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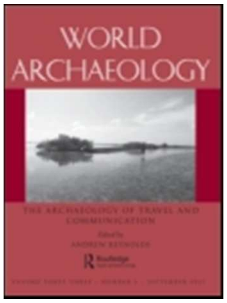

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Constructing chronologies for the late Middle Paleolithic and Upper Paleolithic: limitations and means to overcome them

William E. Banks [1, 2]

1 – CNRS, UMR 5199-PACEA, Université de Bordeaux, Bâtiment B18, Allée Geoffroy Saint Hilaire, CS 50023, 33615 Pessac Cedex, France.

2 – Biodiversity Institute, University of Kansas, 1345 Jayhawk Blvd., Dyche Hall, Lawrence, KS 66045-7562, USA.

E-mail: william.banks@u-bordeaux.fr

Telephone: +33 5 40 00 28 40

Abstract

Improvements in our understandings of the timing and nature of millennial-scale climatic variability combined with improved dating methods and more accurate calibration curves have allowed researchers to better place archaeological cultures within their paleoenvironmental contexts. Since all human cultures operate within an environmental framework, these developments allow researchers to investigate if and how cultural variability is related to temporal shifts in culture-environment relationships. Studying such relationships, however, is dependent on our ability to construct robust chronologies, and this need has been by incorporating Bayesian modeling methods into archaeological investigations. This paper reviews the assumptions and methods behind this practice and argues that while site-specific age models are useful, we should also employ methods with which chronological models for broad archaeological cultures can be constructed. Such a combination approach allows one to thoroughly incorporate available chronological data and build reliable chronologies that are critical to investigations aimed at examining culture-environment relationships.

Keywords

Paleolithic chronology, Bayesian age modeling, collective radiocarbon datasets, culture-environment relationships

Introduction

Based on temporal variability in the structure of fossil faunal and pollen assemblages, archaeologists, paleontologists, and paleoclimatologists had long known that the Last Glacial period was characterized by climatic, and subsequent environmental, changes. However, it was not until a little over 20 years ago that paleoclimatologists discovered that in the northern hemisphere this period was characterized by abrupt and dramatic climatic fluctuations that occurred on millennial and sub-millennial time scales (Dansgaard et al. 1993; Heinrich 1988; Johnsen et al. 1992). Temporal resolution of this Dansaard-Oeschger (D-O) variability has continually increased (Shackleton et al. 2004; Svensson et al. 2008) and is now well-established (Rasmussen et al. 2014). Completely deciphering the complexity of these events and the mechanisms behind them, however, remains problematic (Broecker 2006; Marcott et al. 2011;

Menviel et al. 2014; Roche et al. 2014; Wolff et al. 2010). Detailed analyses of marine and terrestrial climatic archives, along with paleoclimatic simulation methods, have allowed for detailed reconstructions of climatic and environmental conditions across Europe during the Last Glacial (Fletcher et al. 2010; Kageyama et al. 2013; Wu et al. 2007). Analyses of tephra signatures suggest that D-O events were largely synchronous across the North Atlantic and Europe (Austin and Hibbert 2012; Davies et al. 2012), although the expression of these events differed regionally as demonstrated by marine and terrestrial archives (Lane et al. 2012; Fletcher et al. 2010; Harrison and Sanchez Goñi 2010; Sánchez Goñi et al. 2008). Improvements in radiocarbon age calibration curves (Reimer et al. 2013) have allowed researchers to better correlate late Middle Paleolithic and Upper Paleolithic archaeological cultures with particular climatic events and their corresponding environmental frameworks.

With such knowledge, it is possible to correlate archaeological data with D-O climatic variability and related environmental changes more reliably and better infer how these shifting environmental frameworks may have influenced Paleolithic cultural adaptations and demography (Banks et al. 2009; Banks, d'Errico, and Zilhão 2013a; Bertran et al. 2013; Birks et al. 2014; Bradtmöller et al. 2012; d'Errico and Sánchez Goñi 2003; Discamps, Jaubert, and Bachellerie 2011; Gamble et al. 2004; Miller 2012; Schmidt et al. 2012; Weber, Grimm, and Baales 2011). Pertinent questions center on determining if and when shifts in material culture, cultural innovations, or inferred adaptive shifts are associated with environmental changes. More recently, the integration of ecological niche modeling methods, derived from the biodiversity sciences, has allowed for investigations of how technological or organizational changes observed in the Paleolithic archaeological record correlate with ecological niche dynamics (Banks et al. 2009; d'Errico and Banks 2013; Banks, d'Errico, and Zilhão 2013a).

In order to be sure that examinations of culture-environment relationships are in fact capturing or describing some past reality, it is paramount that archaeologists have accurate and robust chronological frameworks at their disposal. The reason being that if one's aim is to determine if and how specific climatic events and related environmental settings are correlated with behavior changes inferred from the archaeological record, it is critical that one be able to determine accurately the appearance and duration of both broad archaeological cultures and potential regional variants within them. This focus on chronology is not new and has figured at the center of numerous archaeological debates, one example being the Middle-to-Upper Paleolithic transitions (e.g., Roebroeks 2008). With accurate archaeological chronological frameworks, one can effectively examine culture-environment relationships and identify instances for which cultural adaptive shifts have an ecological basis. Equally as important is our ability to recognize when adaptive changes do not appear to be related, or at least only marginally so, to environmental or ecological restructuring but rather were more influenced by cultural processes.

Such undertakings are highly dependent on our cultural units of analysis. Archaeologists typically employ the concept of technocomplex to define an archaeological culture based on similar assemblages of material culture remains, produced via the same or similar technological schema(s), which is assumed to reflect to some degree a past cultural reality. Problems related to the definition or classification of an archaeological culture or technocomplex can be reduced or minimized by focusing on well-defined, easily recognized, and unambiguous material culture diagnostics (i.e., *fossiles directeurs*), as is the case with the late Middle Paleolithic and Upper

Paleolithic. With respect to this same time range, questions related to changes within and between technocomplexes, such as whether cultural changes occurred synchronously, are for the most part beyond our grasp. The reason being that the low resolution of both stratigraphic sequences and radiometric age determinations mean that we can only work at a temporal resolution that ranges between 500 and a thousand years (Zilhão 2013). As he points out, however, such chronological limitations are not necessarily a handicap, and can be seen as an advantage, when the focus is on long-term stasis, as well as long-term cultural change.

The concept of technocomplex is associated with known ambiguities, but more importantly it is often divorced from the environmental framework within which a past culture operated. For this reason, the concept of Cohesive Adaptive System (CAS) has been proposed (d'Errico and Banks 2013) and is defined as a cultural entity characterized by shared and transmitted knowledge reflected by a recognizable suite of cultural traits that a population uses to operate within both cultural and environmental contexts. Because a CAS is also defined on the basis of material culture remains, this concept is not divorced from ambiguity. Nonetheless, it does provide the possibility to better understand how the material culture record, shaped by cultural rules and norms, reflects a past cultural entity's relationship with its environment. Regardless of the employed concepts and terminology, it is paramount when constructing chronologies and examining human-environmental relationships that archaeologists be transparent with respect to what they conceive to be a past cultural entity, what data were used in its definition, and how they envision to use such constructs as proxies of past cultural behavior. With such transparency, the classificatory assumptions and priors that underlie a reconstructed chronological framework for a single archaeological culture, or multiple, successive ones, are apparent and can be taken into account and potentially corrected in subsequent work aimed at testing results and proposed hypotheses.

Chronological Frameworks

Of the numerous methods that archaeologists have at their disposal for placing archaeological cultures into a chronological framework, and in turn a paleoclimatic context, the most widely used are stratigraphy, radiometric ages, and diagnostic elements of material culture, although use of the latter is dependent on known stratigraphic sequences or radiometric ages within a prescribed geographic area. Of these methods, stratigraphy is paramount because without a solid understanding of a site’s stratigraphy (including inherent issues such as taphonomic biases, depositional hiatuses and resulting archaeological palimpsests) one cannot reliably interpret material culture remains and age determinations from its specific archaeological levels.

One solution is the inclusion of radiometric dating results into the construction of chronologies, but it is paramount that the use of chronological data be done in conjunction with taphonomic and geomorphological analyses (e.g., refitting, granulometry, micromorphology, geochemistry, etc.)—chronological data cannot be placed before those related to site formation processes and can be of limited utility, or even misleading, if such processes are not taken into account. Of equal importance is the issue of association—meaning that interpreting radiocarbon (^{14}C) ages may be problematic if a reliable association between the dated material and archaeological material culture remains does not exist or is uncertain (Waterbolk 1983). Any chronological construction has a strong potential of being flawed if it incorporates radiometric ages from sites where issues concerning association have not been resolved.

For the latter part of Marine Isotope Stage (MIS) 3 and all of MIS 2, radiocarbon dating is the most widely used method in archaeology and offers relatively good chronological resolution. The accuracy and precision of radiocarbon ages has been improved with the development of new pretreatment protocols for charcoal and bone, ABOx-SC (Bird et al. 1999) and ultrafiltration (Higham, Jacobi, and Ramsey 2006), respectively. These improvements, paired with the creation of a calibration curve that is reliable well into the range of MIS 3 (Reimer et al. 2013), make a focus on ^{14}C ages for building late Middle Paleolithic and Upper Paleolithic chronologies worthwhile. The use of accurate calibration curves is paramount since radiocarbon ages represent measurements of isotope ratios and must be converted into a calendar age range if one wishes to correlate archaeological phenomena to climatic events. Dating methods that produce calendar age estimates (OSL, TL, etc.) also can be used alone or in conjunction with radiocarbon measurements, but their larger standard errors, relative to radiocarbon dating, can be a handicap when the focus is on millennial or sub-millennial time scales. An example of this is the recent publication of single-grain OSL dates from the site of Les Cottés (Jacobs et al. 2015). The authors argue that the OSL dates are largely consistent with the ^{14}C AMS ages on bone, and this is more or less the case, with the exception of Mousterian level US08 (Fig. 1a). What is clear from this figure is that while many of the single-grain dates are consistent with the calibrated ^{14}C ages, the OSL dates' errors from each archaeological level essentially cover the entire range of time represented by the calibrated ^{14}C estimates and their associated errors. For this part of the late Middle and early Upper Paleolithic, the addition of OSL results does not necessarily aid efforts to more precisely define the period of time represented by individual archaeological levels. Nevertheless, luminescence dates can provide complementary information with which to better understand site formation processes and evaluate the homogeneity of the lithostratigraphic units defined within an archaeological sequence.

Another advantage in focusing on radiocarbon data is that there exists a vast corpus of published or readily available ^{14}C ages (e.g., d'Errico et al. 2011; Vermeersch 2005). However, many of the previously run conventional, as well as AMS, ages in such compiled datasets lack published details concerning % collagen, carbon and nitrogen ratios, % carbon at combustion, etc., thus making them difficult to evaluate. Furthermore, these data cannot be used uncritically as many were produced with older pretreatment and conventional counting methods thus calling into question their accuracy. There is no question that the latest pretreatment protocols cited above allow one to obtain reliable ages, with respect to those produced more than 20 years ago. In a number of instances (e.g., Higham et al. 2009), newly obtained ages produced with such methods have served to show that many previously run ages were underestimates. This does not mean, however, that one should systematically discount all conventional and AMS ages produced without the latest protocols as not all are problematic. For example, if one examines the ages used by Banks, d'Errico and Zilhão (2013a) to place the Proto-Aurignacian and Early Aurignacian within their respective chronological and paleoenvironmental contexts, it can be seen that a number of previously run ages correspond well to those produced with the latest pretreatment protocols. Furthermore, when the chronological ranges of these two archaeological cultures were reexamined, the inclusion of more recently published ABOx-SC and ultrafiltration methods did not serve to push back their chronological limits and, in fact, the termination of the Early Aurignacian became slightly younger (Banks, d'Errico, and Zilhão

2013b). When one omits from consideration studies for which the chronology of anatomically modern human entry into Europe is based on sites with problematic stratigraphy or questionable archaeological associations (Benazzi et al. 2011; Higham et al. 2011; Higham et al. 2012a), the more recent radiocarbon ages associated with the Middle-to-Upper Paleolithic transition, analyzed with the latest age modeling methods, have not significantly altered conclusions reached 15 years ago and based on radiocarbon data available at the time (Zilhão and d'Errico 1999). It is also important to keep in mind that with ultrafiltration it is still not clearly understood what exactly the ultrafilters are removing, and while the method is effective in removing small molecular-weight contaminant materials from samples, it does not necessarily remove them all (Brock et al. 2013). Thus, we should not uncritically assume that all ages produced with the latest pretreatment protocols are accurately dating an archaeological event, nor that all ages produced years ago are underestimations.

With respect to radiocarbon ages, a number of statistical methods can be used to compare and interpret them. For example, prior to calibration, since radiocarbon measures are normally distributed, variations of the *t*-test statistic (Sokal and Rohlf 1995) are well-adapted for examining whether different radiocarbon ages come from the same statistical population, how a specific age determination is statistically related to a homogenous sample of ages, or if two different assemblages of ages differ statistically from one another. Once a radiocarbon age is calibrated, the resulting calendar date probability is not normally distributed, so standard statistical methods are no longer applicable. The application of Bayes theorem to the analysis of calibrated dates, often with a focus on individual sites, has become common for analyzing and interpreting radiocarbon age assemblages and constructing chronologies within a methodological framework that takes archaeological and stratigraphic contextual information into consideration (Bronk Ramsey 1995; Bronk Ramsey 1998; Bronk Ramsey 2009; Buck, Cavanagh, and Litton 1996; Lee and Bronk Ramsey 2012).

A Tandem Approach

Constructing archaeological chronologies that can be reliably correlated with D-O climatic events is not possible without the use of calibration and Bayesian statistics. The advantage of Bayesian age modeling techniques, and resultant probability measures, is that they allow one to better constrain the time interval to which a single radiocarbon age, or population of radiocarbon ages, belongs—a crucial endeavor when the goal is to correlate archaeological occupations to documented paleoclimatic variability. The most common approach is to construct age models for specific archaeological sites. It can be argued, however, that a complementary methodology can also provide a valuable contribution to such research: this approach being the consideration of all regionally or multi-regionally available radiometric age data that are grouped or differentiated based on their attribution to specific, successive archaeological cultures and analyzed collectively. Each has its advantages and limitations, and by using the two approaches in concert one should be able to place archaeological cultures in their respective temporal contexts more accurately.

Site-specific Age Models

This approach is of obvious utility when one considers the number of stratified and well-dated archaeological sites for which we possess detailed data with respect to stratigraphy and formational processes. These priors can be used to construct reliable site-specific age models. If an adequate number of reliable sequences are studied individually in this manner, it should be possible, in theory, to better understand peopling or settlement scenarios within the context of a broad archaeological culture or to make comparisons between temporally successive cultures.

While such practice is valuable, this approach can have shortcomings in certain instances. First, it is paramount that age modeling analyses for specific sites fully take into account detailed stratigraphic and site formation data, information related to post-depositional processes, the results of refitting studies, etc. If such data are not considered or are not adequately understood, there exists the possibility that resulting age models may be erroneous and misleading. An example of this can be found in the recent exchange between Higham et al. (2013) and Banks and collaborators (2013b) surrounding the archaeological context of early Upper Paleolithic levels and Bayesian modeling results for the site of Geißenklösterle. In two published studies (Higham et al. 2012a; Higham et al. 2013), new radiocarbon ages from the site and resulting age models are used to argue for a precocious presence of anatomically modern humans in Western Europe. However, the results must be viewed with caution because site formational studies (Teyssandier 2003) and critical analysis of ^{14}C ages (Verpoorte 2005), which predate the most recent dating campaign, have demonstrated that the relationships between the dated samples and Aurignacian occupations of the site are not unambiguous. These problems are compounded when the originally defined archaeological horizons (Hahn 1988) are used as chronological phases to constrain a Bayesian age model (Zilhão 2013). Based on the degree of post-depositional mixing, it has been argued that the Aurignacian levels at the site should be viewed as a continuum and thus a single phase within a Bayesian model's structure (Banks, d'Errico, and Zilhão 2013b).

Another illustration of problematic Bayesian age models derived from sites with possible stratigraphic problems is provided by the site of Les Cottés. When one examines the modeled date ranges for the Proto-Aurignacian (US04 lower) and Early Aurignacian (US04 upper) levels (Talamo et al. 2012; reproduced here in Fig. 1b), it is immediately evident that the Proto-Aurignacian level is much younger than other reliable Proto-Aurignacian contexts in Europe and falls more within the time frame of the Early Aurignacian (Fig. 2). Taking into account the fact that many of the ages from this level come from a portion of the site that is strongly sloped and where levels US04 upper and lower are in direct contact with one another (Talamo et al. 2012), it is entirely possible that many of the dated materials from US04 lower were originally associated with the Early Aurignacian US04 upper.

A final illustration of the importance of stratigraphic priors in age model construction is the example of the Grotte du Renne. The age models produced by Higham et al. (2010) and Hublin et al. (2012) differ quite markedly with respect to the date ranges calculated for the Châtelperronian and Aurignacian occupations of the cave. Aside from the debate concerning whether or not it was appropriate to focus solely on humanly-modified bone for producing ages (Hublin et al. 2012; Higham et al. 2012b) and what influence the inclusion of non-humanly-modified may have on accurately capturing the timing of human occupation of the cave, the differences between these two teams' age models are also the result of how stratigraphic priors are incorporated into the Bayesian age model structure. Higham et al. (2010) keep stratigraphic levels X and IX separate, whereas Hublin and colleagues (2012) group them together based on the existence of a lithic refit between the two levels. These two different structures of stratigraphic priors strongly influence the number of identified radiocarbon age outliers and in turn the chronological intervals for the site's Châtelperronian and Aurignacian occupations.

Secondly, when an emphasis is placed on individual archaeological sequences, the possibility arises that one is inadequately capturing the full time range of an archaeological culture. For example, if one particular region is dominated by stratified sequences and is the focus of age modeling research, then one is potentially missing archeological events from sites outside that region that may not necessarily fall entirely within the temporal range of the archaeological culture in the context of the more restricted geographic framework.

Lastly, a focus on constructing age models for stratified sequences makes it difficult to understand how single component archaeological sites fit within a cultural chronological framework. Calibrated date ranges from single component sites can be compared to age models from stratified sequences, but evaluating their statistical relationships to modeled ranges derived from the latter is rendered difficult.

Age Models for an Entire Archaeological Culture

There exist a number of ways for attempting to capture the full temporal range of a particular archaeological culture. One methodology used recently (Banks, d'Errico, and Zilhão 2013a, 2013b; d'Errico and Banks 2014) is to collectively examine all radiocarbon ages belonging to specific archaeological cultures. By focusing on multiple sites characterized by reliable archaeological contexts with culturally diagnostic material culture remains, radiocarbon ages can be grouped together by archaeological culture, the latter being used as temporal phases in the construction of a Bayesian age model.

Higham et al. (2014) employ an approach that integrates the results of age models for individual archaeological sequences (i.e., sites) into a subsequent, broader model focused on archaeological cultures. As described in their Supplementary Information (Higham et al. 2014), OxCal4.2 (Bronk Ramsey 2009) is used to construct age models for individual site sequences. The probability distribution functions for the simulated boundaries, those which also correspond to the termination a specific archaeological culture at the site, are then inserted as 'priors' within a 'phase' pertaining to that same technocomplex in a more generalized Bayesian model. This latter age model calculates probability distribution functions that estimate date ranges for the beginning and end of the targeted archaeological cultures. With this approach, the stratigraphic priors observed at individual sites are incorporated into the model that examines distinct and successive archaeological cultures.

A similar approach can be followed with the newly available Bayesian age modeling software named ChronoModel (Chronological Modelling of Archaeological Data using Bayesian Statistics; www.chronomodel.fr), which differs somewhat from OxCal with respect to how it views and uses radiocarbon ages to construct probability distributions. With this software, one constructs age models for site sequences, whose individual levels and associated stratigraphic priors can then be grouped together into phases according to archaeological culture. More specifically, each archaeological level within a broader phase includes a set of 'event' models composed of one or several dates/ages with unknown individual errors in addition to experimental errors. Thus, one is able to calculate date ranges for site-specific archaeological levels based on their associated radiocarbon ages (nested in 'events'—either individually or together when there are ages from multiple samples demonstrated to have been contemporaneous), as well as for a particular archaeological culture, the latter being determined by its population of related ‘events’ and associated stratigraphic priors. One advantage of ChronoModel is that the user interface allows one to construct site-specific event models and a broader phase model simultaneously, thereby eliminating the need to run individual site age models, save the probability distribution functions for each boundary, and then incorporate these boundary probabilities into a subsequent phase model, as is the case with OxCal.

These multi-site approaches to building cultural chronologies allow one to capture the full temporal extent of an archaeological culture (Fig. 2) in a way that might not be possible if only particular sites or geographically restricted regions are the focus of study. This is dependent, of course, on the assumption that such age models incorporate a representative sample of radiometric ages. Representativeness of a sample of ages can be increased by the fact that a focus on archaeological cultures as a whole allows one to incorporate ages from single component sites into an age model. A comprehensive approach also has the advantage of potentially minimizing the contribution made by ages that are erroneous due to inadequate pre-treatment methods, contamination, or site formational processes and that were not recognized as outliers when considered with the more restricted context of a site-specific age model. Another advantage is that previously run radiocarbon ages (e.g., non-ABOx-SC or non-ultrafiltration ages) from reliable contexts can be included in the construction of cultural chronologies. When previously run ages are incorporated into a Bayesian age model that also includes ages produced with the latest pre-treatment protocols and the former are not subsequently flagged as outliers, one can take this as a quantitative indication that they provide relevant and reliable information with respect to the timing of archaeological events. Sample size differences between populations of previously runs ages and those produced more recently may play a role in determining which and how many ages are identified as outliers. Experimental modeling work is needed along these lines to better understand the potential influences that differing sample sizes between previously- and newly-produced ages may have.

Discussion and Conclusions

Approaches that only examine individual archaeological sequences and those that analyze ages in a collective manner with respect to a broader archaeological culture have advantages and disadvantages. Using both in conjunction, as done by Higham et al. (2014) and as is possible with ChronoModel, serves to overcome the disadvantages associated with each. For example, take a hypothetical case where we have a site with a number of stratified archaeological levels and with each level are associated a number of radiocarbon ages. Let’s also say that two levels are in contact with one another, appear to represent two different archaeological cultures, and taphonomic studies have demonstrated that there has been mixing of archaeological materials between the two. Without being able to reliably discern between dated materials that are in their original context and those that have been subjected to vertical movement, one would be forced to combine these two levels into a single phase in the Bayesian age model’s structure. Thus, when an age model is produced, one cannot definitively ascertain the chronological time span for each of the different archaeological cultures. If one widens the scope of study to a multi-regional scale and constructs a Bayesian age model that treats each archaeological culture or cohesive adaptive system as a phase and incorporates a representative sample of ages from reliable contexts, the resulting age model will provide a robust temporal interval for each. Moving back to our hypothetical archaeological site for which there was mixing of materials between adjacent and culturally different levels, the chronological intervals derived from the age model of these cultures as a whole can be used a frame of reference to which each of the radiocarbon ages from the mixed levels is compared in order to determine with which archaeological level each dated item was likely originally associated—a practice that could not be undertaken without the broader scale Bayesian age model.

Likewise, with a multi-regional age model that uses a “technocomplex” as its smallest unit of study, it would not be possible to quantitatively ascertain whether there existed temporal variability within an archaeological culture from a geographic standpoint. This limitation could be overcome by examining the temporal ranges for a particular adaptive system provided by age models constructed for individual site sequences against the backdrop of the broader time interval modeled for that same culture. Such a protocol would provide the possibility of identifying temporal differences that have a geographic basis. This, however, may be too optimistic for late Middle and early Upper Paleolithic archaeological cultures (ca. 50–30 ka cal BP) as radiometric dating errors and low stratigraphic resolution typical of this period are such that it is difficult for us to capture such cultural dynamics at a resolution finer than 500 years, at best—a considerable span of time considering the speed at which cultural innovations can spread (Zilhão 2013).

Finally, there exist the issues of how to refine models and how to evaluate the relative reliability of the different approaches. For the former, two possibilities are immediately evident.

Age models can be continually refined as new radiometric ages become available, either from existing sites or from newly discovered, dated sites. Another approach with which to refine age models would be to incorporate data from other chronological markers, such as tephras (e.g., Blockley et al. 2015; Housley et al. 2014). When multiple, diagnostic tephras or cryptotephras are present within a site's stratigraphy, their ages and stratigraphic position can be evaluated against an age model constructed from other radiometric data from the site, and if these two bodies of data are congruent, then they can be combined into a single age model.

Efforts to refine age models, however, do not necessarily pertain to the issue of determining model reliability. To this end, one way to evaluate model reliability would be to construct age models by means of multiple software packages and compare results. If a majority of age models agree with one another, then one could consider their reconstructed chronologies to be reliable. However, if only two software packages are used and their outputs do not agree, then issues related to age model structures, employed priors, and statistical methods used would need to be examined in an effort to determine, if possible, which model is aberrant. Clearly, this is an issue that warrants further work. Returning to the topic of newly discovered and dated sites, characterized by unambiguous cultural attributions and associations between material cultural remains and dated samples, it is also conceivable that the comparison of such data to an existing age model could be a means of evaluating whether the latter is reliable.

A large number of chronological studies in the field of archaeology are focused on individual sites, and while this is of obvious utility, the above discussion highlights certain instances for which such a focus can be problematic. This is especially the case when the focus is on examining how an archaeological culture, in its entirety, relates to D-O climatic variability. By employing approaches that apply Bayesian methods to collective samples of chronological data that are associated with unambiguous, distinct, and successive cohesive adaptive systems, especially approaches that allow site-specific stratigraphic priors to be incorporated into a broader cultural phase model, it is possible to overcome potential limitations associated with site-specific age models, produce age models that rely on more representative samples of past human occupation, especially for regions or archaeological records dominated by single-component sites, and construct broad chronologies that can more accurately place human cultures within their respective paleoenvironmental frameworks. At the same time, by incorporating results from individual sequences, one has an increased potential, with respect to more recent time periods, to recognize temporally differentiated cultural variability within and between regions.

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Figure captions

Figure 1 a) comparison of single grain OSL ages and calibrated 14C AMS ages from the site of Les Cottés (reproduced from Jacobs et al. 2015); b) an excerpt of the Bayesian age model for Les

Cottés concerning the Protoaurignacian and Early Aurignacian levels (modified from Figure 4 of Talamo et al. 2012).

Figure 2 Top: climatic variability between 43 ka and 36 ka cal BP as recorded in the NGRIP ice, along with numbered Dansgaard-Oeschger Interstadials and the approximate temporal boundaries (light grey) of Heinrich Stadial 4 (H4), the latter derived from Sànchez Goñi and Harrison (2010). Superimposed is the internal propagated uncertainty (dark grey) calculated for the age determination of the Campanian Ignimbrite (CI) eruption according to de Vivo et al. (2001).

Bottom: Banks et al.'s (2013b) modeled temporal boundaries between Transitional Industries (TI: Uluzzian and Châtelperronian), the Protoaurignacian (PA), Early Aurignacian (EA), and Evolved Aurignacian (AII). The 68.2% and 95.4% probability intervals for the modeled boundaries between the archaeological cultures are indicated.

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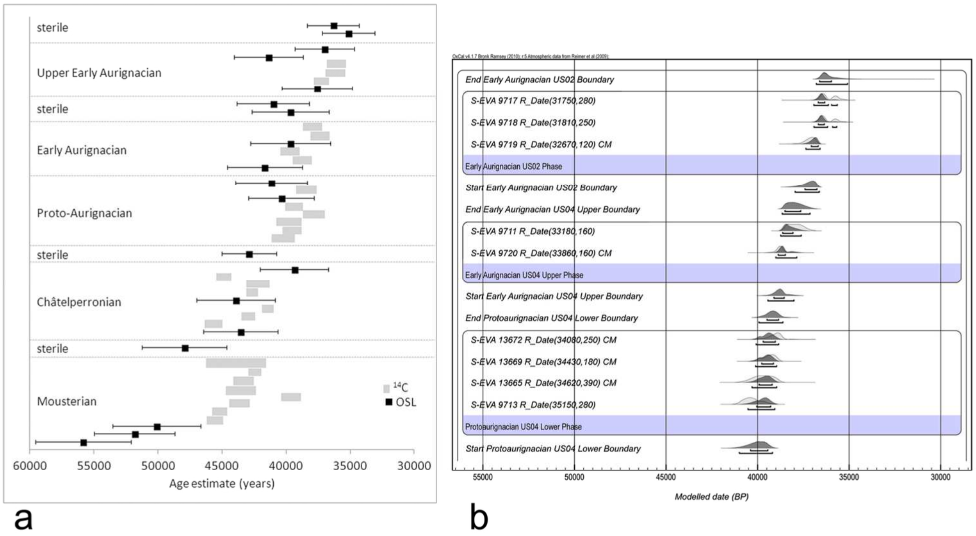

Figure 1 a) comparison of single grain OSL ages and calibrated 14C AMS ages from the site of Les Cottés (reproduced from Jacobs et al. 2015); b) an excerpt of the Bayesian age model for Les Cottés concerning the Protoaurignacian and Early Aurignacian levels (modified from Figure 4 of Talamo et al. 2012).
133x75mm (300 x 300 DPI)

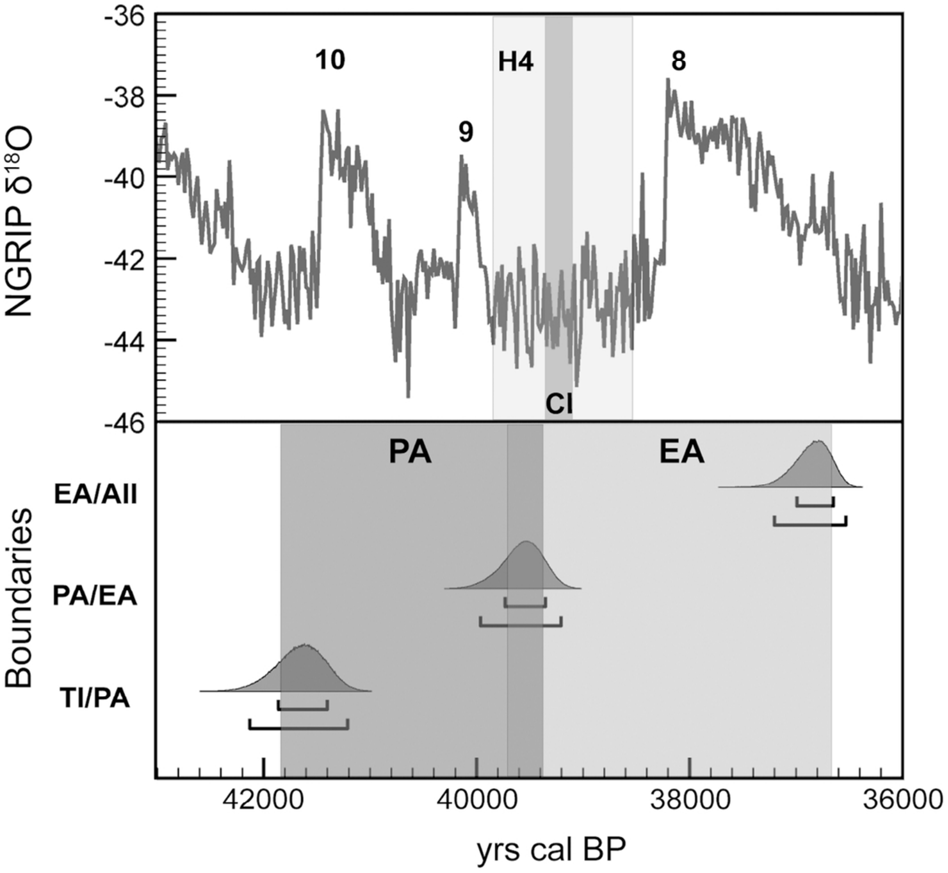

Figure 2 Top: climatic variability between 43 ka and 36 ka cal BP as recorded in the NGRIP ice, along with numbered Dansgaard-Oeschger Interstadials and the approximate temporal boundaries (light grey) of Heinrich Stadial 4 (H4), the latter derived from Sànchez Goñi and Harrison (2010). Superimposed is the internal propagated uncertainty (dark grey) calculated for the age determination of the Campanian Ignimbrite (CI) eruption according to de Vivo et al. (2001).

Bottom: Banks et al.'s (2013b) modeled temporal boundaries between Transitional Industries (TI: Uluzzian and Châtelperronian), the Protoaurignacian (PA), Early Aurignacian (EA), and Evolved Aurignacian (AII). The 68.2% and 95.4% probability intervals for the modeled boundaries between the archaeological cultures are indicated.

108x103mm (300 x 300 DPI)