A new chronostratigraphic framework for the Upper Palaeolithic of Riparo Mochi (Italy)

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Abstract

The rockshelter of Mochi, on the Ligurian coast of Italy, is often used as a reference point in the formation of hypotheses concerning the arrival of the Aurignacian in Mediterranean Europe. Yet, the site is poorly known. Here, we describe the stratigraphic sequence based on new field observations and present 15 radiocarbon determinations from the Middle Palaeolithic (late Mousterian) and Early Upper Palaeolithic (Aurignacian and Gravettian) levels. The majority of dates were produced on humanly modified material, specifically marine shell beads, which comprise some of the oldest directly-dated personal ornaments in Europe. The radiocarbon results are incorporated into a Bayesian statistical model to build a new chronological framework for this key Palaeolithic site. A tentative correlation of the stratigraphy to palaeoclimatic records is also attempted.

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Introduction

The nature, timing and route, or routes, of early modern humans colonising Europe remain a matter of strong debate. The Mediterranean rim assumes importance since it is regarded as one of the two most likely major paths for the dispersal of the Aurignacian – the other being the northern Danube corridor (Conard and Bolus, 2003; Mellars, 2005). The rockshelter of Mochi (or Riparo Mochi), on the Ligurian coast of Italy, lies exactly along the southern trajectory. Its early Upper Palaeolithic sequence is often used as a reference for describing the appearance and evolution of the Aurignacian technocomplex, thought to be authored by modern humans, along the northern Mediterranean coast. Yet, despite the acknowledged importance of the site, details of the stratigraphic sequence are scarce and the chronology is based on a limited radiocarbon corpus. Here we briefly present the history of research at Mochi (with special reference to the unreported excavations from the mid-1990s to present) and the stratigraphic and cultural succession at the site, and we report new data on the chronology of the Late Middle and Early Upper Palaeolithic parts of the sequence.

History of research

Riparo Mochi (43° 47’ 3.66” N, 7° 32’ 4.18” E) is part of the Grimaldi sites in the Balzi Rossi, one of the most important Palaeolithic site complexes in Europe, with over 15 caves, rockshelters and open-air sites found in close proximity. It is a broad dolomitic limestone cavity between the caves of Caviglione and Florestano and one of the few to have been systematically investigated (Fig. 1). The site was discovered in April 1938 by A.C. Blanc and L. Cardini of the Istituto Italiano di Paleontologia Umana (IIPU). In the year of its discovery, Blanc and Cardini performed small-scale testing over three trenches (A, B, C) (Blanc, 1938) (Fig. 2a). Later, they decided to enlarge trench A, known as the “Central trench” (Fig. 2b), which they excavated systematically during three seasons (1941, 1942, 1948). In 1949, Cardini excavated the Middle and Upper Palaeolithic layers of the Central trench (Fig. 2c) using 5 or 10 cm artificial, and nearly horizontal, cuts. He also employed...
advanced recovery techniques to collect all organic and inorganic remains. The east section of the Central trench was then recorded by A. Segre (IIPU; Fig. 3) and this, along with Cardini’s notes, represent the best original documentation of the archaeological remains revealed in that year. The stratigraphic sequence, approximately 10 m deep, consisted of nine macro-units, named A to I from top to bottom (Fig. 3) (Laplace, 1977).

In 1959, Cardini returned to the site for one season to excavate the Upper Palaeolithic layers located at the west and east side of the Central trench (referred to as West and East sector, respectively; Fig. 2d). The Upper Palaeolithic units A to G were excavated, again using 5 or 10 cm artificial cuts, which – however – were labelled differently than the 1949 cuts (see Fig. 3 for a correlation). From 1959, for nearly four decades, the trenches were left open and several sediment collapses affected the West sector which was less protected by the rock cliff (Fig. 2e).

Excavations resumed in 1995, this time led by A. Bietti (University of Rome 1 and IIPU) under the direction of the Soprintendenza Archeologica della Liguria. Bietti’s project involved three main goals:

i. From 1995 to 1998, the aim was to reinvestigate the east section of the East sector in order to correlate sediments and archaeological material with those coming from Cardini’s work, as well as to preserve the stratigraphic profile visible to the public (Fig. 2f). The correlation was robust until the base of a wide and thick hearth was found in unit G, thought to be the top of semi-sterile unit H. Below this, two more hearths were also found, in the sediment that Cardini had previously assigned to unit H (Fig. 4). The first and biggest of them (hearth H) was well-structured and rich in Aurignacian implements. A number of dimensionally homogeneous limestone cobbles – together with few faunal remains and lithics – were covering the hearth (Fig. 4, hearth H, panel A); below, a restricted whitish ash area with faunal remains and lithics (Fig. 4, hearth H, panel B) was present in the centre of an oval structure made of black burnt sediment (Fig. 4, hearth H, panel C) filling a depression about 50 × 80 cms wide and few cms thick (Fig. 4, hearth H, panel D). Archaeological remains were also found. The second structure (hearth HH) was found a few cms below hearth H. No artefacts were found in the sediment separating the two combustion episodes. Hearth HH (Fig. 4, bottom left) was a very small, rounded area of black burnt sediment. No archaeological remains were present inside the burned black area of hearth HH; nevertheless, a small number of lithics, including fragments of bladelets, was found around the firing episode, in the sediment stratigraphically associated to it. These remains suggest to us that this is the first Aurignacian presence at the site. The base of hearth HH reached a sediment, no more than a few cms thick and completely sterile, which, according to Bietti’s fieldnotes, was the only recognisable point in the stratigraphy to signal the transition from Upper to Middle Palaeolithic levels (Fig. 4, hearth HH-right).

ii. The preservation of the stratigraphic profile for scientific reasons and public access was very important. Unfortunately,
Despite successive attempts to consolidate the standing profile through the application of polymers (Primal), the new section periodically collapsed. A major collapse was caused by severe storms at the end of 2000. The Aurignacian units F and G suffered heavier damage forcing Bietti’s team to restore the entire profile pushing it back into the remaining deposit. Following this, a roof was built to protect the East sector and since then, no other major natural damage has affected the site.

iii. From 1998 to 2005, the unexcavated Mousterian layers of the East sector which, in the meantime, were covered by section-collapsed sediment (Bietti et al., 2001) were investigated. The excavation focused on unit H and the top of the unit I in the East sector. It was performed on a 1 m$^2$ grid (Fig. 2), 5 cm artificial cuts, and water-sieving through fine mesh was performed for all removed sediment. Bietti’s health problems limited his presence in the field, until his death in 2006.

Since 2007, the Soprintendenza per i Beni Archeologici della Liguria, in collaboration with one of us (S.G.), initiated a new research project which is ongoing. The current project aims to study Cardini’s and Bietti’s Upper Palaeolithic assemblages and to correlate the separate stratigraphies through a multidisciplinary approach. This includes detailed study of previous excavations’ fieldnotes; sedimentological observations on freshly cleaned sections; study of the Palaeolithic remains; and the production of reliable chronology through renewed radiocarbon dating.

The excavated area is now cleaned and the debris of old excavations and profile collapses have been removed. The field activity has concentrated on refreshing two 1 m-wide areas of the south section, both in the East and in West sectors; this has provided new important information on the stratigraphic and cultural sequence of the site (Grimaldi et al., unpublished data).

**Stratigraphy, lithic assemblages and malacological remains**

**Stratigraphy and sedimentary processes**

Our present knowledge of the sequence of Riparo Mochi is the result of several decades of excavations, carried out by different archaeologists and their teams, each applying their own excavation and documentation techniques. Although the geological aspects of the various exposed profiles were well described, mostly in terms of colour and texture, and very good drawings were also produced, information on the three-dimensional architecture of the lithologic units and the shape of their boundaries was not well explored. In addition, the correlation between lithologic units and artificial cuts is often unclear. In fact, the thickness, depth, and numbering of the artificial cuts varied depending on the excavator.

Most of the cuts are represented by evenly spaced ticks along the profile, but with little correspondence to the lithologic units. The general stratigraphic framework is further complicated, because cuts and lithologic units were grouped into macro-units (A, B, C, etc.) that correspond in fact to groups of different lithologic units, but whose chronostratigraphic position and limits were mainly inferred *a posteriori* upon the characteristics of the embedded cultural remains.

These macro-units are summarised in Table 1, from the reports of Laplace (1977) and Palma di Cesnola (1993) after Cardini’s 1949...
Figure 4. Hearth H (top left, A-D) and hearth HH (bottom left) and their stratigraphical position on the east profile of the East sector of Riparo Mochi. See text for details. Photo: S. Grimaldi.

Table 1
Lithologic description of macro-units A–I and their correlation to the artificial cuts of Cardini’s 1959 excavation of the East sector. The macro-units are tentatively correlated to the alpine glacial divisions and the Greenland oxygen isotope record. See the text for details.

<table>
<thead>
<tr>
<th>Unit</th>
<th>East sector artificial cuts (Cardini, 1959)</th>
<th>Description and traditional assignment of units to the alpine glacial system</th>
<th>Oxygen isotope stages (OIS) and Greenland Interstadials (GI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>N/A</td>
<td>About 60 cm of breccia with frost shattered products in yellowish sandy matrix. No longer visible in the stratigraphic profile. First cold phase of the Late Glacial and the Older Dryas. Würm IV.</td>
<td>OIS 2, ~GI 1d</td>
</tr>
<tr>
<td>B</td>
<td>N/A</td>
<td>About 60 cm of colluvia. Almost completely removed by previous excavations. Fresh and wet phase marking the beginning of the cyclothem. Würm III/IV.</td>
<td>OIS 2</td>
</tr>
<tr>
<td>C</td>
<td>1–11</td>
<td>About 55 cm of frost shattered breccia, with yellowish sandy matrix. A red soil developed during the interstadian marks its upper part. Only slightly observable on the East profile. Transgressive oscillations corresponding to the end of the Würm III.</td>
<td>OIS 2/OIS 3, GI 4 or GI 3 onwards</td>
</tr>
<tr>
<td>D</td>
<td>12–31</td>
<td>About 1.65 m of frost shattered breccia, with yellowish sandy matrix. Climatic minimum of the second part of Würm III.</td>
<td>OIS 3, possibly equivalent to Heinrich Event 3</td>
</tr>
<tr>
<td>E</td>
<td>32</td>
<td>About 20 cm of relatively scarce frost shattered breccia, with yellowish sandy matrix. A less cold oscillation within Würm III.</td>
<td>OIS 3, Greenland Stadial 5</td>
</tr>
<tr>
<td>F</td>
<td>33–49</td>
<td>About 1 m of frost shattered breccia, with yellowish sandy matrix. Climatic minimum of the first part of Würm III.</td>
<td>OIS 3, GI 8-5</td>
</tr>
<tr>
<td>G</td>
<td>50–63</td>
<td>About 50 cm of frost shattered breccia, with yellowish sandy matrix. Progressive oscillations of the first part of Würm III.</td>
<td>OIS 3, GI 11-9</td>
</tr>
<tr>
<td>H</td>
<td>N/A</td>
<td>About 60 cm of blocks and frost shattered breccia, with yellowish sandy matrix. Some concretions are present, and can be referred to the progressive oscillations. Fresh and wet phase marking the beginning of Würm III.</td>
<td>OIS 3</td>
</tr>
<tr>
<td>I</td>
<td>N/A</td>
<td>About 4.30 m of angular breccia and yellowish sandy clay matrix. Würm II.</td>
<td>OIS 3</td>
</tr>
</tbody>
</table>
excavation log of the Central trench. These descriptions are not fully representative of the currently visible sequence and most of the chronostratigraphic terms are no longer in use and are now devoid of meaning.

Recently, new geoarchaeological observations were carried out on all available profiles by one of us (G.B.). This included the re-assessment and description of the entire sequence, as well as textural and soil micromorphology analysis – the latter still in progress. Preliminary data are reported here, limited to the upper 5.5 m of the sequence (i.e. the old C–H macro-units), and mainly inferred from the characteristics of the eastern profile, where lithology and texture are rather homogenous. Other more complex profiles are still under study. Three basic unit types – or facies – are found; each old macro-unit may include one or more of these, interfingered in more or less complex sequences:

Facies 1 Thick layers (up to 60–70 cm) mainly composed of limestone rubble, mostly made up of frost slabs and irregular polyhedra ranging between fine and medium gravel-size; sorting is moderate to poor. The matrix is made up of light brown to light reddish silt loam or silty loam, with more or less developed medium to coarse granular aggregation; it is usually not very abundant and its quantity varies, so that the structure ranges from well-packed openwork to supported skeleton, sometimes with all the inter-skeleton spaces filled up with matrix. Small fragments of amorphous organic matter, sometimes preserving traces of the cellular structure of vegetal tissue and sometimes completely degraded, are common in some of these units. Ash occurs sparsely, while large proportions of the carbonate material is recrystallised.

Facies 2 Finer units are interlayered within the gravely ones. They are usually much thinner (up to 25–30 cm), and are made up of reddish silty clay loam, with minor quantities of limestone skeleton; in these cases, the structure can be matrix-supported; the aggregation is usually well developed, fine to medium granular. Pedodermics deriving from the breaking down and reworking of well developed soils from outside the shelter (alfsols?) can be frequently observed at the microscopic scale. Microscopic evidence of pooling or puddling is provided by small fragments of silty/clayey fining-upwards layers, a few millimetres thick.

Facies 3 “Hearts” are interbedded between these units. They were first observed during Cardin’s excavations and were better documented by Bietti who also made some casts of the uncovered hearths. Presently, they are not very evident within the exposed profiles, where they appear just as lenses that can be detected mostly because of their colour. They can be lighter or even whitish when carbonates deriving from the alteration of ash are common, or greyish-blackish if soot or charcoal is relatively abundant; a patchy mix of these characteristics is also common. These lenses are rather thick, up to 20–25 cm, and include large quantities of the basic components also occurring in the other facies, i.e., limestone rubble and silty clay matrix. At microscopic scale, the ash cannot be observed because large parts of the fine carbonates have recrystallised into micritic coatings and nodules. Only some charcoal and soot indicate that these layers are combustion features. No traces of internal organisation can be observed on the profile within these facies. It must be pointed out that all these characteristics are not enough to show with confidence whether these are real in situ combustion features or just ash dumps. Only the (poorly) organised structure of these features – if observed in its full three-dimensional aspect – may demonstrate that they are actual hearths.

Considering the aforementioned characteristics, the units belonging to facies 2 can easily be identified within the sequence due to the distinctive lithologic contrast with the other two. Those belonging to facies 3 can also be distinguished reasonably well, based upon their darker and/or lighter matrix. Conversely, it may be somewhat tricky to identify secondary facies or simply changes within facies 1. These can be differentiated mostly upon their coarse/fine (>2 mm/≤2 mm) ratio and on the shape and grain-size distribution of the gravel-grade fraction. The boundaries, however, are not always sharp and the textural change may be gradual. As a consequence, the resulting sequence appears rather monotonous: it consists of relatively thin beds and lenses of facies 2 and 3, interlayered within thick and rather homogeneous layers of facies 1. Lateral variations in texture and colour are rather common, and the extension of the units is highly variable. Not surprisingly, these aspects caused certain difficulties in the correlation of units observed in parallel (and rather close) profiles exposed during different excavations.

With regards to the architecture of the shelter’s infilling sequence, the units are usually layer-like and tabular, or lens-shaped and concave-upwards. They are reasonably parallel and with minor undulations or local disturbances. The layers dip gently from west to east and towards the interior of the shelter as well. The general setting of the lithologic units suggests that the current eastern profile is located in a depressed locus of the ancient topography, where the sedimentary processes affecting the shape of the units were somewhat different from those acting in other areas. Several hints suggest that some sort of ponding or puddling may have occurred in this part of the shelter, so that the facies 2 units are somewhat thicker here than elsewhere in the shelter, and pinch towards the exterior part. Also the coarser sediments may have accumulated here at a higher rate, building up a more complex sequence.

The cultural sequence

The cultural sequence of Riparo Mochi was defined mainly after Cardini’s 1949 and 1959 excavations (Blanc, 1953; Blanc et al., 1957–1961; Laplace, 1977). During fieldwork, Cardini and Laplace studied and classified the lithic assemblages on typological grounds. Based on their observations, as well as those of other scholars who studied the collection through time (Kuhn and Stiner, 1992; 1998; Palma di Cesnola, 1993; Kuhn and Bietti, 2000), the cultural sequence may be summed up as follows:

Unit A Proto-Mesolithic (Laplace, 1977) or Epigravettian with geometrics (Palma di Cesnola, 1993). This unit sealed the deposit and was completely removed in the first years of excavation, providing a considerable amount of lithics.

Unit B Almost sterile and completely excavated in the first years of excavation.

Unit C Final Gravettian without Noailles burins. Some authors attributed it to the Early Epigravettian (Palma di Cesnola, 1993). This is one of the richest assemblages of the sequence when the thickness of layers is taken into account. The tools are generally of large dimensions and mainly characterised by burins and endscrapers. Burins of the Noailles type are absent, and the most common types are on truncation, on retouch and simple burins. The endscrapers are shorter than those found in earlier unit D. Backed points, very common in unit D, are rare here. Most of the assemblage is typologically characterised by the presence of non-diagnostic tool morphologies, such as sidescrapers and denticulates, which are very common throughout the cultural sequence.

Unit D Formerly attributed to the Upper Perigordian (Laplace, 1977), it is currently defined as Gravettian with Noailles burins. The lithic assemblage is typologically characterised by Noailles burins, endscrapers on blades as well as on flakes, retouched blades, backed, pointed and truncated bladelets. Some rare microlithic
“cran” points and microburins are also present. Recent studies on the provenance of lithic raw material suggest that among retouched implements, exogenous raw materials prevail. They come from France (western and eastern Provence) between 40 and 200 km away, as well as from Central Italy, up to 150–200 km distant (Kuhn and Bietti, 2000; Bietti et al., 2004). However, the lithic assemblage from the base of unit D (cut 31) is different from the general typological features described for unit D. There, Noailles burins are almost absent, endscrapers are very rare and most of the retouched assemblage is characterised by backed points and backed tools on blades. The substratum is not relevant. Some authors define this basal part of D as “Undifferentiated Gravettian with backed tools” (Palma di Cesnola, 1993).

Unit E Almost sterile but with a hearth and few archaeological remains recovered in 1959.

Unit F Typical Aurignacian assemblage, previously called “Middle Aurignacian” (Laplace, 1977). No real discontinuities have been observed between F and the earlier unit G, neither in the typological features of the lithic assemblage nor in the provenance of the raw material. Some differences include the increased number of crenated or nosed endscrapers. Dufour bladelets are still present but are rare and only in the lowest part of the unit. Interestingly, most of the retouched tools are made from flakes.

Unit G This assemblage has been defined in the past as “Lower Perigordian” (Blanc, 1953), “Protoaurignacian” (Laplace, 1977) or “Aurignacian 0”, and as “Early Aurignacian with Dufour bladelets” (Bietti et al., 2004). The unit has yielded an exceptionally rich early Upper Palaeolithic industry which is of the utmost importance in discussions concerning the arrival of Aurignacian modern humans in the Balzi Rossi region, as well as in the rest of Mediterranean Europe (Kuhn and Stiner, 1998; Alhaique et al., 2000). From a typological standpoint, unit G is divided into two lithic assemblages. The most recent corresponds to artificial cuts 50–57, while the oldest to artificial cuts 58–63, as these were defined in Cardini’s 1959 sequence on the East sector. In general, the lithic assemblage from G is characterised by the abundance of burins, endscrapers, as well as blade and bladelet production – including the typical Dufour type – associated with the presence of prismatic cores. The younger group is characterised by the appearance of flat-nosed endscrapers, and by a decrease in the numbers of retouched bladelets, including the Dufour type. When compared to unit F, non-diagnostic tool morphologies are very abundant here, including the remarkable presence of denticulates. Raw materials are highly variable, both in terms of type and provenance, throughout this unit. Several types of flint, jasper and quartzite are present in large numbers. French flint, such as the “Béduaillienne” and the “Oligocéne”, comes from Provence, from distances that vary from 40 to more than 200 km; the same applies to the Italian raw materials (jasper, “Biancone” flint and “Scaglia” flint) from the Apennines. Several raw materials, for instance quartzite, are circum-local in the general Liguria region while others are strictly local, for example the bad quality quartzite, are circum-local in the general Liguria region. The raw material provenance analyses of lithic artefacts are still ongoing, or Rome (conventional) laboratories.

Table 2 Relative abundances (%) of ornamental, food and accidental marine molluscs in Riparo Mochi (modified after Stiner, 1999).

<table>
<thead>
<tr>
<th>Period</th>
<th>Unit</th>
<th>Total MNI</th>
<th>% Ornamentals</th>
<th>% Food</th>
<th>% Accidental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late Epigravettian</td>
<td>A</td>
<td>1857</td>
<td>51</td>
<td>43</td>
<td>6</td>
</tr>
<tr>
<td>Early Epigravettian</td>
<td>C</td>
<td>368</td>
<td>49</td>
<td>44</td>
<td>7</td>
</tr>
<tr>
<td>Gravettian</td>
<td>D</td>
<td>2446</td>
<td>27</td>
<td>6</td>
<td>67</td>
</tr>
<tr>
<td>Early Aurignacian</td>
<td>F</td>
<td>526</td>
<td>37</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>Protoaurignacian</td>
<td>G</td>
<td>1125</td>
<td>52</td>
<td>45</td>
<td>3</td>
</tr>
</tbody>
</table>

Unit I About 4 m thick with several Mousterian levels. The study of the lithic assemblage is currently ongoing.

Mollusc remains

Riparo Mochi has yielded a rich faunal assemblage. Studies of the vertebrate remains were published by Alhaique (2000), Arellano (2009) and, very recently, by Tagliacozzo et al. (2011); the latter being the most detailed of all but only dealing with Gravettian unit D. Here, we briefly review the invertebrate (molluscan) remains since most of the new radiocarbon dates were produced on marine shell material.

The old excavations (1949 and 1959) in Mochi yielded about 6000 marine shell specimens. Stiner (1999) published a comprehensive account of the malacological collection, and classified it into four groups: ornamental, food refuse, accidental by-product of sponge collection and terrestrial snails co-inhabiting the site. These numbers are shown in Table 2, with the exception of the landsnails.

More than 40 marine taxa were identified in the collection, revealing a predominance of gastropods compared to bivalve shells. Cyclope nerita shells dominate the ornament assemblage followed by Homalopoma sanguineum (16%), Mitra cornicula (5%), Clanculus corallinus (5%), Dentalium sp. (4%), and Nassarius incrassatus (3%). It appears that human preference was for distinct forms, sizes and colouration and this changed remarkably little between the earliest Aurignacian and Epigravettian (Stiner, 1999).

Chronological framework: methods, materials and radiocarbon dates

Previous chronology

Prior to this work, seven radiocarbon dates were available for the Aurignacian units G and F (Table 2). Originally, in 1992, five charcoal samples, collected during the excavations of Cardini in 1959, were submitted by P. Mellars and S. Kuhn to the Oxford Radiocarbon Accelerator Unit (ORAU) (Hedges et al., 1994). They all derive from unit G (cuts 60 to 50) and ranged from ~35 to 32 ka BP. The remaining two charcoals were dated conventionally by beta counting at the now-defunct Radiocarbon Laboratory of the

Unit H Very few lithic remains have been found in this unit; Cardini considered this assemblage a mixture of both Mousterian and Aurignacian implements.

Table 3 Previously available radiocarbon dates for Riparo Mochi. All were produced on charcoal treated with the ABA (Acid-Based-Acid) protocol, either in the Oxford (AMS) or Rome (conventional) laboratories.

<table>
<thead>
<tr>
<th>Lab code</th>
<th>14C</th>
<th>±</th>
<th>Level - cut</th>
<th>Material</th>
<th>Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rome-1</td>
<td>27230</td>
<td>570</td>
<td>Top (hearth)</td>
<td>Charcoal ABA</td>
<td>Bietti et al., 2004</td>
</tr>
<tr>
<td>OxA-3588</td>
<td>12280</td>
<td>580</td>
<td>G 50</td>
<td>Charcoal ABA</td>
<td>Hedges et al., 1994</td>
</tr>
<tr>
<td>OxA-3589</td>
<td>33400</td>
<td>750</td>
<td>G 51</td>
<td>Charcoal ABA</td>
<td>Hedges et al., 1994</td>
</tr>
<tr>
<td>OxA-3590</td>
<td>34680</td>
<td>760</td>
<td>G 56-57</td>
<td>Charcoal ABA</td>
<td>Hedges et al., 1994</td>
</tr>
<tr>
<td>OxA-3591</td>
<td>35700</td>
<td>850</td>
<td>G 59</td>
<td>Charcoal ABA</td>
<td>Hedges et al., 1994</td>
</tr>
<tr>
<td>OxA-3592</td>
<td>34870</td>
<td>800</td>
<td>G 60</td>
<td>Charcoal ABA</td>
<td>Hedges et al., 1994</td>
</tr>
<tr>
<td>Rome-2</td>
<td>37400</td>
<td>1300</td>
<td>Base (hearth)</td>
<td>Charcoal ABA</td>
<td>Bietti et al., 2004</td>
</tr>
</tbody>
</table>
Department of Physics of Rome University (the exact lab-codes for these two determinations were never published, therefore here we call them conventionally “Rome–1” and “Rome–2”). These charcoal samples come from two distinct hearths discovered at the base of unit G in 1999 (~27 ka BP) and at the top of unit F in 1995 (~27 ka BP), respectively. The latter was sampled when the standing section collapsed after the big storm in 2000. The excavator advised caution for this date because contamination of the dated sample with material from overlying units E and D could not be excluded (Bietti et al., 2004).

All samples were pretreated using the Acid–Base–Acid (ABA) protocol which comprises the chemical cleaning of the charcoal using successive steps of HCl, NaOH and HCl, interspersed by water rinses. ABA is the routine method most radiocarbon laboratories employ to clean charred organic matter but has been shown often to be inadequate in the dating of Palaeolithic samples older than ~30 ka BP (Higham et al., 2009; Douka et al., 2010a; Higham, 2011). Therefore, the first step of the dating programme was to check the reliability of these previous charcoal determinations.

**New radiocarbon dates**

Charcoal sample Remaining material from one of the charcoal samples previously dated in Oxford (OxA-3592: 34870 ± 800 BP; cut G 60) was located in the store of the ORAU. About ~150 mg of this material was subjected to the more rigorous ABOx-SC pretreatment. This refined protocol developed by Bird et al. (1999) specifically targets older samples and involves an acid-base treatment (AB), an additional oxidation step with potassium dichromate in sulphuric acid (Ox) followed by stepped combustion (SC). The method employed in the ORAU has been described by Brock et al. (2010).

The new ABOx-SC determination (OxA-19569: 36350 ± 260 BP) (Table 4) is more precise compared to the previous ABA date, but is statistically identical to it. It adds, therefore, further confidence to the rest of the younger but internally consistent determinations from units G and F, also suggesting that the real age of these ABA-treated charcoals perhaps falls at the earliest part of their probability distribution.

Marine shell samples The malacological collection was examined at the storage facilities in the Balzi Rossi. Fifty-three shells were initially selected, of which 14 were dated (Table 4, Fig. 5). These included six C. neritea, three H. sanguineum and two Mytilus cf. galloproviciancis shells, as well as single examples of Nassarius gibbosulus, Cerastoderma glaucum and Trochus sp.

The majority of the dated samples bear traces of human modification; they were mainly transformed into beads by a single perforation or were intentionally fractured by a single blow (Fig. 5). The Cycllope sp. (Mochi-15, 18, 25, 31, 46 and 47), the N. gibbosulus (Mochi-43) and two of the H. sanguineum (Mochi–40 and 42) shells are perforated along the last spiral whorls (E1–2 position of Taborin’s system; Taborin, 1993), while the remaining H. sanguineum (Mochi-35) shell was brought to the site but was never perforated. Mochi-32 and 39, two mussel shells, bear traces of intentional fracturing across their broken edge. Mochi–49 and Mochi-51 (C. glaucum and Trochus sp., respectively) are also fragmented but, in their case, human interference is more difficult to establish.

With the exception of Mochi–42, all samples underwent X-Ray Diffraction (XRD) analyses to determine their mineralogical composition and establish whether they had been affected by diagenetic alteration (precipitation of secondary calcite). XRD samples were prepared using the methods of Chiu et al. (2005) and Douka et al. (2010b) and powder XRD analysis was performed at the Department of Materials (University of Oxford) using the parameters described by Douka et al. (2010b). The analysed shells were found to consist largely of aragonite (the autochthonous shell mineral for the examined species) at an abundance of 100–99.5%, with only minimal traces of calcite detected in some of them (Table 4).

Following XRD analyses, each sample was dated according to the ORAU routine protocol for unaltered shell carbonates (Brock et al., 2010; Douka et al., 2010b). Briefly, 25–50 mg of carbonate powder was reacted with 80% phosphoric acid (H3PO4). The CO2 gas evolved via this process was cryogenically-purified while passing through a liquid N2/methanol-cooled trap to remove less volatile impurities (H2O and phosphoric acid vapour) and was transferred into a glass ampoule in vacuo. The ampoule was then transferred to a purpose built sample collection system interfaced with an EA-CF-IRMS. The CO2 was released into the system, further purified using liquid N2 and Ag and Cu cleanup traps, and was injected into the mass spectrometer. The relative abundance of aragonite/calcite as defined by XRD analyses, a way to identify possible recrystallisation affecting the shell samples, is given in the last column.

Table 4

<table>
<thead>
<tr>
<th>Excavations Cardini 1959</th>
<th>Species</th>
<th>14C date (e)</th>
<th>%</th>
<th>Calibrated ages (95.4%) from to</th>
<th>Aragonite – calcite %</th>
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<tr>
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<td>D 29</td>
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<td>24600</td>
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<td>G 60</td>
<td>19569</td>
<td>36350</td>
<td>260</td>
<td>Charcoal</td>
</tr>
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</table>

Table 4 (ABOx-SC date of OxA-3592; Table 3)

<table>
<thead>
<tr>
<th>Excavations Bietti 1997–2003</th>
<th>Species</th>
<th>14C date (e)</th>
<th>%</th>
<th>Calibrated ages (95.4%) from to</th>
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<td>H 2</td>
<td>19729</td>
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<td>I 3</td>
<td>19289</td>
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<td>150</td>
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<tr>
<td>Mochi 51 (2003)</td>
<td>I 5</td>
<td>19730</td>
<td>34030</td>
<td>200</td>
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<td>I 5</td>
<td>20000</td>
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<td>270</td>
</tr>
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</table>
CF-IRMS system. After measurement, the remaining CO$_2$ was transferred into a graphitisation rig where it was converted into graphite through H$_2$ reduction at 560 °C for 6 h, in the presence of 2–2.5 mg of a Fe$^{3+}$ catalyst. The graphite was pressed into an aluminium target holder prior to $^{14}$C measurement in an HVEE 2.5 MV tandem accelerator (accelerator mass spectrometer). The same procedure was followed for international reference material of geological age (IAEA C1: Carrara Marble) which was analysed alongside the unknown archaeological samples as a way of monitoring and quantifying the introduction of modern contamination during sample pretreatment. Measurements for carbonate background material in the ORAU are consistently greater than 42 ka BP (<0.0053 F$^{14}$C) and average around 53–51 ka BP. Overall, fifteen new radiocarbon dates were produced (one sample, Mochi 51, was dated twice).

The new radiocarbon determinations are shown in Table 4 along with the calibrated ranges obtained using the IntCal09 curve (for the charcoal samples) and the IntCal-Marine09 curve (for the marine shells) (Reimer et al., 2009). A constant marine reservoir of 400 14C years was assumed for the shell determinations which were additionally corrected for the local Mediterranean reservoir ($\Delta R = 58 \pm 85$ 14C years; Reimer and McCormac, 2002). The IntCal-Marine09 curve is preliminary and may slightly change. While the exact variation of both local and global marine reservoirs in the Late Pleistocene are still largely unknown, we believe that in the timeframe of this paper, variations were not much greater than the ones we have corrected for. Preliminary results from experiments with Pleistocene-age marine carbonates closely associated with known-age chronostratigraphic markers (e.g. tephra horizons) showed values very comparable to those we observe today. More data, however, are required and such work is currently being undertaken in Oxford.

**Discussion of the new radiocarbon dates, calibration and Bayesian modelling**

The new radiocarbon dates from Riparo Mochi untangle the chronostratigraphic succession of the early and mid-Upper Palaeolithic levels and, to a lesser extent, that of the late Mousterian at the site. The discussion of the new data is predicated upon a careful consideration of the different excavation periods, which is crucial for proper interpretations.

The majority of radiocarbon determinations were produced on samples coming from the Upper Palaeolithic units of Cardini’s 1959 excavations, at the eastern part of the site. The oldest shell, a perforated *N. gibbosulus* dated at 36750 ± 250 BP (OxA-19290), comes from unit G, cut 57, an area with high artifact density. After correction for marine reservoir and calibration, OxA-19290 is identical ($T = 1.69, \chi^2_5; 0.05 = 9.49$) to the four charcoal determinations from closely related cuts (OxA-3590/G 56-57, OxA-3591/G 59, OxA-3592/G 60; see Table 4). As mentioned previously, however, the charcoal ABA dates (OxA-3590–92) have large standard errors when compared to the more precise ABOx determination, therefore the earliest cuts of G, cuts 60–57/56, must
The rest of the dates follow a consistent decrease in age as we move up the stratigraphy. Only OxA-19802 (30770 ± 150 BP) appears slightly young for its context (G 51) but it should be noted that the small size of this shell meant that thorough cleaning of its surfaces was not possible. This date must therefore be considered with some caution and as a minimum age. In addition, closely associated samples (OxA-3589 and OxA-20360 from G 51 and OxA-3588 from G 50) are all statistically identical at around 33–32 ka BP. This younger cluster corresponds to the most recent lithic assemblage of G and agrees both with stratigraphic as well as techno-typological observations of the lithic remains. For the lower part of F, cuts 49–44, a group of dates (OxA-206629, OxA-19614) at around 32 ka BP is identified. These dates are identical to those obtained from the mid and upper parts of G, cuts 54–50. Given that the transition from G to F was not always clear, it is possible that what we see at the uppermost cuts of G and lowermost cuts of F is part of the same evolved Aurignacian phase. The upper part of unit F, cuts 40–34, is much younger and dates to between 27 and 26 ka BP. Interestingly, the shell dates from this younger cluster (OxA-19857, OxA-19728) match the charcoal determination produced in Rome from the same context (top of F) at 27 ka BP. Based on the traditional assignation of units to specific technocomplexes, this younger cluster of dates at the top of F would mark the end of the classic Aurignacian at the site. However, careful reading of Cardini’s excavation diaries from 1949 (Central trench) and 1959 (East sector) reveals that the upper part of unit F was almost sterile. In 1949, unit F was overall very poor in lithic artefacts and provided rare culturally diagnostic elements. In 1959, due to the steeper angle of the deposits, Cardini decided to excavate unit F in 5 cm and not in 10 cm cuts as usual; he found cuts F 39–41 to be almost sterile and the few, mostly undiagnostic, implements were discovered close to the rockshelter wall. It seems, therefore, that between cuts F 42–41 and D 28, several episodes of very short and/or limited occupation episodes took place, bracketed by very short and/or periodical events of abandonment of the site. It is very possible that material from the richer, overlying unit D was infiltrated down and incorporated into the much poorer, upper cuts of unit F. This is most likely to have happened in the proximity of the rockshelter wall. Furthermore, overlying unit E was neither homogenous nor easy to discern during excavation, and the boundary between F and E was often arbitrary. It is very likely, therefore, that the middle and upper cuts of F do not relate to a truly late Aurignacian persistence, as is often assumed, but rather to a low-frequency/low-intensity intermittent early Gravettian occupation of the site. Ongoing studies of the lithic assemblage from units F and D will shed further light on the issue.

A shell sample (Mochi-18) was found at a hearth in semi-sterile unit E, dug possibly by the Gravettian occupants of the site, also responsible for the formation of overlying unit D. OxA-19801 from E 32 and OxA-19800 from D 29, therefore, securely date the Gravettian at Riparo Mochi, at ~25 ka BP, whether or not this is the first appearance of the technocomplex at the site.

Three shells found during Bietti’s excavations between 1997 and 2003 were also dated. They were recovered from areas of the site thought to represent late Mousterian (unit I) and early UP horizons (heaths H and HH), respectively. However, the four dates we obtained (one specimen was dated twice) reveal that this is very unlikely, at least for two of the specimens. The dates range from 36 to 26 ka BP and are in ‘sequence’, meaning that the ones thought to come from lower Mousterian excavation of unit I (spit 5) are the oldest (~36 ka BP) and the ones from H and HH the youngest (26–24.5 ka BP). However, these shells were discovered during sieving and were not identified or plotted in situ. Investigations on the exact provenance of these young samples from hearth H and spit 3 of unit I, suggest that they have been collected from areas characterised by the presence of disturbed sediment from the collapsed East section. Further to this, it became clear that at the time of the excavation or in the following years, the sieved material from the excavation of hearth HH in 1997 — at a square originally covered by Cardini’s East section which had then collapsed — was mixed with the scanty remains from the disturbed sediment of layer H. It is, therefore, almost certain that the material we dated from the 1997–1999 excavations was in secondary position.

On the other hand, the fragment of Trochus sp. from unit I, spit 5 was recovered in 2003 when the disturbed deposit from the section collapse was fully identified and removed. This sample appears to be truly associated with Mousterian remains deposited during one of the latest Neanderthal visits at the site. It was dated twice (OxA-19730 and OxA-20000) due to suspicion of a technical problem at the lab with the charcoal determination. This specimen was considered reliable. In 2000 from Bietti’s Mousterian unit I, cut 5, was included in the sequence as a terminus post quem, to mark the end of the Mousterian and constrain the start of the Upper Palaeolithic at the site. In this plot, the boundary separating the two phases (transition from

...
unit I to H and G) becomes younger by about 300–400 calendar years (Fig. 7). The sensitivity of this lower part of the model suggests that more data are required to assess the age of the late Mousterian at the site.

Based on the available radiocarbon dates and the modelling results, the Mousterian ends in unit I between 44 and 41.8 ka cal BP (68.2% prob.). The arrival of the Upper Palaeolithic at the site seems to be represented by the hearths labelled as H and HH. However, since no reliable dates are available from these contexts yet, the antiquity of this phase is not directly dated at the moment. The earliest Aurignacian from unit G was dated at ∼37 ka BP or 42.7–41.6 ka cal BP (68.2%). The transition from G to F occurs at ∼32 ka BP or 37.3–36.4 ka cal BP (68.2%) which also dates approximately the split-based point found broken in two pieces, one piece retrieved from cut F 49 and the second from cut G 50. The Gravettian at the site started at 26 ka BP or 30.5–30.2 ka cal BP (68.2%), and possibly earlier (see discussion above on whether the phase starts in the upper part of unit F or in unit D).

Correlation of the sequence with palaeoclimatic records

We attempt below to compare the depositional sequence at Mochi with independent climate proxies from elsewhere to allow us to place the site into a wider palaeoenvironmental context.

Figure 6. Bayesian plot showing, calibrated and modelled, all radiocarbon dates relating to Cardini’s 1959 excavation. Both the old series of ABA dates on charcoal, in light blue, (Table 3) as well as the new determinations on shells and one ABOx-treated charcoal, in grey, (Table 4) are included in the model. The sequence is compared to the Hulu chronology-tuned NGRIP δ¹⁸O record (Svensson et al., 2006; Weninger and Jöris, 2008) and the relevant Greenland Interstadials are numbered, as are the two Heinrich Events (HE3 and HE4). The only dates with higher probability of being outliers are marked with an asterisk. In spite of this, two of them (OxA-19290 and OxA-20629) fit well with the rest of the determinations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
may undermine the results of this exercise. From Cardini's geoarchaeological observations are carried out on the present architecture and succession of the lithologic units. Given that all modern orientations prevailing in the peculiar Balzi Rossi catchment. The texture of the units. In a strictly Alpine perspective, the whole Riparo Mochi sequence is characterised by indicators of moderately cold conditions, i.e. by accumulation of frost slabs, which is in accordance with the general situation of MIS3; conversely, evidence of colder events should be represented by coarser grain-size horizons. Large blocks are included in unit G. Even if these cannot be seen in the East profile, where only slightly larger clasts occur, they are evident in the South profile situated closer to the exterior of the rockshelter, where block-fall is more likely. This ceiling breakdown is the only event really resembling a typical Alpine glacial context throughout the profile and may be correlated with Heinrich Event (HE) 4. This event also corresponds to a short gap in the radiocarbon sequence, which may indicate a phase of site abandonment. There are no other clearly defined climate oscillations within unit G, apart perhaps from the thin facies 2 layer that overlies the basal hearth, and which may be connected to a colluvium of a “terra rossa” (alfisol) that had developed during a previous interstadial event.

Some blocks also occur elsewhere in the profile, for example, at the level of a thick “hearth” layer (facies 3) situated slightly below the middle part of unit D. This may correlate to another Heinrich Event (HE3) occurring around 29 ka cal BP. The occurrence of large blocks in the South profile, however, cannot be verified as for unit G. The fauna of D, also agrees with this assessment of colder and drier conditions and prevalence of Alpine prairies in the middle parts of D (Tagliacozzo et al., 2011), which at its terminal part indicates more humid conditions. We should note here that the duration of unit D cannot be ascertained since the only radiocarbon determination from this unit comes from the lower cuts (D 29). In Fig. 8, therefore, the boundary between D/C and its approximate correlation to the beginning of Greenland Interstadial (GI) 4, may only be a minimum age. More direct dates for the upper part of the unit will elucidate aspects of its formation, such as temporal span and the deposition rates.

In unit E, secondary effects of deep frost are recorded, especially where the facies 2 layer is disrupted and the underlying gravel appears reworked as by slow downslope lobe movements (Bertran et al., 2008). The macroscopic observations fit well with the oxygen isotope record, which suggests prolonged lower temperatures for the associated period (between GIS and GI4). It appears, then, very likely that unit E corresponds to the return to cold stadial conditions during Greenland Stadial 5, immediately following GIS, and is largely contemporaneous with the onset of HE3.

Unit F, on the other hand, does not contain sufficient elements to distinguish traces of D/O cycles in it. While deposition rates for the unit appear to be comparable to that of G, there is no stratigraphic indication for the gap in the radiocarbon dates from F.

Finally, we should point out that the Balzi Rossi catchment may have attenuated the effects of glacial maxima, driving the area towards a more “southern” environment. In this case, the glacial
maxima would have probably been characterised by a diffused instability in the morphogenetic régime, with production of colluvia, debris flow, and occasionally of alluvial deposits (Cottignoli et al., 2002), while strong breakdown of the rockshelter walls would be less frequent.

**Chronological comparison of Mochi with other sequences**

How do the new dates from Riparo Mochi compare with data from other Upper Palaeolithic sequences in Italy and elsewhere? The Protoaurignacian is considered intrusive in Italy. Some prehistorians have suggested that the Protoaurignacian in Liguria originated in southeast France, while that in the Veneto region came from central Europe (Palma di Cesnola, 1993; Milliken, 2007). For others, the Italian Protoaurignacian is thought to have derived from the Balkans and Lower Austria, with a later spread through northern Italy to southeastern France (Broglio, 1994; 1995; Mellars, 2005).

One of the very few Italian Protoaurignacian contexts which has been directly and precisely dated using modern methodologies is layer A2 of Fumane Cave. Bone and charcoal samples from A2 date to ~35.5 ka BP and the start of this earliest Aurignacian phase is calculated to fall between 41.8 and 40.8 ka cal BP (68.2%) (Fig. 9b) (Higham et al., 2009; Higham, 2011).

Less well dated sequences are present in the southern half of the Italian peninsula. One important chronostratigraphic marker, however, the Campanian Ignimbrite (CI) tephra, is preserved there (Fedele et al., 2008). The CI eruption has been dated by De Vivo et al. (2001) at 39.3 ka BP, which is roughly equivalent to ~34.5 to 34.8 ka BP in the radiocarbon timescale. Layers capped by the in-situ volcanic ash ought to be, by definition, older than the eruption. Several southern Italian sites contain Palaeolithic cultural levels sealed by this tephra, thereby providing an independent means for dating late Middle Palaeolithic, transitional (Uluzzian) and Protoaurignacian assemblages older than it (for a description see Giaccio et al., 2006). Castelcivita Cave (Gambassini, 1997) and the Serino open-air site (Accorsi et al., 1979) contain Protoaurignacian remains securely capped by a series of volcanic debris characteristic of the CI eruption which, therefore, must predate it. The antiquity of these layers in Serino and Castelcivita is currently being investigated, but it appears that the Protoaurignacian had certainly arrived in the south of Italy by ~34.5 ka BP, and possibly slightly earlier given that in Castelcivita there is about half a meter of Aurignacian deposits identified in at least 3 distinct lithostratigraphic units (rsa’, gic, ars), just below the CI volcanic debris (Gambassini, 1997).

Based on the current evidence, layer G of Riparo Mochi, dating to around 37–36.5 ka BP, is the oldest directly-dated Aurignacian assemblage in Italy (Fig. 9b). This suggests the likelihood of a north to south spread of the Aurignacian technocomplex, but it is important to note that very few dated sites exist in the middle of the Italian peninsula and this conclusion could easily change with the addition of new data. At present further dating is required to clarify the situation.

Comparisons with dates for other Upper Palaeolithic contexts outside Italy suggest that the date of the Protoaurignacian of Mochi compares closely. In Fig. 9a the start boundaries for the earliest Aurignacian evidence at the sites of Geissenklösterle (Germany), Abri Pataud and Isturitz (France) are compared to the start
boundary for unit G in Mochi. The first two sites were dated recently in Oxford with reliable methodologies (Higham et al., 2011; Higham et al., in press) while for Isturitz only a small number of dates exist for the earliest Upper Palaeolithic (Szmidt et al., 2010). This comparison reveals that the lowestmost Aurignacian levels at Geissenklösterle (AHIII) and Isturitz (C4d) date to the same period as Mochi G, at around 42.7–41.5 ka cal BP (68.2%). The earliest Aurignacian of Abri Pataud dates slightly later to around 41–40 ka cal BP (68.2%), but the assemblage there has always been considered more evolved, so this is not surprising. No Mousterian dates are included in any of these calculations, therefore the start boundaries in the Bayesian models are not well constrained at their earliest end. What is interesting is that there appears to be a close similarity between the dates for the Protoaurignacian and Early Aurignacian sites in Germany on the Danube and on the Mediterranean coast. This might suggest a rapid dispersal of both variants of the Aurignacian across Europe at c. 44–42 ka cal BP. Recent interpretations have suggested that, based mainly on stratigraphic assessment, the Proto-Aurignacian is earlier than the Early Aurignacian. Also based on the data from Italy, the Protoaurignacian is earlier in the north than the south of the peninsula.

Finally, it is worth mentioning that the dates produced on shell beads comprise some of the earliest directly-dated personal ornaments in Europe. Shell beads have gained a particular status among Palaeolithic groups in the last few years, particularly since some earlier in the north than the south of the peninsula. Shell beads have gained a particular status among personal ornaments, which starts only with the appearance of the Aurignacian at the site. In earlier periods, the Mousterian occupants of the site collected shellfish for food and possibly for the manufacture of simple shell tools, but not a single shell bead has been recovered from these lowermost levels.

Conclusions

Riparo Mochi is one of the most important early Upper Palaeolithic sites on the Mediterranean rim. The new chronological framework is robust and suggests that the Protoaurignacian (or Aurignacian with Dufour bladelets) started at the site earlier than previously thought, between 37 and 36 ka BP. The sequence continues upwards with a more evolved Aurignacian phase dating to around 33 ka BP and a Gravettian phase starting at 26 ka BP or earlier. Given the very limited number of reliable dates from the final Mousterian levels at the site, we cannot comment with great confidence on the timing of the Middle to Upper Palaeolithic transition. However, in the absence of a transitional industry interbedded between the Mousterian and Aurignacian layers, a very late persistence of Neanderthals in the Balzi Rossi until about 37 ka BP, would be a strong conclusion to be drawn from the data. More dates from the Mousterian levels in Mochi and other sites in the Balzi Rossi are essential to elucidate the exact timing of the transition. The geological observations on the nature of the sequence, combined with the new chronology, also permit a very tentative correlation of Mochi with the Greenland ice core records.

Overall, Riparo Mochi is exceptional in that no other Mediterranean site, to our knowledge, preserves such a consistent chronological succession with two distinct Aurignacian phases, followed by Gravettian and later archaeological cultural horizons higher up. The combination of a large number of reliable radiocarbon determinations on humanly modified materials, in this case marine shell, coupled with a Bayesian statistical approach and geological field observations has provided valuable insights into the cultural and chronological evolution of the site, confirming Riparo Mochi as a reference sequence for the appearance and evolution of the Upper Palaeolithic — and, by extension, of the spread of Aurignacian modern humans — across Mediterranean Europe.

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