LETTERS

Placing late Neanderthals in a climatic context

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Attempts to place Palaeolithic finds within a precise climatic framework are complicated by both uncertainty over the radiocarbon calibration beyond about 21,500 ^{14}C years BP[1] and the absence of a master calendar chronology for climate events from reference archives such as Greenland ice cores or speleothems[2]. Here we present an alternative approach, in which ^{14}C dates of interest are mapped directly onto the palaeoclimate record of the Cariaco Basin by means of its ^{14}C series[3], circumventing calendar age model and correlation uncertainties, and placing dated events in the millennial-scale climate context of the last glacial period. This is applied to different sets of dates from levels with Mousterian artefacts, presumably produced by late Neanderthals, from Gorham's Cave in Gibraltar: first, generally accepted estimates of about 32,000 ^{14}C years BP for the uppermost Mousterian levels[4,5]; second, a possible extended Middle Palaeolithic occupation until about 28,000 ^{14}C years BP[6]; and third, more contentious evidence for persistence until about 24,000 ^{14}C years BP[6]. This study shows that the three sets translate to different scenarios on the role of climate in Neanderthal extinction. The first two correspond to intervals of general climatic instability between stadials and interstadials that characterized most of the Middle Pleniglacial and are not coeval with Heinrich Events. In contrast, if accepted, the youngest date indicates that late Neanderthals may have persisted up to the onset of a major environmental shift, which included an expansion in global ice volume and an increased latitudinal temperature gradient. More generally, our radiocarbon climatostratigraphic approach can be applied to any 'snapshot' date from discontinuous records in a variety of deposits and can become a powerful tool in evaluating the climatic signature of critical intervals in Late Pleistocene human evolution.

The Neanderthal extinction, and the possible implication of climate therein, has long been the subject of intense debate[7]. Current evidence points to southern Iberia as one of the last Neanderthal strongholds in Europe, where several Middle Palaeolithic occupation sites suggest the regional survival of Neanderthals up to about 30,000–32,000 ^{14}C yr BP[8]. Of these, Gorham's Cave, Gibraltar, has yielded both Middle and Upper Palaeolithic lithic assemblages, with the youngest dates from Mousterian layers converging on about 32,000 ^{14}C yr BP[5,6]. Recently, Finlayson *et al.*[6] provided 22 additional dates on charcoal from a newly excavated level with Mousterian artefacts deep within Gorham's Cave. Of these, the three lowermost dates (28,170 ± 240, 29,210 ± 190 and 32,560 ± 390 ^{14}C yr BP; all errors are reported at one standard deviation) were in stratigraphic order, but several age reversals occurred further up. This was attributed to repeated use (for example, trampling and cleaning) of the same location within the cave as a hearth site over several thousand years[6]. Within the presumed core of this recurrently used combustion area, three dates in stratigraphic order (24,010 ± 160, 26,400 ± 220 and 30,560 ± 360 ^{14}C yr BP) were considered to come from *in situ* superimposed hearths[6]. Although the Finlayson *et al.* results have come under scrutiny[9,10], taken at face value they suggest that Neanderthals may have survived in the area until about 28,000 and possibly until about 24,000 ^{14}C yr BP[6], thus extending the range for their last regional appearance by up to 6,000 ^{14}C yr. More recently, the youngest of these dates has been used to link[11] the final disappearance of Neanderthals from southern Iberia to the climatic conditions associated with Heinrich Event 2 (H2). In that model, the extreme conditions of H2 are proposed to have acted as a 'territory cleanser', allowing subsequent colonization by anatomically modern humans[11]. Over the years a substantial body of evidence from marine and terrestrial reference archives[12–16] and climate models[17] has demonstrated the coupling of southern Iberian environments to North Atlantic variability on millennial and orbital timescales, with the coldest and driest conditions occurring during Heinrich Events, whereas intervening Dansgaard/Oeschger Stadials (or Greenland Stadials, following the terminology of ref. 18) were less extreme. However, the complex sedimentation patterns of cave deposits means that the linking of the archaeological and climate records is not straightforward. Although animal and plant remains from the excavated levels provide some indication of the palaeoenvironmental situation around Gorham's Cave[6], they are discrete samples, representing wide time windows and not forming part of a long, highly resolved and continuous time series that could be compared and correlated with other palaeoclimate records. Moreover, the uncertainty of ^{14}C calibration[1] and differences, sometimes on the order of hundreds of years, between published timescales of reference climate archives[2] complicates the placement of the putative late Neanderthal occupation within the context of millennial-scale variability of the last glacial period. Thus, even if radiocarbon dates could be converted perfectly to calendar years, it would still be unclear where precisely they fit into the succession of rapid climate events of the last glacial period, complicating a proper evaluation of the role of climate in Neanderthal extinction.

One way around this problem is based on the observation that a well-constrained stratigraphic relationship between ^{14}C dates and climate can be established in certain reference sequences that contain a North Atlantic signal of millennial-scale variability. Ocean Drilling Program sediment cores from the Cariaco Basin, Venezuela, provide such a sequence, combining high-resolution palaeoclimate records with ^{14}C dates from planktonic foraminiferans. Previously, ^{14}C and palaeoclimate records from Cariaco ODP Site 1002 were linked to the calendar chronology of the layer-counted GISP2 Greenland ice core[19] to provide calendar age estimates of the ^{14}C timescale back to 50,000 yr BP[3]. However, linking ^{14}C dates from other sites to a Greenland climatic context by using such a comparison involves considerable uncertainty from multiple sources, including the correlation procedure and calendar age chronology itself. An alternative approach is to map ^{14}C dates of interest directly onto the climate record by using the Cariaco ^{14}C series and palaeoclimate series in the depth domain

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(Fig. 1; see Supplementary Table 1 for details). A stratigraphic comparison within the same sediment archive eliminates uncertainties arising from the conversion to calendar ages, and places ^{14}C ages into the climatic framework of the last glacial period.

The different sets of dates from Gorham's Cave discussed above represent an excellent testing ground for the radiocarbon climato-stratigraphic approach outlined above. In essence they can be regarded as providing three distinct case studies on the timing of the latest Middle Palaeolithic: a set of generally accepted but older

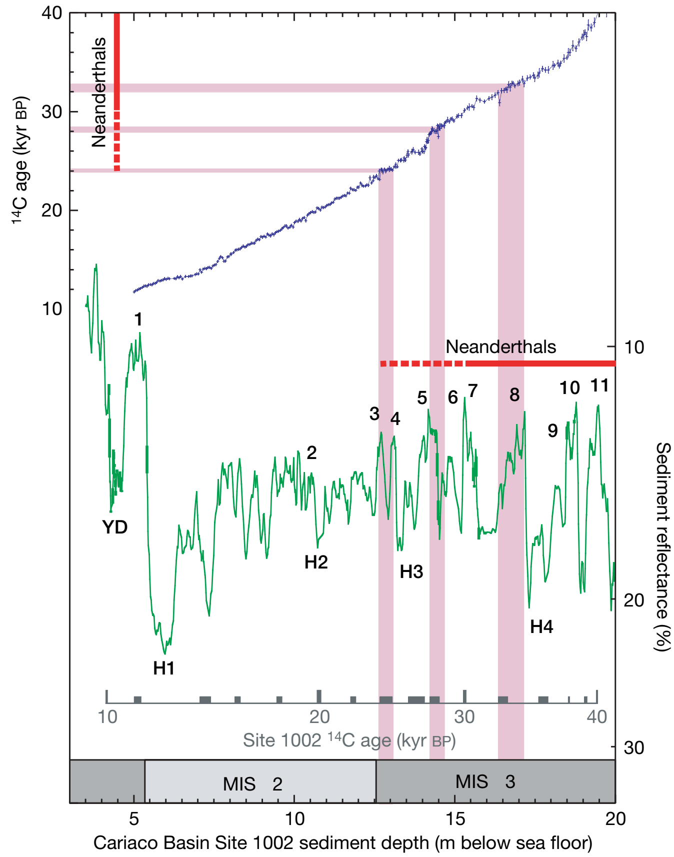

Figure 1 | Mapping Gorham's Cave ^{14}C dates onto the palaeoclimate record of the Cariaco Basin. Radiocarbon and palaeoclimate time series from Cariaco Basin ODP Site 1002 are plotted against depth. Cariaco marine ^{14}C ages (blue) were corrected for surface ocean reservoir age by subtracting 420 years before plotting. Potential changes in past reservoir age result in an additional ±100 years uncertainty[25], which is combined with reported analytical uncertainties according to established procedures[1,26] and plotted as 1σ errors. Sediment reflectance at 550 nm wavelength (green) is a proxy for organic carbon content and corresponds to upwelling, trade-wind intensity and nutrient runoff. Millennial-scale climate oscillations are numbered according to the corresponding Greenland Interstadials (GIS), and Heinrich Events (H) and the Younger Dryas (YD) are also indicated. Approximate ^{14}C ages for the Cariaco palaeoclimate record, taking into account changes in the ^{14}C chronology such as plateaux, are shown along the inset horizontal axis. The width of the tick marks reflects 1σ uncertainty; tick marks falling on a radiocarbon plateau therefore appear wider. Gorham's Cave ^{14}C dates are shown in pink and errors are reported as 1σ, following radiocarbon convention[27]. The dates are as follows: 32,330 ± 390 ^{14}C yr BP on charcoal from a pine-cone scale[5], considered stratigraphically reliable[10] and statistically identical with several other dates from late Middle Palaeolithic levels at Gorham's Cave[4,5]; 28,170 ± 240 ^{14}C yr BP on charcoal, the youngest of the lowermost three dates in stratigraphic order of Finlayson *et al.*[6]; and 24,010 ± 160 ^{14}C yr BP on charcoal, the youngest of the presumed *in situ* hearths[6]. Where the dates intersect the Cariaco ^{14}C chronology, depths can be translated into the sediment reflectance record for precise climatic context. Red bars indicate the late Neanderthal timeline and include the consensus interval for regional survival of Middle Palaeolithic Neanderthals[8] (solid) and their possible extended range[6] (dashed).

age determinations[4,5], younger dates suggesting a possible extended Neanderthal survival[6], and finally more contentious dates for late persistence[6]. Here we use the youngest date considered to be stratigraphically reliable within each data set: first, 32,330 ± 390 ^{14}C yr BP on charcoal identified as pine-cone scale, which is also statistically identical with several other dates from late Middle Palaeolithic levels at Gorham's Cave[4,5,10]; second, 28,170 ± 240 ^{14}C yr BP on charcoal from the lowermost three dates in stratigraphic order of Finlayson *et al.*[6]; and third, 24,010 ± 160 ^{14}C yr BP on charcoal from the presumed *in situ* superimposed hearths[6].

Figure 1 shows that the date of 32,330 ± 390 ^{14}C yr BP translates to an interval in the Cariaco record corresponding to Greenland Interstadial (GIS) 8 and the onset of the ensuing Greenland Stadial (GS) 8. Moreover, visual inspection reveals that the consensus age range of about 30,000–32,000 ^{14}C yr BP for the regional survival of late Neanderthals in southern Iberia[8] extends from the onset of GIS8 to the end of GIS7, an interval characterized by conditions typical of the climate instability of Marine Isotope Stage (MIS) 3 (that is, oscillations between Greenland Stadials and Interstadials). Similarly, the date of 28,170 ± 240 ^{14}C yr BP translates to an interval from the onset of GS6 to the middle of GIS5. None of the above dates falls within intervals corresponding to the more extreme events H3 and H4. In contrast, the younger date of 24,010 ± 160 ^{14}C yr BP extends the Neanderthal occupation to an interval immediately preceding the onset of a major shift in the dominant climate state, which marks the boundary between MIS3 and MIS2. The date falls on a radiocarbon plateau (a short interval of calendar age during which radiocarbon ages change slowly or not at all), which in the Cariaco record represents the interval corresponding to GIS4, GS4 and GIS3. Of particular interest is the end of GIS3, which marks the onset of a long period with reduced range of climate instability, representing the run to Last Glacial Maximum conditions with an accelerated decrease in sea level of 20–30 m (ref. 20) or more[21], and a corresponding expansion of land ice between GIS3 and H2 (Supplementary Fig. 1). In addition, the end of GIS3 marks a partial decoupling between high and low/middle latitudes: whereas Greenland ice cores and subpolar North Atlantic records show a return to cold conditions and increased ice rafting[22–24], the tropical and subtropical North Atlantic, including the Portuguese margin (Supplementary Fig. 1), show sea surface temperatures that continued to be relatively warm until H2. The persistence of interstadial conditions during this interval is also observed in the western Mediterranean Sea, where relatively high sea surface temperatures[12] are consistent with the entrance of warm water from the subtropical gyre, and also further east as suggested by the continued presence of temperate tree populations in Greece (Supplementary Fig. 1). The increased isolation of the Mediterranean Basin as a result of lower sea level may have amplified the warm conditions, resulting in the persistence of a relatively warm western Mediterranean deep water mass and increased precipitation and high lake levels in the eastern Mediterranean, with all lakes rising after 24,000 ^{14}C yr BP and reaching maximum levels between GIS3 and H2 (Supplementary Fig. 1).

Our analysis suggests that the consensus age range of about 30,000–32,000 ^{14}C yr BP for late Neanderthals in southern Iberia[4,5,8], as well as the less contentious age estimate of about 28,000 ^{14}C yr BP by Finlayson *et al.*[6], place their disappearance somewhere between GIS8 and GIS5. The character of this interval is not particularly distinct from the general climate instability of much of MIS3 and does not include Heinrich Events, thereby suggesting a limited role of climate in Neanderthal extinction. By comparison, taken at face value, the youngest and more contentious date of Finlayson *et al.*[6] suggests that Neanderthals at Gorham's Cave may have persisted up to the onset of a major environmental shift, which included an expansion in global ice volume and an increased latitudinal temperature gradient. This would imply a greater role of climate in Neanderthal extinction, not necessarily directly but perhaps in the form of climate-driven intensified competition as a result of increased southward human migration from higher latitudes. This exercise shows that the three sets of dates translate to two very different scenarios on the role of climate in Neanderthal extinction; resolving the chronology of the site through further dating campaigns (as suggested in ref. 9) can therefore have important implications. Finally, with regard to the role of the climatic conditions associated with H2 in the Neanderthal demise[11], Fig. 1 and Supplementary Fig. 1 together clearly indicate that H2 postdates the youngest proposed Neanderthal date[6] by about 3,000 years. This provides an excellent illustration of how our radiocarbon climatostratigraphic approach can reduce the risks of conflating events that are chronologically distinct and therefore not causally related. What emerges is that despite current uncertainties over radiocarbon calibration and the absolute timing of widespread abrupt climate changes, this approach can be used to place critical events in the history of late archaic and modern humans into a precise palaeoclimatic context, leading to better-constrained scenarios on the underlying causes of the observed patterns.

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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