1. ABBA

2.1 Le premier article choisi (Cheung et al. 2021) est un bon exemple de publication multidisciplinaire (autrices principales : chercheuse d'ABBA et sa post-doctorante, ANR NEOGENRE). Elle associe des chercheur.e.s de 7 institutions (dont 5 UMR) et ce concours de disciplines permet de distinguer des individus de l'élite sociale de la culture Cerny (Néolithique moyen) en montrant aussi les interactions bioculturelles à travers les corrélations entre alimentation, pratiques et architecture funéraires.

2.2 Le second (Sellier et al. 2019) est la première publication synthétique sur le cimetière de Kadruka-23 (Soudan, Néolithique ancien ; un grand chantier fédérateur d'ABBA) par 4 membres de l'équipe (dont une doctorante) dans la grande revue anglophone sur l'archéologie de cette région.

2.3 le troisième item présente beDNA La banque d'échantillons et de Données Nationale Archéogénétique (beDNA) qui est une collection d'échantillons archéologiques pour les analyses futures en paléogénétique. Cette collection regroupe les échantillons de fouilles archéologiques récentes, prélevés dans des conditions optimales. Cette collection ayant vocation à être utilisée dans le cadre d'études paléogénétiques, elle est accessible à tout chercheur soumettant une demande d'accès à la collection. Ce n'est pas à proprement parler un projet de recherche mais plutôt une démarche de conservation particulière, à travers une banque d'échantillons destinés à la paléogénétique faisant intervenir toutes les institutions en charge de l'archéologie funéraire.

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The grandeur of death – Monuments, societies, and diets in middle Neolithic Paris Basin

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A R T I C L E I N F O

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Stable isotope analysis
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A B S T R A C T

This study investigates the relationship between monumental funerary structures, social organizations, and diets in Middle Neolithic France. Focusing on the Cerny culture based in the Paris Basin region, we analysed and compared bone collagen stable carbon, nitrogen, and sulfur isotope values of 113 individuals from three different types of Cerny cemeteries: the Passy type (Cerny STP), slab burials (Cerny Slab), and burials without major superstructure (Cerny Flat). Published stable isotopic data from one other Cerny Flat and two contemporaneous non-Cerny cemeteries (n = 140), together with new and published faunal isotopic data (n = 267) from across six different river valleys in the region are also included in the analysis. The results of this study have shown that (1) the Cerny diet was likely rich in animal protein; (2) comparing to all other cemetery types, Cerny STP sites were considerably homogenous isotopically and culturally, and (3) individuals buried in aberrant funerary arrangements tend to have outlying isotopic compositions, suggesting strong correlations between diets and burial practices. Interestingly, as oppose to the distinctly sex-related funerary arrangements, no obvious pattern can be observed in the isotopic compositions between males and females in Cerny cemeteries.

1. Introduction

The Paris Basin (*Bassin parisien*) is an intracratonic basin located in the northern part of France, encompasses all or parts of several modern French administrative regions, including Normandy, Pays de la Loire, Centre–Val de Loire, Île–de–France, Hauts–de–France, Grand Est, and Bourgogne–Franche–Comté (Fig. 1). Supported by an expansive river system, together with favourable climatic conditions, fertile soil, and gentle relief (Jones 1947), the Paris Basin region has been occupied by human settlers as early as the Palaeolithic and Mesolithic periods (Bodu, et al. 2014; Leroi-Gourham and Brézillon 1972; Pigeot 2004; Valentin, et al. 2013). By the end of the 5th millennium BCE, the Paris Basin region has become a crossroads between two main routes of Neolithic dissemination in Western Europe (e.g.(Manen and Hamon, 2018)). While many sites in the area had Danubian roots, the region received further influences from the Mediterranean Neolithic sphere in terms of material culture (Constantin and Vachard 2004; Lichardus-Itten 1986) as well as genetic signatures (Rivollat, et al. 2015). These interactions have created remarkable cultural diversity in the Paris Basin region during the Middle Neolithic period (c. 4700 – 3500 BCE), in a scale that is observed neither in the preceding nor following periods (Chambon and Leclerc 2003; Chambon, et al. 2013). One particularly notable observation is the emergence of the first monumental cemeteries in western Europe (Chambon and Thomas 2010). From massive, earthen long–barrows up to 300 m in length, to large stone slabs weighing several tonnes, these labour intensive, physically imposing ceremonial structures are seen by many as a tell–tale sign that communities are moving away from simple, egalitarian structures to more stratified,

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hierarchal social systems during this period (Duhamel and Midgley 2004; Midgley, 2005). At the same time, these monumental graves stood in stark contrast to their contemporary modest counterparts – cemeteries without superstructure, or the "flat" cemeteries (Thomas et al., 2011b). Based on burial arrangements and recovered ceramics, the monumental cemeteries are all considered part of the Cerny Culture, while the flat cemeteries can be further divided into three major groups under varying degrees of Cerny influence: major (Bostyn, et al. 2018; Chambon, et al. 2010), minor (Chambon, et al. 2006), and completely absent (Augereau and Chambon 2011; Constantin, et al. 1997; Rottier, et al. 2005). These contrasting cemetery architectures are further complicated by other differing but correlated burial traditions such as body positions (flexed vs. supine) (Chambon, et al. 2007) and compositions of grave goods (Thomas 2011). Thus, during the Middle Neolithic period, in a small area of about 100 km in radius around the Seine–Yonne confluence (Fig. 1), several types of stylistically distinctive cemeteries coexisted.

Focusing on the Cerny groups, this study examines the relationship between subsistence economy, burial rites, cultural affiliations, and social organization by reconstructing and comparing the palaeodietary and funerary patterns of eight Cerny sites with two "Non-Cerny" sites (cemeteries with no significant Cerny features) in the Paris Basin region. Using a multi–isotope approach, we present the stable carbon (C), nitrogen (N), and sulfur (S) isotopic compositions of a total of 113 humans and 90 animals from the area. In addition, published C, N, and S isotope measurements of a total of 140 humans and 177 animals from contemporaneous or near contemporaneous sites are included to provide additional insights into the regional isotopic variations (Balasse 1999; Bocherens, et al. 2005; Bocherens, et al. 2011; Drucker, et al. 2018; Naito, et al. 2013; Rey, et al. 2017; Rey, et al. 2019). The main objectives of this study are threefold: (1) to advance our current understanding of the subsistence economy of populations living in the Paris Basin region during the Middle Neolithic period, when funerary monumentalism began to emerge in western Europe, (2) to investigate whether there was any difference in dietary practices between the Cerny and non-Cerny groups, and (3) to explore connections between funerary monumentality and social differentiations (e.g. gender, social-economic status, etc.) among Cerny sites.

2. The Cerny culture

2.1. The Cerny way of death

The Cerny culture was a Middle Neolithic culture that flourished between 4700 and 4300 BCE in the Paris Basin region, also refer to as the Cerny territory *stricto sensu* (Constantin, et al. 1997). In the general absence of residential sites, most of our knowledge of the Cerny social organisation comes from its cemeteries (Thomas 2011). Although first identified and defined by its unique ceramic style (Bailloud 1964), today, the Cerny culture is possibly best known for building some of the first monumental cemeteries in Western Europe (Midgley, 2005; Wunderlich, et al. 2019). In the Paris Basin region, there are three major varieties of Cerny cemeteries: two monumental types and one without superstructure or "flat". A brief description of these cemetery types is provided below.

Cemeteries with Passy-type structures (Structures de Type Passy, or STP – Fig. 2A*)*: named after the eponymous cemeteries in Passy (Duhamel 1997), this type is possibly the most famous of all Cerny cemetery types. STP cemeteries are consisted of long barrows constructed out of timber and earth, where the total lengths of each structure can vary from 25 to 300 m (Duhamel and Mordant 1997). Only a few individuals were buried within each monument, and in some cemeteries, some individuals were buried outside. There appeared to be certain rules about social identities (most apparent categories are sex and age) and burial locations, where only certain individuals were allowed to be buried within, or even associated with the monuments (Chambon 1997; Thomas, et al. 2011a; 2011b). Most of the individuals were buried in the so-called Balloy-type graves, which is consisted of a coffin placed inside a vault, where the body is laid in an extended supine position (Chambon, et al. 2007; Chambon and Thevenet 2014). In this study, five sites, namely Balloy "Les Réaudins" (BLR), Vignely "La Noue Fenard" (VNF), Gron "Les Sabons" (GLS), Passy "La Sablonnière" (PLS), and Passy

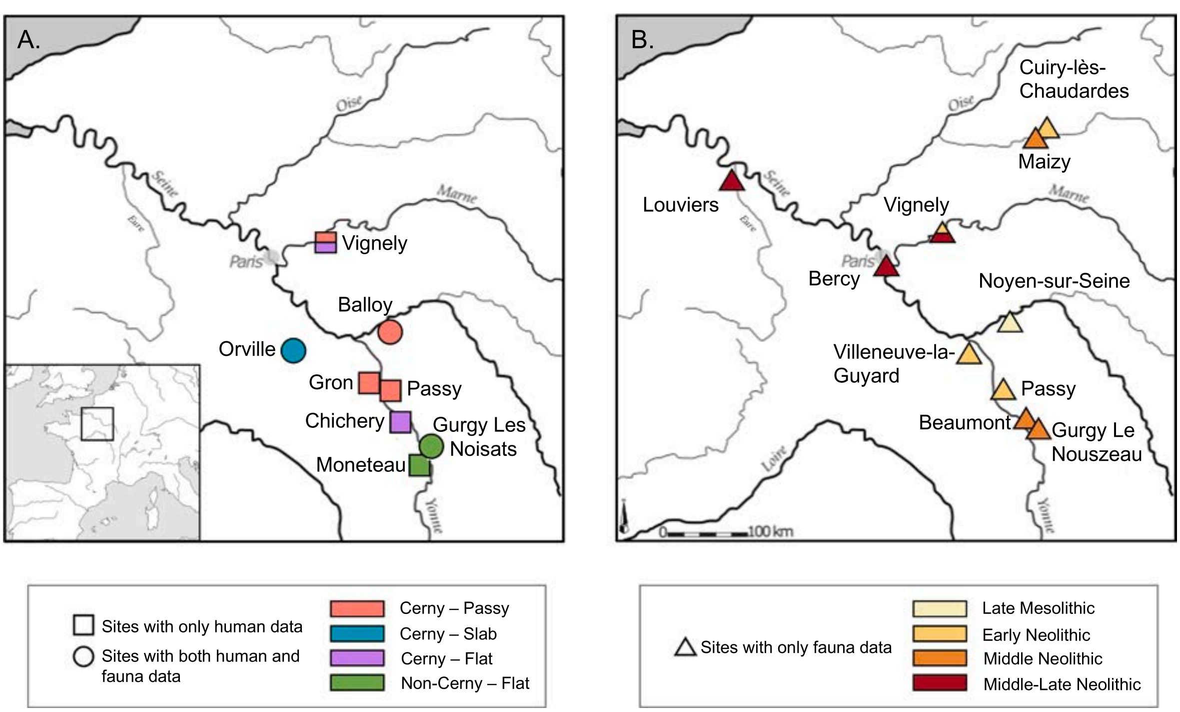

Fig. 1. Maps of the Paris Basin showing locations of all sites mentioned in this study, with reference to the modern city of Paris. A: ■ corresponds to sites with only human data; ● corresponds to sites with both human and faunal data. B: ▲ corresponds to sites with faunal data not directly associated with the humans analysed in this study.

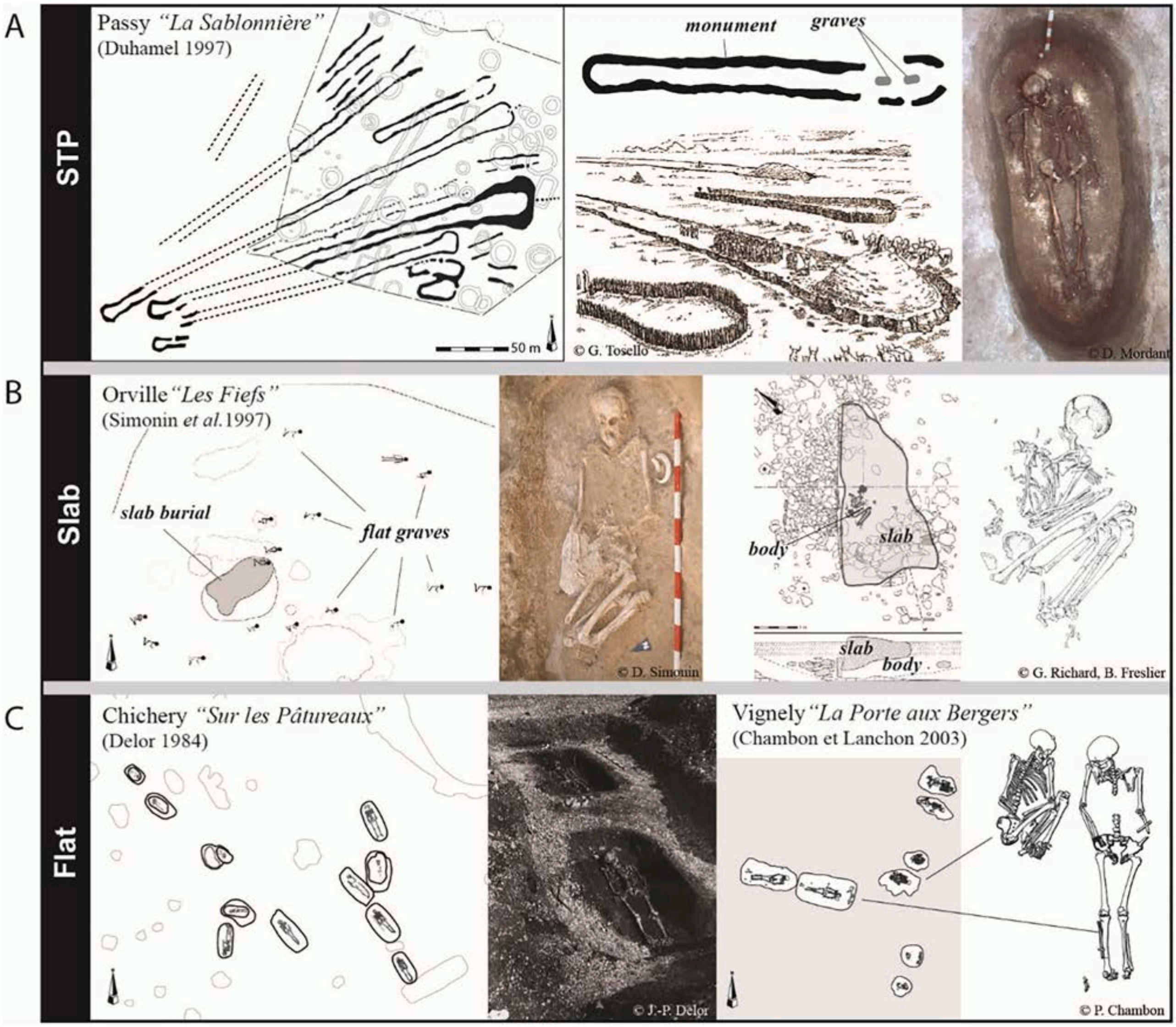

Fig. 2. The three major types of Cerny cemeteries in Paris Basin, monumental (STP, Slab) and flat, also showing the typical burial positions of the deceased seen in the three types of cemeteries, respectively.

"Richebourg" (PR), belong to this category. A total of 70 individuals from these five sites are analysed. A variation of STP cemeteries is the so called Rots-type cemeteries. These cemeteries have monuments similar to those of STP cemeteries, but are only found in Normandy, which is generally considered as the Cerny sphere *lato sensu* (Desloges 1997; Ghesquière, et al. 2019). As it is located outside of our concerned area, groups buried in this type of cemeteries are not addressed in this paper.

Cemeteries with "slab" burials, or the Malesherbes-type (Fig. 2B): "Slab" burials are burials marked by a megalith, which can be either a flat (slab) or standing stone (menhir). These types of burials are often found in the western part of the Paris Basin region, along the banks of the Essonne. In this study, we analysed a total of 20 individuals from Orville "Les Fiefs" (OLF), the biggest "Slab" cemetery found thus far. In OLF, the slab burial is the key grave surrounded by at least 21 flat burials (Simonin, et al. 1997). All but one individual from this site were buried in a flexed position, most of them on the left side.

Flat cemeteries (Fig. 2C): as suggested by the name, these types of cemeteries have no major superstructure. Most of the individuals were buried in an extended supine position inside a Balloy-type grave, only few were buried in flexed position on the side (Bostyn, et al. 2018; Chambon, et al. 2010). Two sites associated with this cemetery types are Vignely "La Porte aux Bergers" (VPB) and Chichery "Sur les Pâtureaux" (CLP). A total of 30 individuals from VPB are analysed. Isotopic measurements of eight individuals from CLP are obtained from a recently published report (Rey, et al. 2019). Note that even though both cemeteries are categorized as "Cerny flat", VPB is considered more closely related to STP cemeteries than CLP (Thomas, 2014b).

While most Cerny cemeteries in the Paris Basin region show connections with cultural spheres from north-eastern France, such as the Rössen Culture, within the same temporal and geographical framework, there are also cemeteries that bear components of other cultures, such as the Chasséen Culture from southern France. Two of such cemeteries included in this study are Gurgy "Les Noisats" (GLN) (Rottier, et al. 2005) and Monéteau "Macherin" (MON) (Augereau and Chambon 2011). GLN and MON are located in the Yonne river valley, about 10 km south of the Cerny flat cemetery of CLP (Fig. 1A). With more than 180 burials in total, most of the burials from these two sites carried no clear Cerny components, and were buried in a flexed position, mainly on the left side. Other than burial positions, individuals from GLN and MON were buried in several grave types that are distinct from the typical Balloy-type seen in most Cerny cemeteries (Chambon, et al. 2013). Interestingly, three individuals in MON (#02–685; #04–89; #04–99) show evidence of affiliation with the Cerny culture, where they were buried in a Balloy-type grave (Chambon, et al. 2006). For the purpose of this study, these two cemeteries are categorized as "non-Cerny". A total of 132 C, N, and S isotope measurements from GLN and MON are obtained from two recently published reports (Rey, et al. 2017; Rey, et al. 2019).

2.2. The Cerny way of life

Unfortunately, so far, residential sites from the Cerny contexts remain few and far in between (Bostyn, et al. 2016; Last 2013; Mordant, D, and D Simonin, 1997). As a result, relatively little is known about the details of their lifeways. Based on limited archaeological evidence and research on related neighbouring sites, it is generally agreed that the Cerny subsistence economy was based primarily on agriculture (agronomy and animal husbandry), supplemented by some limited hunting activities. In terms of staple crops, the Cerny people grew both hulled (emmer wheat: *Triticum dicoccum* and einkorn wheat: *Triticum monococcum*) and naked (likely bread wheat: *Triticum aestivum*) varieties of wheats (Bakels 1999; Bakels 2009). Other crops exploited include barley (*Hordeum vulgare*), pea (*Pisum sativum)*, and poppy (*Papaver somniferum*) (Bakels 2009). Zooarchaeological assemblages are composed predominantly of domestic animals, with cattle being the most numerous, followed by pigs and sheep/goats (Bostyn, et al. 2016; Colas, et al. 2018; Hachem 2010; Hachem 2011; Sidéra 2000; Tresset 1997). Thus far there is no direct evidence for dairying from the Cerny contexts. However, evidence of dairying was found at a nearby Middle Neolithic site Bercy, (Balasse, et al. 2012). Therefore, it is possible that the Cerny groups exploited cattle and sheep/goat for both their meat and dairy products. Other than domestic animals, wild animals such as red deer, wild boars, and aurochs were also consumed – albeit to a much lesser extent (Bostyn, et al. 2016; Tresset 1997). Furthermore, despite the lack of fish bones in the Cerny zooarchaeological assemblages, based on the proximity of Cerny sites to the rivers, the occasional discovery of fishing related artefacts such as hooks in these sites (Bostyn, et al. 2018:276), as well as the continuous practice of fishing throughout earlier and later periods in the region (Augereau and Chambon 2011; Clavel and Arbogast 2005; Dauphin 1989; Drucker, et al. 2018; Naito, et al. 2013), it is safe to assume freshwater resources were utilized to a certain extent.

3. Methods and materials

3.1. Principles of stable isotope analysis

Stable isotope analysis is a well–established methodology for reconstructing past lifeways, allowing archaeologists to address different archaeological questions, including but not limited to topics such as lifestyles, food technology, socio–economic organizations, trading networks, and many more (Katzenberg 2008; Makarewicz and Sealy 2015; Schwarcz and Schoeninger 2012). Traditionally, the most common isotope systems used by archaeologists are those of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$), but recently the suite has grown to include more elements, such as oxygen ($^{18}O/^{16}O$), sulfur ($^{34}S/^{32}S$), and strontium ($^{87}Sr/^{86}Sr$), allowing archaeologists to draw from a wider range of assessments, thus improving the resolution of the analysis. Among these elements, the isotopic analyses of C, N, and S isotopes reveal primarily diet–related information, while those of O and Sr often relayed information regarding to seasonality and/ or mobility. As this study mostly concerns the palaeodietary practices of the Cerny people, the stable isotopes of C, N, and S are analysed.

Stable carbon isotope analysis (expressed as $\delta^{13}C$) is primarily used to identify the consumption of food groups with distinctive $\delta^{13}C$ values, most commonly between C_3 plants, C_4 plants, the marine system, and the terrestrial system (Boutton 1991; Chisholm, et al. 1982; van der Merwe 1982). As both native and cultivated flora of continental Europe during this period are predominately C_3 (Ehleringer and Cerling 2002; Motuzaite-Matuzeviciute, et al. 2013), and our study area is at least 200 km away from the closest coastline, the diets of those involved in this study are likely predominantly based on C_3 terrestrial resources. Thus, $\delta^{13}C$ values will be mainly used to identify individuals with unusual dietary components that have carbon isotope signatures deviate from those of the typical food source groups. In this area these refer to sources such as freshwater resources or wild games. Stable nitrogen isotope analysis (expressed as $\delta^{15}N$) is typically used to infer trophic positions of consumers within a biological system (Hedges and Reynard 2007; O'Connell et al., 2012). In this study, $\delta^{15}N$ values will be primarily used to evaluate animal protein intake among different social groups. Comparing to the stable isotopes of carbon and nitrogen, the stable isotopes of sulfur (expressed as $\delta^{34}S$) are more tied to the geology, and can vary greatly from area to area, especially in freshwater systems (Nehlich 2015). With adequate baseline information, $\delta^{34}S$ values can help to detect the consumption of freshwater resources (Drucker, et al. 2018; Nehlich, et al. 2010; Privat, et al. 2007), as well as mobility (Cheung, et al. 2017a; Richards, et al. 2001) among past populations. In this study, $\delta^{34}S$ values will be used alongside $\delta^{13}C$ and $\delta^{15}N$ values to help elucidate the dietary practices of these Cerny groups.

3.2. Methods and instrumentation

All bone samples were prepared at the Preparation Laboratory at UMR 7269 LAMPEA, Aix-en-Provence (France), and the extracted collagen were analysed at Iso-Analytical Limited (U.K.). Bone collagen was extracted following a modified ABA procedure combining the methodologies outlined in Brock et al. (2010) and Szpak et al. (2017a): bone samples were demineralized in 0.5 M HCl solution at 4°C in chunks (solution changed ever 2–3 days, until bones were fully demineralized); demineralized bones were then placed in 0.125 M NaOH at room temperature for successive 30–minute sessions (until solution stopped changing colour); followed by a 0.5 M HCl treatment at room temperature for 1 h. Samples were thoroughly rinsed with deionized water in between each change of solution. The samples were then gelatinized in a pH3 solution (10^{-3}M HCl) at 75°C for 48 h. The resultant soluble collagen was filtered with Ezee filters™ and subsequently lyophilized.

At Iso-Analytical, samples were analysed with a Europa Scientific™ elemental analyzer, coupled to a mass spectrometer. One in every five samples were measured in duplicates. Precision of measurements were further monitored using an in–house lab standard that has been extracted alongside the archaeological bone samples (CC_REF – cattle femur). Carbon and nitrogen isotope values are reported in "per mil (‰)" and calibrated to VPDB and AIR, respectively, using IA–R068. IA–R038, IA–R069, and a mixture of IA–R046 and IAEA–C7 were used as control check standards. IA–R068, IA–R038, and IA–R069 were calibrated and traceable to the international standards IAEA–CH–6 and IAEA–N–1. IA–R046 was calibrated against and traceable to the international standards IAEA–N–1 and IAEA–C7.

For sulfur isotope analysis, all measurements are reported in "per mil (‰)". Results were calibrated to VCDT using IA–R061. IAEA–SO–5, IA–R068, and IA–R069 were used as control check standards. IA–R061 was calibrated against and traceable to the international standards NBS–127 and IAEA–S–1. IA–R068 and IA–R068 were calibrated against and traceable to the international standards NBS–127 and IAEA–SO–5.

Based the formulae provided in Szpak, et al. (2017b)'s paper, the precisions ($u(R_w)$) of the measurements are determined to be $\pm$ 0.07‰, $\pm$ 0.10‰, and $\pm$ 0.24‰, for $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$, respectively, on the basis of repeated measurements of calibration standards, check standards, in-house lab standard, and sample replicates. Accuracy or systematic errors ($u(bias)$) are determined to be $\pm$ 0.14 for $\delta^{13}C$, and $\pm$ 0.15 for $\delta^{15}N$, and $\pm$ 0.33 for $\delta^{34}S$, on the basis of the difference between the observed and known δ values of the check standards and the long–term standard deviations of these check standards. The total analytical uncertainties are estimated to be $\pm$ 0.16 for $\delta^{13}C$, $\pm$ 0.18 for $\delta^{15}N$, and $\pm$ 0.41 for $\delta^{34}S$. The formulae sheet with details of all measured standards are provided in supplement S1.

The quality of collagen was assessed using the conventional criteria: %collagen between 0.5% and 22% by weight, %C between 15.3% and 47%, %N between 5.5% and 17.3%, %S between 13% and 35%, atomic C/N ratio between 2.9 and 3.6, atomic C/S ratio between 300 and 900, and atomic N/S ratio between 100 and 300 (Ambrose 1990; Bocherens, et al. 2011; DeNiro 1985; Harbeck and Grupe 2009; Nehlich and Richards 2009; van Klinken 1999). Only samples with elemental compositions within these ranges are accepted for analysis.

3.3. Materials

This study examines the bone collagen C, N, and S isotope compositions of humans from 10 Middle Neolithic sites, as well as fauna from 13 contemporaneous or roughly contemporaneous sites in Paris Basin. Skeletal remains from a total of 119 humans and 104 faunas were analysed. An additional 140 humans and 177 faunas from published reports are included for comparison. Not all reports published their data along with collagen quality indicators, for those that do, only data from samples with well-preserved collagen (see previous section for detailed criteria) are included.

All humans have been osteologically analysed, detailed results were described in Thomas' (2011:83-103) report, and general information of each analysed individual is provided in supplement S2. Age-at-death was determined by established methods (Moorrees et al., 1963; Scheuer and Black 2000; Schmitt 2005). Sex identification was conducted using the morphology and morphometry of the mature *ossa coxae* (Bruzek 2002; Murail, et al. 2005).

Table 1 summarizes the principal data of each site where human samples were obtained, listing the major archaeological cultural affiliations, types of cemetery, major burial arrangements, and references for published data.

As all the human samples come from cemeteries, faunal samples directly associated with the humans are not found at all sites. Thus, when directly associated faunal samples are not available, faunal samples from roughly contemporaneous period in the area are used to establish the regional isotopic baseline. Despite not examining any human data from the northern part of the Paris Basin, faunal samples from the Aisne valley: Maizy "Les Grands Aisements" (Le Bolloch, et al. 1986) and Cuiry-lès-Chaudardes "Les Fontinettes"(Ilett and Hachem 2001), and Eure valley: Louviers "La Villette" are included to provide a clearer picture of the overall isotopic variability within the region. Table 2 provides the principal data of each site where faunal samples were obtained, listing the major archaeological cultural affiliations, periods, and references for published data.

3.4. Statistical methods

All statistical tests were performed using R version 3.6.0 (R Core Team 2019) with RStudio (RStudio Team 2018). Data were visualized using the package 'ggplot2' (Wickham 2016) and 'ggpubr' (Kassambara 2020). Distribution normality was tested using a Shapiro-Wilk test. Variance equality was tested using the Levene's test. For groups with normally distributed data and/or sufficient sample size (*n* greater than 15), the parametric tests, unpaired independent Student's *t* tests and one-way ANOVA, were used to determine differences between group means for δ^{13}C, δ^{15}N, and δ^{34}S values. For groups where data are not normally distributed and/or have small sample size ($n < 15$), the non-parametric Wilcoxon and Kruskal-Wallis tests were used. For ANOVA, when differences are detected, post-hoc comparisons were conducted using the Tukey honest significant difference (HSD) tests. For Kruskal-Wallis, when differences are detected, post-hoc comparisons were conducted using the Dunn's test using the package 'dunn.test' (Dinno 2017). A 0.05 probability ($p < 0.05$) is considered significant.

Bivariate standard ellipses were created using the package 'SIBER' (Jackson, et al. 2011), with *p* value set at 66% (for visualization purpose). Variability of different groups were quantified using the following area metrics: convex hull areas (TA), standard ellipse areas (SEA), standard ellipse areas corrected (SEA_C), and standard ellipse areas with Bayesian estimate (SEA_B) (Jackson, et al. 2011). 3-dimensional graphics were created using the packages 'Rcmdr' (Fox, et al. 2015) and 'Rgl' (Adler, et al. 2015). Ellipsoids representing the point concentration of each group has the expected proportion (α) of multivariate-normal observations set as 0.5. Example scripts for the statistical analyses and graphical visualisations of the results are provided in supplement S3.

3.5. Adjustment for regional pattern in isotopic baselines

The sites in this study are scattered across six different river valleys. In order to ensure differences in the isotopic compositions of the humans were due to actual differences in dietary practices but not geographical factors, faunal isotopic data are used to establish the local isotopic baseline of each valley. If a regional pattern in an isotopic system is observed, the following equation is used to estimate the weighted overall shift in the baseline value of the valley relative to the whole region:

Table 1
Summary of sites where human samples were obtained. N refers to total number of individuals analysed.

River Valley	Site Code	Site	Culture	Cemetery type	Cemetery category	Body position and grave type	N	Reference for isotopes
Essonne Valley	OLF	Orville "Les Fiefs"	Cerny	Monumental	Slab	Predominately flexed bodies	18	This study
Seine Valley	BLR	Balloy "Les Réaudins"	Cerny	Monumental	STP	Supine bodies in Balloy type graves	36	
Marne Valley	VNF	Vignely "La Noue Fenard"	Cerny	Monumental	STP	Supine bodies in Balloy type graves	4	
	VPB	Vignely "La Porte aux Bergers"	Cerny	Flat	STP Associated	Predominately supine bodies in Balloy type graves	29	
Yonne Valley	GLS	Gron "Les Sablons"	Cerny	Monumental	STP	Supine bodies in Balloy type graves	5	
	PLS	Passy "La Sablonnière"	Cerny	Monumental	STP	Predominately supine bodies in Balloy type graves	10	
	PR	Passy "Richebourg"	Cerny	Monumental	STP	Predominately supine bodies in Balloy type graves	11	
	CLP	Chichery "Sur Les Pâtureaux"	Cerny	Flat		Predominately supine bodies in Balloy type graves	8	(Rey, et al. 2019)
	MON	Monéteau "Macherin"	Non-Cerny (Chasséen + some Cerny component)	Flat		Predominately flexed bodies	45	
	GLN	Gurgy "Les Noisats"	Non-Cerny	Flat		Flexed bodies	87	(Rey, et al. 2017; Rey, et al. 2019)

Table 2
Summary of sites where faunal samples were obtained. N refers to total number of individuals analysed. For archaeological cultures, RFBS stands for Rubané final du bassin de la Seine, BVSG stands for Blicquy/Villeneuve-Saint-Germain. For periods, Late Mesolithic period corresponds to c. 7000–5000 BCE; Early Neolithic corresponds to c. 5000–4700 BCE; and Middle Neolithic corresponds to c. 4700–3500 BCE.

River Valley	Site code	Site	Culture	Period	N=	Reference
Aisne Valley	CCF	Cuiry-lès-Chaudardes "Les Fontinettes"	RFBS	Early Neolithic	24	(Balasse 1999)
	MGA	Maizy "Les Grands Aisements"	Michelsberg	Middle Neolithic	14	
Eure Valley		Louviers "La Villette"	Chasséen	Middle Neolithic	34	(Bocherens, et al. 2005)
Essonne Valley	OLF	Orville "Les Fiefs"	Cerny	Middle Neolithic	9	This study
Marne Valley	VNF	Vignely "La Noue Fenard"	Michelsberg	Middle Neolithic	5	
	VPB	Vignely "La Porte aux Bergers"	RFBS-BVSG	Early Neolithic	26	
Seine Valley	BLR	Balloy Les Réaudins"	Cerny	Middle Neolithic	24	
		Paris Bercy	Chasséen	Middle Neolithic	9	(Balasse, et al. 1997)
		Noyen-sur-Seine "Hauts des Nachères"		Late Mesolithic	36	(Bocherens, et al. 2011; Drucker, et al. 2018; Naito, et al. 2013)
Yonne Valley	VLG	Villeneuve-la-Guyard		Early Neolithic	7	This study
	PAS	Passy "La Sablonnière"	BVSG	Early Neolithic	20	
	GLN	Gurgy "Les Noisats"		Early/Middle Neolithic	18	(Rey, et al. 2017; Rey, et al. 2019)
	NZ	Gurgy "Le Nouzeau"	Cerny	Middle Neolithic	5	(Rey, et al. 2019)
	BMT	Beaumont "Le Crôt aux Moines"	Chasséen	Middle Neolithic	37	

$$baseline\_shift = \sum_{i=1}^{y}\left((\mu_{site\_i} - \mu_{overall\_i})\left(\frac{n_i}{N}\right)\right) \quad (1)$$

where y is the number of taxa involved, i refers to each individual taxon, μ is the mean isotopic value of a particular taxon (site of interest or overall), n is the number of samples of each taxon from the site of interest, and N is the total number of samples from the site of interest.

Equation (1) is designed so that only selected taxa are considered, and that likes are compared with likes. Archaeologists are encouraged to select taxa most commonly consumed at site/region based on other archaeological evidence. The shift is weighted by the proportion of each taxon among the total assemblage, hence taxa with higher sample numbers (i.e. with better represented means) will contribute heavier towards the offset calculation. The resulting offset (‰) can then be applied to address the shift in human isotopic compositions caused by geographical differences in isotopic baseline values. This adjustment only shifts the isotope data of the concern site(s) along the x- and/or y-axis(axes) to allow better inter-site comparisons. However, it does not change the relative variability of the data. Therefore, the internal spatial patterns of the biplot remain unaltered for intra-site analyses.

4. Results

The summary statistics of all humans and faunas are provided in Table 3. The detailed contextual information and elemental compositions of all analysed specimens are provided in supplement S2.

4.1. Faunal data

Out of the 104 faunal samples analysed, 90 samples have produced well preserved collagen for isotopic analysis. Including the 177 additional previously published fauna data from neighbouring sites, the δ^{13}C and δ^{15}N values for all faunas range from –26.7‰ to –19.0‰ and + 3.3‰ to + 13.8‰, respectively (n = 267). The δ^{34}S values of all faunas range from –19.0‰ to + 15.1‰ (n = 86). As a vast majority of the faunal samples are not directly associated with the human analysed, the faunal isotopic values will only be used to establish regional isotopic baselines, and will not be used to evaluate husbandry practices at these sites.

The δ^{13}C and δ^{15}N baselines of the six river valleys are examined based on the four most common faunal species found in the region: cattle (n = 70), deer (n = 64), pig (n = 46), and sheep/goat (n = 37). Kruskal-Wallis tests reveal that differences in δ^{15}N values among the six valleys are statistically significant in all four species (cattle: $p = 0.0031$; pig: $p = 0.039$; sheep/goat: $p = 0.047$; deer: $p = 0.021$), while differences in δ^{13}C values are only significant in sheep/goat ($p = 0.015$). Post-hoc Dunn-tests confirm that faunas from the Marne valley have higher mean δ^{15}N value than those from other valleys (Fig. 3). The strongest difference is observed between the δ^{15}N values of cattle from the Marne and the Yonne valleys ($\Delta_{mean} = 0.9‰$, $p = 0.0007$), and the biggest difference is observed between the δ^{15}N values of deer from the Marne and the Seine valleys ($\Delta_{mean} = 2.1‰$, $p = 0.0079$). In terms of δ^{13}C values, sheep/goat from the Seine valley have relatively negative δ^{13}C values compare to all other valleys (Δ_{means}: 0.7 – 1.3‰; $p < 0.01$).

In general, the differences in δ^{13}C values among the six valleys are relatively small. Thus, for the purpose of this study, we will consider the regional differences in δ^{13}C baseline negligible. For δ^{15}N values, fauna from the Marne valley consistently produce the highest mean values (except for sheep/goat), therefore it is possible that the δ^{15}N baseline in Marne valley is higher than the other valleys in the region. Equation (1) is used to calculate the difference in the basal δ^{15}N values between Marne Valley and the general region. The four most abundant species: cattle, pig, sheep/goat, and deer are used (see supplement S4 for a detailed breakdown of the calculations). Note that despite the small sample size, the faunal samples from the Marne valley come from two different sites, one pre-dating and one post-dating the Cerny period, thus we believe the isotopic ranges shown in these faunas should adequately encapsulate the baseline of the region.

According to Equation (1), the δ^{15}N baseline of the Marne Valley is about 1.0‰ higher than that of the general Paris Basin region. This adjustment will be applied to all of the humans from the Marne Valley (VPB and VNF) for subsequent analysis, unless noted otherwise.

Stable sulfur isotope data are only available from four river valleys: Essonne, Marne, Seine, and Yonne. Based on the δ^{34}S values of all terrestrial animals, some regional patterns in δ^{34}S values can be observed among the four different valleys (Fig. 4A). The strongest differences are observed between Seine and Essonne (Δ_{mean}: 5.1‰; $p = 0.0012$), and Seine and Marne (Δ_{mean}: 3.5‰; $p = 0.0013$) valleys. The terrestrial faunal δ^{34}S baseline at the Yonne valley is particularly variable, ranging from –10.0‰ to + 15.1‰. Interestingly, both are pigs from Beaumont (Rey, et al. 2019). Apart from the Essonne valley, where the sample size is too small for meaningful statistical analysis, the domesticates from all three valleys have statistically significant differences in their mean δ^{34}S values comparing to the wild animals (Fig. 4B: Δ_{mean_Marne}: 2.6‰; Δ_{mean_Seine}: 5.0‰; Δ_{mean_Yonne}: 4.7‰). S isotope measurements from freshwater resources are only available from the Seine valley. Fig. 4B shows that at the Seine valley, the mean δ^{34}S value

Table 3
Summary statistics of all human and faunal data discussed in this study, including both original and published data. N refers to the total number of accepted data. The human data from the two Marne sites has not been adjusted for the baseline shift. A key for the site codes is provided in Table 1.

Valley	Site	$\delta^{13}C$						$\delta^{15}N$						$\delta^{34}S$					
	Human	Min	Max	Mean	Median	SD	N=	Min	Max	Mean	Median	SD	N=	Min	Max	Mean	Median	SD	N=
Essonne	OLF	−21.2	−20.3	−20.7	−20.7	0.3	18	+9.7	+12.9	+10.4	+10.2	0.7	18	+6.4	+10.1	+8.3	+8.4	1.0	15
Marne	VNF	−21.2	−20.9	−21.0	−21.0	0.1	4	+11.6	+13.0	+12.0	+11.7	0.6	4	+6.1	+8.1	+7.3	+7.5	0.9	4
	VPB	−22.7	−20.8	−21.2	−21.0	0.5	29	+11.1	+15.5	+12.5	+12.2	1.0	29	+5.4	+9.6	+7.6	+7.8	1.2	20
Seine	BLR	−21.5	−20.4	−21.0	−20.9	0.3	36	+9.5	+14.7	+11.2	+11.0	1.1	36	−1.1	+9.7	+5.8	+5.9	2.6	22
Yonne	CLP	−20.9	−20.2	−20.6	−20.7	0.3	8	+10.5	+11.6	+10.9	+10.9	0.4	8	+2.3	+6.3	+4.5	+4.8	1.5	6
	GLN	−21.3	−20.3	−20.7	−20.7	0.2	87	+9.9	+13.4	+11.7	+11.6	0.5	87	+0.2	+6.3	+3.3	+3.4	1.4	27
	GLS	−21.1	−21.0	−21.0	−21.0	0.1	5	+11.3	+11.5	+11.4	+11.4	0.1	5	+7.1	+9.6	+8.4	+8.4	0.9	5
	MON	−21.2	−19.8	−20.6	−20.7	0.3	45	+8.7	+12.1	+10.8	+11.0	0.8	45	+1.6	+10.0	+5.2	+4.9	2.3	17
	PLS	−21.6	−20.7	−21.2	−21.2	0.3	10	+10.2	+14.9	+11.6	+11.4	1.2	10	+4.7	+8.9	+7.4	+7.8	1.4	8
	PR	−21.2	−20.8	−21.0	−21.0	0.1	11	+9.7	+14.4	+11.6	+11.5	1.4	11	+7.5	+10.3	+8.7	+8.7	0.9	9
Total		**−22.7**	**−19.8**	**−20.8**	**−20.8**	**0.3**	**253**	**+8.7**	**+14.9**	**+11.3**	**+11.3**	**0.9**	**253**	**−1.1**	**+10.3**	**+6.1**	**+6.4**	**2.5**	**133**
	Fauna																		
Aisne		−24.5	−20.2	−22.9	−23.0	1.0	38	+5.1	+9.2	+6.7	+6.8	1.0	38	—	—	—	—	—	—
Eure		−24.6	−20.3	−22.0	−22.1	1.0	34	+4.6	+10.8	+7.2	+7.0	1.4	34	—	—	—	—	—	—
Essonne		−22.7	−19.1	−20.3	−19.6	1.5	9	+5.0	+10.9	+8.2	+9.0	2.2	9	+7.2	+11.1	+9.7	+10.1	1.5	5
Marne		−23.8	−19.0	−21.6	−21.9	1.2	31	+4.9	+13.8	+8.3	+7.8	1.9	31	+2.0	+11.8	+8.2	+8.4	2.4	16
Seine		−26.7	−19.1	−22.5	−22.7	1.6	68	+3.4	+12.4	+7.2	+6.8	2.0	68	−19.0	+10.1	+2.3	+4.4	7.0	31
Yonne		−23.7	−19.3	−21.7	−21.6	1.3	87	+3.3	+11.0	+6.9	+6.8	1.3	87	−10.0	+15.1	+5.8	+6.8	5.6	34
Total		**−26.7**	**−19.0**	**−22.1**	**−22.3**	**1.4**	**267**	**+3.3**	**+13.8**	**+7.2**	**+6.9**	**1.6**	**267**	**−19.0**	**+15.1**	**+5.2**	**+6.4**	**+6.0**	**86**

of the freshwater resources are significantly negative comparing to the terrestrial fauna.

4.2. *Human data*

A total of 119 human samples are analysed, of which 113 have yielded well preserved collagen for isotopic analysis. Including the 140 published human data from related sites, all humans have δ^{13}C values ranging from −22.7 to −19.8‰, δ^{15}N values range from + 8.7‰ to + 15.5‰ (n = 253), and δ^{34}S values range from −1.1‰ to + 10.3‰ (n = 132). In total, 66 individuals come from Cerny STP contexts, 18 individuals come from Cerny Slab context, 37 individuals come from Cerny Flat contexts, and 132 individuals come from non-Cerny contexts. The δ^{13}C and δ^{15}N values of all human and faunal data are plotted in Fig. 5. Note that in this figure, the human data from the Marne valley have not been adjusted for the baseline shift.

Individuals under the age of 4 have relatively elevated δ^{15}N values (+12.5 ± 1.4‰) comparing to those above the age of 4 (+11.3 ± 0.8‰). This is likely due to the breastfeeding effect in very young children (Dupras, et al. 2001; Fuller, et al. 2006; Herrscher, et al. 2017). In order to focus our analysis on social organisations, all individuals under the age of 4 (n = 35) are excluded in subsequent analyses.

4.2.1. *Inter-site comparisons*

Hereinafter, all human data from the Marne Valley has been adjusted for the baseline shift in δ^{15}N values. Comparing to those from non-Cerny contexts, ANOVA tests reveal that the humans from the Cerny contexts have slightly lower mean δ^{13}C and δ^{15}N values (Δ_{mean} _δ^{13}C = 0.2‰, p < 0.001; Δ_{mean} _δ^{15}N = 0.4‰, p < 0.001) (Fig. 6A), and a higher mean δ^{34}S value (Δ_{mean} _δ^{34}S = 3.4‰; p < 0.001) (Fig. 6B).

The sites are further divided into four groups based on the cemetery types: Cerny STP, Cerny Slab, Cerny Flat, and non-Cerny (Fig. 6A). One-way ANOVA tests reveal statistically significant differences between the means of all three measurements (δ^{13}C, δ^{15}N, and δ^{34}S) (δ^{13}C: $p < 0.001$; δ^{15}N: $p < 0.001$; δ^{34}S: $p < 0.001$). In terms of δ^{13}C values, the strongest difference is observed between non-Cerny and Cerny STP groups (Δ_{mean} = 0.3‰, $p < 0.001$). For δ^{15}N values, the strongest difference is observed between non-Cerny and Cerny Slab groups (Δ_{mean} = 1.1‰, $p < 0.001$). For δ^{34}S values, the strongest difference is observed between non-Cerny and Cerny Slab groups (Δ_{mean} = 4.3‰, $p < 0.001$). Overall, the non-Cerny group stands out the most, not only in terms of its mean δ^{13}C, δ^{15}N, and δ^{34}S values, but also in terms of its range and overall variability in isotopic compositions (Table 4).

Despite having the highest number of sites (n = 5), and distributed over three river valleys (Seine, Marne, and Yonne), Cerny STP is relatively homogenous in terms of isotopic compositions (ANOVA; δ^{13}C: p = 0.018; δ^{15}N: p = 0.352; δ^{34}S: p = 0.090) (Fig. 7). Individuals from PLS have a slight but significantly lower mean δ^{13}C value than those from BLR (ANOVA: Δ_{mean} = 0.3‰, p = 0.006) (Fig. 7A).

Among the Cerny Flat group (VPB and CLP), the two sites show significant disparity in the means of δ^{13}C and δ^{34}S values (t-tests; δ^{13}C: p = 0.003; δ^{15}N: p = 0.127; δ^{34}S: p = 0.002). Individuals from VPB have lower mean δ^{13}C (Δ_{mean} = 0.4‰) and higher mean δ^{34}S (Δ_{mean} = 3.2‰) values than those from CLP (Fig. 7B). Generally speaking, VPB is more isotopically similar to other Cerny sites than CLP, while CLP shares more affinity with the non-Cerny group in all C, N, and S isotope values.

Among the non-Cerny group (GLN and MON), despite being located in close proximity to each other (<3km), there are strong differences in the means of δ^{15}N and δ^{34}S values between the two sites (t-tests; δ^{13}C: p = 0.097; δ^{15}N: $p < 0.001$; δ^{34}S: p = 0.001). Individuals from GLN have higher mean δ^{15}N (Δ_{mean} = 0.9‰) and lower mean δ^{34}S (Δ_{mean} = 2.2‰) values than those from MON (Fig. 7C).

Results show that all δ^{13}C, δ^{15}N, and δ^{34}S values in humans are significantly different among the two types of Cerny monumental necropolises, Cerny STP and Cerny Slab (Fig. 8). Comparing to those buried in Cerny STP cemeteries (i.e. BLR, VNF, PR, PLS, GLS), those

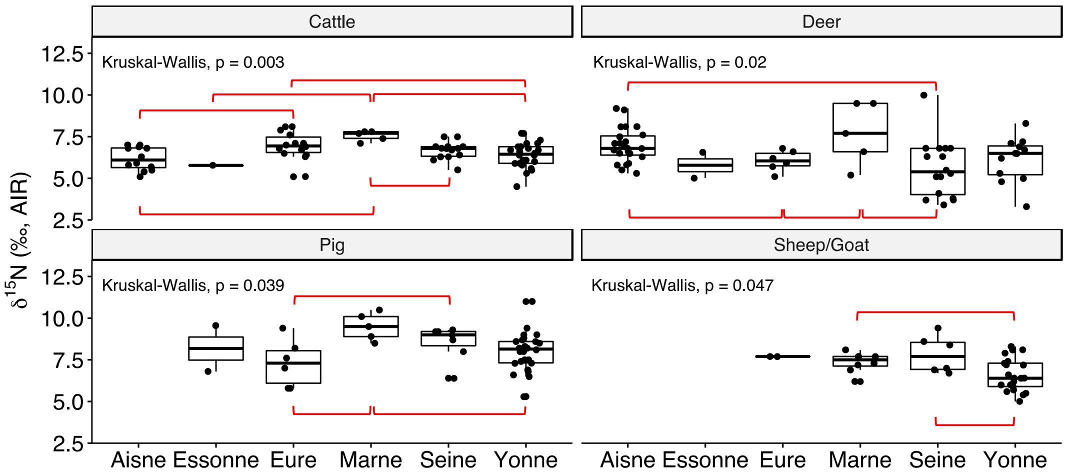

Fig. 3. A comparison of the $\delta^{15}N$ values of the four most common species of animals found in the area: cattle, deer, pig, and sheep/goat. Red brackets indicate pairings with statistically significant differences as determined by post-hoc Dunn tests. Data included both original and published data. For references of published data please refer to Table 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

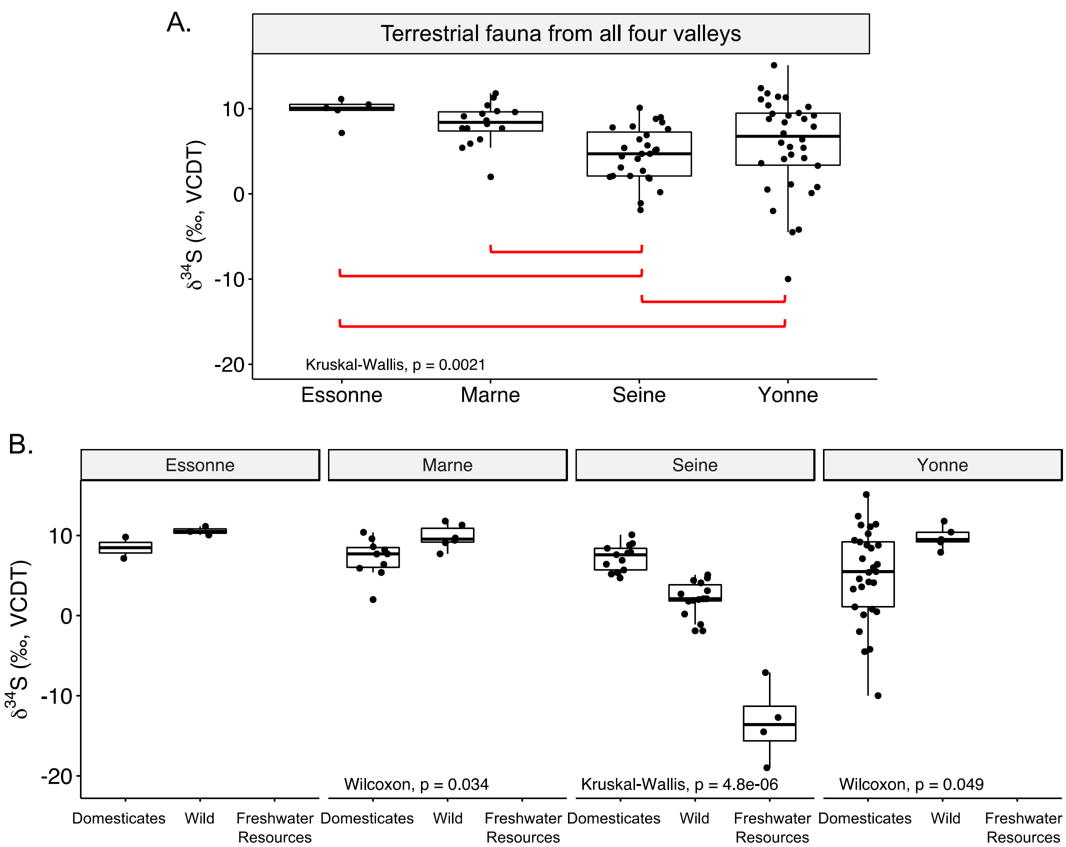

Fig. 4. $\delta^{34}S$ values from fauna from the Paris Basin region. A. boxplot comparing the $\delta^{34}S$ values of all terrestrial fauna. Red brackets indicate pairings with statistically significant differences as determined by post-hoc Dunn tests. B. boxplot comparing the $\delta^{34}S$ values of all domesticated vs. wild fauna from four river valleys, and freshwater resources from the Seine valley. Data included both original and published data. For references of published data please refer to Table 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

buried in Cerny Slab (i.e. OLF) have significantly elevated mean $\delta^{13}C$ (*t*-test: $\Delta_{mean} = 0.3‰$, $p < 0.001$) and $\delta^{34}S$ values (*t*-test: $\Delta_{mean} = 0.9‰$, $p = 0.049$), and relatively depleted mean $\delta^{15}N$ value (*t*-test: $\Delta_{mean} = 0.7‰$, $p < 0.001$).

4.2.2. Intra-site comparisons

4.2.2.1. Location of burials. A total of six monumental cemeteries (STP or Slab) are involved in this study. For four of these cemeteries (BLR, OLF, PR, and VNF), some burials are located outside of the monumental structures. We compare the C, N, and S isotope compositions among individuals being buried within and outside of the monumental structures from these four sites, respectively (Fig. 9). There is statistically significant difference in the mean $\delta^{13}C$ values between those buried within and outside of monumental structures in BLR (Wilcoxon; $p = 0.02$), as well as in $\delta^{15}N$ values in PR (Wilcoxon; $p = 0.05$). No difference

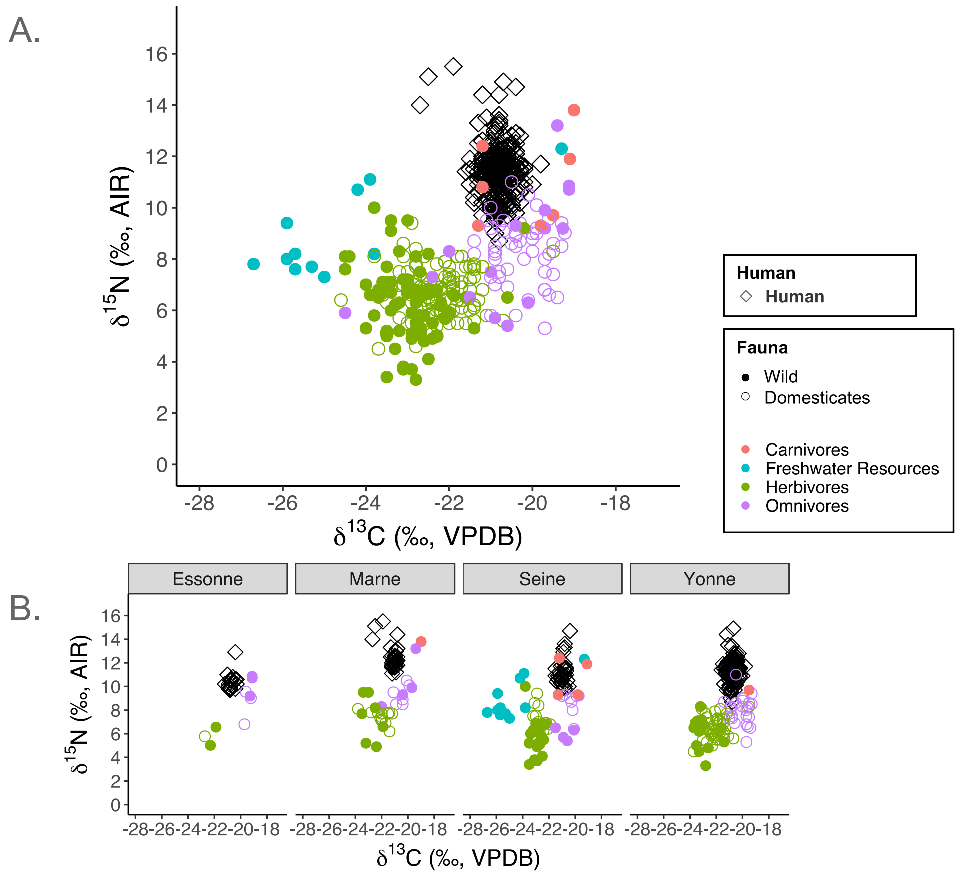

Fig. 5. Overall human and fauna (baseline shift for the Marne Valley not applied). Data included both original and published data. For references of published data please refer to Table 1 (for human data) and Table 2 (for faunal data). VNF and VPB data are not adjusted for the baseline shift in δ^{15}N values.

can be observed in the mean δ^{34}S values between the two groups at all four sites.

4.2.2.2. Burial positions. No difference can be observed in the mean δ^{13}C and δ^{34}S values between the two types of burial positions (supine vs. flexed) at all six sites. However, in PR, those buried in a flexed position have statistically lower mean δ^{15}N values than those buried in a supine position (Wilcoxon; $\Delta_{mean} = 1.2‰$, $p = 0.048$) (Fig. 10). Note that the individual buried in supine position in MON is the individual buried in a Balloy-type grave (#04–99).

4.2.2.3. Burial goods. Following the discussions on the symbolic meanings of Neolithic grave goods in Europe (Augereau and Chambon 2003; Salanova 1998), individuals are categorized into four groups according to the quantity and quality of (non-perishable) burial goods (Thomas 2011:577-579; Thomas and Chambon 2018). Only Cerny sites are considered for this analysis. Quality of burial goods can be divided in two broad groups: "common" and "precious", according to the energy required to procure the object (i.e. labour-intensive production, or the involvement of exotic raw materials) and the rarity of the object among Cerny burials generally. Common objects include flint blades, raw flakes, and bone awls, while precious objects include complete ceramics, ornament made from bones of wild animals (e.g. bear, wolf, boar, deer), and a type of triangular bone spatula found uniquely in STP burials called the "Eiffel tower" spatula. The four categories are roughly as follow: very rich (5 or more common goods or at least one precious object), rich (3 to 5 common objects or at least one object made of multiple elements, e.g. neckless made of numerous beads), poor (<3 common objects), and very poor (no grave good). For more detailed descriptions of grave goods found with each individual, please refer to supplement S5. As shown in Fig. 11, there is no obvious trend observed among those buried in varying degrees of grave good richness, except for BLR (Kruskal-Wallis δ^{13}C: $p = 0.016$), where a post-hoc Dunn's test reveals that the strongest difference is observed between the rich and the very poor ($\Delta_{mean} = 0.5‰$, $p = 0.003$). No difference can be observed in the mean δ^{34}S values among all level of burial good richness at all seven sites.

4.2.2.4. Sex. Only sites with at least 5 of each sex are considered in this comparison. Wilcoxon tests reveal that statistically significance differences in δ^{13}C and δ^{15}N values are only observed in the two Non-Cerny sites (Fig. 12). No difference can be observed in the mean δ^{34}S values between the two sexes at all five sites.

5. Discussion

5.1. δ^{13}C, δ^{15}N, and δ^{34}S baselines

While it is possible to separate the fauna by general feeding patterns (i.e. herbivory, omnivory, and carnivory), most of the species have significant overlapping δ^{13}C, δ^{15}N, and δ^{34}S values (Fig. 5). Accordingly, it is not possible to qualify or quantify the proportion of different animal species in the human diets. Hence, the subsequent discussion of human dietary patterns will refrain from making specific inferences about the respective proportion of each dietary component. A comparison of faunal isotope measurements from 14 Mesolithic and Neolithic sites from six river valleys suggested that the geographic variability in the δ^{13}C baseline in Paris Basin is relatively limited. Some regional patterns can be observed in the δ^{15}N values, notably from Marne valley (Fig. 3). This issue should be rectified after applying the baseline adjustment on

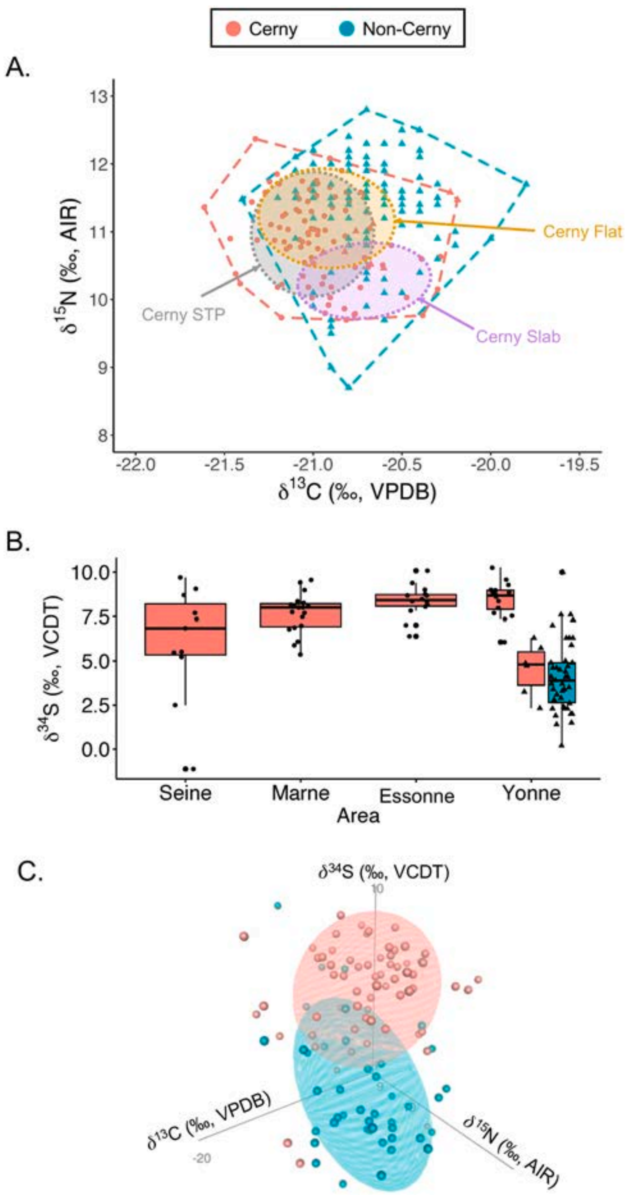

Fig. 6. Comparing human data by culture. A: stable carbon and nitrogen isotope compositions of the two cultural groups, each group described by a convex hull (outer dotted line). Cemetery types are described by bivariate standard ellipses (shaded area); B: stable sulfur isotope compositions of two cultural groups, organized by river valleys; C. 3D plot comparing all three isotope measurements between the two cultural groups. In A, "Cerny STP" refers to samples from BLR, GLS, PLS, PR, VNF; "Cerny Flat" refers to samples from CLP and VPB; "Cerny Slab" refers to samples from OLF; and "Non-Cerny" refers to samples from GLN and MON. In A and B, ● corresponds to original data from this study; ▲ corresponds to data obtained from published reports. VNF and VPB data have been adjusted for the baseline shift.

Table 4
Area metrics based only on carbon and nitrogen isotope compositions of all humans above the age of 5 (n = 218). TA refers to convex hull areas; SEA refers to standard ellipse areas; SEA_C refers to standard ellipse areas corrected, and SEA_B refers to standard ellipse areas with Bayesian estimate. See Fig. 6A for the visualisation of the convex hulls and standard ellipses described by these metrics.

	Cerny STP (n = 51)	Cerny Slab (n = 17)	Cerny Flat (n = 32)	Non-Cerny (n = 118)
TA	1.995	0.872	1.515	3.465
SEA	0.465	0.306	0.405	0.608
SEA_C	0.474	0.326	0.418	0.614
SEA_B. modes	0.456	0.276	0.390	0.604

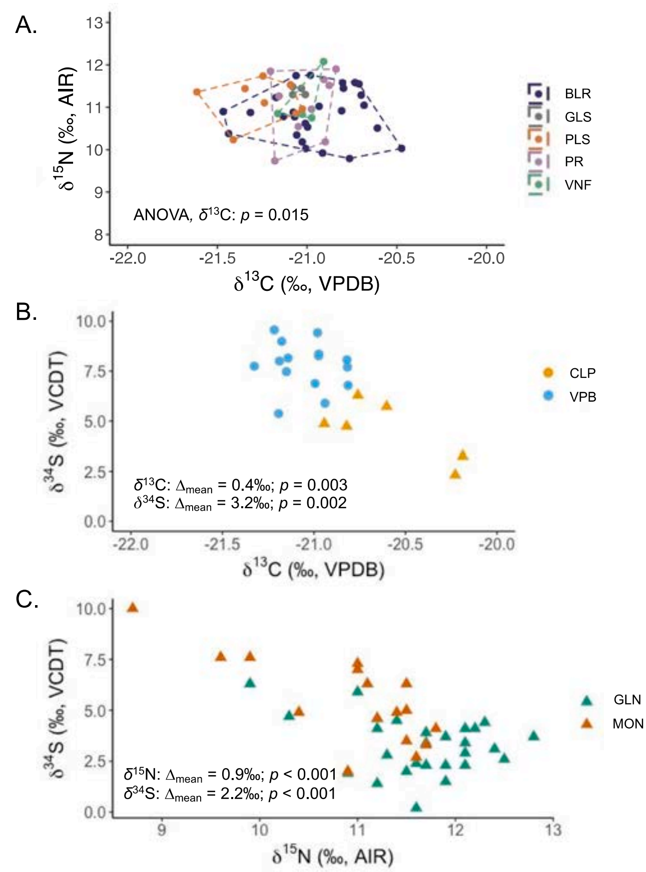

Fig. 7. Significant isotopic comparison within groups: A. Comparison between the $\delta^{13}C$ and $\delta^{15}N$ values of individuals from the Cerny STP sites; B. Comparison between the $\delta^{13}C$ and $\delta^{34}S$ values of individuals from the Cerny Flat sites; C. Comparison between the $\delta^{15}N$ and $\delta^{34}S$ values of individuals from the non-Cerny sites. ● corresponds to original data from this study; ▲ corresponds to data obtained from published reports. VNF and VPB data have been adjusted for the baseline shift.

the human data from the Marne valley as calculated by Equation (1). Hence, all differences observed in $\delta^{13}C$ and $\delta^{15}N$ values of humans presented in this study should reflect actual differences in dietary patterns.

The $\delta^{34}S$ baseline of the region is much more complicated. At first glance, there is no apparent pattern observed when only terrestrial faunal $\delta^{34}S$ values are considered (Fig. 4A). However, when all human and (terrestrial) faunal data are plotted together, it appears that the terrestrial $\delta^{34}S$ baseline does roughly corresponds with the underlying geological formations (Fig. 13). The bedrocks of the region are mostly consisted of later Mesozoic (Cretaceous) and early Cenozoic (Eocene and Oligocene) formations. Fig. 13 shows that elevated $\delta^{34}S$ values are associated with younger bedrocks, where more depleted $\delta^{34}S$ values are associated with older bedrocks.

Therefore, the difference in mean $\delta^{34}S$ values observed between Cerny and non-Cerny groups (Fig. 6B) was likely due to geological, rather than cultural factors. While all sites in the Yonne valley are located on Cretaceous age bedrock, the sites in the upper Yonne valley (CLP, BMT, GLN, and MON) are situated on older formations than those in the lower Yonne valley (VLG, GLS, PR, PLS) (Fig. 13). This also explains how CLP, a Cerny Flat site located on the same geological

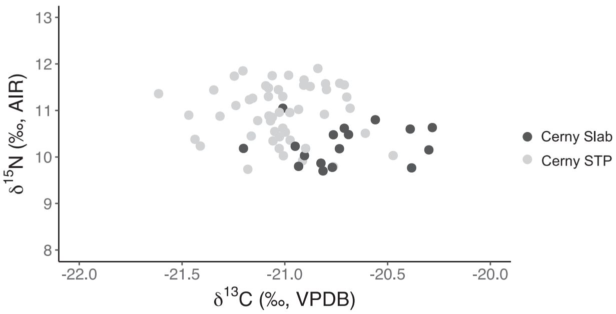

Fig. 8. Comparisons between the two types of monumental necropolises in Paris Basin. Cerny Slab refers to OLF, Cerny STP refers to BLR, VNF, PR, PLS, and GLS. All data are original data from this study. VNF data have been adjusted for the baseline shift.

formation as the non-Cerny sites, has mean δ^{34}S value more similar to those from the non-Cerny sites than those from the Cerny sites (Table 3).

While the differences in δ^{34}S values between domestic and wild animals (Fig. 4B) in three of the four valleys are significant, the largely overlapping ranges made it difficult to use it to detect casual consumption of wild animal protein. However, this observation may offer an alternative avenue to examine animal husbandry practices in the region. For example, the ranges of δ^{34}S values observed among the domesticates (Fig. 4A) could indicate different husbandry regimes: those characterised by a smaller range of δ^{34}S values among the domesticates, such as BLR (σ: 1.7‰) could indicate a relatively heavy-handed management approach, while sites with larger δ^{34}S ranges (e.g., σ_{BMT}: 7.8‰; σ_{GLN}: 3.9‰) may be indicative of a "free-range" approach, where livestock were raised over a larger area, potentially crossing over to regions with different geological bedrocks (Rey, et al. 2019). While current evidence is only limited to stable sulfur isotope data, and that not all faunal remains were directly associated with the cultural groups analysed, this interpretation remains speculative, but more research on this topic may yield further insight into animal husbandry practices in the region.

In theory, this pattern in δ^{34}S baseline should allow us to identify possible non-locals based on outlying δ^{34}S values in humans.

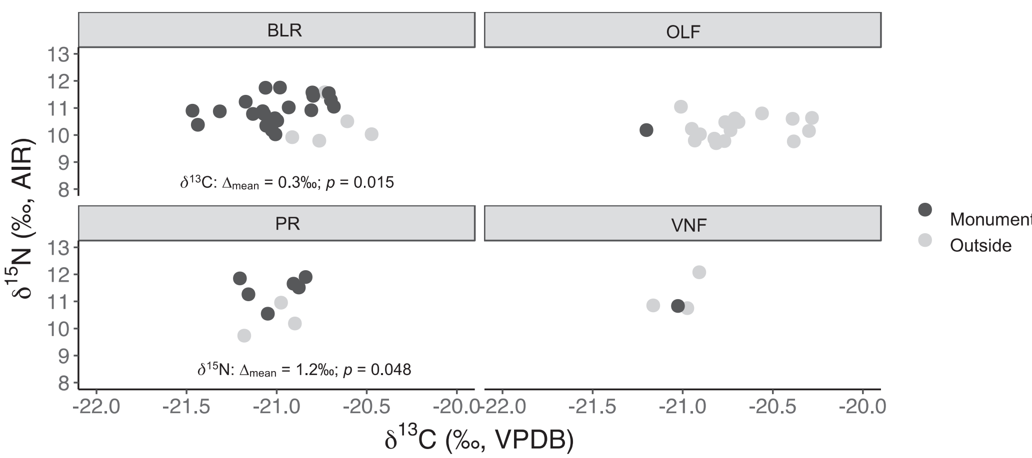

Fig. 9. Comparisons between locations of burial in regard to monumental structure(s) in each cemetery. All data are original data from this study. VNF data have been adjusted for the baseline shift.

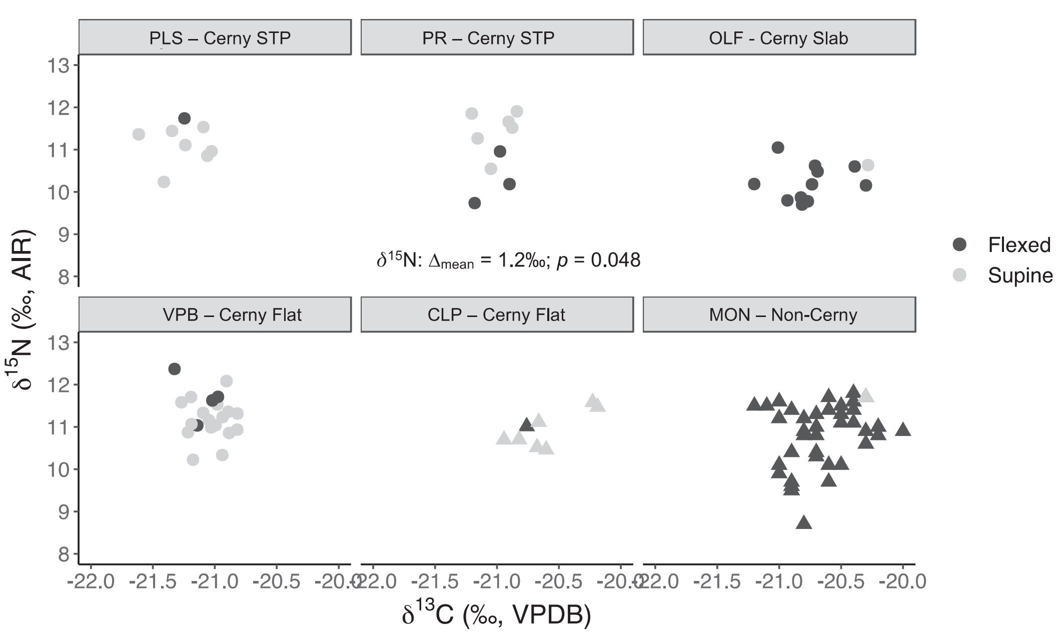

Fig. 10. Comparisons between burial positions in each cemetery. ● corresponds to original data from this study; ▲ corresponds to data obtained from published reports. VPB data have been adjusted for the baseline shift.

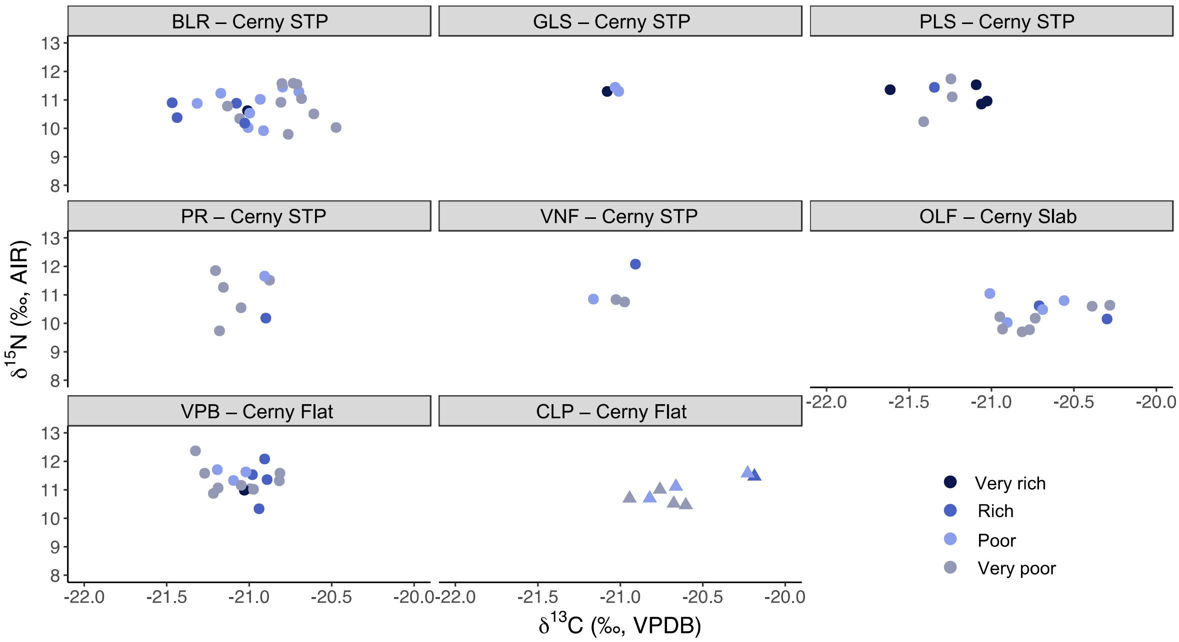

Fig. 11. Comparisons among individuals with varying degree of burial good richness in each cemetery. ● corresponds to original data from this study; ▲ corresponds to data obtained from published reports. VNF and VPB data have been adjusted for the baseline shift.

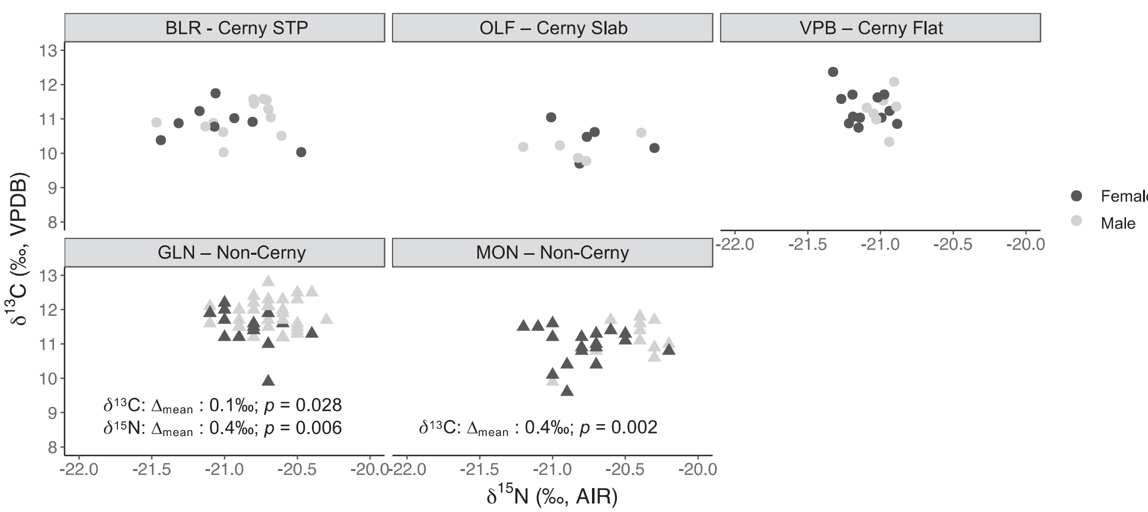

Fig. 12. Comparisons between the two sexes in each cemetery. ● corresponds to original data from this study; ▲ corresponds to data obtained from published reports. VPB data have been adjusted for the baseline shift.

Unfortunately, S isotope measurements are only available from freshwater resources from the Seine River. δ^{34}S values in freshwater systems are known to be extremely variable and fluctuate greatly depending on seasonality, geology, and proximity to other water sources. For example, the δ^{34}S values of a 1,050 km stretch of the Danube water can range from + 2.8 to + 17.1‰ (Nehlich, et al. 2010; Pawellek, et al. 2002). A much smaller river, the river Arno (~240 km) in northern Tuscany, Italy, has δ^{34}S values between –10.9 and + 16.3‰ (Cortecci, et al. 2002). In the Seine River, even just within the small stretch between BLR and Noyen-sur-Seine (<20 km), the mean δ^{34}S values of freshwater resources is quite large (Noyen-sur-Seine: –15.4 ± 3.2‰; BLR: –7.1‰). Thus, without S isotope measurements from other rivers in the region, we remain sceptical regarding using δ^{34}S values to evaluate palaeomobility activities within the Paris Basin region. Having said that, Fig. 4B and Fig. 5B show that freshwater resources in the Seine have evidently more negative δ^{13}C and δ^{34}S values than those from the terrestrial systems. Therefore, it is possible to argue that relatively negative δ^{13}C and δ^{34}S values in humans may be indicative of freshwater resources consumption, at least in sites along the Seine River.

5.2. Subsistence economy and general dietary patterns in the Paris Basin region

Generally speaking, the δ^{13}C and δ^{15}N values of all humans fall within the expected range of groups that subsisted primarily on C_3 terrestrial resources (Fig. 5). Constrained by the lack of baseline data from the Essonne, Marne, and Yonne rivers, the consumption of freshwater resources can only be evaluated at BLR. The extremely tight range in the δ^{13}C values of the BLR community (δ^{13}C: –21.0 ± 0.3‰) suggested that the group likely obtained most of their dietary protein from a restrictive source, which likely came from the terrestrial (δ^{13}C: –22.1 ± 1.2‰) rather than freshwater system (δ^{13}C: –24.7 ± 2.0‰). A weak correlation between the δ^{13}C and δ^{34}S values ($R = 0.45, p = 0.17$) further substantiated the proposition that freshwater resources likely did not

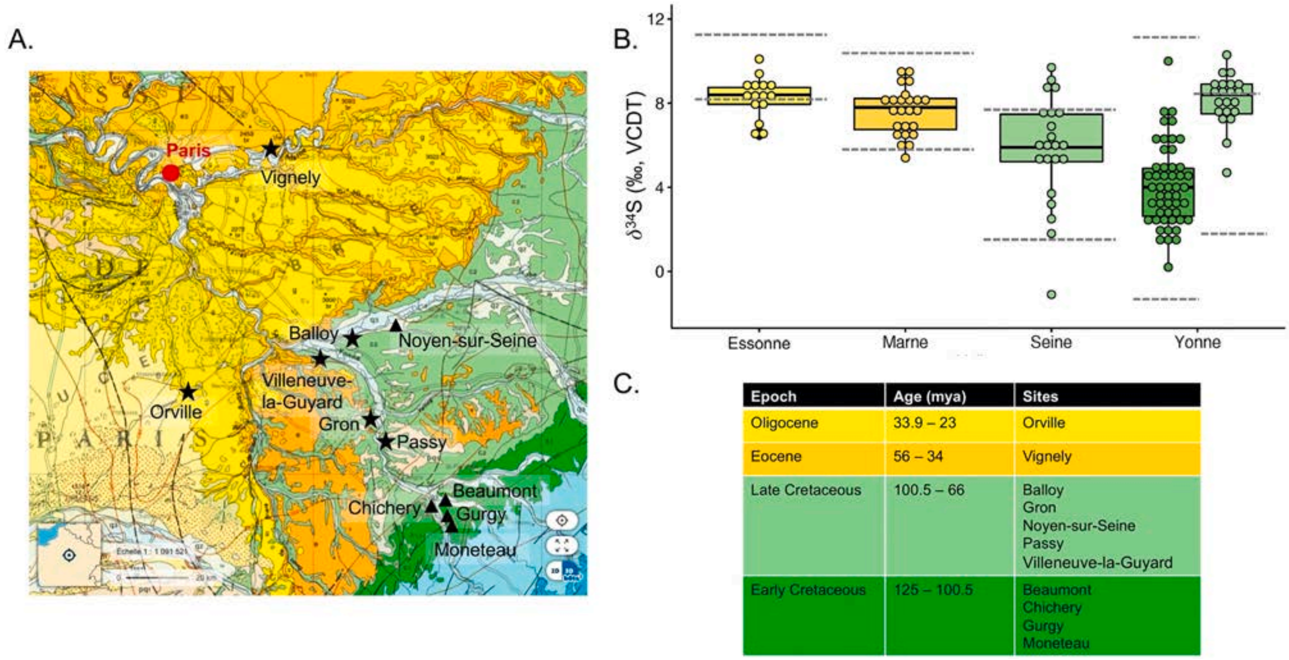

Fig. 13. Establishing a sulfur baseline for the Paris Basin region: A. geological map of the region obtained from Géoportail (https://www.geoportail.gouv.fr/), indicating the locations of sites mentioned in this study with reference to the modern city of Paris.★ corresponds to sites with original sulfur data, ▲ corresponds to sites with sulfur data from published reports. B. boxplot showing δ^{34}S values of humans from the four valleys, colour coded by the underlying geology of each respective site. Grey dotted lines indicate the range of standard deviations from the means of terrestrial faunal data from each valley. C. table showing the age of the four major types of bedrock in concern. For references of published data please refer to Table 1 (for human data) and Table 2 (for faunal data).

constitute a major component of the BLR diet.

A comparison between the dietary breadths of the Cerny and non-Cerny groups suggested that the dietary practices of the Cerny groups were more standardized. As shown in Fig. 5 and Table 4, despite occupying a much smaller geographical range, the isotopic variation of the Non-Cerny group is considerably larger than those of the Cerny group. One explanation is that the Cerny groups were more socially and economically organized than the non-Cerny groups. By definition, the practice of agriculture directs all (or most) food production labour into producing a smaller range of food products (plants and animals) more efficiently. As a result, agricultural societies tend to enjoy improved quantity, but reduced diversity of food (Dudley and Alexander 2017). Thus, the relatively homogeneity in isotopic composition among the Cerny sites may have reflected a standardized dietary pattern associated with an agricultural-dependent lifestyle. This pattern is especially stark among the Cerny STP group, as comparing to inter-group differences among the Cerny flat and non-Cerny groups (Fig. 7). This suggests that despite being scattered across three river valleys, the Cerny STP group is strongly connected through burial practices, social organizations, as well as subsistence economy. Moreover, isotopic evidence agrees with other archaeological evidence, that among the Cerny flat group, VPB was likely more closely associated with the Cerny STP group than CLP.

While it is not possible to further quantify the specific dietary components of these Middle Neolithic communities, a general comparison between the mean δ^{15}N values of the Cerny humans (+11.5 ± 1.2‰; baseline adjustment for the Marne humans not applied) and those of the overall fauna revealed that the humans have comparable mean δ^{15}N value with those of the carnivores (+11.0 ± 1.6‰), and much higher than those of the omnivores (+8.2 ± 1.5‰) and herbivores (+6.6 ± 1.2‰). Considering that the diet–tissue trophic enrichment factor is typically assumed to be around 3–5‰ per trophic level (Bocherens and Drucker 2003; Hedges and Reynard 2007), the large spacing between the mean δ^{15}N values of human and fauna suggested that all these communities consumed a considerable amount of animal protein.

Furthermore, a study that looked at the oral health of a total of 10 Cerny sites in the Paris Basin region (n = 160) revealed the raw frequency of carious teeth among the Cerny population is more in line with hunter-gatherer groups (Thomas 2011:522). Dental caries is often associated with a high consumption of cariogenic foods, such as cereals (Gupta, et al. 2013; Lingstrom, et al. 2000; Moynihan 2016; Selwitz, et al. 2007; Tayles, et al. 2009). Therefore, it is argued that the occurrence of dental caries tends to be higher in agricultural populations than in hunter-gatherer groups (Cohen and Armelagos 1984; Larsen 1995; Powell 1985; Temple and Larsen 2007). The overall prevalence of dental caries among the Cerny groups is relatively low (4.1%) comparing to agricultural populations (3 – 40%), and is more comparable with hunter-gatherer populations (0.1 – 8%) (Caselitz 1998; Larsen, et al. 1991; Walker and Hewlett 1990). Thus, the Cerny groups were likely agricultural groups that relied heavily on animal protein.

5.3. Inter-site comparisons

Regarding the two different types of monumental Cerny sites, other than the types of funerary monuments, the most significant distinction between Cerny STP and Cerny Slab burials are the burial positions. Burials in Cerny STP sites are typically buried in a supine position, where burials in Cerny Slab sites are typically buried in a flexed position. Many archaeologists working in the region agree that the supine position likely reflected incoming influence from the Rhine basin's *Mittelneolithikum* cultures (Boës 2003; Chambon, et al. 2007; Chambon and Thevenet 2016; Jeunesse 1997; Mordant, 1997; Simonin, et al. 1997), while the flexed burial position could be attributed to several cultures, based on the similarity in burial practices and other archaeological evidence, some archaeologists believe that there are links between the Cerny Slab site of OLF with those from the local Early Neolithic Blicquy/Villeneuve-Saint-Germain (BVSG) cultures (Simonin, et al. 1997). As shown in Fig. 8, individuals buried in Cerny Slab (i.e., OLF) have very different isotopic compositions comparing to those buried in Cerny STP (i.e. BLR, VNF, PR, PLS, GLS). While differences in δ^{34}S values can be explained by geology (Fig. 13), differences in δ^{13}C and δ^{15}N values are likely related to diets. The difference in the mean δ^{15}N values between the two groups suggested the Cerny Slab group either consumed less animal protein, or that their dietary protein was obtained from lower trophic animals (i.e. herbivores), than those from Cerny STP sites (Fig. 8). Without the δ^{13}C baseline of all major food groups, especially those from plants, the difference in δ^{13}C values is harder to explain. Nevertheless, based on isotopic evidence, it is clear that the two groups had systematically distinctive dietary practices. Thus, if burial positions are in fact indicative of cultural origins, our results would suggest that these two lines of cultural origins also differ strongly in terms of subsistence economy. Even though our current data cannot fully explain the difference in isotopic compositions between the two types of Cerny sites, the observation is nonetheless thought-provoking, and raise further questions about the current cultural categorizations of communities in Middle Neolithic Paris Basin. What does being part of the Cerny culture really means? An osteological study done by Thomas (2011) reported that individuals from the Cerny Slab contexts (OLF + Malsherbes "La Chaise" + Malesherbes "Les Marsaules") were taller than the rest of the Cerny populations (Cerny STP + Cerny Flat). Further distinctions in skull morphology were also observed and confirmed with multivariate statistical analyses (Thomas 2011:494-501). All these seem to suggest that other than dietary and burial practices, individuals from the Cerny Slab context may also be biologically different than those from other Cerny contexts.

5.4. Intra-site comparisons

It is presumed that sites with monumental structures, i.e. Cerny STP and Cerny Slab, would have stronger social differentiations than those without, i.e. Flat sites (with or without Cerny component). In many archaeological cultures, hierarchy in socio-economic status is sometimes reflected in dietary patterns. A common phenomenon is that individuals of higher socio-economic status – as represented by richer grave goods and/or elaborate tomb structures –consume a higher proportion of animal protein, and hence have higher δ^{15}N values than those from a lower social class (Ambrose, et al. 2003; Cheung, et al. 2017b; Le Huray and Schutkowski 2005; Pearson, et al. 2013). However, this is not the case here. As shown in Fig. 9 and Fig. 11, the relationships between δ^{15}N values and funerary arrangements are erratic, suggesting that social differentiation at Cerny sites were not necessarily related to the amount of animal protein intake. Another interesting observation is that individuals who were buried in a "special arrangement" – whether it be buried within the monuments (Fig. 9) or buried in a position that was not the "norm" within the site (Fig. 10) – also have distinctive isotopic compositions comparing to the rest of the group. While the sample sizes of these aberrant burials are generally too small for the difference to be picked up by statistical tests, the pattern is unmistakable. These burial arrangements clearly reflected certain aspects of the buried individual's background, including diets, were different from the rest of the group. Nevertheless, it is important to stress that in the Middle Neolithic Paris Basin, social-economic status, as reflected by the variety of the burial features, cannot be merely explained, nor described by the quantity of animal protein intake, but the association between social groups and dietary practices was both complex and contentious.

Furthermore, there is no consistent pattern in the isotopic compositions of individuals buried in different burial positions within sites (Fig. 10). For example, both PLS and PR are Cerny STP sites, where individuals were predominately buried in a supine position. However, the flexed burial in PLS has the highest δ^{15}N value among all, while those from PR has statistically significant lower δ^{15}N values than the rest of the community (Fig. 8). The sample size of our dataset is too small to draw any definite conclusions, however it is possible that the factors involved in determining burial positions could be different on the intra- and inter-site levels.

The individual (adult male) from MON buried in a Balloy-type grave (supine position; #04–99) had relatively elevated δ^{13}C and δ^{15}N values comparing to the rest of the MON population (Fig. 10). However, his isotopic measurements are completely outside of the "Cerny" convex hull (Fig. 6A). This suggested that his diet was not particularly similar to those coming from the Cerny groups. More isotopic as well as archaeological evidence will be needed to better explain this individual's particular burial arrangement.

Last but not the least, it is important to point out that while there is no difference observed in the dietary patterns between the two sexes in any of the Cerny sites, the opposite is observed in the two Non-Cerny sites (Fig. 12). Even though the original report stated that the differences between the sexes are not clearly distinct but only showed "a slight tendency" (Rey, et al. 2019), statistical tests revealed that the differences are indeed significant, which is particularly notable given the isotopic variations of all food sources in this region are rather limited. This difference is surprising in two ways. First, Thomas (2014b) reported that funerary arrangements in Cerny STP sites were highly gendered: monumental structures were sex-specific, and certain grave goods, specifically hunting equipment, were always associated with males. Thus, some differences in the dietary patterns between the two sexes among the Cerny sites are expected. The fact that there is no discernible distinction between the isotopic compositions of the two sexes in any Cerny sites suggests that the "gendered" treatment of males and females did not extend to diets. This is further supported by oral health data, which revealed that males and females in Cerny sites suffered similar level of dental pathologies (Thomas 2011). Thus, among Cerny groups, the two sexes may have different treatments/ status after death, but in life, the two sexes received similar sustenance, at least in terms of macronutrients intake. Secondly, the differences observed between the males and females in GLN are mostly in δ^{15}N values, while the differences in MON are mostly in δ^{13}C values (Fig. 12). Note that GLN and MON are located within 3 km from each other with overlapping chronologies (Chambon, et al. 2004). Thus, the differing isotopic compositions in male vs. female diets in non-Cerny sites are clearly not geological, but reflected differences in dietary compositions between the two sexes at these sites. Unfortunately, with current data it is not possible to make explicit inferences about the dietary differences of the two sexes at these sites.

6. Conclusion

This study uses stable carbon, nitrogen, and sulfur isotope analysis to reconstruct and compare the past dietary patterns of individuals from 10 Middle Neolithic sites in Paris Basin. Eight of the sites belong to the predominant culture in the region, the Cerny culture, where two of the sites show significant non-Cerny components. Due to the lack of samples from certain key source groups (i.e. plants and freshwater resources), we are not able to evaluate the subsistence economy of both Cerny and non-Cerny groups in more specificity. Nevertheless, our results have showed that comparing to the non-Cerny groups, Cerny groups, especially STP groups, had relatively standardized diets. In addition, all groups consumed a considerable amount of animal protein. The accessibility of animal protein, therefore, likely explain why the amount of animal protein consumed was not related to one's social-economic standing.

Furthermore, our results have demonstrated that during the Middle Neolithic period, the Paris Basin region was a highly dynamic and culturally diverse region. While the cultural sphere was dominated by Cerny culture during this time, it is important to stress that "Cerny culture" was consisted of a number of subgroups, notably expressed through different funerary arrangements. Of the four main types of groups analysed in this study, the Cerny STP group (BLR, VNF, GLS, PLS, PR) stood out as a tight knitted group with relatively standardized burial practices, social organizations, and dietary practices. For the Cerny Flat group, VPB is isotopically and archaeologically more similar to the STP group than CLP. The two "Non-Cerny" sites (GLN, MON) shown strong intra-group differences, suggesting this group waw less strictly organized. Moreover, the Cerny Slab group was unique in many ways.

Despite being categorized as a Cerny site, most of the individuals were buried in a flexed position – an unusual practice among Cerny cemeteries. Previous published osteological evidence also put forward the preposition that Cerny Slab group were likely culturally and biologically different from the other Cerny groups. Our stable isotope data from OLF, a Cerny Slab site, also shows statistically significant distinctions comparing to other Cerny sites. Future works comparing other aspects of the Cerny Slab group with other Neolithic populations will allow a more comprehensive evaluation of the nature of this group.

On an intra-site level, we observed that most of the aberrant burials – burials that do not conform to the general funerary pattern at a particular site – have outlying stable isotope measurements. However, there is no clear pattern between burial patterns and dietary practices. Therefore, it is not clear how do all these different burial patterns translate in terms of social organization. Nevertheless, it is clear that certain lifestyles (i.e. expressed in outlying stable isotope compositions) and distinctions were carried through after one's death and expressed as differing burial patterns. Interestingly, there is no sex-based difference in all three stable isotope measurements observed among all Cerny groups. This shows that even though Cerny men and women were treated differently after death, they likely had similar access to food resources in life. The opposite is observed in the non-Cerny groups.

This study has provided a basis for examining the social-cultural diversity in Middle Neolithic Paris Basin within the interconnecting spheres of culture, geography, and biology. Future studies should try to establish a more comprehensive baseline database of the region, or even consider additional analytical approaches, such as dental wear, strontium isotope ($^{87}Sr/^{86}Sr$), or compound specific isotope analyses, to better elucidate the relationship between dietary practices and social organizations in these sites.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2021.101332.

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A Neolithic Burial ground from Upper Nubia as seen from recent work at Kadruka 23 (KDK23)

Pascal Sellier, Louiza Aoudia, Emma Maines and Philippe Chambon

An archaeo-anthropological excavation of a new cemetery

Located in Upper Nubia, within the northern Dongola Reach, the Kadruka concession lies between Kerma (to the north) and Kawa (to the south) and corresponds, mostly, to the Wadi el-Khowi, which is part of the former course of the River Nile (nowadays flowing some 19km to the west). Between 1985 and 2002, the whole concession was surveyed by Jacques Reinold, under the auspices of the SFDAS (Reinold 1987; 2001; 2004). He discovered more than 150 sites within the Kadruka district, amongst which he recognised 17 Neolithic burial mounds. Over the 17 years, he had the opportunity to excavate six of them either (almost) entirely (KDK1 N=124; KDK13 N=*c.* 30; KDK18 N=165; KDK21 N=288 out of an estimated total of *c.* 300 burials), or partially (KDK2 N=116 out of an estimated total of 1000 burials; KDK22 N=30 out of 150 estimated burials). So there are more than 750 individuals from six cemeteries excavated by Reinold; however, none of those sites have been fully published, and it is difficult to appreciate the representativeness of each burial sample. Since 2014, a multi-site and multidisciplinary project has operated at Kadruka (MaFSaK, Mission archéologique Franco-Soudanaise à Kadruka), jointly led by Langlois, Chambon and Sellier, funded by QSAP-06, with the collaboration of SFDAS and NCAM, with two main focuses: the Neolithic funerary dimension, and the analysis of the settlements of the Neolithic and the pre-Kerma periods.

Part of the QSAP-06 project is the thorough excavation of a new cemetery from the Middle Neolithic period in the Kadruka area, namely the burial mound KDK23, discovered by Osman Idriss in the autumn of 1988 and first visited by Reinold in the winter of 1989 (after a test, he did not select KDK23 for further excavation). The present KDK23 excavation is much more than a supplementary site in the Kadruka area; it should shed new light on Neolithic burial practices and funerary *chaînes opératoires*, and should provide definite bioarchaeological data to establish the sequence of the 'peopling corridor' of the Upper Nubian Nile Valley, as well as analysing evidence for the presumed hierarchisation of the Neolithic societies. KDK23 was chosen because of its intermediate dimensions ('only' 40m in diameter and 1.5m high above the plain) and its relatively good preservation: in November 2013, scarce fragmented bones and a few potsherds seemed to indicate a low erosional impact and Reinold's 1989 test work had barely affected the burials (encompassing cleaning of the surface, excavation of two child burials, a 'q-shaped' superficial test trench and the reopening of a probable looter's pit that provided parts of at least three skeletons).

Eventually the preservation of the human remains proved worse than expected: as is usual in desert contexts, only the mineral portion of the bones was preserved, which produced a high level of fragmentation. The archaeo-anthropological excavation (six campaigns up to now) needed to be slow and cautious because of the fragility of the bones, which were embedded in a very solid ground made of compacted silt layers from the Nile, and affected by a lot of fissures, all over the mound. Each bone was observed and recorded *in situ* and most of the biological and anthropological data was recorded directly in the field.

Spatial organisation

The KDK23 cemetery occupies the top of a small mound surrounded by palaeochannels of the ancient Nile. Usually but erroneously called a 'kôm' (which means 'tell', by assimilation with Near-Eastern or Balkan Neolithic sites), this mound proved to be of natural origin, according to geomorphological study and electromagnetic survey. It represents the remnants of a terrace of the Nile, most probably surrounded by water in Neolithic times: an 'island of the dead' in the middle of an ancient course of the River Nile.

There is no evidence for any other human activities apart from the Middle Neolithic burial ground on the mound. The first six working seasons have led to the discovery, excavation and full recording of 126 human burials, within an area of less than 110m^2 (in addition to one dog, one cattle deposit, and a few more undetermined features), which makes for a very high density of more than one subject per square-metre (Figure 1). The graves are neither visible from the surface nor underground: no burial markings could be detected, and it has been impossible to perceive the limits of any burial pits, apart from in a few exceptional cases (but the limits can often be assessed from the osteological analysis). Most of them are primary, individual burials but there is a high level of reopening, inter-cutting and disturbing of the graves. No direct dating of the human bones has yet been possible (no collagen was left for radiocarbon quantitative analysis, according to our preliminary tests) but other materials are being tested. According to the grave-goods (pottery, faunal remains, lithic technology, etc.), the cemetery has been tentatively dated from the first half of the 5th millennium BC (Middle Neolithic A: Usai 2016), and most of the burials can be positively compared to those from the R12 cemetery (Salvatori and Usai 2008) or from KDK21, both earlier than KDK1 (second half of the 5th millennium BC: Reinold 1987; 2001). Comparisons with smaller assemblages (for instance, el-Multaga, southern Dongola Reach: Peressinotto *et al.* 2004), with cemeteries from Early Neolithic (el-Barga: Honegger 2004), or with cemeteries from Central Sudan

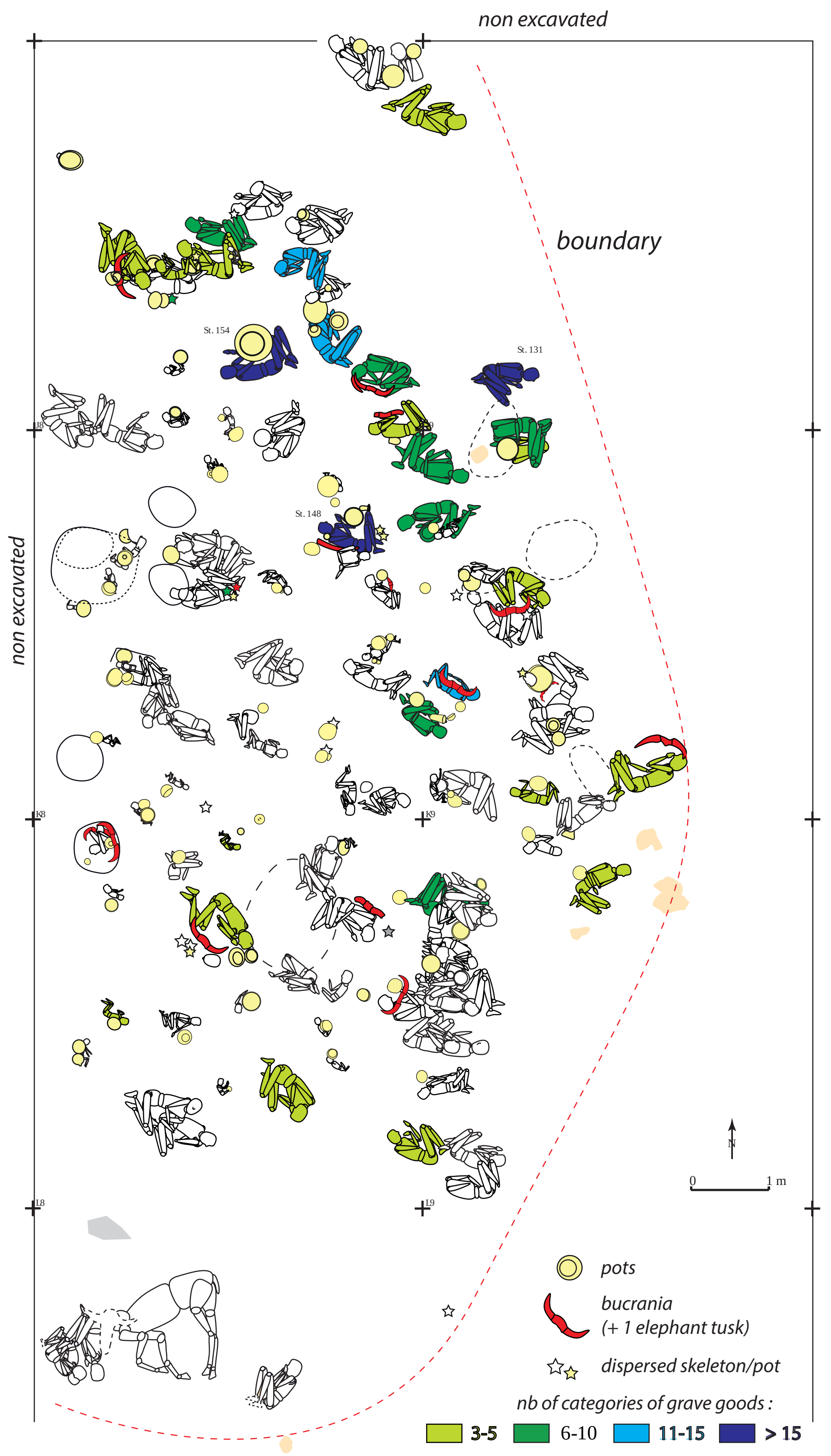

Figure 1. Schematic plan of the KDK23 burial ground, with the grave-goods as the key-feature (from white to dark purple: no grave-good or only pottery vessels to more than 15 different categories of grave-goods). The known boundaries of the cemetery are indicated by the dotted line (East and South). Drawing by P. Chambon.

(el-Kadada, Ghaba: Reinold 1987; 1992; 2008; Salvatori *et al.* 2016) are beyond the scope of this paper.

The general view of the cemetery does not fit Reinold's hypothesis of a concentric organisation around an earlier (and richer) burial at the highest point of the mound, and it is different from R12, which is less dense. Despite the small size of the KDK23 mound, the burial ground occupies only a small part of it, more or less at the top but shifted northwards, probably no more than 25m north-south by 12m east-west. The limits of the cemetery have been clearly reached on the southern and eastern sides (Figure 1): No burials at all are to be found further eastwards or southwards, indicating that a physical limit should have initially existed. On this basis, the overall shape of the burial ground appears more or less ellipsoid and the final number might be around 200-250 individuals. The burial density is irregular: one can see many empty spaces compared to bundles of burials where many subjects were associated through reopening and inter-cutting of burial pits. The general organisation is still visible: rows of burials are separated by narrow corridors without any graves. A main row, oriented NNW-SSE, is parallel to the eastern boundary of the cemetery and to another row (westwards); two short rows or bundles of graves lie N-S (bottom of Figure 1) and W-E (top of Figure 1). In our view, those are deliberate associations of individuals, with a clear intention of co-locating some people for social or family reasons.

An ordinary mortality profile without selection

Despite the observations and measurements recorded in the field, it is often not possible to determine the individuals' sex and age, apart from the non-adults' age at death. When feasible, this has been been done by reliable and accurate methods (Bruzek 2002; Bruzek *et al.* 2017; Schmitt 2005; Moorrees *et al.* 1963a; 1963b; Al Qahtani 2009; Primeau *et al.* 2016). The life-table, especially the probabilities of death, was figured out according to Sellier's methodology (1996), which allows us to detect potential 'demographic anomalies'.

The mortality profile of non-adults (Figure 2) fits well into a standard life table (Ledermann 1969) corresponding to a life-table at birth of 30 years. In the KDK23 cemetery, both sexes are buried and all ages are represented, from stillborn to old age. There is no evidence of any kind of selective burial practice, particularly for the youngest (Maines *et al.* 2017), and the mortality profile corresponds to an 'ordinary' ancient mortality, an 'attritional mortality' (without selection and without crisis). It contains females and males, with no significant differences (although a general sex-ratio cannot be calculated, due to the poor state of preservation of hip-bones), and adults and non-adults of all ages. Sex or age are not a criterion for spatial distribution within the cemetery, except for the youngest (stillborn, neonates and infants), concentrated at the top of the mound with shallower burials. This 'ordinary population' gives no argument for an elite burial ground.

Analysed as a whole, the R12 cemetery appears totally different from KDK23 (Figure 2), with a clear burial selection: from Table 8.1 in Judd (2008, 84-86), we could determine the probabilities of death, which are much more accurate than mere percentages of the deceased: the probabilities of death for age-groups 0 years and 1-4 years are significantly different from the standard-table model, and are far too low for an ancient population (1q0= 95 ‰ and 4q1 = 70 ‰, three or four times lower than expected).This means that stillborn neonates and infants were buried elsewhere and their corpses had no access to the R12 cemetery.

This burial selection can also be demonstrated, but only for the first age-group (0 years), at KDK18 and KDK1 (Maines *et al.* 2018; Maines 2019). If possible, it would be interesting to distinguish between the two periods of the Middle Neolithic (A and B) at R12 (Salvatori and Usai 2008; Usai 2016), to see if that strong burial selection is typical (or not) of the second period, as it seems to be in the later cemeteries from Kadruka (KDK 18 and KDK1), as opposed to the earlier (KDK21 and KDK23) where it seems that the whole deceased population was admitted to the burial ground (Maines 2019).

Main burial features

The standard disposal of the dead is an individual primary burial (Figures 1 and 4, Plates 1, 2, 3), with the subject laid in a lateral right or left position, with flexed or hyper-flexed lower limbs (flexed hips and knees), and flexed forearms (hands often in front of the face or near the chin). A small majority rests on the left side (57/97, i.e. 59%), much less than at R12 (82% of the determined position: Salvatori and Usai 2008, 129). In both the KDK23 and R12 cemeteries, there is no correlation and no spatial distribution according to sex, age or position, but the clusters of associated and inter-cutting graves of KDK23 often clearly show a prevailing side, left (for instance, in the northern group) or right. The prevailing orientation of the corpse (Figure 3) is approximately on a NW-SE axis with a wide variability around it (a quadrant of nearly 100°), with 49 cases (including numerous neonates and infants) having the head to the NW and 31 to the SE (and the remaining 15 in the NE-SW quadrants). Within the compacted silts of the mound, it is

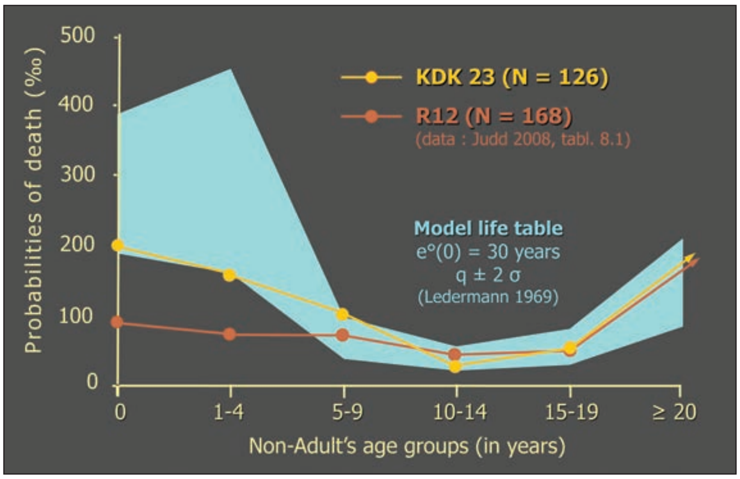

Figure 2. Probabilities of death (calculation according to Sellier 1996) for the non-adult age-groups of KDK23 (N=126) and R12 (N=168), compared with a standard life-table from Lederman 1969 (expectancy of life at birth of 30 years, ± 2 SE). Please note that those figures are not mere percentages of the deceased. Figures for R12 are recalculated from Judd 2008, 84-86 (table 8.1). Drawing by P. Sellier.

Plate 1. St.131: very wealthy burial of an elderly woman: containing many bone tools, lithic segments in situ *including a sickle, raw bone material, a stone palette, mussel shells, flint flakes, and a bracelet in hippopotamus ivory. Most of her artefacts and her stock of bone material are gathered at her back (a kind of 'tool box'?).*

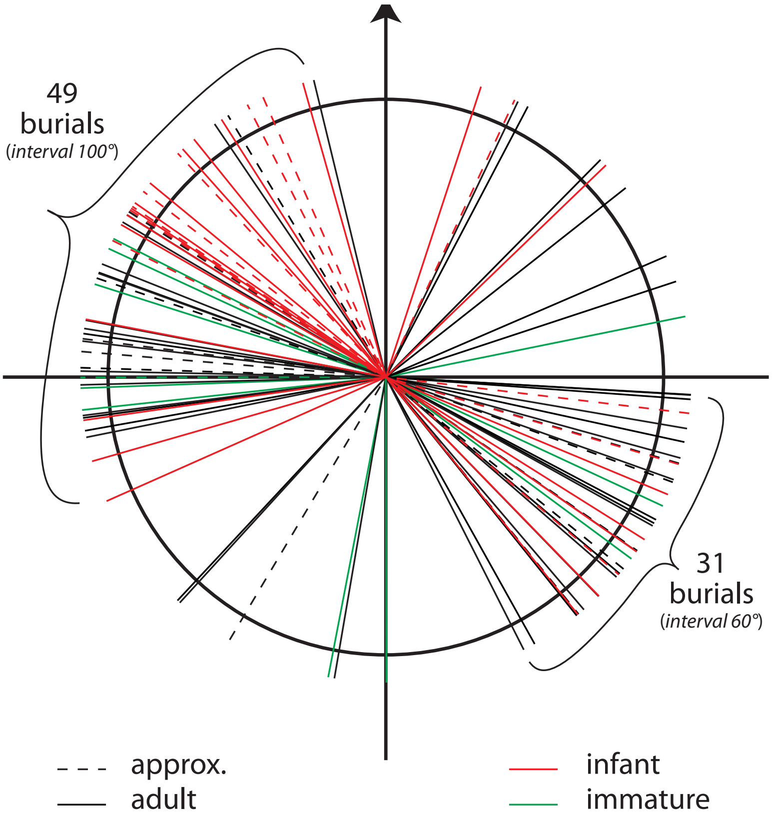

Figure 3. Orientation of the KDK23 burials (feet at the centre, head on the circumference), showing the prevailing SE-NW (49 cases) and NW-SE (31 cases) feet-head orientations over a total of 95. Stillborn, neonates and infants are in red (prevailing position: head to the NW), other non-adults in green, adults in black. Drawing by P. Chambon.

usually impossible to detect the limits of the pit of any burial, the graves having been simply dug into the mound (the ancient terrace of the River Nile). Nevertheless, the position of the skeleton and the archaeo-anthropological analysis clearly show how narrow the grave was (1.2m at most, for the maximum length/diameter, with a maximumm depth of 0.7m), with many constraints that have often maintained the feet in a vertical position, and the spine or the neck in a bent position.

If one looks closer, one can realise that some hands and feet that should have fallen down by the law of gravity are still in pefect connection and position, contrary to the rules of corpse decay (Duday *et al.* 1990; Duday 2009; Sellier 1992), as if they had been maintained by desiccation (prior to final decay). Conversely, quite a number of joints were not held in their strict anatomical position (for instance, rotation of the head of the humerus, as in Plate 2; slipping down of the scapula, dislocation of the sacro-iliac joint, etc.); such displaced bones are the signs of the former disposal of a corpse wrapping or of a cover that could have been a rug or an animal hide (now disappeared). In a few cases, like in burial St.93 (Plate 3, Figure 4), the general hyper-flexed position suggests that the corpse had been tied. As far as that specimen, St.93, is concerned, the strong constraints and the bundle-like overall aspect give evidence for a probable desiccated (i.e. naturally mummified) subject before its burial in the narrow grave.

The youngest individuals – stillborn, neonates and infants less than 1 year of age – are found in a greatmore differing positions than the older children and adults; almost all possibilities can be seen, even a prone and flexed position ('frog position'), as in the case of the neonate St.25 (Plate 4). For this age-group, displaced or moved bones are very common. Both those signs, manifold positions and numerous dislocations, are evidence for the use of small containers, like baskets, for the little corpses; this also explains why the infants' pottery vessels were placed much higher than the skeletons (they were laid upon the basket).

On the mound, no signs of ritual or commemorative activities were left. Nevertheless, the burials were not forgotten, for many were associated with new ones, if not merely reopened. This means that the location of the graves was remembered (perhaps marked in a way that did not leave any remains) and, moreover, that the individuals' identity was known. This provides evidence for deliberate association, reopening and inter-cutting of graves. An example of the association of five subjects is given in Figure 5: four stages to eventually gather one child of 6-7 years old and four adults.

Plate 2. Two stages of the excavation of burial St.148 (an elderly woman), one of the wealthiest graves: five vessels (including one calciform), many bone tools, lithics, raw bone material (mostly cattle ribs), a stone palette, mussel shells, a needle, beads (semi-precious stone and ceramic), coloured pebbles, and half of an elephant tusk (lower level).

Plate 3. *St.93: hyper-flexed individual, with many burial constraints, giving evidence for the tying up and probable previous dessication of the body*

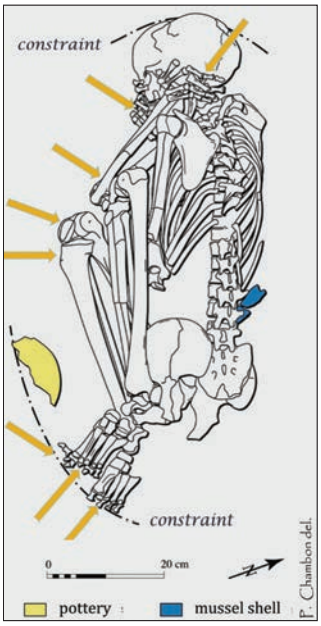

Figure 4. St. 93 (drawing P. Chambon).

Grave-goods

In the KDK23 burials, grave-goods were mostly either equipment or food for the afterlife, or personal adornment (perhaps along with clothing?). In comparison to other cemeteries across the Kerma Basin, grave goods were not numerous, although it is rare that the deceased had no items at all. However, objects made of organic material could have disappeared. The standard deposit consisted of (usually) two pottery vessels (Plate 6) (sometimes one, seldom more than two: Plate 2); the pots were placed upon the corpse, usually upright (opening upwards), over the adults' rug/cover and above the non-adults' basket/container (Plates 4 and 5). They seem to be functional objects and a lot of them were worn, repaired (with frequent holes for repairing) and even trimmed and reshaped, as in the case of two specimens of caliciform beakers. They were probably containers for food or beverages, as illustrated by the vessels of the neonates and youngest infants: inside one of the vessels, there is always a sort of spoon, made of ceramic, a trimmed cup, or even an oyster shell (Plate 5).

Items of personal adornment as well as other objects were closely associated with the body. Beads, necklaces, etc. were made of a range of materials including amazonite, carnelian, ceramic, and ostrich egg-shell; ivory bangles were made from hippopotamus tusk and there were some stone labrets (one *in situ*, in front of the chin of St.135, which originally pierced the deceased's lower

Plate 4. St.25: stillborn/neonate burial in a prone and flexed position ('frog position'), with two pottery vessels.

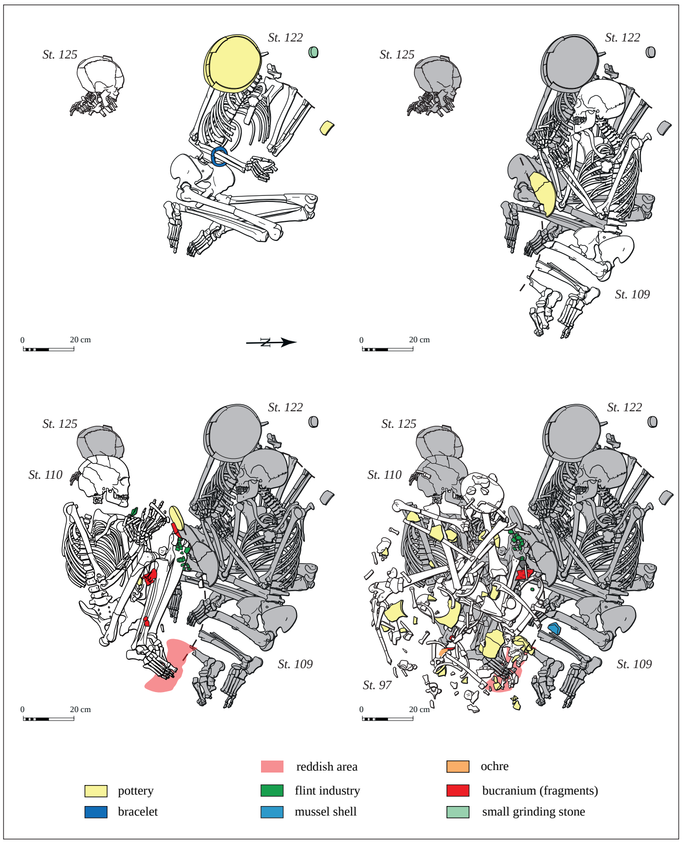

Figure 5. Four stages of the St.97-110 assemblage from KDK23. St.125 (child, 6-7 years old) and St. 122 (middle-aged adult female) were laid first (originally undamaged and complete), later damaged by the reopening of the grave and the deposits of St.109 (elderly adult, sex indeterminate), then St.110 (adult, sex and age indeterminate). The last step is the upper deposit of St.97 (young adult female), a complete but fully dislocated skeleton, probably coming from an earlier stage of the reopening (Drawing by P. Chambon).

Plate 5. St.37: neonate burial with two pottery vessels on the subject and an oyster shell (like a spoon into the largest pot).

lip). Bone artefacts included awls, chisels, needles etc.; and there were polished stone axes, flint flakes and lunates *in situ* corresponding to a tool such as a sickle. Usually, artefacts were standardised and the same object was present in quantity; there was sometimes a kind of prevailing artefact in some burials (e.g. bone artefacts or stone axes or lunates/sickles, etc.). Nevertheless, these grave-goods included non-functional or unfinished artefacts (e.g. pre-formed ostrich-egg-shell beads, pre-shaped flint cores etc.), with, quite often, raw materials (cattle or gazelle bones, flint pebbles, red or yellow colourant, half an elephant tusk: Plate 2). Mussel or oyster shells were sometimes numerous and could have been a sort of container, like the sheath/container made of a hippopotamus tusk (Plate 6). There were also 'symbolic' objects such as bucrania (one or two, usually cattle; like the pottery vessels, bucrania were positioned near the edge of the pit and over the body), probably referencing a herding context (sickles or microliths could similarly evoke agricultural activities). Artefacts and raw materials were often close together (Plates 1, 2), sometimes along the back of the corpse or under the head, as if in a container or perhaps in relation to the wrapping/covering of the body.

Plate 6. St.134: burial of a 30-39 year old woman, with a large bucranium, two vessels, and a case or sheath made of hippopotamus tusk.

There is a special distribution of the wealthiest graves (Figure 1). The transition from no grave-goods (or only pots) to more than 15 different categories of grave-goods, shows the richer deposits located within a small area, near the top of the mound, to the north of the present excavation.

Unusual burials

Some of those individuals with many grave-goods, or with special grave-goods, might have had a special status within the KDK23 living population. This was probably the case for the elderly woman, St.148 (Plate 2), who has a wealthy burial, as far as the number and variety of grave-goods is concerned, including half of an elephant tusk (a unique specimen in the cemetery); or the case of another woman, St.131 (Plate 1), who was buried with many sickle elements and bone artefacts.

Some unique cases of disposal of the dead must also be mentioned (the latter two subjects are also unusual because they suffered a violent death, see below). St.144-145 (Plate 7) is actually a double burial (that is, two simultaneous inhumations) of two women and St.89 (Plate 8) is the sole secondary burial of the cemetery. It is a very partial skeleton, whose bones were collected long after the body decayed and the main joints dislocated, and it was brought back to KDK23 for burial. The skeleton only encompasses: the cranium, the mandible (completely separated from the cranium), a large part of the left upper limb (scapula, clavicle, humerus, radius, ulna, trapeze carpal bone, 4 metacarpals and 1 phalanx), the right hip-bone and the proximal 4/5 of the right femur, 6 right and 5 left ribs, the whole thoracic column, the 2nd and 7th cervical and the 1st lumbar vertebrae. Among those dislocated and separated remains, we unexpectedly found some bones with good preserved articulation (in their natural anatomical position): the left elbow and the column from C7 to L1 with the five left ribs still in position (Plate 8). It can be inferred that these connected remains became naturally desiccated (mummified) and were then put, with the other bones, in a bag for transportation and secondary burial at KDK 23 (reconstruction: Plate 8)

Interpersonal violence

Four individuals were victims of extreme violence, as evidenced by several blunt-force traumas with impact markers specific to perimortem fractures on 'fresh' bone (Walker 2001; Symes *et al.* 2012; Loe 2016). These preliminary observations concern the secondary burial St.89, one of the

Plate 7. St.144-145: a double-burial of two adult women (buried simultaneously); on the left, St.144 shows a multifractured skull due to perimortem blunt-force trauma.

subjects of the double burial St.144-145 and two individual burials (St.134 and St.152). St.152 is the only male (30-49 years old), and shows a single blunt-force trauma, inside the left pelvis, near the iliac crest and the antero-superior iliac spine. The mark of the weapon corresponds perfectly to the edge of a stone axe (like those found in other burials). St.134, a 30-39 year old woman, shows exactly the same type of trauma, at the same place (a little lower and more inside the left pelvis), also due to the edge of a hafted stone axe (Plates 6 and 9). The woman St.144 (a middle-aged adult) had been buried at the same time as St.145 (an adult, possibly female); she presents a multi-fractured skull, with at least three impacts on the right frontal and parietal bones, due to a heavy tool (the missing fragments have fallen inside the cranium) and several blunt-force marks on the anterior and right lateral faces of the last three thoracic vertebrae, T10, T11 and T12 (the weapon penetrated the right side of the abdomen). The secondary burial St.89 (Plate 8) is that of a 30-59 year old woman; her cranium has a large perimortem blunt-force trauma all along the left fronto-parietal zone (up to the eyebrow) (Plate 10); three impacts of a pointed weapon (pike or spear) penetrated her right pelvis (and perforated the acetabulum) (Plate 11), and her right femur has been broken perimortem (distal fracture, near the knee).

The blows, often repeated in the same place, have affected the cranium (two cases), the thigh, abdomen (lower thoracic vertebrae), and pelvis (three cases), and all were applied face to face, at point blank range with a hafted weapon (spear or hafted stone axe); each producing a lethal wound. The victims with many traumas (St.89 and St.144) have been 'over-killed' or were facing several assailants. Each of the four cases is different and there is nothing like a scheme or repetitive sequence. If different disposals of the dead have been granted to them (secondary, double, simple primary), they nevertheless are all fully integrated into the cemetery and into the overall funerary practices of the population, even if St.89 probably died far away (the remains being repatriated later as a secondary burial). Thus, there is no evidence for sacrifice, execution or 'accompanying death' (Testart 2004). Conflict or interpersonal violence are the best hypotheses.

New funerary features

The image of the KDK23 cemetery, as it emerges, is altogether different from other Neolithic burial grounds from Upper Nubia. It is indeed an 'ordinary' population, with all categories represented (according to sex, age, occupation etc.), involved in herding and agriculture, with strong links to a domesticated world (sickles, cattle bucrania etc.). In addition, it is an organised group managing a clear spatial

Plate 8. Two stages of the excavation of the secondary burial St.89, with a proposed reconstruction: a sort of bag containing selected mummified remains of an adult female of 30-59 years of age (reconstruction: C. Martha).

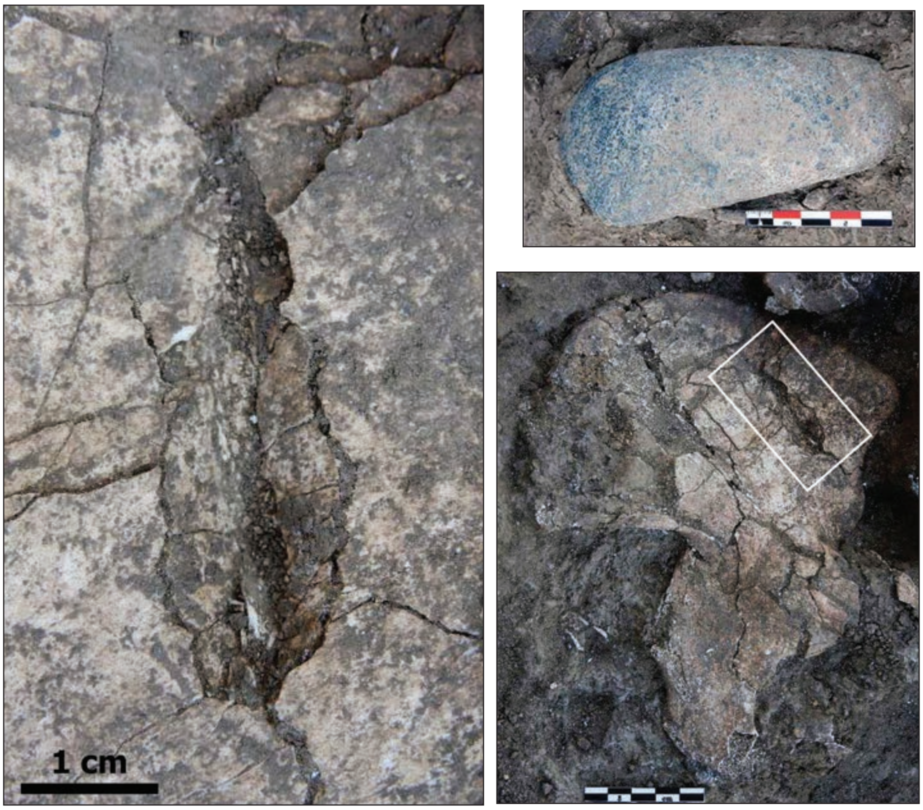

Plate 9. St.134: perimortem blunt-force trauma at the medial (inner) part of the left hip-bone, compared to a polished stone axe from another burial (note how the edge of the axe fits the wound).

distribution of the deceased on this 'island of the dead', with many deliberate associations or gathering of subjects, and with some individuals having a special status probably linked to their occupation. Other new features are to be underlined, such as the evidence for containers (baskets for infants?), corpse wrappings, and perhaps rugs (or mats or animal hides) for adult burials; all of which might be connected to the transportation of the dead to/on the island.

Around half of the KDK23 cemetery has been excavated so far, but we do not yet know if that half is representative of the whole. Indeed, each campaign has brought new and distinct burials, providing original data. In 2014, the important result was the high proportion of infants and neonates; in 2015, the first dense rows of burials began to appear; the following year, burials with bucrania multiplied and an unusual secondary burial was found; the first 2017 campaign showed much deliberate gathering and inter-cutting of graves, and the second brought to light the wealthiest burials; and finally, the last season provided the first double burial (one with lethal injuries). We can fear (and be delighted at the same time) the variability of KDK23 funerary practices, for other new burial features will surely appear in the coming years.

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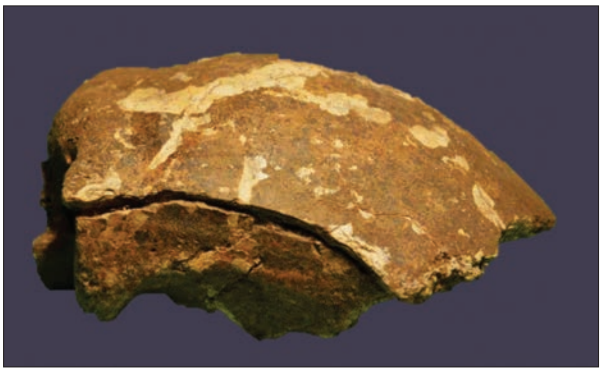

Plate 10. St.89: blunt-force trauma on left fronto-parietal area of the cranium.

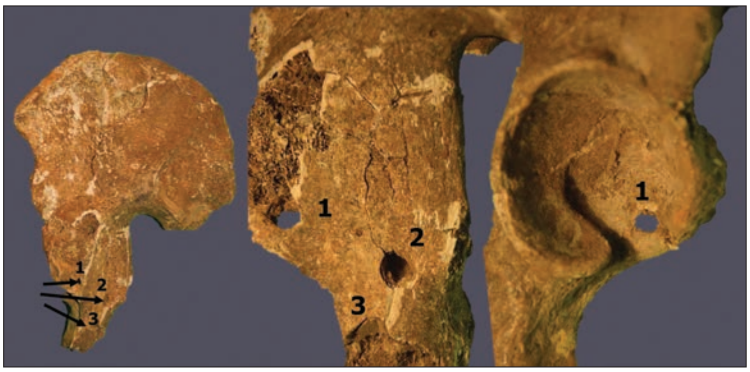

Plate 11. St.89: medial and lateral view of right os coxae (hip-bone) with 3 perimortem sharp-force traumas (number 1 perforated the acetabulum).

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2.3 beDNA : banque d'échantillons et de Données Nationale Archéogénétique

La banque d'échantillons et de Données Nationale Archéogénétique (beDNA) n'est pas à proprement parler un projet de recherche mais plutôt une démarche de conservation particulière, à travers une banque d'échantillons de grande ampleur, destinée à la paléogénétique, qui fait intervenir tous les organismes en charge de l'archéologie funéraire. beDNA est géré essentiellement par l'équipe ABBA mais associe d'autres équipes (AGène) et des compétences propres à la conservation (Musée de l'Homme au sein du MNHN).

Présentation : préserver le futur

beDNA est un projet ayant pour objectif le prélèvement *systématique* d'échantillons archéologiques humains sur les opérations en cours et à venir afin de préserver au mieux les restes d'ADN pour des analyses paléogénétiques futures. Ce projet a été initié en 2016 par Philippe Chambon, Céline Bon, Pascal Sellier et Aline Thomas (UMR7206 Éco-Anthropologie, équipes ABBA et AGène). Il a très vite été présenté au ministère de la Culture (prescripteur régalien des fouilles archéologiques en France) et au Conseil national de la recherche archéologique (CNRA) qui l'ont immédiatement soutenu. La phase test du projet beDNA en région Île-de-France a débuté en septembre 2020 à la suite de la création d'un contrat destiné au recrutement d'une personne dédiée au projet et référente de la banque beDNA (Pauline Ehrhardt, IE).

Fig. 1. Prélèvement à Tremblay-en-France (Photo S. Lafosse, avec l'autorisation d'A. Mayer, responsable d'opération)

Problématique : un projet nécessaire

Plusieurs constats sur la paléogénétique en France sont à l'origine de ce projet. En effet, la paléogénétique est devenue aujourd'hui une discipline majeure dans l'étude des populations humaines du passé. Cette discipline a apporté une somme d'informations aux études ostéologiques des vestiges anthropobiologiques humains, à la fois du point de vue « populationnel » (évolution et relations des groupes humains, agents pathogènes, etc.) et du point de vue archéologique (relations de parenté, sexe biologique, individus extérieurs au groupe, etc.). Malgré les avancées technologiques dans cette discipline, l'objet d'étude de la paléogénétique, l'ADN ancien, est une molécule fragile, difficilement conservée dans les ossements du fait d'une dégradation constante au cours du temps. L'ADN ancien est également assez facilement pollué par l'ADN moderne de nos propres cellules. En outre, cette vulnérabilité inhérente à l'ADN ancien est associée à des contraintes matérielles qui entravent la paléogénétique en France aujourd'hui : l'éparpillement des échantillons archéologiques dans une multitude de structures, des moyens de prélèvement et de conservation hétérogènes et le manque de standardisation des demandes d'analyse (un certain « chacun pour soi »).

Né de ces constats, le projet beDNA a pour objectif de faciliter le développement des études paléogénétiques sur les restes archéologiques découverts en France. Ce projet implique : (1) la création d'une base de données accessible à tous les chercheurs porteurs d'un projet d'étude génétique ; (2) la mise en place d'un protocole de prélèvement des échantillons commun à toutes les opérations archéologiques, avec la prescription par l'État de tels prélèvements ; (3) un espace de stockage dédié au projet (banque beDNA), au Musée de l'Homme (MNHN Paris) ; (4) un processus d'évaluation et d'approbation par l'État des demandes d'analyse d'échantillons (pouvoir régalien assisté d'une expertise scientifique).

☞ Une note des *Bulletins et Mémoires de la Société d'Anthropologie de Paris* présentant le projet beDNA de façon plus détaillée est disponible à l'adresse suivante : https://journals.openedition.org/bmsap/11516

☞ Une page web dédiée au projet : https://www.ecoanthropologie.fr/fr/bedna-9101

Fig. 2. Sachets de prélèvements avant leur transfert au Musée de l'Homme (photo V. Bayard)

La phase-test en cours : la région Île-de-France

Depuis le début de la phase de test, le projet a pu être présenté à l'ensemble des opérateurs archéologiques en Île-de-France, dont l'implication dans le projet est primordiale (État, opérateurs publics et privés) et les prescriptions (par le préfet *via* le Service régional de l'archéologie, SRA d'Île-de-France) sont désormais systématiques. Des prélèvements ont été effectués sur l'ensemble des restes humains (sauf crémation) découverts depuis octobre 2020. Les services archéologiques sont autonomes pour les prélèvements et le projet beDNA est efficace, même sans déplacement direct sur le terrain.

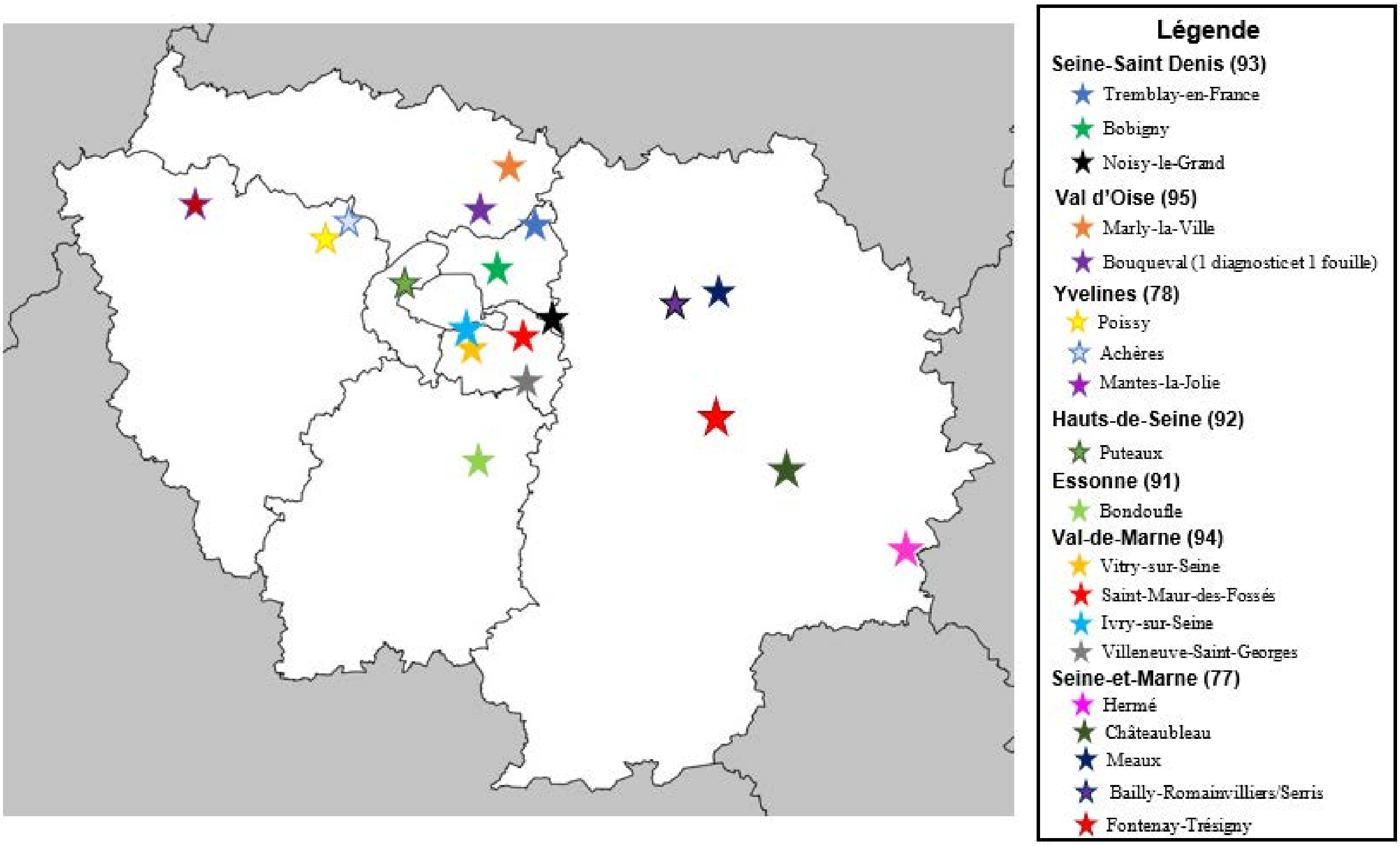

Fig. 3. Carte de la région Île-de-France avec les sites ayant fourni jusqu'à présent des restes humains pour le projet beDNA

Au mois d'avril 2023, la base de données beDNA a enregistré 198 individus prélevés représentant un total de 343 échantillons, provenant de 20 fouilles et diagnostics archéologiques : Tremblay-en-France, Marly-la-Ville, Bouqueval (diagnostic), Bondoufle, Vitry-sur-Seine, Saint-Maur-des-Fossés (2 diagnostics), Ivry-sur-Seine, Hermé, Bobigny, Meaux, Noisy-le-Grand, Villeneuve-Saint-Georges, Bouqueval (fouille), Châteaubleau, Poissy, Mantes-la-Jolie, Puteaux, Achères, Bailly-Romainvilliers/Serris et Fontenay-Trésigny. Les retours d'expérience et le bilan sont nettement positifs.

Perspectives

Dans la suite de la phase de test, qui se terminera en 2025, le parcours de l'échantillon du terrain de fouille à la banque beDNA va continuer à être optimisé, en poursuivant la réalisation et divers essais de prélèvement sur différents types de sites archéologiques (cimetières, nécropoles, tombes isolées, sépultures collectives, restes humains épars en contexte funéraire ou non, diagnostics, fouilles programmées, etc.). Les actions de formation se poursuivent (sur le terrain et dans un « cours Muséum » dédié) et les retours d'expérience des archéo-anthropologues et des responsables d'opération des sites archéologiques enrichissent notre démarche. Le parcours de l'échantillon de la banque beDNA aux laboratoires de paléogénétique doit également être testé, notamment les procédures d'accès et d'autorisation ainsi que les échantillonnages pour étude paléo-génétique par les diverses équipes scientifiques. Si tout cela est jugé positif, le projet sera élargi à une autre région, voire à toute la France, mais ce sera un changement de dimension qu'il nous faudra anticiper.

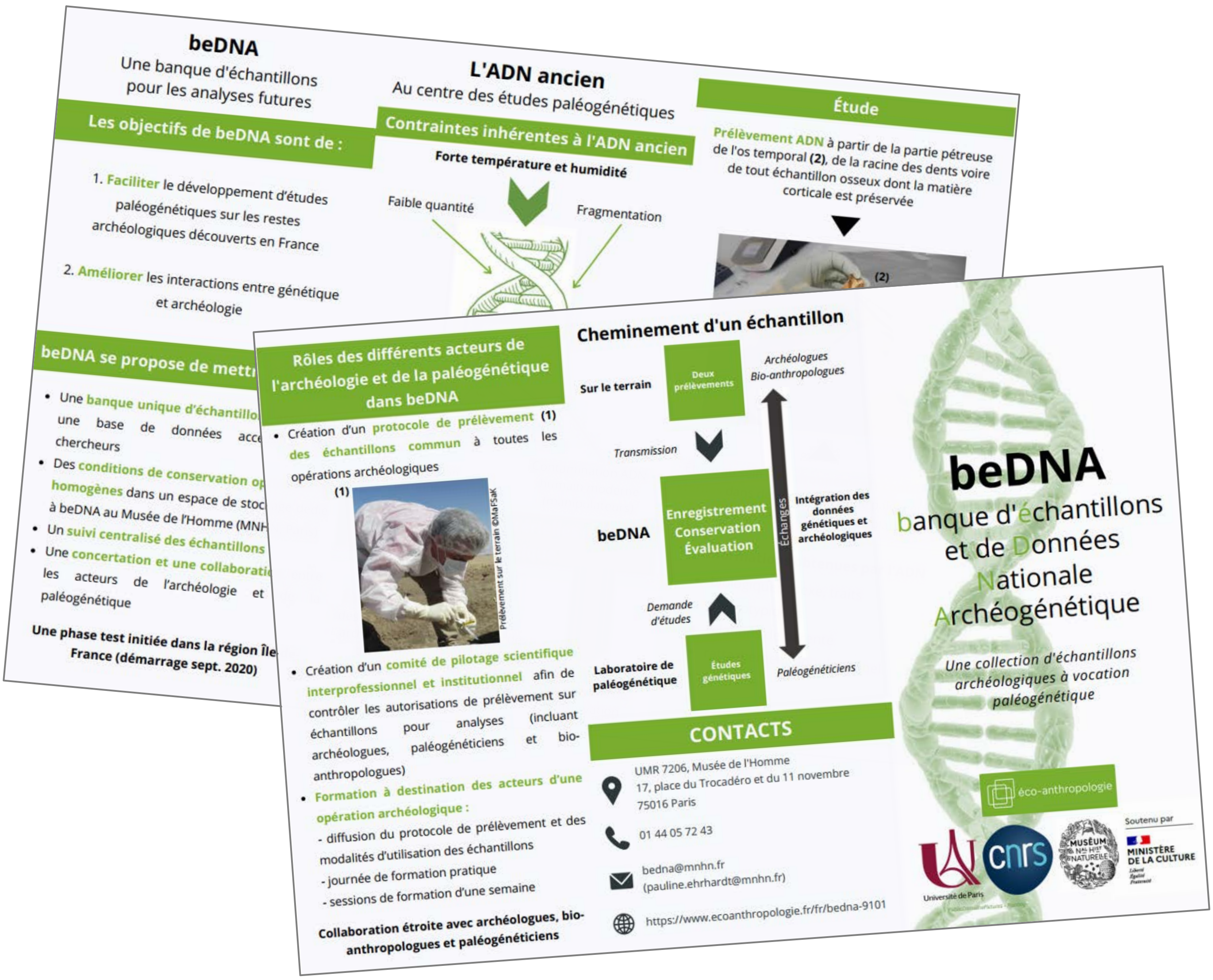

fig. 4. Le « dépliant beDNA », diffusé aux opérateurs et aux acteur/rice.s de l'archéologie