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EUBAR: A DATABASE OF ^{14}C MEASUREMENTS FOR THE EUROPEAN BRONZE AGE. A BAYESIAN ANALYSIS OF ^{14}C-DATED ARCHAEOLOGICAL CONTEXTS FROM NORTHERN ITALY AND SOUTHERN FRANCE

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ABSTRACT. The chronological framework of European protohistory is mostly a relative chronology based on typology and stratigraphic data. Synchronization of different time periods suffers from a lack of absolute dates; therefore, disagreements between different chronological schemes are difficult to reconcile. An alternative approach was applied in this study to build a more precise and accurate absolute chronology. To the best of our knowledge, we have collected all the published ^{14}C dates for the archaeological sites in the region from the Ebro River (Spain) to the Middle Danube Valley (Austria) for the period 1800–750 BC. The available archaeological information associated with the ^{14}C dates was organized in a database that totaled more than 1600 ^{14}C dates. In order to build an accurate and precise chronology, quality selection rules have been applied to the ^{14}C dates based on both archaeological context and analytical quality. Using the OxCal software and Bayesian analysis, several ^{14}C time sequences were created following the archaeological data and different possible scenarios were tested in northern Italy and southern France.

INTRODUCTION

The Bronze Age and Iron Age in protohistoric Europe are often characterized by a qualitative division. Since the beginning of the discipline, archaeologists have been trying to divide time into well-defined timespans, usually based on the typological analysis of human artifacts, in particular metallic objects and pottery. Such conventional periods or phases constructed from the archaeological record generally serve as the base for all archaeological study. Three main problems with such a chronological system are (1) the lack of uniform acceptance of those phases among scholars, (2)the differences in the terminology used for defining phases, and (3) the amount of good quality contexts and the diligence given to ensuring context reliability remain low.

The result is a plurality of phases, which are defined differently from one country to another and from one school to another, and whose origins are rooted in the traditional studies carried out in each country over the 20th century. This approach represents a clear stumbling block for any research with a macroscale geographic view. Moreover, the criteria adopted for correlating phases from different regions are frequently based on the presence/absence of archaeological materials with a fossil guide value.

In order to relate each archaeological phase to an absolute chronology, the radiocarbon dating technique combined with Bayesian statistical analysis represent a powerful tool (Buck et al. 1996; Bayliss et al. 2007; Bronk Ramsey 2009a). In the last few decades, the increase of ^{14}C-dated archaeological contexts for the Bronze Age and Iron Age has slightly improved the situation. This article highlights the existing problems through a comprehensive review of all the available information from ^{14}C-dated archaeological contexts in southern France and northern Italy during part of the 2nd and the beginning of the 1st millennium BC (1800–750 BC).

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THE BRONZE AGE AND IRON AGE TRANSITION IN PREHISTORIC EUROPE

The debate about a uniformed and unambiguous chronological framework for the Bronze Age and the beginning of the European Iron Age is far from settled among the scientific community. Defining a structured division in phases, based primarily on the typochronological seriation of human artifacts, has been one of the primary aims in archaeological studies over the last century. The first attempt in this field can be recognized in the German school with the works of Paul Reinecke (1899, 1900, 1902, 1965). He was responsible for the division of the Bronze Age into *Bronzezeit A-D* (2200–1200 BC) and *Hallstatt A-B* (1200–750 BC) for the chronology north of the Alps, which has for a long time represented the basis for the European chronology. The starting point of his chronological framework was the combination of the typological method with the dating of single contexts through a combination finds. For instance, a particular kind of pottery handle named *ad ascia* is traditionally a fossil guide for the first phases of the Middle Bronze Age in northern Italy (Bernabò Brea et al. 1997; Cattani 2011), while the term *cilindro-retta* is usually used as a proof for the start of the *Bronzo Recente* phase in the north Italian LBA (Cocchi Genick 2004; Cattani 2009; Cattani et al. 2010).

The other European chronologies were partially modeled on Reinecke's periodization with the technique called cross-dating introduced by Flinders Petrie (1899). The analysis of the pottery assemblages and the association of "central European" typologies with imported ceramics from the eastern Mediterranean, especially Attic pottery with fossil-guide function, was based on the idea of the contemporaneity of the same elements located in different places, without taking into account the possibilities of time gaps between the date of manufacture and the time of deposition (Olivier 1999; Trachsel 2004; Arnold 2012).

Studies carried out by Herman Mülller Karpe (1959) in the territories north and south of the Alps allowed for the correlation of the north Italian chronological framework with the Austrian/German one through the analysis of metallic typologies. We chose to combine the territories of the northern part of Italy and southern France because we are dealing with the same historical phenomena, evidenced by the adoption of new pottery and metallic typologies, which are characterized by different chronologies in different places. Therefore, the transition from a given period to the successive one must be understood as the moment in which the social changes that led to such innovations took place. Hence, ^{14}C dating represents a compelling technique to this end.

Northern Italy

Traditionally, in the area south of the Alps, which now corresponds to northern Italy, the Bronze Age has been divided into four conventional phases: *Bronzo Antico* (BA), *Bronzo Medio* (BM), *Bronzo Recente* (BR), and *Bronzo Finale* (BF). The Early Bronze Age (BA) is formed by two phases (BA1 and BA2); the Middle Bronze Age (BM) is divided into three subphases BM1, BM2, and BM3; the Late Bronze Age is conventionally divided in two phases. The first one is named *the Bronzo Recente*, comprising two subphases, *BR1* and *BR2*, and the second one is the *Bronzo Finale*, usually formed by BF1, BF2, and BF3. The following phase is the Iron Age (Fe).

The most relevant differences in the Italian chronology relates to the LBA, for which two different positions have been proposed, the first one of Renato Peroni and his school and the second one based on Raffaele De Marinis' studies. According to Peroni (1990, 1995, 1996), the beginning of the Iron Age should be set at 1020 BC. The date, also according to the chronology supported by Lothar Sperber (1987), was established after a typological analysis and cross-dating of bronze artifacts recovered north and south of the Alps (Giardino 1995; De Marinis 2005; Pacciarelli 2005). The recent works of A J Nijboer based on the analysis of ^{14}C dates from Latial contexts agree with this high chronology (Nijboer et al. 1999–2000; Nijboer and van der Plicht 2008; van der Plicht et al. 2009). The other school is led by De Marinis who organized the first three phases of the Bronze Age framework on the stratigraphic sequence of the settlement of Lavagnone (in northern Italy). According to his position, the beginning of the Iron Age should be placed in the end of the 10th and beginning of the 9th century BC (De Marinis 1999, 2005). This aligns with the studies of Christopher Pare (1996, 1998), who set the start of the Iron Age in the Italian Peninsula between 960 and 920 BC.

Southern France

In southern France, the Bronze Age has conventionally been divided into three main phases: *Bronze Ancien* (BA), *Bronze Moyen* (BM), and *Bronze Final* (BF). The Early Bronze Age is traditionally composed of three subphases: BA1, BA2, and BA3. The Middle Bronze Age is made up of two subphases, BM1 and BM2. Finally, the Late Bronze Age is composed of three subphases, BF1, BF2, and BF3, and it is followed by the Iron Age (Fer).

A division of periods for the French chronology was first proposed in the work of J Déchelette (1910), and contemporary with Reinecke's system. After this research, the creation of a chronological framework composed of three main phases is attributed to J-J Hatt (1955a,b, 1958), and it is consolidated by J-P Millotte (1970). Along with the north Italian chronology, the Late Bronze Age in southern France constituted the most debated timespan of the whole sequence. Hatt's division of the LBA includes a further partition in two subphases marked by the letters *a* and *b* for both the BF2 and the BF3. Starting from the 1970s, a new subdivision of the LBA was proposed by a group of French protohistorians, who grouped the *Bronze Final* 1-2a, 2b-3a, and 3b-*Hallstatt Ancien* (Brun 1984; Brun and Mordant 1988; Gaucher 1992; Lachenal 2010). Brun argued that the divisions between the phases *a* and *b* of the BF2 and the BF3 were more pronounced than those between the main phases BF1, BF2, and BF3. The influence can clearly be traced to Reinecke's division and the tendency to correlate the French chronological sequence to the one adopted for regions north of the Alps is a common denominator in protohistoric research. Among the recent works in this field, we can cite the studies about the so-called Rhine-Swiss-Oriental French culture in the LBA (David-Elbiali and Moinat 2005; Brun et al. 2009; David-Elbiali 2009; David-Elbiali and David 2009; Milcent 2009).

EUBAR: SITES, CONTEXTS, AND SAMPLING

The available information originates from a new European database, which has been developed in the last two years by the author and is available at the webpage www.telearchaeology.org. Its structure takes the recently published Database of Catalan Radiocarbon Dates[3] as a starting point. The EUBAR database includes information about more than 1500 ^{14}C-dated archaeological contexts already published from a wide territory between the Ebro and Danube rivers. The area includes the northeastern part of the Iberian Peninsula, southern France, northern Italy, Switzerland, Austria, and southern Germany. The analyzed timespan goes from 1800 to 750 BC, with that end date determined by the Hallstatt plateau: a plane on the calibration curve, caused by variations in solar activity, which prevents us from taking into account dates between 750 and 400 because the results would be characterized by too large a timespan, and so would not be useful for a statistical analysis (Van Geel et al. 1996, 1998; Speranza et al. 2000; Tinner et al. 2003; Dergachev et al. 2004; van der Plicht et al. 2004; Swindles et al. 2007; Barceló 2008).

The data set used for this analysis is composed of a total of 687 ^{14}C dates, 221 come from 87 north Italian archaeological sites and 466 from 214 southern French sites. All the ^{14}C dates have been

3. The Catalan database can be seen at http://www.telearchaeology.com/c14; an English version will be soon available.

recalibrated using the software OxCal v 4.2 (Bronk Ramsey 2009a) and the most recent calibration curve, IntCal13 (Reimer et al. 2013). The data set and its references can be consulted from the webpage (http://www.radiocarbon.org/) as an online supplement of the journal *Radiocarbon*. The dates used for the analysis, including the outliers, are marked in bold.

The analyzed regions of northern Italy are Valle d'Aosta, Piemonte, Lombardia, Liguria, Trentino-Alto Adige/Südtirol, Veneto, Friuli-Venezia Giulia, Emilia-Romagna, and Toscana. In southern France, sampled regions include Aquitaine, Midi-Pyrénées, Languedoc-Roussillon, Provence-Alpes-Côte d'Azur, Poitou-Charentes (only the department of Charente), Limousin, Auvergne, and Rhône-Alpes. The distribution in space of collected data is not homogenous; the average is one ^{14}C-dated archaeological site every 1267 km^2 (Figure 1).

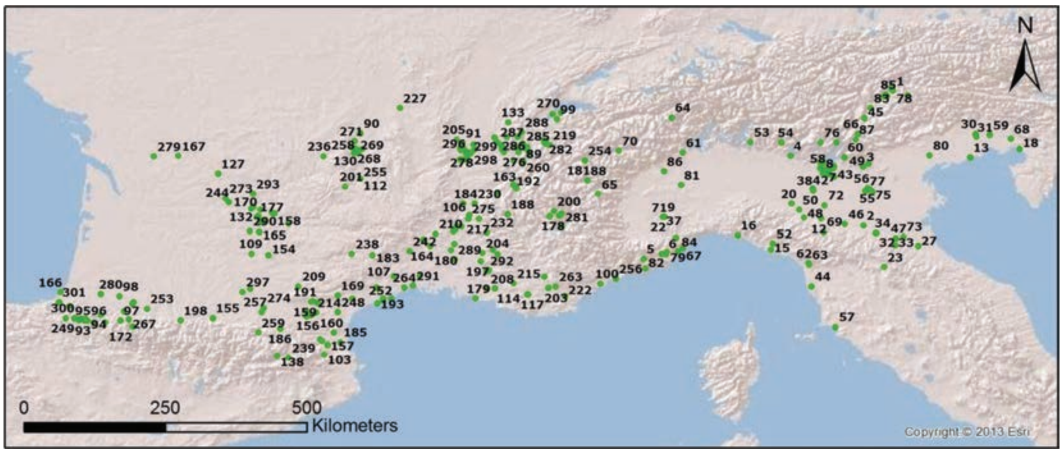

Figure 1 Map of the sites included in the data set; the numbers correspond to the ID numbers of the data set. Overlapping labels have not been reported.

Our challenge has been to collect extensive information about the archaeological contexts dated by ^{14}C, dispersed throughout different journals and monographs. In several cases, this huge source of data has been integrated in direct communication with the authors of the publications, who offered us the opportunity of developing a more up to date database. In the EUBAR database, each ^{14}C date is followed by a description of the provenance of the sample and the associated context. Where available, the archaeological phase of the dated contexts has been noted in the references.

DATA ANALYSIS

Sample Context Prescreening

The accuracy and precision of ^{14}C dates depends first of all on the accuracy and precision of the related archaeological contexts, and on any degree of error introduced during their analytical processes, including sample preparation and measurement (Boaretto 2007; Regev et al. 2012). It is therefore important to verify whether the selected contexts from which the ^{14}C dates are recovered can be considered closed and well defined.

Due to the extreme variety of the sources, the quality and completeness in the description of the published archaeological record can vary significantly. Regarding ^{14}C in particular, the exact location of the ^{14}C sample is sometimes very difficult to find, or cannot be retrieved from the published material; hence, association with a given context is impossible to ascertain. In addition, problems related to the postdepositional process, like bioturbation, affect the quality of the dated samples and thus should be detected during the archaeological excavation. These factors lower the chronological value and quality of many of the collected samples and are directly responsible for an increase in uncertainty.

In spite of such problems, to the best of our knowledge we collected all the available dates, recalibrated them, and identified the possible outliers by evaluating the archaeological record and using Bayesian modeling. As an outcome, this research represents a starting point for future studies and points to the necessity of enlarging the amount of ^{14}C dates from good archaeological contexts. After the collection, the ^{14}C dates were selected for modeling based on a set of parameters that define the quality of the dates. As we were not dealing with first-hand data, but with data coming from a wide variety of excavations, we were compelled to check context reliability as reported in the references. As a consequence, a prescreening of the sample was required.

Initially, a distinction between long-lived samples (wood and wood charcoal) and short-lived samples (charred seeds and bones) was made. In the case of charred seeds a further distinction would be necessary based on the amount of seeds found together. This is related to clustered seeds versus single seeds. As the latter could more easily move by bioturbation between different layers/strata, a cluster of seeds would be of better quality for ^{14}C dating. Yet, this type of information was not available in the report; therefore, we preferred seeds, as short-lived, for the chronology rather than wood charcoal. The date of the wood charcoal should be interpreted carefully, and in general charcoal samples represent a *terminus post quem* in relation to the dated event. Of the total amount of samples, 73% of the dates come from long-lived samples like charcoal and wood, while short-lived samples (mainly bones, followed by seeds) represent only 22% of the dataset. For 37 samples, such information is missing.

As a general rule, among the samples priority was given to ^{14}C dates recovered from *in situ* clusters of carbonized seeds or bones in articulation associated to finds and contexts that have a primarily ceramic or metallic inventory (e.g. more than one type of diagnostic pottery or metal object) found *in situ* (Boaretto 2009). Other than these contexts, which might be rare, contexts with short- or long-lived material were considered and analyzed, like destruction layers and installations (pits, metallurgical areas). On the other hand, fills and mixed contexts were avoided or rated low in the later analysis of the dates. Single short-lived materials, like a charred seed or a bone, are also of low importance due to the possibility of intrusiveness or residuality of the sample in relation to the context.

Errors can also be related to the preparation of the sample in the laboratory, a process that aims to separate the original carbon-bearing material from the extrogeneous carbon and to obtain a reliable date (Mook and Streurman 1983). Therefore, in order to control for uncertainty it is necessary to know the chemical pretreatment and to have details on the measurements of the samples. Regrettably, for many samples this information is lacking as it is not reported in the references. We therefore rely on the precision quoted by the lab as a parameter for the quality of the date.

For the analysis carried out herein, we took into account only samples coming from archaeological contexts that could be described as monophasic from the analysis of metallic and pottery typologies. Discarded contexts were thus discarded that included more than one conventional phase. In the same way, materials divided into artificial archaeological horizons, rather than stratigraphically, were not considered reliable, as a clear association with the sample cannot be verified.

Northern Italy

Although 221 ^{14}C dates were available, 170 samples were removed after prescreening, leaving 51 dates originating from 19 different sites. In order to visualize the quality of the 51 samples retained for analysis, they have been represented in a plot (Figure 2). We have used as a model the plot developed for the chronology of the Early Bronze Age in the southern Levant (Regev et al. 2012). The *x* axis contains the archaeological sites in alphabetical order, while the *y* axis represents the chronology expressed in years BC.

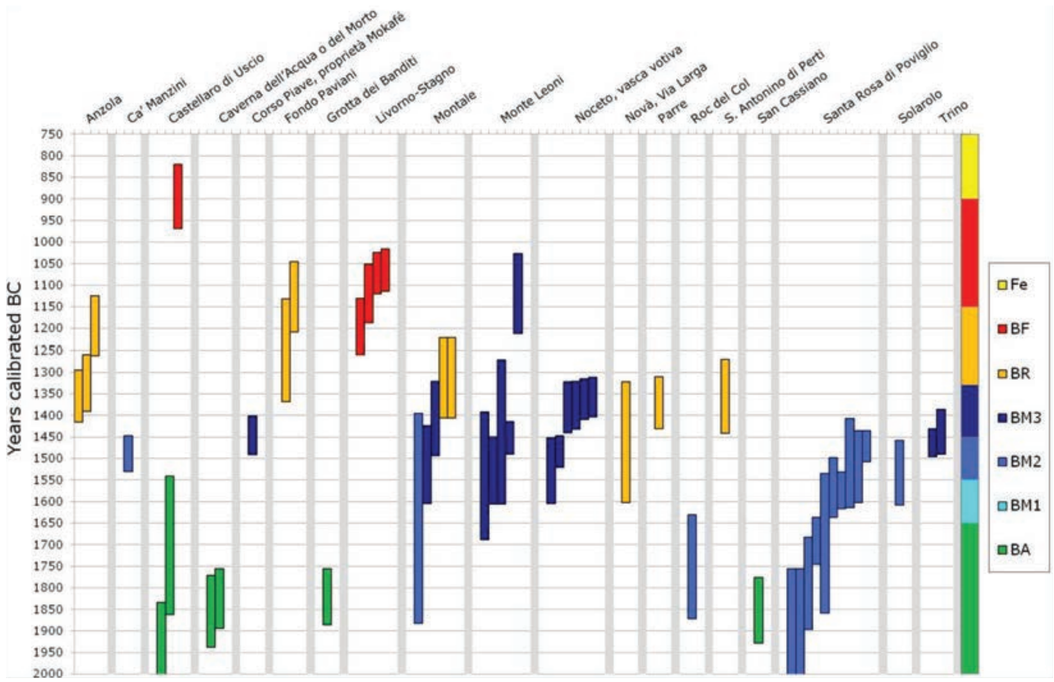

Figure 2 Filtered 1σ calibrated ^{14}C dates for the Bronze Age and the beginning of the Iron Age in northern Italy with the corresponding archaeological phases as reported in the references. Each colored line represents one date. The reader is directed to the online version of this article to view the figure in full color.

Each bar corresponds to a ±1σ calibrated interval of a single ^{14}C date; ±1σ calibrated ranges were used for clarity. This has no influence in the Bayesian model applied to the final set of dates. The color corresponds with the conventional chronology as it is defined in the legend. The conventional chronological framework is shown on the right. It is clear that not all the data fit the traditional chronological framework proposed for north Italian regions, with dates from some sites showing a large spread beyond the limits of the periods according to the conventional chronology (e.g. Santa Rosa di Poviglio).

The reasons for the rejection of dated samples are multiple. In some circumstances, samples were collected during survey projects conducted for geoarchaeological campaigns. This is the case for the dates from the settlements of Castello del Tartaro, Fabbrica dei Soci, Perteghelle, and three samples from Fondo Paviani, which were gathered during the Alto-Medio Polesine-Basso Veronese Project (Whitehouse 1993, 1994, 1997). Likewise, the samples from prehistoric features like agricultural ditches (Stanghelle Est) and infrastructure (Strada Meridionale su Argine) were not taken into account. In other sites (Lazise-La Quercia, Molina di Ledro, etc.), the samples originate from vertical wooden features in the settlement; therefore, the association with material objects is hard to obtain.

These dates can be useful for defining the phases of building of a lake dwelling, but they are not appropriate for our analysis. Other dates, like those from the Arano necropolis, were not associated with archaeological materials, as the grave did not have funerary assemblages. Hence, although they represented short-lived samples, we decided to reject them. Eventually, dates that represented more than one archaeological phase were removed from the filtered data set. Nevertheless, most of the samples were eliminated due to information about the context being poor or even absent.

Southern France

From an original data set of 466 dates, after the sample prescreening, we obtained 96 dates originating from 44 different sites (Figure 3). A large amount of dates were rejected in the filtering process because they derived from unpublished data; hence, the information about the associated context was not available. Many such dates were included in the online database BANADORA (http://www.archeometrie.mom.fr/banadora/) developed by the CNRS, the Université Claude Bernard - Lyon 1 and the Université Lumière - Lyon 2.

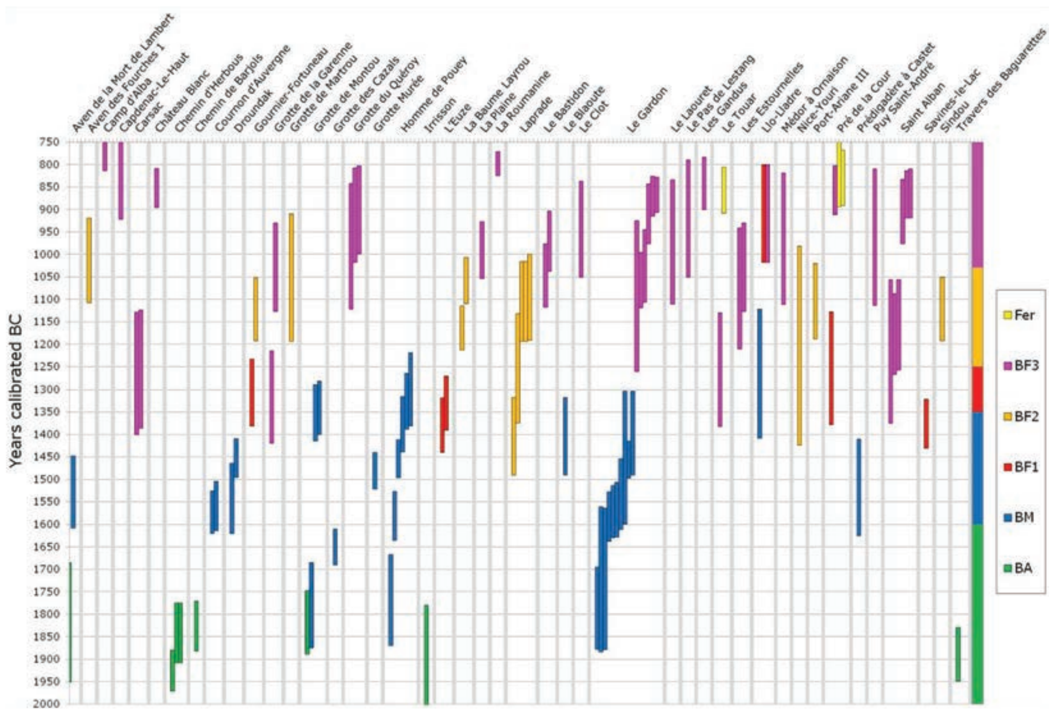

Figure 3 Filtered 1σ calibrated ^{14}C dates for the Bronze Age and the beginning of the Iron Age in southern France with the corresponding archaeological phases as reported in the references. Each colored line represents one date. The reader is directed to the online version of this article to view the figure in full color.

Other dates were not associated with pottery or metallic typologies with guide-fossil function or they were not of monophasic contexts; thus, they were eliminated from the filtered data set. As a general rule, the six criteria adopted for rejecting unreliable north Italian dates were valid also for the southern French archaeological contexts. The prescreening against the original data set resulted in only a few reliable dates derived from the six archaeological phases (BA, BM, BF1, BF2, BF3, Fer) following Hatt's division.

Modeling Methods (Modeling Bronze Age/Iron Age Transition)

The dates were analyzed according to the principles of statistical Bayesian analysis (Bayes 1763; Buck et al. 1996) using the software OxCal v 4.2 (Bronk Ramsey 2009a), which calculates the posterior probability distributions of an existing sequence of dates. Thanks to the association between the samples and the good contexts, it was possible to build sequences of ^{14}C dates ordered according to the archaeological phase they belong to. This kind of information (*a priori*) forms the parameters that condition our data; thus, such an approach represents the backbone of our research.

This mathematical theory was introduced in order to define the probability of success for cases in which the observed data are provided with qualitative or semi-qualitative information about the relative relationships between the samples and the expected results. With the aim of detecting the ^{14}C timespan of an archaeological phase, the samples were ordered according to the different conventional phases. In each phase, the samples were distributed in a chronological order, from oldest to youngest. If the resolution of the context was good, it allowed us to analyze also the subphases of an archaeological phase. We managed to get into particular detail in phases characterized by a long timespan, like the Middle Bronze Age in northern Italy (phases *Bronzo Medio* 1, 2, and 3) and the Late Bronze Age in southern France (phases *Bronze Final* 1, 2, and 3). The criteria for the analysis were adopted and followed as systematically as possible.

We have only presented dates that have had their reliability checked previously, according to the rules already mentioned. We ran two models (contiguous and sequential) for the same data in order to check variations in the results. In the contiguous models, the software calculates the transitions between each phase and provides this information according to the 1σ and 2σ probabilities. Slightly different are the sequential models, in which each phase has two boundaries, one for the start and the other for the end. The effect of those boundaries is a constriction of the dates in two limits. This could lead to the creation of chronological gaps among phases, whose causes can be related to the distribution of the dates included in the data set. A great advantage of this modeling is that it enables the reduction of uncertainty by narrowing down the largest ranges of dates, caused by the presence of the plateau in the calibration curve (Reimer et al. 2013), and rendering relatively precise dates to each archaeological layer dated.

Wherever possible, two chronological models were run separately for each sample type, short-lived and long-lived. The results were then compared with each other in order to evaluate the possible differences in years caused by the old-wood effect. Regrettably, just one multilayered site (Montale in northern Italy) provided more than one reliable date for contiguous phases. We decided to run a model with these dates and check the results with the general sequence.

Definition, Identification, and Removal of Archaeological and Analytical Outliers from the Sequences

An additional importance of the modeling is identification of the outliers. A date can be defined an outlier when the agreement index is less than 60%. In such cases, the confidence interval of the date does not statistically fit into the phase from which it originates. The reasons for data being defined as outliers were specified before they were removed from the sequence (Bronk Ramsey 2009b). It was not just the agreement index that was considered, we also took into account the type of sample and the context. As a general rule, bones and seeds were preferred over wood and charcoal. Samples that appeared as outliers in the model were given additional consideration, and a careful analysis was conducted in order to ensure the possible reason for their "unfitting" date. Although the earliest sample of the earliest phase and the latest one of the sequence were frequently characterized by a low agreement index, we did not consider them automatically as outliers (Regev et al. 2012).

After the identification, the outliers were removed one by one and the model was run after each removal. The result can change after each removal; a date that was marked as an outlier in the previous model can increase the agreement index after the elimination of another date and hence be included in the model. Dates with an agreement index of 55–60% were left in the sequence.

Northern Italy

The available dates from northern Italian contexts after the sample prescreening were distributed into five archaeological phases (BA, BM2, BM3, BR, BF). Regrettably, no reliable dates were left after the preselecting of the dates for the beginning of the Iron Age (Fe phase).

As the first phase of the Middle Bronze Age (*Bronzo Medio* 1) did not produce reliable dates, we introduced it artificially into the OxCal model using the *Interval* tool, which is used to calculate the timespan between two events in a sequence, without deciding *a priori* of a predetermined time duration for the missing phase. In order to visualize in a simple way the distribution of short-lived samples in the sequence, they were marked with an asterisk in the models. A contiguous model and a sequential one (Figures 4–5) were run several times in order to create a reliable sequence. In both models, nine samples were characterized by a low agreement index and hence eliminated from the Bayesian analysis.

From the phase *Bronzo Medio* 2 (BM2), five samples were removed. The first four samples are charcoal originating from the settlement of Santa Rosa di Poviglio in the Padan Plain (GX-16298; GX-16299; GX-15011; GX-14032). Although they came from a well-defined archaeological context, they are slightly old for the archaeological phase to which they are supposed to belong. As already noticed in the references (Cremaschi 2004), this can be due to an old-wood effect, which could correspond to the intensive deforestation in evidence in the first phase of the Terramare settlement. Beta-48687, collected at Roc del Col, is also too old for the BM2 phase; it could be attributed to an old-wood effect as the dated sample is charcoal and was part of a 15-mL sample sent to the laboratory, in which perhaps there were adult logs older than the dated context (Nisbet 2004).

From the phase *Bronzo Medio* 3 (BM3), one sample (GrN-9274) from the data set of the settlement of Monte Leoni was removed because it was too recent, as already observed in the references. The rest of the outliers were from the Late Bronze Age: two samples from the *Bronzo Recente* (BR) phase and one for the *Bronzo Finale* (BF) phase. The first two are a charred seed from the Novà, Via Larga site (GrA-5216), coming from the US 10, which is too old, and a charcoal from the US 8 collected in the Fondo Paviani settlement (LTL-5285), which on the contrary is too recent. The last date to be removed is charcoal from layer 2 of the Castellaro di Uscio settlement (Gif-7214), which is also too recent. After the removal of analytical outliers, 42 dates from 17 archaeological sites composed the contiguous and the sequential model. We also modeled the stratigraphic sequence of the Montale settlement (Figure 6) which provided five reliable ^{14}C dates: one for the BM2, two for the BM3, and another two for the BR. The results agree with the general sequence proposed for northern Italy.

Southern France

Contiguous and sequential models (Figures 7–8) were also created with the ^{14}C dates from archaeological sites in southern France. The outliers were mainly distributed in the last phases of Late Bronze Age (BF1, BF2, and BF3). One date from charred seeds gathered at the settlement area of Llo (Gif-3744) is too old for the BF1 phase, as already noted by the author (Campmajo 1983). It highlights the need to check the reliability among also short-lived samples. Sample ARC-1618,

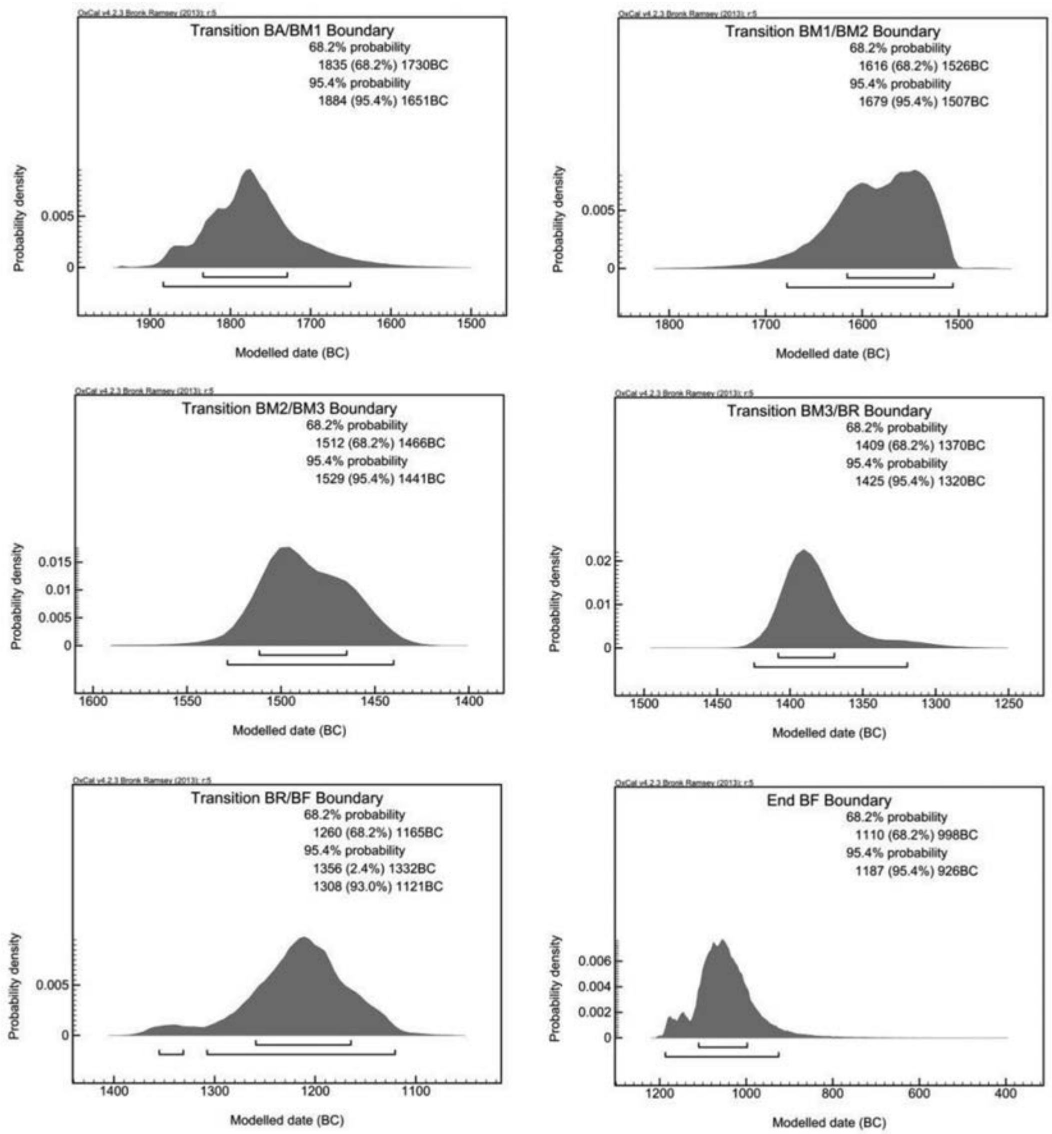

Figure 4 Transition boundaries of the contiguous model for archaeological contexts located in northern Italy (A_{model} = 122.4; $A_{overall}$ = 123.5).

which was collected in the Laprade settlement, is too old for the BF2 phase. It is the oldest date in the data set of this site, which comprises four other dates that fit correctly into the Bayesian model.

Nine dates obtained from charcoal samples were eliminated from the BF3 phase. Two samples collected in the village of Carsac (MC-2287, MC-2285) were removed for being too old for the archaeological contexts to which they belong. One date from layer C2d of the Grotte de la Garenne site (Ly-7184) is too old. Perhaps it is due to problems of contamination from the lower levels, in which materials typologically dated to the BF2 was found (Carozza 1994). Furthermore, Lachenal (2011) inserts the date (Ly-7185) from the upper occupation layer C2c in the BF2 phase. It highlights the existence of disagreements in the chronotypological chronological description of human artifacts.

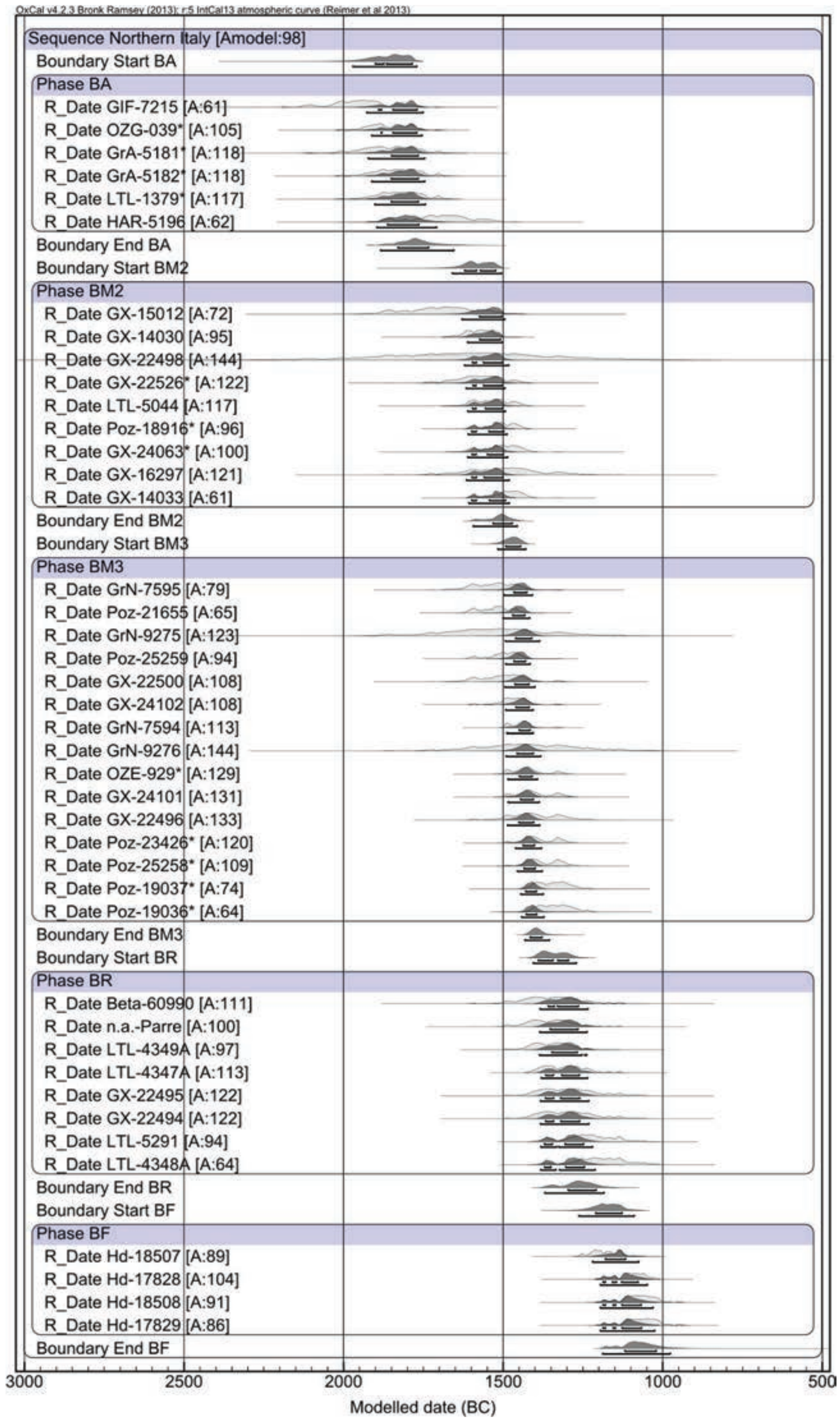

Figure 5 Sequential model for archaeological contexts located in northern Italy (A_{model} = 98.4; $A_{overall}$ = 96.1).

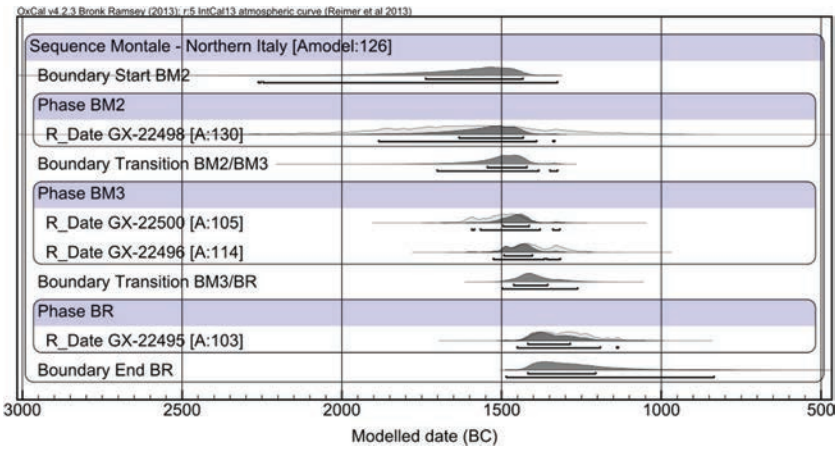

Figure 6 Contiguous model for the settlement of Montale located in northern Italy (A_{model} = 126.1; $A_{overall}$ = 126.2).

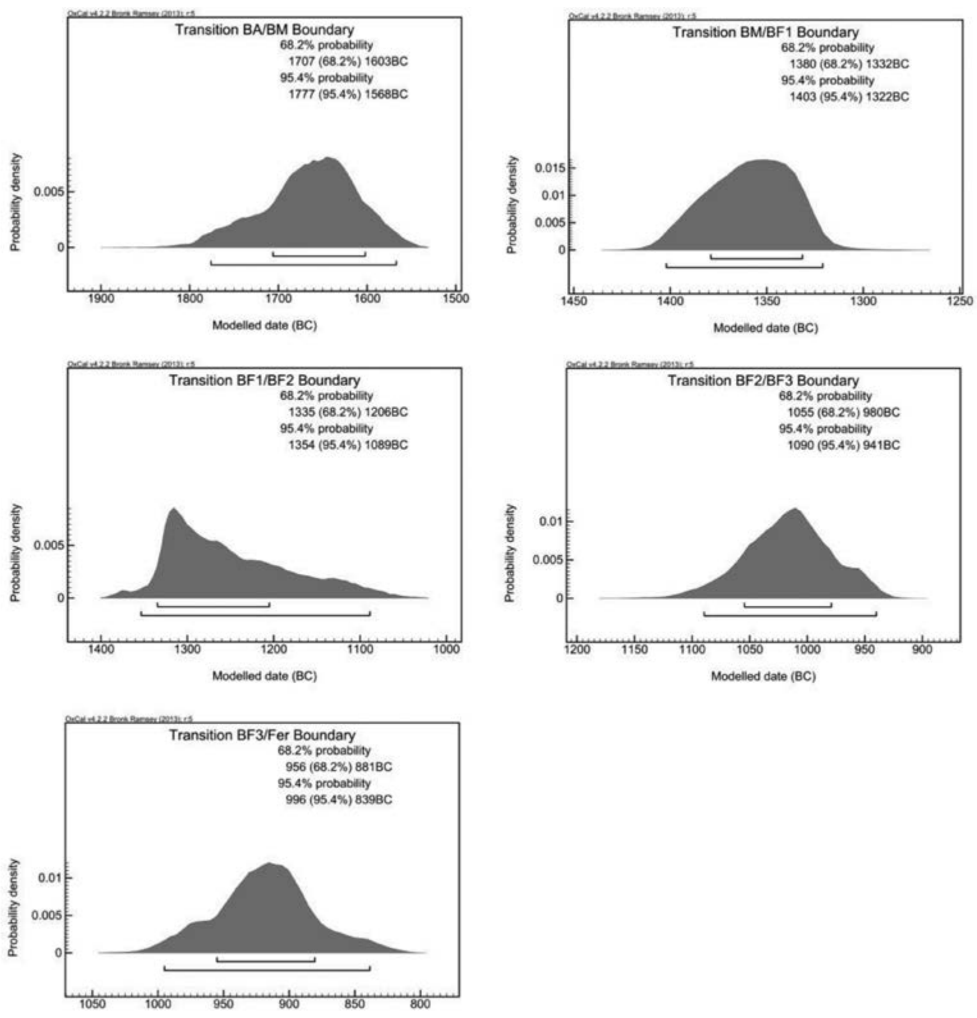

Figure 7 Transition boundaries of the contiguous model for archaeological contexts located in southern France (A_{model} = 145.7; $A_{overall}$ = 135.9).

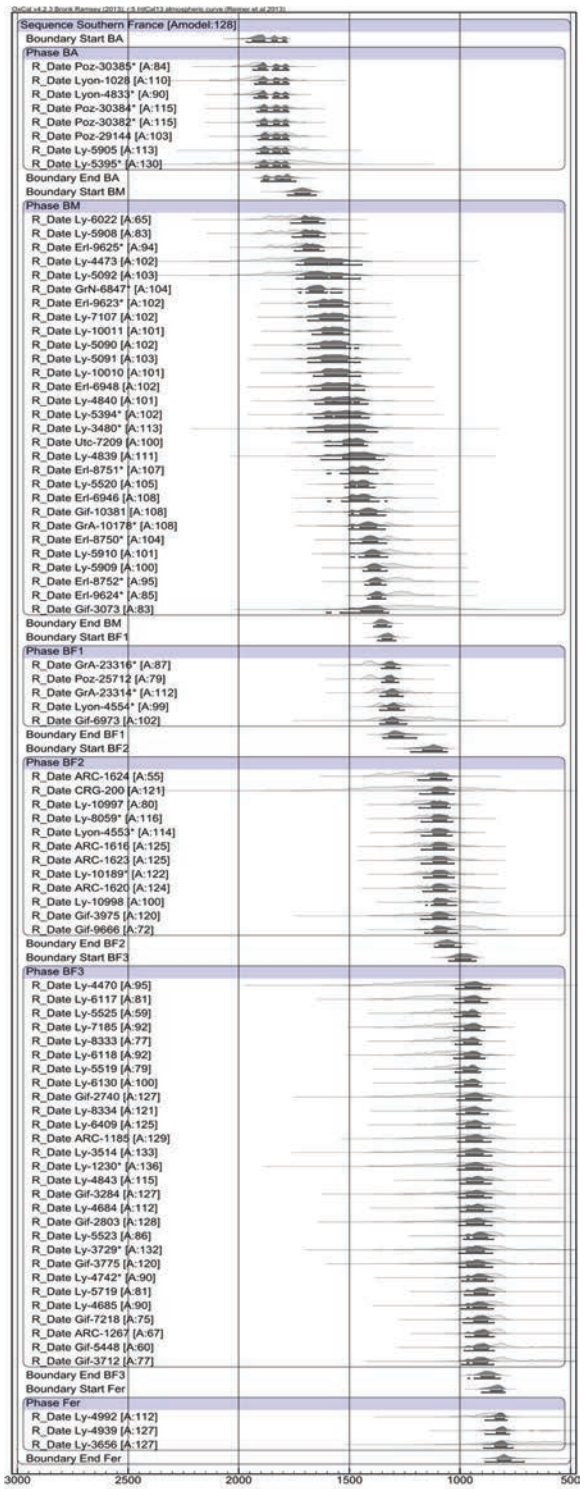

Figure 8 Sequential model for archaeological contexts located in southern France (A_{model} = 128.1; $A_{overall}$ = 102.1).

The sample collected from the settlement of Le Touar (Ly-4542) is too old for the BF3 phase, maybe due to an old-wood effect. Three dates (Ly-4743, Ly-5097, Ly-4686) from the site of Saint Alban seem to be slightly too old; in this case, we cannot exclude a higher beginning of the BF3 phase in the area of the site, in particular taking into account the marginal northern position of the settlement, located close to the Jura Mountains. Eventually, two dates were removed because they were deemed too recent. The first one was collected at the site of La Roumanine (Ly-8244) and the second one originates from the necropolis of Camp d'Alba (Ly-7433). As a result of this second selection with the removal of analytical outliers, 85 dates from 41 archaeological sites composed the contiguous and the sequential model.

DISCUSSION

Through the Bayesian modeling with OxCal v 4.2 (Bronk Ramsey 2009a), we produced two new chronological models for the Bronze Age in northern Italy and southern France (Figure 9). During the process of prescreening of collected samples according to their chronological value, a large amount of dates were rejected, prior to the start of Bayesian modeling. Problems related to the sampling strategies still remain. In many cases, the results of ^{14}C dating are used as a substitute for the chronotypological analysis of human artifacts and when diagnostic pottery or metallic typologies are missing. Consequently, association between the two variables was frequently lacking and the selected dates were fewer than expected. Therefore, we decided to include in the models dates characterized by a large standard deviation (±100 yr), although we are aware that it would be preferable to use dates with a shorter duration when available.

Another problem is the absence of ^{14}C-dated multilayered sites. Separately modeling dates from contiguous layers in the stratigraphy of individual sites could have yielded different models for each site. Combining such information would have allowed us to detect a possible degree of overlap between cultural horizons and the existence of regional variations. However, sufficient research is currently lacking to test this theory.

When a sequence of phases is run, the model manages to narrow the dates of the phase between the *Start Boundary* and *End Boundary*. Such a process implies a possible creation of temporal gaps among archaeological phases. Analyzing the results of the sequential models, few discontinuities in times were detected in the models for northern Italy and southern France for the 1σ confidence intervals. We did not take into account, in any of the models, the values represented by the beginning of the first phase, which is the *Start Boundary* of the Early Bronze Age, or the end of the last phase represented by the *End Boundaries* of phases *Bronzo Finale* and *Fer*.

Northern Italy

Taking into account the limited numbers of ^{14}C dates for this period and the size of the region, it must be stressed that these results highlight the need for further research and the necessity of an increase in the amount of dates from good archaeological contexts. The results of the modeling must be considered as a first step toward a ^{14}C-dated chronology for the Bronze Age in northern Italy. The adoption of good sampling strategy in the future can fill the gaps and improve the strength of the models.

Although we do not observe a relevant difference (more than 100 yr) between the ^{14}C chronology and the conventional one, it should be noted that both in the sequential model and in the contiguous model all the analyzed phases start and end before traditional dates proposed for these regions. This implies that the new ^{14}C chronology for the Bronze Age in northern Italy is slightly higher than the

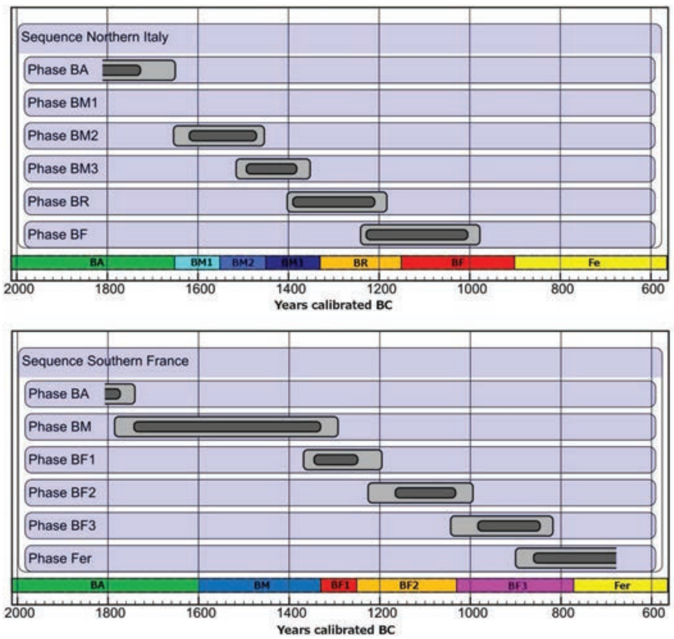

Figure 9 Results of the Bayesian modeling for northern Italy and southern France. Only the analyzed subphases have been represented. The conventional chronology is shown above the *x* axis. The ^{14}C scheme is a simplification of the results obtained through a sequentially phased Bayesian modeling: for the boundaries of each phase we chose the first value of the Start Boundary and the last value of the End Boundary for 1σ probability (dark gray blocks) and for 2σ probability (light gray blocks).

conventional one. Regrettably, the number of short-lived samples is few; moreover, they refer to the first three phases, are lacking in the last two phases. As a consequence, we could not run a separate model for seed and bone samples. In any case, the distribution of such samples in the phases does not suggest a problem related to an old-wood effect in the first three phases. The results obtained from statistical modeling of those samples collected from the Montale settlement are perfectly in agreement with the general ^{14}C chronological framework.

A debated topic, as already mentioned, is the beginning of the Iron Age in northern Italy. Unfortunately, there are still only a few dates for this period and no reliable dates were selected for analysis. Moreover, problems related to the typological description of material culture must be underlined. In particular, there are still difficulties in the distinction of artifacts typologically dated to the 10th century BC from those of the 9th century BC (Giovanni Leonardi, personal communication).

According to our models, the end of the LBA (BF) is placed in the contiguous model in the interval 1110–998 BC at 1σ probability and 1187–926 at 2σ. It is dated between 1119 and 1021 BC for 1σ probability and 1189–977 BC at 2σ in the sequential model. However, these results cannot provide a compelling answer for the beginning of Iron Age in northern Italy, since only one dated archaeological site for the BF phase is included and no Iron Age dates were inserted in the analysis in order to bracket the transition from the other side.

Concerning the discontinuity observed in the sequential model, the main temporal gap is located between the phases BA and BM2. Its duration is ~120 yr taking into account the 1σ values of the more recent dates for the End Boundary of the Early Bronze Age and the beginning of the Start Boundary for the Bronzo Medio 2 phase. This discontinuity is caused in part by the absence of a BM1 phase. If we take into account the 2σ confidence intervals, the gap disappears.

Southern France

In southern France, the results obtained by the Bayesian modeling are in close agreement with the traditional dates proposed for the transitions among Bronze Age phases. There is remarkably solid agreement on the beginning of the BF1, BF2, and BF3 phases between the traditional and ^{14}C chronologies. This demonstrates the reliability of the filtered dates.

The distribution of short-lived samples in the sequence is quite homogenous among the different phases. As a result of this, we could run a sequential model with bone and seed samples in order to test if a significant variation could be appreciated. The result showed that no differences can be detected; hence, we can discard an old-wood effect in the analyzed data.

The most significant changes relate to the beginning of the Middle Bronze Age (BM) and the Iron Age transition. The BM phase seems to start ~150 yr before the date adopted in the conventional chronology. Also, the transition to the Iron Age appears slightly higher in the ^{14}C model. In the contiguous model, the transition between BF3 and Fer is located in the interval 874–820 BC at 1σ probability and 904–806 BC for 2σ. These values are confirmed in the sequential model, in which the beginning of the Iron Age is dated within the interval 862–809 BC at 1σ probability and between 902 and 798 BC for 2σ. In any case, we have to highlight the problems of calibrating for the Hallstatt plateau, whose beginning corresponds to the traditional date proposed for the start of Iron Age in southern France, 775–750 BC (Janin 1992; Brun et al. 2009; Lachenal 2011). Moreover, only long-lived samples from two sites, Le Touar and Pré de la Cour, were selected for the Fer phase. In the future, new dates from good archaeological contexts could improve the situation and reduce the uncertainty.

As was the case with the north Italian model, time gaps were detected in the sequential model of the ^{14}C chronology of southern France for the 1σ confidence intervals. Such discontinuities are located between the three phases of Late Bronze Age, BF1, BF2, and BF3. These gaps disappear if we consider the 2σ values of the probability distributions.

CONCLUSION

This article proposes a new chronological model based on Bayesian statistical analysis of ^{14}C dates from reliable archaeological contexts in northern Italy and southern France. Although the number of reliable dates for macroscale research remains low, it has been possible to develop four different models with the software OxCal, two contiguous ones and two sequential ones.

Focusing on descriptive statistics, the ^{14}C chronology of northern Italy seemed to be slightly higher than the conventional one, while that of southern France is confirmed by the models presented in the article. However, a higher beginning of the Middle Bronze Age was detected. In both cases, the results claim the absolute necessity of an increase in the amount of ^{14}C dates from selected archaeological contexts. Moreover, we should investigate the problems of sampling and the errors in the traditional description of the material culture.

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