doi:10.1038/nature05195

Late survival of Neanderthals at the southernmost extreme of Europe

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The late survival of archaic hominin populations and their long contemporaneity with modern humans is now clear for southeast Asia[1]. In Europe the extinction of the Neanderthals, firmly associated with Mousterian technology, has received much attention, and evidence of their survival after 35 kyr BP has recently been put in doubt[2]. Here we present data, based on a high-resolution record of human occupation from Gorham's Cave, Gibraltar, that establish the survival of a population of Neanderthals to 28 kyr BP. These Neanderthals survived in the southernmost point of Europe, within a particular physiographic context, and are the last currently recorded anywhere. Our results show that the Neanderthals survived in isolated refuges well after the arrival of modern humans in Europe.

The association between Neanderthals and Gibraltar dates to 1848 when a Neanderthal cranium was discovered at Forbes's Quarry[3]. The excavation of the Devil's Tower rock shelter in 1925–26 by Dorothy Garrod produced a second Neanderthal cranium with associated Mousterian industry[4]. It has since been established beyond doubt that the Neanderthals were the makers of the Mousterian in western Europe[5]. In Gibraltar there are currently eight Neanderthal occupation sites on the 6-km-long 426-m-high rock. The presence of Mousterian technology in Gorham's Cave, Gibraltar, was established during excavations made between 1948 and 1954 (ref. 6). The site was revisited from 1995 with a view to establishing the timing of the Middle to Upper Palaeolithic transition. A date of 32.28 ± 0.42 kyr BP (OxA-7857) was obtained for the uppermost Mousterian levels[7]. Before 1997 all excavations and soundings had been made in the external part of the cave. Problems of contamination of radiocarbon samples from wet, unprotected, exterior, parts of caves have recently been brought to light[2]. Here we describe the results of a series of excavations deep within Gorham's Cave between 1999 and 2005.

Excavations have been made of 29 m^2 of cave floor. The stratigraphy is composed of four levels (Fig. 1). Level I corresponds to Phoenician and Carthaginian (eighth to third century BC) horizons; level II corresponds to a brief occupation during the Neolithic. The two levels of interest in this paper are levels III and IV. The technology associated with level III, from which 240 artefacts have been recovered so far, is Upper Palaeolithic. The raw materials are predominantly flints, cherts and some quartzites. Three horizons have been identified, two corresponding to occupation during the Solutrean (Supplementary Information) and a higher horizon that corresponds to the Magdalenian (Supplementary Information). Aurignacian and Gravettian are absent. The technology associated with level IV, with 103 artefacts recovered so far, is exclusively Mousterian with flints, cherts and quartzites (Supplementary Information). Previous excavations by Waechter[6] also attributed the Upper Palaeolithic to the Solutrean and Magdalenian. Barton[7] and Pettit & Bailey[8] found only a few, undiagnostic, Upper Palaeolithic pieces in their profiles.

Figure 1 and Table 1 present 30 accelerator mass spectrometry (AMS) dates in stratigraphic position for levels III and IV in the deepest part of the cave. The samples were identified as individual pieces of charcoal under a microscope before being dated. The 22 AMS dates from the upper part of level IV span a 10-kyr period between 33 and 23 kyr BP. We have not attempted to calibrate the dates in view of the uncertainty surrounding calibration beyond 26 kyr cal BP[9]. The dates suggest a favoured location that was visited repeatedly over many thousands of years. Its situation, where natural light penetrates deep into the cave and where a high ceiling permits ventilation of smoke, is unique within the cave system, and hearths were made in the same location many times. This repeated use is confirmed by the stratigraphic distribution of the dates within level IV that indicate localized alterations due to use and reuse (for example trampling and cleaning) in the area around the position of the hearths but dates in stratigraphic sequence within the location of the hearths themselves. Thus, three samples (16, 17 and 20; Fig. 1) came from *in situ* Mousterian superimposed hearths. These three dates provide a stratigraphic sequence from $24{,}010 \pm 320$ to $30{,}560 \pm 720$ yr BP. Taken together, all the dates show that Neanderthals occupied the site until 28 kyr BP and possibly as recently as 24 kyr BP. The evidence in support of the 24 kyr BP date is more limited than for 28 kyr BP, which is taken as the latest well-supported

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occupation date. The level III dates represent a different occupation pattern and are consistent with sporadic visits to the cave during the Solutrean and Magdalenian and are separated from the Mousterian occupation by a stratigraphic gap of at least 5 kyr (Fig. 1 and Table 1).

Geochemical detrital ratios such as K/Al and Mg/Al are constant within each level at Gorham's Cave and different from each other. Level IV has a particular composition that differs from the rest of the sequence (Supplementary Information). Representative samples from all levels were analysed geochemically and mineralogically (Supplementary Information). The resulting data have been used as proxies to establish a sedimentary regime for the deep part of the cave, geochemical ratios acting as fingerprints in each level[10]. The sediments sampled were predominantly composed of clay minerals, calcite and quartz, with small quantities of dolomite, ankerite and feldspars. Levels III and IV are clearly differentiated. Level IV has a geochemical characterization that is clearly different from other levels that contain Mg/Al and K/Al ratios that are almost twice as high (Supplementary Information). A sharp change in concentration of most of the elements analysed was detected between levels III and IV, suggesting a sudden change in environmental conditions and/or occupational pattern. Together with the absence of Upper Palaeolithic tools in level IV and of any dates older than 19 kyr BP in level III, the geochemical results confirm that there is no contamination of level IV from the upper levels and that the boundary between levels III and IV is sharp and clear.

Taphonomic study (Supplementary Information) indicated that all taxa and animal sizes, according to weight, showed evidence of human-induced damage (for example cut-marks, percussion scars and conchoidal breakage), affecting 14.4% of identified specimens. This is in agreement with other Middle Palaeolithic sites[11,12].

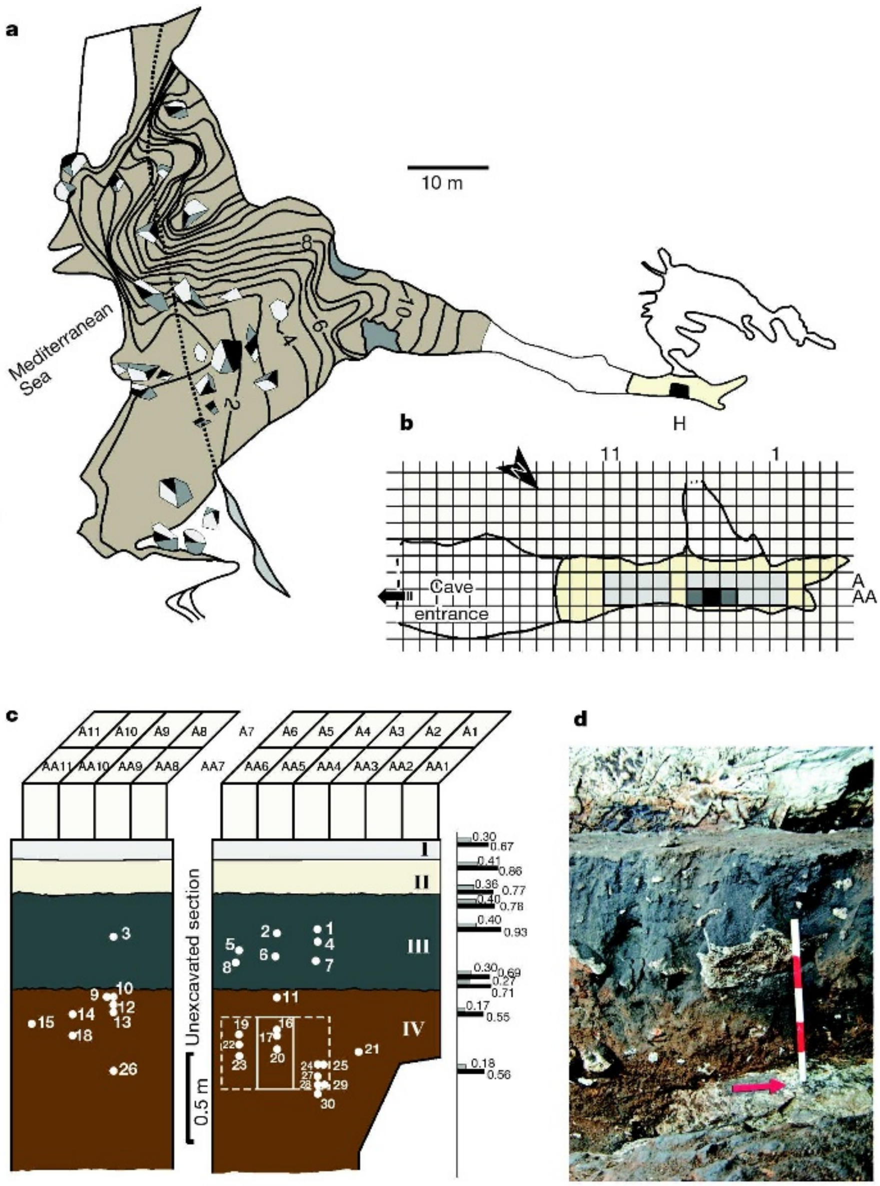

Figure 1 | Plan of Gorham's Cave including the section excavated. **a**, General plan of Gorham's Cave showing, at the right, the excavated area in the deep part of the cave (yellow) and the location of the hearth site (black). **b**, Detail of the excavated area (light grey) with the hearth site (black) and the hearth radius of influence (dark grey; see **c**). **c**, Stratigraphy of the excavated inner part of Gorham's Cave described in the text. Numbered dots indicate the positions of charcoal samples; the corresponding AMS dates are given in Table 1. The white rectangle marks the position of the Mousterian hearth site (see also Supplementary Information). Hatched lines indicate the hearth's radius of influence indicated by charcoal concentrations. The column on the right gives K/Al (black bars) and Mg/Al (grey bars) values for specific points in the stratigraphy (see Supplementary Information for details). The grid above the figure shows the 1 × 1 m squares excavated. **d**, Photograph showing the section at AA2–AA3. Level IV (brown, below) is clearly differentiated from level III (grey, above). The red arrow indicates north.

Table 1 | The 30 AMS dates in the sequence illustrated in Fig. 1

Sample no.*	Laboratory reference	AMS radiocarbon age (yr)†	$^{13}C/^{12}C$ ratio (‰)
1	Beta-181896	13,870 ± 80	−24.0
2	Beta-185343	10,880 ± 80	−25.4
3	Beta-181895	12,460 ± 100	−24.0
4	Beta-184047	12,640 ± 100	−25.4
5	Beta-196780	13,820 ± 100	−24.6
6	Beta-196777	12,540 ± 100	−24.9
7	Beta-181893	16,420 ± 120	−25.5
8	Beta-184042	18,440 ± 160	−21.7
9	Beta-196785	26,070 ± 360	−25.6
10	Beta-196784	28,360 ± 480	−26.1
11	Beta-185344	27,020 ± 480	−25.0
12	Beta-196786	29,910 ± 600	−24.7
13	Beta-196787	31,480 ± 740	−23.7
14	Beta-196792	30,310 ± 620	−24.7
15	Beta-185345	23,780 ± 540	−25.0
16	Beta-196775	24,010 ± 320	−24.0
17	Beta-196773	26,400 ± 440	−23.2
18	Beta-196791	28,570 ± 480	−25.2
19	Beta-196779	29,400 ± 540	−25.4
20	Beta-196776	30,560 ± 720	−24.5
21	Beta-184045	31,110 ± 460	−23.7
22	Beta-196778	29,720 ± 560	−24.8
23	Beta-196782	23,360 ± 320	−22.4
24	Beta-196768	31,290 ± 680	−25.8
25	Beta-196772	31,780 ± 720	−23.1
26	Beta-196789	32,100 ± 800	−24.5
27	Beta-196769	31,850 ± 760	−23.5
28	Beta-196770	28,170 ± 480	−25.9
29	Beta-184048	29,210 ± 380	−25.2
30	Beta-196771	32,560 ± 780	−25.1

Level III dates are numbered 1 to 8; level IV dates are numbered 9 to 30. Three dates from the hearth position are numbered 16, 17 and 20.
* Sample numbers are those used in Fig. 1.
† Errors shown are 2σ.

Carnivore activity is present, but it is not conspicuous (only 5.7% of the remains were affected by carnivore tooth-marks). Post-depositional alterations are not especially destructive; trampling, which produced surface scratches, was the principal factor (7.8%). No bone fragments or artefacts could be refitted. Evidence of re-sedimentation or reworking was not observed either. This confirms that most taxa represented at Gorham's Cave were brought from the surrounding environments by humans and butchered inside the cave with a subsequent negligible access to scavengers.

The sequence of radiocarbon dates presented, including 14 dates at or statistically younger than 30 kyr BP, are the only currently reliable ones that establish the persistence of Neanderthals and associated Mousterian technology after 30 kyr BP. Earlier claims are now dismissed or are uncertain for a variety of reasons and in particular after the revision of dates on bone with the use of ultrafiltration treatment, a treatment only meaningful for dates on bone[13]. Hyaena Den (UK) is now considered older than 30 kyr BP[2]; the Vindija (Croatia) Neanderthals have been re-dated to between 32 and 33 kyr BP or older[14]; Zafarraya (Spain) is now discarded for several reasons[15]; the Mezmaiskaya, Russia, Neanderthal is now dated to at least 36 kyr BP[16]. The single AMS date on *Cervus* bone for Caldeirão (Portugal)[17] will require revision and is likely, given the result for Hyaena Den of similar age[2], to be older than 30 kyr BP. Finally, the single ^{14}C date, from *Patella* shells, from Figueira Brava, Portugal, is not statistically younger than 30 kyr BP[17].

The last Neanderthals that occupied Gorham's Cave had access to a diverse community of plants and vertebrates on the sandy plains, open woodland and shrubland, wetlands, cliffs and coastal environments surrounding the site. Such ecological diversity might have facilitated their long survival. The overall pattern of fauna and vegetation in the late Mousterian level IV is consistent with that occurring outside the cave for the greater part of the Late Pleistocene and indicates Mediterranean glacial refugium conditions with a Thermo/Meso-Mediterranean, subhumid climate (Supplementary Information). It consisted of a broad mosaic of mesothermophilous plant communities, open parkland habitats and seasonal fresh and brackish water sources (Supplementary Information).

The Neanderthals therefore persisted in Mediterranean environments that had acted as glacial refugia for many species throughout the Quaternary period[18]. The presence of Aurignacian technology in Bajondillo, Málaga, about 100 km east of Gibraltar at around 32 kyr BP (ref. 19) and of sporadic Gravettian sites after this[20] indicates that the late survival of Neanderthals and the arrival of modern humans was a mosaic process in which pioneer groups of moderns and remnant groups of Neanderthals together occupied a highly heterogeneous region for several thousand years. The low density of early Upper Palaeolithic sites in southern Iberia[20] and the late presence of Neanderthals, reported in this paper, indicate that for a long time populations of both Neanderthals and modern humans were thinly scattered across the region. The absence of transitional industries that have been attributed to Neanderthal–modern cultural contact[21], as are found in northern Iberia and France (Châtelperronian), adds weight to the view of limited contact between Neanderthals and moderns in southern Iberia. The transition from the Middle to the Upper Palaeolithic was not, in southern Iberia at least, a sudden rupture but instead took the form of a long and diffuse spatio-temporal mosaic involving populations at low density.

METHODS

Cave deposits often have a complex sedimentation and the possibility of mixing of sediments cannot be discounted. Representative samples were therefore taken from each level at Gorham's Cave and were analysed, both geochemically and mineralogically, with the aim of checking the homogeneity of the stratigraphic levels and the conditions in the cave. The resulting data have been used as proxies to establish a sedimentary regime and conditions within the cavity. The four stratigraphical levels (I–IV) were sampled. Sediment samples were dried and homogenized in an agate mortar for mineralogical and geochemical analyses.

Bulk mineral compositions were obtained by X-ray diffraction (XRD) in accordance with international recommendations[22]. X-ray diffractograms were obtained with a Philips PW 1710 diffractometer with CuKα radiation and an automatic slit. Resulting diffractograms were interpreted with Xpowder software[23]. Major element measurements (Mg, Al, K, Ca, Mn and Fe) were obtained by atomic absorption spectrometry (AAS; Perkin-Elmer 5100 spectrometer) with an analytic error of 2% in the Analytical Facilities (CIC) of the University of Granada. Al, K, Ca, Ti, Mn, Fe, Cu and Sr have also been quantified with an X-ray fluorescence scanner in the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) laboratories. The XRF-core scanner TATSCAN-F2 (ref. 24) was set to determine bulk intensities of major elements on split sediment sections at intervals of 0.5 cm with an accuracy in standard powder samples of better than 0.20 wt%. A depth correction was performed to compare AAS and XRF-scanner data, indicating a high correlation between techniques. Analyses of trace elements including Ba were performed with inductively coupled plasma–mass spectrometry (ICPMS) after digestion with HNO_3 plus HF. Measurements were performed in triplicate by spectrometry (Perkin-Elmer Sciex Elan 5000), with Re and Rh as internal standards. Variation coefficients determined by the dissolution of ten replicates of powdered samples were more than 3% and 8% for analyte concentrations of 50 and 5 p.p.m., respectively[25].

High-resolution geochemical mapping was performed with an XRF scanner in sediments proceeding from level IV (Supplementary Information). Results indicate a sublaminar sedimentation slightly turbated by limestone dropstone, flint tools, fossil bones and carbonate nodules. This confirms that sedimentation in level IV does not correspond to 'breccia' or chaotic deposits.

The 30 AMS dates presented in this paper were analysed by Beta Analytic Inc. All samples were pretreated to eliminate secondary carbon components. The samples were first gently crushed and dispersed in deionized water. They were then given acid washes with hot HCl to eliminate carbonates, and alkali washes with NaOH to remove secondary organic acids. The alkali washes were followed by a final acid rinse to neutralize the solution before drying. Chemical concentrations, temperatures, exposure times and number of repetitions, were applied according to the scarcity of the sample. Each chemical solution was neutralized before application of the next. During these serial rinses, mechanical contaminants such as associated sediments and rootlets were eliminated. This type of pretreatment is considered a 'full pretreatment'.

Received 12 April; accepted 25 August 2006.
Published online 13 September 2006.

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

Acknowledgements We thank all those who have participated in this project. The project Palaeomed was co-funded by the Government of Gibraltar and the European Union Interreg IIIB Programme Medocc. Palynological and geochemical investigations were funded by Fundación Séneca, Murcia, Spain, and Ministerio de Educación y Ciencia, DGI, Spain, respectively. Geomorphological work was funded by Ministerio de Educación y Ciencia, DGI, Spain.

Author Contributions C.F., F.G.P., J.R.-V. and C.B.S. were responsible for project direction and management. C.F. coordinated the writing. Multidisciplinary work was divided as follows: archaeology and curation—F.G.P., J.M.G.L., A.S.P., J.B.P., F.G.G., K.B., C.A.V. and A.V.; geomorphology and sedimentology—J.R.-V., F.J.J.E., F.M.R. and T.S.; taphonomy—I.C. and Y.F.J.; palaeoecology—C.F., D.A.F. (general), G.F. (palaeolandscape), E.A. (anthracology), J.S.C., P.L., J.A.L.S., N.F. (palaeobotany), C.P.G.-O. (herpetological taxonomy), J.A.R.C. (mammalian taxonomy) and A.S.M. (avian taxonomy). All authors discussed and interpreted the results and commented on the manuscript.

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