A Neolithic population model based on new radiocarbon dates from mining, funerary and population scaled activity in the Saint-Gond Marshes region of North East France

Kevan Edinborough[a,*], Rémi Martineau[b], Alexa Dufraisse[c], Stephen Shennan[d], Marie Imbeaux[b], Anthony Dumontet[b], Peter Schauer[e], Gordon Cook[f]

[a] Melbourne Dental School, Faculty of Medicine, Dentistry and Health Sciences, Level 5, 720 Swanston Street, The University of Melbourne, Victoria 3053 Australia

[b] CNRS, UMR 6298, ARTEHIS, Archéologie Terre Histoire Sociétés, University of Bourgogne Franche-Comté, 6 bd Gabriel 21000 Dijon, France

[c] CNRS UMR 7209, AASPE, Archéozoologie et Archéobotanique. Sociétés, pratiques et environnements, Museum National d'Histoire Naturelle, Paris, France

[d] Institute of Archaeology, University College London, 31-34 Gordon Square, Bloomsbury, London WC1H 0PY, United Kingdom

[e] Department of Archaeology, University of Cambridge, Downing Street, Cambridge, CB2 3DZ, United Kingdom

[f] Scottish Universities Environmental Research Centre, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, G75 0QF, United Kingdom

*Corresponding author

E-mail address: kevan.edinborough@unimelb.edu.au

Abstract

We present and model new radiocarbon data for the Neolithic marshes of Marais de Saint-Gond Marne in France. We then provide the first radiocarbon-based synthesis of human activity in this region. The earliest flint mine pits dug in France were dated to between 7518 and 7356 cal BC (95% probability) in the Mesolithic period. A Neolithic sequence of activity has been reconstructed in detail for the mine and hypogeums in the Vert-la-Gravelle "La Crayère" site. Using summed probability distribution frequencies with new radiocarbon results from flint mines, hypogeum-burials and settlements, we show the peak of regional population is consistent with the advent of the hypogeum construction during the Néolithique récent/ Néolithique final between 3650 and 2900 cal BC (95% probability).

Keywords: Neolithic; Mesolithic; Mining; Hypogeums; Radiocarbon; France

1. Introduction

Figure 1. The main Neolithic sites of Les Marais de Saint-Gond (Marne, France). Map M. Imbeaux and R. Martineau.

1.1 Introduction

We present a regionally scaled modelling method, that allows comparison of a significant number of radiocarbon dates from Neolithic mines and quarries and burial chambers (hypogeums) in the Champagne region (Saint-Gond, Marne department, France) to the East of the Paris Basin. We compare different categories of site activity, and examine the relationship between burial customs, mining activity and settlement practices. Our weighted simulation-based radiocarbon model uses all the available radiocarbon evidence from sites including hypogeums (see below), to approximate relative population fluctuations through time and relate them to mining and burial activity. Our population scaled approach using radiocarbon data allows us to cross-compare archaeological sequences previously inferred from culturally attributed pottery and lithics in the region.

1.2 Project background

This joint project between French and British teams uses aerial prospection, walk-over surveys, site-mapping, excavations, artefact studies, geological investigations, and bioarchaeological and palaeoenvironmental analyses to provide the most detailed archaeological knowledge possible for this Neolithic region. We also take a quantitative approach using large aggregated radiocarbon and flint and copper-based datasets (Schauer *et al.* 2020; Edinborough *et al.* 2020).

Generally speaking, there are four different approaches to estimate the variations in the density of the pre- and protohistoric populations: the study of variations in the intensity of occupation of the territory by counting the number of sites by chronological and cultural periods, the estimation of the degree of anthropisation of the environment by paleoenvironmental studies, palaeodemographic studies in physical anthropology and genomics, and the statistical estimation of variations in population density from the dating of archaeological sites. Here we use the last, following a particularly well-developed and conservative methodological approach using radiometric data and simulation (Shennan *et al.* 2013; Edinborough *et al*. 2017; Crema and Bevan 2020).

Despite its widespread success, the radiocarbon-based ‘’dates as data’’ approach has been seen to have limitations by some, related to a misunderstanding of the current method and its early applications, or an unawareness of published methodological and computational advances readily available in the literature. The weighted Summed Probability Distribution (henceforth SPD) approach demonstrably works if used correctly (Edinborough *et al.* 2017). Since 2013 it has employed a useful hypothesis testing approach, allowing for instance, a conservative simulation-based test of the available archaeological data against an exponential or other null model of population growth (Shennan *et al.* 2013). In essence, the weighted SPD method accounts for sources of potential errors and enables one to assess the utility of each model by a significance test, expressed by a global probability value generated for each model (Crema and Bevan 2020).

1.3 Regional setting: Les Marais de Saint-Gond

This region is geologically unique in Europe, containing flints from both Campanian chalk and Bartonian Tertiary limestone. The marshes of Saint-Gond (140 m) are located at the foot of the cuesta d'Île-de-France (220 m), at the contact between the plain of chalk Champagne and the plateau of Brie champenoise. The east of the plateau de Brie is made up of the Tertiary of the eastern end of the central Paris basin plateaus, while the west of this region is made up of the Cenomanian chalk which outcrops into the "dry" (or chalky) Champagne.

In the south-western part of the Marne, particularly in the Marais de Saint-Gond, high-quality flints were exploited from the Palaeolithic and the Mesolithic periods. The Neolithic period saw an intensification of flint mining and other activity. Numerous collective burials, hypogeums (rock-cut burial chambers) and a few gallery graves have been discovered since the XIXth century. Many tombs are located close to the flint mines, and in the case of “La Crayère” (Vert-la-Gravelle) are cut into them, alongside settlement (dwelling) sites. Securely dated event horizons until now were often speculative, as characteristic artefacts, notably pottery, are often absent, so the vast majority of ancient activity in this under-researched region of France was poorly dated.

The Saint-Gond Marshes region includes more than 300 listed Neolithic sites and features although the vast majority remain undated by radiocarbon. Only a fraction of these sites include remains that can be dated chronologically or culturally. The chronology of the main cultural periods are presented at the bottom of figure 5. In this paper we analyze the results of sites that we have radiocarbon dated. We chose these sites because they had good stratigraphy and available organic remains that may yield accurate radiocarbon measurements to establish a chronological baseline for the Neolithic of this region as this study is the first synthesis of radiocarbon data for this region. For an expanded discussion of the key sites we dated, see Supplementary Information. Most of these sites are located north of the marshes, on the slopes of the cuesta of Île-de-France. These steep slopes were used to dig flint mines and hypogeums. More than 120 hypogeums are grouped into necropolises (figure 1). There are also five gallery graves. Dozens of mines are located near these collective burials. Four dwellings have been excavated and dozens of traces have been identified. Eight earth-fast polissoirs, stone axes and four menhirs (three of which were destroyed in ancient times) are also present. Hundreds of knapping workshops have been identified by walk-over surveys.

All chronological periods of the Neolithic are represented in this region and we use italicized French nomenclature for archaeological periods to avoid confusion (see bottom of figure 4, below) with the currently agreed dates for cultural divisions (Manning *et al.* 2014). The *Néolithique ancien* is known from two sites. A crucial single burial is attributed to the Linear Pottery Culture (5200-4900 cal BC), at Vert-la-Gravelle (Vert-Toulon) "Le Bas des Vignes" (Chertier and Joffroy 1966, Chertier 1988). A dwelling site of the Blicquy/Villeneuve-Saint-Germain culture (4900-4700 cal BC) is under excavation at Villevenard "Les Hauts de Congy" (Martineau *et al.* 2020).

Cultural attributes from archaeological artefacts indicate that the *Néolithique moyen* period is also present in Broussy-le-Grand "L'Ourlet". *Néolithique moyen* I (4700-4300 cal BC) is represented by the Cerny Videlles culture and an assemblage from the western Bischheim (Charnot 2019). Other pottery at the site can be attributed to the Balloy group. In terms of cultural affiliation and dating, the flint mine of Vert-la-Gravelle "La Crayère" could correspond to the Michelsberg or to the Northern Chassean culture (*Néolithique moyen* II, 4300-3700 cal BC). The presence of a few transverse arrowheads in the mine could be attributed to the Northern Chassean culture (Bostyn 2018).

Most Neolithic sites in this region are attributed to the *Néolithique récent* (3600-2900 cal BC) with one occupation layer at the dwelling site of Broussy-le-Grand "L'Ourlet" (Charnot 2019) and a dwelling site at Val-des-Marais (Morains-le-Petit) "Le Pré à Vaches" (Martineau *et al.* 2014). All the collective burials of this region including the hypogea and gallery graves date from this period (3600-2900 cal BC), a time of major collective burial construction throughout the Paris Basin (Bailloud 1974). The scarcity of ceramics in tombs and the 'quasi-absence' of coeval settlements (see below) makes it impossible for the moment to define the archaeological culture that corresponds to the many collective burials in the Paris Basin, and in fact a large part of the northern half of France (Chambon and Salanova 1996, Cottiaux *et al*. 2014, Salanova *et al.* 2011). Until now all known collective burials in northern France were included in the Seine-Oise-Marne culture. Recently they have been divided up between the Seine-Oise group and the Marne group (Salanova *et al.* 2011). The *Néolithique final* period, between 2900 and 2400 cal BC, is represented by the dwelling site of Ecury-le-Repos "Le Clos", where pottery discovered is characteristic of the Gord culture (Villes 1983).

1.4 Flint mines in St. Gond

The presence of large quantities of very good quality flint in secondary chalk and tertiary limestone explains the presence of mines covering such surfaces, exploited over long periods of time. The well-preserved mining site of Vert-la-Gravelle (Vert-Toulon) "La Crayère" is of particular interest here, as there are very few of these types of mining contexts in Europe. Many other mining centers are well-known in France; in Pays d'Othe, Jablines (Bostyn and Lanchon 1992), Normandie (Desloges *et al.* 2010), Oise and elsewhere in Europe, in England at Grime's Graves and on the South Downes (Healy

2018; Edinborough 2020), Germany (Arnhofen), The Netherlands (Rijckholt) and Belgium (Spiennes, Collet *et al.* 2008), but in these complexes the burials are unclear, and dwellings are very rare (only in Jablines region and in Krzemionky in Poland). The unique importance of this site is the subject of a forthcoming paper focused entirely on excavations at Vert-la-Gravelle (Vert-Toulon) “La Crayère” and surrounds (Martineau in Prep).

The flint mines of St-Gond belong to a mining complex comprising a lot of collective burials, dwellings, flint-knapping workshops, earth-fast polissoirs. 46 flint mines grouped in seventeen mining sectors have been identified in this region. They are distributed along the south-east of the Côte d’Île-de-France, on the hill slopes, which provide easy access to the flint outcrops. Five of these mines have been excavated, and many others have been detected by aerial photographs or by pedestrian surveys (Martineau *et al.* 2014, 2019). The total area of mines detected in the south-western Marne covers an approximate area of about 300 hectares.

1.5 Hypogeums in St. Gond

166 hypogeums have been discovered in 38 necropolises in the Marne department. In Les Marais de Saint-Gond region, 128 hypogeums are grouped into 19 necropolises with 19 other collective burials located in the north-east, on the Côte des Blancs. Five gallery graves are also known in Les Marais de Saint-Gond and a small fraction of these burials are radiocarbon dated. The lack of excavations prompted samples from collections to be targeted, but these are not easy to access as the process can be destructive and may not contain enough collagen to yield a measurement. Several related artefacts in the National Museum of Archaeology have been restored with old carbon-based preservatives, which further complicates accurate radiocarbon measurement (see methods).

Fortunately, in some instances thousands of highly characteristic archaeological artefacts do make it possible to culturally attribute certain tombs to the Néolithique récent and the beginning of the Néolithique final periods (3600-2900 cal BC; Chambon and Salanova 1996, Cottiaux and Salanova 2014, Martineau *et al.* 2016, Blin 2015, Chambon *et al.* 2017). These finds consist mainly of deer antler axe sheaths/tine pick with transversal handles, deer antler tool handles (see figure 2 below), bone-punch/poinçon, ornaments (discoid chalk beads, keel-shaped deer antler pendants, doubled drilled sconces, Unio mother-of-pearl, etc.) and flat-bottomed truncated cone-shaped pottery.

Figure 2. Upper panel, archaeological Excavation at Vert-la-Gravelle “La Crayère” showing north facing necropolis burial chambers (hypogeum 2, in center under red/black survey scale) cut into north facing flint mine face. Lower Panel, Antler tine pick, with shaft-hole and use-wear, from deer antler axe sheath with transversal handle from Villeneuve-Saint-Vistre-et-Villevotte “Montaubar”. Photos R. Martineau.

1.6 Flint mine and hypogea necropolis of Vert-la-Gravelle "La Crayère"

As it uniquely contains both flint mines and a hypogea necropolis, the best studied mine in this region now is undoubtedly the Vert-la-Gravelle "La Crayère" site, excavated from 2013 to 2020. The site is located on a steep slope, on the eastern side of the Toulon hill. A flint seam located at an altitude of 192 m was exploited using several types of structures: deep cylindrical prospecting pits, shallow pits, bell pits and an open faced 'cutting front' which is the chief characteristic of this site. A series of successive cuttings were made towards the hill side end in one or more mining chambers. At the end of the flint extraction, the successive excavations form large excavated surfaces resembling an open-pit quarry. This type of exploitation is extremely rare in Europe. The mine delivered thousands of flint scatters from mine exploitations and debitage, as well as a few hammerstone tools and transverse arrowheads. In the mine's debris several dozen antler fragments were found, as well as some very well-preserved antler picks and levers.

Vert-la-Gravelle "La Crayère" also includes a necropolis of four hypogeums, three of which are perfectly preserved. The tombs do not have antechambers. They have square chambers of 8 to 10 m^2 that are accessed via a corridor 2.3 to 4.2 m long. Pottery, numerous ornaments, and the flint, bone and antler tools discovered in the burial chambers of the hypogeums are characteristic of the *Néolithique récent*, between 3600 and 2900 cal BC. The site's stratigraphy shows two successive ancient occupations. The hypogeum corridors were excavated in the upper part of the flint mine, about one meter above the exploited flint bank. The flint mine therefore predates the hypogeums. Among the many hypogeum necropolises in the region, the "La Crayère" site at Vert-la-Gravelle is the only one that combines collective burials and flint mining. Here, these two types of structure are closely intertwined. However, it is clear that the hypogeums do not reuse ancient mine exploitations; the morphologies and organization of each type of digging are totally distinct. The proximity of these two occupations initially suggested that the hypogeums were dug shortly after flint mining, and an intra-site radiocarbon analysis fully incorporating all this site's complex stratigraphic relationships is now in preparation.

Elsewhere, the cases of Gavà (Barcelona, Spain; Borell *et al.* 2015), Spiennes (Belgium; Toussaint *et al.* 1997, Collet and Toussaint 1998), Cissbury (England), Vertus "Granval" (Marne, France; Coutier *et al.* 1962), or Salinelles "La Vigne du Cade" (Gard, France; Peyrolles 1959, Beyneix 2003, p. 165-166) and others, despite being very interesting, are very different from those of Vert-la-Gravelle "La Crayère". In those cases burials seem to be coeval with mining exploitation, which is stratigraphically not the case in "La Crayère".

2. Methods

2.1 Radiocarbon Samples, Pre-treatments

All the sites containing datable artefacts have been systematically sampled. In Vert-la-Gravelle "La Crayère » and Loisy-en-Brie « 56 Grande Rue » some stratigraphic units contain no deer-antler fragments or seeds, so identified wood charcoal fragments must be selected for radiocarbon dating. Charcoal fragments were analyzed with the specific objective of undertaking radiocarbon dating series. We selected the most appropriate charcoal fragments to avoid the "old wood" effect and to improve the accuracy of radiocarbon dating. Selection of charcoal fragments was based on the identification of short-lived taxa and their dendro-anthracological analysis (Dufraisse *et al.* 2018 and 2020), see Supplementary Information: Methods of charcoal selection to improve the accuracy of radiocarbon dating).

Anthracological analysis of the Vert-la-Gravelle site allowed the identification of hazelnut (*Corylus avellana*), yew (*Taxus baccata*), maple (*Acer* sp.), ash (*Fraxinus excelsior*), and elm (*Ulmus* sp.). At the Loisy-en-Brie site, dogwood (*Cornus* sp.), hornbeam (*Carpinus betulus*), deciduous oak (*Quercus* s.p.), and wild cherry (*Prunus avium* type) samples were identified.

All radiocarbon samples listed (see Table 1) were processed and measured in collaboration with the Scottish Universities Environmental Research Centre (SUERC) Radiocarbon Dating Laboratory at East Kilbride, Glasgow. All methods including sample, pretreatment, CO_2 generation and purification, graphitization, and accelerator mass spectrometry (AMS) measurement were as described in Dunbar *et al.* (2016). All new measurements we obtained are detailed in the main text table 1. Certain samples from the French National Museum of Archaeology were not successfully processed by SUERC as they had old carbon present in the form of old varnish related preservatives (see Supplementary Information for full radiocarbon and sample and results listings).

2.2 Radiocarbon calibration models

Radiocarbon data are calibrated with rcarbon calibration software (Crema and Bevan 2020) using the IntCal 2020 calibration curve (Reimer *et al.* 2020).

Following standard chronometric hygiene procedures where data of greater than a 200 year standard error are excluded from this type of analysis (Shennan *et al.* 2013, Timpson *et al.* 2014, Edinborough *et al.* 2020), a series of summary Summed Probability Distribution (SPD) models are presented for the 11 sites in the Les Marais de Saint-Gond region (Champagne, Marne) using rcarbon code (Bevan and Crema 2020; Crema and Bevan 2020) (Fig. 3, 4).

We then combine all the data from this region into a dataset (see Supplementary Information) to test a null model of exponential population growth there (Fig. 5; plot A; Shennan *et al.* 2013; Edinborough *et al.* 2017; Bevan *et al.* 2017; Crema and Bevan 2020).

After accounting for excavation and wealth related biases (variation in sampling intensity concerning the number of samples dated at a site) by binning all the radiocarbon data by site into 100-year intervals, to explain the following computational process we paraphrase Crema and Bevan (2020) as follows. We use a Monte-Carlo simulation approach consisting of a three-stage process: 1) fit an exponential growth model to the observed SPD 2) generate random samples from the fitted model; and 3) uncalibrate the samples.

The resultant set of radiocarbon dates is calibrated and aggregated (summed but not normalized Weninger *et al.* 2015 Weninger and Edinborough 2020) to generate an expected SPD of the fitted model taking into account the calibration process. This process can be repeated n times (here we use n=1000 and n=10000 for comparison) to generate a distribution of weighted SPDs (which also considers the effect of sampling error) that can be compared to the observed data.

Higher or lower than expected density of observed SPDs for a particular year will indicate local divergence of the observed SPD (real data in dotted red line) from the fitted model (grey band on the figure), and the magnitude and frequency of these deviations can be used to assess the goodness-of-fit/efficacy of the model via a global test (global p value). By employing a computer run of n=10,000 simulations (only 1000 simulation runs yields very similar results), the simulation process allows us to account for the vagaries of the calibration curve, possible AMS machine measurement error, and false positive results (Crema and Bevan 2020). These extremely conservative test results are then illustrated in red or blue vertical bands, where real data radiocarbon results deviate from the exponential null of taphonomic loss and population growth (Shennan *et al.* 2013). Here, radiocarbon data are not normalized after calibration (Weninger *et al.* 1986, 2015, 2017, 2020; Bevan *et al.* 2017). The resultant plots then tell us whether our model demonstrates a statistically significant positive (vertical red band) or negative (vertical blue band) population event, to a 95% confidence threshold (grey band) in our population model.

For methodological consistency, we use rcarbon freeware (Bevan and Crema 2020) to calibrate and plot our radiocarbon measurements, and we also list the resultant calibrated date results to two standard deviations (see Supplementary Information), using the standard IntCal 2020 calibration curve (Reimer *et al.* 2020).

3. Results

3.1 Following Radiocarbon publishing protocol (e.g., Edinborough et al 2016) we present a summary date list of the radiocarbon measurements obtained in this project here in table 1.

We then model and calibrate all the available the radiocarbon results below. For further information about each archaeological context where the radiocarbon data was obtained, and for all the available radiocarbon data for this region accordingly with calibrated results, please see table S1 in Supplementary Information and the accompanying supplementary site level information for more archaeological data.

Table 1. N = 30 New radiocarbon measurements. See Supplementary Information for more information and site level discussion of radiocarbon samples and calibrated results. This table details new measurements from Mesolithic and Neolithic dwellings/settlements, burial sites, and mining contexts.

Figure 3. SPD rcarbon plot clearly showing the sum of two very early Mesolithic dates at the site of Loisy-en-Brie "56 Grande Rue" pit F, possibly the earliest flint mining structure dated in France.

3.2 Mesolithic

The two dates attributed to the Mesolithic period have been obtained from two deer-antler fragments coming from the same stratigraphic unit (US19) of pit F of Loisy-en-Brie “56 Grande Rue” mine.

Using OxCal (Bronk Ramsey 2008; 2020) we conducted a pooled mean X2 test (Ward and Wilson 1978) of two putatively Mesolithic radiocarbon measurements from Pit F (US19), to see whether or not the results from the antler we dated from the pit were consistent with each other. Pooling the measurements before calibration provides a narrower date range after calibration. The OxCal based test results are as follows, R_Combine (8365,26), 95.4% probability the pooled event occurred between 7518BC (63.3%) 7422BC, and 7415BC (32.1%) 7356BC; X2-Test: df=1 T=2.0 (5% 3.8). Although pit deposits are often mixed, because our result indicates both results are consistent with each other, we propose they can be from the same Mesolithic depositional event, even if the antler are from different individuals.

Figure 4. Summary Summed Probability Distribution panel plot of sites dated, including those previously dated and mentioned in the text, enabling accurate like-for-like comparison of the calibrated radiocarbon data for the Neolithic period in the St. Gond Region; “n=” number of radiocarbon dates calibrated. Radiocarbon results are not normalized after summing, and so sum to one (Weninger *et al*. 2015; Bevan *et al.* 2017).

3.3 Neolithic

Here we summarize the key radiocarbon results that shed new light on the Neolithic for this region, whilst more site level detail is provided in supplementary information, with reference to the summary of results as shown calibrated and summed in Figure 4 using Rcarbon software (Crema and Bevan 2020).

In Vertus "Granval" three antler picks were discovered with the skeleton of a woman at the bottom of an extracting shaft. Two of these picks have been dated; the third sample has failed. The results make it possible to set the exploitation between 3355 and 3102 cal BC (VG1, 4520 +/- 28) and between 3310 and 2904 cal BC (VG3, 4390 +/- 40), which corresponds to the *Néolithique récent* and the beginning of the *Néolithique final* periods.

Twenty-nine new dates were obtained for Vert-la-Gravelle “La Crayère” (see table 1 and Supplementary Information). Sixteen concern the mining structures and five concern the unique rock cut hypogeums. The start date of the mine activity corresponds to an occupation situated between 4341 and 3637 cal B.C., in *Néolithique moyen II* and possibly attributable to the *Chasséen* horizon, which is in an anterior position to the original excavation and use of the hypogeums.

We obtained a new date ranging between 3346 and 3097 cal BC from a deer antler axe sheath with transversal handle. This result originated from the hypogeum of Villeneuve-Saint-Vistre-et-Villevotte « Montaubar and so confirms that the hypogeum period of construction is circumscribed, within half of a millennium.

For the dwelling site of Ecury-le-Repos « Le Clos » two samples from pottery sherds have been analysed. One has failed (GU47229) and the other one (SUERC-78934) has confirmed the attribution to the *Néolithique final* period, already highlighted by the pottery study, whereas another date has an attribution to the *Néolithique récent*. Occupation of this site during these two periods cannot be excluded, whereas pottery is clearly attributable to the Néolithique final and notably to the *Gord* culture.

Figure 5. Summed Probability Distribution (SPD) models.

A. SPD population model using available radiocarbon data weighted into 100 year bins for the Marne region (St. Gond data plus "Le Brabant" site; n = 98; see below). Red dotted line = real data. Grey area is the simulated exponential null model based on the real data; red shading = period of positive deviation from exponential null model, significant to a 95% confidence interval.

B. Unweighted/unbinned SPD (grey area of plot) of St. Gond mines (N= 30 radiocarbon dates)

C. Unweighted/unbinned SPD (grey area of plot) of St. Gond Hypogeums (N= 33 radiocarbon dates)

D. Unweighted/unbinned SPD (grey area of plot) of St. Gond dwellings (N= 7 radiocarbon dates)

Dates of generally agreed cultural historical divisions are shown at the bottom of the plot, where the solid grey bar represents the range of culturally attributed dates known for dwelling sites that still require radiocarbon dating.

3.4 Weighted SPD population model using all available and screened Radiocarbon data from the region of Marne/St. Gond

All available radiocarbon data (n-98) was binned into 100-year intervals, which reduced excavation/sampling bias (Edinborough *et al.* 2017). A 200-year moving average was fitted to the real data, seen as the red dotted line for visual clarity (see also Timpson *et al.* 2014), with the grey band created by 10,000 simulations of 98 radiocarbon dates created under an exponential null model across the date range. There is a period of significantly higher population (Number of radiocarbon dates: 98; Number of bins: 33; statistical significance computed using 10,000 simulations following Edinborough's protocol (*et al.* 2017), and the model's global p-value was: 0.0498. For comparison we replicated our results with just 1000 simulations, where the smaller run of the simulation yields very similarly and significant results (see Supplementary Information). In sum, we see a period of significantly high population in the Marne region between 3369-3061 cal BC, coeval with the SPD of plot C hypogeums in St. Gond (see below), thus co-occurring with hypogeum construction, long after the initial peak of mining activity.

3.5 Mining

Development of mining (Plot B) begins in 4350 and ends in 2900 cal BC, and is in agreement with the relative dating, which shows a strong development in the Middle Neolithic, and a continuity of exploitation in the *Néolithique récent* period until the *Néolithique final*. The end of mining is the same as the hypogeum phenomenon (plot C) mining stops at the beginning of the *Néolithique final* (Supplementary).

3.6 Hypogeums

The period of the hypogeums (plot C) is now well defined in time, calibrated, between 3650 and 2900 cal BC which is perhaps unsurprisingly coincident with the 3369-3061 BC phase of higher population than predicted by the model calculated in plot A, given the amount of hypogeum data. The beginning, the development and the decrease of the phenomenon are well defined. Most of the dates are situated between 3350 and 3100, and then decrease from 3100 and up to 2900. It appears that the major period of the hypogeum construction is shortlived, lasting at most some 250 years, which is in agreement with the results obtained by Chambon *et al.* (2017).

3.7 Houses/Dwelling

The few *Néolithique ancien* and *Néolithique moyen* dwelling sites have not yet been radiocarbon dated, but we do know sites whose ceramic typology corresponds to the period 4900-3900 cal BC (grey rectangle under plot D).

Figure 6. A comparison of weighted SPD population models (A) with binned hypogeum data (same analysis in figure 5A). Plot B = same analysis as A, but without the hypogeum data included in figure 5. Number of radiocarbon dates: 54. Number of bins: 24. Statistical Significance computed using 10,000 simulations, global p-value: 0.72563 = not globally significant, indicating yet more radiocarbon data is required to investigate this region and time frame at this analytical scale.

On a cautionary note, when you remove the hypogeum data from the regional analysis, in figure 6B, the remaining data are apparently not sufficient to yield a global significance for that model. Although modelled population is seen to rise at the same time, in figure 6B there is no significant trend above the exponential population trend. Furthermore, taken in its entirety, our analyses in Figure 5 indicates that the appearance and development of collective burials and hypogeums in this region do not appear to be entirely explained by the presence of mining, which is already largely developed at this period.

4. Discussion

Firstly, the two Mesolithic dates obtained in Loisy-en-Brie “56 Grande Rue” (see figure 3), are the oldest yet for a flint mine in France. If this first observation is confirmed in this region or elsewhere, it provides us with a new perspective on flint exploitation in this period, as our results support the case for pre-Neolithic mining and exploitation of flint in this region.

These deer-antler fragments suggest that flint mining began very early here, and is the first evidence, in France, of a flint mining structure dated to the Mesolithic period. While it is not surprising, caution is required, as Mesolithic mining structures are extraordinarily rare. In Europe, the only flint mine dated to the Mesolithic is the Krumlovzky lès site (Moravia, Czech Republic), where chert was exploited in shafts (Oliva 2010, 2011, 2015, 2018). 13 dates (between 9660 and 5478 cal BC) correspond to the early and late Mesolithic there (Oliva 2019, p. 195). The care that needs to be taken when dating pits is illustrated by Pit D of Loisy-en-Brie “56 Grande Rue”; this site was initially dated to the *Néolithique moyen* (between 4555 and 4369 cal BC), but three samples from the same pit correspond to the *Néolithique récent*, so it is probable that the *Néolithique moyen* charcoal is intrusive.

Other than these two remarkable earlier (Mesolithic) dates our models show that most sites detailed in figure 4 start around the same time (around 4350 cal BC). At Vert-la-Gravelle “La Crayère”, a recent discovery of a mine exploited during the *Néolithique moyen I*, between 4700 and 4300 cal BC, remains to be radiocarbon dated, but shows that the mining extraction begins during the phase that succeeds the *Néolithique ancien* (Martineau *et al.* 2021). Les Marais de Saint-Gond may benefit from targeted excavation as direct evidence for mining and flint exploitation in the *Néolithique ancien* is currently absent. As we know of other mines exploited in this period in France, in Espins “Foupendant” and Soumont-Saint-Quentin “Les Longrais” (Calvados) (Charraud 2015, Desloges *et al.* 2010), future survey and excavation may yet reveal this activity. Petrographic and paleontological evidence for the diffusion of Saint-Gond flint (microscopic observations) indicate that it covers a large area of northeast France (Imbeaux *et al.* 2018). As an estimated 50,000 worked flint pieces (debitage) were found in the Saint-Gond dwelling site of Villevenard “Les Hauts de Congy” (Blicquy Villeneuve-Saint-Germain culture) this largescale flint workshop is directly related to an intensive exploitation of flint from then on.

Thus, the *Néolithique moyen* (NM) period undergoes a dramatic intensification, if not explosion, of both flint extraction and related economic activity at this period that requires further investigation, as it is apparently not associated with any evidence for a population increase (c.f. Schauer 2020). In our case study region, mining activity developed from 4350 cal BC to 3800 cal BC, possibly with a short interruption of around one century, until 2900 cal BC, continuous throughout this period and concurrent with settlement evidence. The current radiocarbon evidence indicates mining activity is less intense after the NMII period.

We suspect the presence of the *Balloy* group culture in the dwelling of Broussy-le-Grand “L’Ourlet” (Charnot 2019) although little data and burials are known for the *Néolithique récent* period in this region. Arguably the activity in this phase could be explained by a unique hypogeum ''innovation'' at a local population peak wherein new cultural innovations are more likely with significantly more people interacting, or perhaps by immigration of new people and their traditions (Edinborough 2005; 2009; Edinborough *et al.* 2020), both are hypotheses to be explored and tested in the future as more archaeological data is excavated and dated.

During the later period of mining activity, hypogeums are constructed between 3650 and 2900 cal BC. Settlement activity continues until the *Néolithique final*, after 2900 cal BC. This is the first time a hypogeum has been identified within the regional mining settlement-complex, a remarkable if not unique finding, as Neolithic mining complexes containing a deliberately cut funerary site are extraordinarily rare in Europe. A more detailed site level analysis hypothesizing a precise sequence of radiocarbon dated construction events within each mine shaft is ongoing for “La Crayère”.

In the surrounding regions of Saint-Gond, other hypogeums were dug and used during the *Néolithique final* period but some of them remain to be radiocarbon dated. To the North in Loisy-en-Brie “Les Gouttes d’Or” (Chertier *et al.* 1994), Ay-Champagne « Varmery » (Chertier 1967) and Bouy « Les Varilles » (Blin 2015) and to the South-east in Ramerupt “Cours Première” (Aube) and Rosnay l’Hôpital “Les Guallérandes” (Aube). Of the same period, Plichancourt “Les Monts” st. 631 (Marne) and Bréviandes « ZAC Saint-Martin » (Marne) are two collective burials but their interpretation as hypogeums is not certain (Bonnabel *et al.* 2014). It follows that these sites require further archaeological analysis to test our current results.

The rarity of hypogeums dated after 2900 cal BC in the Saint-Gond region indicate that they were not dug nor used in significant numbers during the *Néolithique final* period in this region. The societies continue to use collective burials, but these are in the form of megalithic gallery graves. Five monuments of this type were used in the *Néolithique récent* and *Néolithique final* periods in this region (show figure 1), providing us with good evidence for these burial customs.

Despite our comprehensive dating strategy, burials remain lacking for the Middle Neolithic period. Settlements remain rare for all periods although the BVSG site of Villevenard “Les Hauts de Congy” is currently under excavation (*Cerny* and *Bischheim* periods indicated at Broussy-le-Grand “L’Ourlet”, see grey bar bottom of figure plot). At present, unlike the other periods, mines are completely absent from the *Néolithique final* period here, so targeted excavations are urgently required to test whether or not this is the case.

In northern France, the *Néolithique récent* (3600-2900 cal BC) is poorly understood and mainly represented by collective burials. Until the 2012 discovery at “La Crayère” and the first spatial studies in this region, mining activity remained quite unknown and unconnected to hypogeum construction. We have now formally related one of the many flint mine complexes in this region to a period of dense occupation with radiocarbon based evidence. This result is supported by numerous culturally dated tombs and various other categories of sites. Whilst systematic mining clearly started in the *Néolithique moyen* 700 years before hypogeums were built in the *Néolithique récent*, despite the presence of a short radiocarbon gap between 3800 and 3700 cal BC and despite the lack of cultural knowledge for these periods, we suspect that mining and burial activities may have continued from the *Néolithique moyen* to the *Néolithique récent,* a point that warrants further archaeological investigation.

There are more than 350 collective burials from the *Néolithique récent* and *Néolithique final* in the Paris Basin (Peek 1975, Bailloud 1974, Chambon and Salanova 1996). 166 hypogeums have been discovered in the Marne department, of which 128 are in the Saint-Gond Marshes area and 19 in the Côte des Blancs. Five gallery graves are known in this region. These collective burials contained between 2 (de Baye 1880) and 170 individuals (Blin 2011, 2015). Despite the lack of knowledge concerning the quantity of human deposition within most of these tombs unfortunately discovered too early in the history of the discipline, we can estimate that they would have contained on average 20 to 30 individuals per tomb. The total number of the estimated buried population could amount to more than 3000 individuals. Probably only on the basis of the skulls, J. de Baye (1880) extrapolated that there were around 1000 individuals, from the hundred hypogeums that he discovered.

In the *Néolithique récent* period new funeral practices, the desire to group the dead in a collective place, changes in funeral recruitment criteria perhaps relating to worsening sanitary conditions (epidemics), may be due to changes in demographic structure. The increase in population density observed in the Saint-Gond region may be linked to a period of collective burial construction and use as indicated by the more conservative yet encouraging population modeling shown in figure 6. Our new radiocarbon analyses helps explain the presence of numerous collective burials in this micro-region. Here, the positive population signal, significantly above the exponential model of population growth (figure 5), is coeval with hypogeum construction during the *Néolithique récent*.

In summary, many Neolithic sites in the Marais de Saint-Gond region remain datable by radiocarbon, making it possible to test, refine or refute the models proposed here. Our findings at this population scale of analysis now help us target future excavation and analyses to shed new light on Neolithic occupation, mining, and burial practices in the Paris Basin and beyond. It is still necessary to continue quantifying, mapping, and dating the sites of the Marais de Saint-Gond, and excavations of dwellings/settlement sites remain central and essential, so proportions and spatial variation of the various classes of site can be more firmly established.

Data Availability/Appendix/Supplementary Information

1. Data sheet of all Marne/St. Gond region radiocarbon samples (.csv).

2. Text document further detailing the key sites, with our charcoal selection methods (.doc).

Acknowledgements

The authors would like to acknowledge colleagues and institutions for their help.

The UCL Neomine Team; Andy Bevan; Mike Parker-Pearson; Tim Kerig.

Bernie Weninger (Cologne University).

Rolande Simon-Millot for her help in the sampling of objects in the National Museum of Archaeology (MAN) in Saint-Germain-en-Laye, France.

Marie-Caroline Charbonnier (INRAP) who let us use the radiocarbon data of the Fère-Champenoise site.

Marie Charnot for the organization of the EAA 2019 session in Bern (Switzerland).

Excavation teams of the Saint-Gond Marshes project, students in archaeology at the University of Burgundy Franche-Comté (France).

Excavation fundings and administrative helps: French Ministry of Culture (Regional Service of Archaeology of the Regional Direction of Cultural Affairs in Champagne-Ardenne, Grand-Est region), National Center of Scientific Research (CNRS), Archéologie Terre Histoire Sociétés (ARTEHIS) lab, les Communautés de communes d’Epernay et des Paysages de Champagne, le Département de la Marne.

We are very grateful to the Leverhulme Trust for Research Project Grant RPG-2015-199 for the financial support that made this project possible.

References

Bailloud, G., 1974. *Le Néolithique dans le Bassin parisien*, IIe supplément à Gallia Préhistoire, CNRS.

de Baye, J., 1880. *L'archéologie préhistorique*, Paris, Ernest Leroux.

Bevan, A., Colledge, S., Fuller, D., Fyfe, R., Shennan, S. and Stevens, C., 2017. Holocene fluctuations in human population demonstrate repeated links to food production and climate. *Proceedings of the National Academy of Sciences*, 114(49), pp.E10524-E10531.

Bevan, A, Crema E.R., 2020. *rcarbon: Methods for calibrating and analysing radiocarbon dates*. https://github.com/ahb108/rcarbon.

Beyneix A., 2003. *Traditions funéraires néolithiques en France méridionale*. 6000-2200 avant J.-C., ed. Errance.

Blin, A., 2011. *La gestion des sépultures collectives du Bassin parisien à la fin du Néolithique*, thèse de l'Université de Paris Ouest Nanterre La Défense.

Blin, A., 2015. Mortuary practices as evidence of social organization in the Neolithic hypogea of the Paris basin, *European Journal of Archaeology*, p. 580-598.

Bonnabel, L., Basset, G., Desbrosse-Degobertière, S., Laurelut, C., Nasri, R., Paresys, C., Thiol, S., Vauquelin, B., 2014. Archéologie préventive et sépultures collectives : le renouvellement des données champenoises, *in* C. Laurelut, et J. Vanmoerkerke (dir.), *Occupations et exploitations néolithiques : et si l'on parlait des plateaux ?,* actes du 31e colloque Internéo de Châlons-en-Champagne, oct. 2013, *Bulletin de la société archéologique champenoise*, 107, 4, p. 407-421.

Borell F., Bosch J., Majo T., 2015, Life and death in the Neolithic variscite mines at Gavà (Barcelona, Spain), *Antiquity*, p. 72-90.

Bostyn, F., 2018. Le mobilier lithique des structures d'extraction de Vert-La- Gravelle « La Crayère », in : Martineau, R. (dir.), *Les occupations néolithiques des Marais de Saint-Gond. Volume 2. Vert-la-Gravelle (Vert-Toulon, Marne) « La Crayère »*. Minière de silex et nécropole d'hypogées, Rapport de fouilles et prospections programmées 2016-2018, ARTEHIS, Direction Régionale des Affaires Culturelles/Service Régional de l'Archéologie de Champagne-Ardenne, p. 216-227.

Bostyn F., Lanchon, Y. (dir.), 1992. *Jablines « Le Haut Château » (Seine-et-Marne): une minière de silex au Néolithique*. Documents d'Archéologie Française, 35, Paris.

Bronk Ramsey, C., 2020. *OxCal Calibration Software*. https://c14.arch.ox.ac.uk/oxcal.html. Visited June, 2020

Bronk Ramsey, C. 2008. Radiocarbon dating: revolutions in understanding, *Archaeometry*, 50.2: p. 249-75.

Chambon, P., Salanova, L., 1996, Chronologie des sépultures du IIIe millénaire dans le bassin de la Seine, *Bulletin de la Société préhistorique française*, 93, 1, p. 103-118.

Chambon, P., Blin, A., Bronk Ramsey, C., Kromer, B., Bayliss, A., Beavan, N., Healy, F., Whittle, A., 2017. Collecting the dead: temporality and disposal in the Neolithic *hypogée* of Les Mournouards II (Marne, France), *Germania*, p. 3-143.

Charnot, M., 2019, La céramique néolithique de Broussy-le-Grand « L'Ourlet » (Marne). Approche typologique et technologique, *Revue Archéologique de l'Est*, t. 68, p. 5-38.

Charraud, F., 2015, Exploitation minière et gestion des lames en silex du Cinglais au Néolithique ancien : de la minière d'Espins (Calvados) « Foupendant » aux habitats du Nord-Ouest de la France, *Bulletin de la Société Préhistorique Française,* 112, 2, p. 317-338.

Chertier, B., Joffroy R., 1966, La sépulture danubienne de Vert-la-Gravelle, *Bulletin de la Société préhistorique française*, 63, CCXXVIII-CCXXXIII.

Chertier, B., 1988. La sépulture danubienne de Vert-le-Gravelle (Marne), lieu-dit Le Bas des Vignes, *Préhistoire et Protohistoire en Champagne-Ardenne*, 12, p. 31-69.

Chertier, B., 1967, L'hypogée de Warmery-Haut à Ay-Champagne (Marne), *Bulletin de la Société préhistorique française*, t. 64, p. 651-658.

Chertier, B., Bouttier-Nicolardot, C., Nicolardot J.-P., 1994, L'hypogée néolithique de Loisy-en-Brie (Marne), lieu-dit Les Gouttes d'Or, *Préhistoire et protohistoire en Champagne-Ardenne*, 18, p. 23-53.

Collet, H., Toussaint, M., 1998. Découverte d'un squelette humain néolithique sur le site minier de Spiennes (Hainaut, Belgique) : étude préliminaire. in : Bostyn, F., Hachem, L. Eds., Internéo 2 – 1998, *Journée d'information du 14 novembre 1998 (Paris, 1998)*, Association INTERNÉO, p. 113-124.

Collet, H., Hauzeur A., Lech J., 2008, The prehistoric flint mining complex at Spiennes (Belgium) on the occasion of its discovery 140 years ago, in P. Allard, F. Bostyn, F. Giligny, J. Lech (ed.), *Flint Mining in Prehistoric Europe*. Interpreting the archaeological records, European Association of Archaeologists, 12th meeting, Cracow, Poland, 19-24 sept. 2006, p. 41-77.

Coutier, L., Benoist, E., Brisson, A., 1962. Découverte d'un squelette néolithique dans un puits d'extraction de silex en Champagne, *Bulletin de la Société préhistorique française*, t. 59, n° 7-8, p. 491-493.

Cottiaux R., Salanova L. (dir.), 2014, *La fin du IVe millénaire dans le Bassin parisien. Le Néolithique récent entre Seine, Oise et Marne (3500-2900 avant notre ère),* Revue Archéologique de l'Est n°34 et Revue Archéologique d'Île-de-France n°1, 552 p.

Cottiaux, R., Salanova, L., Brunet, P., Hamon, T., Langry-François, F., Maingaud, A., Martineau, R., Mille, B., Polloni A., Renard C., Sohn, M., 2014, Le Néolithique récent dans le Bassin parisien (3600-2900 avant notre ère) : périodisation et faciès régionaux, in : Cottiaux R., Salanova L. (dir.), *La fin du IVe millénaire dans le Bassin parisien. Le Néolithique récent entre Seine, Oise et Marne (3500-2900 avant notre ère),* supplément 34 de la Revue Archéologique de l'Est et supplément 1 de la Revue Archéologique d'Île-de-France, p. 455-529.

Crema, E., & Bevan, A. 2020. Inference from large sets of radiocarbon dates: software and methods. *Radiocarbo n*, 1-17. doi:10.1017/RDC.2020.95

Desloges, J., Ghesquière, E., Marcigny, C., with the collaboration of Charraud, F., 2010, La minière Néolithique ancien/moyen I des Longrais à Soumont-Saint-Quentin (Calvados), *Revue archéologique de l'Ouest,* 27, *1-18.*

Dufraisse, A., Bardin, J., Picornell-Gelabert, Ll., Coubray, S., Garcia-Martinez, M.S., Lemoine, M., Vila Moreiras, S. 2020. Pith location tool and wood diameter estimation: validity and limits tested on seven taxa to approach the length of the missing radius on archaeological wood and charcoal fragments. *Journal of Archaeological Science Reports*, 29: 102166 https://doi.org/10.1016/j.jasrep.2019.102166

Dufraisse, A., S. Coubray, O. Girardclos, A. Dupin, M. Lemoine, 2018. Contribution of tyloses quantification in earlywood oak vessels to archaeological charcoal analyses: estimation of a minimum age and influences of physiological and environmental factors *Quaternary International* Vol. 463, Part B: 250-257 https://doi.org/10.1016/j.quaint.2017.03.070

Dunbar, E., Cook, G.T., Naysmith, P., Tripney, B.G., Xu, S, 2016. AMS ^{14}C dating at the Scottish Universities Environmental Research Centre (SUERC) radiocarbon dating laboratory. *Radiocarbon* 58 (1): p. 9–23.

Edinborough, K. 2005. *Evolution of bow-arrow technology* [doctoral dissertation]. University of London.

Edinborough, K. 2009. Population history and the evolution of mesolithic arrowhead technology in South Scandinavia. In: Shennan, S, editor. *Pattern and process in cultural evolution*. Berkeley: University of California Press, p. 191–202.

Edinborough, K., Martindale, A., Cook, G.T., Supernant, K. and Ames, K.M., 2016. A marine reservoir effect ΔR value for kitandach, in Prince Rupert Harbour, British Columbia, Canada. *Radiocarbon*, 58(4), pp.885-891.

Edinborough, K., Shennan, S., Teather, A., Baczkowski, J., Bevan, A., Bradley, R., Cook, G., Kerig, T., Pearson, M.P., Pope, A., Schauer, P., 2020. New radiocarbon dates show Early Neolithic date of flint-mining and stone quarrying in Britain. *Radiocarbon*, p. 1-31.

Edinborough, K., Porčić, M., Martindale, A., Brown, T.J., Supernant, K., Ames, K.M., 2017. Radiocarbon test for demographic events in written and oral history. *Proceedings of the National Academy of Sciences*, 114(47), p. 12436-12441.

Imbeaux, M., Affolter, J., Martineau, R., 2018. Diffusion régionale du silex crétacé des minières de Saint-Gond (Marne, France) au Néolithique récent et final, *Bulletin de la Société préhistorique française,* t. 115, 4, p. 733-767.

Manning, K., Timpson, A., Colledge, S., Crema, E., Edinborough, K., Kerig, T. and Shennan, S., 2014. The chronology of culture: a comparative assessment of European Neolithic dating approaches. *Antiquity*, 88(342), p.1065-1080.

Martineau, R., Charpy, J-J., Affolter, J., Lambot, B., 2014. Les minières de silex néolithiques des marais de Saint-Gond (Marne), *Revue Archéologique de l'Est*, 63, p. 25-45.

Martineau, R., Charpy, J-J., Langry-François F., Polloni A., avec la collaboration de Huard P., Spiès F., Thiol S., 2016, Les nécropoles d'hypogées de La Grifaine et Les Ronds Buissons à Chouilly (Marne), *Gallia Préhistoire*, n° 56, p. 127-193.

Martineau, R., Imbeaux, M., Affolter J., Charpy, J-J., Bostyn, F., Dumontet, A. 2019, The Neolithic Flint Mines of Les Marais de Saint-Gond and La Côte des Blancs (Marne, France), in : H. Collet et A. Hauzeur (eds), Mining and Quarrying. Geological Characterisation, Knapping Processes and Distribution Networks during Pre- and Protohistoric Times. Proceedings of the 7th International Conference of the UISPP Commission on Flint Mining in Pre- and Protohistoric Times, Mons et Spiennes, 28 sept- 1 oct. 2016, *Anthropologica et Praehistorica*, 128. Bruxelles : SRBAP, p. 101-118.

Martineau, R., Dumontet, A., Denaire, A., 2020, L'habitat Villeneuve-Saint-Germain de Villevenard "Les Hauts de Congy" (Marne), Journée de l'archéologie en Champagne-Ardenne, Châlons-en-

Champagne, 6 décembre 2019, *Bulletin de la Société archéologique champenoise*, t. 113, n° 1, p. 61-62.

Martineau, R., Dumontet, A., Desmeulles, J., Imbeaux, M., Charpy, J-J., Delencre, F., 2021, Puits et chambres d'exploitation du silex à Vert-la-Gravelle (Vert-Toulon) « La Crayère » (Marne), Journée de l'archéologie en Champagne-Ardenne, 11 décembre 2020, *Bulletin de la Société Archéologique Champenoise*.

Oliva, M. (dir.), 2010. Prehistoric mining in the "Krumlovský les" (southern Moravia). Origin and development of an industrial-sacred landscape, *Anthropos*, vol. 32, N.S. 24, Brno.

Oliva M., 2011. Chert Mining in the Krumlov Forest (Southern Moravia), in: Marta Capote Susana Consuegra Pedro Díaz-del-Río Xavier Terradas (ed.), *Proceedings of the 2nd International Conference of the UISPP Commission on Flint Mining in Pre- and Protohistoric Times (Madrid, 14-17 October 2009)*, BAR International Series 2260, p. 97-107.

Oliva, M., 2015. Mesolithic chert mining in the Krumlov Forest /Krumlovský les/ (south Moravia) in the context of the Neolithisation of central Europe, *Památky Archeologické*, CVI, p. 5-42.

Oliva, M., 2018. Mezolit na Moravěve světle novych vyzkumů a poznatků. Le mésolithique en Moravie sous l'optique des recherches nouveaux, *Acta Mus. Moraviae, Sci. soc.,* CIII: 1, p. 3–33.

Oliva, M., 2019. Krumlovský les: mining and ritual memory and transformation, Anthropos, vol. 40, N.S. 32, Brno.

Peek, J., 1975, Inventaire des mégalithes de la France. Région parisienne, *Ier supplément* à *Gallia Préhistoire*, CNRS.

Peyrolles, D. et R., 1959, Les galeries de mines de la Vigne du Cade*, Bulletin de la Société préhistorique française*, t. 56, n° 9-10, p. 525-531.

Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., Palmer, J. G., Pearson, C., van der Plicht, J., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Turney, C. S. M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S. M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A. and Talamo, S., 2020. THE INTCAL20 NORTHERN HEMISPHERE RADIOCARBON AGE CALIBRATION CURVE (0–55 CAL kBP), *Radiocarbon*. Cambridge University Press, p. 1–33. doi: 10.1017/RDC.2020.41.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.,B., Buck, C.,E., Cheng H., Edwards, R.L., Friedrich, M., Grootes, P.,M., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon*. Jan;55(4): p. 1869-87.

Salanova, L., Brunet, P., Cottiaux, R., Hamon, T., Langry-françois F., Martineau R., Polloni A., Renard C., Sohn M., 2011, Du Néolithique récent à l'âge du Bronze dans le Centre Nord de la France : les étapes de l'évolution chrono-culturelle, in : F. BOSTYN, E. MARTIAL and I. PRAUD, Le Néolithique du Nord de la France dans son contexte européen: habitat et économie aux 4e et 3e millénaires avant notre ère, 29e colloque Interrégional sur le Néolithique, oct. 2009, Villeneuve d'Ascq, *Revue Archéologique de Picardie*, n° spécial 28, p. 77-101.

Schauer, P., Shennan, S., Bevan, A., Cook, G., Edinborough, K., Fyfe., R, Kerig, T., Pearson, M.P., 2020. Supply and demand in prehistory? Economics of Neolithic mining in northwest Europe. *Journal of Anthropological Archaeology* 54: p. 149–216.

Shennan, S., Downey, S.S., Timpson, A., Edinborough, K., Colledge, S., Kerig, T., Manning, K., Thomas, M.G., 2013. Regional population collapse followed initial agriculture booms in mid-Holocene Europe. *Nature Communications* 1(4):2486.

Timpson, A., Colledge, S., Crema, E., Edinborough, K., Kerig, T., Manning, K., Thomas, M.G. and Shennan, S., 2014. Reconstructing regional population fluctuations in the European Neolithic using radiocarbon dates: a new case-study using an improved method. *Journal of Archaeological Science*, 52, p. 549-557.

Toussaint, M., Collet, H. & Vander Linden, M., 1997. Découverte d'un squelette humain dans le puits de mine néolithique ST11 de Petit-Spiennes (Hainaut). *Notae Praehistoricae* 17, p. 213-219.

Villes, A., 1983. Le site du « Clos » à Ecury-le-Repos et le Néolithique final en Champagne, *Bulletin de la société archéologique champenoise*, 2, p. 3-74.

Ward, G.K., Wilson, S.R., 1978. Procedures for comparing and combining radiocarbon age determinations: a critique. *Archaeometry*, *20*(1), p. 19-31.

Weisgerber G., 1999, *5000 Jahre Feuersteinbergbau : die Suche nach dem Stahl der Steinzeit*, (Deutschen Bergbau-Museum Bochum, 77), 3rd edition.

Weninger, B., and Edinborough, K. 2020. Bayesian 14C-Rationality, Heisenberg Uncertainty, and Fourier Transform: The Beauty of Radiocarbon Calibration. *Documenta Praehistorica* 47, XLVII, p. 536-559.

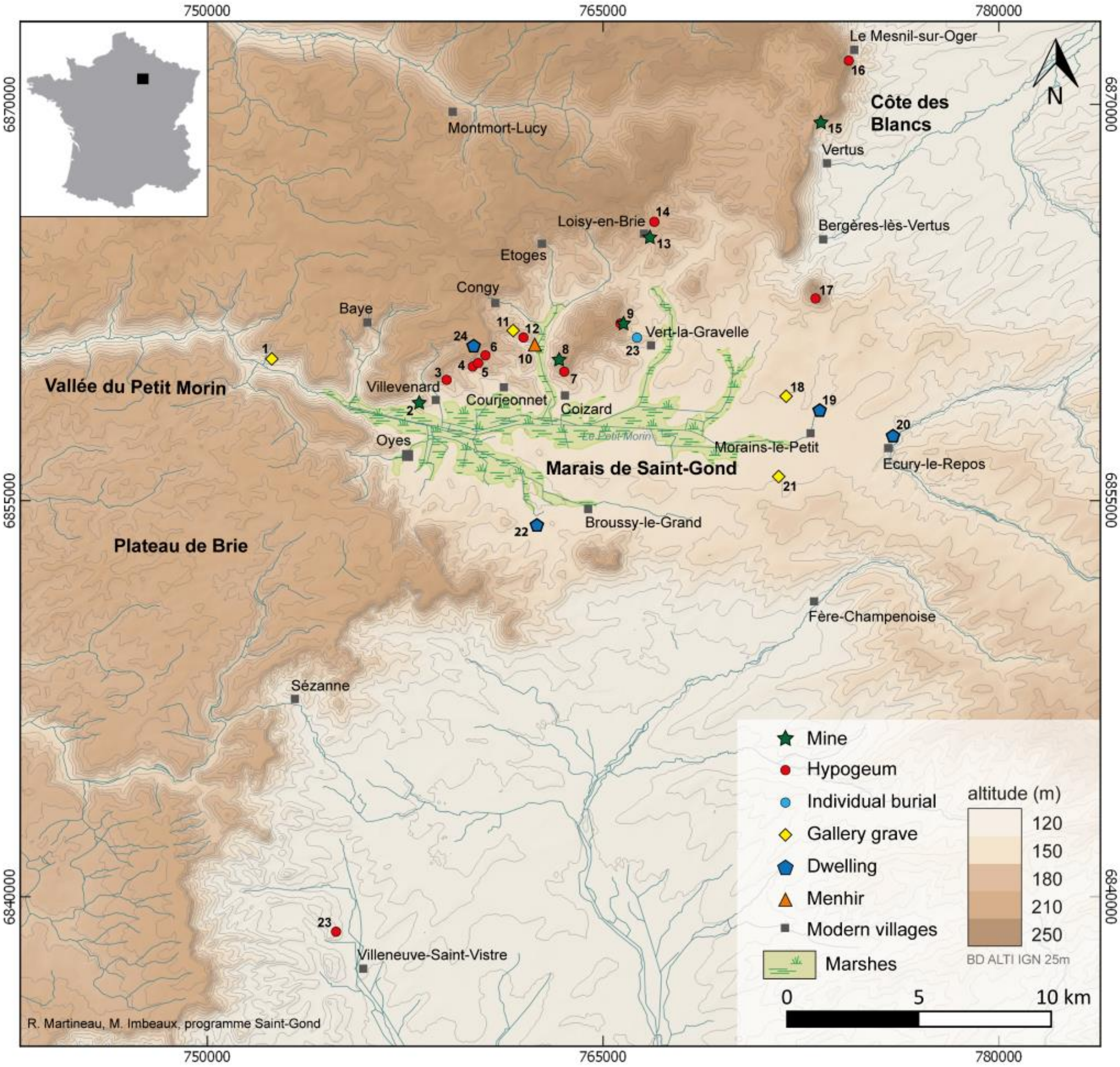
Weninger, B., 2017. Niche construction and theory of agricultural origins. Case studies in punctuated equilibrium. Appendix. *Documenta Praehistorica* XLIV, 6- 17, doi: 10.4312/dp.44.1

Weninger, B., Clare, L., Jöris, O., Jung, R., Edinborough, K. 2015. Quantum theory of radiocarbon calibration. *World Archaeology* 47(4): p. 543–566.

Weninger, B., 1986. High-precision calibration of archaeological radiocarbon dates. *Acta Interdisciplinaria Archaeologica* 4(1): p. 1–53.

Woodbridge, J., Fyfe, R.M., Roberts, N., Downey, S., Edinborough, K. and Shennan, S., 2014. The impact of the Neolithic agricultural transition in Britain: a comparison of pollen-based land-cover and archaeological 14C date-inferred population change. *Journal of Archaeological Science*, 51, p .216-224.

list of Figure/Table captions



1. Bannay "Le Reclus"
2. Villevenard "La Craïère"
3. Villevenard "Les Ronces"
4. Villevenard "Les Houyottes"
5. Courjeonnet "Les Vignes Jaunes"
6. Courjeonnet "La Pierre Michelot"
7. Coizard "Le Razet"
8. Coizard "La Haie Jeanneton"
9. Vert-la-Gravelle "La Crayère"
10. Congy "Pierre Frite"
11. Congy "Les Hayettes"
12. Congy "Les Cornabaux"
13. Loisy-en-Brie "56 Grande Rue"
14. Loisy-en-Brie "Les Gouttes d'Or"
15. Vertus "Grandval"
16. Le Mesnil-sur-Oger "Les Mournouards"
17. Coligny "Le Mont-Aimé"
18. Aulnay-aux-Planches "La Plaque"
19. Morains-le-Petit "Le Pré à Vaches"
20. Ecury-le-Repos "Le Clos"
21. Aulnay-aux-Planches "Au-dessus du Chemin des Bretons"
22. Broussy-le-Grand "L'Ourlet"
23. Villeneuve-Saint-Vistre-et-Villevotte "Montaubar"
24. Vert-la-Gravelle "Le Bas des Vignes"
25. Villevenard "Les Hauts de Congy"

Figure 1. The main Neolithic sites of Les Marais de Saint-Gond (Marne, France).

Figure 2. Upper panel, archaeological Excavation at Vert-la-Gravelle "La Crayère" showing north facing necropolis burial chambers (hypogeum 2, in center under red/black survey scale) cut into north facing flint mine face. Lower Panel, Antler tine pick, with shaft-hole and use-wear, from deer antler axe sheath with transversal handle from Villeneuve-Saint-Vistre-et-Villevotte "Montaubar". Photos R. Martineau.

Mine ID	Site	Site Location	Lab Code	14C age (years BP)	Error (1σ)	Context	Extra context no	Sample	Species	δ 13C (‰)	δ 15N (‰)	C/N ratio (Molar)
N/A	Ecury-le-Repos	Le Clos	SUERC-78934	4233	24	N/A	N/A	Charcoal on pottery sherd	N/A	-25	N/A	N/A
M225	Loisy-en-Brie	56 Grande Rue	SUERC-73217	1535	29	Pit G	US5	Charcoal	*Quercus* sp.	-25.5	N/A	N/A
N/A	Loisy-en-Brie	56 Grande Rue	SUERC-76031	8327	37	Pit F	US19	Deer antler	N/A	-22.7	5.1	3.4
N/A	Loisy-en-Brie	56 Grande Rue	SUERC-76032	4673	35	Pit D	US11	Deer antler	N/A	-22.3	7.1	3.4
M225	Loisy-en-Brie	56 Grande Rue	SUERC-78924	4734	25	Pit D	US11	Deer antler	N/A	-22.2	6.1	3.2
M225	Loisy-en-Brie	56 Grande Rue	SUERC-78925	4713	28	Pit D	surface	Deer antler	N/A	-22.3	6.2	3.2
M225	Loisy-en-Brie	56 Grande Rue	SUERC-78929	8399	35	Pit F	US19	Deer antler	N/A	-22.6	3.4	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-73218	5299	32	HY4 (but TR3 sediment)	US96	Deer antler	N/A	-20.6	3.4	3.3
M113	Vert-la-Gravelle	La Crayère	SUERC-73219	5244	32	TR3	US16	Deer antler	N/A	-21	3.3	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-73223	5149	29	TR1	US37	Deer antler	N/A	-21.3	3.2	3.4
M113	Vert-la-Gravelle	La Crayère	SUERC-73224	5252	26	TR3	US51	Deer antler	N/A	-21.5	3	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-73225	5238	31	ST9-PU3	US123	Deer antler	N/A	-22.1	4.9	3.3
M113	Vert-la-Gravelle	La Crayère	SUERC-73226	5085	27	HY4 (but TR3 sediment)	US72	Deer antler	N/A	-22	4.9	3.4
M113	Vert-la-Gravelle	La Crayère	SUERC-75325	4343	34	HY2	US 12	Charcoal	*Corylus* sp.	-28.1	N/A	N/A
M113	Vert-la-Gravelle	La Crayère	SUERC-75326	4458	34	ST7-PU4	US 90	Charcoal	*Corylus* sp.	-25 (assumed)	N/A	N/A
M113	Vert-la-Gravelle	La Crayère	SUERC-75327	4893	34	TR1	US 118	Charcoal	*Corylus* sp.	-25.7	N/A	N/A
M113	Vert-la-Gravelle	La Crayère	SUERC-78911	4508	22	HY2	US86	Charcoal	N/A	-24.7	N/A	N/A
M113	Vert-la-Gravelle	La Crayère	SUERC-78912	4590	22	ST7	US145	Charcoal	N/A	-25	N/A	N/A
M113	Vert-la-Gravelle	La Crayère	SUERC-78913	4719	22	HY1	US138	Charcoal	N/A	-26.6	N/A	N/A
M113	Vert-la-Gravelle	La Crayère	SUERC-78914	5386	28	TR1	US37	Deer antler	N/A	-21.5	3.1	3.3
M113	Vert-la-Gravelle	La Crayère	SUERC-78915	5340	29	TR3	US65	Deer antler	N/A	-20.3	3.6	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-78919	5328	29	TR1	US118	Bone - deer antler?	N/A	-20.7	4.2	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-78920	5371	29	TR3	US125	Deer antler	N/A	-21.5	4.3	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-78921	5346	29	TR1	US167	Deer antler/stuck with glue	N/A	-22.3	5.3	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-78922	5315	27	TR3	US74	Deer antler	N/A	-20.8	3.1	3.2
M113	Vert-la-Gravelle	La Crayère	SUERC-78923	5392	27	TR1	US100	Deer antler	N/A	-23.8	6.8	3.2
M113	Vert-La-Gravelle	La Crayère	SUERC-79162	4125	30	Hypogeum HY2 or HY4	N/A	Deer antler	N/A	-21.6	10.7	3.3
M113	Vert-la-Gravelle	La Crayère	SUERC-79163	4393	27	Hypogeum HY2 or HY4	N/A	Bone	N/A	-20.8	10.4	3.2
M158	Vertus	Granval	SUERC-73227	4520	28	Bottom of well	pic n°1	Deer antler	N/A	-20.9	3.2	3.3
M226	Villeneuve-Saint-Vistre	Montaubar	SUERC-73228	4498	28	Hypogeum	N/A	Deer antler	N/A	-21.1	4	3.2

Table 1. N = 30 New radiocarbon measurements. See Supplementary Information for more information and site level discussion of radiocarbon samples and calibrated results. This table details new measurements from Mesolithic and Neolithic dwellings/settlements, burial sites, and mining contexts.

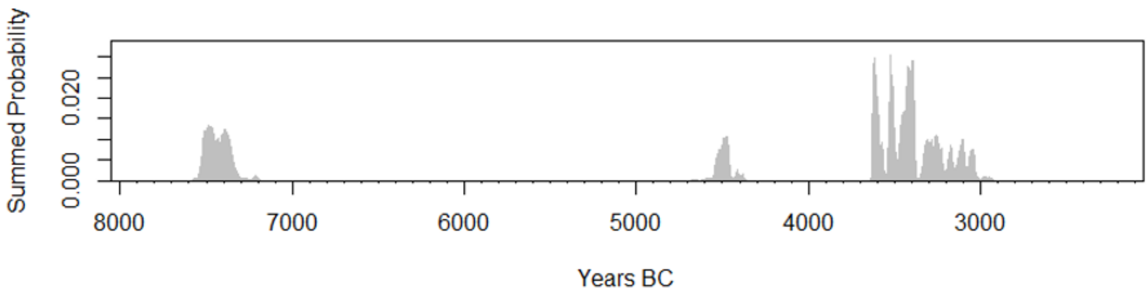


Figure 3. SPD rcarbon plot clearly showing the sum of two very early Mesolithic dates at the site of Loisy-en-Brie "56 Grande Rue" pit F, possibly the earliest flint mining structure dated in France.

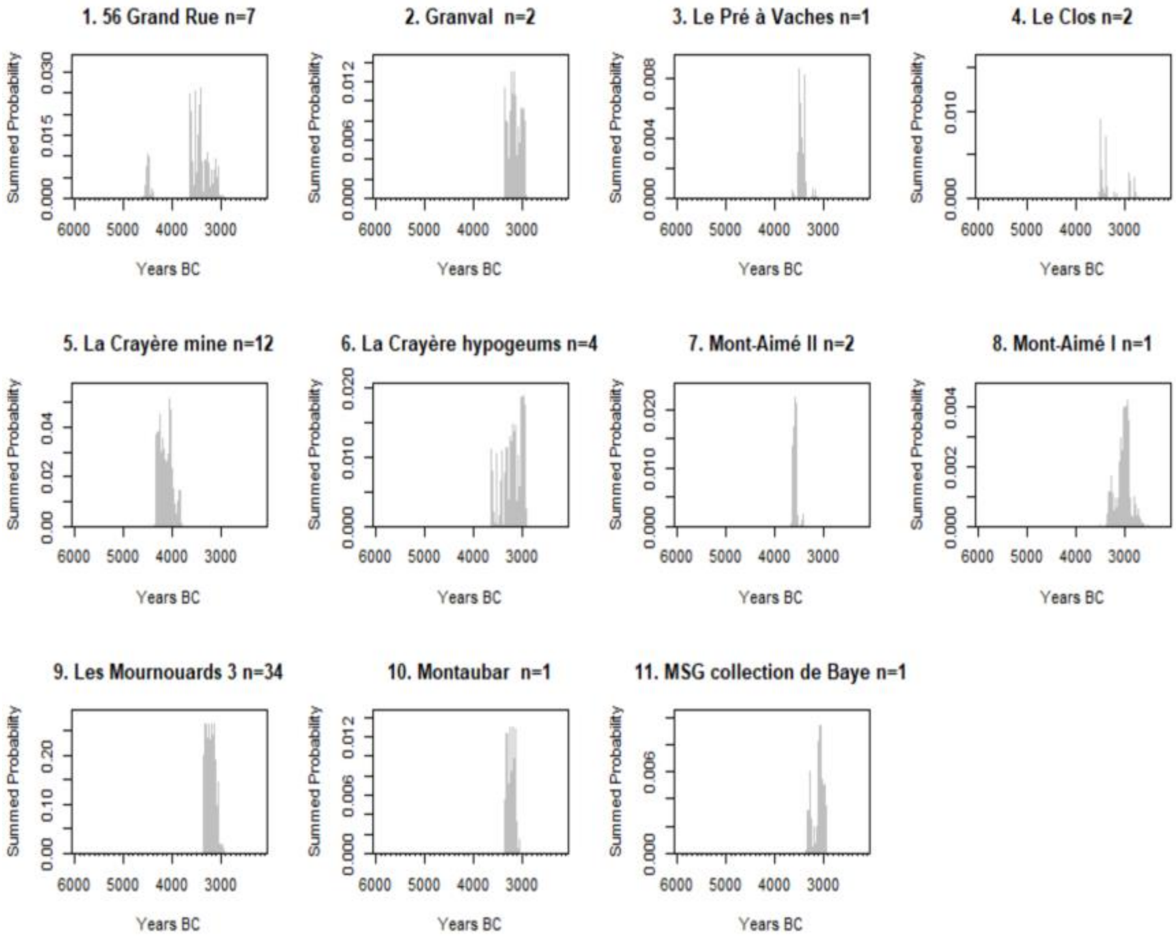


Figure 4. Summary Summed Probability Distribution panel plot of sites dated, including those previously dated and mentioned in the text, enabling accurate like-for-like comparison of the calibrated radiocarbon data for the Neolithic period in the St. Gond Region; "n=" number of radiocarbon dates calibrated. Radiocarbon results are not normalized after summing, and so sum to one (Weninger *et al*. 2015; Bevan *et al.* 2017).

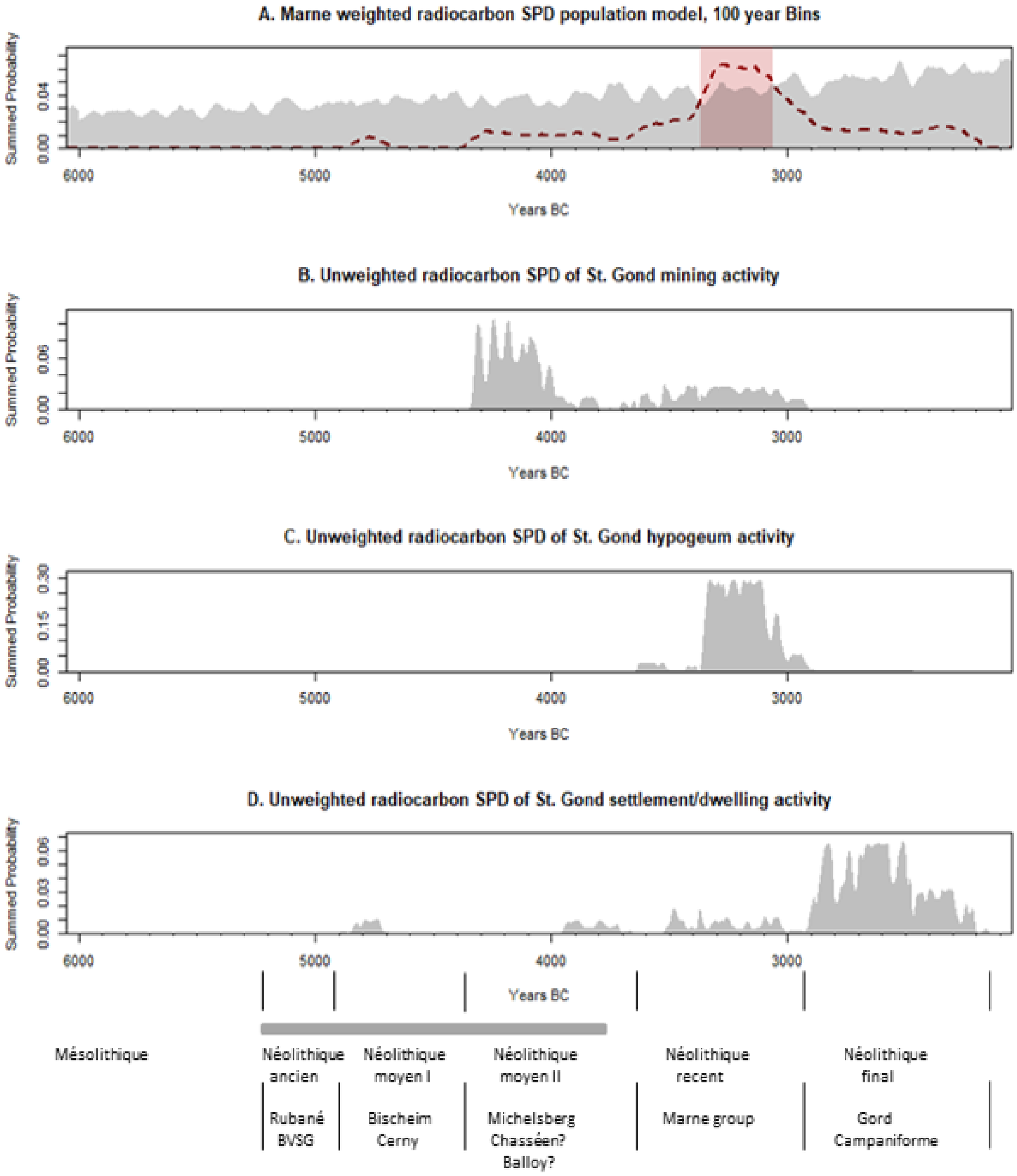


Figure 5. Summed Probability Distribution (SPD) models.

A. SPD population model using available radiocarbon data weighted into 100 year bins for the Marne region (St. Gond data plus "Le Brabant" site; n = 98; see below). Red dotted line = real data. Grey area is the simulated exponential null model based on the real data; red shading = period of positive deviation from exponential null model, significant to a 95% confidence interval.

B. Unweighted/unbinned SPD (grey area of plot) of St. Gond mines (N= 30 radiocarbon dates)

C. Unweighted/unbinned SPD (grey area of plot) of St. Gond Hypogeums (N= 33 radiocarbon dates)

D. Unweighted/unbinned SPD (grey area of plot) of St. Gond dwellings (N= 7 radiocarbon dates)

Dates of generally agreed cultural historical divisions are shown at the bottom of the plot, where the solid grey bar represents the range of culturally attributed dates known for dwelling sites that still require radiocarbon dating.

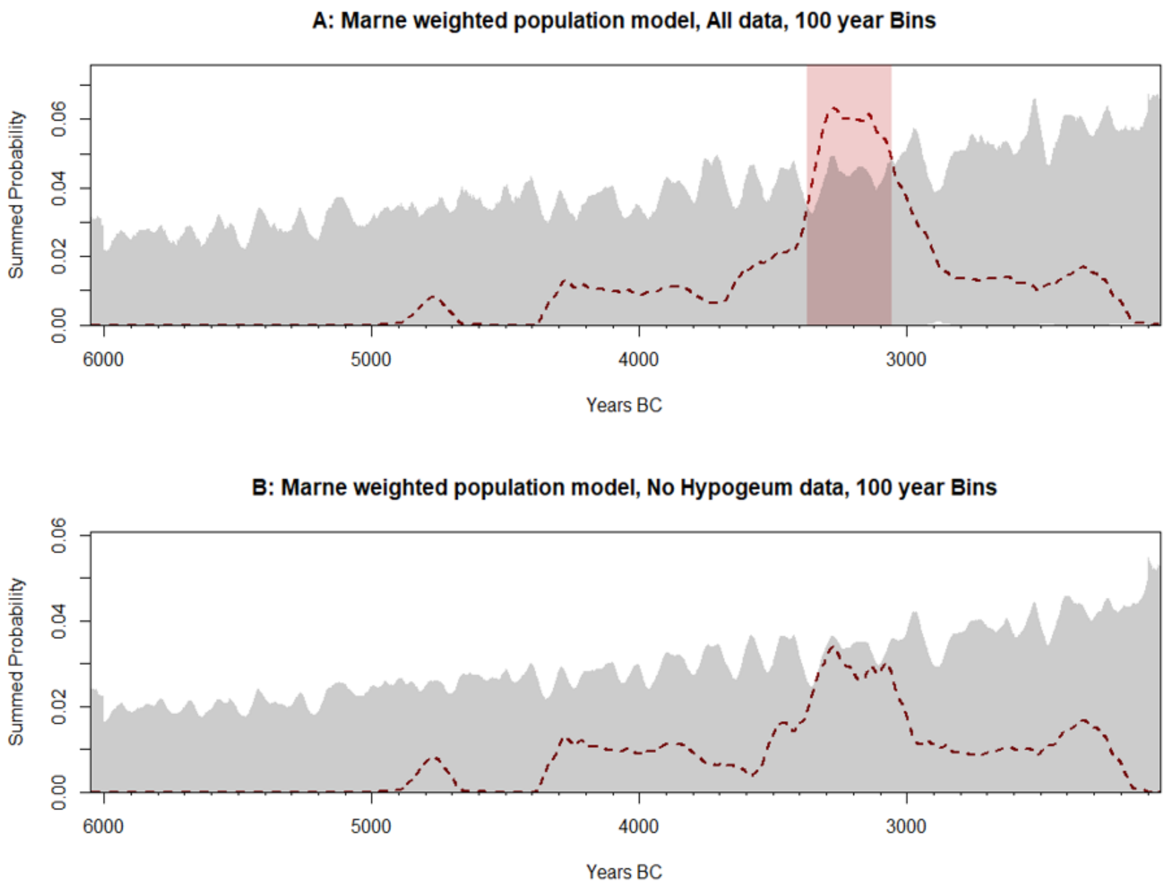


Figure 6. A comparison of weighted SPD population models (A) with binned hypogeum data (same analysis in figure 5A). Plot B = same analysis as A, but without the hypogeum data included in figure 5. Number of radiocarbon dates: 54. Number of bins: 24. Statistical Significance computed using 10,000 simulations, global p-value: 0.72563 = not globally significant, indicating yet more radiocarbon data is required to investigate this region and time frame at this analytical scale.