

# A rock engraving made by Neanderthals in Gibraltar

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**The production of purposely made painted or engraved designs on cave walls—a means of recording and transmitting symbolic codes in a durable manner—is recognized as a major cognitive step in human evolution. Considered exclusive to modern humans, this behavior has been used to argue in favor of significant cognitive differences between our direct ancestors and contemporary archaic hominins, including the Neanderthals. Here we present the first known example of an abstract pattern engraved by Neanderthals, from Gorham's Cave in Gibraltar. It consists of a deeply impressed cross-hatching carved into the bedrock of the cave that has remained covered by an undisturbed archaeological level containing Mousterian artifacts made by Neanderthals and is older than 39 cal kyr BP. Geochemical analysis of the epigenetic coating over the engravings and experimental replication show that the engraving was made before accumulation of the archaeological layers, and that most of the lines composing the design were made by repeatedly and carefully passing a pointed lithic tool into the grooves, excluding the possibility of an unintentional or utilitarian origin (e.g., food or fur processing). This discovery demonstrates the capacity of the Neanderthals for abstract thought and expression through the use of geometric forms.**

Middle Paleolithic | symbolism | art | Iberia | cognition

Considerable debate surrounds the Neanderthals' cognitive abilities (1–7), and the view that the Neanderthals did not have the same cognitive capacities as modern humans persists in the literature (8) despite evidence to the contrary (9–15). One of the arguments against Neanderthals' modern cognition is their apparent inability to generate cave art (16–19). The earliest evidence of rock art is typically associated with the arrival of modern humans (MH) in Western Europe ~40 kyr (20, 21). The dating of calcitic layers covering painted dots at El Castillo Cave, Spain has pushed back this starting point beyond 41 kyr, opening the possibility of a Neanderthal authorship (22). Possible hypotheses include (i) the earliest rock art was produced by MH before their arrival in Europe but remains unidentified; (ii) rock art was created by Neanderthals or other archaic hominins and predated the arrival of MH; (iii) MH developed rock art on arrival in Europe; and (iv) rock art was developed in Europe after the arrival of MH.

The lack of associated archaeological remains precludes assigning the El Castillo paintings to a specific population. Other factors contributing to the difficulty in testing the foregoing hypotheses include persistent uncertainties in the chronology of archaeological sites at the so called Middle-to-Upper Paleolithic transition in Europe (23–25) and in the taxonomic affiliation of their inhabitants during this period (26–28).

Recent excavations at Gorham's Cave led to the discovery in an area at the back of the cavity, below basal archaeological level IV, of an abstract pattern engraved into the bedrock. Level IV is an archaeological horizon containing exclusively Mousterian artifacts (29–31) deposited between 38.5 and 30.5 cal kyr BP (29, 32)

(SI Appendix, Table S1). In this paper, we describe this engraving, provide additional contextual data demonstrating its attribution to Mousterian Neanderthals, reconstruct how it was created, and discuss implications of our findings for Neanderthal culture and cognition.

## Gorham's Cave

Gorham's Cave is located in Gibraltar, a small promontory situated at the southern extreme of the Iberian Peninsula (Fig. 1). The eastern side of Gibraltar faces the Mediterranean Sea and is subjected to intense wave action, which has led to the formation of steep cliffs and large sea cavities (33). Gorham's Cave is one of these caverns. In the cave, the surface of fresh rock is a white, slightly crystallized lime-dolostone of Jurassic age. In its natural state, the same rock is light gray, fine-grained, and rough because of surface weathering caused by condensation of sea spray, mainly during the summer season, when the humid easterlies are dominant. Within the cave, the weathering of this rock has produced a network of 10–40 mm deep × 1–9 mm wide dissolution cracks (SI Appendix, Fig. S1).

## Significance

**The production of purposely made painted or engraved designs on cave walls is recognized as a major cognitive step in human evolution, considered exclusive to modern humans. Here we present the first known example of an abstract pattern engraved by Neanderthals, from Gorham's Cave in Gibraltar. It consists of a deeply impressed cross-hatching carved into the bedrock of the cave older than 39 cal kyr. The engraving was made before the accumulation of Mousterian layer IV. Most of the lines composing the design were made by repeatedly and carefully passing a pointed lithic tool into the grooves, excluding the possibility of an unintentional or utilitarian origin. This discovery demonstrates the Neanderthals' capacity for abstract thought and expression.**

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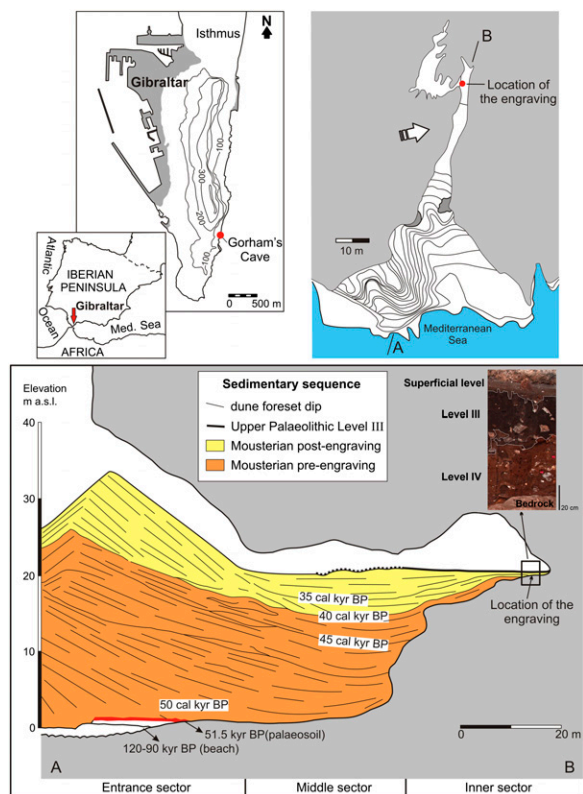
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**Fig. 1.** Location of Gorham's Cave, Gibraltar, in the Iberian Peninsula and schematic map of the Gibraltar Peninsula with altitudes and contours at 100-m intervals (*Upper Left*), topographic plan of Gorham's Cave showing the location of the engraving (*Upper Right*), and interpretative geological section of Gorham's Cave based on the work of Jiménez-Espejo et al. (33) (*Lower*). (*Inset*) Location of levels III and IV within the general cave sequence.

Starting in 1989, sections of Gorham's Cave have been excavated as part of the Gibraltar Caves Project, under the supervision of the Gibraltar Museum. The long-term occupation of this site by Neanderthals first came to light in the 1950s (34), and numerous subsequent excavations in the cave entrance have been performed (35). The inner sector was excavated at the beginning of this century by the Gibraltar Museum, and the first results were published by Finlayson et al. (29). Fig. 1 shows a chronostratigraphic interpretative section of Gorham's Cave, based on the work of Jiménez-Espejo et al. (33) previous publications (29, 34, 36–38), and new data. The nature and sedimentary features of the fill of the cave differ between the entrance and the inner sector. The sequence at the entrance is characterized by a massive aeolian accumulation related to transgressive coastal dunes that migrated during Marine Isotope Stage 3 highstand substages and/or cold, arid periods. These sandy sediments, coming from nearby pocket beaches, covered the emerged shore platform (32) and reached the foot of the cliffs in places even climbing the slopes as thick sand ramps.

In the inner sector (also known as the Upper Gallery), the sedimentary sequence is thinner and composed mostly of fallen fragments of roof and wall, aeolian dust, and karstic clay, owing to the cave morphology. X-ray diffraction (XRD) indicates that the sediments inside the cave are composed predominantly of clay minerals, calcite and quartz, with small quantities of dolomite, ankerite, and feldspars (29). In this sector, archaeological levels III and IV are of clearly different textural composition. Level III, of a mean depth of ~60 cm, consists of a sandy sediment with dark-brown clay in a sandy matrix with a strong organic component that includes discrete lumps of charcoal. Fallen fragments of angular limestone and speleothem are a feature of the middle part of this

level. Level IV is a 25- to 46-cm-thick beige-colored pure clay horizon with an abundance of discrete lumps of charcoal and a hearth (29, 32) (*SI Appendix, Table S1*). Levels III and IV also differ in elemental composition, with the former containing close to twice the Mg/Al and the highest K/Al ratio. Such marked variation suggests a sudden change in environmental conditions (29).

Level IV is attributed to the Mousterian, based on the technology and typology of the stone tools found therein (30, 31) (*SI Appendix, SI Text, Fig. S2, and Table S2*). The 294 lithics from this level are composed chiefly of three varieties of flint and a fine-grained quartzite, which can be found on fossil beach deposits near the cave and in flint seams in the Jurassic units of the rock. Technological analysis of the assemblage indicates that the knappers used discoidal and Levallois reduction methods. Evidence for this includes seven discoidal cores and three Levallois cores, two of which were prepared using the recurrent centripetal technique; identification of a range of deliberate platform preparation types, including monofacial, bifacial, and multifacial faceting; the presence of Levallois flakes; and the dominance of flakes over blades. The size of the flint flakes appears to be conditioned by the small size of the nodules available in the breccia at the entrance of the cave. The retouched tools most often seen in the level IV assemblage are sidescrapers and denticulates. Notches and pieces with abrupt retouches are present as well. Lithics with Upper Paleolithic technological and typological affinities are absent in this level (31).

In contrast, the lithics from the overlying level III lack Middle Paleolithic features, display Upper Paleolithic affinities, and include tools and debitage pieces diagnostic of the Solutrean (29) (*SI Appendix, Fig. S3 and Table S3*). No tools and debitage pieces characteristic of the Early Upper Paleolithic (Aurignacian, Gravettian) are found in this assemblage. The vertical distribution of culturally diagnostic artifacts recovered in the 90-cm band of sediment above the engraving shows no indication of admixture between the two levels or localized intrusion of Upper Palaeolithic items into Mousterian level IV (*SI Appendix, Fig. S4*). This indicates that the engraving was carved into the bedrock before the accumulation of Mousterian level IV and was protected by at least 40 cm of sediment after deposition of that level.

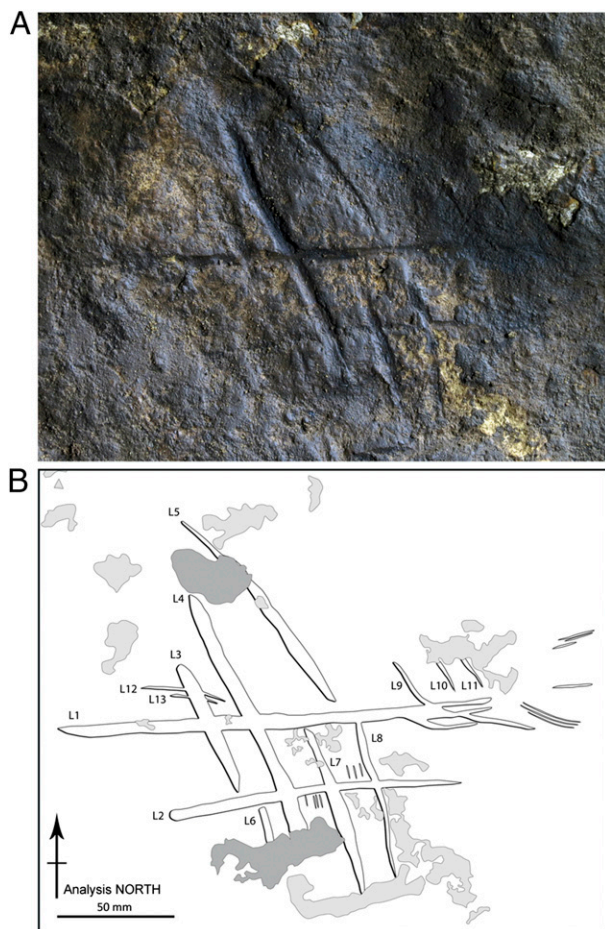
Radiocarbon dating has provided a large time span for level IV, ranging from 38.5 to 30.5 cal kyr BP, controversially interpreted as possible evidence of a late Neanderthal survival in southern Iberia (26, 29, 37). Such controversy does not appear to have significant implications for the dating of the engraving, which logically must be older than the oldest—and for this reason, probably also more reliable— $^{14}\text{C}$  determination from level IV (38.5 cal kyr BP), obtained from a sample collected at the very bottom of this level.

### The Engraving

The engraving is found on a flat area located at the center of a 1-m<sup>2</sup> natural platform of the bedrock elevated 40 cm over the cave floor (*SI Appendix, Fig. S5*). Covering an area of ~300 cm<sup>2</sup>, it consists of eight deeply engraved lines (L1–L8) forming an incomplete criss-cross pattern, obliquely intersected by two groups of three (L9–L11) and two (L12 and L13) short thin lines (Fig. 2). The overlying 40-cm level IV sediment was excavated during the 1997–2005 and 2011–2012 field seasons. The engraved pattern differs strikingly from the 1- to 4-cm-deep alteration cracks and other networks of natural fissures present on the exposed surfaces of the fine-grained lime-dolostone of the cave (*SI Appendix, Fig. S1*).

Three thin layers are identified on the engraved rock surface (Fig. 3 and *SI Appendix, Fig. S6*): a white 2- to 4-mm-thick lower layer 1, a light-brown 0.5-mm-thick intermediate and discontinuous layer 2, and an upper black 0.1- to 1-mm-thick layer 3. The engraved lines are covered only by layer 3, whereas the unmodified rock surface is covered by all three layers. Mineralogical and elemental analysis revealed marked differences in composition across these layers (*SI Appendix, Figs. S7 and S8*). Layers 1 and 2





**Fig. 2.** (A) Engraving from Gorham's Cave. (B) Engraved lines L1–L13. Dark gray and light gray identify old and recent breaks, respectively. (*SI Appendix, Fig. S21* shows the order of the engraving lines, breaks, and formation of the duricrust.) Note that the "Analysis North" shown here was used only to describe the order of the engraving lines.

contain a substantial proportion of calcite and dolomite coming from the substrate, along with neof ormation of hydroxylapatite  $[\text{Ca}_5(\text{PO}_4)_3\text{OH}]$ . Layer 3 is a duricrust composed of Mn-rich hydroxylapatite  $[\text{Mn}_2\text{Ca}_3(\text{PO}_4)_3\text{OH}]$  (39). Such differences and microstratigraphy indicate that layer 1 is a white alterite that formed as a result of ancient weathering of the lime-dolostone substrate. It was on this weathered rock surface that the engraving

was made. Subsequently, the rock was covered by deposition of archaeological level IV, consisting of blown dust/sand, karstic clay, guano, and archaeological remains. As it fell on the sediments, percolating water and bat acidic urine (rich in phosphate ions) altered minerals composing level IV and caused the migration of cations toward the bottom of this level, at the contact between the engraving-bearing alterite and the sediment.

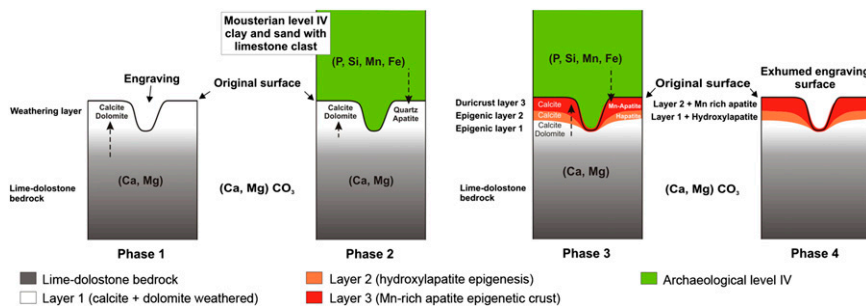
The manganese component of layer 3 likely derives from the decomposition of organic matter present on the surface during the accumulation of stratigraphic level III. This is consistent with the high proportion of organic matter observed in level III and mechanisms proposed to account for the deposition of manganese in cave environments (40). Epigenesis of the calcareous substrate by phosphorous- and manganese-rich solutions led to differentiation of layers 2 and 3 from the top of layer 1. In the engraving, where the weathered lime-dolostone composing layer 1 was removed by the engraving process, a slight epigenesis of the rock occurred, forming only layer 3. This type of epigenetic process is responsible for the excellent preservation of the grooves' microfeatures by hardening of the bedrock surface; layer 3 has protected the engraving with a thin mineral coat (Fig. 3).

Chemical analysis of the duricrust (*SI Appendix, Figs. S7 and S8*) and observation of lime-dolostone weathering patterns resulting from condensation on the cave wall and bedrock suggest that at the moment at which the engraving was made, the surface of the otherwise extremely hard lime-dolostone was affected by some degree of weathering that facilitated the engraving process.

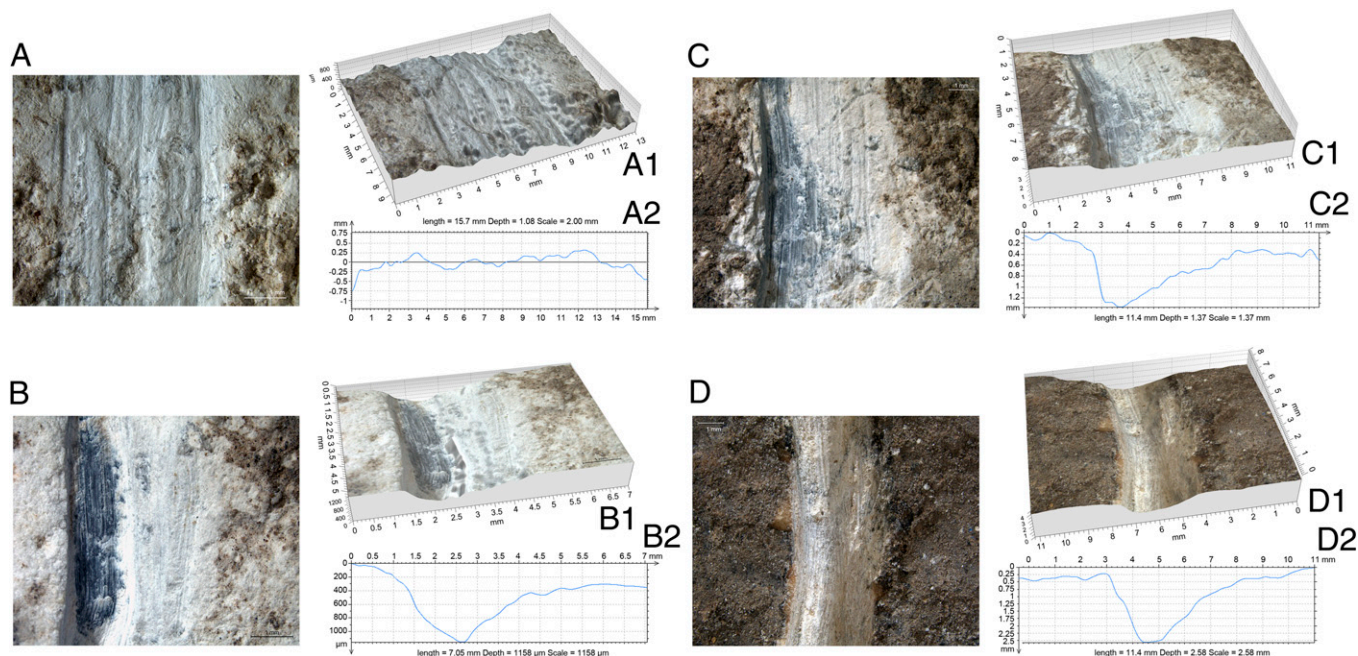
### Experimental Marking of Weathered Blocks from Gorham's Cave

To identify how and for what reason the engraved pattern was made, we (i) undertook microscopic and morphometric analysis of the archaeological engraving; (ii) made experimental incisions with different tools (*SI Appendix, Fig. S9*) and actions on weathered blocks of lime-dolostone (Fig. 4 and *SI Appendix, Figs. S10 and S11*); and (iii) produced 3D reconstructions of the whole pattern and individual groove sections (*Movie S1* and *SI Appendix, Fig. S12*).

Unique movements of the stone tool tip on weathered lime-dolostone produced superficial incisions, pointed at both ends, with a maximum width of 0.8–2.35 mm and a depth of 0.1–0.3 mm (*SI Appendix, Table S4*). These incisions reveal in places parallel internal striations produced by contact with the tool tip protrusions that are comparable in morphology and size to archaeological engraving lines L9–L13. These striations differ significantly in size and internal morphology from the remainder of the engraving making up the Gorham's Cave composition. Producing deep regular incisions with clean edges by repeatedly passing the tool tip into the groove with a to-and-fro movement proved to be extremely difficult, owing to the hardness of the rock



**Fig. 3.** Formation of the three layers of rock alteration in which the engraving is located. Phase 1 refers to the process of alteration by weathering of the exposed lime-dolostone surface (layer 1). The archaeological engraved marks were made on this weathered (soft) surface, which was covered by the Middle Paleolithic sediments of level IV (phase 2). The downward migration of phosphorus and manganese and the upward migration of magnesium and calcium generated two new alteration layers (2 and 3) from the original weathering layer 1 (phase 3). The duricrust layer 3, composed of Mn-rich apatite, protected the original engraving with a black endured coat. Finally, the archaeological excavations at Gorham's Cave exposed this ancient engraved rock surface (phase 4).



**Fig. 4.** Microphotographs (A–D), 3D reconstructions (A1–D1), and sections of lines (A2–D2) engraved by experimental tools 1 (A), 2 (B), 3 (C), and 4 (D). (Scale bar: 1 mm.)

and surface discontinuities stopping in places the tool tip during its progress and producing jerky outlines (*SI Appendix, Table S4*). Attempts to apply this technique resulted in wide superficial grooves associated with numerous side striations and fringes at both ends. Such features are not seen on the lines composing the Gorham's Cave engraving. Incisions produced when cutting a fresh pork skin with a lithic blade on weathered lime-dolostone (*SI Appendix, Fig. S10*) also differ from the Gorham's Cave lines. Similar in width to those produced by a unique displacement of a stone tool tip (*SI Appendix, Table S4*), they differ from the latter by their more sinuous and discontinuous outlines and appreciable changes in width within lines, owing to reduced contact of the blade cutting edge in concave areas of the rock surface.

Incisions produced by carefully and repeatedly passing a pointed tool or a cutting edge into the groove in the same direction (Fig. 4 and *SI Appendix, Fig. S11*) are morphologically and dimensionally similar to Gorham's lines L1–L8 (Fig. 2). They exhibit a pointed start and a pointed or fringed end, variable sections, and subparallel or intersecting internal striations produced by changes in the location of the tool tip in contact with the groove surface at each successive passage.

Of the four tools used in this action, tool n.1 suffered a break during the sixth stroke. With the tip morphology produced by the break unsuitable for deepening the groove, the subsequent passing of the tool resulted in a wide superficial abrasion rather than an incision (Fig. 4 A–C and Fig. 5). This suggests that only robust pointed tips or cutting edges could produce incisions similar to L1–L8, and that the maker or makers of the archaeological engraving had a good knowledge of the tool properties required to produce such lines. Experimental consideration of the number of strokes proved necessary to reach the width and depth recorded on archaeological lines L1–L8 allowed evaluation of the minimum and maximum number of strokes applied by the Paleolithic maker (Fig. 5 and *SI Appendix, Table S5*).

Microscopic analysis of the archaeological engraving identified diagnostic features (*SI Appendix, Figs. S13–S19*) also detected on the experimental engraving and minimal erosion of the bedrock surface outside the engraving, supporting the view that our

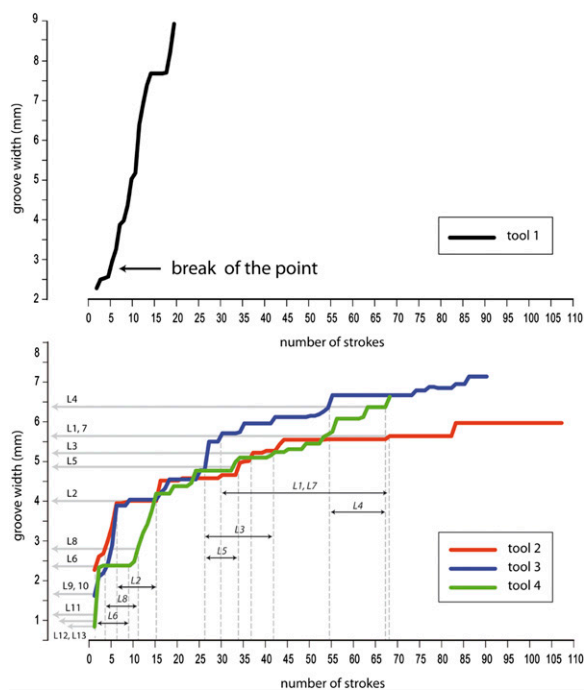
evaluation of the number of strokes applied on the archaeological engraving is realistic. Our evaluation assumes a similar degree of weathering of the blocks engraved experimentally and the bedrock at the moment at which the engraving was made, however. Considering that the thickness of the weathered rock layer ranges between 0.7 and 1 mm in the former (Fig. 4), and that 40–45 strokes were needed to reach unweathered lime-dolostone and 75–85 strokes were needed to expose it, on one-half of the groove section, a thicker layer of weathered rock would affect the calculation of the number of strokes only on archaeological lines L1, L4, and L7. In contrast, a thinner layer, or its virtual absence—the current situation on most of the cave's exposed bedrock—would result in a significant increase in the predicted number of strokes required to produce the archaeological engraving. The additive nature of duricrust on some engraving lines (e.g., *SI Appendix, Fig. S20*) may have reduced the lines' depth and width and biased the measurements, resulting in an underestimation of the number of strokes.

## Discussion

Our results demonstrate that formation of the duricrust preserved the same diagnostic features on the engraving as those documented experimentally when the engraving was reproduced on the same rock type (Fig. 4 and *SI Appendix, Fig. S11*). These features include distinct outlines of groove sections, internal striations produced by contact with protruding asperities of the engraving tool, and clues indicating the order of the engraving at intersections (Fig. 4 and *SI Appendix, Figs. S14–S19*). A comparison with experimental engraving shows that L1–L8 were engraved with a robust lithic point by repeatedly passing the tool tip into the groove in the same direction, and that L9–L13 were created by single strokes with a similar tool (*SI Appendix, Fig. S20*).

Striations left on a flat lime-dolostone block when experimentally cutting mammal skin with a stone tool clearly differed from those discovered at Gorham's Cave (*SI Appendix, Fig. S10*). According to our experiments, a minimum of 54 strokes were needed to engrave the widest and deepest line (L4), and between 4 and 30 strokes were needed to engrave each of the other





**Fig. 5.** Changes in the maximum width of experimental multiple stroke lines produced by four experimental tools when the tool tip was repeatedly passed into the groove in the same direction (*SI Appendix, Tables S4 and S5*). (Upper) Graph illustrating the rapid increase in groove width occurring after the accidental break of point n.1 (*SI Appendix, Fig. S21 A–C*). (Lower) Graph evaluating the number of strokes necessary to engrave each archaeological line by comparing their maximum width with the number of passages experimentally proved to be required to achieve the same width.

multiple stroke lines (Fig. 5 and *SI Appendix, Tables S4 and S5*). We calculated that the number of strokes needed to carve the complete pattern ranged from 188 to 317. These figures must have been even higher if the lime-dolostone was only minimally weathered when the engraving occurred. Considerable effort and neuromotor control are required to deepen lines on this rock type with multiple strokes without accidentally exiting the main groove and marking the surface adjacent to it or producing fringed terminations. No accidental exits and only a single fringed termination, at the end of L1, were detected.

A study of line-end morphology, crossings, and changes in line direction after intersections revealed that horizontal L1 and L2 were made first and engraved from left to right followed by L3–L8, which were incised from top to bottom. L1 was deepened by a single stroke at this stage or when L9–L11 and L12 and L13 were engraved (*SI Appendix, Figs. S19 and S21*). Each of these two groups is consistent with the use of a single tool in one session, from top left to the bottom right. Engraved lines L4–L6 are damaged by the removal of two potlids occurring before formation of the duricrust, suggesting that the engraved pattern remained visible for some time before being covered by accumulation of level IV and the ensuing creation of the duricrust. This alteration layer was subsequently damaged by desquamations exposing the underlying white lime-dolostone (*SI Appendix, Figs. S17–S20*).

## Conclusions

The oldest secure evidence for representational and abstract depictions has been reviewed recently (27). Engraved geometric designs earlier than the Early Upper Paleolithic have been reported in both Africa and Eurasia. A number of cases have been of unclear nature (41, 42) but a consistent number of objects bearing finely engraved patterns are present from Middle

Paleolithic/Middle Stone Age contexts. Nevertheless, the Gorham's Cave engraving represents the first case in which an engraved pattern permanently marks a space within a habitation area in a cave.

The oldest radiocarbon dating of level IV, ~39 cal kyr BP, fixes a *terminus ante quem* for the production of the engraving. MHs were present in Western Europe at this time but had yet to reach the southern end of the Iberian peninsula (29, 43). Apart from the painted dots from El Castillo, which are of uncertain cultural and taxonomic attribution, no cave or mobiliary art is known for this period in Europe. The well-known striking instances of Aurignacian (MH) depictions from Germany and France (44–46) are more recent than the Gorham's Cave engraving and bear no apparent similarity to it. This argues against the possibility that Neanderthals produced this design under the cultural influence of MH and instead suggests independent invention. Although a similar inference was recently made with respect to some technological innovations, such as lissoirs (47), this is the first example of nonutilitarian engraving.

Up to now, symbolic thought among the European hominins that preceded MHs has been inferred indirectly from burials, the use of black and red pigments (9), perforated and pigment-stained marine shells (10, 11), and cut marks resulting from the extraction of feathers or ornamental alteration of bird claws (12–15). The engraving at Gorham's Cave represents the first directly demonstrable case in which a technically elaborated, consistently and carefully made nonutilitarian engraved abstract pattern whose production required prolonged and focused actions, is observed on the bedrock of a cave. We conclude that this engraving represents a deliberate design conceived to be seen by its Neanderthal maker and, considering its size and location, by others in the cave as well. It follows that the ability for abstract thought was not exclusive of MHs.

## Methods

**Mineralogical Analysis.** Mineralogical analysis was carried out at the University of Huelva and Rovira i Virgili University by powder XRD on a Bruker AXS D8-Advance diffractometer using Ni-filtered CuK $\alpha$  radiation at 40 kV and 30 mA. Randomly oriented powders were scanned from 3° to 65° 2 $\theta$  with a step size of 0.02° and a counting time of 0.6 s per step. Oriented aggregates were obtained from sedimentation and were scanned from 1° to 30° 2 $\theta$  using a step size of 0.02° and a counting time of 1.2 s per step. The samples were also examined by scanning electron microscopy on carbon-coated loose powder mounts, using a JEOL JSM-5410 instrument operated at 20 kV and equipped with an energy-dispersive X-ray analytical system (Oxford Link ISIS) and back-scattered electron imaging.

**Experimental Engraving.** Seven stone tools (*SI Appendix, Fig. S9*) were used to experimentally incise three weathered blocks of lime-dolostone. The blocks were recovered during the excavation of level IV at the back of the cave. The stone tools were Mousterian archaeological implements found out of context in the outer area of Gorham's Cave. *SI Appendix, Table S4* summarizes information on the tools used and the experimental protocol. Four actions were performed: (i) single stroke lines produced by a unique continuous displacement of the tool tip over the block surface; (ii) multiple stroke lines produced by repeatedly passing the tool tip or a cutting edge into the groove in the same direction; (iii) multiple stroke lines produced by repeatedly passing the tool tip into the groove with a to-and-fro movement; and (iv) incisions produced when cutting a fresh pork skin with flint and microquartzite blades.

The maximum and minimum widths of the incisions were recorded with a digital caliper after each new passage of the tool. The morphology of incision start and end points was recorded as well; on multiple stroke lines, the following were recorded: (i) number of incisions necessary to reach the unweathered lime-dolostone; (ii) occurrence of incisions corresponding to the accidental exiting of the tool tip in the middle or at the end of the main groove; and (iii) superficial lines running close and parallel to the main groove resulting from accidental contact of the tool tip with the block surface during the engraving process (48, 49). Experimental engraving was photographed with a motorized Leica Z6 APOA, equipped with a DFC420 digital camera linked to an LAS Montage and Leica Map DCM 3D computer software. Section, width, and 3D models of selected portions of the experimental

engraving were produced by exporting depth maps obtained with the LAS Montage into the Leica Map DCM 3D software.

The Gorham's Cave engraved lines were extensively examined and photographed with macro lenses and a HIROX VCR-800 digital microscope at magnifications ranging from 20x to 160x. The microscope was moved over the engraving using an arm attached to a photo tripod, to avoid vibrations and contact with the rock. Particular attention was given to documenting (i) the occurrence of surface features, from the literature (48, 49) or produced experimentally in the framework of the present study, which could be used to reconstruct the craftsman's action, and (ii) the type of tool used and the order of the engraved lines. The location of the duricrust in relation to the engraving and the state of preservation of the engraving were examined as well. The width, depth, and sections of the archaeological engraving were calculated with TIVMI software (<http://projets.pacea.u-bordeaux.fr/TIVMI/>), using the 3D model for the engraving generated using Agisoft Photoscan Standard Edition.

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The widths obtained with this method were verified by comparing them with those measured on photos of the archaeological engraving.

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