Change fast or change slow? Late Glacial and Early Holocene cultures in a changing environment at Grotta Continenza, Central Italy

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Abstract

This work contextualises the sequence of Grotta Continenza, a cave with a rich sequence of Late Glacial to Early Holocene archaeological levels spanning from the Late Upper Palaeolithic to the Neolithic, within the framework of southern Italy cultural adaptation to environmental change. The sequence is dated by Bayesian modelling of radiocarbon dates and event durations are computed, including hiatuses in sedimentation and gaps in culture development; these data are used in association with sedimentology and soil micromorphology to assess sedimentary models that can explain the environmental change.
Techno-typological and behavioural aspects of Late Upper Palaeolithic populations are correlated with environmental change, mostly during Younger Dryas.

Keywords
Late Upper Palaeolithic; Mesolithic; climate change; Italy; Bayesian modelling; sedimentary processes

1. Introduction

The transition from Late Upper Pleistocene to Early Holocene was characterised by fast and dramatic climatic change (Bond et al., 1997; Drescher-Schneider et al., 2007; Magri and Sadori, 2009; Combourieu-Nebout et al., 2013; Desprat et al., 2013; Di Rita et al., 2013; Joannin et al., 2013); rapid cultural turnover affected also the cultures developing in this period, as people had to cope with novel environmental situations (Berger and Guilaine, 2009) and constantly modify their lifestyle.

The links between environmental and cultural change from 14,000 to 6,000 calendar years BP are reasonably well-known in northern Italy, with data deriving from excavations in caves and in open-air sites (Castelletti et al., 1994; Boschian, 1997; Boschian et al., 1997; Kozlowski et al., 2003; Cusinato et al., 2004; Dalmeri, 2005; Boschian and Fusco, 2007; Tozzi and Dini, 2007; Peresani et al., 2012, Fontana et al., 2016).

However, the quality of these data decreases southwards, where very few Mesolithic sites – mostly caves - were explored. Even fewer of these sites include long stratigraphic sequences spanning the whole Late Upper Pleistocene to Early Holocene transition (Martini et al., 2005; Mussi et al., 2008; Lo Vetro and Martini, 2016; Visentin et al., 2016). Consequently, cultural change from late Upper Palaeolithic to Mesolithic and from Mesolithic to Neolithic is not well documented in the central and southern Italian peninsula.

The available data show that the transition from Late Upper Palaeolithic to Mesolithic in southern Italy was rather gradual and included subtle behavioural/economic change within the same hunting-gathering lifestyle. This gradual process contrasts with the abrupt and deep change between the Late Epigravettian (Late Upper Palaeolithic) and the Sauveterrian (Early Mesolithic) communities of Northern Italy - down to Tuscany (Astuti et al., 2005), even if it must be observed that the transition was somewhat more gradual in some sites of the Alpine area (Riparo Cogola: Cusinato et al., 2004). In most of the studied sites, this revolution is testified by the techno-typological aspects of the lithic industries (Isola Santa: Kozlowski et al., 2003), and is also marked by a gap of at least 400 years in the radiocarbon sequences.

The subsequent transition from the Mesolithic to the Neolithic is complex in the South: here, an early and diffuse Neolithic colonisation is documented by several rich settlements, contrasting with the previous sparse peopling recorded by few Late Upper Palaeolithic and Early Mesolithic settlements, and by only two Late Mesolithic sites (Biancofiore and Coppola (Eds.), 1997; Dini et al., 2008; Franco, 2011). These data indicate that the transition from subsistence to production economy, i.e. from Mesolithic to Neolithic cultures, was very fast in the South, with the new lifestyle substituting almost abruptly the previous one. This process was not substantially different from what happened in the North, where the transition was also abrupt, even if the later arrival of the Neolithic groups resulted in a longer lasting Mesolithic.

Within this framework, Grotta Continenza is particularly relevant because it includes a long sedimentary sequence including the whole Pleistocene-Holocene transition, from 15,500 to 7,000 cal BP (13,500-5,000 BCE). Within this sequence, human occupation is almost continuous and well-documented from the Late Upper Palaeolithic, to both phases of the Mesolithic and to the Early Neolithic (*Ceramica Impressa*/Impressa pottery cultural facies).

The goal of this paper is to contextualise the Grotta Continenza sequence within the framework of southern Italy cultural change, regarding the timing of the whole sequence, event duration and environmental change, with particular focus on the cultural aspects of the LUP-Meso transition.

2. The site

2.1. Geology and geomorphology

Grotta Continenza is a cave situated on the southern side of the Fucino Basin (Fig. 1), a roughly oval, 16x12 km-wide tectonic depression with a flat bottom. This basin was formerly occupied by a lake, whose level oscillated several times during the Late Pleistocene and Early Holocene, and was finally reclaimed in several stages between the Roman Age and the 19th century (Giraudi, 1989). The cave is situated on the northern side of Mt. Labrone, at 710 m asl, i.e. 43 m above the present-day plain, which corresponds approximately to the bottom of the old lake. The whole site and its infilling sediments are included within the altitude belt (685-715 m asl) where morphological and sedimentary traces of the 20,000-18,000 y BP highest stand of the Fucino Lake were observed (Giraudi, 1989). However, no primary lake sediments or geomorphological indicators of the ancient shoreline were observed inside the cave or around it.

The cave opens at the base of an about 30 m-high limestone cliff representing the hanging wall of one of the several faults that limit the Fucino Basin. The local rocks are mainly Cretaceous mudstones-wackestones, with subordinate grainstones.

The outer and main part of the cave is a rock-shelter about 20 m wide and 7-8 m deep (Fig. 2), which develops into an about 8x8 m cave, partly oriented along a secondary fault approximately perpendicular to the cliff. The ceiling of the inner cave is at present rather low (1.5 m in the highest parts), subhorizontal and shaped by dissolution potholes. Poorly developed speleothems (stalactites and some drapery) mantle ceiling and walls, whereas part of the floor is covered by a thick flowstone (Giraudi, 1999).

The mountain side around Grotta Continenza is rather steep, often dipping up to 45° and more, and with widespread subvertical rock outcrops and cliffs. This landscape is dissected by short and steep ravines partly occupied by colluvial fans (sensu Blikra and Nemec, 1998) originating from the dismantling of the cliffs. At present, the fans are partly stabilised by shrub and subordinate wood vegetation that has been expanding fast in the last decades.

One of these fans originates from the cliffs located uphill the cave and flows down somewhat to the west of the entrance. A side lobe of this fan turns to the east and enters the outer shelter, with progressively decreasing dip as it accumulates gravel and coarser clasts on a small terrace in front of the cave (Fig. 3).

2.2. Archaeology

Archaeological excavations started in 1978 (Grifoni et al., 2011; Serradimigni, 2013) and were carried on until 2013 by the Department of Archaeological Sciences of the Pisa University, putting into light a 9 m-thick sequence of archaeological levels, testifying to a continuous use of the cave from the Late Upper Palaeolithic to the Neolithic. This sequence includes an unprecedented documentation - at least in central and southern Italy - of at least three cultural transitions: from LUP (Late Epigravettian, layers 48-30) to Early Mesolithic (Sauveterrian, units 29-25), from Sauveterrian to Late Mesolithic (Castelnovian, units 24-23), and eventually from Castelnovian to Early Neolithic (Impressa pottery, units 23-3). The Late Epigravettian was divided into three phases (EP1, EP2, EP3) following the techno-typological characteristics of the stone tool assemblage.

All the layers excavated at Grotta Continenza include several anthropic features connected to different aspects of everyday life: heaps of domestic waste, pits, hearths, pebble pavements, burials in graves and on the ground (Serradimigni and Colombo, 2016; Serradimigni et al., 2016).

The cave was apparently used only for dwelling during the earliest phases of the Epigravettian (Fig. 4 a-b) (EP1 and EP2, layers 48-35), as indicated by at least five hearths, a large pit and a large amount of lithics and domestic waste. Domestic use is still testified by three hearths during the latest Epigravettian phase (EP3, layers 34-30), but the burials found in layers 34-33 and 32-31 (Fig. 4 c) (Grifoni Cremonesi, 1998; Serradimigni et al., 2012) indicate that the cave was used for the first time also as a burial site. The remains of at least seven individuals were found in the layers of the Late Epigravettian phase.

The cave was still used for dwelling by the Mesolithic people, even less intensively, as well as for burials, as indicated by one burial and numerous unconnected human remains (Fig. 4 d-e).

Accessing the inner cave had probably become difficult because of sediment accumulation when the cave was used by the Castelnovian people, but the unconnected remains of nine individuals indicate that this part was still used as a burial area. Domestic spaces were located in the outer rock-shelter and at the entrance to the inner cave, which was occupied by a several square metres wide combustion feature.

The cave use changed again with the Neolithic (Fig. 4 f), when the spaces fit for dwelling were limited to the outer rock-shelter, and the inner cave had been reduced to a very low passage accessible only by crawling. During this phase, the cave was used only for funerary practices, with a minimum number of individuals (mostly unarticulated) estimated to at least 45, many of which were infants. The corpses were apparently deposed directly on the ground, without any arrangement of stones around or upon them. Only one individual - a mature woman - was found (layers 7-4) still articulated and reclined onto two vases containing the incinerated remains of two 4-8 years old individuals (Grifoni Cremonesi and Mallegni, 1978).

Sparse features, like hearths, pits, pits filled by lacustrine silt, and trampled pavements whose function is not always clear were also found.

3. Materials and methods

The sequence of Grotta Continenza was examined at eye-scale and described following the standard suggested by Catt (1991), putting into evidence the textural characteristics of the units, as well as their spatial organisation and stratigraphy.

Field logs and graphical or photographic documentation of about 35 years of excavations were widely consulted and represent the core of the information available about stratigraphy, texture and architecture of the lithologic units and about their phasing with the cultural horizons. It must be pointed out that direct memory of the sequence is available because the authors participated actively in the excavations (R.G.C. as principal investigator for the whole period; G.B. first as student and then as geoarchaeologist, more or less desultorily for the whole period; M.C and M.S. first as students and later as archaeologists for the last 20 years). However, the documentation techniques changed progressively through time and in some cases are now considered as incomplete, mostly for the earliest excavation phases that correspond to fragments of fading personal memory. Nevertheless, almost all the sequence can be reliably reconstructed with good detail.

Samples for grain-size, $CaCO_3$, and organic carbon analyses were collected from a profile exposed between squares rows 0 and 1, along the longitudinal axis of the shelter. Considering the remarkable textural variability within the lithologic units, it must be taken into account that these analyses do not represent accurately the composition of the sediments throughout the whole cave, but give only a general view of their characteristics.

The size of the bulk samples depended on the average grain-size of the unit. The coarse (> 2 mm) component was measured on the whole sample at 1 Φ precision by wet sieving, while aliquots of 50-100 g of the fine component (< 2 mm) were graded at 0.5 Φ by wet sieving for the 2-0.063 mm fraction, and by Bouyoucos aerometer for the < 0.063 mm fraction; grain-size analyses of the fine (< 2 mm) fraction were carried out also on HCl 1N decalcified samples. The fine carbonates were measured by comparison with pure $CaCO_3$ blank in a Dietrich-Frühling calcimetre, on 0.1-0.2 g aliquots of sediment sieved at 0.5 mm. The organic matter was measured by Loss On Ignition (LOI) method below the temperature of decomposition of calcite (470°C), on samples of 5 g, sieved at 0.25 mm. It must be pointed out that the sand-size fraction of the sediment often includes very large amounts of finely fragmented bone (mostly fishbone), which cannot be removed from the samples without destroying also part of the mineral component; consequently, the grain-size data are in some cases strongly biased by anthropic inputs.

Undisturbed sediment monoliths for thin section preparation were also collected, following the same criteria highlighted for the bulk ones; the very stony units were not sampled if the fine fraction was too few. The monoliths were air-dried at 30°C in ventilated oven for 7 days, and then impregnated by low-viscosity acetone-diluted polyester resin under moderate suction; polymerisation was carried out under atmospheric pressure for about 90 days.

The thin sections were cut by a diamond disk and ground to 30 µm by corundum abrasive powders, using petroleum for cooling, and covered by a standard optic glass slide. Depending on the monolith size, 90x60 mm or 60x45 mm thin sections were prepared.

Twenty thin sections were observed under a Leica DM/LP standard petrographic microscope equipped with reflected light and UV/blue epifluorescence kits. The descriptions follow the standard formalised by Bullock et al. (1985) and Stoops (2003) for soil thin sections.

The typological classification used in describing the stone tools discovered at Grotta Continenza was based on the Laplace typological list (Laplace, 1964, 1966, 1968).

Pièces écaillées were classified according to the Cremilleux and Livache list (Cremilleux and Livache, 1976).

The typometric analysis was carried out following the *criteria* proposed by Laplace (Laplace, 1968), Bagolini (Bagolini, 1968, 1971) and Guerreschi (Guerreschi, 1975).

In the case of fragmented blanks (which are the most common artefacts of the laminar complex), width (whole for not retouched, reconstructed for tools) was the criterion used in differentiating blades and bladelets. This limit is conventionally set to 12 mm (Bagolini, 1968, 1971; Laplace, 1968; Wierer, 2012).

The technological study was carried out following the methodology introduced by several French scholars: J. P. Tixier (1984), M. Gallet (1998), J. Pelegrin (1988; 2000), B. Valentin (2000). Regarding the study of M. Gallet (1998), which involves mostly Neolithic industries, some simplifications were necessary to adapt it to the study of the Palaeolithic complex.

Bayesian modelling was applied to the sequence of dates, using the program OxCal v. 4.2 (Bronk Ramsey, 2009a) and the calibration curve IntCal13 (Reimer et al., 2013). The objective was to test different models with the following goals:

1. check for outliers in the sequence of dates (Bronk Ramsey, 2009b), in order to discuss the reasons why they do not fit into the stratigraphic sequence and to possibly remove them from the analysis. This point was particularly relevant in choosing which dates included from units 45 and 39 should be included within the final model;
2. determine the duration of the cultural phases and of the gaps, as well as assess which intervals should be considered as gaps, and if these gaps correspond to erosional phases or to hiatuses in cave use by humans;
3. compute depositional models (Bronk Ramsey, 2008) - ideally one for each of the options determined in the aforementioned points - combining stratigraphy, sedimentology, chronology and cultural evolution, to be used in climate reconstruction, as well as in normalising the density of cultural remains versus time.

4. Results

4.1. The sequence

The cave infill is a complex sequence of lithologic units that were explored only in a relatively limited part of the cave. As in most cave infillings, the lithological units are discontinuous and their shape is seldom layer-like, planar and horizontal; wedge- or lens-like sedimentary bodies are common. Unconformities or paraconformities (“anthropic” or “natural”) are apparently rather common and their presence may be underestimated because the coarse texture of the sediments sometimes complicates or blurs the boundaries between units. Consequently, the following description is necessarily a summary of the real aspect of the Continenza sequence.

The uppermost units, from 30 upwards, were excavated mostly in the outer rock-shelter and in a shallow exploratory trench within the inner cave. The lower units (45 to 31) were excavated in a wide area corresponding to about 30% of the outer shelter, on its eastern side (Fig. 5 and fig. 6). Units from 48 to 45, which are sterile of cultural remains, were observed in a small exploratory pit extended down to the bedrock. These units are layer- or lens-shaped, variously dipping and rather discontinuous, sometimes with more or less undulating limits that can be complicated by the occurrence of large cobbles and blocks within the sediment. Erosion surfaces that are mostly anthropic, like small pits, burials, hearths, small stone piles, etc., often cut the sequence. Burials, or functional pits and depressions occurring at almost all levels are one of the most evident characteristics of the Continenza sequence, and may have reworked the sediments at all levels. However, also some other major hiatuses can be observed within the sequence; these are likely non-anthropic and are one of the most relevant focuses of this paper.

The texture is mostly coarse (> 2 mm), dominated by poorly sorted angular limestone rubble; larger clasts, up to 1 m size blocks, are common but units dominated by medium or fine gravel are the most frequent. The shape of the clasts is rather equant. Grain-size and quantity of the coarse fraction are not directly correlated. The fine fraction (< 2 mm) is represented by variable amounts of sand- to clay-size particles. The spaces among coarse clasts can be more or less completely filled by the fine fraction or can be void; consequently, the structure is respectively clast-supported to openwork. Matrix-supported units are less frequent.

The fine fraction often includes large amounts of finely comminuted and dispersed organic matter, which sometimes gives the whole sediment mass a dark blackish colour.

In general, the texture is rather irregular, or even chaotic in some areas. The units are rather discontinuous, and their texture may change laterally, originating a complexly interlayered framework of units and subunits.

4.1.1. Architecture and texture of the stratigraphic units

The lowermost units of the sequence (layers 48 to 45) were observed in the very limited area of an exploratory 2x1 m trench, aimed at possibly finding the cave bedrock under the oldest archaeologically sterile sediments. Consequently, few information is available on the geometry of this part of the sequence. The sedimentary bodies are apparently tabular, with some dip towards the outside of the cave (northwards), whereas the bedrock dips more strongly eastwards as well as towards the outside of the cave. The sediments are made up of skeleton-supported, unsorted limestone rubble, with few brownish to yellowish clay loam fine fraction.

The units from layer 45 to 32 were observed in an approximately 8x4 m area (Fig. 2) situated on the eastern side of the site, oriented along the NW-SE longitudinal axis of the cave, in the outer shelter area. These units are mostly layers, often thinning-out, slightly concave upwards (mostly units 40 to 32) along the transversal profile of the cave and gently dipping towards the outside of the cave. The limits are plane to sometimes undulating.

The texture is decreasingly stony through unit 45 to 42, with skeleton clasts comprised within the fine to medium gravel-size classes. The fine fraction is rich in silt, which decreases slightly from 45 to 42 (Fig. 7).

Unit 41 is characterised by an abrupt drop in coarse fraction, which is less than 5% of the whole sediment mass. Sand is abundant within the fine fraction (about 25-30%), but it is largely comprised of bone fragments, mostly fish, that are not attacked by laboratory decalcification during grain-size analyses. Consequently, the sediment is mainly silty, unlike the underlying ones whose texture is gravelly even if silt is dominant within the fine fraction.

In units 40 to 32 the coarse fraction is relatively few (less than 20%), with some secondary peaks in units 40, 38 and 37, and the structure ranges from skeleton-supported to very subordinate matrix-supported. The clasts are somewhat larger in units 39 and 33-32, whereas fine and very fine gravel is particularly common in units 36 to 33. Clay increases slightly from unit 41 to 37, and peaks in 37, 35 and 33. Carbonates are almost constant from 39 to 36 and then increase steadily up to unit 33, with a maximum in 37. The correspondence between clay and carbonates maxima in units 37 and 33 indicates that these clay-size particles are in fact fine carbonates; conversely, the clay peak in 35 is only partially paralleled by the carbonates, suggesting that fine silicates are more frequent in this unit.

The organic matter is abundant in unit 39, which is characterised by a homogeneous black or dark blackish brown hue. Variable amounts of organic matter correspond to variations in colour and partly to matrix quantity in units 38-32, whereas an evident decrease in OM characterises units 32-31. More or less continuous lighter greyish horizons, usually 2-3 cm-thick, are intercalated within the dark sediment, together with thicker strata of medium to fine gravel in brown matrix (Fig. 8). Under a microscope, the grey horizons are rich in calcite pseudomorphs on Ca-oxalates (ash) deriving from wood combustion.

In general, the layering is prevalently plane and parallel within this part of the sequence (units 48-31), with some northwards dip which decreases upwards. The clasts are unsorted and angular, with average size included within the classes of medium and fine gravel, but large clasts (blocks and some boulders) are common.

There are no evident major discontinuities or erosion features, but the thickness of units 38 to 35 is thinner than most of the other units of the sequence, suggesting that there may have been some change in depositional rates. Some relatively abrupt change in the fine fraction texture and $CaCO_3$ and OM content between these unit may also indicate a hiatus, which in this case would be represented by a paraconformity, even if no clear evidence of erosional features was observed in the field. Burial pits and other anthropic erosional features occur mostly at the bottom of unit 39 and from unit 36 down into 39, through 37 and 38.

Not surprisingly in a cave depositional environment, some lateral variability in unit shape and thickness is evident all over the excavated surface ad throughout the sequence. The layers sometimes pinch out between other units, small heaps of gravel often occur at the top of the units, cobbles and blocks are randomly embedded in finer units and lateral textural changes are extremely frequent.

The sequence of units 48-31 is limited at the top by an evident unconformity that divides the more or less regularly layered lower units from the overlying more complexly organised sequence of units 30-22 (Fig. 5). Unlike the underlying ones, units 30-22 dip eastwards and originate a low-angle cone-shaped talus, whose southern and northern sides dip respectively into the cave and to the outside. This cone is a side lobe diverting from the main body of the steep colluvial fan situated several metres to the west of the cave (Fig. 3); it enters the shelter from the west and its dip decreases abruptly while it covers the horizontally layered sediments lying in front of the cave.

Unit 30 is situated at the bottom of this shape and comprises a set of subunits (30c, 30b, 30a) organised in a sort of crude progradation lobe that terminates approximately in the middle of the transversal profile (square row -1). Here, a bulky lobe includes cobbles and some blocks, followed upslope by a “tail” of smaller clasts. All these clasts are angular, subspherical or prolate and angular; they are usually oriented a(transversal) b(imbricated) (*sensu* Collinson and Thompson, 1982:148). The fine fraction is light brownish and associated with medium to fine gravel in discontinuous layers (30c), whereas it is very scarce or absent in the coarser and clast-supported horizon 30c, to openwork in 30b-30a. Organic matter is very few, following the trend started with unit 32.

These units probably include more coarse and angular limestone gravel, cobbles and some boulders than the other ones, with somewhat frequent elongated clasts, even if a correct evaluation of the quantity of these elements is difficult because of their erratic occurrence within the sediments.

Above unit 30, the distal part of the talus (unit 29) extends further eastwards (until square row -3), forming a thick and homogeneous progradation lobe of relatively fine unsorted rubble, with a concentration of cobbles and blocks in the frontal part of the lobe. The fine fraction is very few and most of the distal part of the lobe is cemented by calcite deposited by water dripping from the ceiling, forming a whitish breccia. The central part of the talus (square rows 2 to 7) is finely layered and includes a sequence of wavy lenses and discontinuous layers (units 29-26) thinning out eastwards, sometimes bifurcating. Here, unit 29 is much thinner and made up of medium gravel, angular, unsorted and chaotically dispersed; some large cobbles are irregularly dispersed within the sediment, but the platy ones usually lie parallel to the unit boundaries. The structure is openwork with occasional yellowish fine fraction almost without organic matter; fine carbonates are common.

Some wavy and discontinuous sandy loam lenses are interbedded within the gravelly part of unit 29, and were partly winnowed from upslope parts of the unit.

The upper part of the lobe sequence (units 28-26), as well as the overlying layers (units 25-22), are limited to the western part of the cave, where the ceiling is higher and did not stop the deposition of the sediments. Units 28-26 are stony, with few to common medium to fine gravel; clay increases steadily within the fine fraction, with a peak in unit 29, where a relatively high maximum of carbonates suggest the presence of finely dispersed calcite. The finer sediments of these units cover the larger clasts (cobbles and some blocks) with inhomogeneous layers that are much thinner than the size of the cobbles, giving the whole set of units a wavy aspect.

Units 25-22 are organised - like the underlying 28-26 ones - in a complex heap-like set of rather thin and wavy, discontinuous and irregular lenses. This part of the sequence is also frequently disturbed by anthropic features like shallow pits and hearths; consequently, it may be difficult to ascertain the occurrence of discontinuities and the entity of reworking or erosion.

These units are rich in gravel organised in openwork layers with few fine fraction, or chaotically dispersed in matrix-supported structure; angular clasts lying parallel to the deposition planes are also common. Some layers are richer in organic matter and fine fraction, which is mostly silty loam.

Considering the complex interlayering of the stratigraphic units within this part of the sequence, it is difficult to assess the occurrence of major discontinuities. However, the boundary between units 25 and 24 is strongly concave (Fig. 5, grid rows 3-6; Fig. 6, grid lines D-F) and this shape is evident also more to the outside of the shelter. Therefore, this depression is probably not a local peculiarity of the unit limit, but can be considered as a discontinuity within the sequence.

From unit 21 upwards, the sequence is dominated by gravelly sediment with crude layering and few silty loam matrix; the sedimentary structures are largely disrupted by intensive anthropic use of the cave, including several Neolithic burials.

4.1.2. Soil micromorphology

The components observed at microscope scale are relatively few and were all found in most of the samples examined. Sediments collected from different units, or in distinct locations within the same unit, differ generally in the quantity of the components, which depends strongly on the sampling position within the unit because of lateral variations in sediment composition.

The basic mineral components are dominated by local limestone fragments, whose size ranges from silt to gravel. Limestone grains are normally angular or subangular and show moderate or null surface alteration, indicated by dissolution rims and/or protruding sparite veins. Quartz is dominant among the silicate minerals, normally occurring as silt- to medium sand-size, angular monocrystalline grains; it must be pointed out that quartz, as well as the other silicate minerals, do not occur in the local limestone. Feldspars (mostly sanidine or microcline) are few to frequent, showing the same morphological characteristics of quartz. Prismatic euhedral or subhedral bottle-green to black clinopyroxene occurs only from unit 42 upwards and is associated with colourless volcanic glass shards; it decreases upwards until it disappears almost completely in unit 30. The size of pyroxene and glass shards ranges from coarse silt to fine sand-size. Calcite occurs frequently as subhedral to anhedral sparite crystals, from very fine to coarse sand. Micrite, or more frequently microsparite, is widespread and occupies wide and irregularly distributed areas of the sediment; in some cases it gives the whole micromass a crystallitic b-fabric.

Rounded or subrounded reddish aggregates, fine sand- to very fine gravel-size, occur in units 45-31 These aggregates are mostly composed of clay loam impregnated by Fe-oxides, as suggested by the typic stipple-speckled b-fabric and the reddish colour; they include also some very fine silicate skeleton (mostly quartz) whereas calcite can never be observed. They resemble closely the micromass of *terra rossa*-like Alfisols, from which they probably derive.

The microstructure of the sediment is mainly crumb-like, moderately compact to loose, with unsorted or very poorly sorted unaccommodating aggregates; simple packing voids are dominant, and are commonly filled up with microsparitic or sometimes sparitic calcite. Evident and well-developed laminar microstructure (Fig. 9a) occurs in units 35, 32, 25 and 23 and is always associated with silt cappings situated on skeleton grains and aggregates.

Calcite coatings, hypocoatings and coatings are rather frequent, occurring mostly from unit 35 upwards, corresponding to am abrupt increase in fine carbonates within the sediments (Fig. 7); in some cases, the whole sediment mass is weakly cemented by microsparite.

The association of coatings with hypocatings is the most frequent pedofeature, with coatings generally organised in two generations: the first is mostly finely acicular and the second one is microsparitic to sparitic. Calcite sometimes infills completely the voids among basic mineral components and aggregates, forming an irregular continuum of micosparitic to sparitic anhedral crystals.

Pseudomorphic aggregates of fine micrite on Ca-oxalate crystals (whewellite and/or weddellite) are common (Fig. 9b, c) and can be referred to ash residues (Canti, 2003). These pedofeatures appear throughout the lower part of the sequence (units 43-31), particularly in 37 and 32-31, which include several hearths. Within these hearths, the pseudomorphs are organised in regular shapes resembling their original position within the vegetal tissues, whereas they are chaotically dispersed within the sediment in the other units.

The organic matter is the most evident characteristic of the lower part of the sequence; units 40-38 and 36-33 are particularly rich in this component, which gives them a dark brown or black colour at eye-scale; its occurrence in other units is indicated by secondary or isolated peaks in the diagram in Figure 7. At microscope scale, the organic matter is amorphous and thoroughly comminuted, including unidentifiable bits few μm wide, as well as larger fragments of vegetal cells and sometimes also of tissues; it is prevalently humified and often displays dark brown hues, whereas completely charred fragments are less frequent. In units 39, 36 and 34 the whole groundmass is masked by extremely abundant organic matter, which often hides the underlying features of the samples. Charcoal is also very common, with very fine to up to few cm-large fragments.

Bone, mostly of fish, is widespread throughout the sequence and in some units is the main component of the sand-size fraction, originating a sort of bone-sand that often includes burned fragments.

4.2. Lithic industries

4.2.1. Raw material procurement

The raw material of the whole lithic assemblage is flint; extensive sourcing surveys indicate that the raw material sources can be located within the two different types of the “Maiolica” formation outcrops (white and grey flint), as well as within the adjacent outcrops of the “Marne a Fucoidi”, and of the “Scaglia Rossa Umbro-Marchigiana”. The provenance of a fifth lithotype has not been identified yet, but it resembles raw materials cropping out on the Majella Mountain, in the S. Bartolomeo gorge area, near Roccamorice (Fig. 10).

The “Maiolica” flint is characterised by various shades of grey and white and is the most frequently exploited raw material (about 75%), whereas the “Marne a Fucoidi” grey-black flint and the “Scaglia Rossa” fine reddish flint are less common (11% and 5% respectively).

The closest “Maiolica” outcrops are situated on Mount Genzana, about 30 km south-east of the site (Danese, 2003), or alternatively on Mount Mentino, about 25 km to the west (Colombo et al., 2011). “Scaglia Rossa” outcrops are situated about 50 km to the north at high elevation in the Campo Imperatore area, close to the Gran Sasso Mountain; alternatively, they can be found much farther (about 80 km) to the north-east in the Montagna dei Fiori area. Other outcrops were mapped also in the Lazio region, about 70 km to the west, but the collected samples do not show the same characteristics of the Continenza assemblage (Colombo et al., 2011).

The amount of the various raw material types in the cultural phases is summarised in table 1.

4.2.2. Late Upper Palaeolithic (Late Epigravettian) (units 48-30)

The lithic assemblage of the Late Epigravettian contexts (units 45 to 30) includes 61,797 artefacts, divided as follows: 32,650 *debris*, 28,795 *débitage* products, 352 cores. Among the *débitage* products 7,559 are retouched tools (7,685 primary types).

Following the characteristics of the lithic assemblage, the Late Epigravettian complex can be divided into the three following phases, starting from the older one.

EP1 (units 44-41, 15,500-14,000 cal BP [13,500-12,000 BCE])

Within this earliest phase, the lithic industry is somewhat undifferentiated and is characterised by low laminarity.

The short end-scrapers are slightly more common than the long ones, but this ratio will tend to decrease throughout the sequence, until parity at the end of the Late Epigravettian.

Among the backed tools, only the backed points and bladelets are common, whereas the other specialised tools, like truncated and truncated backed tools are still not frequent; the geometric tools are absent. Among the common tools, the short scrapers are more frequent than the long ones and the points are well represented even if they decrease in the recent units.

EP2 (units 40-35, 14,000-13,500 cal BP [12,000-11,500 BCE])

The most outstanding characteristic of this *facies* is the occurrence of the backed-truncated tools, which appear in unit 38 and characterise the whole Late Upper Palaeolithic of Grotta Continenza. From unit 39 onwards, the long scrapers dominate over the short ones, in accordance with the contemporaneous increase of the ratio between blades and flakes. The backed tools are more frequent than the common ones and the laminarity increases.

EP3 (units 34-30, 12,000-11,000 cal BP [10,000-9,000 BCE])

The first unit of this phase represents an abrupt shift from the evolutionary trend of the previous cultural phases, with the development of the typical facies of the Late Epigravettian characterised by geometric tools (common segments, few triangles and trapezes/trapezoids). The remarkable spread of the microburin technique is strictly connected to the production of geometric tools.

The phase characterised by geometric tools ends with unit 31 and does not continue into the Sauveterrian units, where the Sauveterrian points predominate instead.

The provenance of the raw material also changes. The flint types are the same, whereas their ratio changes: the grey flint collected from the "Maiolica" outcrops decreases, whereas the use of the unknown provenance flint increases.

Four *chaînes opératoires* for blade-bladelet and flake production can be identified within the Epigravettian assemblage: two of these aimed at producing blades/bladelets by progressive reduction of medium-size (10-20 cm) (Fig. 11 A) and small size (less than 10 cm) flint blocks (Fig. 11 B); one exploited core-flakes (Fig. 11 C); the last one, is of the expedient type and aimed at producing flakes. Even if the *chaînes opératoires* remained generally the same throughout the Late Epigravettian, it is also clear that the objectives of the production changed through time, aiming at the microlithisation of the industry. The bladelets were always the main product (more than 50%) and the blades decreased from 14% in EP1 to 7% in EP3, whereas the microbladelets became relevant in EP3 (40%), with a trend according to the introduction of geometric tools in EP3.

Blade/bladelet size was standardised by post-flaking modification of the blanks: length was trimmed by blank fracturing and width was reduced by retouch. From EP1 to EP3 the size of the backed tools decreases about 1 cm in average (Fig. 12, panel a) (Serradimigni, 2011).

About 50% of the whole complex was flaked by direct percussion using hard strikers; the remaining part was flaked by soft one or organic hammer, although these types are not always easily distinguishable (Pelegrin, 2000) because of gesture variability (position, length and energy of the striking movement), which strongly affects the formation of diagnostic features. Soft striker knapping (stone or wood/antler/bone) increased remarkably at the transition from EP2 to EP3 and became as frequent as the hard striker one.

Some relevant changes can be observed at the boundary between units 35 and 34, i.e. at the EP2-EP3 transition, testifying to an innovation of various aspects of the lithic technology:

- geometric tools, which were not produced in previous periods, appear and increase strongly and fast;
- the microburin technique appears for the first time and becomes rather common;
- the *pièces écaillées* increase strongly, whereas they were rare in EP2 and EP1;
- the use of the cave changes and burial practices become more and more common.

The techno-economic aspects announcing the adoption of a sort of Mesolithic economy start already in EP3: the increase of geometric tools frequency (Fig. 12, panel b and panel c) is probably related to the availability of preys following from climate change: faunal studies indicate a decrease in ungulate biomass, the disappearance of *Equidae*, rarity of bovids, and the increase of bird hunting and of fishing (Tozzi, 1999).

4.2.3. Sauveterrian (Sauv, units 29-25, 11,000-10,200 cal BP [9,000-8,200 BCE])

The lithic assemblage of the Early Mesolithic Sauveterrian (units 29 to 25), includes 1'092 *débitage* products and 18 cores; the retouched tools are about 11% of the whole assemblage.

The flint procurement areas were the same as during the Epigravettian phase.

The *débitage* was focussed on the production of flakes and small flakes (73%), whereas blades/bladelets were less common (27%) and mostly used to fashion specialised tools like triangles and Sauveterre points, the latter being more frequent than the geometric tools. Flat and very flat flakes were dominant, often of micro/hypermicrolitic size.

The backed tools (44%) prevail on common tools (31%), and the end-scrapers are only 12 (10%). The geometric tools include 4 crescents and 6 triangles, with relative quantities similar to those of EP3. The Sauveterre points are the most widespread tools (13), whereas scrapers and denticulates are prevalent among the common tools (Usala, 2011).

4.2.4. Castelnovian (Cast, unit 24-23, 8,500?-8,200 cal BP [6,500?-6,200 BCE])

The whole industry of the Castelnovian phase includes only 535 artefacts, including debris, cores and tools, with 12% of retouched tools. It is not a rich assemblage, but some techno-typological considerations can be drawn from its study (Usala, 2011).

From the technological point of view, small flint nodules (5-10 cm) were exploited, aiming at producing standardised bladelets and microbladelets. These were modified by retouch to obtain microlithic backed tools. The technique of blade/bladelet detachment by pressure can be recognised on about 40 bladelets and one core. Conversely, direct and indirect percussion were employed in obtaining the other blank types. The ratio between laminar and non-laminar blanks is the opposite of the Sauveterrian one, with a clear predominance of laminar products.

Among the retouched tools, the trapezoidal geometrics are the best represented (22%) and also other typical Castelnovian elements are present, as the Montbani bladelets.

4.2.5. Neolithic (Neo, units 23-3, 8,000-7,000 cal BP [6,200-5,000 BCE])

The Neolithic is represented by a relatively small quantity of cultural remains, belonging to the Adriatic Impressa Pottery cultural facies, which represents the earliest Neolithic in the Adriatic area of Italy. The use of the cave was peculiar, as several incineration burials were found clustered along the eastern bottom wall of the cave.

Soil micromorphological observations indicate that the cave was mostly used for stabling animals, as most of the Mediterranean Neolithic cave sites (Angelucci et al., 2009).

4.3. Chronology

Radiocarbon dating of the Grotta Continenza sequence was carried on progressively during all the excavations period, since the very beginning. Consequently, laboratories and dating techniques changed through time and the results may not be fully homogeneous, though all datings were carried out on charcoal (Tab. 2).

Results of simple calibration at 1 σ and 2 σ by Oxcal v. 4.2 (Bronk Ramsey, 2009a), IntCal13 curve (Reimer et al., 2013), are reported in Figure 13. In a very general perspective, the ages obtained are organised coherently with the stratigraphy and reflect our current knowledge of the Late Upper Palaeolithic to Neolithic chronology in central and southern Italy. However, several inversions occur throughout the sequence, mostly between units 45 and 39 and to some extent also between 26 and 24.

Two tentative sequences of dates were analysed by bayesian modelling under the program OxCal v42.2 (Bronk Ramsey, 2009a), in order to determine which one fitted better the available stratigraphic and cultural data. The differences affect mostly the lower part of the sequence, from unit 35 downwards. Option 1 included Con35 (R-1198), Con37 (LY-10755), Con39 (LY-10663), Con40 (LY-10754), Con44 (LTL-1250a), Con45 (LTL-6187a); Option 2 included Con35 (R-1198), Con37 (LY-10755), Con39 (LY-10663), Con39 (LTL-6188a), Con43 (LTL-1249a), Con45 (LTL-6187a). Both options were also run after removing the *a priori* unfitting date Con31C (R-1196), and Option 1 was also tested after removing the problematic date Con40 (LY-10754).

Additionally, all these models were tested after inserting one gap between units 26 and 23 (Sauv-Cast) and also a second one between units 35 and 34 (EP2-EP3).

The results of the bayesian analysis for the tested models are summarised in Table 1-supplementary material for Option 1 and in Table 2-supplementary material for Option 2, reporting agreement values between likelihood and posterior data, as well as outlier values for each date.

The results show that the overall model agreement values for Option 1 are acceptable (i.e. > 60%) only if either of the dates Con31C (R-1196) and Con40 (LY-10754) is removed from the models. The agreement values of the single dates are about 16% and 28%, with outlier values around 50% and 20% respectively. Overall model agreement values > 100% result only if both the aforementioned dates are removed. The date Con45 (LTL-6187a) shows outlier values that are slightly higher than the 10% imposed maximum, whereas its agreement is always very good. Eventually, it must be pointed out that the overall model agreement decreases slightly when one gap is inserted into the sequences, and somewhat more if the included gaps are two.

Models of Option 2 were also run after removing Con31C (R-1196) even if the overall model agreement was > 60% when this date was included in the sequence, because its outlier values were 47-48%. Outlier values slightly higher than 10% occur in few cases, mostly in the lower part of the sequence. Inserting gaps into the sequence does not alter significantly the agreement of the models. Results for Option 2 with two gaps are represented in Figure 14.

Considering the aforementioned results, depositional models were run only for Option 2 and excluding Con31C (R-1196) (Tab. 3 – Supplementary material). Of the outliers, Con45 (LTL-6187a) was retained as it marks the bottom of the sequence. The overall model agreement is acceptable only for the sequences without gaps or including only the Sauv-Cast one, with outliers usually not much greater than 10% (Fig. 15). Including two gaps decreases the agreement to 25%.

5. Discussion

5.1. Sediments

At Grotta Continenza, three main deposit types can be distinguished by their lithological and textural characteristics, unit shape, and origin (Boschian, 2001; Boschian and Ghislandi, 2011). The lithology of the coarse fraction of all these deposit types is the same, i.e. local limestone deriving from the formation cropping out locally; consequently, the distinction is largely based on the shape of the sedimentary units and on the texture and shape of the clasts.

A) Calcareous rubble deriving from the dismantling of the cave ceiling and walls. Size and shape of the clasts result from the intensive fracturing of the rock, which produces mostly - but not exclusively - small roughly cubic blocklets. The texture often changes somewhat abruptly within distinct areas of the same unit, because the clast size is controlled by the irregular spacing of the fractures of the cave ceiling. In some cases, it can be observed that the texture of the sediment matches the fracturing pattern of the overlying rock, with accumulations and small heaps of clast corresponding to the main fractures. Moreover, the clasts did not accumulate on the ground as a homogeneous "rain" of stones, but more likely as a patchy set of small rock-falls erratically distributed in space and time, producing irregularities in the thickness of the units. It can also be observed that these sediments usually do not include sedimentary structures that may suggest medium-energy transport.

This facies can be distinguished from B) primarily by the shape of the stratigraphic units, because the textures do not always differ significantly. It corresponds to the whole lower part of the sequence, from the bottom to the top of unit 31.

Some very gentle dip towards the outside of the cave was initially due to the shape of the bedrock, and consequently decreased upwards as the shape of the depositional surface levelled because of the deposition of a progradating talus in front of the cave. However, no evidence of gravitational processes displacing or reworking the units can be observed in the sequence.

Gelifraction acting on a rock mass already fractured by tectonics was the primary agent producing the clasts, but these cannot be reliably used in estimating the intensity of frost because their size and shape were pre-determined by the tectonic fracturing pattern. However, some seismic triggering of rock-falls cannot be excluded, because the Fucino is situated in a high seismic hazard area where major earthquakes are documented recently and in historic times (Galadini et al., 1997), also by stalagmite fracturing inside the Continenza cave.

B) External colluvium inputs. These are organised in a coarse-grained fan-shaped debrisflow/debrisfall (*sensu* Blikra and Nemec, 1998) deriving from the steep screes covering the hill side around the cave. The fan diverted abruptly from the main debrisflow cone and expanded with moderate dip on a terraced surface that was almost level because of previous deposition of roof spall that had progressively reduced the original dip of the area in front of the shelter. Here, the talus expanded for some metres eastwards, where its toe approached the entrance of the cave and started to progressively close the access to the inner spaces.

The features of the lower horizons of the cone (unit 30), i.e. the discontinuous matrix-rich layers, the generally chaotic arrangement of mainly unsorted clasts within the openwork layers, as well as the a(t) a(i) organisation of the larger clasts in the frontal part of the lobes, suggest debrisflow accumulation of the large clasts by rolling, and of the fine fraction by flow. Soil micromorphological aspects (Bertrand and Texier, 1999) suggest that this debrisflow was not originated under cold or nival condition, but in a milder environment.

In general, the aspect of this unit and the processes involved in its formation suggest fast deposition. The absence of cultural remains and of organic matter within the sediment suggest also that the cave was not used in the period when these deposits accumulated, but it must also be pointed out that unit 30 may have formed extremely fast and therefore it may not have been a reason to abandon the cave for a period longer than a season.

However, the deposition of the debrisflow talus continued also later, when the cave was again occupied, even if not very intensely, as indicated by the occurrence of cultural remains in units 29 to 25. In these units the texture is even less sorted than in the underlying one and the stones are randomly distributed, tilted and only sometimes clearly parallel to the bedding planes.

The occurrence of elongated and bifurcating lenses of fine sediment sandwiched between coarser horizons suggests also some solifluxion under colder conditions, as also indicated by the occurrence of laminated microstructure at microscope scale (Bertran, 2005; Van Vliet-Lanoë, 1985; 2010)

C) Sediments of anthropic origin. These are prevalently inputs of flint, bone (mostly fish bone), continental mollusc shells, amorphous organic matter, ash and charcoal within sediments originated by the processes discussed under A) and B).

Ash and charcoal are often organised in well-preserved combustion features or reworked in dumps. In general, these sediments are characterised by very dark brown to blackish hue, due to the abundance of organic matter (Boschian, 2001), which is directly related to the abundance of cultural remains. Even if contributions due to colluvium of the upper horizons of soils developed outside the cave cannot be excluded *a priori*, it is likely that large part of the organic matter derives from human activities carried out inside the cave.

These sediments include also the so-called “bone sand”, i.e. high quantities of finely fragmented, comminuted and partly burned bone (Fig. 5 d), which is commonly present at Grotta Continenza in the LUP strata, and may represent intensive processing of animal resources, as well as intentional use of bone for fuel (Rabinovich and Hovers, 2004; Roebroeks and Villa, 2011) in areas were firewood was scarce.

These anthropic components are mostly concentrated in the lower part of the sequence, in the LUP units, with peaks in 40 to 32, but are also always mixed with variable proportions of sediments of type A). Units 39 to 33 are characterised by extremely abundant amorphous organic matter finely alternating with grey ash horizons, organised somewhat cyclically. This aspect may suggest that the cave was occupied cyclically and that ash was dispersed over the inner surface.

Organic matter is less frequent in the upper part of the sequence (30 to 22), which is extremely stony and characterised by lighter hues and few fine grey matrix including mostly reworked ash.

In particular, a thick ash dump, characterised by small and discontinuous lenses of fine sediment and ash, fills a wide depression on the top of unit 25 at the entrance of the inner cave, and its thickness increases towards the inside.

5.2. Chronology

Inversions in the radiocarbon sequence, i.e. ages not coherent with the stratigraphic sequence, can be due to excavation errors or to *ab antiquo* and recent reworking of the sediments. In the case of Grotta Continenza, the first hypothesis can be ruled out because the good quality of fieldwork documentation indicates that the stratigraphic context of the sedimentary infill was respected.

Mixing of datable components into older contexts can happen in sedimentary units with openwork structure, where small- to medium-size charcoal can be translocated downwards through the voids of the sediment. This may be the case of the upper part of the Grotta Continenza sequence, where openwork structure units alternate with units where the fine component is abundant and not coherent. Though this process does not seem to be very likely, it may be the case of unit 24, whose age is similar to the results obtained from units 22-20.

Reworking, with consequent inclusion of charcoal fragments into more recent units, is much more likely in parts of the sequence affected by *ab antiquo* disturbance, i.e. where the units are separated by erosional boundaries. This is a generalised problem of the Grotta Continenza sequence: local erosion features – burials and other pits/holes - occur frequently from unit 34 upwards, suggesting generalised sediment reworking. Age inversions occur also in the lowermost part of the sequence, where there are no burials, but in this case reworking is probably due to pits and *en cuvette* hearths that mobilised older charcoal and sediment.

Single dates clearly not fitting in an otherwise regular sequence may be fixed by empirically removing them (e.g. Con24 LTL-6186a; Con25 R-552; Con31C R-1196). Conversely, the problem is much more complex for units 45 to 39, whose dates are widely spread around some possible general trend that can just be perceived but not hypothesised with confidence.

The use of Bayesian modelling and the computation of the outliers within the date sequences indicates that the dates Con31C (R-1196) and Con40 (LY-10754) do not fit the model and should therefore be removed from the analysis. Moreover, it appears also that the most reliable sequence within the intricate set of dates available for units 45 to 39 is Option 2, whose overall model agreement is higher, with relatively low outlier values.

The lowest part of the sequence, where the ages are strongly scattered, is characterised by rather loose and randomly dispersed rubble with few fine fraction, suggesting that the sediment was easily reworked by people moving within the cave catchment. Moreover, some traces of shaping of the cave floor, as well as still enigmatic stone features including imported lacustrine silt, were observed in units 43 to 41, even if a clear interpretation of this evidence is difficult because the excavated area is too small. Consequently, it is likely that also some of the dated charcoal samples were reworked *ab antiquo*.

Conversely, the finely layered sediments of units 38-32 suggest moderate mixing, which probably involved only components of adjacent layers. In this case the resulting ages are reasonably well aligned, with the exception of Con34 (R-558) and Con32 (R-557) that have large sigma values and are situated on a section of the calibration curve with wiggles and plateau.

The erosion surface between units 25 and 24 can probably explain the inversion of the dates corresponding to these units. The sediment of these units is rather coarse and with openwork structure, so that the translocation of fine elements – including charcoal – through the units is not unlikely.

Whatever dates are kept or removed from the sequence, two main gaps can be observed within the modelled sequence of dates, at the boundaries between units 35 and 34 and between units 25 and 24, the latter much longer than former. It is noteworthy that these gaps correspond to shifts in the typology and/or technology of the lithic industry.

5.3. Discontinuities, Hiatuses and (Time) Gaps

Two discontinuities can be observed within the stratigraphic sequence of Grotta Continenza: one separates unit 30 from the underlying unit 31, the other one separates unit 25 from 24.

The first one can be considered as a paraconformity, because the strata at its sides are roughly parallel and there is little evidence that it is an erosional surface. Unit 31 apparently pinches out to the east under 30 and its easternmost part may have been eroded, but its termination may represent the toe of a debrisflow as well. In any case, some reworking at the top of 31 is likely, as debrisflows normally disturb the top centimetres of the underlying strata during the first phases of deposition (Blikra and Nemec, 1998), but there is apparently no evidence of a major hiatus in the sequence.

The discontinuity situated between units 25 and 24 (Sauv-Cast gap) is more evidently a disconformity marked by an erosion surface that shapes the sequence of units 28-25. The strata underlying the erosion are abruptly truncated by a depressed shape that modified the top of the talus. This depression is filled by predominantly fine sediments of anthropic origin (ash and ash dumps), whose layering follows the shape of the erosion surface with decreasing dip. In this case there is a hiatus in the sequence.

A third possible discontinuity may be indicated by a time gap in the sequence of dates between units 35 and 34 (EP2-EP3 gap), whose ages are separated by an interval much wider than the adjacent ones. This possibility is corroborated by a typological change in the Late Upper Palaeolithic industries, because the boundary between these units corresponds to the transition EP2-EP3. However, no evidence of erosion features was observed within the stratigraphic sequence and the two units apparently lie directly in contact. Unit 34 includes less organic matter and is much lighter than the other units of this part of the sequence; however, this characteristic does not seem to be relevant as it is shared also by unit 36, which unfortunately was not dated but is part of a set of layers with well-aligned ages.

"Gaps" within suites of radiocarbon dates are generally referred to as time intervals with no dates. However, radiocarbon sequences are discontinuous by definition because dates represent discrete points on the line of time; therefore, any interval between dates is ideally a gap, whatever its length. In order to evaluate whether a gap is really a gap or the “product of sampling from a pattern of unvarying occupation intensity through time” Rhode et al. (2014: p. 567) suggest to verify whether the gap length fits within a negative exponential distribution, which represents a uniform-frequency probability distribution. It stems from this perspective that long gaps are not unexpected even in sequences represented by an acceptably large number of dates and that it may be quite difficult to determine whether these long gaps reflect population changes or simply result from statistical behaviour if the sequences include few dates.

The two large gaps “Sauv-Cast gap” and “EP2-EP3 gap” are evident within the reduced (Option 2) date set of Grotta Continenza and represent the tail of the distribution (Fig. 16, panel A), whereas the boundary between units 31 and 30 is not marked by a gap. The sequence follows a negative exponential distribution (Fig. 16, panel B), even if some clustering of dates in the mid part of the sequence is evident, showing that the Grotta Continenza date set is statistically reliable. The gap distribution includes small steps that commonly occur also in simulated sequences with very large numbers of dates, and even the largest gaps are statistically compatible with the theoretical negative exponential distribution, even if the probability for each of them is rather low. However, the probability that two of these large gaps occur contemporarily within the same sequence is quite low.

It must also be pointed out that the “Sauv-Cast gap” is marked by an important hiatus in the stratigraphic sequence, whereas the “EP2-EP3 gap” occurs within a set of units characterised by low-energy deposition without significant erosional processes. It can be inferred that the “Sauv-Cast gap” really represents a hiatus, because of its low probability of appearing by chance, and that it was partly caused by erosion connected to human activities, which removed part of the sequence. In fact, the inverted dates available for units 25 and 24 (respectively too old and too young) suggest that erosion played a minor role in shaping the hiatus, and that it did not enhance significantly a real break in the frequentation of the cave.

The theoretical probability of the “EP2-EP3 gap” to appear within the Continenza radiocarbon sequence is not negligible, but becomes much lower if it is postulated that it appears in association with the “Sauv-Cast” one; however low, this possibility should be considered. Nevertheless, this gap apparently does not correspond to a discontinuity in the stratigraphic record, thus the short sediment thickness separating unit 35 from 34 would indicate a sudden decrease in deposition rate. This aspect, as well as the contrast with the deposition rate of the preceding and subsequent phases, are well represented by the depositional model (Fig. 15), which in this case is rather suggestive of a hiatus in deposition, mostly if the 35-34 transition is compared with the similar – even if larger – Sauv-Cast gap. At eye-scale, unit 35 is not different from the underlying ones, characterised by abundant organic sediment with fine gravel, whereas 34 is coarser and less organic and may represent a slow accumulation of roof spall when the cave was occupied less intensely by humans. The abrupt change in the tool assemblage supports this hypothesis, and considering that large part of the sediments underlying the transition is composed of domestic waste, a break in cave use may have slowed significantly the deposition of sediments. This is true if “dates as data” (Rick, 1987; Steele, 2010) can be used as proxies of population trends, mostly as summed probability plots (Williams, 2012; Contreras and Meadows, 2014, and literature therein), and periods with no dates can be interpreted as indicators of decreasing occupation intensity of sites/areas. In this case, the summed probability of the dates included in the Option 2 sequence (Fig. 17) shows two main minima with zero probability corresponding to the two main gaps; secondary minima correspond to unit 30, which is almost sterile, and to discontinuous dating of the lowermost part of the sequence.

5.3. Sediments, climate and humans

The Grotta Continenza sediments indicate that the sequence can be divided into three main depositional phases (units 45-31; unit 30; units 29-22) characterised by distinct sedimentary processes.

The results of depth versus time bayesian modelling (Fig.15) suggest that deposition rates varied several times throughout the sedimentary history of the site, following climate change, as recently tuned by tephrochronology (Blockley et al., 2012).

All the first part of the sequence (units 45-31) is characterised by deposition of more or less tabular units deriving from roof spall and including abundant anthropic components. External inputs are testified at microscope scale by common reddish clay loam aggregates (“pedorelics”) deriving from the dismantling of Alfisols that had previously developed in the area outside the cave. These observations are in accordance with wider-scale information about Central Italy, indicating slope instability in mid-montane and montane areas (Giraudi et al., 2011). Relatively moderate sedimentation rates characterised the oldest part of the sequence (units 45-40), corresponding to the end of the Late Glacial Maximum GICC05 GS-2a event and to the first part of the Late Glacial Interstadial (events GI-1e, GI-1d and GI-1c *pro parte*), as well as to the earlier Late Epigravettian phase EP1.

Starting from the beginning of the relatively warm GI-1c (units 39-35), the deposition rate increased strongly. The human component in the sediments was strong, as also indicated by a peak of dates in the summed probability plot (Fig. 17), including remarkable percentages of amorphous organic matter, domestic waste and the highest number of cultural remains, comprised within the EP2 assemblage. Relatively high clay content in these units (Fig. 7) also suggests sediment run-off linked to soils erosion under an increased rainfall régime, while the vegetation cover was still re-expanding.

The EP2 phase represented the maximum occupation intensity by the Late Epigravettian people, who used intensely Grotta Continenza for dwelling and for domestic activities when the relatively mild LGI climate favoured the peopling of the area. The inner part of the cave was still wide and easily accessible and could be used for shelter.

Approximately at the end of the LGI, sediment deposition rates decreased, reaching a minimum between units 35 and 34, during the GS-1-Younger Dryas (Fig. 15); conversely, slightly higher deposition rates and rubble accumulation characterise unit 32, which corresponds to the earliest phase of the Holocene. The sediments are composed of frost shattered calcareous rubble, which characterises the stony event of unit 34, and of relatively abundant silty loam that may point to loess deposition in a cold and aridic environment. Pedorelics and colluvium products are almost absent, showing that the aridic climate did not favour hill-wash and debrisflow reactivation, despite the probably thin vegetation cover of the Younger Dryas. The occurrence of ice lensing within the sediments of units 35-32 corroborates the hypothesis of a cold peak with periods of deep seasonal frost.

The summed probability plots suggest that the LUP people abandoned the cave during this harsh climatic phase, probably for at least 200 years. When the site was populated again after this phase, the typological aspects of the lithic assemblage were new and the cave was again used for dwelling, but with lesser intensity, whereas burial use became relevant.

A new sedimentation style started with unit 31: eastwards dipping layers of well-organised gravel including horizons with variable amounts of fine fraction suggest the onset of debrisflow deposition from the outside of the cave. These processes culminated with unit 30, testifying to a phase of strong external input due to the activation of the debrisflow cone situated outside the cave, and continued at least up to units 28-27, corresponding roughly to the Preboreal. The (re-)activation of debrisflow processes was probably due to increased rainfall on a still unstable landscape that was undergoing initial stages or re-afforestation.

Despite the dramatic fall in the number of cultural remains (Fig. 7), there is still some good evidence of the EP3 cultural phase with a peak around 11,200 cal BP (Fig. 17), until unit 30 when it eventually terminated. From unit 29, the lithic industries show distinct Mesolithic characteristics, concluding a trend of progressive size reduction and typological change that had started already during the EP3 phase. The spaces available for domestic use within the site started decreasing as the external sediments were filling up the cave, reducing the height of the ceiling within the inner cave. Some increase in the occupation intensity, culminating between 10,000 and 10,800 BP, characterises the occupation of the cave by Sauveterrian people, who continued using the spaces like the EP3 dwellers.

The depositional phase corresponding to units 29-25 was characterised by deposition of somewhat finer rubble including common frost slabs, some sparse blocks and cobbles and few matrix. Towards the eastern part of the inside of the cave, these sediments are finer and derive from the mixing of roof spall and debrisflow at the entrance of the inner cave, under a ceiling that had become very low; consequently, this part of the site was not used for domestic activities and the only cultural remains are here connected with burials.

Conversely, debrisflow deposition was still dominant in the area under the high rock-shelter wall, where the talus deposits include heap-like lenses and irregular layers, relatively rich in organic matter and cultural remains; the grain-size smaller than in the previous phases and frequent lenses of in-washed fine sediment are interbedded within the rubble. These characteristics suggest that the hill sides were stabilised by the expanding vegetation, limiting the input of coarse material into the site. The remarkable accumulation of medium-fine gravel under the shelter wall overhang was probably due – at least partly – to the activation of a fracture situated exactly above this locus.

Disturbance and reworking due to human activity are widespread, including artificial pits and hearths associated with ash dumps. Large part of the fine sediment is made up of ash, including the typical microscopic micrite pseudomorphs on Ca-oxalates. However, large quantities of more or less fine euhedral to anhedral crystalline $CaCO_3$ may indicate ash recrystallisation within the sediment under strong water percolation, as well as deposition of carbonates transported in solution by dripwater.

This phase ended at around 10,200 cal BP and was followed by a gap of about 1800 years (Tab. 3) in the radiocarbon chronology. Though it is not unlikely that this gap corresponds to a period when the cave was not used by people, the strong anthropic reworking of the stratigraphic units does not allow to assess exactly its real meaning within the cave occupation history.

Above this gap, sedimentation in unit 24-22 was characterised by a style similar to the previous one, with discontinuous lenses and layers of gravel interlayered with ash and/or organic lenses, and with common anthropic discontinuities. It is noteworthy that the beginning of this phase (unit 24), coincides with the 8.2k cold event and that traces of ice lensing and deep seasonal frost resulting from the winter temperature drop can be found within units 23 and 22.

These sediments are somewhat chaotic and unsorted, deriving from sporadic reactivation of the debrisflow, but human activities affected their formation – or reworking – more strongly than environmental agents. Such sort of sediments, generally characterised by an inhomogeneous association of unsorted stones, variable amounts of fine sediments and domestic waste deposits are common in Mesolithic contexts and were previously observed in other sites (Boschian, 1997; 2006). Because of these characteristics, the assessment of the stratigraphy and of the timing of the events is strongly biased; this may also be the reason why the ages of these unit fit the local chronology of the industries, but are also associated with Neolithic cultural remains.

From unit 20 upwards, for almost 1.5 m thickness, the cultural context is clearly Neolithic, with common burials and other traces of human presence. Sedimentation is characterised mostly by chaotic calcareous rubble with few matrix, including micromorphological evidence (spherulites, burned dung, etc.) of animal stabling (Angelucci et al., 2009) inside the cave. It is not unlikely that the strong deposition rate was due to the reactivation of slope processes by more or less intensive grazing on fragile soils, because of deforestation and grass cover shrinkage.

6. Conclusions

The first traces of human presence at Grotta Continenza date back to about 15,500 cal BP (Fig. 18), during the Late Glacial. During this periods, cave sediments comprised of gelifraction products accumulated steadily, slightly increasing the deposition rate during the warmer phases, probably because of moderate colluvial inputs. The cave offered a wide shelter from the still cold climatic conditions and was continuatively used for dwelling for about 2,000-2,500 years. Two different cultural facies of the Late Upper Palaeolithic Epigravettian culture (EP1 and EP2) developed gradually during this time span, without dramatic economic and techno-typological changes. The raw material procurement areas were the same, suggesting similar mobility patterns mostly concentrated on a sub-local area, with relatively rare but continuous inputs from far-off areas. The occupation of the cave intensified and reached its maximum during the EP2, when remarkable amounts of organic matter and domestic waste were accumulated together with other cultural remains within the cave catchment.

A completely new lifestyle started with EP3, including novel cultural elements announcing the onset of some sort of Mesolithic economy. Geometric tools and microburin technique became a relevant part of the lithic assemblage; tool microlithisation increased, after having started in the previous phases, anticipating the extremely microlithic character of the Sauveterrian. These aspects probably testify to a shift in hunting weapon production, connected to faunal change. The raw material procurement areas also changed: the far-off sources were abandoned, whereas new raw materials of still unknown origin appeared.

The EP3 phase lasted not more than 1000-1100 years (from 12,160 to 11,010 cal BP, median ages), and was rather short if compared with the previous ones. In fact, EP3 is apparently separated from the previous phases by a gap of at least 800-900 years in the radiocarbon chronology, (from 13,120 to 12,160 cal BP, median ages) (Tab. 3). This gap cannot be easily explained, because no discontinuities occur in the sequence although the units that yielded the two industries are in direct stratigraphic contact. The depositional model (Fig. Cont_Opt2_1Gap_DepMod_Outl_no31) indicates in this case a dramatic drop in deposition rate, that would resemble more a stratigraphic discontinuity. However, even if the age of the oldest EP3 unit had been obtained from a reworked sample and was expunged from the model, the resulting deposition rate would be much lower than in any other phase.

This change corresponds to the Younger Dryas, GS-1 GICC05 event (Blockley et al., 2012), when deposition was moderate because the aridic climate did not favour sediment transport. The few cave sediments ascribed to this phase include roof spall rubble and aeolian dust, corroborating the hypothesis of low deposition rates. After the end of the Younger Dryas, the increased rainfall favoured colluvium and a thick talus accumulated very fast into the cave, partly filling it and limiting the spaces available for dwelling. This situation suggests that the climatic conditions were unfavourable for human settlement, as also testified by the decrease of cultural remains within the cave.

The Continenza Mesolithic Sauveterrian phase dates from about 11,000 cal BP to 10,000 cal BP (ending at 10'160 cal BP, median age) (Tab. 3), probably lasting less than 1,000 years. Rather unexpectedly, it is in chronological continuity with the Epigravettian, unlike in several northern and central Italian sites, where a 400-years hiatus separates the Late Upper Palaeolithic from the Sauveterrian, e.g. Isola Santa (Kozlowski et al. 2003), or Cogola Rock-shelter (Cusinato et al., 2004). Considering also the analogies in the stone tool assemblage and economy, it is likely that the same groups of foragers continued frequenting Grotta Continenza through time, progressively adapting their behaviour to the Holocene climate change. Fishes – mostly *Salmo trutta* – from the nearby Fucino lake had been a major food source in all the preceding periods, but the increase of the remains of these animals within the cave sediments suggests that the Late Upper Palaeolithic and mostly Mesolithic people specialised their toolkit for fishing when broadening the food sources become a necessary practice in the changing environment. Also the procurement of the lithic raw material changed, showing reduced mobility testified by an additional significant decrease of materials coming from far-off areas.

At Continenza, the typical Sauveterrian cultural elements are attenuated if compared to the same features that identify the Early Mesolithic in northern and central Italy. This phenomenon characterises most sites of central-southern Italy, where local facies can be identified, each one with specific peculiarities deriving from the characteristics of the local Late Epigravettian. Consequently, the early Mesolithic of this area can be described as an attenuated Sauveterrian *facies*, or a Sauveterroid aspect of the Late Epigravettian that lasted until the Early Holocene.

The cultural break between Sauveterrian and Castelnovian is much more evident than between Epigravettian and Sauveterrian at Continenza. It is also marked by a large gap in the radiocarbon sequence that may have lasted up to 2,000 years (Tab. 3), largely corresponding to the Boreal. Even if anthropic erosion and reworking are evident at this level in the stratigraphic sequence, it is not unlikely that the cave was really abandoned for some time, even if the causes are not clear. By this time, debrisflow processes had almost completely filled the cave, so that only the outer rock-shelter was fit for dwelling, but it is not unlikely that other still unknown causes may have concurred.

Apparently, the cave was occupied again shortly after the onset of the Atlantic (8540 cal BP, median age), just before the 8.2k event, and the occupation of the cave by Castelnovian people did not last more than 500 years.

Unlike the Sauveterrian, the Continenza Castelnovian complex is characterised by all the distinctive features of the typical Castelnovian: the lithic industries reverted predominantly to the production of blades-bladelets, even if the chipping technique was different (mostly by pressure), aimed at producing trapezoidal tools. Also the composition of the raw material assemblage points to a sharp break with the previous tradition, as the Maiolica flint types decrease abruptly whereas the unknown materials - probably local - increase significantly.

The available information about the Castelnovian culture at Grotta Continenza is scanty, mostly because the excavated units are few and thin. Evidence of extended hearths and ash dumps may testify to domestic activities and to the use of the cave for shelter, but the large number of sparse human bones found in the sediments suggest intensive use for burials.

Following the Bayesian modelling of the radiocarbon sequence, the Neolithic use of the cave would have started around 8000 cal BP, but the information available from other sites of the area suggests that this estimate is somewhat older than expected. The cave was used mostly for burials, but soil micromorphological indicators of the presence of ovicaprine dung suggest that sheep and/or goats were also stabled in the rock-shelter. By this time, the inner cave was accessible only by crawling through a narrow passage, but was still used for burial.

The succession of cultural complexes at Grotta Continenza represents a unique case in central and southern Italy, with a complete sequence including the latest phases of the Upper Palaeolithic, the Mesolithic and the Neolithic. Cultural change accelerated through time, from a slow evolution of some technological aspects in the early phases, to faster modifications in the later ones. It is noteworthy that the major and abrupt changes, involving deep technological and economic innovation, happened after hiatuses in the frequentation of the cave (and probably of the area), suggesting that new people may have replaced the previous occupants of the cave after the periods of abandonment. Environmental change affected cultural modifications in most cases, supporting the hypothesis that adverse conditions foster adaptation more than the favourable ones.

If the scanty evidence coming from other central-southern Italian sites of this period is considered, Grotta Continenza can be considered as a reference site for the peculiarities that differentiate this area from the northern part of Italy.

References

Angelucci D.E., Boschian G., Fontanals M., Pedrotti A., Vergès J.M., 2009. Shepherds and karst: the use of caves and rock-shelters in the Mediterranean region during the Neolithic. World Archaeology 41 (2), 191-214.

Astuti, P., Dini, M., Grifoni Cremonesi, R., Kozlowsky, S., Tozzi, C., 2005. L’industria mesolitica di Grotta Marisa (Lecce, Puglia) nel quadro delle industrie litiche dell’Italia meridionale, Rivista di Scienze Preistoriche 55, 185-208.

Bagolini, B., 1968. Ricerche sulle dimensioni dei manufatti litici preistorici non ritoccati. Annali dell’Università di Ferrara (Nuova Serie), Sezione XV-Paleontologia umana e paletnologia, I, 10, 195-219.

Bagolini, B., 1971. Ricerche sulla tipometria litica dei complessi epipaleolitici della Valle dell’Adige. Preistoria Alpina 7, 243-276.

Berger, J.-F., Guilaine, J., 2009. The 8200 cal BP abrupt environmental change and the Neolithic transition: A Mediterranean perspective. Quaternary International 200, 31-49.

Bertran, P., 2005. Stratigraphie du site des Peyrugues (Lot), une coupe de référence pour le dernier Pléniglaciaire en Aquitaine. Quaternaire 16, 25-44.

Bertran, P., Texier, J.-P., 1999. Facies and microfacies of slope deposits. Catena 35, 99–121.

Biancofiore, F., Coppola, D. (Eds), 1997. Scamuso. Per la storia delle comunità umane tra il VI e il III millennio nel Basso Adriatico. Università di Roma “Tor Vergata”, Roma.

Blikra, L.H., Nemec, W., 1998. Postglacial colluvium in western Norway: depositional processes, facies and palaeoclimatic record. Sedimentology 45, 909-959.

Blockley, S.P., Lane, C.S., Hardiman, M., Rasmussen, S.O., Seierstad, I.K., Steffensen, J.P., Svensson, A., Lotter, A.F., Turney, C.S.M., Bronk Ramsey, Ch., Intimate Members, 2012. Synchronisation of palaeoenvironmental records over the last 60,000 years, and an extended INTIMATE event stratigraphy to 48,000 b2k. Quaternary Science Reviews 36, 2-10.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., Priore, P., Cullen, H., Hajdas, I., Bonani, G., 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science 278, 1257--1266.

Boschian, G., 1997. Sedimentology and Soil Micromorphology of the Late Pleistocene and Early Holocene Deposits of Grotta dell'Edera (Trieste Karst, NE Italy). Geoarchaeology 12 (3), 227-249.

Boschian, G., Mallegni, F., Tozzi, C., 1997. The Fredian rock-shelter. An Epigravettian and Mesolithic age site in the Serchio basin (N Tuscany): palaeoecology and cultural and human remains. Quaternaria Nova 5 (1995), 45-80.

Boschian G., 2001. Breve nota sui depositi di riempimento della Grotta Continenza di Trasacco (Conca del Fucino, Italia centrale). In Grossi G., Irti U., Malandra C. (Eds) Atti del II convegno di Archeologia “Il Fucino e le aree limitrofe nell’antichità”, Archeoclub d'Italia, Avezzano, pp. 33-37.

Boschian, G., 2006. Chapter 4: Geoarchaeology of Pupićina cave. In Miracle P. T. and Forenbaher S. (eds.) “Prehistoric herders in Istria (Croatia): The archaeology of Pupićina Cave”, Volume 1, Archaeological Museum of Istria, Pula, pp. 123-162.

Boschian, G., Fusco, F., 2007. Figuring out no-one’s land. Why was the Karst deserted in the Late Glacial? In Whallon R. (Ed.) Late Paleolithic Environments and Cultural Relations around the Adriatic - Environements du Paléolithique final et rapports culturels autour de l’Adriatique, Proceedings of the XV World Congress UISPP, BAR S1716, Oxbow, Oxford, pp. 15-26.

Boschian, G., Ghislandi, S., 2011. Nuovi dati geoarcheologici sulle grotte Continenza e Maritza. In Irti U. (Ed.) Atti del III convegno di Archeologia “Il Fucino e le aree limitrofe nell’antichità”, Archeoclub d'Italia, Trasacco, pp. 40-54.

Bronk Ramsey, C.B., 2008. Deposition models for chronological records. Quaternary Science Reviews 27 (1), 42-60.

Bronk Ramsey, C.B., 2009a. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337-360.

Bronk Ramsey, C., 2009b. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51 (3), 1023-1045.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., Babel, U., 1985. Handbook for Soil Thin Section Description, Waine Research Publications, Wolvehampton.

Canti, M.G., 2003. Aspects of chemical and microscopic characteristics of plants ashes found in archaeological sites. Catena 54, 339-361.

Castelletti, L., Maspero, A., Tozzi, C., 1994. Il popolamento della Valle del Serchio (Toscana settentrionale) durante il Tardiglaciale e l’Olocene antico. Monografie di Natura Bresciana 20, 189-204.

Catt, J.A., 1991. Paleopedology manual. Quaternary International 6, 1-95.

Collinson, J.D., Thompson, D.B., 1982. Sedimentary Structures. London, Allen & Unwin.

Colombo, M., Pepe, M., Serradimigni, M., Usala, M., 2011. Dati e test sperimentali sulle materie litiche silicee provenienti dai territori limitrofi al bacino del Fucino. In Irti U. (Ed.) Atti del III convegno di Archeologia “Il Fucino e le aree limitrofe nell’antichità”, Archeoclub d'Italia, Trasacco, pp. 581-583.

Combourieu-Nebout, N., Peyron, O., Bout-Roumazeilles, V., Goring, S., Dormoy, I., Joannin, S., Sadori, L., Siani, G., Magny, M., 2013. Holocene vegetation and climate changes in the central Mediterranean inferred from a high-resolution marine pollen record (Adriatic Sea). Climate of the Past 9 (5), 2023-2042.

Contreras, D.A., Meadows, J., 2014. Summed radiocarbon calibrations as a population proxy: a critical evaluation using a realistic simulation approach. Journal of Archaeological Science 52, 591-608.

Cremilleux, H., Livache, M., 1976. Pour le classement des piéces écailées, Dialektiké. Cahiers de Typologie Analytique, Université de PAU, Institut Universitaire de Recherche Scientifique, 1-13.

Cusinato, A., Dalmeri, G., Kompatscher, K., Hrozny Kompatscher, M., 2004. Gli insiemi litici della sequenza preistorica di Riparo Cogola e la problematica relativa alla transizione tra Epigravettiano e Mesolitico in area alpina. Preistoria Alpina 40, 125-154.

Dalmeri, G., 2005. Studi sul Riparo Cogola (Carbonare di Folgaria - Trento) frequentazione umana e paleoambiente. Preistoria Alpina 40, 91-98.

Danese, E., 2003. Approvvigionamento della selce nei settori marsicano e aquilano dell’Abruzzo. Dati preliminari, Atti della XXXVI Riunione Scientifica, Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 605-609.

Desprat, S., Combourieu-Nebout, N., Essallami, L., Sicre, M. A., Dormoy, I., Peyron, O., Siani, G., Bout Roumazeilles, V., Turon, J. L., 2013. Deglacial and Holocene vegetation and climatic changes in the southern Central Mediterranean from a direct land-sea correlation, Climate of the Past 9, 767–787.

Dini, M., Grifoni Cremonesi, R., Kozłowski, S.K., Molara, G., Tozzi, C., 2008. L'industria castelnoviana della Grotta di Latronico 3 (Potenza, Italia), Preistoria Alpina 43, 49-74.

Di Rita, F., Anzidei, A. P., Magri, D. 2013. A Late glacial and early Holocene pollen record from Valle di Castiglione (Rome): Vegetation dynamics and climate implications. Quaternary International 288, 73–80.

Drescher-Schneider, R., de Beaulieu, J.-L., Magny, M., Walter-Simonet, A.-V., Bossuet, G., Millet, L., Brugiapaglia, E. L., Drescher, A., 2007. Vegetation history, climate and human impact over the last 15 000 years at Lago dell'Accesa (Tuscany, Central Italy), Vegetation History and Archaeobotany 16, 279–299.

Fontana, F., Visentin, D., Wierer, U. 2016. MesoLife. A Mesolithic perspective on Alpine and neighbouring territories. Quaternary International 423, 1-4.

Franco, C. 2011. La fine del Mesolitico il Italia. Identità culturale e distribuzione territoriale degli ultimi cacciatori-raccoglitori. Quaderno 13, Società Preistoria e Protostoria Regione Friuli-Venezia Giulia, Trieste.

Galadini, F., Galli, P., Giraudi, C. 1997. Geological investigations of Italian earthquakes: New paleoseismological data from the Fucino plain (Central Italy). Journal of Geodynamics 24, 87-103.

Gallet, M., 1998. Pour une technologie des débitages laminaires préhistorique. Dossier de documentation archéologique 19, CNRS.

Giraudi, C., 1989. Lake levels and climate for the last 30'000 years in the Fucino area (Abruzzo, Central Italy). A review. Palaeogeography, Palaeoclimatology, Palaeoecology 70, 249-260.

Giraudi, C., 1999. Chronological assessment and palaeoenvironmental implications of the speleothems from the of the edge of Fucino Plain (Abruzzo, central Italy). Il Quaternario 12 (1), 79-84.

Giraudi, C., Magny, M., Zanchetta, G., Drysdale, R.N., 2011. The Holocene climatic evolution of Mediterranean Italy: A review of the continental geological data. The Holocene 21 (1), 105-115.

Grifoni, R., Mallegni, F., 1978. Testimonianze di un culto ad incinerazione nel livello a ceramica impressa della Grotta Riparo Continenza di Trasacco (L'Aquila) e studio dei resti umani cremati. Atti Società Toscana di Scienze Naturali, Memorie, Serie A 85, 253-279.

Grifoni Cremonesi, R., Serradimigni, M., Usala, M., 2011. Le campagne di scavo dal 2001 al 2009 nella Grotta Continenza di Trasacco (AQ). I livelli dell'Epigravettiano finale, del Mesolitico e del Neolitico antico. In Irti, U. (Ed.) Atti del III Convegno di Archeologia, "Il Fucino e le aree limitrofe nell'antichità", Archeoclub d'Italia, Trasacco, pp. 27-39.

Guerreschi, A., 1975. L'epigravettiano di Piancavallo (Pordenone). Preistoria Alpina 11, 255-293.

Joannin, S., Vannière, B., Galop, D., Peyron, O., Haas, J. N., Gilli, A., Chapron, E., Wirth, S., Anselmetti, F., Desmet, M., Kozlowski, S.K., Tozzi, C., Cremaschi, M., Dini, M., 2003. L'industria di Isola Santa in Toscana e la sua posizione nel Sauveterriano italiano. Rivista di scienze preistoriche 53, 193-239.

Laplace, G., 1964. Essai de typologie systematique. Annali dell'Università di Ferrara, Nuova Serie, Sezione XV - Paleontologia umana e paletnologia, Ferrara.

Laplace, G., 1966. Recherches sur l'origine et l'èvolution des complexes leptolithiqes. Ecole Française de Rome, suppl. 4, Paris.

Laplace, G., 1968. Recherches de typologie analythique. Origini 2, 7-64.

Lo Vetro, D., Martini, F., Mesolithic in Central–Southern Italy: Overview of lithic productions. Quaternary International 423, 279-302.

Magny, M., 2013. Climate and vegetation changes during the Lateglacial and Early-Mid Holocene in Lake Ledro (southern Alps, Italy), Climate of the Past 9, 913–933.

Magri, D. and Sadori, L., 2009. Late Pleistocene and Holocene pollen stratigraphy at Lago di Vico (central Italy), Vegetation History and Archaeobotany 8, 247–260.

Martini, F., Colonese, A.C., Wilkens, B., 2005. Grotta della Serratura (Marina di Camerota - SA). La malacofauna dei livelli gravettiani ed epigravettiani. Considerazioni paleoecologiche. In Malerba G., Visentini P. (Eds.) Atti del 4° Convegno Nazionale di Archeozoologia, Quaderni del Museo Archeologico del Friuli Occidentale 6, Pordenone, , pp. 87-96.

Mussi, M., Cocca, E., D'Angelo, E., Fiore, I., Melis, R., Russ, H., 2008. Tempi e modi del ripopolamento dell'Appennino centrale nel Tardiglaciale: nuove evidenze da Grotta di Pozzo (AQ). In Mussi, M. (Ed.) "Il Tardiglaciale in Italia – lavori in corso", BAR International Series 1859, Oxford, pp. 111-131.

Pelegrin, J., 1988. Débitage expérimental par pression « du plus petit au plus grand ». Technologie préhistorique, notes et monographies techniques 25, CNRS, Paris, 37-53 .

Pelegrin, J., 2000. Les techniques de débitage laminaire au Tardiglaciaire : critères de diagnose et quelques réflexions. L'Europe centrale et septentrionale au Tardiglaciaire. Memoires du Musée de Préhistoire d'Ile de France, 73-86.

Romandini, M., Peresani, M., Gurioli, F., Sala, B., 2012. *Marmota marmota*, the most common prey species at Grotta del Clusantin: Insights from an unusual case-study in the Italian Alps. Quaternary International 252, 184-194.

Rabinovich, R., Hovers, E., 2004. Faunal analysis from Amud Cave: preliminary results and interpretations. International Journal of Osteoarchaeology 14 (3-4), 287-306.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M. and Grootes, P.M., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. Radiocarbon 55 (4), 1869-1887.Roebroeks, W., Villa, P., 2011. On the earliest evidence for habitual use of fire in Europe. Proceedings of the National Academy of Sciences 108 (13), 5209-5214.

Rhode, D., Brantingham, P.G., Perreault, C., Madsen, D.B., 2014. Mind the gaps: testing for hiatuses in regional radiocarbon date sequences. Journal of Archaeological Science 52, 567-577.

Rick, J.W., 1987. Dates as data: an examination of the Peruvian pre-ceramic radiocarbon record. American Antiquity 52 (1), 55-73.

Serradimigni, M., 2013. L'industria litica dei livelli epigravettiani di Grotta Continenza (Trasacco, AQ): studio, revisione e inquadramento nell'ambito delle coeve industrie dell'Italia adriatica centro-meridionale, Tesi di Dottorato in Scienze della Terra-Preistoria, XXIV ciclo, Università di Siena.

Serradimigni, M., Colombo, M., 2016. Grotta Continenza (Trasacco - AQ): le strutture da fuoco e le strutture infossate dei livelli del Paleolitico superiore e del Mesolitico. In: Atti del IV Convegno di Archeologia "Il Fucino e le aree limitrofe nell'antichità", Archeoclub d'Italia, Avezzano, pp. 41-48.

Serradimigni, M., Colombo, M., Chiarenza, N., Grifoni Cremonesi, R., Astuti, P., Galotta, A., Usala, M., 2012. Analyse spatiale des objets d'art mobilier du dépôt épigravettien de la Grotta Continenza (Abruzzes, Italie) et leur rapport avec les sépultures et les structures de combustion. in Clottes, J. (Ed.), L'art pléistocène dans le monde, Actes du Congrès IFRAO (Tarascon-sur-Ariège, Ariège - Ariège - Pyrénées, France - 6/11 settembre 2010), Symposium "Art mobilier pléistocène", N° spécial de Préhistoire, Art et Sociétés, Bulletin de la Société Préhistorique Ariège-Pyrénées 65-66, Société Préhistorique Ariège-Pyrénées Tarascon, pp. 1523-1541.

Serradimigni, M., Colombo, M., Grifoni, R., 2016. Grotta Continenza (Trasacco - AQ): uso funerario e uso abitativo della cavità dal Paleolitico Superiore all'Età dei Metalli. In: Atti del IV Convegno di Archeologia "Il Fucino e le aree limitrofe nell'antichità", Archeoclub d'Italia, Avezzano, pp. 49-57.

Steele, J., 2010. Radiocarbon dates as data: quantitative strategies for estimating colonisation front speeds and event densities. Journal of Archaeological Science 37, 2017-2030.

Stoops, G., 2003. Guidelines for Analysis and Description of Soil and Regolith Thin Sections. Soil Science Society of America, Madison, Wisconsin, USA.

Tixier, J. P., 1984. Préhistoire de la pierre taillée, 2 : économie du débitage laminaire. III Table ronde de technologie lithique, Meudon-Bellevue. Diffusion Association pour la promotion et la diffusion des connaissances archéologiques, Antibes.

Tozzi, C., 1999. L'alimentazione dei mesolitici in Italia. Actes des 7^{e} Rencontres culturelles interdisciplinaires de l'Alta Rocca "Le boir et le manger", Musée de l'Alta Rocca, Levie, pp. 63-66.

Tozzi, C., Dini, M., 2007. L'Epigravettiano finale nell'Alto Versante Tirrenico: casi studio dell'area Toscana. L'Italia tra 15.000 e 10.000 anni fa. In Martini, F. (Ed.) Cosmopolitismo e regionalità nel Tardoglaciale, Studi di Archeologia Preistorica 5, Edizioni Millenni, Firenze, pp. 95-128.

Usala, M., 2011. Note preliminari sull'industria litica di Grotta Continenza (Trasacco-Aq). In Irti U. (Ed.) Atti del III convegno di Archeologia "Il Fucino e le aree limitrofe nell'antichità", Archeoclub d'Italia, Trasacco, pp. 526-530.

Van Vliet-Lanoë, B., 1985. Frost effects in soils. In: Boardman, J. (ed.) Soils and Quaternary Landscape Evolution, Wiley, New York, 117-158.

Van Vliet-Lanoë, B. 2010. Frost action. In Stoops, G., Marcelino, V., Mees, F. (Eds), Interpretation of Micromorphological Features of Soils and Regoliths. Elsevier, Amsterdam, 81-108.

Valentin, B., 2000. L'usage des percuteurs en pierre tendre pour le débitage des lames. Circonstance de quelques innovations au cours du Tardiglaciaire dans le bassin parisien. In: Pion, G. (Ed.), Le paléolithique supérieur récent: nouvelles données sur le peuplement et l'environnement-Actes de la Table Ronde de Chambery, Societé Préhistorique Française, 252-260.

Visentin, D., Carrer, F., Fontana, F., Cavulli, F., Cesco Frare, P., Mondini, C., Pedrotti, A. 2016. Prehistoric landscapes of the Dolomites: Survey data from the highland territory of Cadore (Belluno Dolomites, Northern Italy). Quaternary International 402, 5-14.

Wierer, U., 2012. Variability and standardization: The early Gravettian lithic complex of Grotta Paglicci, Southern Italy. Quaternary International 30, 1-24.

Williams, A.N., 2012. The use of summed radiocarbon probability distributions in archaeology: a review of methods. Journal of Archaeological Science 39, 578-589.

Figure captions

Figure 1. Location map. A: general location of Grotta Continenza within Central Italy. B: Overview of the Fucino Lake basin. C: View of Grotta Continenza from the Fucino Plain; the cave is situated at the foot of the cliff indicated by the arrow. D: deeper part of the excavation area.

Figure 2. Plan of Grotta Continenza and adjacent area. The debrisflow cone (fan-like symbols) entering the cave from the east is cut at its toe by a recent erosion scarp (comb line). Excavation areas inside the cave are represented by grey areas: light grey: 0-4 m deep; medium grey: 4-7 m deep; dark grey: explorative pit with bedrock at 9.5 m. The solid arrow indicates the transversal profile of Fig. 5, the open one indicates he longitudinal profile of Fig. 6.

Figure 3. Debrisflow cone (red symbols) situated to the west of the cave (see also Fig. 2). Grotta Continenza (white arrow) is located to the right (eastern) side of the cone toe. In the background is the Fucino Plain, formerly occupied by the lake.

Figure 4. Cave plan shape change through time, with age decreasing from bottom to top (stratigraphic order) and from right to left. Red: main combustion features; blue: burials with fully or partially articulated human remains; yellow: pits and troughs. Dotted line: dripline. Dashed line: in a-e, limit between outer shelter and inner cave; in f, extension of the shelter at the beginning of the excavations.

Figure 5. Transversal stratigraphic profile NE-SW of Grotta Continenza, reporting unit numbers and the main cultural phases. Red lines: gaps and hiatuses.

Figure 6. Longitudinal stratigraphic profile NW-SE of Grotta Continenza, reporting unit numbers and the main cultural phases. Red lines: gaps and hiatuses.

Figure 7. Physical and routine chemical analyses of sediment samples from Grotta Continenza, correlated with artefact density (N of artefacts/excavated sediment volume). Coarse/fine (>2 mm/< 2 mm), coarse fraction grain-size, fine fraction grain-size (undecalcified and decalcified samples); carbonates, organic matter (LOI), artefact density. Red lines represent hiatuses/gaps.

Figure 8. Field photo of part of the longitudinal profile of fig. 6, showing units from 39 to 32. Units 39 to 37 are finely layered, with intercalated thick greyish ash strata and evenly deposited fine gravel. Historical picture of the late 1990s, extensively restored. Scale bar: 20 cm.

Figure 9. Microphotographs of soil micromorphological samples from Grotta Continenza. a: ashy sediment rich in amorphous organic matter, with lenticular microstructure deriving from ice lensing, unit 23. PPL, scale bar 500 μm. b: micrite pseudomorphs on Ca-oxalates, partly dissolved and recrystallized, unit 22. PPL, scale bar 50 μm. c: as in b, XPL. d: finely comminuted and partly burned bone fragments (mostly fish and macromammalofauna) with amorphous organic matter-rich micromass, unit 39. PPL, scale bar 500 μm.

Figure 10. Distribution of the main raw material outcrops in the area surrounding Grotta Continenza. Black circle: Grotta Continenza; 1: Montagna dei Fiori (Scaglia Rossa Umbro-Marchigiana); 2: Sabina area (Scaglia Rossa Umbro-Marchigiana); 3: Monte Mentino (Maiolica, Marne a Fucoidi); 4: Majella Mountain, S. Bartolomeo area (light brown flint); 5: Monte Genzana (Maiolica, Marne a Fucoidi); 6: Campo Imperatore (Scaglia Rossa Umbro-Marchigiana).

Figure 11. *Chaines opératoires* of laminar blank production.

Figure 12. Main characteristics of the lithic industry of Grotta Continenza. a: microlithisation trend of backed tools (PD: backed points; LD: backed blades) within the sequence; length versus units. b: typological trend of the backed tools; tool percentage versus cultural phase. c: shape and size of the backed tools group (triangles and crescents).

Figure 13. Complete calibrated datings dataset for Grotta Continenza. OxCal v. 4.2 (Bronk Ramsey, 2009a).

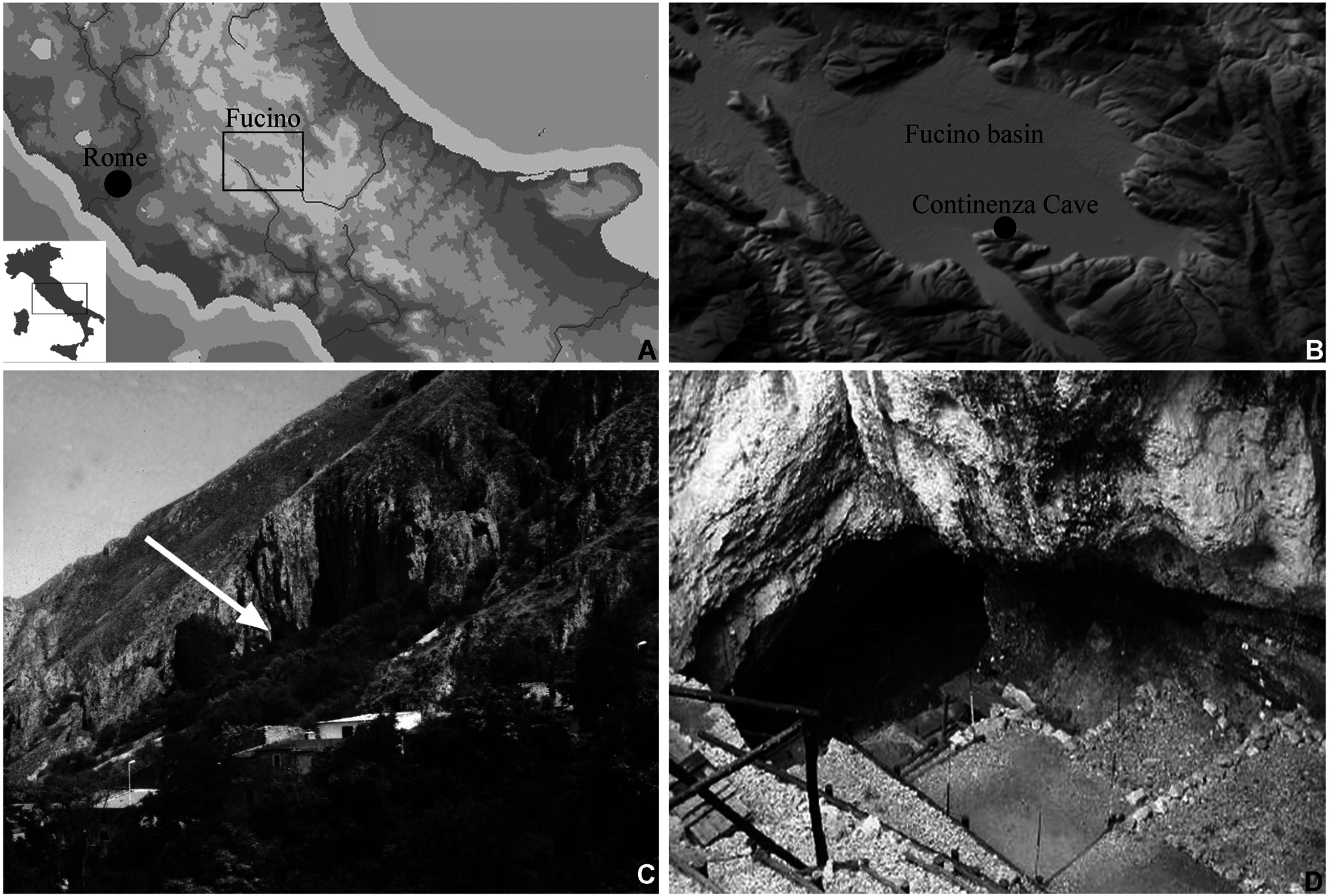
Figure 14. Output of likelihood (open curves) and posterior (solid curves) distribution of the Bayesian model (OxCal v. 4.2, Bronk Ramsey, 2009a) for Option 2, with three cultural phases (EP1-EP2; EP3-Sauv; Cast-Neo) and two gaps (EP2-EP3 and Sauv-Cast).

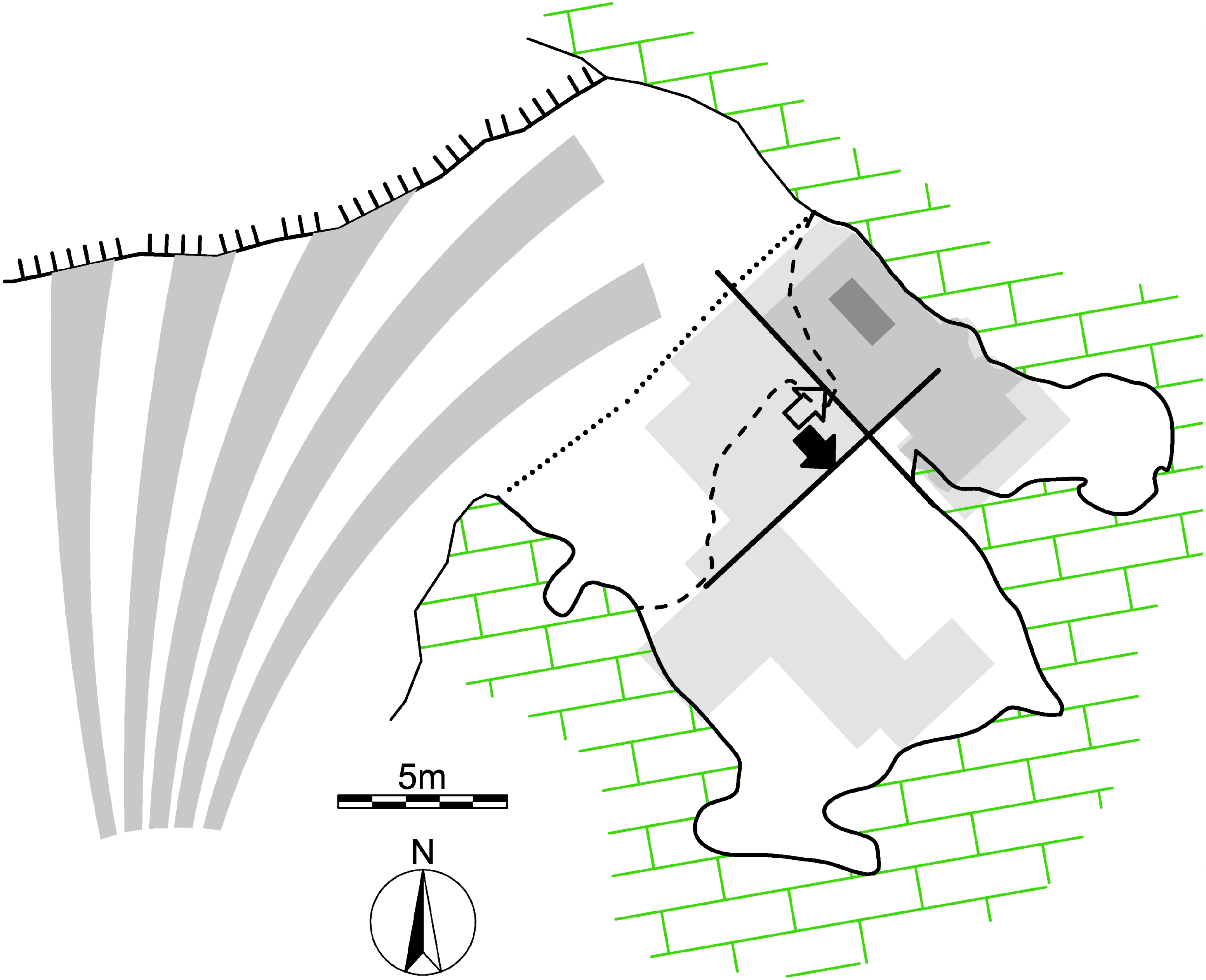
Figure 15. Depositional model (OxCal v.4.2) for Option 2, with two P_Sequences (EP1-EP2-EP3-Sauv and Cast-Neo) and one gap (Sauv-Cast) for Grotta Continenza.

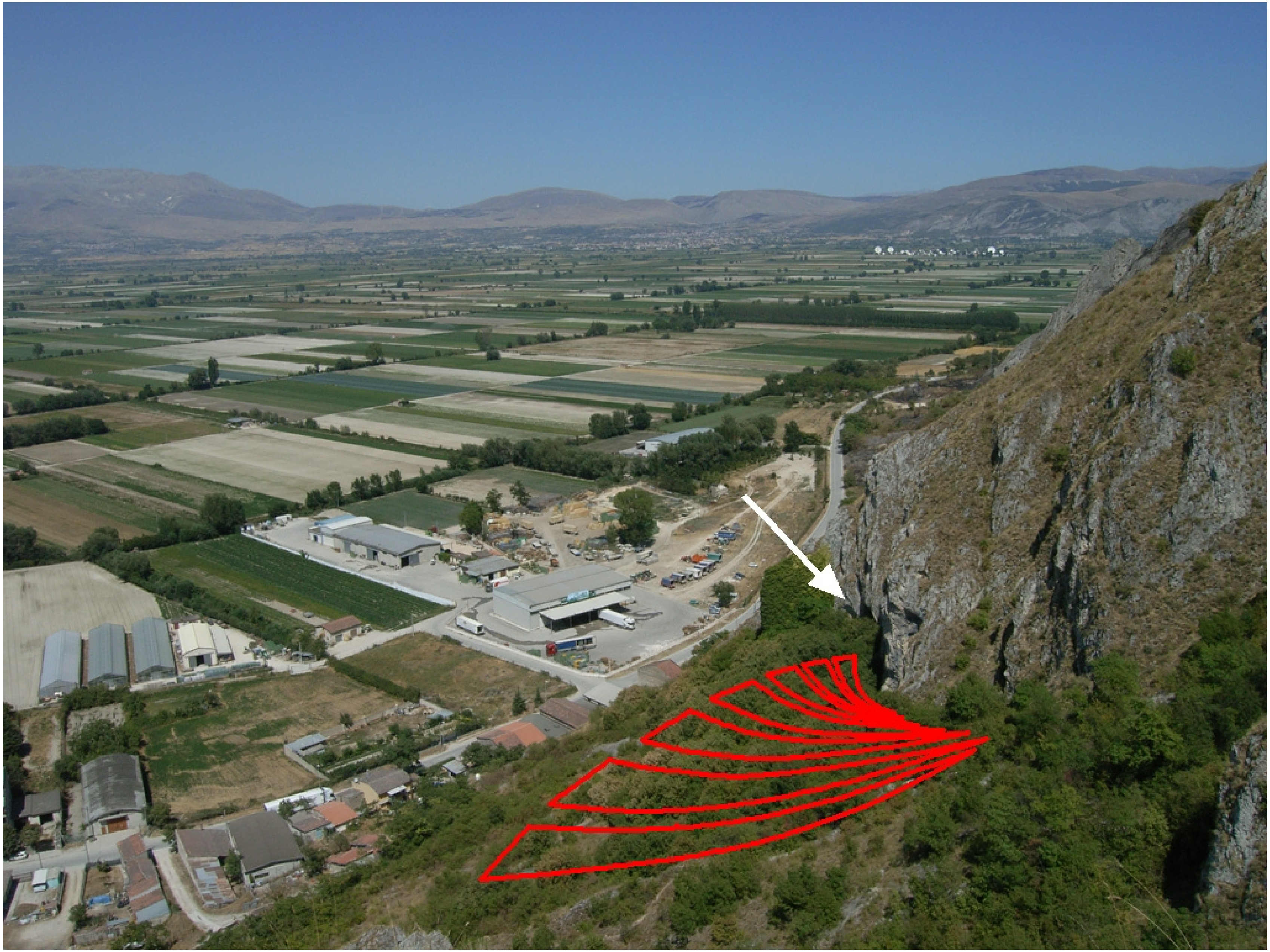
Figure 16. Gap length distribution and probability. Panel A: black solid squares: gap length versus cumulated gap length, showing exponential distribution pattern with short gaps clustered near the origin, steady increase along the curve and widely spaced maximum gaps. Some steps occur within the distribution, as frequently also in simulated distributions (cfr. Rhode et al., 2014: fig. 5). Blue crosses: probability (p) that any single gap in the sequence is greater than the represented gap; numbers indicate boundaries between lithologic units. The probabilities for the two largest gaps are low but not fully negligible. Panel B. Probability (p) of a waiting time of exactly x years between two dated events, with λ representing the average gap length.

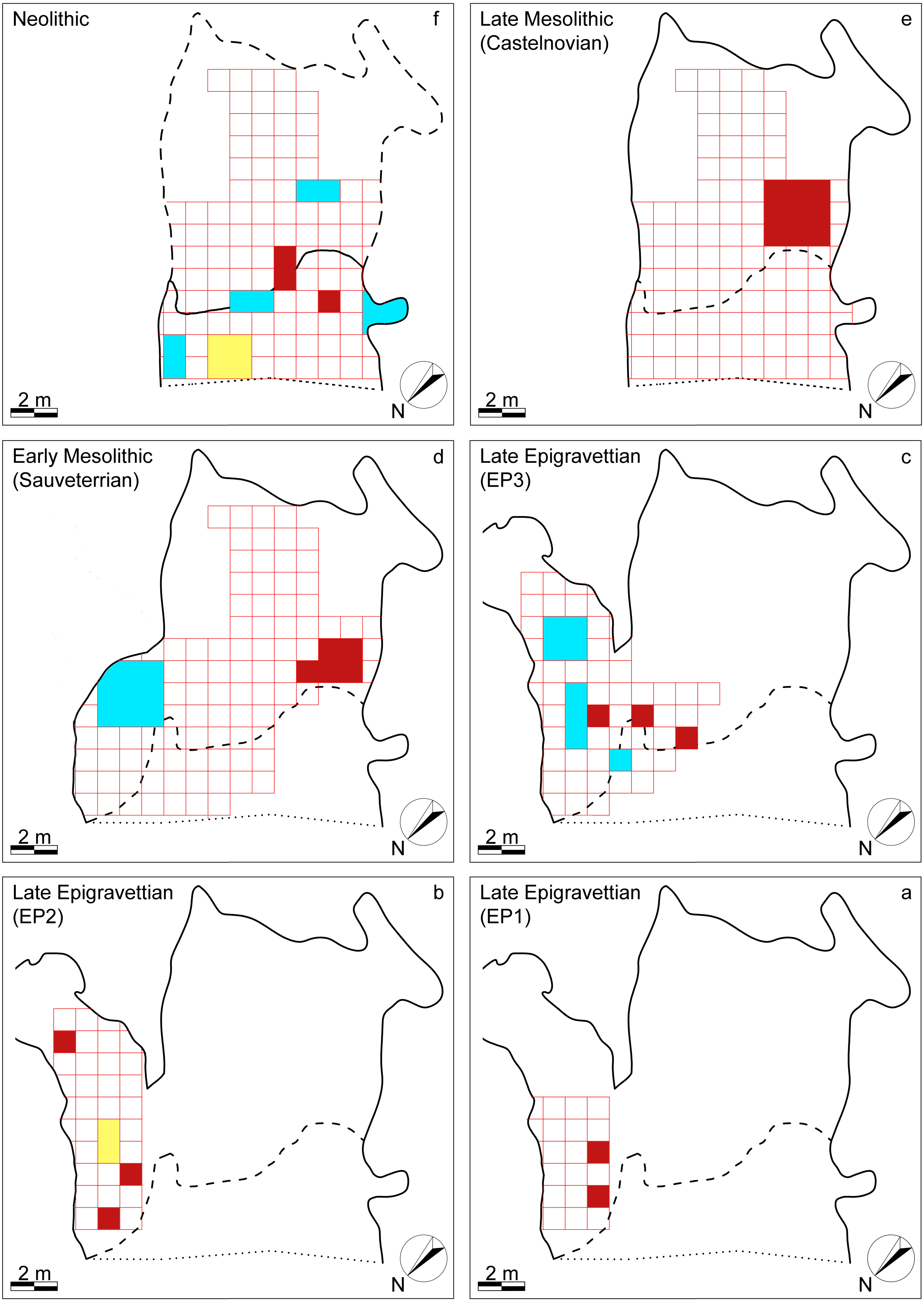
Figure 17. Tentative probability density plot for Option 1 (black line) and for the whole set of dates (shaded area) of Grotta Continenza.

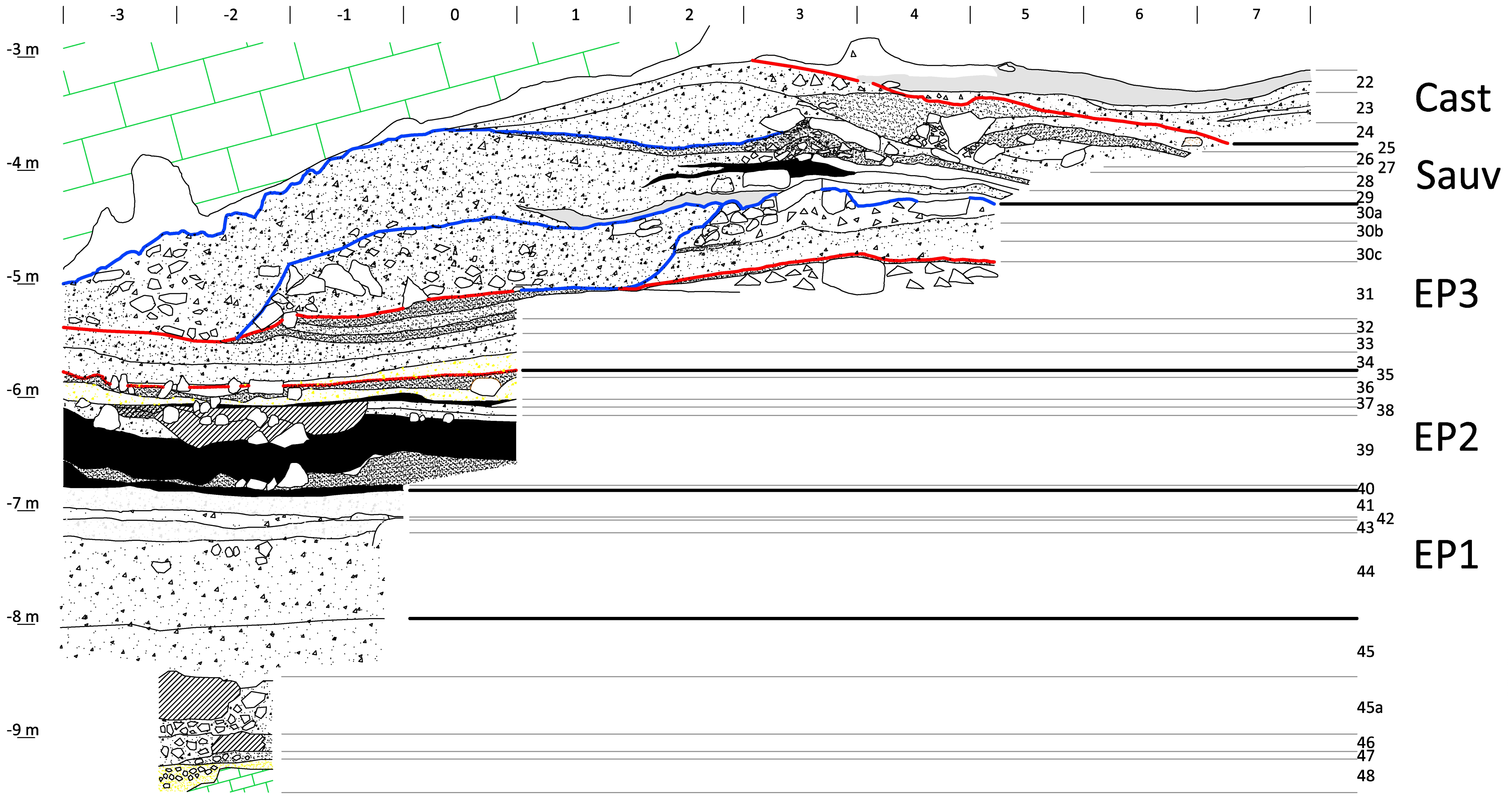
Figure 18. Floating bar diagram showing 1 σ (red) and 2 σ (black) ages of the boundaries of all Option 2 phases at Grotta Continenza, with approximate durations of cultural phases (coloured areas) and gaps (grey areas). Limits were set at the median ages of the boundaries computed by OxCal v. 4.2; the minimum span of the gaps (dark grey areas) is defined by the youngest 1 σ age of the lower boundary and the oldest 1 σ age of the upper boundary.

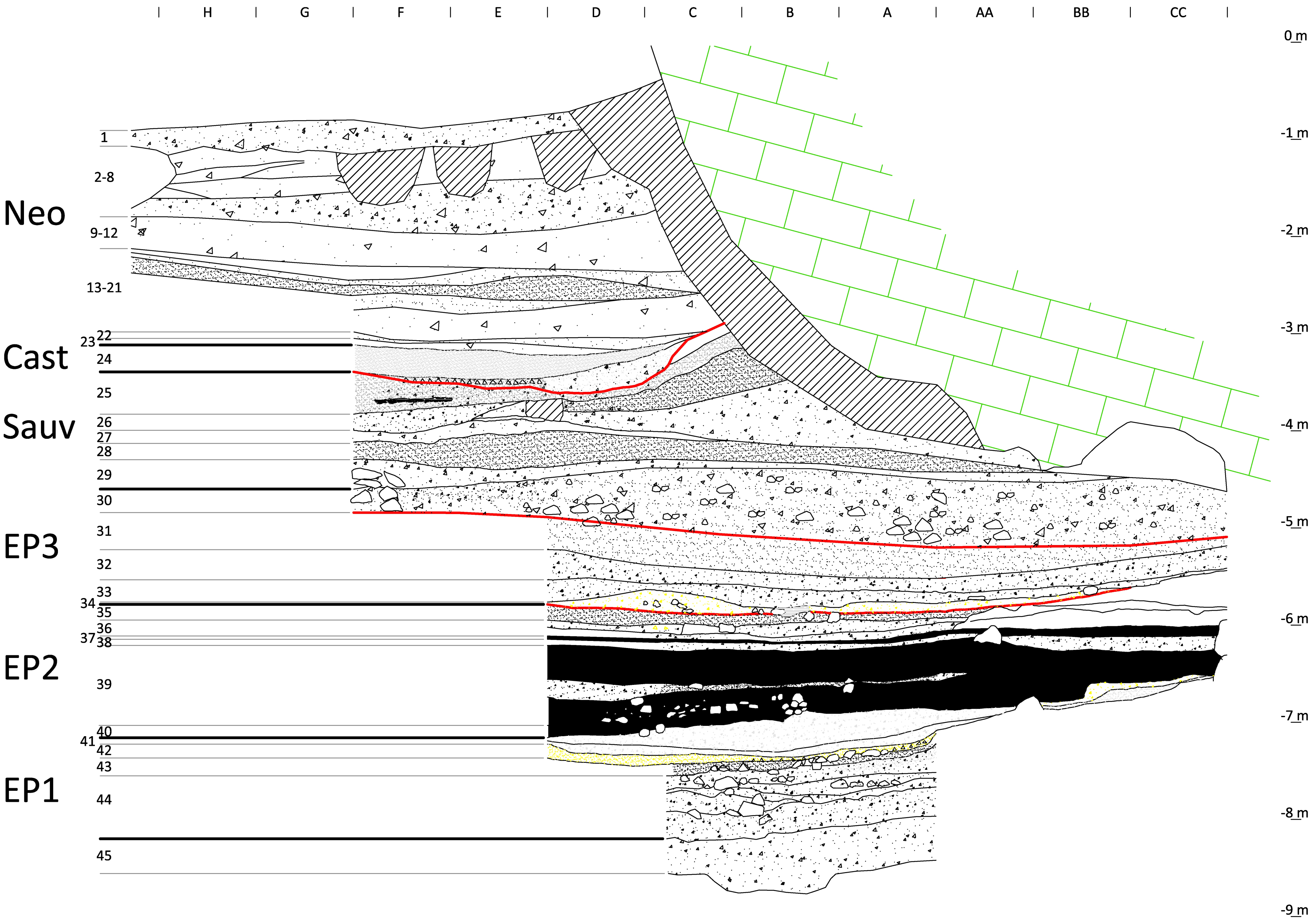

Fucino
Rome
A
Fucino basin
Continenza Cave
B
C
D

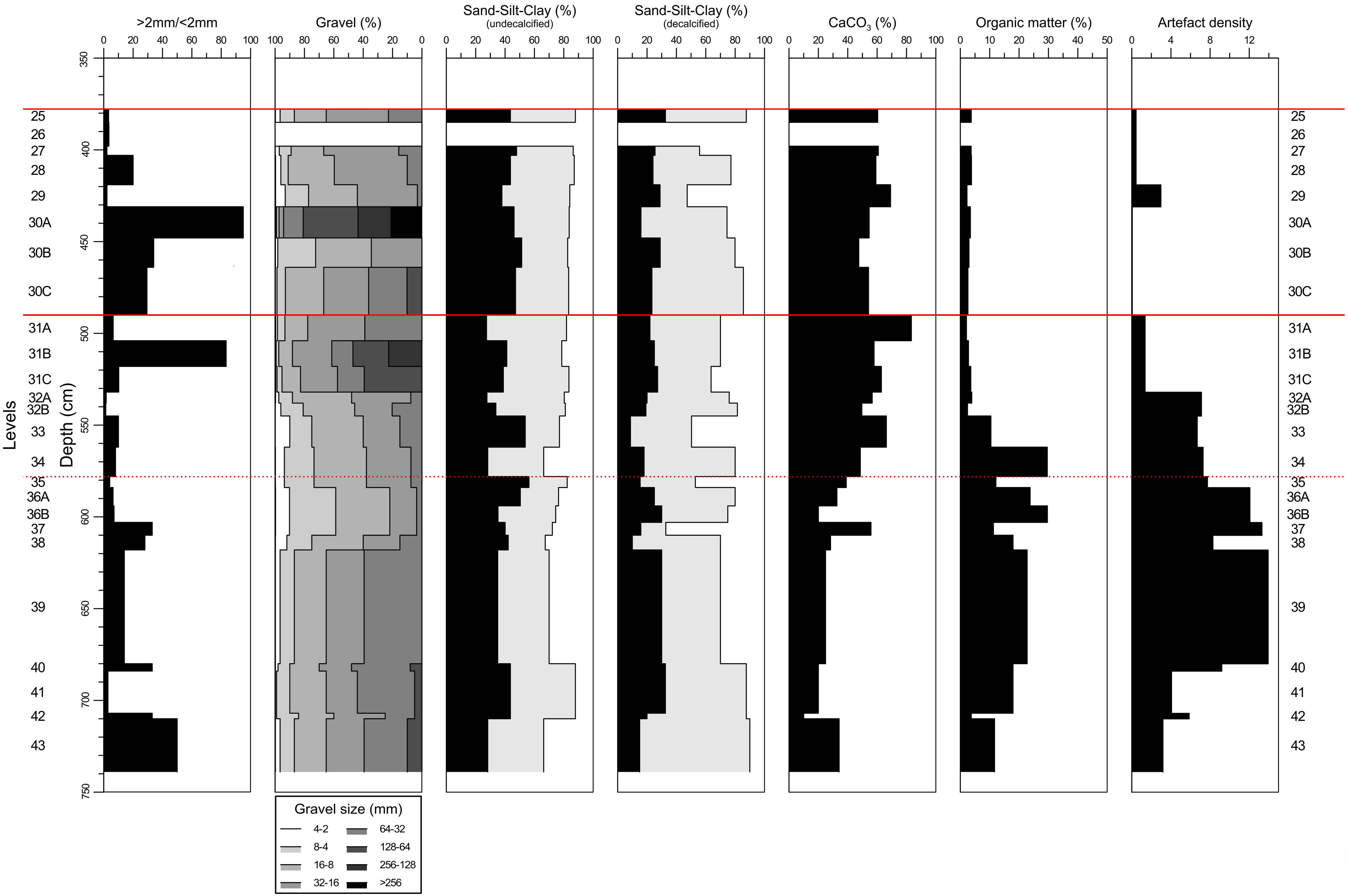

5m
N

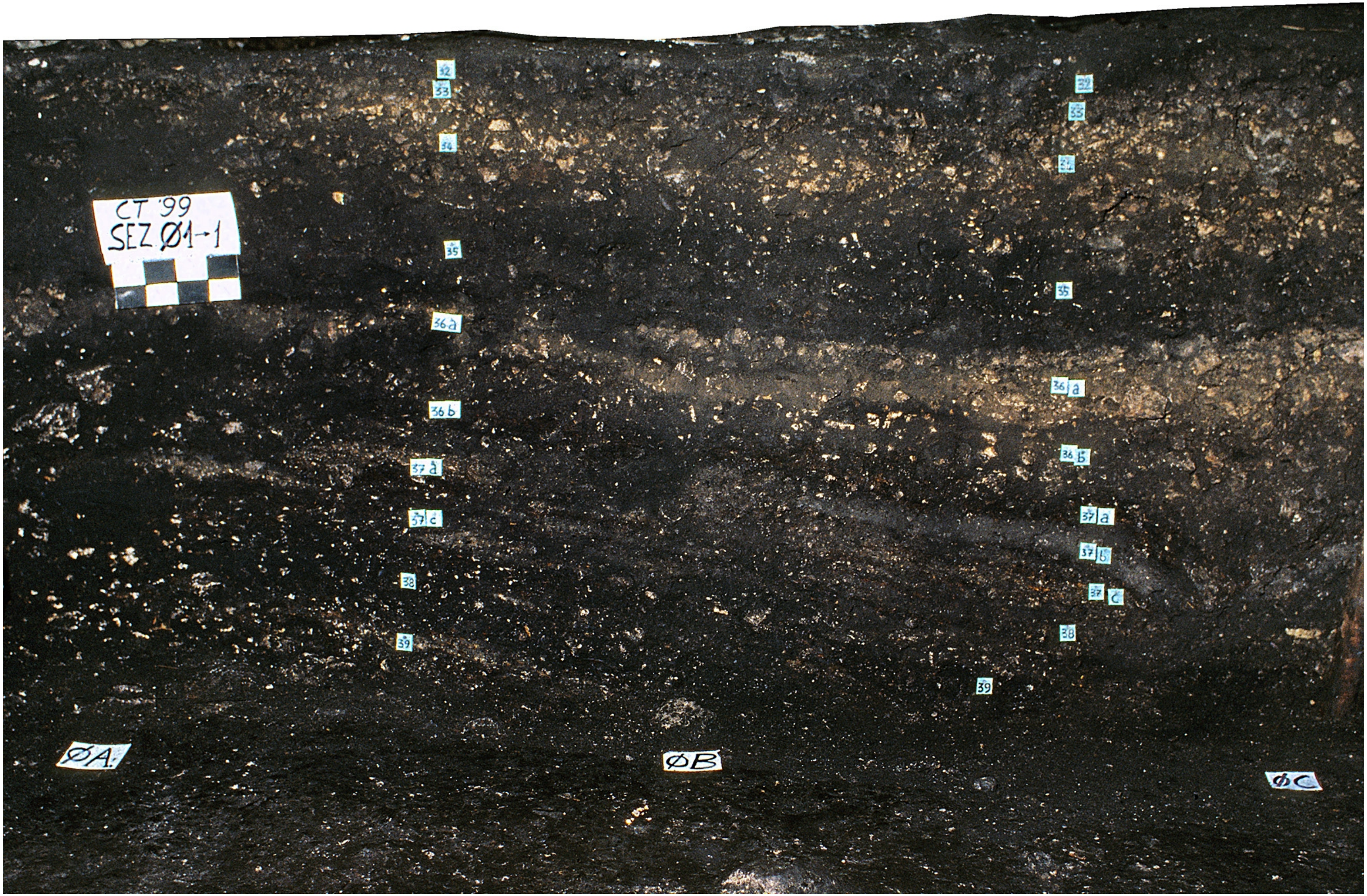


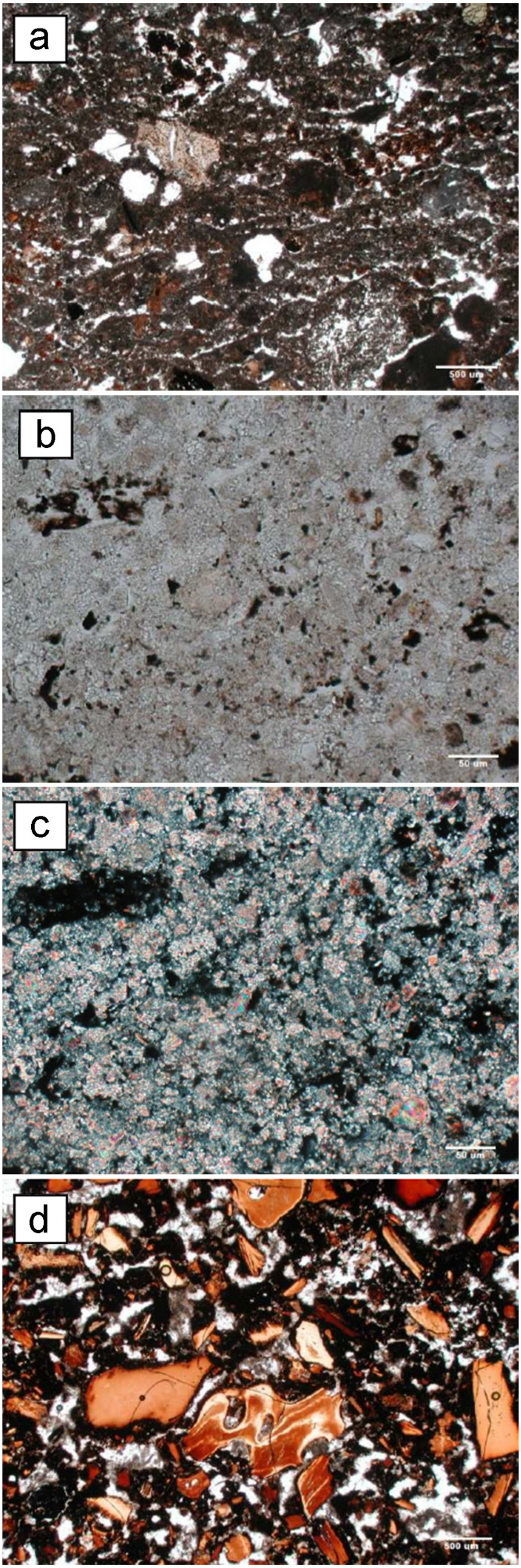

Neolithic
f
Late Mesolithic
(Castelnovian)
e
Early Mesolithic
(Sauveterrian)
d
Late Epigravettian
(EP3)
c
Late Epigravettian
(EP2)
b
Late Epigravettian
(EP1)
a
2 m
N

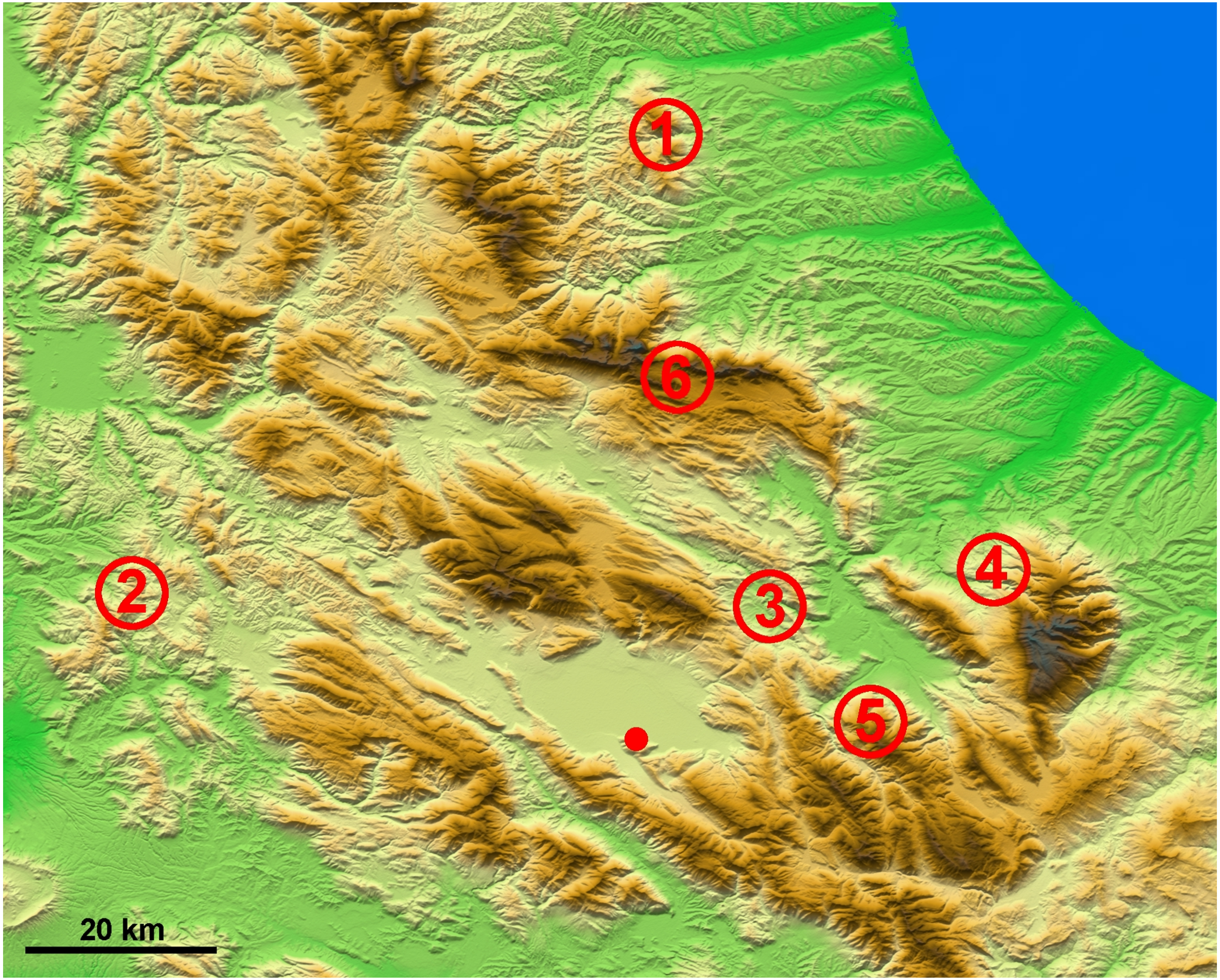

-3
-2
-1
0
1
2
3
4
5
6
7
-3 m
-4 m
-5 m
-6 m
-7 m
-8 m
-9 m
22
23
24
25
26
27
28
29
30a
30b
30c
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
45a
46
47
48
Cast
Sauv
EP3
EP2
EP1

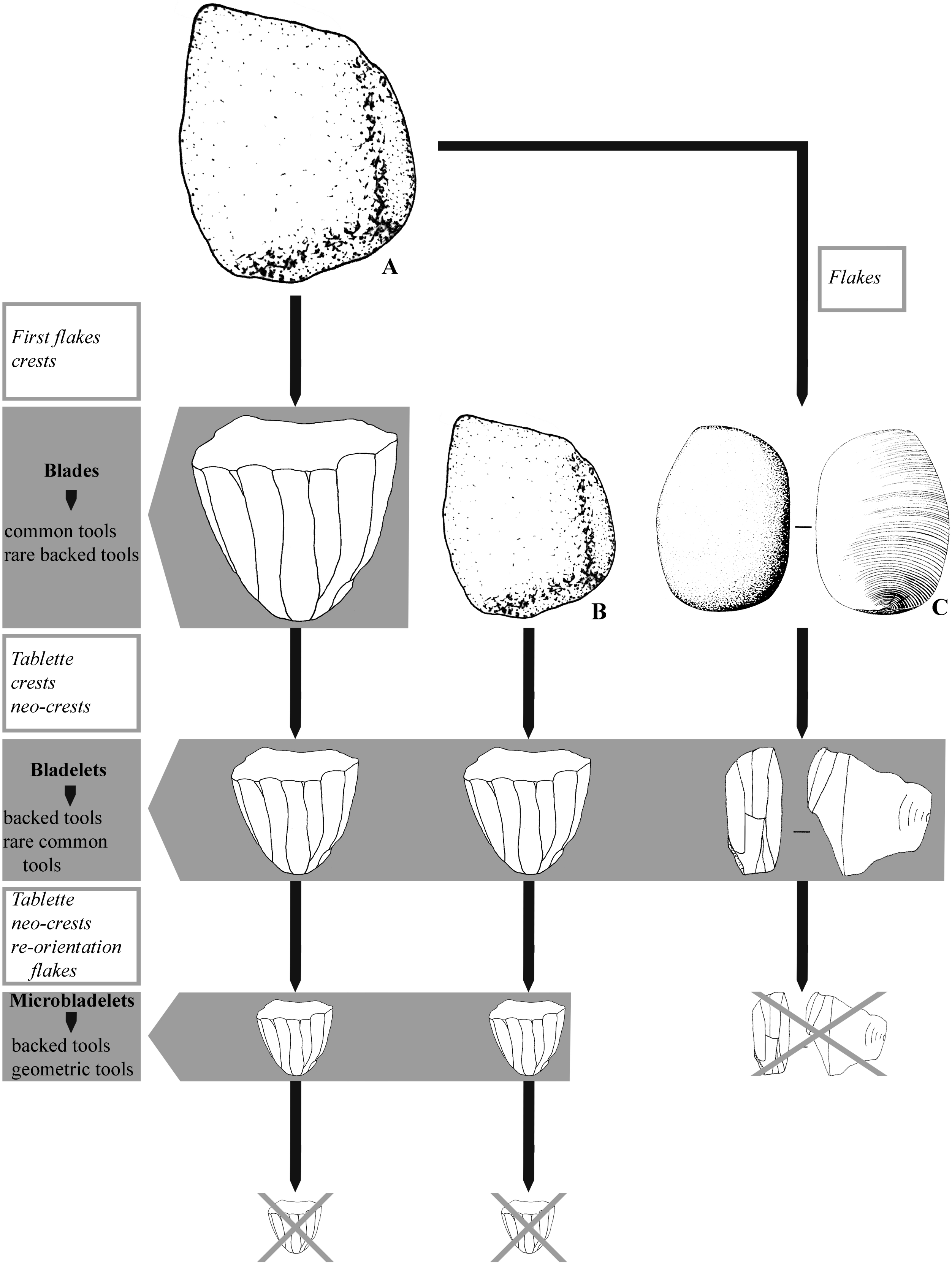

H
G
F
E
D
C
B
A
AA
BB
CC
0 m
-1 m
-2 m
-3 m
-4 m
-5 m
-6 m
-7 m
-8 m
-9 m
Neo
Cast
Sauv
EP3
EP2
EP1
1
2-8
9-12
13-21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45

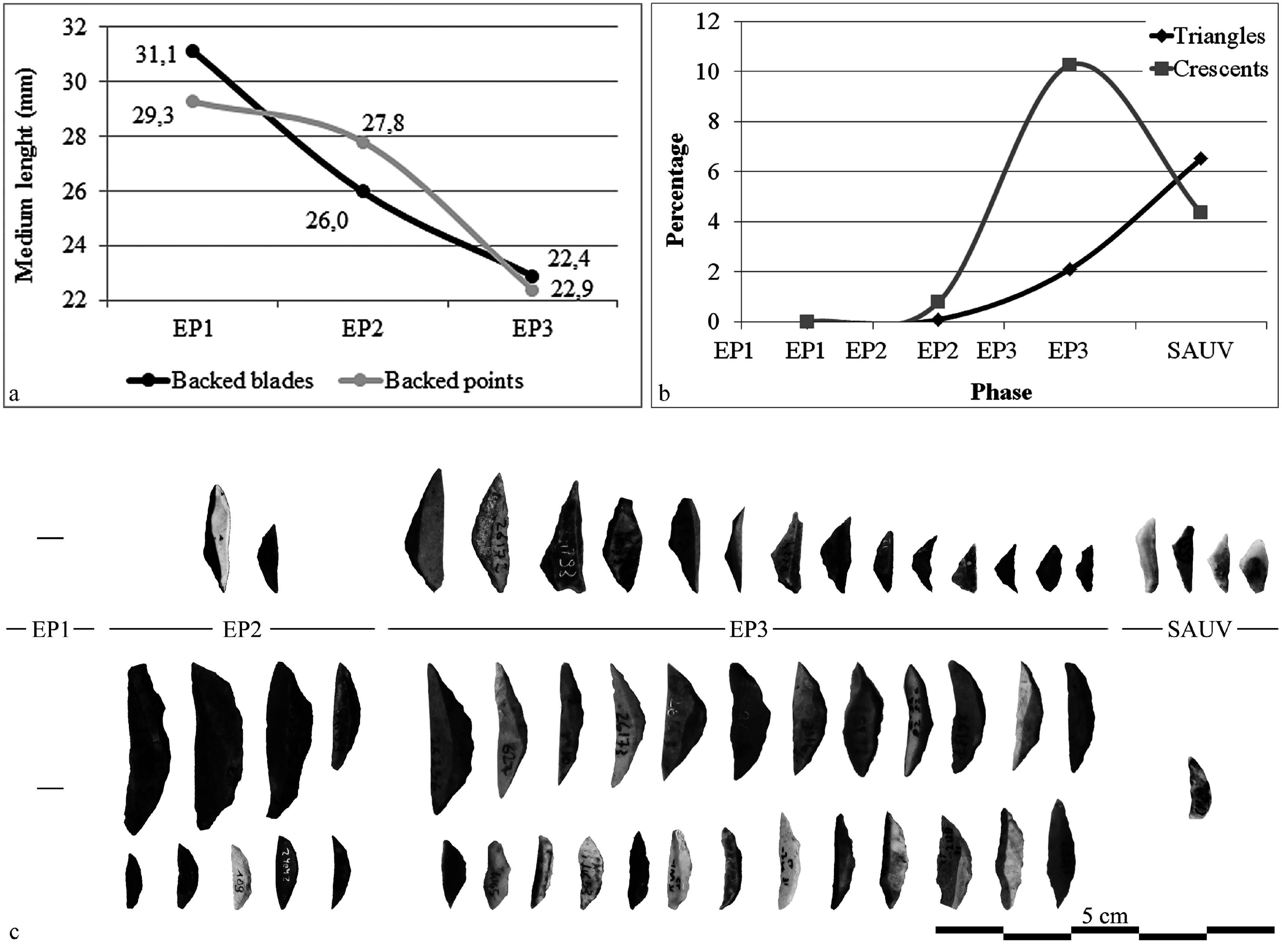

>2mm/<2mm
Gravel (%)
Sand-Silt-Clay (%)
(undecalcified)
Sand-Silt-Clay (%)
(decalcified)
CaCO$_3$ (%)
Organic matter (%)
Artefact density
0
20
40
60
80
100
0
10
20
30
40
50
0
4
8
12
Levels
Depth (cm)
350
400
450
500
550
600
650
700
750
25
26
27
28
29
30A
30B
30C
31A
31B
31C
32A
32B
33
34
35
36A
36B
37
38
39
40
41
42
43
Gravel size (mm)
4-2
8-4
16-8
32-16
64-32
128-64
256-128
>256


CT '99
SEZ 01→1
32
33
34
35
36a
36b
37a
37c
38
39
32
33
34
35
36a
36b
37a
37b
37c
38
39
0A
0B
0C

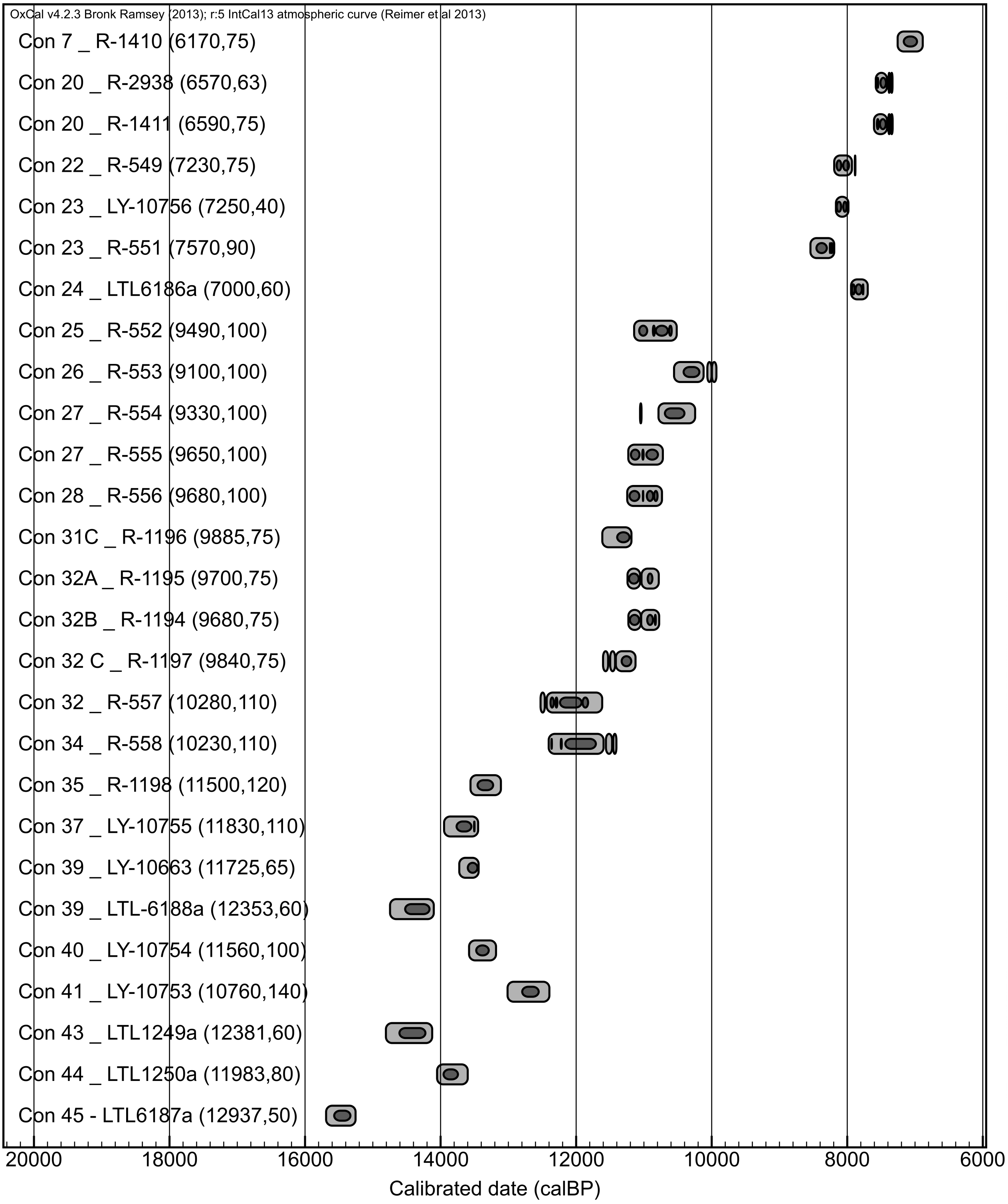

a
500 um
b
50 um
c
50 um
d
500 um

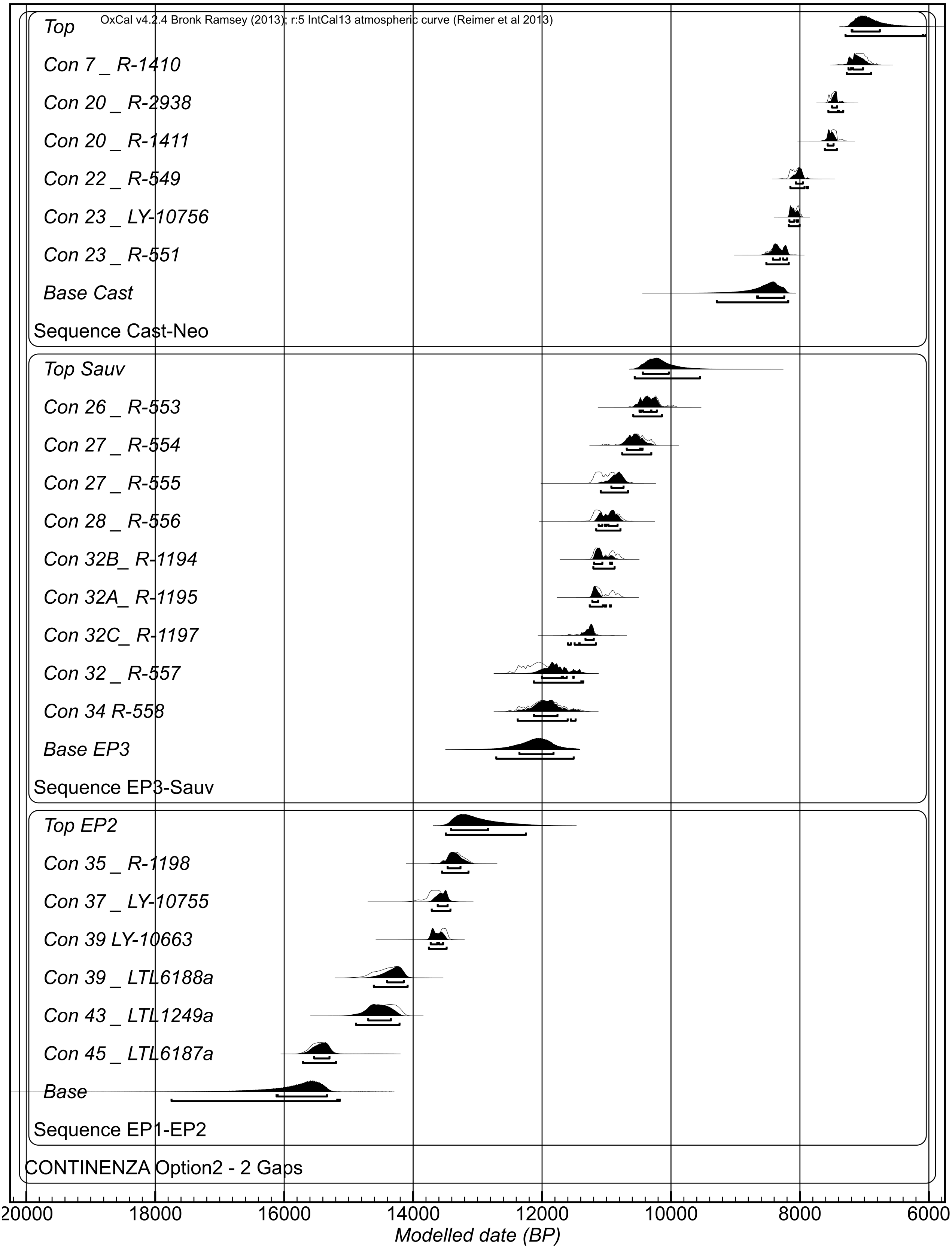

①
⑥
②
③
④
⑤
20 km

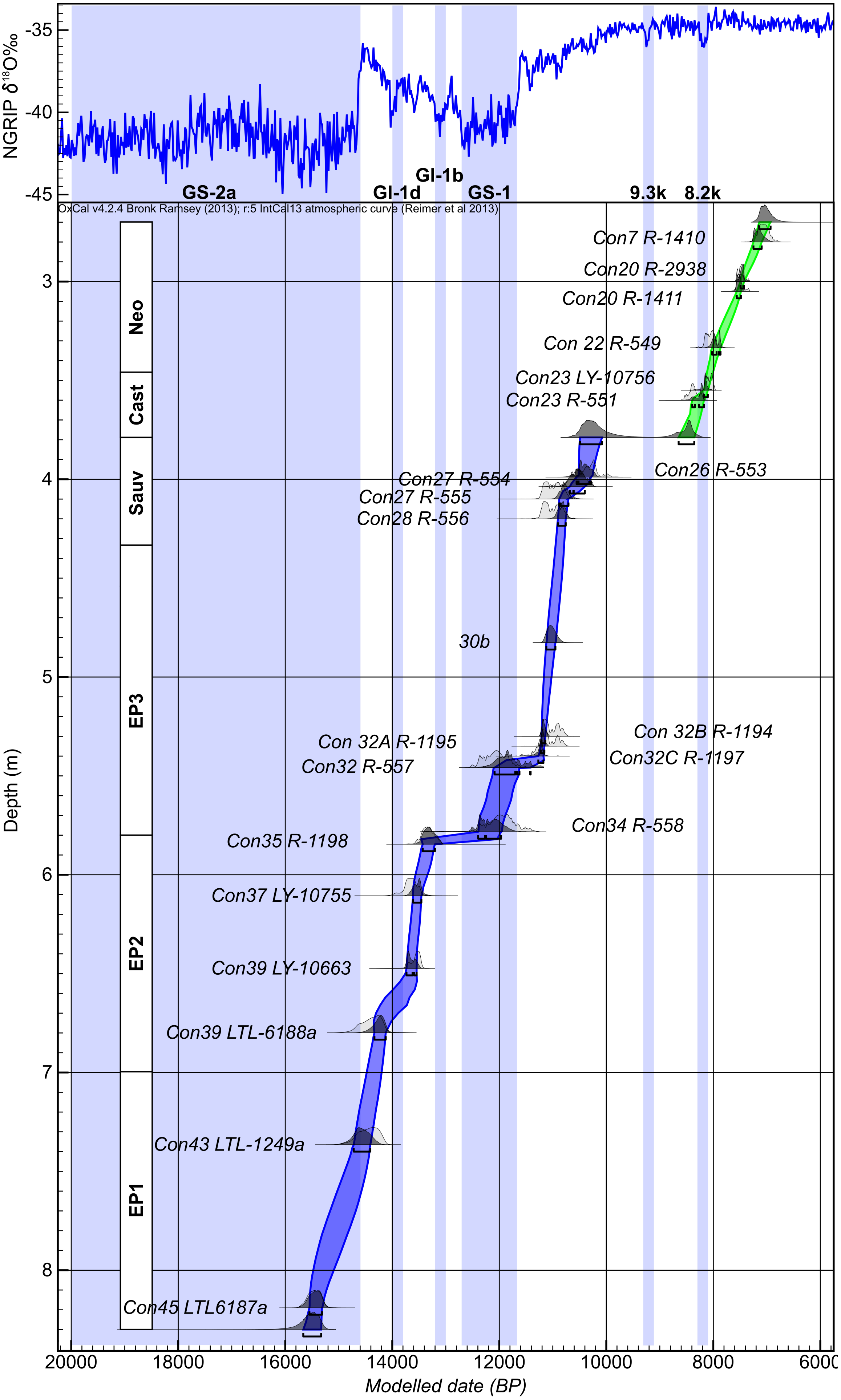

A
Flakes
First flakes
crests
Blades
common tools
rare backed tools
B
C
Tablette
crests
neo-crests
Bladelets
backed tools
rare common tools
Tablette
neo-crests
re-orientation flakes
Microbladelets
backed tools
geometric tools

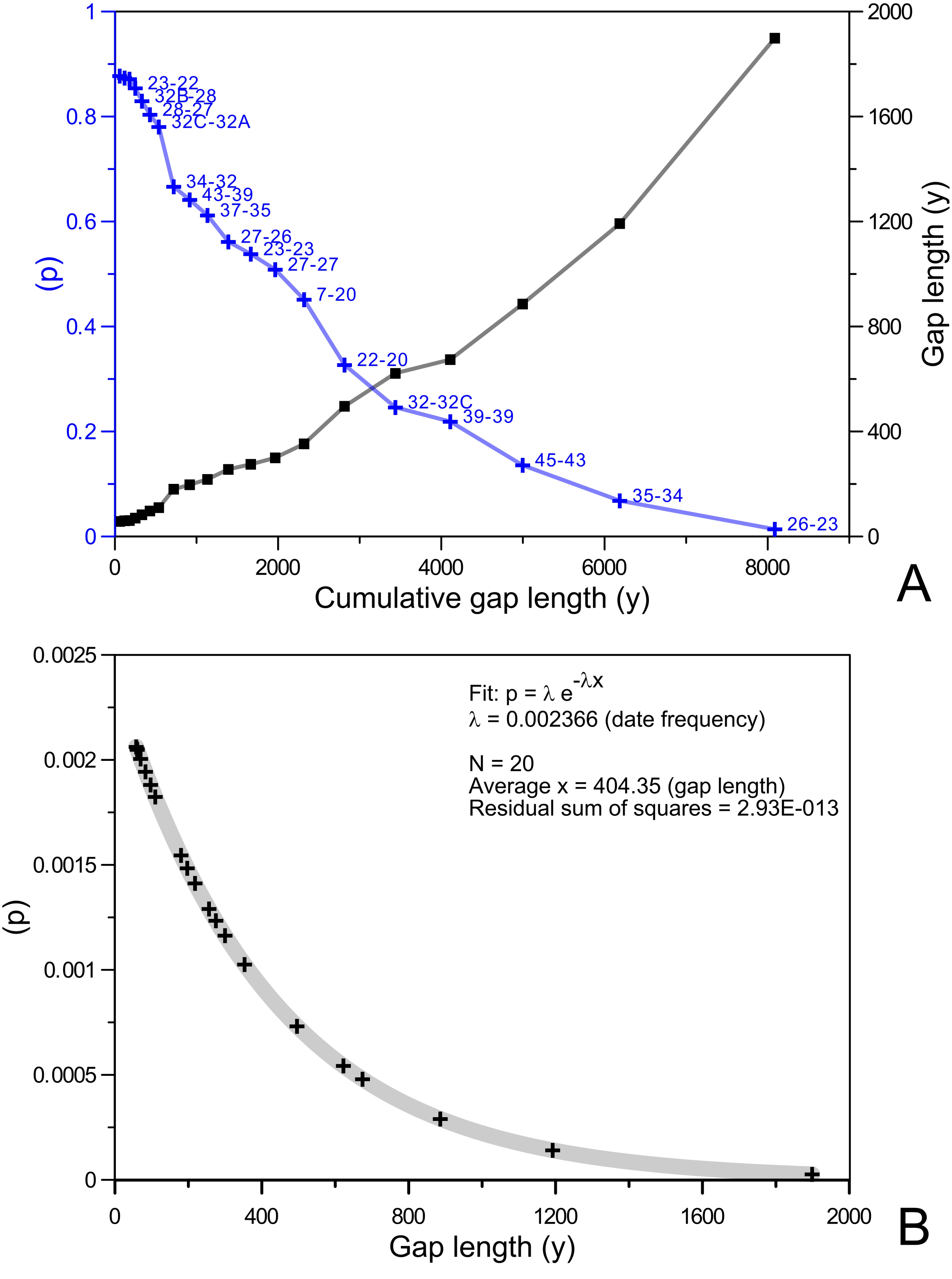


Medium lenght (mm)
32
30
28
26
24
22
31,1
29,3
27,8
26,0
22,4
22,9
EP1
EP2
EP3
Backed blades
Backed points
a
Percentage
12
10
8
6
4
2
0
Triangles
Crescents
EP1
EP1
EP2
EP2
EP3
EP3
SAUV
Phase
b
EP1
EP2
EP3
SAUV
5 cm
c

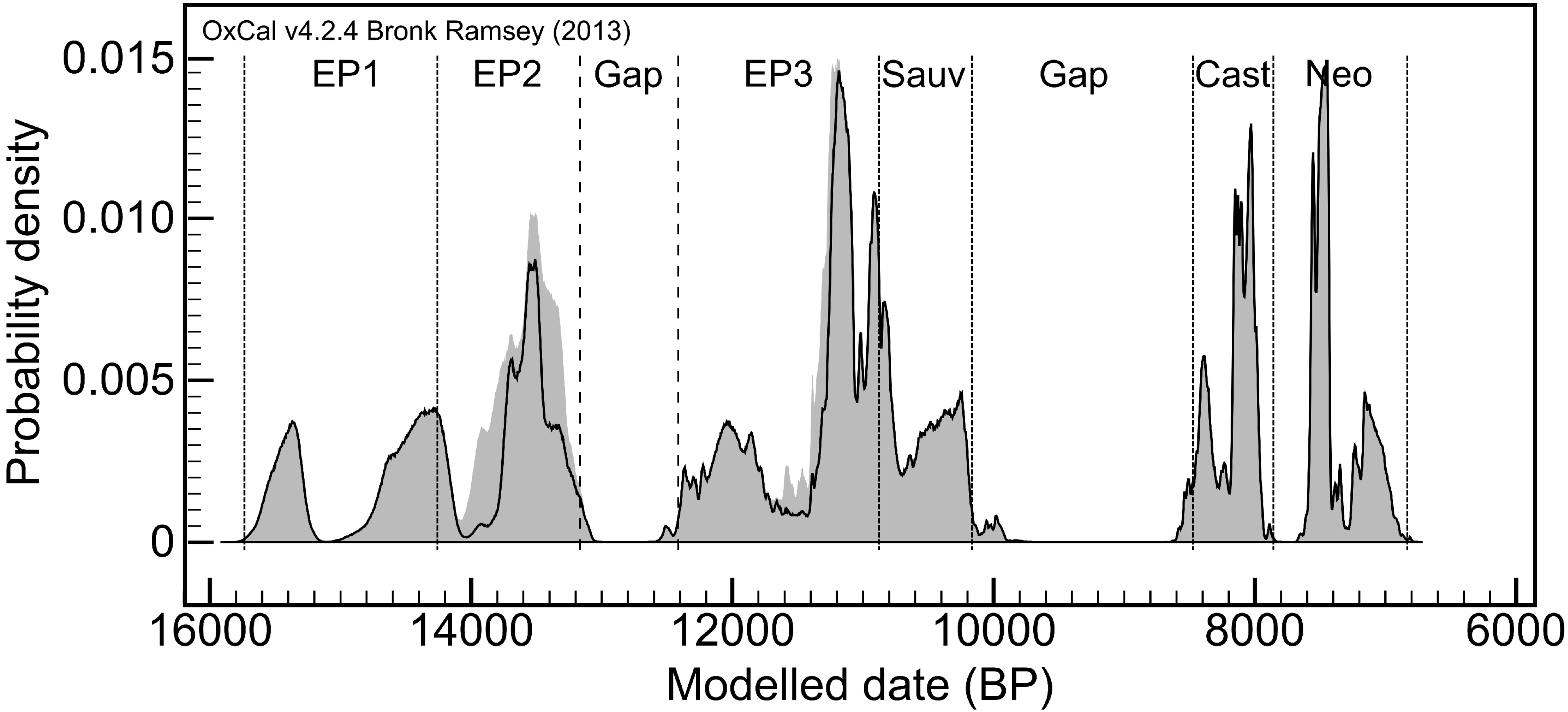

OxCal v4.2.3 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Con 7 _ R-1410 (6170,75)
Con 20 _ R-2938 (6570,63)
Con 20 _ R-1411 (6590,75)
Con 22 _ R-549 (7230,75)
Con 23 _ LY-10756 (7250,40)
Con 23 _ R-551 (7570,90)
Con 24 _ LTL6186a (7000,60)
Con 25 _ R-552 (9490,100)
Con 26 _ R-553 (9100,100)
Con 27 _ R-554 (9330,100)
Con 27 _ R-555 (9650,100)
Con 28 _ R-556 (9680,100)
Con 31C _ R-1196 (9885,75)
Con 32A _ R-1195 (9700,75)
Con 32B _ R-1194 (9680,75)
Con 32 C _ R-1197 (9840,75)
Con 32 _ R-557 (10280,110)
Con 34 _ R-558 (10230,110)
Con 35 _ R-1198 (11500,120)
Con 37 _ LY-10755 (11830,110)
Con 39 _ LY-10663 (11725,65)
Con 39 _ LTL-6188a (12353,60)
Con 40 _ LY-10754 (11560,100)
Con 41 _ LY-10753 (10760,140)
Con 43 _ LTL1249a (12381,60)
Con 44 _ LTL1250a (11983,80)
Con 45 - LTL6187a (12937,50)
20000
18000
16000
14000
12000
10000
8000
6000
Calibrated date (calBP)

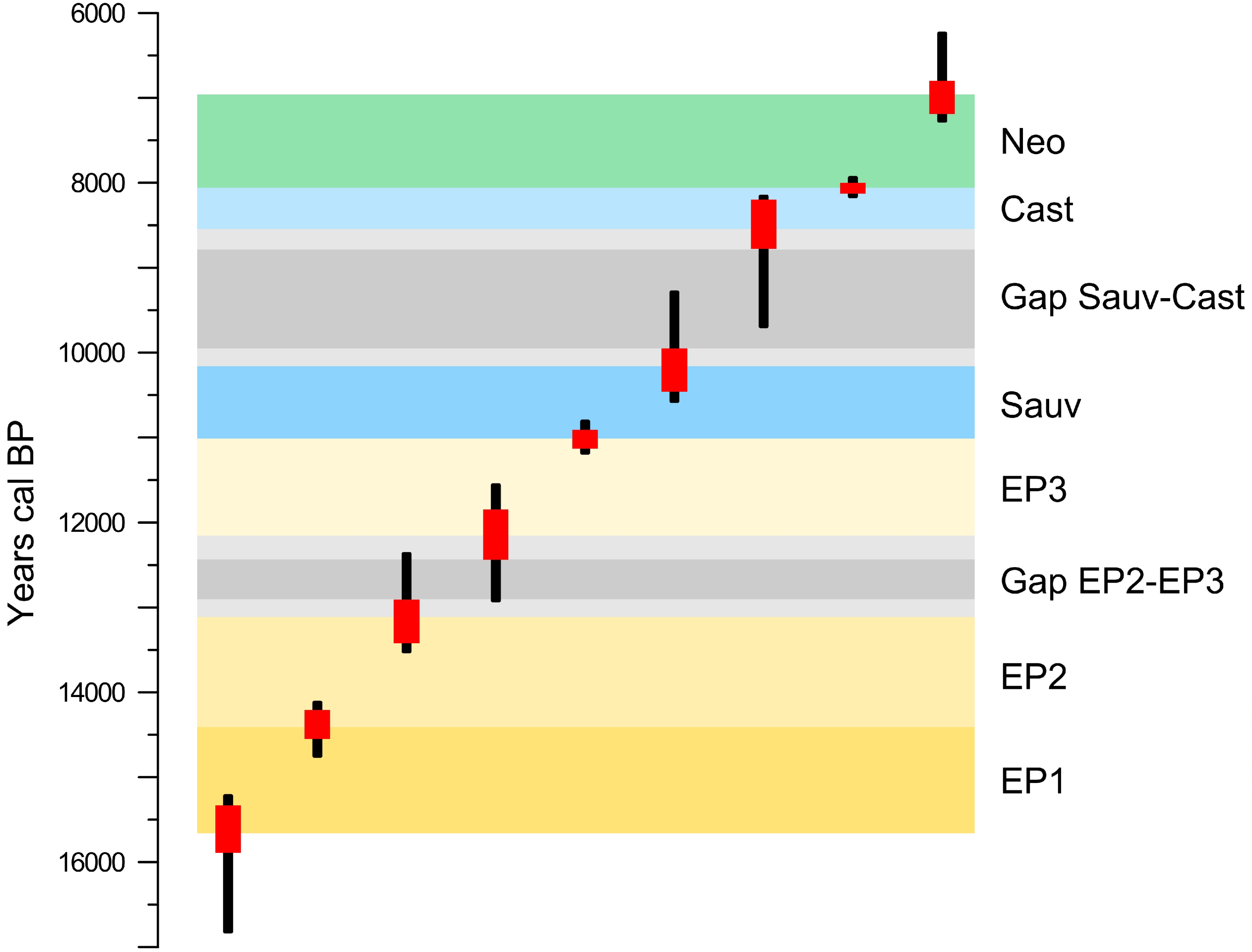

OxCal v4.2.4 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Top
Con 7 _ R-1410
Con 20 _ R-2938
Con 20 _ R-1411
Con 22 _ R-549
Con 23 _ LY-10756
Con 23 _ R-551
Base Cast
Sequence Cast-Neo
Top Sauv
Con 26 _ R-553
Con 27 _ R-554
Con 27 _ R-555
Con 28 _ R-556
Con 32B_ R-1194
Con 32A_ R-1195
Con 32C_ R-1197
Con 32 _ R-557
Con 34 R-558
Base EP3
Sequence EP3-Sauv
Top EP2
Con 35 _ R-1198
Con 37 _ LY-10755
Con 39 LY-10663
Con 39 _ LTL6188a
Con 43 _ LTL1249a
Con 45 _ LTL6187a
Base
Sequence EP1-EP2
CONTINENZA Option2 - 2 Gaps
20000
18000
16000
14000
12000
10000
8000
6000
Modelled date (BP)


NGRIP δ¹⁸O‰
-35
-40
-45
GS-2a
GI-1d
GI-1b
GS-1
9.3k
8.2k
OxCal v4.2.4 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Depth (m)
3
4
5
6
7
8
Neo
Cast
Sauv
EP3
EP2
EP1
Con7 R-1410
Con20 R-2938
Con20 R-1411
Con 22 R-549
Con23 LY-10756
Con23 R-551
Con26 R-553
Con27 R-554
Con27 R-555
Con28 R-556
30b
Con 32A R-1195
Con32 R-557
Con 32B R-1194
Con32C R-1197
Con34 R-558
Con35 R-1198
Con37 LY-10755
Con39 LY-10663
Con39 LTL-6188a
Con43 LTL-1249a
Con45 LTL6187a
20000
18000
16000
14000
12000
10000
8000
6000
Modelled date (BP)



1
0.8
0.6
0.4
0.2
0
(p)
2000
1600
1200
800
400
0
Gap length (y)
23-22
32B-28
28-27
32C-32A
34-32
43-39
37-35
27-26
23-23
27-27
7-20
22-20
32-32C
39-39
45-43
35-34
26-23
0
2000
4000
6000
8000
Cumulative gap length (y)
A
0.0025
0.002
0.0015
0.001
0.0005
0
(p)
Fit: $p = \lambda e^{-\lambda x}$
λ = 0.002366 (date frequency)
N = 20
Average x = 404.35 (gap length)
Residual sum of squares = 2.93E-013
0
400
800
1200
1600
2000
Gap length (y)
B


OxCal v4.2.4 Bronk Ramsey (2013)
EP1
EP2
Gap
EP3
Sauv
Gap
Cast
Neo
Probability density
0.015
0.010
0.005
0
16000
14000
12000
10000
8000
6000
Modelled date (BP)


6000
8000
10000
12000
14000
16000
Years cal BP
Neo
Cast
Gap Sauv-Cast
Sauv
EP3
Gap EP2-EP3
EP2
EP1

Cultural Phase	“Maiolica” (%)	“Scaglia Rossa” (%)	“Marne a Fucoidi” and others (%)	Unidentified (%)
Cast	51	3.6	16.4	29
Sauv	72.3	1.7	12.5	13.5
EP3	75.9	3.9	12.6	7.6
EP2	75.3	5.1	13.9	5.7
EP1	77.3	5.7	10.3	6.7

Table 1. Distribution of flint raw material per cultural phase.

Level	Lab #	^{14}C Age	Method	Phase
Con 7	R-1410	6170±75	C	Neo
Con 20	R-2938	6570±63	C	Neo
Con 20	R-1411	6590±75	C	Neo
Con 22	R-549	7230±75	C	Neo
Con 23	LY-10756	7250±40	AMS	Cast
Con 23	R-551	7570±90	C	Cast
Con 24	LTL6186a	7000±60	AMS	Cast
Con 25	R-552	9490±100	C	Sauv
Con 26	R-553	9100±100	C	Sauv
Con 27 C/-2	R-554	9330±100	C	Sauv
Con 27 D/-2	R-555	9650±100	C	Sauv
Con 28	R-556	9680±100	C	Sauv
Con 31 C	R-1196	9885±75	C	EP3
Con 32 A	R-1195	9700±75	C	EP3
Con 32 B	R-1194	9680±75	C	EP3
Con 32 C	R-1197	9840±75	C	EP3
Con 32	R-557	10280±110	C	EP3
Con 34	R-558	10230±110	C	EP3
Con 35	R-1198	11500±120	C	EP2
Con 37	LY-10755	11830±110	AMS	EP2
Con 39	LY-10663	11725±65	AMS	EP2
Con 39	LTL-6188a	12353±60	AMS	EP2
Con 40	LY-10754	11560±100	AMS	EP2
Con 41	LY-10753	10760±140	AMS	EP1
Con 43	LTL1249a	12381±60	AMS	EP1
Con 44	LTL1250a	11983±80	AMS	EP1
Con 45	LTL6187a	12937±50	AMS	EP1

Table 2. Set of radiocarbon dates for the Grotta Continenza sequence. All datings were carried out on charcoal, by conventional (C) or AMS technique. Cultural phases include three Late Upper Palaeolithic (Late Epigravettian) horizons (EP1, EP2, EP3), two Mesolithic (Sauveterrian and Castelnovian) horizons (Sauv, Cast), and one Neolithic (Early Impressa Ware) horizon (Neo).

Ages	68.2%		95.4%				
	from	to	from	to	mu	sigma	median
Top sequence	7,190	6,800	7,270	6,240	6,890	290	6,960
Base Neo	8,130	8,000	8,160	7,940	8,050	60	8,060
Base Cast	8,780	8,200	9,690	8,160	8,670	420	8,540
Top Sauv	10,460	9,950	10,570	9,290	10,070	340	10,160
EP3-Sauv	11,130	10,910	11,180	10,810	11,000	100	11,010
Base EP3	12,440	11,850	12,920	11,560	12,200	320	12,160
Top EP2	13,420	12,910	13,520	12,370	13,050	300	13,120
EP1-EP2	14,550	14,210	14,750	14,120	14,420	160	14,400
Base sequence	15,890	15,330	16,820	15,220	15,800	470	15,660

Durations	68.2%		95.4%				
	from	to	from	to	mu	sigma	median
Neo	860	1,270	720	1,790	1,160	290	1,100
Cast	120	770	20	1,630	620	430	490
Gap Sauv-Cast	1,110	2,060	210	2,180	1,400	510	1,510
Sauv	530	1,100	330	1,770	930	360	860
EP3	830	1,480	530	1,980	1,200	340	1,170
Gap EP2-EP3	460	1,330	0	1,500	850	400	880
EP2	930	1,600	750	2,140	1,360	360	1,300
EP1	860	1,590	560	2,540	1,390	510	1,280

Table 3. Boundary ages, phase and gap durations for model Option 2, for 1 σ and 2 σ confidence as resulting from Bayesian modelling (OxCal v. 4.2, Bronk Ramsey, 2009a).

	Models with no gaps								Models with one gap (Sauv-Cast)								Models with two gaps (Sauv-Cast and EP2-EP3)							
			no 31C		no 40		no 31C 40				no 31C		no 40		no 31C 40				no 31C		no 40		no 31C 40	
	A	O	A	O	A	O	A	O	A	O	A	O	A	O	A	O	A	O	A	O	A	O	A	O
Con7 (R-1410)	101.1	9	100.6	9	101.2	9	100.9	9	99.1	9	99.0	9	99.1	9	99.2	9	98.1	10	97.5	**10**	96.7	**10**	98.9	9
Con20 (R-2938)	104.7	8	104.4	8	105.0	8	104.1	9	105.8	7	105.0	8	105.8	7	104.1	9	104.8	8	104.2	8	104.7	8	105.1	8
Con20 (R-1411)	103.8	8	103.4	9	104.0	8	103.2	9	104.1	8	103.7	8	104.4	7	103.1	9	103.4	9	103.1	9	103.4	9	103.9	8
Con22 (R-549)	105.1	8	104.6	9	105.3	8	104.4	9	105.4	8	105.1	8	105.6	8	104.3	9	104.8	9	104.5	9	105.0	8	105.2	8
Con23 (LY-10756)	103.1	7	102.1	8	103.2	7	101.9	8	103.9	6	103.0	7	103.9	6	101.9	8	103.0	7	102.4	8	102.8	8	103.0	7
Con23 (R-551)	101.9	8	101.3	9	102.0	8	101.3	9	99.3	7	98.7	8	99.5	7	98.0	9	98.5	8	98	9	98	8	98.8	8
Sauv-Cast Gap	no	no	no	no	no	no	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Con26 (R-553)	104.7	9	104.7	9	104.9	9	104.3	9	106.2	7	106.0	8	106.6	7	105.7	8	100.3	8	103.9	6	99.9	9	102.4	8
Con27 (R-554)	109.9	8	109.4	8	110.0	8	109.2	9	112.1	7	111.3	8	111.9	7	110.5	8	111.7	8	113.6	6	111.5	8	111.9	8
Con27 (R-555)	92.4	9	90.6	9	92.6	9	90.5	9	92.6	8	91.2	8	92.9	8	90.7	9	92.7	9	92.6	7	92.9	9	91.4	8
Con28 (R-556)	105.6	7	102.4	8	106.0	7	102.3	8	105.8	7	103.2	7	106.2	7	102.4	8	105.5	8	104.8	6	105.8	8	103.2	8
Con31C (R-1196)	**16.7**	**50**	no	no	**16.4**	**47**	no	no	**16.5**	**52**	no	no	**16.4**	**49**	no	no	**16.6**	**49**	no	no	**16.4**	**46**	no	no
Con32B (R-1194)	121.8	7	115.5	8	121.7	7	115.5	8	122.5	6	116.4	7	122.2	7	115.6	8	121.7	7	118.2	5	121.5	8	116.4	7
Con32A (R-1195)	116.4	9	129.3	8	115.9	9	129.1	8	118	8	130.1	7	117.1	8	129.2	8	115.9	9	132.2	6	115.3	9	130.1	7
Con32C (R-1197)	103	8	105.0	8	103.2	8	105.1	8	103.6	7	105.7	8	103.7	7	105.1	8	104.4	8	108.4	6	104.1	8	106.7	8
Con32 (R-557)	95.3	9	95.0	9	95.4	9	94.9	9	95.8	9	95.5	9	95.6	9	95.1	9	70.8	**12**	76.1	10	70.5	**12**	74.9	10
Con34 (R-558)	93.4	10	93.8	10	93.8	10	93.9	10	93.8	10	93.9	10	94.0	10	93.8	10	112.7	9	114.7	7	112.7	9	113.7	8
EP2-EP3 Gap	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	yes	yes	yes	yes	yes	yes	yes
Con35 (R-1198)	107	9	106.9	9	105.5	8	105	9	107.6	8	107.4	8	106.2	8	105.1	9	111.4	8	110.2	6	107.4	8	106.6	8
Con37 (LY-10755)	62.6	**12**	61.8	**11**	90.6	9	89.9	9	62.9	12	62.3	**11**	90.9	8	90.0	9	64.1	**12**	66.1	8	91.6	9	92.1	8
Con39 (LY-10663)	116.7	6	117.0	8	77.3	9	76.3	9	117.3	6	117.5	7	78.1	8	76.7	9	116.0	7	120.4	5	76.0	9	76.8	8
Con40 (LY-10754)	**27.8**	**21**	**28.2**	**17**	no	no	no	no	**28.2**	**21**	**28.4**	**17**	no	no	no	no	**27.2**	**21**	**29.5**	**15**	no	no	no	no
Con44 (LTL1250a)	104	8	103.5	9	105.6	8	104.9	9	104.4	8	104.9	8	106.6	7	104.9	9	103.6	9	95.2	7	104.7	9	103.9	8
Con45 (LTL6187a)	95.4	**15**	96.9	**13**	93.5	**17**	98.5	**12**	81	**29**	85.8	**24**	81.0	**29**	95.3	**15**	99.6	10	65.9	**45**	99.1	10	86.1	**24**
Amodel	**50.7**		81.2		63.9		104.7		**48.8**		78.7		62.0		103.2		**50.2**		74.7		63.5		101.2	
Aoverall	**56.3**		81.4		72.1		105.5		**55.2**		80.9		71.0		104.4		**54.8**		77.5		63.9		103.3	

Table 1-supplementary material. Results of OxCal v. 4.2 (Bronk Ramsey, 2009a) runs for the set of dates included in Option 1. The option was tested under three versions: no gaps, one gap and two gaps. Each of these versions was tested under four sub-versions; including all dates, excluding Con31C (R-1196), excluding Con40 (LY-10754), excluding Con31C (R-1196) AND Con40 (LY-10754). Overall and model agreement are reported, as well as agreement (A) and outlier values (O) for each modelled date; bold figures indicate values beyond the acceptable limit.

	Models with no gaps				Models with one gap				Models with two gaps			
			no 31C				no 31C				no 31C	
	A	O	A	O	A	O	A	O	A	O	A	O
Con 7 (R-1410)	100.6	9	100.9	9	99.4	9	98.9	10	97.3	10	97.6	10
Con20 (R-2938)	104.8	8	103.9	9	104.3	8	104.0	9	105.0	8	104.2	9
Con20 (R-1411)	103.4	9	103.1	9	103.3	9	103.1	9	103.7	8	103.2	9
Con22 (R-549)	104.9	8	104.3	9	104.5	9	104.2	9	104.7	9	104.4	9
Con23 (LY-10756)	102.9	7	101.7	9	102.6	8	102.0	8	103.1	7	102.2	8
Con23 (R-551)	101.9	8	101.2	9	98.3	9	97.1	9	95.6	9	95.0	9
Sauv-Cast Gap	no	no	no	no	yes	yes	yes	yes	yes	yes	yes	yes
Con26 (R-553)	104.6	9	104.3	9	105.1	8	104.5	9	95.5	9	98.0	9
Con27 (R-554)	109.8	8	109.0	9	111.0	8	110.6	9	111.7	8	111.3	9
Con27 (R-555)	92.5	9	90.3	9	92.7	9	90.5	9	92.9	9	90.9	9
Con28 (R-556)	105.7	8	102.1	9	105.8	8	102.2	8	105.8	8	102.3	8
Con31C (R-1196)	**16.3**	**48**	no	no	**16.6**	**47**	no	no	**16.4**	**48**	no	no
Con32B (R-1194)	122.0	7	115.2	8	121.5	7	115.4	8	121.7	7	115.4	8
Con32A (R-1195)	116.0	9	128.8	8	115.1	9	129.0	8	115.9	9	129.2	8
Con32C (R-1197)	102.8	8	104.8	9	102.6	8	104.8	9	105.2	8	106.4	8
Con32 (R-557)	95.1	9	94.7	10	95.1	9	94.8	9	63.3	**13**	68.5	**11**
Con34 (R-558)	93.6	10	93.7	10	93.6	10	93.7	10	109.4	9	111.4	9
EP2-EP3 Gap	no	no	no	no	no	no	no	no	yes	yes	yes	yes
Con35 (R-1198)	105.2	9	104.7	9	105.0	9	104.9	9	107.2	8	106.6	9
Con37 (LY-10755)	92.1	9	91.1	9	91.9	9	91.3	9	93.6	9	93.0	9
Con39 (LY-10663)	72.9	**12**	73.7	**11**	73.3	**11**	73.5	**11**	72.2	**12**	72.4	**11**
Con39 (LTL-6188)	111.3	9	111.0	9	111.2	9	111.1	9	111.2	9	111.2	9
Con43 (LTL-1249)	96.9	9	96.3	9	96.7	9	96.5	9	96.7	9	96.6	9
Con45 (LTL-6187)	97.6	**12**	100.2	10	98.0	**12**	98.5	**11**	98.4	**12**	98.5	**12**
Amodel	65.3		105.4		64.8		103.8		62.4		101.3	
Aoverall	72.3		105.1		71.8		104.0		67.1		99.8	

Table 2-supplementary material. Results of OxCal v. 4.2 (Bronk Ramsey, 2009a) runs for the set of dates included in Option 2. The option was tested under three versions: no gaps, one gap and two gaps. Each of these versions was tested under two sub-versions; including all dates and excluding Con31C (R-1196). Overall and model agreement are reported, as well as agreement (A) and outlier values (O) for each modelled date; bold figures indicate values beyond the acceptable limit.

	Models with no gaps		Models with one gap		Models with two gaps	
	A	O	A	O	A	O
Con 7 (R-1410)	98.6	10	94.3	8	95.6	4
Con20 (R-2938)	113.1	7	115.1	7	97.8	2
Con20 (R-1411)	115.5	7	111.4	6	98.0	2
Con22 (R-549)	105.9	8	67.5	**12**	90.6	9
Con23 (LY-10756)	98.1	**11**	81.5	**23**	70.8	**29**
Con23 (R-551)	91.7	10	73.4	9	94.2	6
Sauv-Cast Gap	no	no	yes	yes	yes	yes
Con26 (R-553)	95.9	9	78.5	**11**	**38.4**	**62**
Con27 (R-554)	101.6	8	105.4	8	71.0	**29**
Con27 (R-555)	73.5	**11**	74.5	**12**	86.3	**14**
Con28 (R-556)	81.9	10	82.7	9	88.9	**11**
Con32B (R-1194)	128.2	7	128.0	7	97.1	3
Con32A (R-1195)	131.4	8	131.9	7	97.1	3
Con32C (R-1197)	116.6	8	115.7	8	97.3	3
Con32 (R-557)	75.3	**13**	75.8	**14**	**17.1**	**83**
Con34 (R-558)	83.9	**13**	84.8	**13**	**51.7**	**48**
EP2-EP3 Gap	no	no	no	no	yes	yes
Con35 (R-1198)	101.4	10	101.7	10	73.9	**26**
Con37 (LY-10755)	83.5	10	84.1	10	73.0	**27**
Con39 (LY-10663)	64.3	**13**	65.6	**13**	**30.6**	**69**
Con39 (LTL-6188)	107.2	10	107.3	**11**	70.3	**30**
Con43 (LTL-1249)	92.2	9	93.1	9	71.5	**29**
Con45 (LTL-6187)	102.5	9	102.4	9	75.9	**24**
Amodel	84.2		67.1		**33.9**	
Aoverall	86.3		70.4		**25.0**	

Table 3-supplementary material. Results of OxCal v. 4.2 (Bronk Ramsey, 2009a) runs for depositional models on the set of dates included in Option 2, excluding Con31C (R-1196). The option was tested under three versions: no gaps, one gap and two gaps. Overall and model agreement are reported, as well as agreement (A) and outlier values (O) for each modelled date; bold figures indicate values beyond the acceptable limit.