated between the *final LBK in lower Alsace* (but also in other regions north and south in the Rhine valley and its catchments) and the *start of the Middle Neolithic* in this area by a comprehensive study recently published by Denaire and co-workers (2017).

After a brief *Hinkelstein* "pioneer period", with settlers coming in from the middle Rhine and appearing rapidly within 20 years (with solely five settlements close to the river known), it was only "*during the Grossgartach phase* that *all the former LBK territory was re-inhabited"*.

The size of these later sites, however, was smaller as compared to the ones of the LBK, with hamlets of a few contemporary farmsteads only (Leprovost 2012; Denaire 2009, 2012, 2014).

We have no detailed knowledge of the vegetation present after the final demise of the many LBK settlements in the Lower Alsace, but previous clearing of the forest for agriculture, the continuous and massive use of firewood, and for the construction of large houses over many generations in a densely populated landscape probably will have reduced initially thick forests to a large extent.

It seems possible that these MN newcomers from the east were welcomed with a "clean slate" of deciduous flora very slowly growing back, constantly being trimmed by the multitude of small and large wild fauna roaming, with only the near Vosges to the southwest carrying major, densely forested areas. All wild species present would be important, together with the freshly imported domesticated livestock, to further prevent a rapid regeneration of a dense forest, thereby maintaining the open landscapes by continuously contributing to the clearance of its regrowth.

All domestic species extensively kept would not only import nutrients (especially nitrogen) from un-cultivated areas, but also recycle crop and food waste thereby effectively maintain soil fertility via manuring the intensively cultivated garden plots of the village. Cattle would be the major providers of meat and dairy products, their somewhat lower $\delta^{13}C$ in our study possibly indicating that they were being kept over the wintertime on fodder from shadier woodland. Sheep and goats possibly would be fed on the meadows and fields closer to the Middle Neolithic village (with slightly higher $\delta^{15}N$ values), In contrast, domestic pigs might range around more freely, feeding on an omnivorous diet like the boars (with only a low amount of animal protein at Oberschaeffolsheim, the SI values being close to the ones of the herbivores) and mostly slaughtered within the first one to two years of their life (Schley and Roper, 2003). The wild species, roaming through the same open landscape and hunted at a much smaller scale by the farmers, contributed only a small percentage to human subsistence.

A current study (Balasse and co-workers) looking at serial teeth samples from our study site will help to uncover husbandry practices on an *intra-annual scale*. In addition, with the use of new elaborate laboratory techniques (such as lipid chromatography) an even closer look at subsistence practices in the Neolithic will be possible (Casanova et al., 2020).

At present however, many Neolithic sites that stretch from the Rhine valley in Alsace to the middle Danube catchment in Hungary seem to show a ***remarkable overall consistency of SI values for both humans and faunal remains*** with a few individual or site outliers only (see Hedges et al., 2013, 383).

Summary

Subsistence and animal husbandry practices in the Lower Alsace region in the Middle Neolithic – studied using stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) in faunal remains from the excavation site of Oberschaeffolsheim.

Studies of stable isotope (SI) ratios ($\delta^{13}C$ and $\delta^{15}N$) of bone collagen and sequential teeth samples of different faunal species have yielded important information on foraging, management practices and trophic levels within and between species. When sites reaching from Alsace to the Carpathian Mountains of the Linearbandkeramik (LBK) culture of the early Neolithic were compared, faunal and human data showed great homogeneity, with few outliers apparent only (Bickle et al., 2013).

In 2017 a detailed archaeological excavation was performed at the site of *Oberschaeffolsheim* (already known since 1922), which is located a few kilometers west of Strasbourg and dated to the Middle Neolithic (Grossgartach period). The findings that were published included over 11,000 animal bones from a variety of domesticated (80%) and wild (20%) species.

In our report 71 faunal samples that were gathered from Oberschaeffolsheim (19 domesticated pigs, 8 wild boars, 16 cattle, 9 aurochs, 8 red deer, 10 sheep or goat and one roe deer) were analysed for their stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) using bone collagen that was extracted, lyophilized, and weighed with the final IS measurements performed with Isotope-Ratio-Mass-Spectroscopy (IRMS). A total of 66 specimens yielded data and showed a *very homogeneous $\delta^{13}C$ and $\delta^{15}N$ distribution between domestic* (Mean ± SD for $\delta^{13}C$: – 21.7 ‰ ± 0,8 ‰, range -23.5 ‰ to -19.5 ‰ and for $\delta^{15}N$ values: 7.2 ‰ ± 0.9 ‰, range 4.5 ‰ to 8.8 ‰) *and wild species*. This is compatible with feeding strategies in a rather *open environment for both domestic and wild species alike*, with the only exception of shy deer, which show significantly lowered $\delta^{15}N$ (5.4 ‰ ± 1.6 ‰), possibly thriving in less manured fields.

A comparison with SI faunal and human data from several Neolithic sites in Alsace, the Paris and Loire basin and an area in southern and central Germany showed a large extent of overlap of our bone collagen values for domesticated and wild herbivores and omnivores with the data published, with only few outliers in the samples that were compared, and trophic levels of the respective local farmers (whenever available) signifying a large amount of domestic herbivore protein in their daily diet.

Considering husbandry practices at *Oberschaeffolsheim in the Middle Neolithic,* I postulate that after the time gap of a minimum of 150 years between the LBK and the start of the MN, a period when Lower Alsace was not inhabited, a wide-open landscape welcomed the new arrivals, a “clean slate”, that allowed a “mixed browsing” - around the newly built smaller village with their manured fields - for both domestic and wild fauna alike. In my isotope data no specialisation in domestic livestock management (including the pigs) seem to have been practiced.

Zusammenfassung

Zur Subsistenz und Tierhaltung des Mittleren Neolithikums im unteren Elsass anhand der lokalen Fauna der Fundstelle Oberschaeffolsheim - Eine Studie an stabilen Isotopen-Verhältnissen von $\delta^{13}C$ und $\delta^{15}N$.

Untersuchungen der Verhältnisse Stabiler Isotope (SI), im Besonderen von $\delta^{13}C$ und $\delta^{15}N$, gewonnen aus Knochenkollagen und sequentiell beprobtem Dentin verschiedener Tierspezies haben detaillierte Informationen über Fütterung, Weidehaltung und die „trophischen Stufen" innerhalb und zwischen verschiedenen Spezies an vielen Fundorten erbracht. Der Vergleich zahlreicher Fundstellen der Linearbandkultur (LBK) des frühen Neolithikums, reichend vom Elsass im Westen bis zu den Karpaten im Osten hat eine große Übereinstimmung dieser Daten, mit nur wenigen abweichenden Befunden, erbracht (Bickle et al., 2013).

Im Jahr 2017 fand in *Oberschaeffolsheim,* einer bereits seit 1922 bekannten Fundstelle, die nur wenige Kilometer westlich von Straßburg liegt, eine großflächige Ausgrabung statt. Sie wird in das Mittlere Neolithikum datiert (Großgartach Periode) und die Funde (detailliert 2019 publiziert) beinhalteten über 11.000 Tierknochen von überwiegend domestizierten (80%), aber auch wilden Spezies (20%).

In meiner Studie wurden 71 Tierknochen dieser Ausgrabung (19 domestizierte Schweine, 8 Wildschweine, 16 Rinder, 9 Auerochsen, 8 Hirsche, 10 Schafe oder Ziegen und ein Reh) hinsichtlich ihrer SI-Werte ($\delta^{13}C$ und $\delta^{15}N$) analysiert. Dabei wurde das Knochenkollagen extrahiert, lyophilisiert, gewogen und die SI-Messungen mittels Isotopen-Ratio-Massen-Spektroskopie (IRMS) durchgeführt.

In 66 Proben konnten Daten erhoben werden, welche eine *sehr homogene $\delta^{13}C$ und $\delta^{15}N$ Verteilung beim Vergleich zwischen domestizierten und wilden Spezies* erbrachte (MW ± SD für $\delta^{13}C$: – 21.7 ‰ ± 0,8 ‰, von -23.5 ‰ bis -19.5 ‰ und für $\delta^{15}N$: 7.2 ‰ ± 0.9 ‰, von 4.5 ‰ bis 8.8 ‰), Werte, welche gut mit *Fütterung und Grasen in offener Landschaft für beide Gruppen* in Einklang zu bringen sind. Eine Ausnahme sind scheue Hirsche, welche signifikant erniedrigte $\delta^{15}N$-Werte (5.4 ‰ ± 1.6 ‰) aufwiesen.

Der Vergleich mit SI-Befunden von Fauna und menschlichen Bestattungen aus dem Neolithikum von Elsass, dem Pariser und dem Loire Becken sowie einem nahegelegen Bereich Deutschlands weist eine oft große Übereinstimmung der $\delta^{13}C$ und $\delta^{15}N$ Werte sowohl für domestizierte als auch wildlebende, wiederkäuende und omnivore Spezies, mit nur wenigen Abweichungen, auf. Der Vergleich mit Werten lokaler Bauern zeigt, dass zu ihrer Ernährung *tierisches* Protein einen wesentlichen Anteil beitrug.

Aufgrund der SI-Befunde der Fauna aus *Oberschaeffolsheim* postuliere ich, dass nach einem Zeitraum von etwa 150 Jahren - zwischen dem Ende der LBK und dem intensiven Beginn des MN -, in dem das Untere Elsass *nicht besiedelt* war, die neu eintreffenden Ansiedler von einer sehr offenen Landschaft, ohne die ehemalige wohl dichte Bewaldung, willkommen geheißen wurden, welche eine „gemischte Weidehaltung" um das Dorf, sowohl für ihr domestiziertes Vieh, als auch lokale Wildtiere erlaubte.

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Introduction

The Research Questions

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This material was sampled, selected, and initially prepared for analysis
by ***M. Blanz*** in cooperation with ***M. Balasse*** and ***M. Fabre*** on October 19th and 20th, 2022, at the **Centre de conservation et d'étude d'Alsace** (CCE, 11 rue Champollion - 67600 Sélestat, Alsace, France).

All collagen extractions were performed by ***G. Grabner*** after the introduction to the technique by ***M. Blanz*** and under her supervision at the former laboratory of **HEBA**,
Vienna Institute for Archaeological Science, VIAS, Josef-Holaubek-Platz 2 (UZA II), 1090 Wien

Quality control limits were set according to: Guiry, E. J., & Szpak, P. (2021). Improved quality control criteria for stable carbon and nitrogen isotope measurements of ancient bone collagen. https://doi.org/10.1016/j.jas.2021.105416 Journal of Archaeological Science, 132 (October 2020), 105416.

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SPECIES	COMMON	SKELETAL	SIDE(L=LEFT	Inventory	STRUCTURE	CONTEXT	AMOUNT	ID	EXTRACTION	Sample	Collagen weight	Vial weight	Collagen + vial	Collagen	Corr. %C	Corr. %N	C/N	$\delta^{13}C$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{15}N$ (‰)	
	NAME	ELEMENT	(R=RIGHT)	number	NUMBER		TAKEN (g)		DATES	weight (mg)	for IRMS /µg	g	g	yield			(atomic)	uncorrected	corrected	uncorrected	corrected	Comments
Sus domesticus	pig	humerus	R	13	108	3	1.3	OBE_Susd.01	05.12.-7.12.2022	225,5	355	17,0439	17,0621	8,1%	41,92	14,93	3,28	-22,027	-22,137	7,126	7,426	
Sus domesticus	pig	humerus	R	14	108	1	1.5	OBE_Susd.02	05.12.-7.12.2022	206,3	344	17,1167	17,1273	5,1%	41,40	14,86	3,25	-21,499	-21,609	7,481	7,781	
Sus domesticus	pig	humerus	R	16	328	5	1.7	OBE_Susd.03	05.12.-7.12.2022	220,6	340	17,0593	17,068	3,9%	30,64	10,68	3,35	-20,446	-20,556	6,320	6,620	
Sus domesticus	pig	humerus	R	17	328	5	2.4	OBE_Susd.04	05.12.-7.12.2022	214,6	342	17,0503	17,0539	1,7%	33,99	12,03	3,30	-20,575	-20,685	6,657	6,957	
Sus domesticus	pig	humerus	R	18	419	5	3.1	OBE_Susd.05	05.12.-7.12.2022	211,9	327	17,1118	17,1269	1,7%	42,67	15,31	3,25	-21,729	-21,839	8,124	8,424	
Sus domesticus	pig	humerus	R	24	310	1	2.2	OBE_Susd.06	05.12.-7.12.2022	211,7	374	16,995	17,0035	4,0%	39,90	6,26	7,44	-24,435	-24,545	7,013	7,313	rejected
Sus domesticus	pig	humerus	R	31	177	56	1.8	OBE_Susd.07	05.12.-7.12.2022	217,8	336	16,9616	16,9701	3,9%	41,53	14,98	3,23	-21,776	-21,886	7,689	7,989	
Sus domesticus	pig	humerus	R	39	177	35	1.8	OBE_Susd.08	05.12.-7.12.2022	212,2	367	17,0099	17,0155	2,6%	40,62	14,54	3,26	-21,760	-21,870	7,770	8,070	
Sus domesticus	pig	humerus	R	40	177	34	3.3	OBE_Susd.09	05.12.-7.12.2022	227,1	324	17,0897	17,0954	2,5%	40,28	14,45	3,25	-21,230	-21,340	7,386	7,686	
Sus domesticus	pig	humerus	R	54	177	54	2.1	OBE_Susd.10	05.12.-7.12.2022	210,6	334	16,9632	16,9837	9,7%	42,48	15,16	3,27	-21,616	-21,726	5,528	5,828	
Sus domesticus	pig	humerus	R	55	177	54	1.7	OBE_Susd.11	05.12.-7.12.2022	220,4	371	17,1188	17,1303	5,2%	40,69	14,85	3,20	-20,869	-21,249	7,147	7,568	
Sus domesticus	pig	humerus	R	56	177	54	1.7	OBE_Susd.12	05.12.-7.12.2022	212,8	334	17,025	17,0373	5,8%	40,55	14,64	3,23	-21,726	-21,836	5,981	6,281	
Sus domesticus	pig	humerus	R	61	485	1	1.8	OBE_Susd.13	05.12.-7.12.2022	214,9	343	17,0695	17,0778	3,9%	41,85	14,93	3,27	-21,312	-21,422	6,673	6,973	
Sus domesticus	pig	humerus	R	63	484	14	2.5	OBE_Susd.14	05.12.-7.12.2022	211,6	335	17,0333	17,0446	5,3%	42,76	15,39	3,24	-21,251	-21,361	7,642	7,942	
Sus domesticus	pig	humerus	R	69	446	21	1.6	OBE_Susd.15	05.12.-7.12.2022	212,7	355	17,0346	17,0434	4,1%	36,94	13,08	3,29	-20,908	-21,018	6,426	6,726	
Sus domesticus	pig	humerus	R	77	446	33	1.3	OBE_Susd.16	05.12.-7.12.2022	222,3	357	17,0379	17,0496	5,3%	42,88	15,52	3,22	-21,623	-21,733	7,523	7,823	
Sus domesticus	pig	humerus	R	78	446	33	1.5	OBE_Susd.17	05.12.-7.12.2022	211,7	376	17,0392	17,0545	7,2%	41,73	14,99	3,25	-20,876	-20,986	8,002	8,302	
Sus domesticus	pig	humerus	R	80	446	31	1.6	OBE_Susd.18	05.12.-7.12.2022	210,8	323	17,081	17,0919	5,2%	39,91	14,25	3,27	-21,051	-21,161	5,570	5,870	
Sus domesticus	pig	humerus	R	81	446	35	1.7	OBE_Susd.19	05.12.-7.12.2022	214,3	341	17,0017	17,0076	2,8%	46,76	16,79	3,25	-21,719	-21,829	5,655	5,955	
Sus scrofa	wild boar	femur	R	21	419	10	2.2	OBE_Suss.20	13.12.-15.12.2022	226,6	350	17,203	17,2155	5,5%	39,25	14,18	3,23	-22,001	-22,111	6,469	6,769	
Sus scrofa	wild boar	femur	R	23	264	6	2.2	OBE_Suss.21	13.12.-15.12.2022	201,9	360	17,0683	17,0776	4,6%	39,15	13,9	3,29	-21,101	-21,211	7,824	8,124	
Sus scrofa	wild boar	femur	R	30	177	62	1.5	OBE_Suss.22	13.12.-15.12.2022	229,6	325	16,9883	16,9972	3,9%	41,52	14,91	3,25	-21,893	-22,003	7,144	7,444	
Sus scrofa	wild boar	femur	R	43	177	43	1.6	OBE_Suss.23	13.12.-15.12.2022	214	350	16,9933	17,0009	3,6%	38,89	14,02	3,24	-21,030	-21,140	6,106	6,406	
Sus scrofa	wild boar	femur	R	49	485	30	2.4	OBE_Suss.24	13.12.-15.12.2022	206,5	377	17,0466	17,0584	5,7%	42,78	15,51	3,22	-21,759	-21,869	6,648	6,948	
Sus scrofa	wild boar	femur	R	62	485	1	3.0	OBE_Suss.25	13.12.-15.12.2022	212,2	348	17,0221	17,0292	3,3%	41,87	15,07	3,24	-21,236	-21,346	6,555	6,855	
Sus scrofa	wild boar	femur	R	64	446	1	2.3	OBE_Suss.26	13.12.-15.12.2022	204,8	349	17,1344	17,1456	5,5%	43,38	15,69	3,23	-21,293	-21,403	7,934	8,234	
Sus scrofa	wild boar	femur	R	66	446	3	3.0	OBE_Suss.27	13.12.-15.12.2022	227,7	375	16,9464	16,9605	6,2%	41,84	15,18	3,22	-20,976	-21,086	6,477	6,777	
Bos taurus	cattle	tibia	R	19	419	6	3.0	OBE_Bost.28	21.11.-23.11.2022	220,9	332	17,0293	17,0453	7,2%	23,49	8,48	3,23	-22,008	-22,118	6,787	7,087	
Bos taurus	cattle	tibia	R	22	380	1	3.4	OBE_Bost.29	21.11.-23.11.2022	209	361	16,9596	16,9692	4,6%	35,89	12,91	3,24	-20,598	-20,708	4,240	4,540	
Bos taurus	cattle	tibia	R	25	310	1	1.7	OBE_Bost.30	21.11.-23.11.2022	209,3	341	16,9366	16,9565	9,5%	41,68	15,12	3,22	-19,348	-19,458	6,683	6,983	
Bos taurus	cattle	tibia	R	26	310	1	1.9	OBE_Bost.31	21.11.-23.11.2022	219,1	364	17,0336	17,0443	4,9%	12,42	4,34	3,34	-22,347	-22,457	5,870	6,170	rejected
Bos taurus	cattle	tibia	R	27	419	2	2.0	OBE_Bost.32	21.11.-23.11.2022	221,7	370	16,9977	17,0036	2,7%	42,29	15,33	3,22	-21,917	-22,027	6,695	6,995	
Bos taurus	cattle	tibia	R	47	177	75	2.5	OBE_Bost.33	21.11.-23.11.2022	227	379	17,0568	17,0763	8,6%	42,43	15,48	3,20	-22,244	-22,354	7,212	7,512	
Bos taurus	cattle	tibia	R	53	177	54	2.1	OBE_Bost.34	21.11.-23.11.2022	212,6	347	17,0293	17,0327	1,6%	16,93	6,4	3,09	-22,992	-23,102	6,259	6,559	
Bos taurus	cattle	tibia	R	58	485	10	2.0	OBE_Bost.35	21.11.-23.11.2022	218,9	376	17,0666	17,0818	6,9%	41,94	15,25	3,21	-22,548	-22,658	5,705	6,005	
Bos taurus	cattle	tibia	R	65	446	2	1.8	OBE_Bost.36	21.11.-23.11.2022	222,8	374	17,0847	17,0902	2,5%	40,16	14,43	3,25	-22,375	-22,485	6,845	7,145	
Bos taurus	cattle	tibia	R	67	446	3	1.6	OBE_Bost.37	21.11.-23.11.2022	218,3	342	17,0084	17,02	5,3%	38,55	13,93	3,23	-22,459	-22,569	7,948	8,248	
Bos taurus	cattle	tibia	R	71	446	32	1.7	OBE_Bost.38	21.11.-23.11.2022	227,7	333	16,9154	16,9331	7,8%	42,20	15,47	3,18	-21,565	-21,675	6,783	7,083	
Bos taurus	cattle	tibia	R	73	446	13	2.5	OBE_Bost.39	21.11.-23.11.2022	207,6	362	17,0134	17,0197	3,0%	39,05	14,18	3,21	-21,707	-21,817	7,242	7,542	
Bos taurus	cattle	tibia	R	75	446	28	1.8	OBE_Bost.40	21.11.-23.11.2022	228,6	335	17,0324	17,0606	12,3%	42,32	15,39	3,21	-21,689	-21,799	7,137	7,437	
Bos taurus	cattle	tibia	R	76	446	13	2.1	OBE_Bost.41	21.11.-23.11.2022	225,6	336	17,0244	17,0471	10,1%	43,26	15,81	3,19	-23,065	-23,175	7,499	7,799	
Bos taurus	cattle	tibia	R	79	446	39	1.5	OBE_Bost.42	21.11.-23.11.2022	210,7	345	17,0288	17,0351	3,0%	32,78	11,86	3,22	-22,144	-22,254	6,180	6,480	
Bos taurus	cattle	tibia	R	82	446	34	2.2	OBE_Bost.43	28.11.-23.11.2022	211,1	335	17,0366	17,0477	5,3%	37,98	13,82	3,21	-21,227	-21,337	7,696	7,996	

Table 1, Page 2: Bone collagen $\delta^{13}C$ and $\delta^{15}N$ data.

This material was sampled, selected and initially prepared for analysis by *M. Blanz in cooperation with M. Balasse and M. Fabre* on October 19th and 20th, 2022, at the ***Centre de conservation et d'étude d'Alsace*** (CCE, 11 rue Champollion - 67600 Sélestat, Alsace, France).
All collagen extractions were performed by *G.Grabner after the introduction to the technique by M.Blanz and under her supervision* at the former laboratory of ***HEBA, Vienna Institute for Archaeological Science, VIAS,*** Josef-Holaubek-Platz 2 (UZA II), 1090 Wien
Quality control limits were set according to: Guiry, E. J., & Szpak, P. (2021). Improved quality control criteria for stable carbon and nitrogen isotope measurements of ancient bone collagen. https://doi.org/10.1016/j.jas.2021.105416
Journal of Archaeological Science, 132 (October 2020), 105416.

SPECIES	COMMON NAME	SKELETAL ELEMENT	SIDE(L=LEFT (R=RIGHT)	Inventory number	STRUCTURE NUMBER	CONTEXT	AMOUNT TAKEN (g)	ID	EXTRACTION DATES	Sample weight (mg)	Collagen weight for IRMS /µg	Vial weight g	Collagen + vial g	Collagen yield	Corr. %C	Corr. %N	C/N (atomic)	$\delta^{13}C$ (‰) uncorrected	$\delta^{13}C$ (‰) corrected	$\delta^{15}N$ (‰) uncorrected	$\delta^{15}N$ (‰) corrected	Comments
Bos primigenius	aurochs	humerus	L	15	328	5	3.0	OBE_Bosp.44	28.11.-30.11.2022	218,2	376	16,9982	17,005	3,1%	40,57	14,58	3,25	-22,397	-22,507	6,240	6,540	
Bos primigenius	aurochs	humerus	L	33	249	1	1.5	OBE_Bosp.45	28.11.-30.11.2022	221	333	17,0309	17,0375	3,0%	39,19	14,27	3,20	-21,432	-21,542	7,536	7,836	
Bos primigenius	aurochs	humerus	L	41	485	22	1.5	OBE_Bosp.46	28.11.-30.11.2022	214,4	322	17,003	17,0118	4,1%	39,36	14,33	3,20	-21,066	-21,176	6,652	6,952	
Bos primigenius	aurochs	humerus	L	42	485	21	2.0	OBE_Bosp.47	28.11.-30.11.2022	221,6	370	17,0019	17,007	2,3%	39,73	14,57	3,18	-23,644	-23,754	6,291	6,591	
Bos primigenius	aurochs	humerus	L	57	485	11	1.9	OBE_Bosp.48	28.11.-30.11.2022	222,9	334	17,0327	17,0469	6,4%	29,34	10,74	3,19	-21,484	-21,594	6,955	7,255	
Bos primigenius	aurochs	humerus	L	59	485	30	2.2	OBE_Bosp.49	28.11.-30.11.2022	219,8	337	16,9574	16,9709	6,1%	43,73	15,98	3,19	-21,424	-21,534	6,099	6,399	
Bos primigenius	aurochs	humerus	L	60	485	15	1.8	OBE_Bosp.50	28.11.-30.11.2022	210,7	363	17,0843	17,1006	7,7%	34,58	12,54	3,22	-21,150	-21,260	6,601	6,901	
Bos primigenius	aurochs	humerus	L	68	446	21	2.0	OBE_Bosp.51	28.11.-30.11.2022	224,8	358	17,0327	17,0445	5,4%	40,69	14,98	3,17	-22,552	-22,662	6,819	7,119	
Bos primigenius	aurochs	humerus	L	70	446	15	2.0	OBE_Bosp.52	28.11.-30.11.2022	224,2	343	17,0743	17,0863	5,4%	40,43	14,85	3,18	-21,372	-21,482	7,642	7,942	
Cervus elaphus	red deer	humerus	L	20	419	5	2.9	OBE_Cerv.53	28.11.-30.11.2022	201,7	339	17,0939	17,1042	5,1%	42,04	15,27	3,21	-21,782	-21,892	3,756	4,056	
Cervus elaphus	red deer	humerus	L	38	177	35	2.0	OBE_Cerv.54	28.11.-30.11.2022	220,2	359	17,008	17,0163	3,8%	35,95	13,19	3,18	-22,187	-22,297	7,686	7,986	
Cervus elaphus	red deer	humerus	L	45	328	1	2.2	OBE_Cerv.55	28.11.-30.11.2022	214,4	340	17,0328	17,0424	4,5%	41,83	15,33	3,18	-21,747	-21,857	4,018	4,318	
Cervus elaphus	red deer	humerus	L	50	485	27	2.2	OBE_Cerv.56	28.11.-30.11.2022	220,6	373	17,0302	17,0403	4,6%	37,66	13,72	3,20	-22,217	-22,327	5,026	5,326	
Cervus elaphus	red deer	humerus	L	52	177	54	2.1	OBE_Cerv.57	28.11.-30.11.2022	221,3	No sample after lyophilization		X	X	X	X	X	X	X	X	X	rejected
Cervus elaphus	red deer	humerus	L	72	446	32	1.5	OBE_Cerv.58	28.11.-30.11.2022	213,3	336	17,023	17,0333	4,8%	42,04	15,38	3,19	-22,624	-22,734	4,865	5,165	
Cervus elaphus	red deer	humerus	R	74	446	13	1.7	OBE_Cerv.59	28.11.-30.11.2022	213,8	No sample after lyophilization		X	X	X	X	X	X	X	x	X	rejected
Cervus elaphus	red deer	humerus	L	84	446	36	2.5	OBE_Cerv.60	28.11.-30.11.2022	212,2	323	17,0216	17,0231	0,7%	X	X	X	X	X	X	X	X	rejected
Caprinae	sheep (?)	tibia	R	28	485	4	2.2	OBE_Capr.61	13.12.-15.12.2022	228,6	340	16,963	16,9666	1,6%	35,62	13,27	3,13	-21,150	-21,260	7,081	7,381	
Caprinae	sheep/goat	tibia	R	29	177	62	1.4	OBE_Capr.62	13.12.-15.12.2022	227,6	368	17,0767	17,0989	9,8%	43,21	15,68	3,22	-21,011	-21,121	6,536	6,836	
Caprinae	sheep/goat	tibia	R	34	177	1	2.2	OBE_Capr.63	13.12.-15.12.2022	225,9	326	17,0892	17,1068	7,8%	42,17	15,32	3,21	-21,326	-21,436	8,467	8,767	
Caprinae	sheep	tibia	R	35	443	1	2.0	OBE_Capr.64	13.12.-15.12.2022	222,8	376	17,056	17,0729	7,6%	41,31	15	3,21	-22,115	-22,225	5,916	6,216	
Caprinae	sheep/goat	tibia	R	36	177	41	2.4	OBE_Capr.65	13.12.-15.12.2022	221	373	17,0558	17,0719	7,3%	39,68	14,52	3,19	-22,042	-22,152	7,745	8,045	
Caprinae	sheep/goat	tibia	R	37	177	41	2.0	OBE_Capr.66	13.12.-15.12.2022	212,4	338	17,076	17,088	5,6%	41,45	15,17	3,19	-19,969	-20,079	6,644	6,944	
Caprinae	sheep/goat	tibia	L	44	177	45	2.9	OBE_Capr.67	13.12.-15.12.2022	229,3	367	17,1173	17,1289	5,1%	39,92	14,7	3,17	-22,331	-22,441	7,692	7,992	
Caprinae	sheep	tibia	R	46	328	2	2.4	OBE_Capr.68	13.12.-15.12.2022	212,7	332	17,075	17,094	8,9%	41,62	15,41	3,15	-20,416	-20,526	7,509	7,809	
Caprinae	sheep	tibia	L	51	485	27	1.3	OBE_Capr.69	13.12.-15.12.2022	219,1	345	17,1285	17,1387	4,7%	40,93	15,23	3,14	-21,970	-22,080	7,742	8,042	
Caprinae	sheep/goat	tibia	L	84	446	34	2.6	OBE_Capr.70	13.12.-15.12.2022	202,4	367	17,0729	17,0898	8,3%	41,79	15,41	3,16	-23,372	-23,482	7,154	7,454	
Capreolus capreolus	roe deer	metacarp	unknown	48	177	75	2.1	OBE_Capreol.71	13.12.-15.12.2022	225,8	372	16,9994	17,0052	2,6%	41,42	15,19	3,18	-21,037	-21,147	3,993	4,293	