A rock engraving made by Neanderthals in Gibraltar

Joaquín Rodríguez-Vidal[a], Francesco d'Errico[b,c], Francisco Giles Pacheco[d], Ruth Blasco[e], Jordi Rosell[f,g], Richard P. Jennings[h], Alain Queffelec[b], Geraldine Finlayson[e], Darren A. Fa[e], José María Gutiérrez López[i], José S. Carrión[j], Juan José Negro[k], Stewart Finlayson[e], Luís M. Cáceres[a], Marco A. Bernal[h], Santiago Fernández Jiménez[j], and Clive Finlayson[e,1]

[a]Departamento de Geodinámica y Paleontología, Facultad de Ciencias Experimentales, and Marine International Campus of Excellence (CEIMAR) Universidad de Huelva, 21071 Huelva, Spain; [b]Centre National de la Recherche Scientifique, Unité Mixte de Recherche 5199-PACEA, University of Bordeaux, F-33615 Pessac, France; [c]Department of Archaeology, Cultural, and Religious Studies, University of Bergen, 5020 Bergen, Norway; [d]Gibraltar Caves Project, Gibraltar; [e]The Gibraltar Museum, Gibraltar; [f]Àrea de Prehistòria, Universitat Rovira i Virgili, 43002 Tarragona, Spain; [g]Institut Català de Paleoecologia Humana i Evolució Social, 43007 Tarragona, Spain; [h]Research Laboratory for Archaeology, University of Oxford, Oxford OX1 2HU, United Kingdom; [i]Museo Histórico Municipal de Villamartín, 11650 Villamartin, Spain; [j]Department of Plant Biology, University of Murcia, 30100 Murcia, Spain; and [k]Department of Evolutionary Ecology, Estación Biológica de Doñana, Consejo Superior de Investigaciones Científicas, 41092 Sevilla, Spain

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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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[1]To whom correspondence should be addressed. Email: clive.finlayson@gibmuseum.gi.

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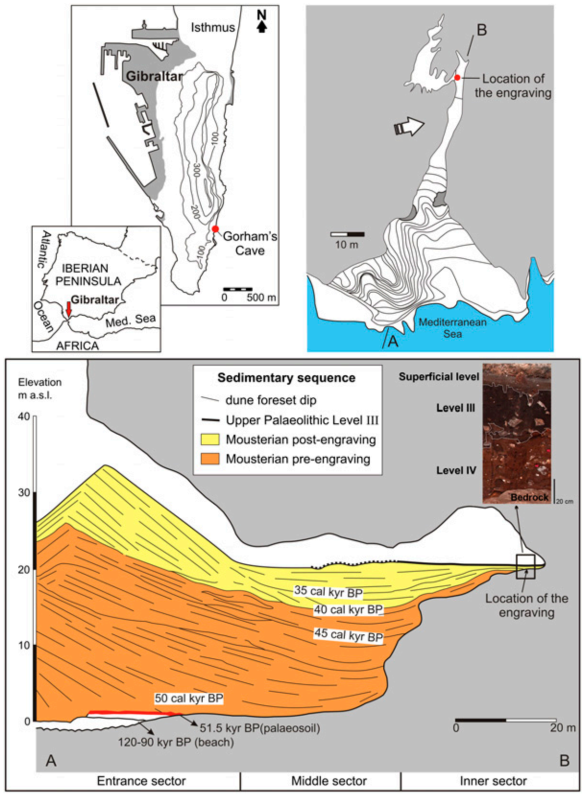

Fig. 1. Location of Gorham's Cave, Gibraltar, in the Iberian Peninsula and schematic map of the Gibraltar Peninsula with altitudes and contours at 100-m intervals (*Upper Left*), topographic plan of Gorham's Cave showing the location of the engraving (*Upper Right*), and interpretative geological section 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 Palaolithic 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}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^2 natural platform of the bedrock elevated 40 cm over the cave floor (*SI Appendix*, Fig. S5). Covering an area of ∼300 cm^2, it consists of eight deeply engraved lines (L1–L8) forming an incomplete crisscross 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

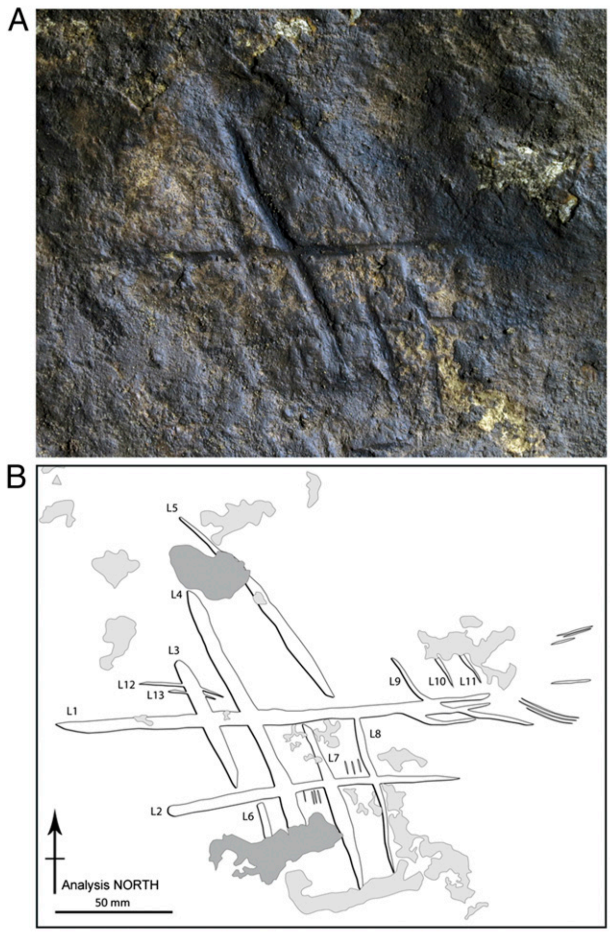

Fig. 2. (*A*) Engraving from Gorham's Cave. (*B*) Engraved lines L1–L13. Dark gray and light gray identify old and recent breaks, respectively. (*SI Appendix*, Fig. S21 shows the order of the engraving lines, breaks, and formation of the duricrust.) Note that the "Analysis North" shown here was used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

contain a substantial proportion of calcite and dolomite coming from the substrate, along with neoformation of hydroxylapatite [$Ca_5(PO_4)_3OH$]. Layer 3 is a duricrust composed of Mn-rich hydroxylapatite [$Mn_2Ca_3(PO_4)_3OH$] (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

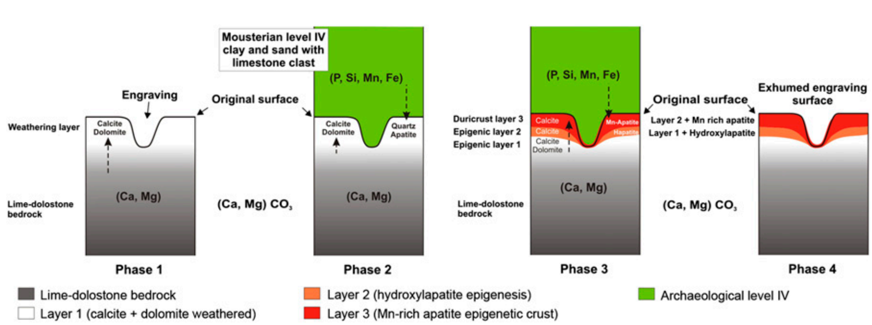

Fig. 3. Formation of the three layers of rock alteration in which the engraving is located. Phase 1 refers to the process of alteration by weathering of the exposed lime-dolostone surface (layer 1). The archaeological engraved marks were made on this weathered (soft) surface, which was covered by the 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).

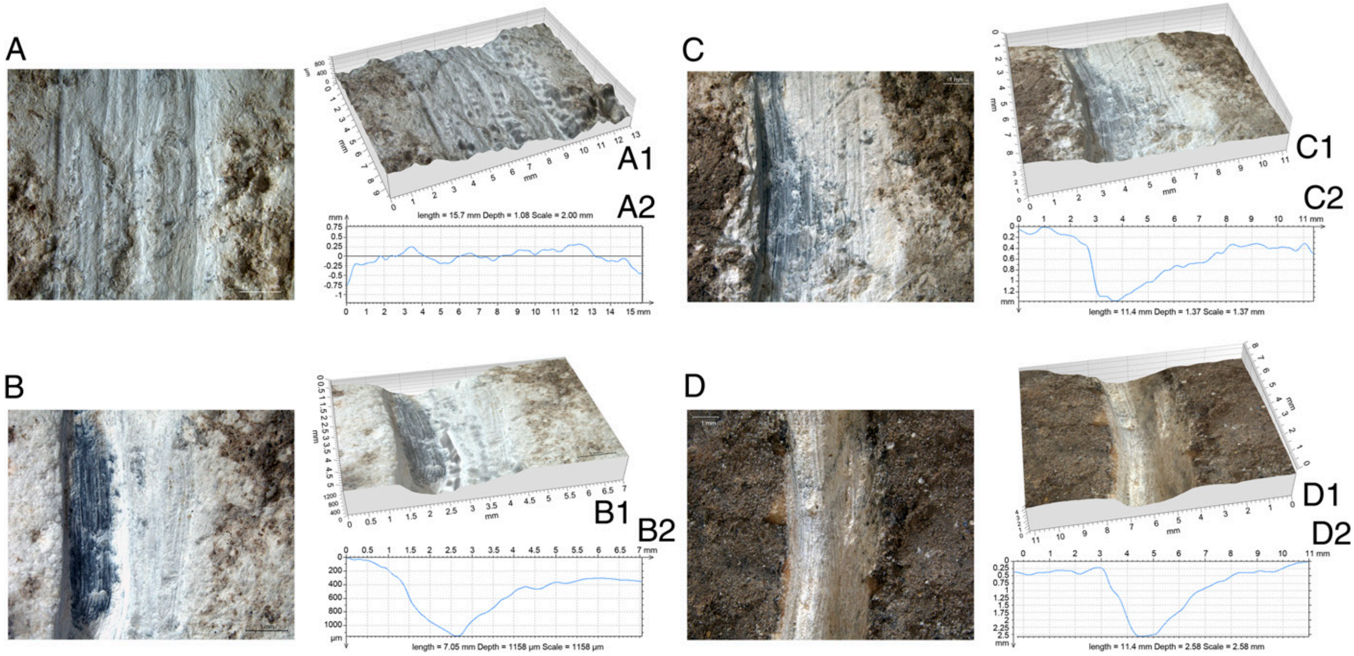
Fig. 4. Microphotographs (*A–D*), 3D reconstructions (*A1–D1*), and sections of lines (*A2–D2*) engraved by experimental tools 1 (*A*), 2 (*B*), 3 (*C*), and 4 (*D*). (Scale bar: 1 mm.)

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

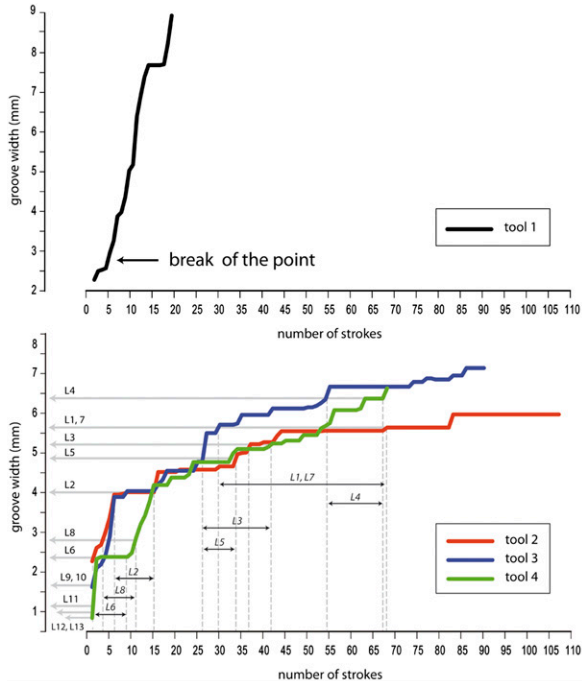

Fig. 5. Changes in the maximum width of experimental multiple stroke lines produced by four experimental tools when the tool tip was repeatedly passed into the groove in the same direction (*SI Appendix*, Tables S4 and S5). (*Upper*) Graph illustrating the rapid increase in groove width occurring after 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 CuKα radiation at 40 kV and 30 mÅ. Randomly oriented powders were scanned from 3° to 65° 2θ 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° 2θ 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 20× to 160×. 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. The widths obtained with this method were verified by comparing them with those measured on photos of the archaeological engraving.

ACKNOWLEDGMENTS. We thank Philip Kenny for illustrating Fig. S5 (*SI Appendix*), and Montserrat Montcusí (Universitat Rovira i Virgili) and Juan C. Fernández-Caliani (Universidad de Huelva) for help with the geochemical analyses. The excavations and scientific research associated with Gorham's Cave and Vanguard Cave were funded by Her Majesty's Government of Gibraltar. This research also was supported by funding from the Spanish Ministry of Science and Innovation (Projects CGL2010-15810/BTE, CGL2012-38434-C03-03, CGL2012-38358, CGL-BOS-2012-34717, and OAPN 261/211), Generalitat de Catalunya (Project 2014 SGR 900), the European Research Council (Program FP7/2007/2013, TRACSYMBOLS 249587), Marine International Campus of Excellence (CEIMAR), and Project Origines II, Aquitaine Region. R.B. is the recipient of a Beatriu de Pinós postdoctoral research fellowship (Generalitat de Catalunya and COFUND Marie Curie Actions, EU-FP7).

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Supporting Information

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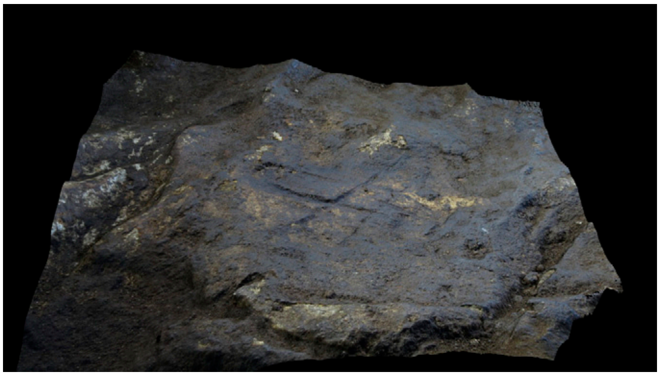


Movie S1. Three-dimensional model for the Gorham's engraving generated and mapped using Agisoft Photoscan Standard Edition (44 pictures, 220,000 points, 10,000,000 faces). The sections and measurements were processed with TIVMI (http://projets.pacea.u-bordeaux.fr/TIVMI/). The 3D video was created using Autodesk 3ds Max and Adobe Premiere Pro CC.

Movie S1

Other Supporting Information Files

SI Appendix (PDF)

A rock engraving made by Neanderthals in Gibraltar

Joaquín Rodríguez-Vidal, Francesco d'Errico, Francisco Giles Pacheco, Ruth Blasco, Jordi Rosell, Richard Jennings, Alain Queffelec, Geraldine Finlayson, Darren A. Fa, José María Gutiérrez López, José S. Carrión, Juan José Negro, Stewart Finlayson, Luís M. Cáceres, Marco A. Bernal, Santiago Fernández Jiménez, Clive Finlayson

Supporting Information Appendix

- Supplementary text 1

- Figures S1-S21

- Tables S1-S5

- Supplementary references

Supplementary text

Text S1. Lithic assemblage from Gorham's Cave level IV

Level IV was first excavated between 1997 and 2005, when 222 lithics were recovered. See (S1) for a detailed description of this assemblage and (S2) for a discussion of its stratigraphic context. Level IV was excavated again in 2011 and 2012, when 72 additional lithics were found.

Description of the lithic assemblage

In total, 294 lithics have been recovered in Level IV to date. They include 21 cores, 155 flakes, 10 retouched flakes, 20 flake fragments, and 20 pieces of debitage (Table S2). Sixty-six nodules, two thirds of which were made of quartzite, must have been intentionally brought into the cave since they are absent in the compact dolomite composing the cave walls. Flint dominates the assemblage (42%). Of the 155 flakes, 95 are made on flint, 55 on quartzite, and 5 on radiolarite. Three types of flint featured in the assemblage: grey-green, black and red. Radiolarite chert is present in low proportion. These raw materials are common around the Rock of Gibraltar. Similar nodules of sandstone, quartzite and quartz to those used in the cave can be found in the alluvial-marine formations outcropping along the coastline and river mouth basins near the Rock. On the other hand, flint comes from different seams within the Rock. In summary, all the raw materials are autochthonous and were probably collected at fossil beaches near the caves (S3-S6).

Two core types were recorded in Level IV (Table S2): Levallois (n = 3), Discoidal (n = 7). Two of the Levallois cores, made on a fine-grained quartzite and flint, are recurrent centripetal. One of these is made on a flake fragment. The centripetal technique was preferentially applied to rounded pebbles.

The flakes are almost exclusively non-cortical, suggesting that primary lithic reduction did not occur at the rear of the cave. More than half have unifacial striking platforms, followed by bifacial and multifacial forms. The high number of unifacial platforms is indicative of discoidal reduction methods, while the presence of bifacial and multifacial platforms is indicative of the Levallois method (S7, S8). There is high variability in the morphology of the striking platforms. The straight striking surfaces are the most common followed by the single-angle striking surfaces. The bulbs on the ventral surface share almost equal proportions of marked and diffused forms. The negative scars on the dorsal surface indicate the presence of pseudo-Levallois and Levallois centripetal lithic reduction both for flint and sandstone, with some flaking planes forming cutting edges that are very suitable for use. Small and medium sized flakes dominate the assemblage. The blade index (S9) is low with flint being the dominant raw material present as blades.

The proportion of tools in the assemblage is low (10/294). Medium or large sized flakes were used to produce tools. Six were made on flint and four on quartzite. There are two abrupts, two notches, two denticulates, and four side-scrapers, including a transverse form and a side-transverse scraper with worked cutting edges that come to a point. Two side-scrapers are shaped on Levallois points using simple retouch. Both are made on flint. The notches are made on the ventral side of quartzite pieces, while the denticulates exhibit simple, deep and direct retouch on the left side in one piece and on the transverse side in the other. Pacheco et al (S1) also recorded one quartzite and one limestone unifacial chopper.

Raw material variability does not drive platform shape or the alteration of the dorsal surface, and these two main raw material types are fine grained and could be knapped in a similar manner.

<u>Interpretation of the lithic assemblage</u>

A number of diagnostic features undoubtedly attribute Level IV lithics to the Mousterian: 1) preferential Levallois and discoidal lithic reduction techniques, demonstrated by the presence of ten cores, unifacial, bifacial and multifacial platforms on two thirds of the flakes, and centripetal Levallois flakes and points; 2) low laminar index and medium-small size flakes; 3) presence of typical side scrapers, denticulates and notches; 4) absence of stone tools with diagnostic Upper Palaeolithic forms such as those recovered in overlying Solutrean and

Magdalenian levels. The paucity of cores and cortical flakes indicates that primary reduction did not take place in the rear of the cave. This activity may have occurred near or at the front of the cave, or at a raw material source. The presence of un-retouched flakes and the small number of cores in the assemblage indicates that secondary reduction took place at the back of the cave to produce side scrapers, denticulates and notches. The medium-small size of the blank and retouched tools is due to the size of available raw material rather than exhaustion. Considering that the Mousterian in Iberia and elsewhere in Europe is only associated with Neanderthals, we conclude that the lithics from Gorham's Cave level IV reflect Neanderthal use of the rear of this cavity.

Supplementary Figures

Figure S1. Tectonic and solution-etched cracks on the exposed surfaces of the fine-grained lime-dolostone of the Gorham’s Cave walls. These cracks have also been observed in the older surfaces of bedrock that were covered by Pleistocene sediments, and also by alteration layers. The plot shows the clear difference in width/depth ratio between the archaeological engraved lines and natural cracks. Grey dots represent superficial lines whose depth, ranging between 200μm and 700μm, could not be precisely measured. The results show that there is no statistically significant difference in the width of natural cracks and the archaeological lines but that the width of the superficial lines is significantly lower than the other two. On the other hand, there is a statistically significant difference between the depth of the natural cracks and that of the engraving, which are shallower. The depth of the superficial engraved lines is statistically significantly even shallower than either the engraving or the natural cracks: 1) natural cracks –blue dots (width): mean=4.4372 (95% CL 4.0162-4.8581); 2) natural cracks –blue dots (depth): mean = 19.7 (95% CL 17.74-21.66); 3) anthropogenic engraved lines –red dots (width): mean = 5.2717 (95% CL 4.6163-5.927); 4) anthropogenic engraved lines –red dots (depth): mean = 1.18 (95% CL 0.822-1.538); 5) superficial anthropogenic engraved lines –grey dots (width): mean = 1.6286 (95% CL 1.0847-2.1725); and 6) superficial anthropogenic engraved lines –grey dots (depth): mean = 0.236 (95% CL 0.187-0.285).

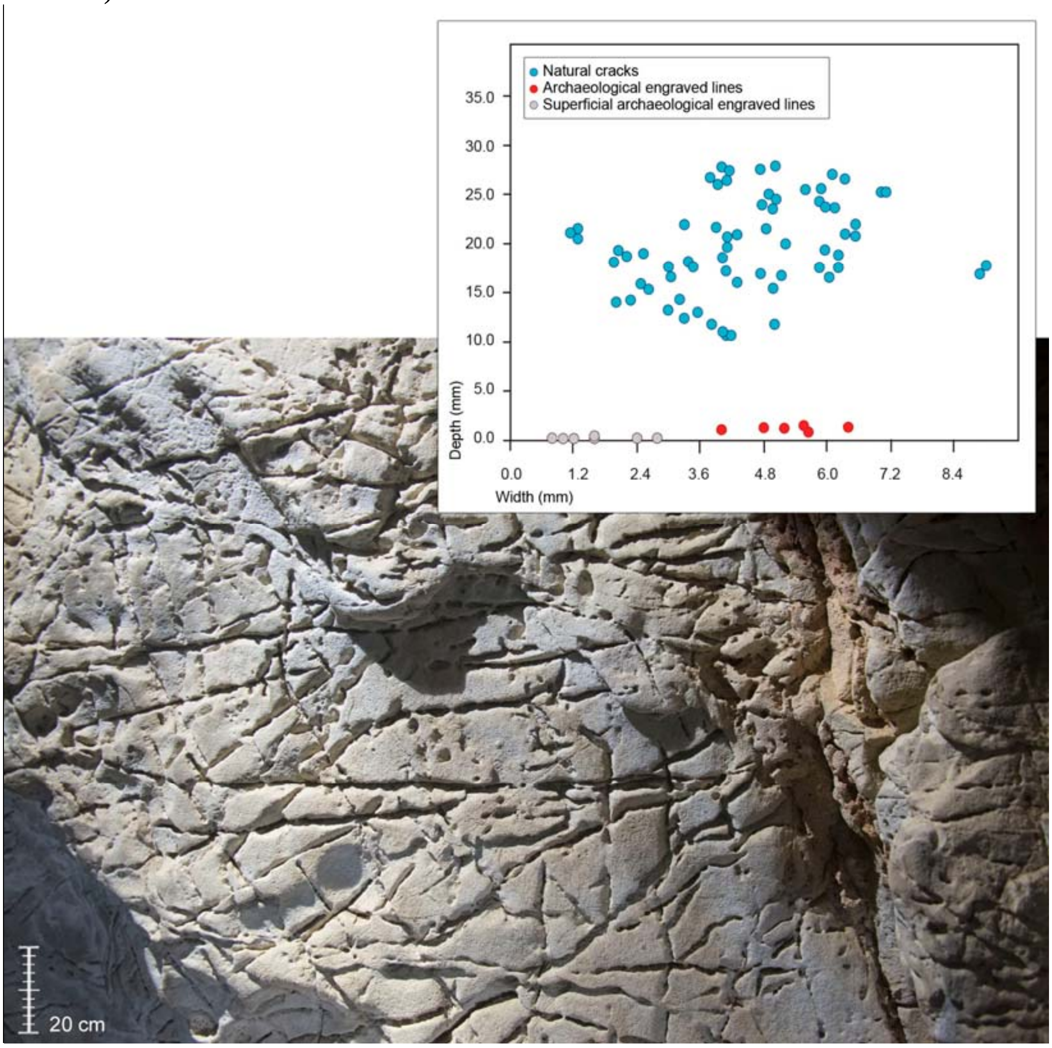


Figure S2. Mousterian tools from Level IV of Gorham's Cave: 1) GOR'05-AA5-IV-38/ Coarse-grained quartzite; 2) GOR'05-AA5-IV-38/ Coarse-grained quartzite; 3) GOR'05-AA5-IV-46/flint; 4) GOR'05-AA5-IV-46/flint; 5) GOR'05-A6-IV-95/flint; 6) GOR'07-AA5-IV-2/flint.

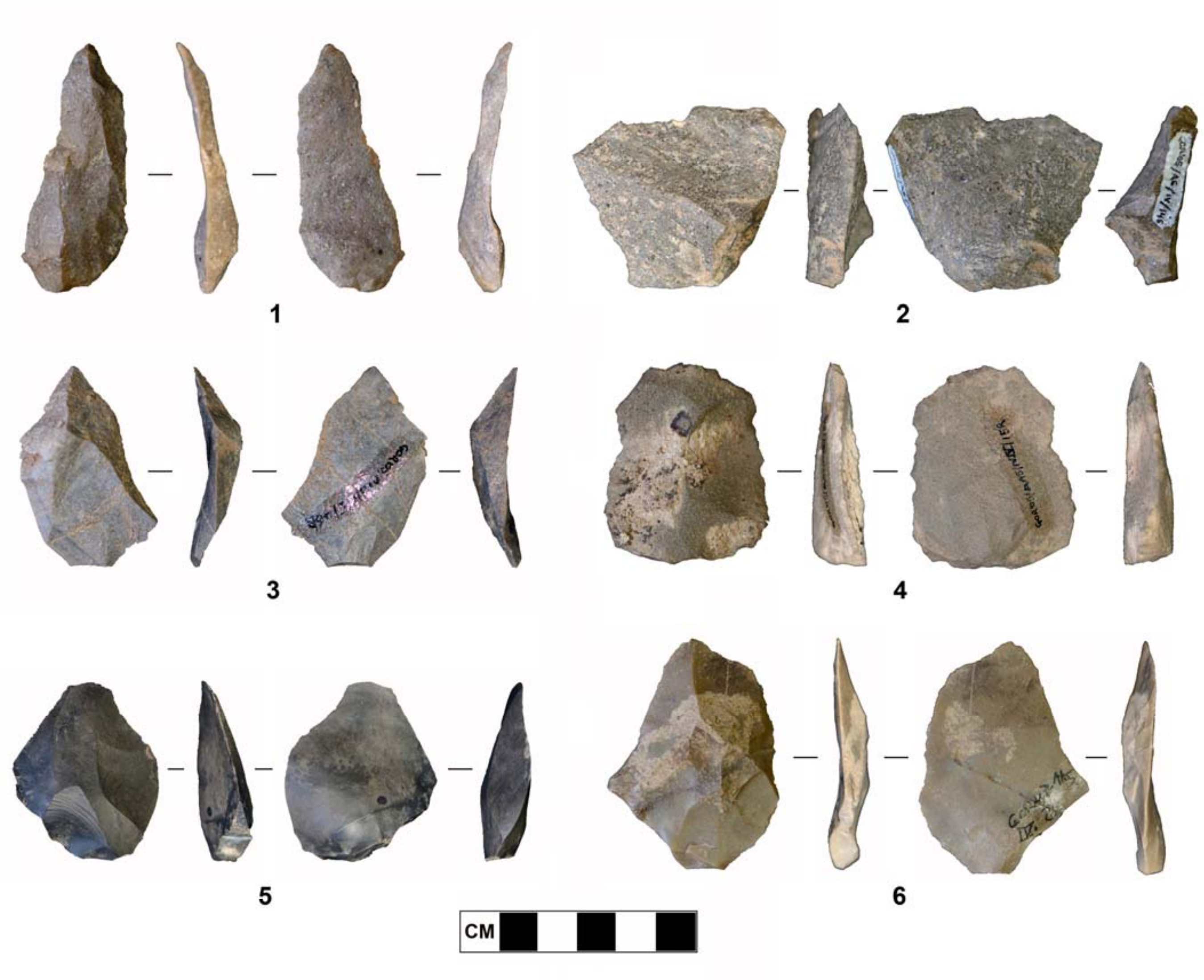


Figure S3. Typical Solutrean tools from Gorham's Cave Level III: Unifacial tools (1 to 3), bifacial laurel-leaf point (4), tanged points (6-8), bifacial pedunculate point (5). All are made on flint.

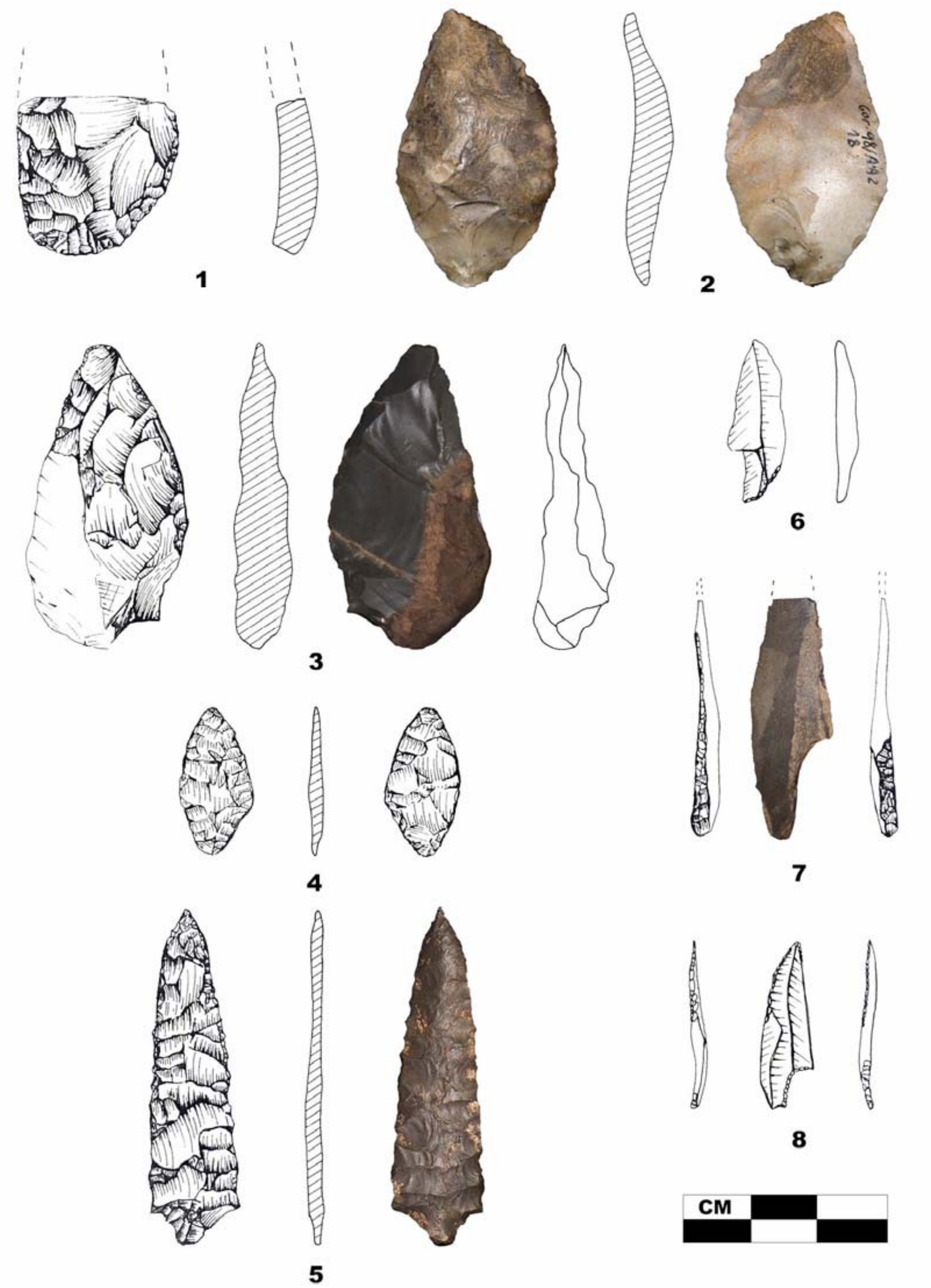


Figure S4. Vertical distribution of Mousterian and Solutrean lithic artifacts located 45 cm either side of the N-S profile above the engraving. The dotted line identifies the limit between levels IV and III. The engraving was covered by ~ 40 cm of sediment belonging to level IV.

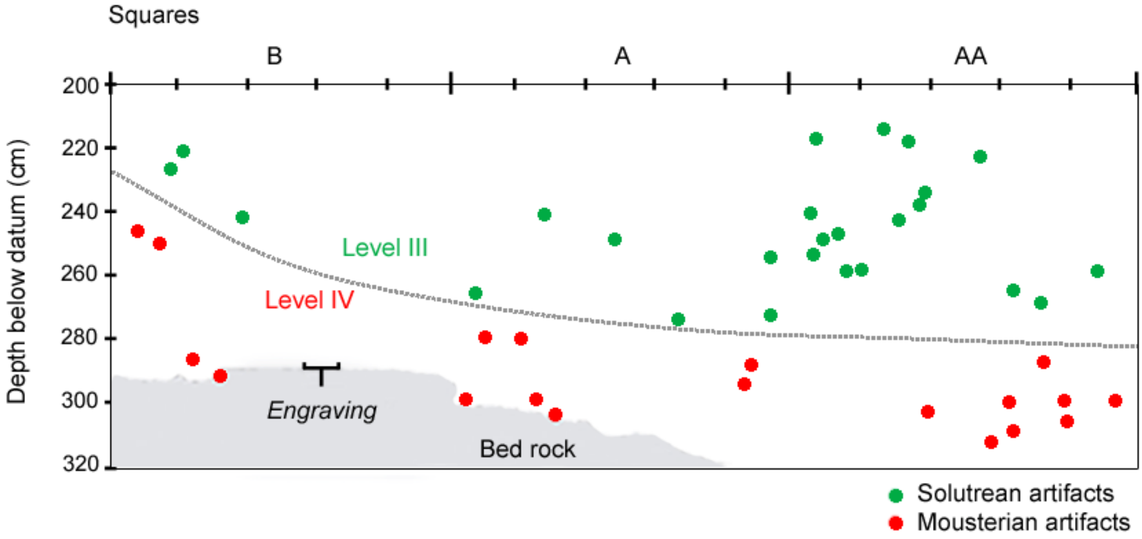


Figure S5. (A) Plan of the Upper Gallery in Gorham’s Cave showing the location of the engraving. (B) Section of the cave drawn in (A) indicating the location of main archaeological levels on the exposed profiles, the reconstructed limit between level III and IV, and the location of the engraving. (C) photo showing, from the bottom to the top, the engraving (circled), the exposed bedrock, and level IV. Notice an *in situ* Levallois core partially exposed on level IV profile.

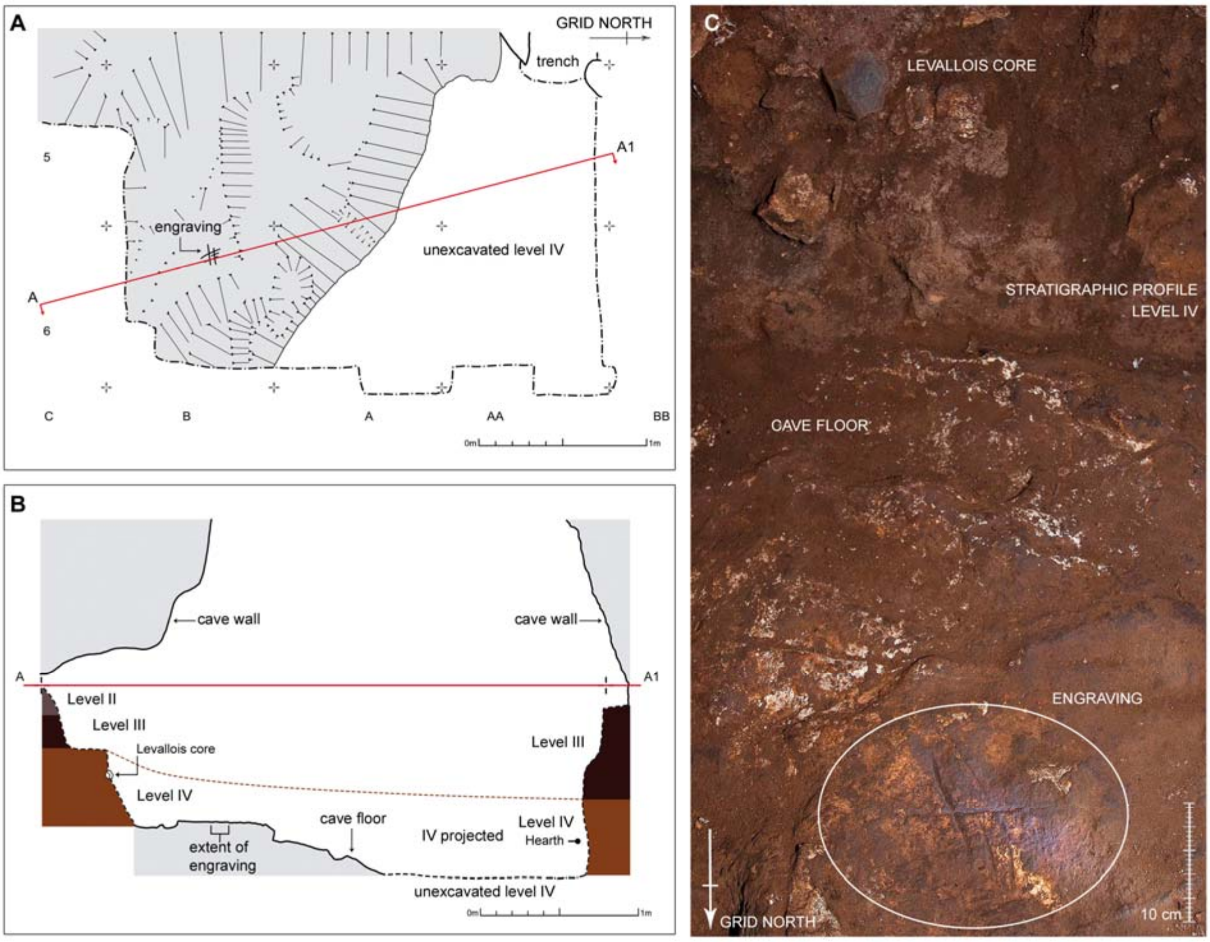


Figure S6. Detail of the duricrust damaged by desquamations showing three microscopic layers of alteration: a white lower layer (layer 1), a light brown intermediate layer (layer 2), and an upper black layer (layer 3).

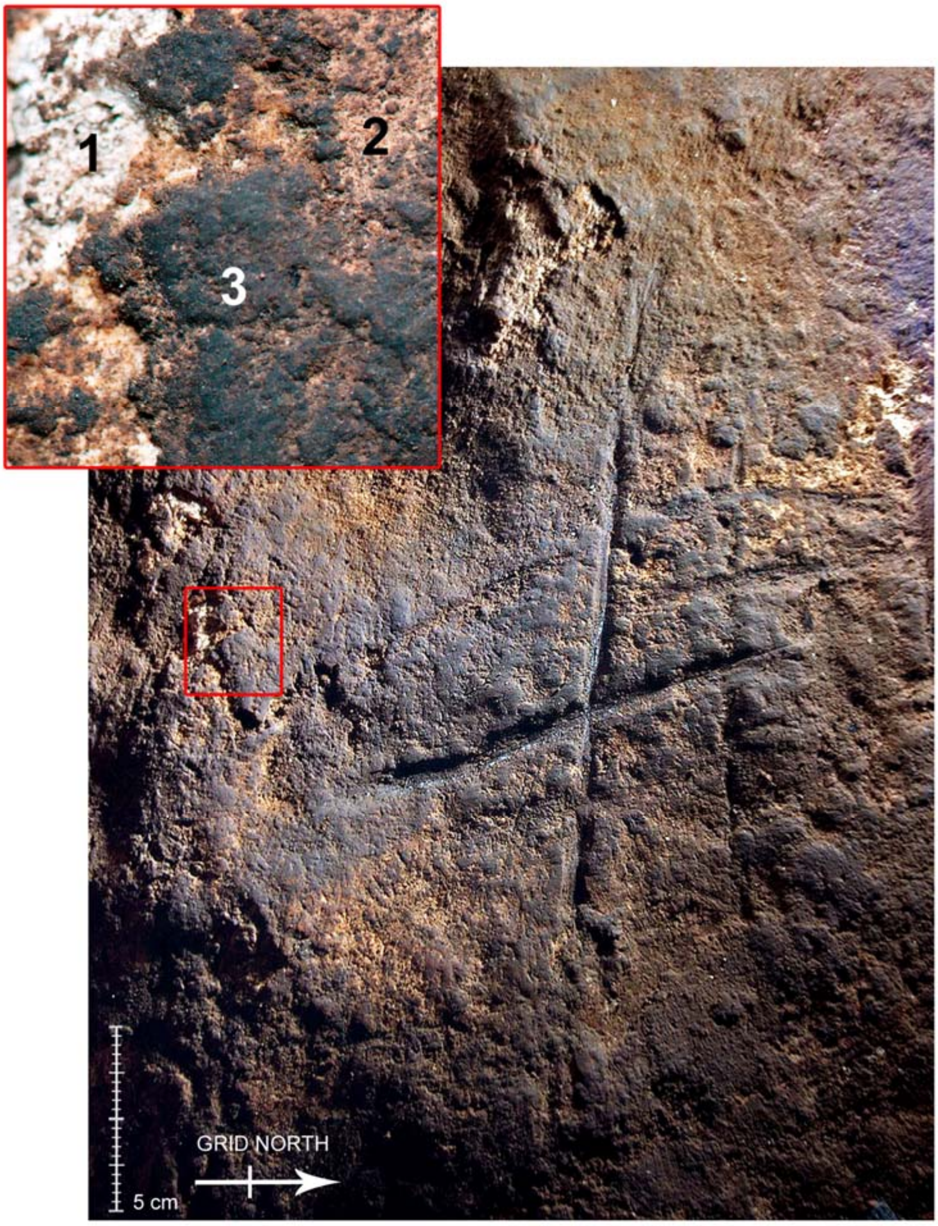


Figure S7. X-ray Diffraction (XRD) analysis showing the mineralogical composition of white layer 1, orange-brown layer 2, and black layer 3

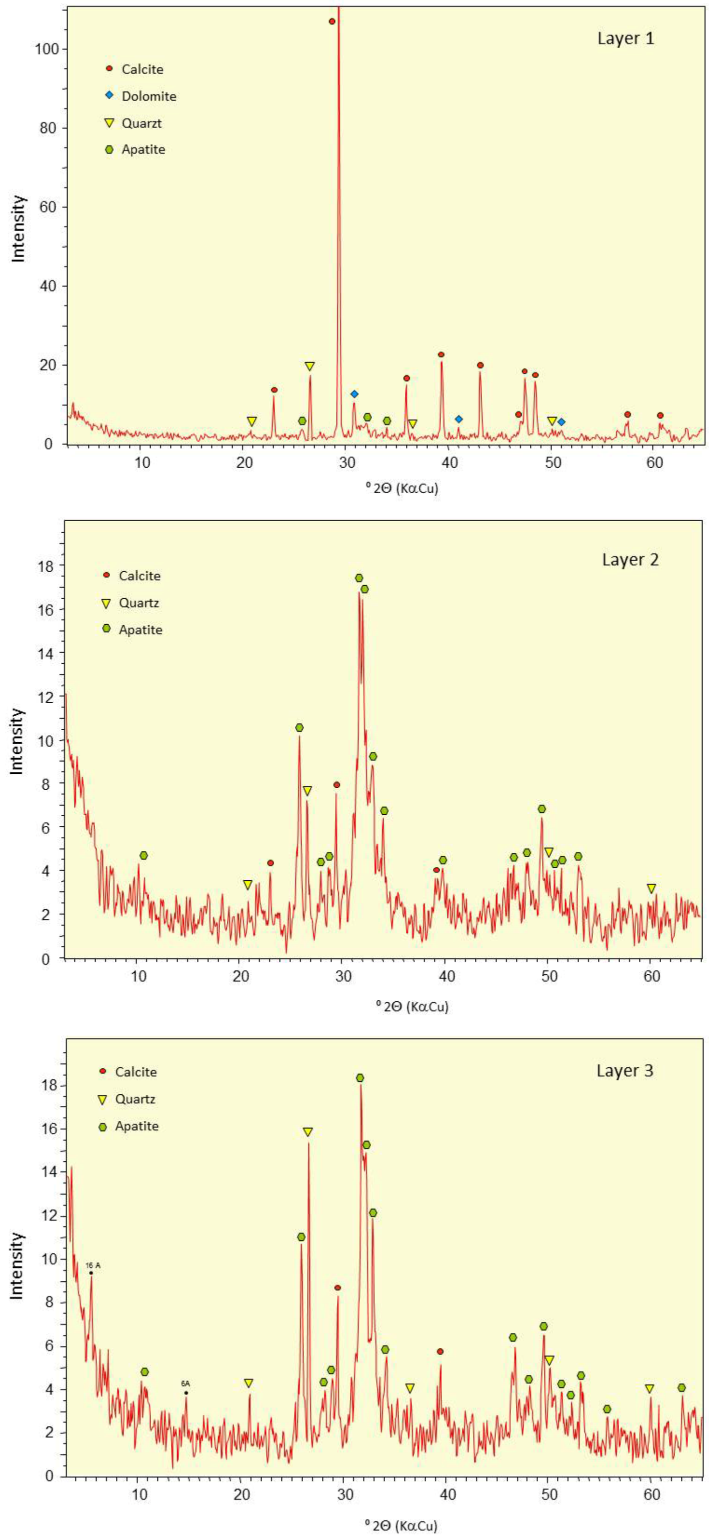


Figure S8. Scanning Electron Microscope (SEM) images and Energy Dispersive Spectrometry (EDS) analyses of the alteration layers: (A) Back-scattered image of the transition between the light brown layer 2 (at the top) and the duricrust layer 3 (at the bottom), (B) secondary electron image of white layer 1, and (C) secondary electron image of black layer 3.

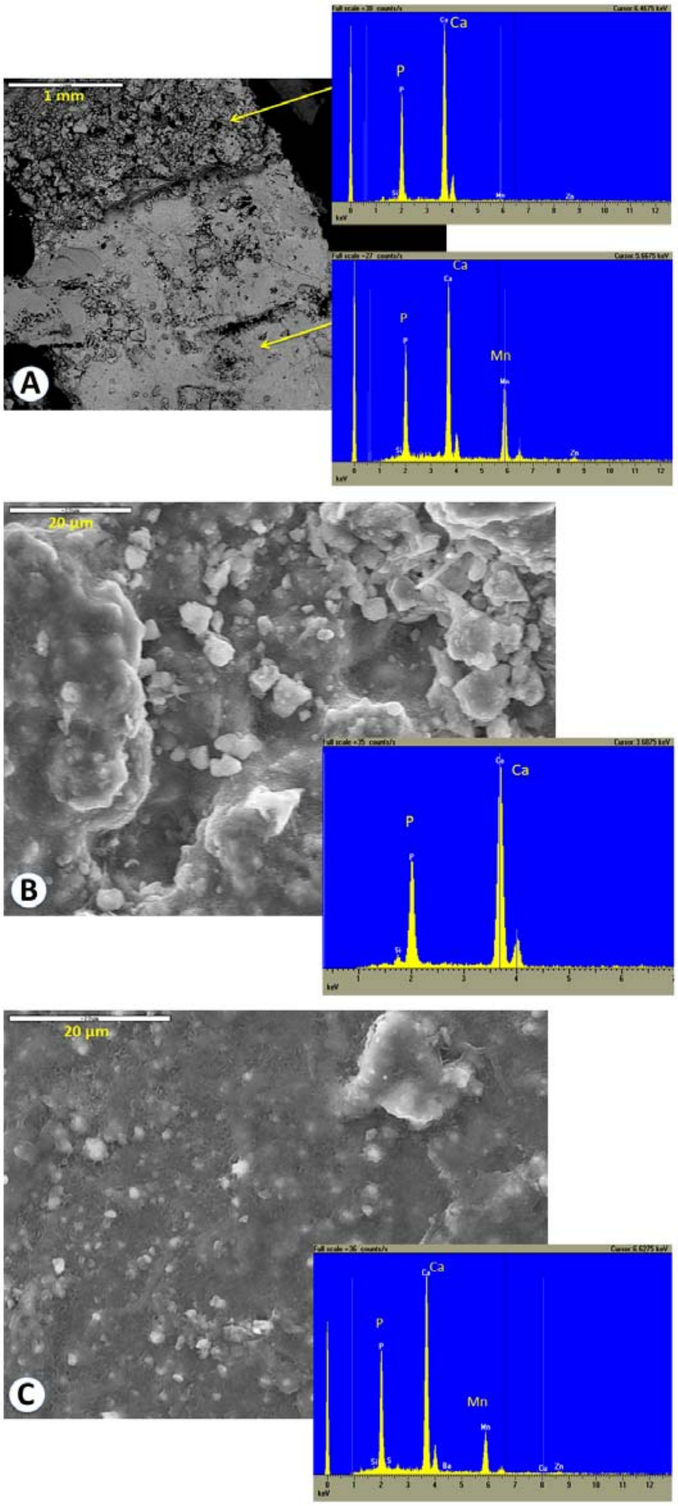


Figure S9. Stone tools used to experimentally engrave weathered blocks of lime-dolostone. The hatched lines indicate the area of the tools which were active during the engraving process (see Table S4 for a description of the tools and actions).

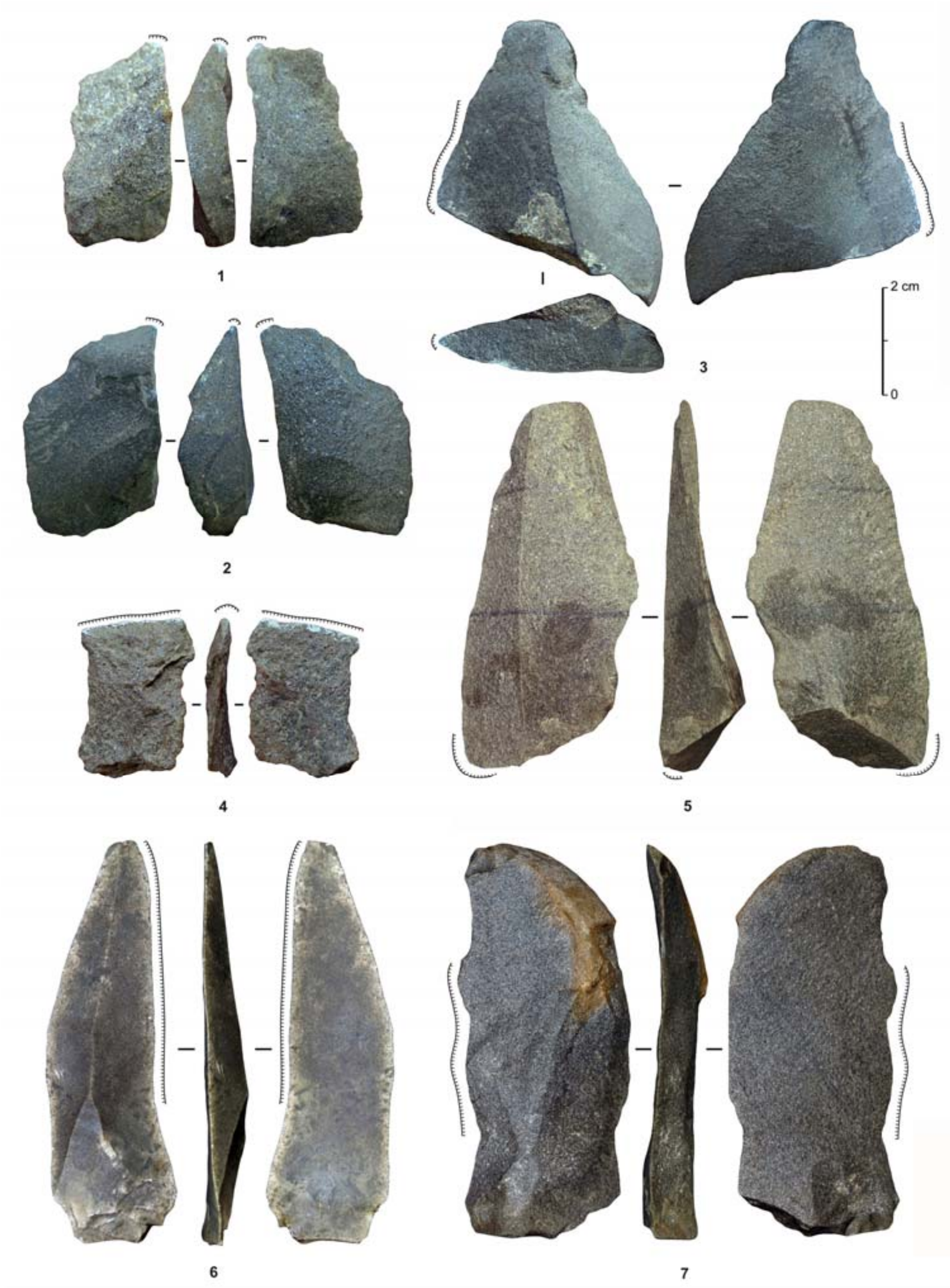


Figure S10. Incisions produced experimentally when cutting a fresh pork skin on a weathered block of lime-dolostone with a flint (left) and a microquartzite (right) blade (left: experimental tool n. 6; right: experimental tool n. 7, see Table S4). Scale bar = 1 cm.

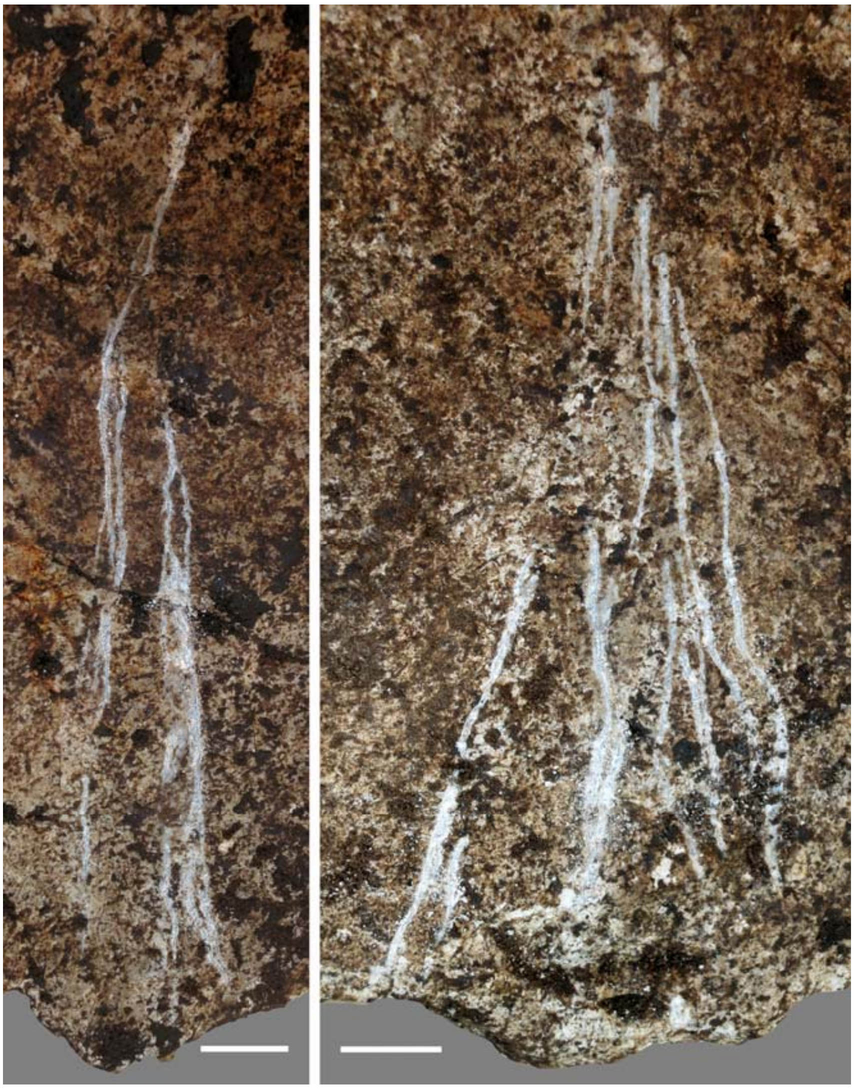


Figure S11. Experimental multiple stroke lines engraved by repeatedly passing the tool tip into the groove in the same direction (from top to bottom). Numbers indentify the tools used (see Figure S9 and Table S4). Scale bar = 1 cm.

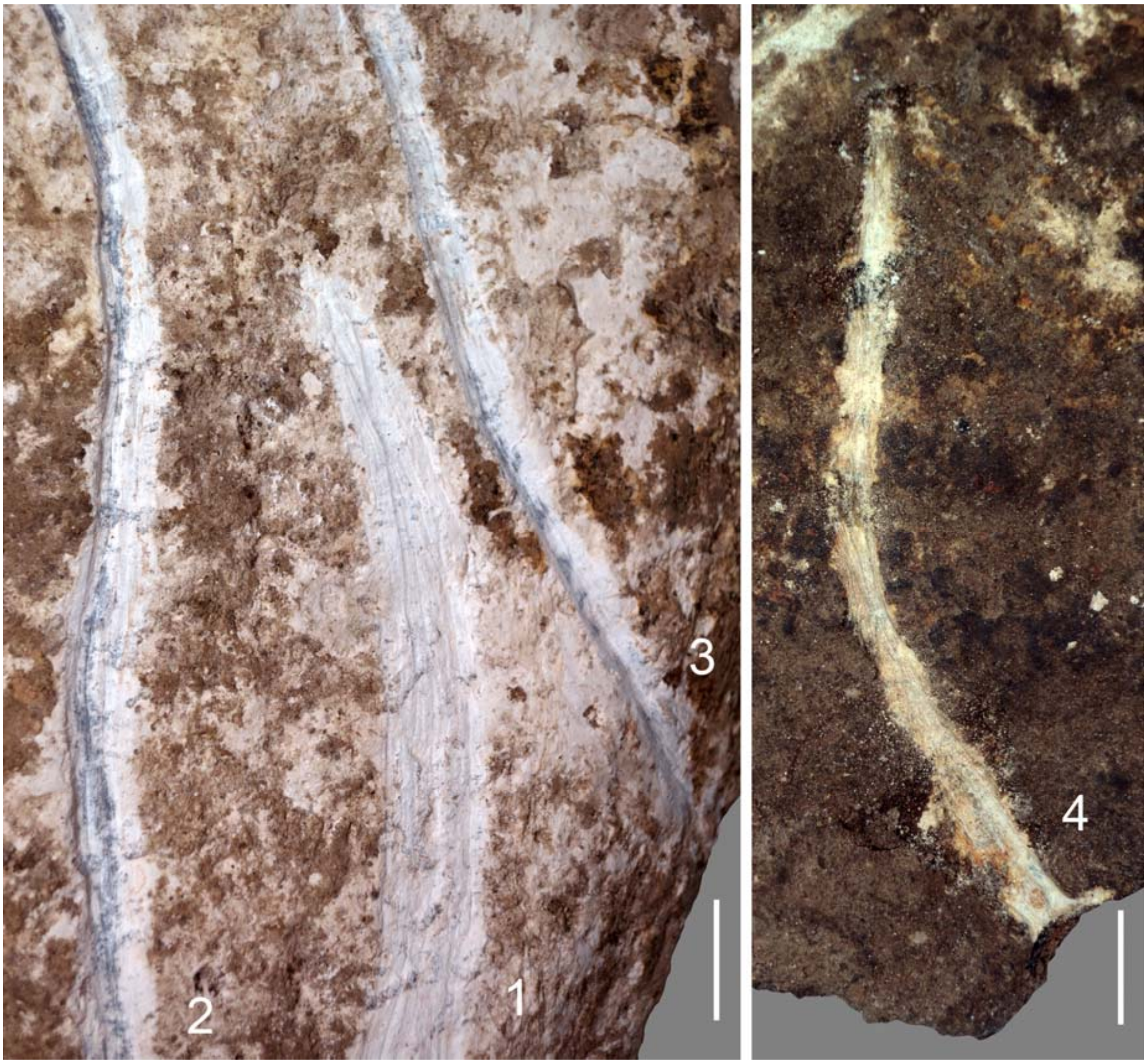


Figure S12. Sections of the lines composing the Gorham's Cave engraving, reconstructed from the 3D model of the engraved surface.

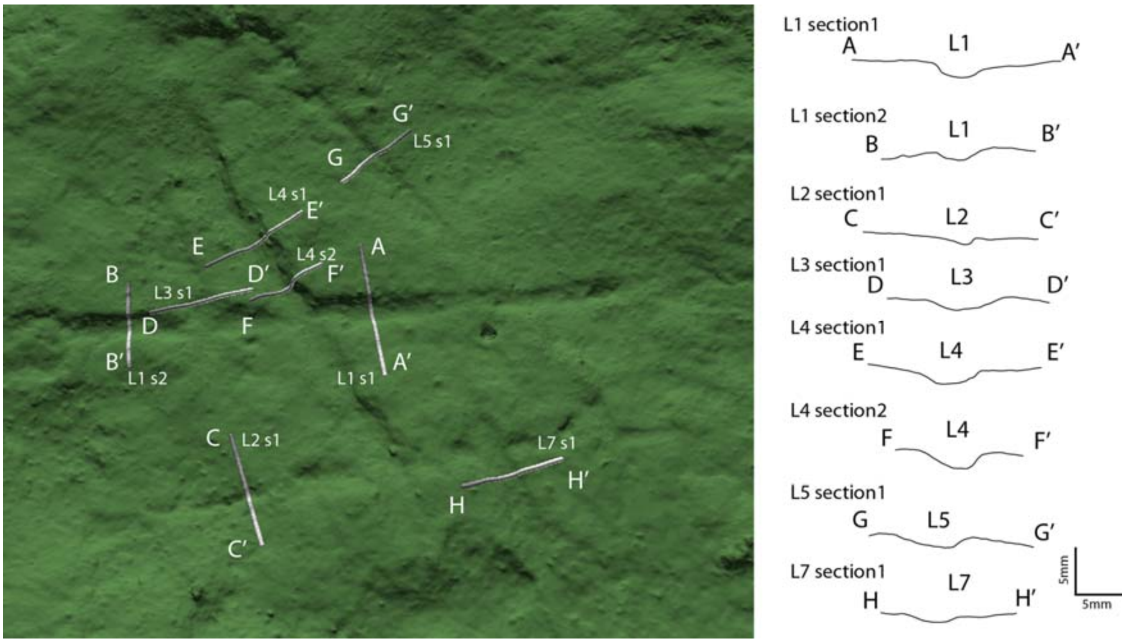


Figure S13. Photo of the engraving with location and number of the microscopic images presented in the Supplementary figures S14-S20.

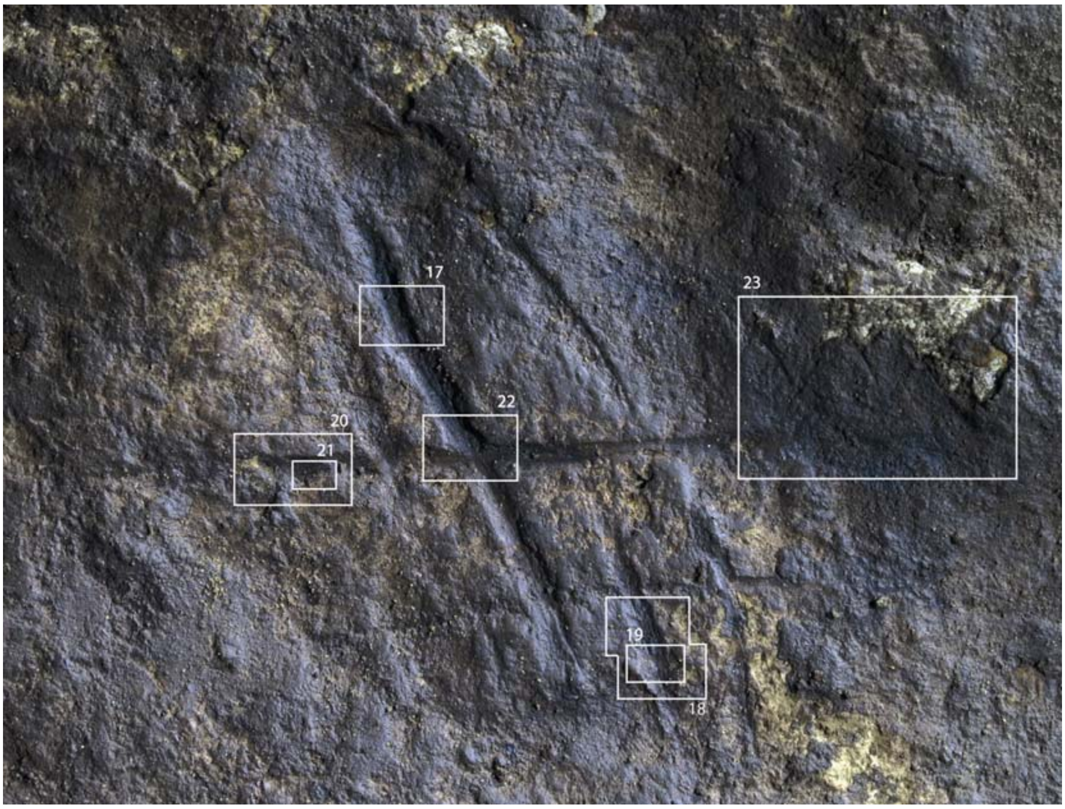


Figure S14. Close-up view of line L4 showing the morphology of the groove and internal subparallel striations hardened by the duricrust. Scale = 1 mm.

Figure S15. Close-up view of line L7 showing the morphology of the groove and, at places, the remnants of subparallel striations hardened by the duricrust as well as areas outside the groove with discontinuous duricrust. Scale = 1 mm.

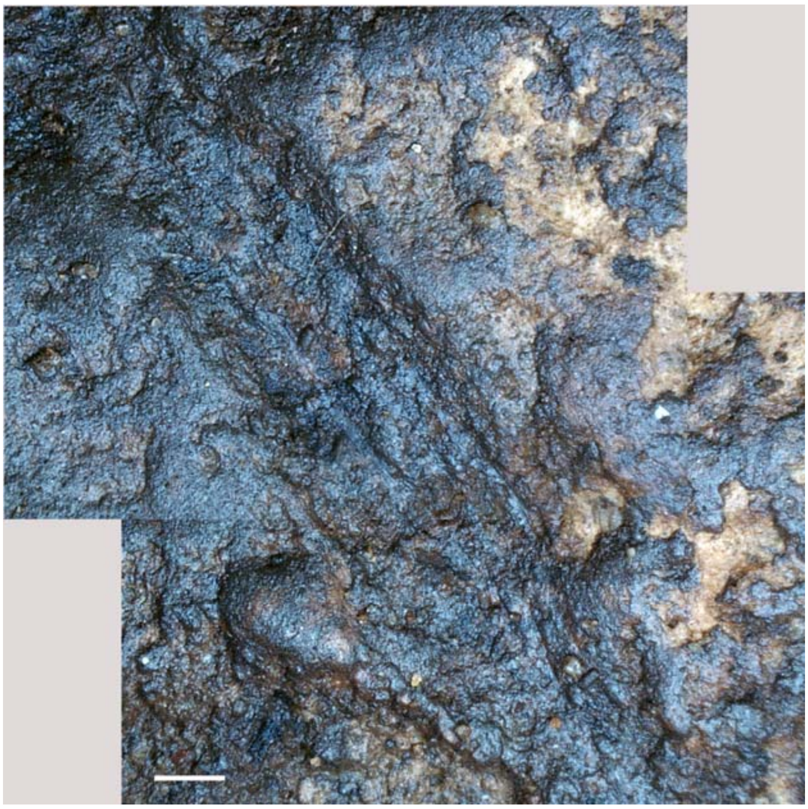


Figure S16. Detail of Figure S15 revealing local scalloping of the groove bottom and area displaying well preserved striations produced by protrusions of the tool tip during its displacement into the groove. See Figure 4 for comparable features on experimental engraving. Scale = 1 mm.

Figure S17. Close-up view of line L1 showing the flat bottom of the groove and a localized damage of the duricrust exposing the underline lime-dolostone. Scale = 1 mm.

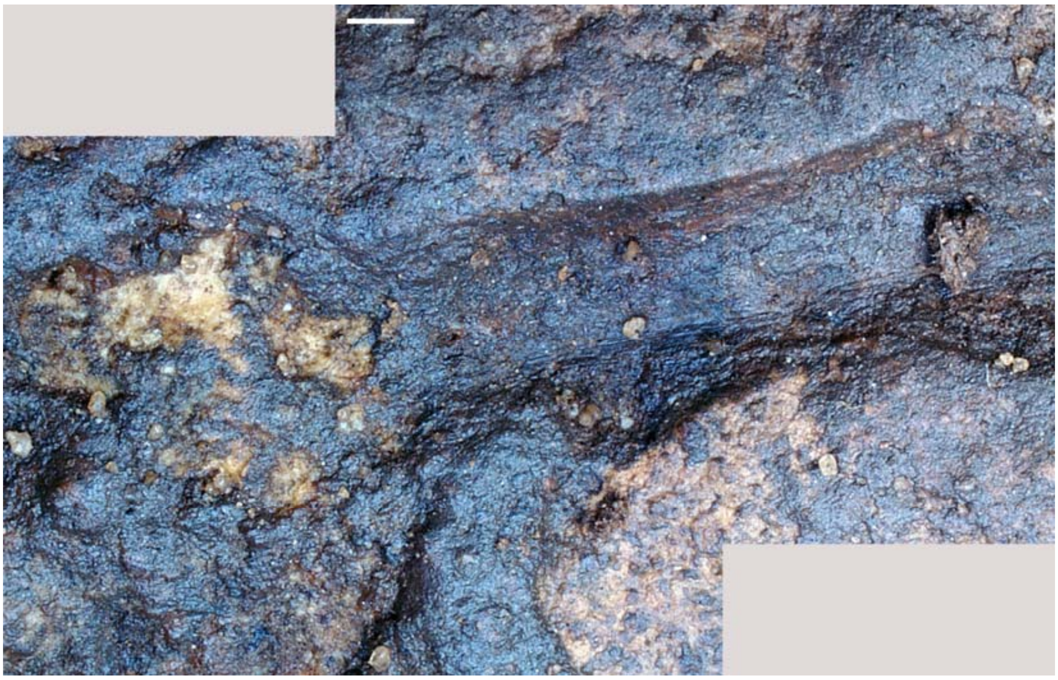


Figure S18. Detail of Figure S17 revealing well preserved striations hardened by the duricrust. See Figure 4 for comparable features on experimental engraving. Scale = 1 mm.

Figure S19. Close-up view of the crossing of lines L1 and L4 revealing the presence of a single stroke line engraved, at the end of the engraving process, in L1. Scale = 1 mm.

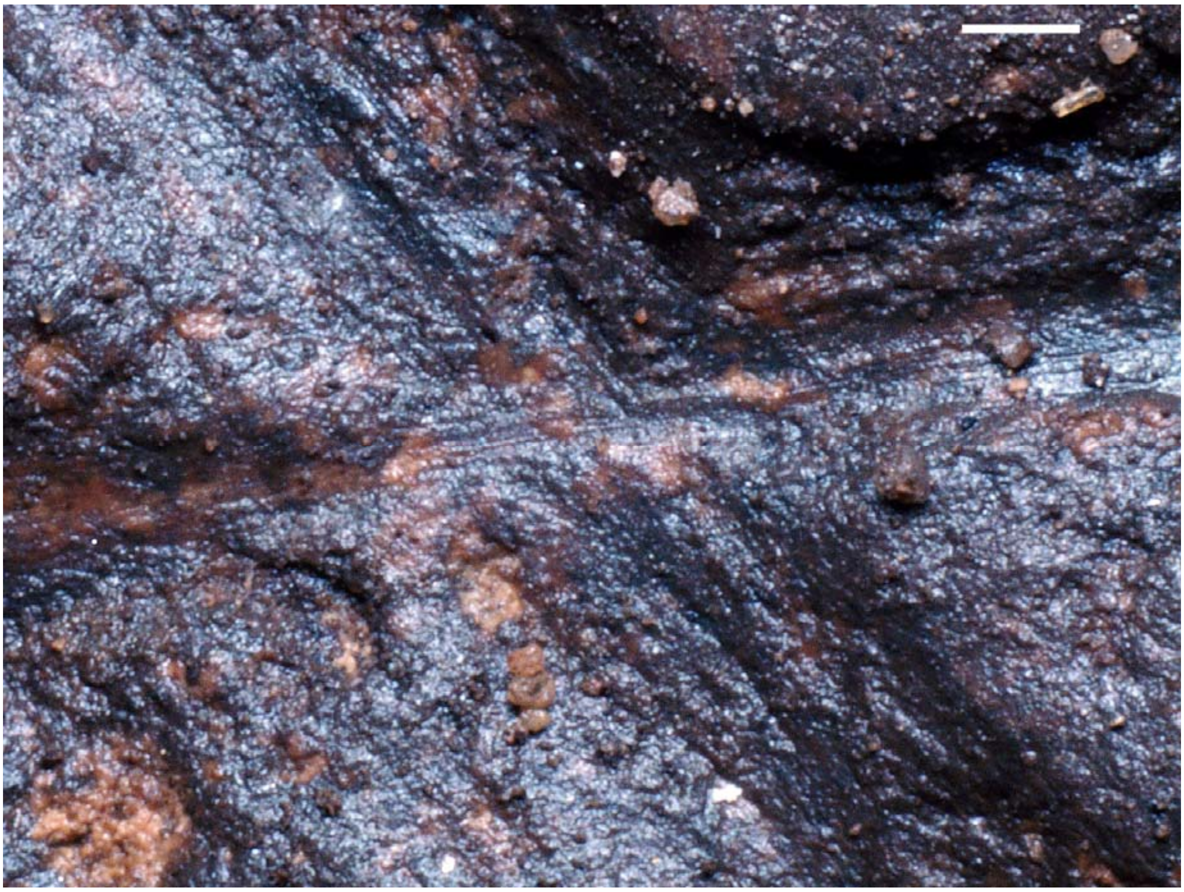
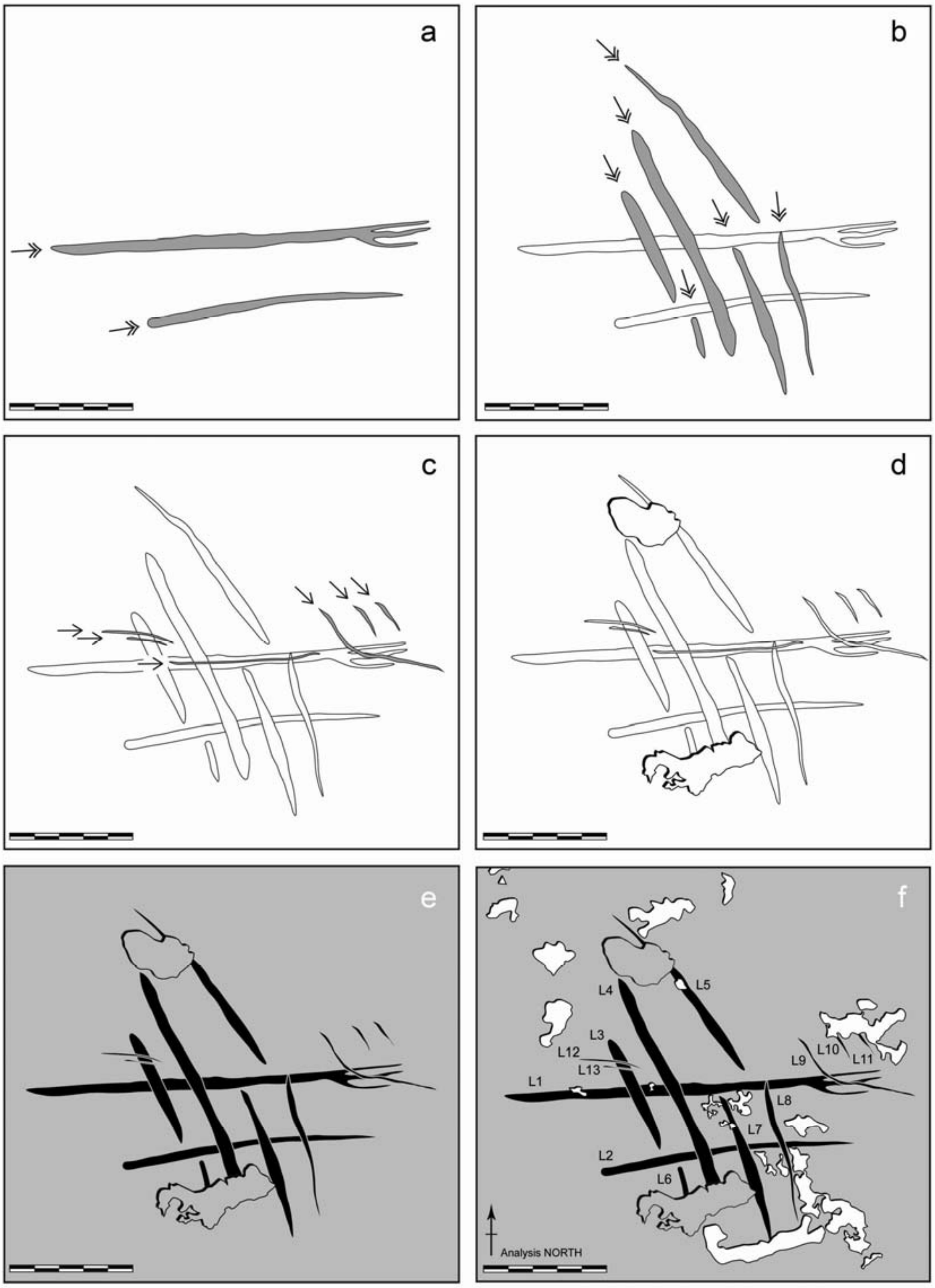


Figure S20. Macrophoto of lines L9-11 and crossing of L9 and L1. Notice a) the removal of the duricrust (top right) damaging L10 and L11 and demonstrating their antiquity, b) the obliteration of L9 and fringes at the end of L1 by the duricrust, c) the slenderness and similar internal morphology of L9-11 suggesting single strokes made by the same tool in rapid succession, d) change of direction of L9 when crossing L1 suggesting the tool was displaced from top left to down right. Scale = 1 cm.

Figure S21. Sketch summarising the order of the engraving lines, breaks, and formation of the duricrust. Engraved lines belonging to a new engraving episode are in grey, breaks in white. Arrows indicate the direction of the tool. Simple head arrows indicate single stroke lines, double arrows multiple stroke lines in one direction. Gray background in “e” identifies the formation of the duricrust. Scale = 5 cm.



Supplementary Tables

Table S1. AMS ^{14}C dates from level IV of Gorham's Cave (data from Finlayson et al. 2006 - ref.29 in the manuscript).

Lab. Code	Material	Conventional radiocarbon age yr BP	$\delta^{13}C$ (‰)	Cal. age yr BP IntCal09 (2σ)
B-196785	charcoal	26,070±180	-25.6	30,440-31,120
B-196773	charcoal	26,400±220	-23.2	30,620-31,290
B-238791	charcoal (H)	26,470±220	-24	30,690-31,320
B-185344	charcoal	27,020±240	-25	31,050-31,620
B-185346	charcoal	27,280±220	-	31,140-31,890
B-238784	charcoal (H)	27,930±250	*	31,470-32,880
B-196770	charcoal	28,170±240	-25.9	31,630-33,130
B-196784	charcoal	28,360±240	-26.1	31,810-33,340
B-196791	charcoal	28,570±240	-25.2	31,930-33,930
B-238792	charcoal (H)	28,800±280	*	32,430-34,500
B-184048	charcoal	29,210±190	-25.2	33,300-34,540
B-184049	charcoal	29,240±190	-	33,320-34,550
B-238785	charcoal (H)	29,280±280	-26.3	33,230-34,620
B-238781	charcoal (H)	29,320±300	-23.7	33,230-34,650
B-196779	charcoal	29,400±270	-25.4	33,330-34,660
B-196778	charcoal	29,720±280	-24.8	33,520-34,890
B-238782	charcoal (H)	29,750±330	-23.6	33,460-34,970
B-238787	charcoal (H)	29,760±310	-24.4	33,510-34,960
B-196786	charcoal	29,910±300	-24.7	33,690-35,080
B-196792	charcoal	30,310±310	-24.7	34,460-36,180
B-196776	charcoal	30,560±360	-24.5	34,570-36,270
B-238788	charcoal (H)	30,630±340	-24.6	34,610-36,270
B-184045	charcoal	31,110±230	-23.7	35,030-36,340
B-196768	charcoal	31,290±340	-25.8	35,050-36,510
B-196787	charcoal	31,480±370	-23.7	35,090-36,620
B-196772	charcoal	31,780±360	-23.1	35,180-36,900
B-196769	charcoal	31,850±380	-23.5	35,160-37,080
B-196789	charcoal	32,100±400	-24.5	35,300-37,710
B-196771	charcoal	32,560±390	-25.1	36,460-38,460

(*) the original sample was too small for a 13C/12C ratio measurement. However, a ratio including both natural and laboratory effects was measured during the ^{14}C detection to derive a Conventional Radiocarbon Age, suitable for applicable calendar calibration. (H) Hearth samples.

Table S2. Lithics recovered from Gorham's Cave Level IV.

Raw material	Nodule/NB	Levallois		Discoid		Retouched flakes	Cores[a]	Flakes[b]	Choppers	Flake fragments	Debris	Total
		Cores	Flakes	Cores	Flakes							
Fine-grained quartzite	3 (5)	1 (33)	8 (29)	3 (43)	26 (33)	4 (40)[c]	-	12 (26)	-	3 (15)	1 (5)	61 (21)
Coarse-grained quartzite	44 (67)	-	1 (4)	4 (57)	4 (5)	-	7 (64)	4 (9)	-	6 (30)	11 (55)	81 (28)
Flint	5 (8)	1 (33)	17 (61)	-	47 (59)	6 (60)[d]	2 (18)	31 (66)	-	6 (30)	8 (40)	123 (42)
Radiolarite	-	1 (33)	2 (7)	-	3 (4)	-	2 (18)	-	-	5 (25)	-	13 (4)
Other raw materials**	14 (21)	-	-	-	-	-	-	-	2 (100)	-	-	16 (5)
Total	66 (22)	3 (1)	28 (10)	7 (2)	80 (27)	10 (3)	11 (4)	47 (16)	2 (1)	20 (7)	20 (7)	294

Nodule/NB: Natural Base (unmodified lump of rock brought to the cave). Percentages are indicated in brackets.

[a] indeterminate debitage technique (e.g., exhausted core).

[b] limestone, dolomite, quartz, and quartzite.

[c] 1 side-scraper and 3 denticulates.

[d] 3 side-scrapers, 1 denticulate and 2 side-scrapers shaped on Levallois points using simple retouch.

Table S3. Lithic recovered from Gorham's Cave Level III (Solutrean).

		Fine-grained quartzite	Large-grained quartzite	Flint	Radiolarite	Other raw materials	Total
NB		45	2	2	1	9	59
NH	Core	5	4	2	-	1	12
	Flake	-	3	1	-	-	4
SP	Core	10	3	-	1	1	15
	Flake	-	-	8	-	-	8
OR	Core	2	-	1	-	-	3
	Flake	1	1	1	-	-	3
Tool type*	Side-scraper	-	-	1	-	-	1
	End-scraper	-	-	1	-	-	1
	Denticulate scraper	-	-	1	-	-	1
	Notches	-	-	2	-	-	2
	Shouldered blade	-	-	1	-	-	1
	Double-backed blade	-	-	1	-	-	1
	Shouldered backed point	-	-	1	-	-	1
	Tanged backed point	-	-	1	-	-	1
	Double-ended foliate point	-	-	1	-	-	1
	Bifacial foliate point	-	-	1	-	-	1
	Double-ended bifacial foliate point	-	-	1	-	-	1
	Tanged bifacial foliate point	-	-	1	-	-	1
Flake fragments		2	2	16	1	1	22
Debris		2	-	2	-	-	4
Total		67	15	46	3	12	143

NB: Natural Base (unmodified lump of rock brought to the cave, presenting in some cases evidence of utilisation as hammers); NH: Non-Hierarchical (cores with only one or two removals with no apparent predetermined knapping strategy; SP: Sub-Parallel (parallel removals on the longitudinal direction of the core); OR: Orthogonal (knapping planes are superimposed successively with scars of the preceding removal used as striking platforms of the following removal.

* tool type definition according to Laplace (S9, S10).

Table S4. Data on the experimental tools, the actions in which they were used, and the dimensions of the resulting engraved lines.

Tool n°	Raw material	Tool type	Activity	Active area	Orientation of the tool	Cutting angle (°)	Number of strokes	Fracture of the tool	Max width (mm)	Min width (mm)	Max depth (mm)
1	MQ	naturally pointed flake	MSL	flake distal end	perp. to ventral side	49	21	1 (6th)	2.35* 8.96**	1.45* 6.82**	0.5**
2	MQ	Levallois core rej. flake	MSL	flake distal end	perp. to core striking plat.	41	107	1 (1st)	2.27* 5.97**	1.53* 3.68**	1.2**
3	MQ	proximally broken flake	MSL	proximal break	perp. to break	37	90	-	1.62* 7.14**	0.6* 4.37**	1.3**
4	MQ	rectangular flake	MSL	distal cutting edge	parallel to distal CE	26	68	-	0.84* 6.63**	0.49* 3.49**	2.5**
5	MQ	laminar flake	TAF	flake butt	perpendicular to butt	na	~50	-	10.1	4.1	1.1
6	FL	blade	CS	lateral cutting edge	parallel to the lateral CE	na	9	-	0.45	0.30	0.3
7	MQ	blade	CS	lateral cutting edge	parallel to the lateral CE	na	9	-	1.2	0.6	0.3

MQ: microquartzite; FL: flint; MSL: multiple stroke line in one direction; TAF: to-and-fro motion; CS: cutting skin in one direction; perp: perpendicular; plat.: platform; CE: cutting edge; na: not applicable; rej: rejuvenation; * first stroke; ** last stroke

Table S5. Results of the morphometric and technological analysis of the lines composing the Gorham's Cave engraving (see Fig. 2 for line identification).

Line	Length (mm)	Max Width (mm)	Depth ** (mm)	Orientation	Technology	Direction (N-S-E-W)	Same tool	Min. Num. strokes ***	Max. Num. strokes***
1	168	5,6	1,39 / 1,06	horizontal	multiple stroke	W-E	-	30	68
2	112,5	4	0,69	horizontal	multiple stroke	W-E	-	7	15
3	55	5,2	1,14	oblique	multiple stroke	NW-SE	-	27	42
4	100*	6,4	1,45 / 1,93	oblique	multiple stroke	NW-SE	-	54	65
5	93	4,8	1,14	oblique	multiple stroke	NW-SE	-	27	34
6	15*	2,4	-	oblique	multiple stroke	NW-SE	-	4	9
7	69	5,6	0,79	oblique	multiple stroke	N-S	-	30	68
8	63	2,8	-	oblique	multiple stroke	NW-SE	-	4	11
9	78	1,6	-	oblique	single stroke	NW-SE	1	1	1
10	14*	1,6	-	oblique	single stroke	NW-SE	1	1	1
11	13*	1,2	-	oblique	single stroke	NW-SE	1	1	1
12	33	1	-	oblique	single stroke	NW-SE	2	1	1
13	17	0,8	-	oblique	single stroke	NW-SE	2	1	1

* lines damaged by breaks
** based on sections retrieved from the 3D reconstruction of the engraving
*** based on the maximum width of experimental engravings

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