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Authors
Hallett, Emily Y
Marean, Curtis W
Steele, Teresa E
et al.

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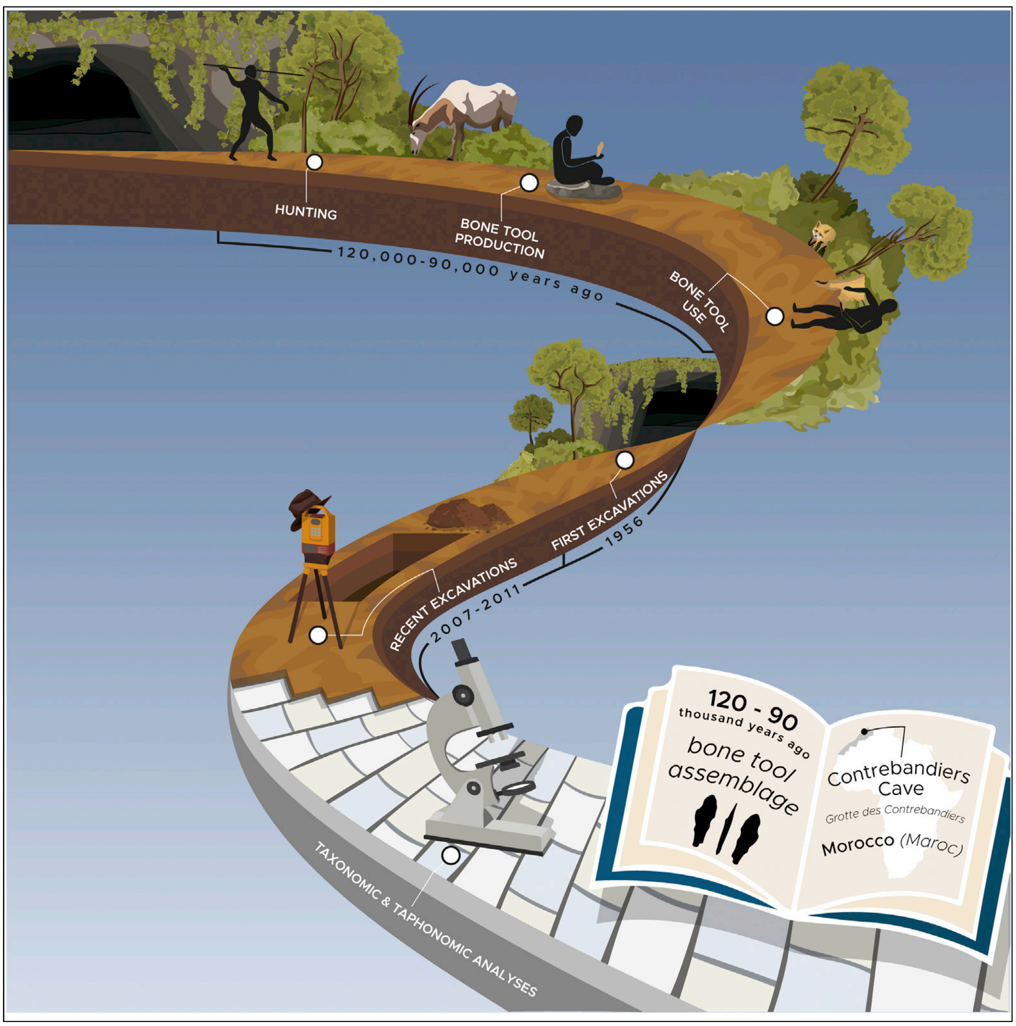

Emily Y. Hallett, Curtis W. Marean, Teresa E. Steele, ..., Deborah I. Olszewski, Mohamed Abdeljalil El Hajraoui, Harold L. Dibble

hallett@shh.mpg.de

Highlights

Bone tools from Contrebandiers Cave, Morocco, dated to 120,000 to 90,000 years ago

Bone tools likely used for leather and fur working, and other activities

Carnivore bones from cave show they were skinned for fur removal

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A worked bone assemblage from 120,000–90,000 year old deposits at Contrebandiers Cave, Atlantic Coast, Morocco

Emily Y. Hallett,[1,2,3,13,*] Curtis W. Marean,[2,3,4] Teresa E. Steele,[5,6] Esteban Álvarez-Fernández,[7] Zenobia Jacobs,[8] Jacopo Niccolò Cerasoni,[1] Vera Aldeias,[6,9] Eleanor M.L. Scerri,[1] Deborah I. Olszewski,[10] Mohamed Abdeljalil El Hajraoui,[11] and Harold L. Dibble[2,6,10,12]

SUMMARY

The emergence of *Homo sapiens* in Pleistocene Africa is associated with a profound reconfiguration of technology. Symbolic expression and personal ornamentation, new tool forms, and regional technological traditions are widely recognized as the earliest indicators of complex culture and cognition in humans. Here we describe a bone tool tradition from Contrebandiers Cave on the Atlantic coast of Morocco, dated between 120,000–90,000 years ago. The bone tools were produced for different activities, including likely leather and fur working, and were found in association with carnivore remains that were possibly skinned for fur. A cetacean tooth tip bears what is likely a combination of anthropogenic and non-anthropogenic modification and shows the use of a marine mammal tooth by early humans. The evidence from Contrebandiers Cave demonstrates that the pan-African emergence of complex culture included the use of multiple and diverse materials for specialized tool manufacture.

INTRODUCTION

Bones that were intentionally shaped and used as tools have been considered a hallmark of modern human behavior (d'Errico et al., 2012a) as they require substantial time and labor investments and elaborate production sequences (Henshilwood et al., 2001). Here we describe a bone tool assemblage likely used for leather and fur production from Contrebandiers Cave, dated to ∼120–90 thousand years (ka) ago. Clothing and fur were likely necessary in the expansion of *Homo sapiens* into cold habitats during the Pleistocene. However, fur and other organic clothing materials are extremely unlikely to preserve in the fossil record. Genetic studies of clothing lice suggest an origin for clothing as early as 170 ka ago with *H. sapiens* in Africa (Toups et al., 2011). In this article, we present evidence for fur removal found on carnivore bones dated to as early as 120 ka ago at Contrebandiers Cave in Morocco. The combination of carnivore bones with skinning marks and bone tools likely used for fur processing provide highly suggestive proxy evidence for the earliest clothing in the archaeological record.

Bone tools vary regionally and are typically described as either formal or informal. This study follows d'Errico et al.'s concise definition of formal bone tools as ''functional artifacts shaped with techniques specifically conceived for bone, such as scraping, grinding, grooving, and polishing'' (d'Errico et al., 2012a), and therefore we add that formal bone tools can be identified as such because they are also shaped pieces of bone, antler, ivory, or tooth that bear manufacture marks. Following Tartar's definition of intermediate bone tools as ''not formally worked and only recognizable by the percussion marks at their ends'' (Tartar, 2012), we add that informal bone tools are pieces of bone that were used without prior shaping and therefore do not bear manufacture marks.

Informal and formal bone tools appear in several Pleistocene archaeological sites in Africa and Europe, with the earliest evidence of bones used as tools to dig termite mounds (Backwell and d'Errico, 2001) dating to ∼2.0 million years (Ma) old (d'Errico and Backwell, 2003). At the site of Swartkrans, South Africa, four horn cores and one bone display grinding marks that suggest these digging tools were intentionally shaped and are therefore formal bone tools ranging in age from ∼1.8 to 1.0 Ma ago (d'Errico and Backwell, 2003).

[1]Pan-African Evolution Research Group, Max Planck Institute for the Science of Human History, 07745 Jena, Germany

[2]Institute of Human Origins, Arizona State University, Tempe, AZ 85287, USA

[3]School of Human Evolution and Social Change, Arizona State University, Tempe, AZ 85287, USA

[4]African Centre for Coastal Palaeoscience, Nelson Mandela University, Gqeberha, Eastern Cape 6031, South Africa

[5]Department of Anthropology, University of California at Davis, Davis, CA 95616, USA

[6]Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, 04103 Leipzig, Germany

[7]GIR PREHUSAL, Department of Prehistory, Ancient History and Archaeology, University of Salamanca, 37002 Salamanca, Spain

[8]Australian Research Council Centre of Excellence for Australian Biodiversity and Centre for Archaeological Science, School of Earth, Atmospheric and Life Sciences, University of Wollongong, Wollongong, NSW 2522, Australia

[9]Interdisciplinary Center for Archaeology and the Evolution of Human Behaviour, University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

[10]Department of Anthropology, University of Pennsylvania, Philadelphia, PA 19104, USA

[11]Institut National des Sciences de l'Archéologie et

Continued

However, the majority of bone tools from the Earlier Stone Age of southern Africa were not intentionally shaped, although they do appear to have been used for a variety of tasks (Stammers et al., 2018). In addition, bone tools shaped using methods often applied to stone—such as hammerstone percussion for flake removal—are found in Olduvai Beds I and II in Tanzania and are dated to ~2.0–1.8 Ma ago (Deino, 2012) and 1.338 ± 0.024 Ma ago (Domínguez-Rodrigo et al., 2013), respectively. An additional five bone tools from Olduvai Beds II-IV likewise exhibit shaping methods conceived for stone, and one bone tool from site WK East A, Olduvai Bed IV (0.93–0.8 Ma) is a preform of a barbed point that was likely shaped through scraping (Pante et al., 2020). A bifacially flaked handaxe made on the bone fragment of a large mammal was discovered in Acheulean contexts dated to 1.4 Ma from Konso, Ethiopia (Sano et al., 2020), and bone tools shaped through hammerstone percussion also appear in Acheulean contexts (Saccà, 2012) dated to ~327–260 ka ago (Michel et al., 2008) during the Middle Pleistocene in Italy. Bones used as tools have been documented in Marine Isotope Stage 9 Middle Pleistocene deposits from Schöningen 12 II in Germany (Julien et al., 2015). From the Middle Paleolithic of France, five formal bone tools manufactured by Neanderthals are known from two sites dated to ~50–45 ka (Soressi et al., 2013; Martisius et al., 2020). Soressi et al. describe *lissoir* formal bone tools made by Neanderthals in Europe and interpret these *lissoirs* as being used as leather working tools (Soressi et al., 2013).

Formal bone tools begin to appear occasionally in the Middle Stone Age archaeological records in Africa, but consistent bone tool manufacture and diverse bone and antler tool types are not typically found until ~48 ka ago, during the Upper Paleolithic of Eurasia (Hublin et al., 2020; Langley et al., 2020) and ~44 ka ago during the Later Stone Age of Africa (d'Errico et al., 2012b). Three formal bone tools were described from Broken Hill cave in Zambia and include two "gouges" and one bone point (Barham et al., 2002). The dating of deposits remains unresolved at Broken Hill, Zambia, but indirect dating in combination with problematic direct dating suggests that the Broken Hill formal bone tools are ~300–130 ka old (Barham et al., 2002). In Central Africa, formal bone tools from three MSA sites at Katanda, Democratic Republic of the Congo, include 12 barbed and unbarbed points and one "dagger-like" object from sites dated to 82 ± 8 ka ago (Feathers and Migliorini, 2001; Yellen et al., 1995), although the associations have been questioned (Klein, 2009). The oldest formal bone tools from Southern Africa are from Klasies River Main site in Cave 1A and include three notched artifacts that were most likely used for a range of activities, including animal skin and plant processing (Bradfield and Wurz, 2020). The Klasies River Main site notched bone tools have a likely minimum age of ~100 ka, as the dated overlain deposits have a U-series age from stalagmite of 85–101 ka (Bradfield and Wurz, 2020; Vogel, 2001). In addition, a bone point used as a hafted arrowhead was identified in Klasies River Main Cave 1 is from layer 19, directly below layers dated to 63.4 ± 2.6 ka (Bradfield et al., 2020; Jacobs and Roberts, 2008). The Blombos Cave assemblage in South Africa originally described in 2001 included 28 formal bone tools classified as "awls" and "points" from layers dated to ~71 ka ago (Henshilwood et al., 2001). Follow-up studies have revealed an additional nine pieces at Blombos (d'Errico and Henshilwood, 2007), and improved chronologies estimate the age of the bone tool-bearing layers to be ~80 ka (Jacobs et al., 2013). In addition, a bird bone that was shaped into an awl was recovered from the M3 archaeostratigraphic phase at Blombos, which has been dated to ~125 ka ago or older (d'Errico and Henshilwood, 2007). The Sibudu assemblage in South Africa contains two formal bone tools from layers dated to 72.5 ± 2 ka ago that include one wedge and one notched piece (d'Errico et al., 2012a). There are also 21 formal bone tools at Sibudu that are dated to ~64–57 ka ago (d'Errico et al., 2012a). Finally, in North Africa, a formal "bone knife" tool from Dar es-Soltan I cave was identified in Aterian deposits dated to ~90 ka ago (Bouzouggar et al., 2018) and "spatule" bone tools from Aterian deposits have been identified at El Mnasra (El Hajraoui, 1993, 1994; El Hajraoui and Debénath, 2012).

When comparing early formal and informal bone tool assemblages from Africa and Eurasia to those from the later African MSA ~100 ka, it is clear that the latter are: (1) geographically more widespread, (2) include greater numbers of them, and (3) reveal a higher diversity of types. However, it is not until the African Later Stone Age (~44 ka ago) (d'Errico et al., 2012b) and Eurasian Upper Palaeolithic (~48 ka ago) (Hublin et al., 2020; Langley et al., 2020) that there is an explosion of diverse and more elaborate bone tool forms.

Contrebandiers Cave (33°55′18.2″N, 6°57′42.4″W) is located on the Atlantic coast of Morocco (Figure 1), some 250 meters (m) from the current coast. Cut into Pleistocene calcarenites, it is 30 m deep with an entrance 28 m wide. Originally excavated in the 1950s and 1970s by Abbé Roche, a new Moroccan-American joint excavation began in 2007 directed by Harold Dibble and Mohamed Abdeljalil El Hajraoui

du Patrimoine, 10001 Rabat, Morocco
[12]Deceased June 10, 2018
[13]Lead contact
*Correspondence: hallett@shh.mpg.de
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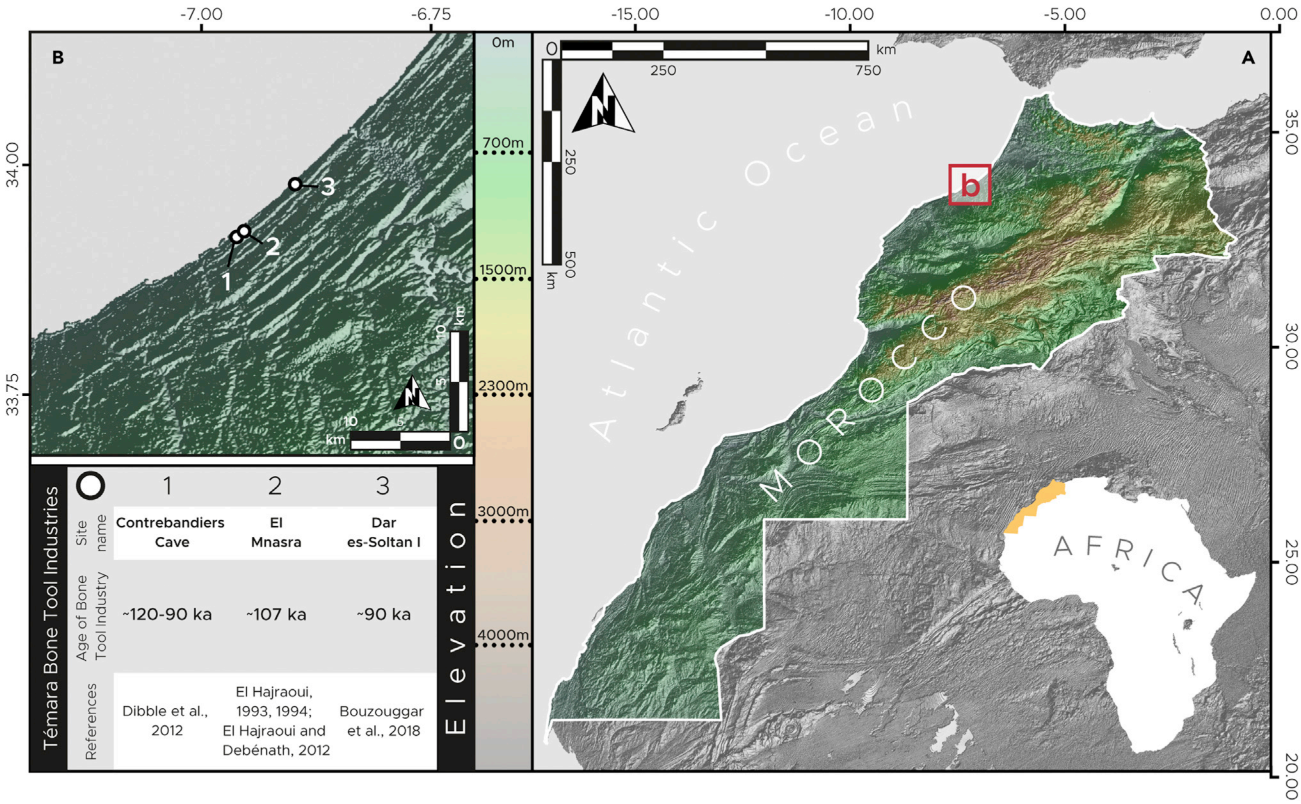

Figure 1. Contrebandiers Cave, El Mnasra, and Dar es-Soltan I are coastal caves with bone tools in stratified archaeological deposits in the Témara region of Morocco. Elevation map of Morocco, where km refers to kilometers, and ka refers to thousands of years
Map of (A) Morocco with (B) location of Contrebandiers Cave and archaeological sites mentioned in text.

(Dibble et al., 2012). The recent excavations used modern methods to ensure a high degree of contextual control, which included the point-proveniencing of all objects larger than 25 mm with a total station, and the screening of smaller objects from 7-L buckets with 1 cm and 2 mm mesh (Dibble et al., 2012).

Roche's previous excavations removed nearly all of the younger Iberomaurusian Later Stone Age (LSA) and Neolithic deposits (Dibble et al., 2012). A small amount of Iberomaurusian material remained in the front of the cave (Supplemental Information), and elsewhere in Morocco similar materials have been dated to 23,459–12,568 calibrated years before present (Staff et al., 2019). The bone tools described here come from the underlying so-called Maghrebian Mousterian and Aterian deposits (Figure S1), which are now assigned to the pan-African MSA (Dibble et al., 2013). Ages for the MSA layers have been estimated using three techniques (electron spin resonance, thermoluminescence, and optically stimulated luminescence dating) (Supplemental Information), all of which gave concordant results (Table S1) and indicate that the MSA bone tool-bearing layers began ~120 ka ago and ended ~90 ka ago (Dibble et al., 2012) (Supplemental Information).

RESULTS

At Contrebandiers Cave, 62 bone tools were identified in MSA deposits, and one bone tool was identified in LSA deposits. Here we describe the MSA bone tools from Layers IV-2, V-1a, V-1b, V-2, 4, 5A, 5B, 5C, 5D and 6B. These were shaped in diverse ways through: (1) scraping bone blanks with a lithic tool to create a regularized and desired shape; (2) polishing portions of bone during the manufacture phase to create smoothed and regular surfaces; (3) bone shaped by knapping with a stone; and/or (4) bone shaped from use by *H. sapiens*. Forms of bone tools include spatulates and other intentionally shaped pieces in a range of diverse types.

Spatulate tools made on rib bones (Figures 2–4 and S2) (N = 7) were identified in Contrebandiers Cave MSA Layer IV-2 (Table S2). A number of studies indicate that spatulates may have been used in hide preparation

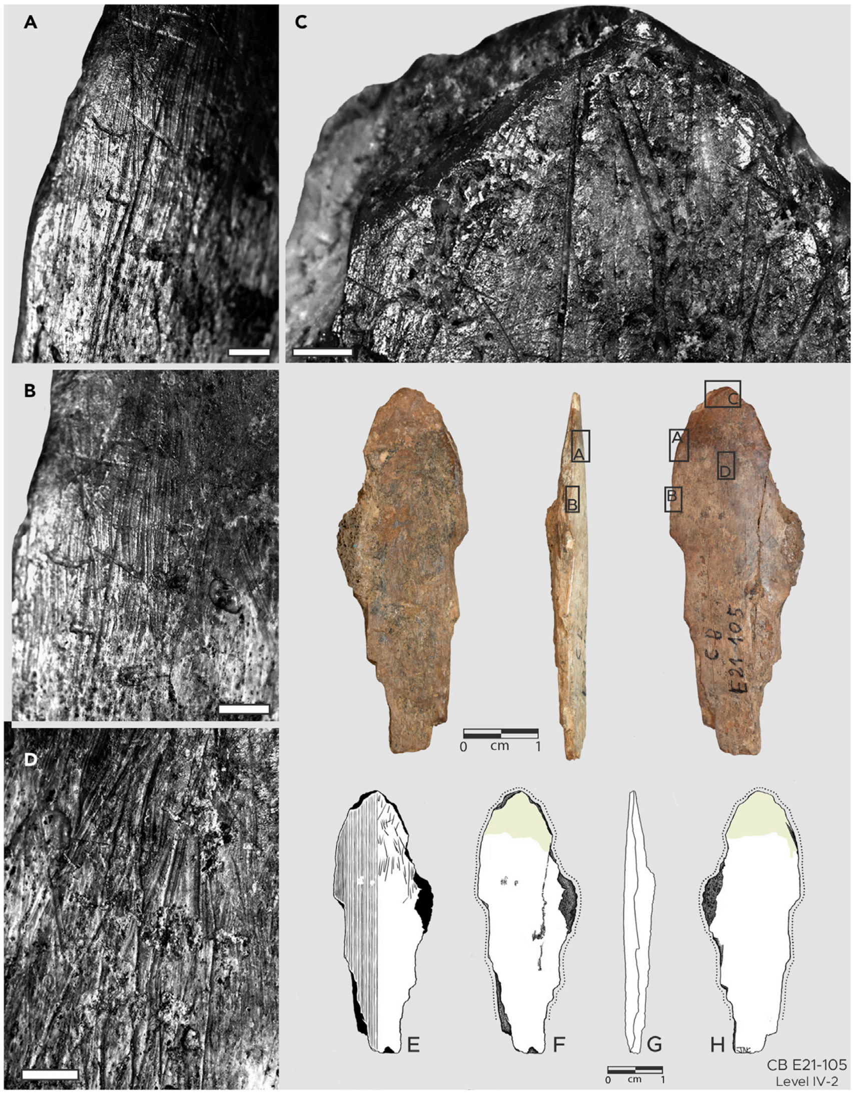

Figure 2. CB E21-105 spatulate bone tool photographs and illustration

(A, B, and D)Show somewhat wavy, rather than straight striations, due to the unevenness of retouched lithic edges and lateral movement of the lithic edge against the bone blank.

(C) Is an example of short, deep, non-parallel striations restricted to limited areas of a bone tool that were interpreted as resulting from use. (A and B) show examples of sheen and polish from use and restricted to the sides of the piece.

(D) Shows what are interpreted as manufacture marks on the body of the tool, and the lack of sheen and polish on the body away from the end and sides. (A–D) are microscope photographs with 1 cm scale.

(E–H) Illustrates both sub-parallel shaping marks covering the extent of the surface and short, irregular marks from use. Yellow areas on F and H represent the lightly burned and darkened area at the tip of this bone tool, where polish and sheen from use are frequent. Dotted outlines on (F and H) represent the extent of polish.(E–H) illustrated by J. N. Cerasoni.

during leather working activities (Soressi et al., 2013; Tartar, 2009). Ethnographic study of spatulate use in Africa is limited (Badenhorst, 2009), but in his 1796 publication, the explorer Le Vaillant described the Khoekhoe in South Africa using spatulate-shaped sheep rib bones as "a kind of chisel" to prepare hides for clothing ((Le Vaillant, 1790), p. 305). Our analyses of use-wear studies of archaeological spatulates and *lissoirs* also support their function as leather-working tools (Semenov, 1964; Soressi et al., 2013), as do experimental studies of manufacture and use (Tartar, 2009). Two bone "gouges" from MSA deposits at Broken Hill, Zambia, have been interpreted as resembling "spatulas" from younger Later Stone Age deposits in southern Africa (Barham et al., 2002). "Spatulas" are not unique to Contrebandiers Cave and the

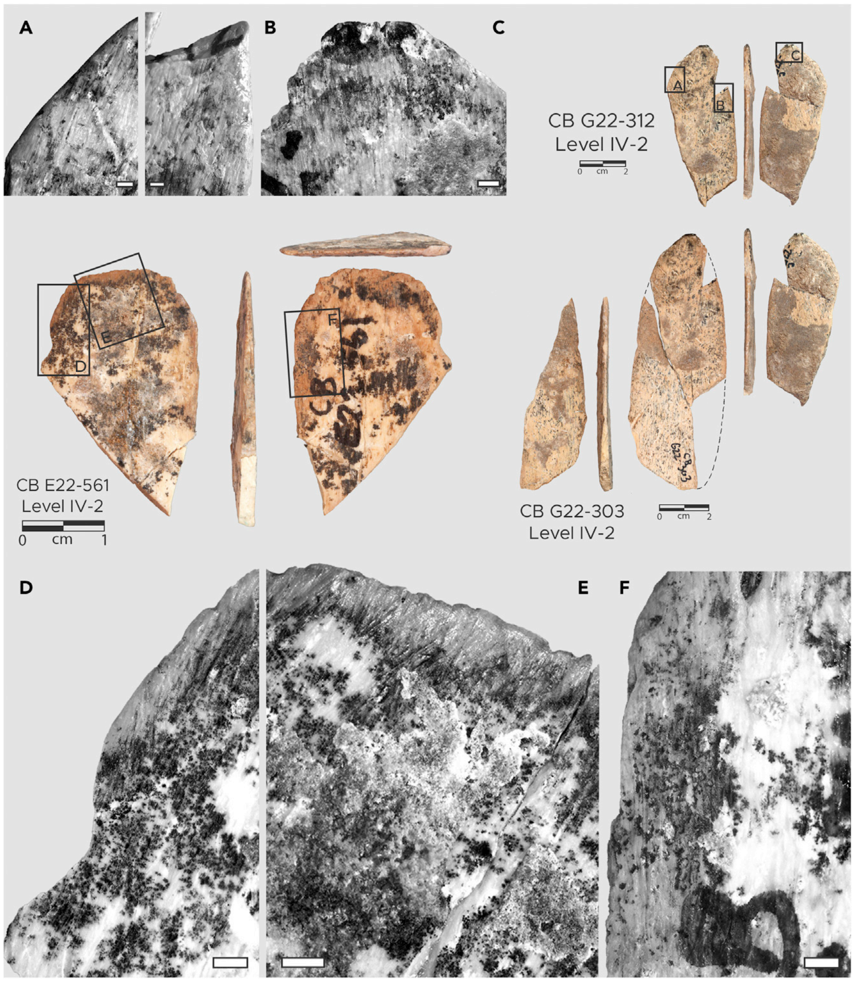

Figure 3. Spatulate tools made on rib bones from Contrebandiers Cave

(A–C) On specimen CB G22-312 are microscope photographs showing manufacture marks and smoothed edges from use, with post-depositional damage at the tip. CB G22-312 and CB G22-303 represent a spatulate bone tool refit, where the dashed lines represent an estimate of what the bone tool would look like complete.

(D–F) On specimen CB E22-561 show manufacture marks on the body and edges of the piece and polish restricted to the edges and tip. (A–F) are microscope photographs with 1 cm scale.

manufacturing processes and use-wear of Moroccan MSA spatulates have been described in detail for the neighboring MSA site of El Mnasra (El Hajraoui, 1993, 1994; El Hajraoui and Debénath, 2012). Spatulate-shaped tools are ideal for scraping and thus removing internal connective tissues from leathers and pelts during the hide or fur-working process, as they do not pierce the skin or pelt.

At Contrebandiers Cave, zooarchaeological analyses (Hallett, 2018) identified sand fox (*Vulpes rueppellii*), golden jackal (*Canis aureus*) and wildcat (*Felis silvestris*) skeletal remains bearing marks consistent with skinning for fur removals (Crezzini et al., 2014) that were found within the MSA deposits (Table S3). Cut marks were found on radius, ulna, tibia, and mandible fragments (Figures 5, and S5) for these three species of carnivores (*V. rueppellii* N = 12 bear cut marks, which is 9% of the total MSA sand fox remains, for *C. aureus* N = 2 bear cut marks, which is 7% of the total MSA golden jackal remains, and for *F. silvestris* N = 2 bear cut marks, which is 8% of the total MSA wildcat remains). This pattern of cut marks is consistent with modern fur removal techniques, where initial incisions are made on the forelimbs and the hind limbs to detach the skin from the paws. The skin is then pulled towards the head in one piece, and to finally detach the skin from the animal's head, incisions are made near the lips, resulting in cut marks on the mandible (Burch, 2002). In contrast, the bovids at Contrebandiers were processed for meat removal (Hallett, 2018),

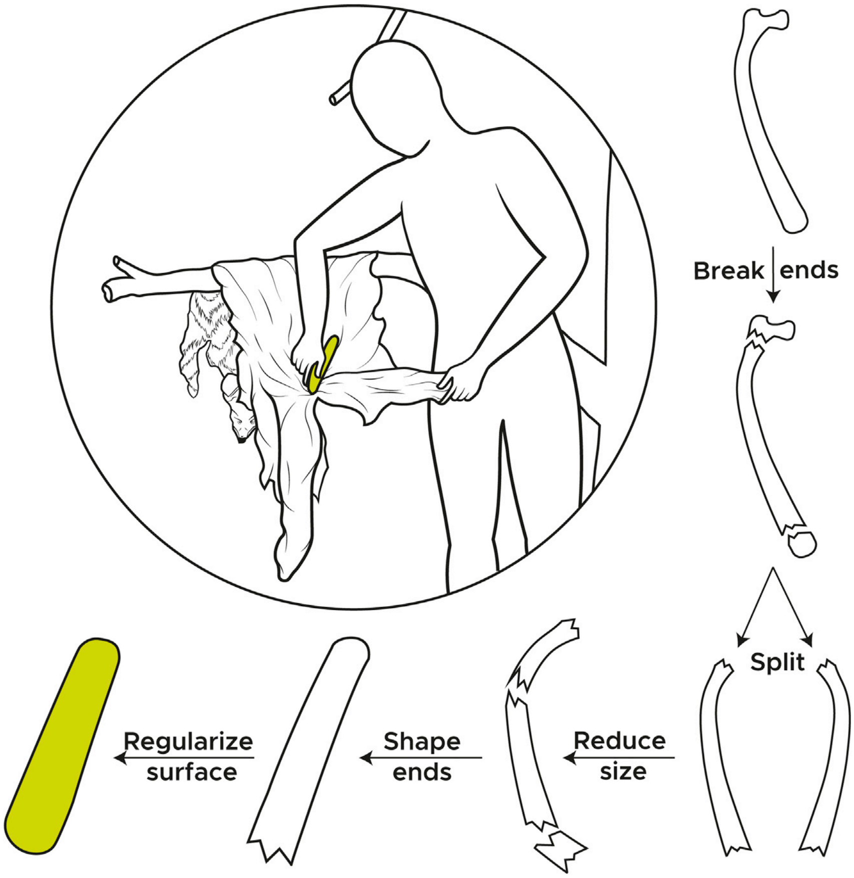

Figure 4. Spatulate bone tool manufacture stages

To manufacture a spatulate, a rib bone is broken at the ends, split lengthwise, reduced in size, and shaped then regularized with a lithic edge. Polish on the Contrebandiers Cave spatulates is interpreted as the result of use against the interior portion of skin to scrape hides for leather or fur preparation. Illustrated by J. N. Cerasoni.

as the distributions of cut marks are located on the middle and proximal shafts of all long bones, where muscle mass is concentrated (Figure S5). This shows that the distributions of cut marks on carnivores associated with fur processing are inconsistent with meat removal butchery patterns; the carnivores were only skinned and were not butchered for meat. No evidence for ornaments made on bone was found in the Contrebandiers Cave faunal assemblage.

The combination of carnivore bones bearing marks consistent with skinning and spatulates in MSA contexts at Contrebandiers Cave is a highly suggestive indicator that early humans were practicing fur removal. This shows that various animal resources were used for different purposes other than for food and that a diversity of tools were used for different activities.

Other Contrebandiers Cave MSA bone tools include three pieces that resemble hand-held pressure-flakers (Figure 6, and S3) produced in modern experimental studies (d'Errico et al., 2012a; Doyon et al., 2019). The earliest pressure flakers date to ~125–105 ka ago at Lingjing, China (Doyon et al., 2019). Pressure flaking technology was suggested by Mourre et al. (2010) with a date of ~75 ka ago at Blombos Cave, South Africa, and d'Errico et al. (2012a) described pressure flakers with a date of ~64–57 ka ago at Sibudu Cave, South Africa. Significantly in North Africa, small and finely flaked stone tool foliates found in association with Marine Isotope Stage (MIS) 5 classic Aterian tanged artifacts may also have been pressure flaked (Scerri, 2017). Stone tools shaped by hand-held pressure flaking are regularly documented by ~20 ka ago in Eurasia during the Upper Paleolithic (e.g. Bradley et al., 1995; Mourre et al., 2010).

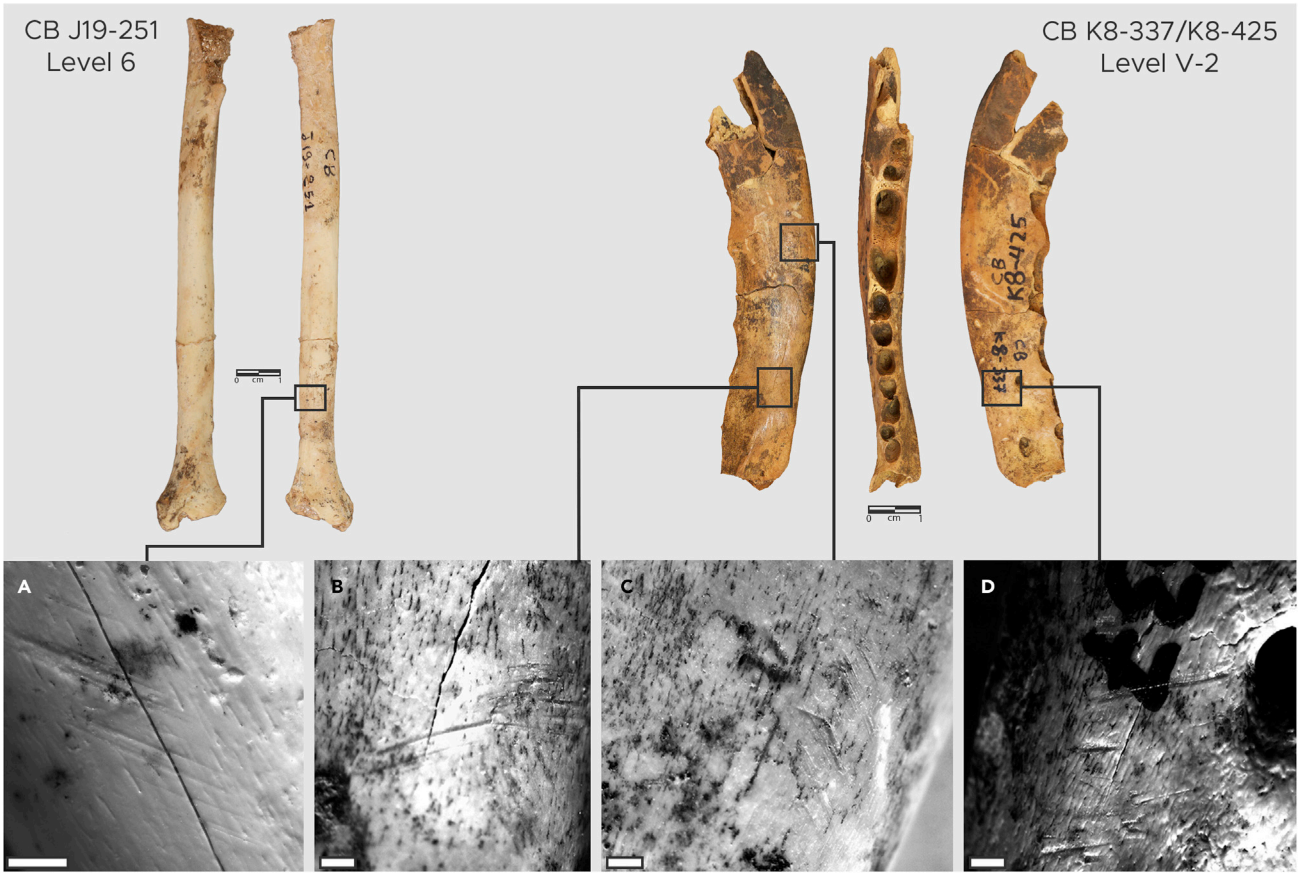

Figure 5. Skinned fox bones from Contrebandiers Cave

(A–D) CB J19-251 is a cut-marked fox tibia showing marks consistent with skinning, and CB K8-337/CB K8-425 is a cut-marked fox mandible showing marks consistent with skinning. (A–D) on specimens CB J19-251 and CB K8-337/CB K8-425 are microscope photographs with 1 cm scale.

At Contrebandiers Cave, in Layer V-1b (dated to 113 $\pm$ 7 ka, see Supplemental Information), a cetacean tooth tip (CB K8-1641) was discovered, bearing marks consistent with use as a hand-held pressure flaker (Figure 6). Whale, dolphin, and seal remains have been identified in MSA sediments in South Africa (Klein, 1976), yet none have been confirmed in Pleistocene North Africa (Steele and Álvarez-Fernández, 2011) except the piece we report here. In Lower and Middle Paleolithic contexts in Europe, elephant ivory fragments with striations on their surfaces were incorrectly identified as ivory points and later re-classified as pseudo-points (Villa and d'Errico, 2001). However, the striations and chipping on CB K8-1641 (Figure 6) are consistent with surface modification identified on hand-held pressure flakers as described in d'Errico et al. (2012a). No elephant remains were identified at Contrebandiers Cave, and the morphology of this piece indicates it is likely a cetacean tooth fragment and not elephant ivory (Espinoza et al., 1990). It is nonetheless possible that this marine mammal damaged its tooth tip from feeding on hard substances such as shellfish, bony fish, squid, or other marine vertebrates. Future use-wear analyses on this specimen could clarify whether the observed striations and chipping are anthropogenic or non-anthropogenic in nature. While species identification should be confirmed through molecular techniques, morphology and biogeography suggest that the tooth is likely from a sperm whale (*Physeter macrocephalus*) tooth. This specimen represents the use of a marine mammal tooth by humans ~113 ka.

Other formal and informal—as well as possible—bone tools include: (1) 13 ''retouchers'', (2) 28 shaped pieces that do not conform to a yet-known type (Figure S6), (3) two split-rib pieces that are likely the discarded byproducts from spatulate manufacture (see Tartar (Tartar, 2009) for the process of bone tools manufacture from split-ribs), and (4) three pieces with regular and smooth surfaces that appear to be the result of use rather than manufacturing (Figure S4, and Table S2). These bone tools will be analyzed for

Figure 6. Cetacean tooth pressure flaker
(A–D) On CB-1641 are microscope photographs showing marks interpreted as resulting from use as a hand-held pressure flaker, with 1 cm scale.

manufacturing traces and use-wear in future studies of the Contrebandiers Cave artifacts and are not described in detail here.

DISCUSSION

Excavations led by El Hajraoui at El Mnasra over twenty-five years ago uncovered spatulate bone tools in Aterian contexts (El Hajraoui, 1993) that were largely ignored in discussions of MSA bone tool technology and remained undated until recently. El Hajraoui continued to describe Aterian bone tools in subsequent studies (El Hajraoui, 1994; El Hajraoui and Debénath, 2012). Recently available chronologies at El Mnasra estimate the age of bone tool-bearing Aterian layers to be ~107 ka (Jacobs et al., 2012). Together, the Contrebandiers Cave, El Mnasra (El Hajraoui, 1993, 1994; El Hajraoui and Debénath, 2012) and Dar es-Soltan I (Bouzouggar et al., 2018) bone tool assemblages show that there is an archaeological tradition (El Hajraoui, 2019) of bone tool technology in the MSA of North Africa from 120 to 90 ka. Bone tools appear to be a pan-African phenomenon in the MSA well before they appear at similar levels of abundance in Europe.

By ~120 ka ago in North Africa, people occupied Contrebandiers Cave, hunting 67 species of vertebrate animals (Hallett, 2018) for food and hides. The Contrebandiers Cave bone tools demonstrate that by ~120 ka ago, *H. sapiens* began to intensify the use of bone to make formal tools, and bone was intentionally shaped for specific tasks that included leather and fur working. This versatility appears to be at the root of our species, and not a characteristic that emerged after *H. sapiens* expanded their range into Eurasia. The early, pan-African emergence of formal bone tool technology also highlights the role of the entire African continent in the development of modern human morphology and behavior (Hublin et al., 2017; Richter et al., 2017; Scerri et al., 2018). Given the level of specialization of the bone tool material culture at Contrebandiers Cave, it is likely that earlier examples will be found.

Limitations of the study

In the current study it was not possible to analyze the Contrebandiers Cave bone tools for residue identification. In addition, no experimental manufacture or use of bone tools was included in the current study. Published reference collections were consulted for the identification of tool types, manufacturing techniques, and interpretation of use-wear on the Contrebandiers Cave bone tools. While our study used 40X magnification to identify traces of use-wear on bone tools interpreted as being used for skinning, we did not use 100X-500X magnification to directly diagnose the contact material(s) each bone tool was used on.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

- KEY RESOURCES TABLE
- RESOURCE AVAILABILITY
  - Lead contact
  - Materials availability
  - Data and code availability
- EXPERIMENTAL MODEL AND SUBJECT DETAILS
- METHOD DETAILS
  - Excavation methods
  - Zooarchaeological methods
  - Methods for identifying bone tools
  - Methods for recording use wear
  - Bone tool imaging methods
  - Stratigraphy methods
  - Methods for dating the deposits
  - Dating the central excavation area (CEA)
  - Dating sector V
  - Dating sector IV
  - Checking the reliability of the OSL chronology
  - Other Contrebandiers cave bone tools
  - MSA stone artifacts
- QUANTIFICATION AND STATISTICAL ANALYSIS

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2021.102988.

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AUTHOR CONTRIBUTIONS

E.Y.H. conceived and performed the study and wrote initial drafts of the paper; T.E.S. provided comparative bone tool data and background research; Z.J. performed OSL dating and analyses of the site, and wrote the ages portion of this paper; E.Y.H., T.E.S., and E.A.F. identified, analyzed and interpreted the function of the bone tools; V.A. studied the stratigraphy and geology of the site; H.L.D. and M.E.H. are the project and excavation co-directors and permit holders; H.L.D. contributed to excavation methodology and stone tool studies; D.I.O. contributed to the stone tool studies; M.E.H. contributed to bone tool studies and Moroccan prehistory; E.Y.H., C.W.M., and E.M.L.S. took the lead in contextualizing results and writing the paper; J.N.C. and E.Y.H. created the figures and revised the main text. All authors contributed to the writing of this paper.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

One or more of the authors of this paper received support from a program designed to increase minority representation in science. While citing references scientifically relevant for this work, we also actively worked to promote gender balance in our reference list. The author list of this paper includes contributors from the location where the research was conducted who participated in the data collection, design, analysis, and/or interpretation of the work.

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REFERENCES

Aitken, M.J. (1985). Thermoluminescence Dating (Academic Press).

Aldeias, V., Goldberg, P., Dibble, H.L., and El-Hajraoui, M. (2014). Deciphering site formation processes through soil micromorphology at Contrebandiers Cave, Morocco. J. Hum. Evol. *69*, 8–30. https://doi.org/10.1016/j.jhevol.2013.12.016.

Almeida Évora, M. (2015). Use-wear methodology on the analysis of osseous industries. In Use-Wear and Residue Analysis in Archaeology, J.M. Marreiros, J.F. Gibaja Bao, and N. Ferreira Bicho, eds. (Springer International Publishing), pp. 159–170. https://doi.org/10.1007/978-3-319-08257-8_8.

Andrews, P. (1990). Owls, Caves and Fossils: Predation, Preservation and Accumulation of Small Mammal Bones in Caves, with an Analysis of the Pleistocene Cave Faunas from Westbury-Sub-Mendip, Somerset, U.K. (University of Chicago Press).

Andrews, P., and Cook, J. (1985). Natural modifications to bones in a temperate setting. Man (London) *20*, 675–691. https://doi.org/10.2307/2802756.

Backwell, L., d'Errico, F., and Wadley, L. (2008). Middle stone age bone tools from the Howiesons poort layers, Sibudu cave, South Africa. J. Archaeological Sci. *35*, 1566–1580. https://doi.org/10.1016/j.jas.2007.11.006.

Backwell, L.R., and d'Errico, F. (2001). Evidence of termite Foraging by Swartkrans early hominids. Proc. Natl. Acad. Sci. - PNAS *98*, 1358–1363. https://doi.org/10.1073/pnas.98.4.1358.

Backwell, L.R., and d'Errico, F. (2004). The first use of bone tools: a reappraisal of the evidence from Olduvai Gorge, Tanzania. Palaeontol. Africana *40*, 95–158.

Badenhorst, S. (2009). An ethnographic and historical overview of hide processing in southern Africa. Ann. Transvaal Mus. *46*, 37–43. https://doi.org/10.10520/EJC83689.

Barham, L.S., Pinto Llona, A., and Stringer, C.B. (2002). Bone tools from Broken Hill (Kabwe) cave, Zambia, and their evolutionary significance. Before Farming *2*, 1–12. https://doi.org/10.3828/bfarm.2002.2.3.

Behrensmeyer, A.K. (1978). Taphonomic and ecologic information from bone weathering. Paleobiology *4*, 150–162. https://doi.org/10.1017/S0094837300005820.

Behrensmeyer, A.K. (1982). Time resolution in fluvial vertebrate assemblages. Paleobiology *8*, 211–227. https://doi.org/10.1017/s0094837300006941.

Behrensmeyer, A.K., Gordon, K.D., and Yanagi, G.T. (1986). Trampling as a cause of bone surface damage and pseudo-cutmarks. Nature *319*, 768–771. https://doi.org/10.1038/319768a0.

Binford, L.R. (1981). Bones: Ancient Men and Modern Myths (Academic Press).

Blumenschine, R.J. (1988). An experimental model of the timing of hominid and carnivore influence on archaeological bone assemblages. J. Archaeological Sci. *15*, 483–502. https://doi.org/10.1016/0305-4403(88)90078-7.

Blumenschine, R.J., Marean, C.W., and Capaldo, S.D. (1996). Blind tests of inter-analyst correspondence and accuracy in the identification of cut marks, percussion marks, and carnivore tooth marks on bone surfaces. J. Archaeological Sci. *23*, 493–507. https://doi.org/10.1006/jasc.1996.0047.

Bouzouggar, A., Humphrey, L.T., Barton, N., Parfitt, S.A., Balzan, L.C., Schwenninger, J.-L., Hajraoui, M.A.E., Nespoulet, R., and Bello, S.M. (2018). 90,000 year-old specialised bone technology in the Aterian middle stone age of North Africa. PLoS One *13*, e0202021. https://doi.org/10.1371/journal.pone.0202021.

Bradfield, J., Lombard, M., Reynard, J., and Wurz, S. (2020). Further evidence for bow hunting and its implications more than 60 000 years ago: results of a use-trace analysis of the bone point from Klasies River Main site, South Africa. Quat.Sci. Rev. *236*, 106295. https://doi.org/10.1016/j.quascirev.2020.106295.

Bradfield, J., and Wurz, S. (2020). A functional assessment of the notched bone artefacts from Klasies River Main site. South Afr. Archaeological Bull. *75*, 128–136.

Bradley, B.A., Anikovich, M., and Giria, E. (1995). Early upper palaeolithic in the Russian plain: Streletskayan flaked stone artefacts and technology. Antiquity *69*, 989–998. https://doi.org/10.1017/S0003598X00082521.

Brain, C.K. (1981). The Hunters or the Hunted?an Introduction to African Cave Taphonomy (University of Chicago Press).

Burch, M. (2002). The Ultimate Guide to Skinning and Tanning: A Complete Guide to Working with Pelts (Fur, and Leather (Lyons Press).

Campana, D.V. (1989). Natufian and Protoneolithic Bone Tools : The Manufacture and Use of Bone Implements in the Zagros and the Levant (B.A.R.).

Campmas, E. (2012). Caractérisation de l'occupation des sites de la région de Témara (Maroc) au Pléistocène supérieur et nouvelles données sur la subsistance des hommes du Paléolithique moyen d'Afrique du Nord: Exemples des approches taphonomiques et archéozoologiques menées sur les faunes d'El Harhoura 2 et d'El Mnasra. PhD (Université Bordeaux 1).

Crezzini, J., Boschin, F., Boscato, P., and Wierer, U. (2014). Wild cats and cut marks: exploitation of Felis silvestris in the Mesolithic of Galgenbühel/Dos de la Forca (South Tyrol, Italy). Quat. Int. *330*, 52–60. https://doi.org/10.1016/j.quaint.2013.12.056.

d'Errico, F. (1993). Criteria for identifying utilised bone: the case of the Cantabrian "Tensors". Curr.Anthropol. *34*, 298–311. https://doi.org/10.1086/204172.

d'Errico, F., and Backwell, L.R. (2003). Possible evidence of bone tool shaping by Swartkrans early hominids. J. Archaeological Sci. *30*, 1559–1576. https://doi.org/10.1016/S0305-4403(03)00052-9.

d'Errico, F., and Backwell, L. (2009). Assessing the function of early hominin bone tools. J. Archaeological Sci. *36*, 1764–1773. https://doi.org/10.1016/j.jas.2009.04.005.

d'Errico, F., Backwell, L., Villa, P., Degano, I., Lucejko, J.J., Bamford, M.K., Higham, T.F.G., Colombini, M.P., and Beaumont, P.B. (2012b). Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa. Proc. Natl. Acad. Sci. - PNAS *109*, 13214–13219. https://doi.org/10.1073/pnas.1204213109.

d'Errico, F., Backwell, L.R., and Wadley, L. (2012a). Identifying regional variability in middle stone age bone technology: the case of Sibudu cave. J. Archaeological Sci. *39*, 2479–2495. https://doi.org/10.1016/j.jas.2012.01.040.

d'Errico, F., Giacobini, B., and Puech, P.-F. (1984). An experimental study of the technology of bone-implement manufacture. Masca J. *3*, 71–74.

d'Errico, F., and Henshilwood, C.S. (2007). Additional evidence for bone technology in the southern african middle stone age. J. Hum. Evol. *52*, 142–163. https://doi.org/10.1016/j.jhevol.2006.08.003.

Deino, A.L. (2012). 40Ar/39Ar dating of Bed I, Olduvai Gorge, Tanzania, and the chronology of early Pleistocene climate change. J. Hum. Evol. *63*, 251–273. https://doi.org/10.1016/j.jhevol.2012.05.004.

Dibble, H.L., Aldeias, V., Álvarez-Fernández, E., Blackwell, B., Hallett-Desguez, E., Jacobs, Z., Goldberg, P., Lin, S.C., Morala, A., Meyer, M., et al. (2012). New excavations at the site of Contrebandiers cave, Morocco. Paleoanthropology *2012*, 145–201. https://doi.org/10.4207/PA.2012.ART74.

Dibble, H.L., Aldeias, V., Jacobs, Z., Olszewski, D.I., Rezek, Z., Lin, S.C., Alvarez-Fernández, E., Barshay-Szmidt, C.C., Hallett-Desguez, E., Reed, D., et al. (2013). On the industrial attributions of the Aterian and Mousterian of the Maghreb. J. Hum. Evol. *64*, 194–210. https://doi.org/10.1016/j.jhevol.2012.10.010.

Dibble, H.L., Holdaway, S.J., Lenoir, M., McPherron, S.P., Roth, B., and Sanders-Gray, H. (1995). Techniques of excavation and analysis. In The Middle Paleolithic Site of Combe-Capelle Bas (France), H.L. Dibble and M. Lenoir, eds. (The University Museum, University of Pennsylvania), pp. 27–40.

Dirks, P.H.G.M., Berger, L.R., Roberts, E.M., Kramers, J.D., Hawks, J., Randolph-Quinney, P.S., Elliott, M., Musiba, C.M., Churchill, S.E., de Ruiter, D.J., et al. (2015). Geological and taphonomic context for the new hominin species Homo naledi from the Dinaledi Chamber, South Africa. eLife *4*, e09561. https://doi.org/10.7554/elife.09561.

Domínguez-Rodrigo, M., and Barba, R. (2006). New estimates of tooth mark and percussion mark frequencies at the FLK Zinj site: the carnivore-hominid-carnivore hypothesis falsified. J. Hum. Evol. *50*, 170–194. https://doi.org/10.1016/j.jhevol.2005.09.005.

Domínguez-Rodrigo, M., de Juana, S., Galán, A.B., and Rodríguez, M. (2009). A new protocol to differentiate trampling marks from butchery cut marks. J. Archaeological Sci. *36*, 2643–2654. https://doi.org/10.1016/j.jas.2009.07.017.

Domínguez-Rodrigo, M., Pickering, T.R., Baquedano, E., Mabulla, A., Mark, D.F., Musiba, C., Bunn, H.T., Uribelarrea, D., Smith, V., Diez-Martin, F., et al. (2013). First partial skeleton of a 1.34-million-year-old paranthropus boisei from bed II, Olduvai Gorge, Tanzania. PLoS One *8*, e80347. https://doi.org/10.1371/journal.pone.0080347.

Doyon, L., Li, H., Li, Z., Wang, H., and Zhao, Q. (2019). Further evidence of organic soft hammer percussion and pressure retouch from Lingjing (Xuchang, Henan, China). Lithic Technology *44*, 100–117. https://doi.org/10.1080/01977261.2019.1589926.

El Hajraoui, M. (1993). Nouvelles découvertes néolithiques et atériennes dans la région de Rabat «Grotte d'El Mnasra». In Mediterrâneo, pp. 105–121.

El Hajraoui, M.A. (1994). L'industrie osseuse atérienne de la grotte d'El Mnasra (Région de Témara, Maroc). Préhistoire Anthropologie Méditerranéennes, LAPMO Université de Provence CNRS *3*, 91–94.

El Hajraoui, M.A. (2019). Les Premiers Habitants de Rabat et Région: aux Origines du Comportement Humain Moderne (Ministère de la Culture et des Communications).

El Hajraoui, M., and Debénath, A. (2012). L'industrie osseuse. In Villes et sites d'archéologie Marocaine, Royaume du Maroc, M.A. El Hajraoui, A. Debénath, R. Nespoulet, and H.L. Dibble, eds., pp. 179–188.

Espinoza, E.O., Mann, M.-I., LeMay, I.P., and Oakes, K.A. (1990). A method for differentiating modern from ancient. Curr. Res. Pleistocene *7*, 81–83.

Feathers, J.K., and Migliorini, E. (2001). Luminescence dating at Katanda — a reassessment. Quat. Sci. Rev. *20*, 961–966. https://doi.org/10.1016/S0277-3791(00)00041-X.

Fisher, D.C. (1981). Crocodilian scatology, microvertebrate concentrations, and enamel-less teeth. Paleobiology *7*, 262–275. https://doi.org/10.1017/S0094837300004048.

Fisher, J.W. (1995). Bone surface modifications in zooarchaeology. J. Archaeological Method Theor. *2*, 7–68. https://doi.org/10.1007/bf02228434.

Frison, G. (1982). Bone butchering tools in archaeological sites. Can. J. Anthropol. *2*, 159–167.

Galbraith, R.F., Roberts, R.G., Laslett, G.M., Yoshida, H., and Olley, J.M. (1999). Optical dating of single and multiple grains of quartz from Jinmium rock shelter, northern Australia: Part I, Experimental Design and Statistical Models. Archaeometry *41*, 339–364. https://doi.org/10.1111/j.1475-4754.1999.tb00987.x.

Guérin, G., Murray, A.S., Jain, M., Thomsen, K.J., and Mercier, N. (2013). How confident are we in the chronology of the transition between Howieson's Poort and Still Bay? J. Hum. Evol. *64*, 314–317. https://doi.org/10.1016/j.jhevol.2013.01.006.

Hallett, E.Y. (2018). Zooarchaeological and Taphonomic Analyses of Pleistocene Vertebrate Fauna from the Middle and Later Stone Age Occupations at Contrebandiers Cave, Atlantic Coast, Morocco (PhD (Arizona State University).

Haynes, G. (1982). Utilization and skeletal disturbances of North American Prey Carcasses. Arctic *35*, 266–281.

Haynes, G. (1988). Longitudinal studies of african elephant death and bone deposits. J. Archaeological Sci. *15*, 131–157. https://doi.org/10.1016/0305-4403(88)90003-9.

Hearty, P.J., Hollin, J.T., Neumann, A.C., O'Leary, M.J., and McCulloch, M. (2007). Global sea-level fluctuations during the Last Interglaciation (MIS 5e). Quat.Sci. Rev. *26*, 2090–2112. https://doi.org/10.1016/j.quascirev.2007.06.019.

Henshilwood, C.S., D'Errico, F., Marean, C.W., Milo, R.G., and Yates, R. (2001). An early bone tool industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the origins of modern human behaviour, symbolism and language. J. Hum. Evol. *41*, 631–678. https://doi.org/10.1006/jhev.2001.0515.

Hublin, J.-J., Ben-Ncer, A., Bailey, S.E., Freidline, S.E., Neubauer, S., Skinner, M.M., Bergmann, I., Le Cabec, A., Benazzi, S., Harvati, K., and Gunz, P. (2017). New fossils from Jebel Irhoud, Morocco and the pan-African origin of Homo sapiens. Nature *546*, 289–292. https://doi.org/10.1038/nature22336.

Hublin, J.-J., Sirakov, N., Aldeias, V., Bailey, S., Bard, E., Delvigne, V., Endarova, E., Fagault, Y., Fewlass, H., Hajdinjak, M., et al. (2020). Initial upper palaeolithic Homo sapiens from Bacho Kiro cave, Bulgaria. Nature (London) *581*, 299–302. https://doi.org/10.1038/s41586-020-2259-z.

Iovita, R. (2011). Shape variation in Aterian tanged tools and the origins of projectile technology: a morphometric perspective on stone tool function. PLoS One *6*, e29029. https://doi.org/10.1371/journal.pone.0029029.

Jacobs, Z., Hayes, E.H., Roberts, R.G., Galbraith, R.F., and Henshilwood, C.S. (2013). An improved OSL chronology for the Still Bay layers at Blombos Cave, South Africa: further tests of single-grain dating procedures and a re-evaluation of the timing of the Still Bay industry across southern Africa. J. Archaeological Sci. *40*, 579–594. https://doi.org/10.1016/j.jas.2012.06.037.

Jacobs, Z., Meyer, M.C., Roberts, R.G., Aldeias, V., Dibble, H., and El Hajraoui, M.A. (2011). Single-grain OSL dating at La Grotte des Contrebandiers ('Smugglers' Cave'), Morocco: improved age constraints for the Middle Paleolithic levels. J. Archaeological Sci. *38*, 3631–3643.

Jacobs, Z., and Roberts, R.G. (2008). Testing Times: old and new chronologies for the Howieson's poort and still bay industries in environmental context. Goodwin Ser. *10*, 9–34.

Jacobs, Z., Roberts, R.G., Nespoulet, R., El Hajraoui, M.A., and Debénath, A. (2012). Single-grain OSL chronologies for middle palaeolithic deposits at El Mnasra and El Harhoura 2, Morocco: implications for late Pleistocene human–environment interactions along the Atlantic coast of northwest Africa. J. Hum. Evol. *62*, 377–394. https://doi.org/10.1016/j.jhevol.2011.12.001.

Jacobs, Z., Wintle, A.G., Roberts, R.G., and Duller, G.A.T. (2008). Equivalent dose distributions from single grains of quartz at Sibudu, South Africa: context, causes and consequences for optical dating of archaeological deposits. J. Archaeological Sci. *35*, 1808–1820. https://doi.org/10.1016/j.jas.2007.11.027.

Jalvo, Y.F., and Andrews, P. (2003). Experimental effects of water abrasion on bone fragments. J. Taphonomy *1*, 145–161.

Julien, M.-A., Hardy, B., Stahlschmidt, M.C., Urban, B., Serangeli, J., and Conard, N.J. (2015). Characterizing the Lower Paleolithic bone industry from Schöningen 12 II: a multi-proxy study. J. Hum. Evol. *89*, 264–286. https://doi.org/10.1016/j.jhevol.2015.10.006.

Klein, R.G. (1976). The mammalian Fauna of the Klasies River Mouth sites, southern Cape Province, South Africa. South Afr. archaeological Bull. *31*, 75–98. https://doi.org/10.2307/3887730.

Klein, R.G. (2009). The Human Career: Human Biological and Cultural Origins, Third Edition (University of Chicago Press).

Langley, M.C., Amano, N., Wedage, O., Deraniyagala, S., Pathmalal, M.M., Perera, N., Boivin, N., Petraglia, M.D., and Roberts, P. (2020). Bows and arrows and complex symbolic displays 48,000 years ago in the South Asian tropics. Sci. Adv. *6*, eaba3831. https://doi.org/10.1126/sciadv.aba3831.

Le Vaillant, F. (1790). Travels into the interior parts of Africa, by the way of the Cape of Good hope; in the years 1780, 81, 82, 83, 84 and 85. Translated from the French of M. Le Vaillant (Graisberry and Campbell).

Marean, C.W. (1991). Measuring the post-depositional destruction of bone in archaeological assemblages. J. Archaeological Sci. *18*, 677–694. https://doi.org/10.1016/0305-4403(91)90029-O.

Martisius, N.L., McPherron, S.P., Schulz-Kornas, E., Soressi, M., and Steele, T.E. (2020). A method for the taphonomic assessment of bone tools using 3D surface texture analysis of bone microtopography. Archaeological Anthropological Sci. *12*, 251. https://doi.org/10.1007/s12520-020-01195-y.

McPherron, S.P., and Dibble, H.L. (2002). Using Computers in Archaeology: A Practical Guide (McGraw-Hill Mayfield).

Michel, V., Boschian, G., and Valensi, P. (2008). Datation ESR de dents d'aurochs du site Paléolithique inférieur de Castel di Guido (Italie). Archeosciences.Revue D'archéométrie, 51–58. https://doi.org/10.4000/archeosciences.962.

Mourre, V., Villa, P., and Henshilwood, C.S. (2010). Early use of pressure flaking on lithic artifacts at Blombos cave, South Africa. Science *330*, 659–662. https://doi.org/10.1126/science.1195550.

Newcomer, M.H. (1974). Study and replication of bone tools from Ksar Akil (Lebanon). World Archaeology *6*, 138–153.

Oliver, J.S. (1989). Analogues and site context: bone damages from shield trap cave (24CB91), carbon county, Montana, USA. In Bone Modification, R. Bonnichsen and M.H. Sorg, eds. (Center for the Study of the First Americans)), pp. 73–98.

Olsen, S.L., and Shipman, P. (1988). Surface modification on bone: trampling versus butchery. J. Archaeological Sci. *15*, 535–553. https://doi.org/10.1016/0305-4403(88)90081-7.

Pante, M., Torre, I.d.l., d'Errico, F., Njau, J., and Blumenschine, R. (2020). Bone tools from Beds II–IV, Olduvai Gorge, Tanzania, and implications for the origins and evolution of bone technology. J. Hum. Evol. *148*, 102885. https://doi.org/10.1016/j.jhevol.2020.102885.

Richter, D., Grün, R., Joannes-Boyau, R., Steele, T.E., Amani, F., Rué, M., Fernandes, P., Raynal, J.-P., Geraads, D., Ben-Ncer, A., et al. (2017). The age of the hominin fossils from Jebel Irhoud, Morocco, and the origins of the middle stone age. Nature *546*, 293–296. https://doi.org/10.1038/nature22335.

Roche, J. (1976). Cadre chronologique de l'Épipaleolithique marocain.Actes du IXè Congrès. In Colloque II: Chronologie et Synchronisme dans la Préhistoire Circum-Méditerranéenne. held in Nice, G. Camps France, ed., pp. 153–167.

R Core Team (2020). R: A Language and Environment for Statistical Computing (R Foundation for Statistical Computing).

RStudio Team (2019). RStudio: Integrated Development for R (RStudio, Inc.).

Saccà, D. (2012). Taphonomy of palaeloxodon antiquus at Castel di Guido (Rome, Italy): proboscidean carcass exploitation in the lower palaeolithic. Quat. Int. *276-277*, 27–41. https://doi.org/10.1016/j.quaint.2012.03.055.

Sano, K., Beyene, Y., Katoh, S., Koyabu, D., Endo, H., Sasaki, T., Asfaw, B., and Suwa, G. (2020). A 1.4-million-year-old bone handaxe from Konso, Ethiopia, shows advanced tool technology in the early Acheulean. Proc. Natl. Acad. Sci. *117*, 18393. https://doi.org/10.1073/pnas.2006370117.

Scerri, E.M.L. (2017). The North african middle stone age and its place in recent human evolution. Evol.Anthropol. *26*, 119–135. https://doi.org/10.1002/evan.21527.

Scerri, E.M.L., Thomas, M.G., Manica, A., Gunz, P., Stock, J.T., Stringer, C., Grove, M., Groucutt, H.S., Timmermann, A., Rightmire, G.P., et al. (2018). Did our species evolve in subdivided populations across Africa, and why does it matter? Trends Ecol. Evol. *33*, 582–594. https://doi.org/10.1016/j.tree.2018.05.005.

Schwenninger, J.-L., Collcutt, S., Barton, N., Bouzouggar, A., Clark-Balzan, L., Hajraoui, M., Nespoulet, R., and Debénath, A. (2010). A new luminescence chronology for Aterian cave sites on the Atlantic Coast of Morocco. In South-Eastern Mediterranean Peoples between 130,000 and 10,000 Years Ago, E.A.A. Garcea, ed. (Oxbow Books), pp. 18–36.

Semenov, S.A. (1964). Prehistoric Technology; an Experimental Study of the Oldest Tools and Artefacts from Traces of Manufacture and Wear (Barnes & Noble).

Shipman, P. (1981). Life History of a Fossil: An Introduction to Taphonomy and Paleoecology (Harvard University Press).

Shipman, P., and Rose, J. (1983). Early hominid hunting, butchering, and carcass-processing behaviors: approaches to the fossil record. J. Anthropological Archaeology *2*, 57–98. https://doi.org/10.1016/0278-4165(83)90008-9.

Shipman, P., and Rose, J.J. (1984). Cutmark Mimics on modern and fossil bovid bones. Curr.Anthropol. *25*, 116–117. https://doi.org/10.1086/203091.

Shipman, P., and Rose, J.J. (1988). Bone tools: an experimental approach. In Scanning Electron Microscopy in Scanning Electron Microscopy in Archaeology, S.L. Olsen, ed. (BAR International Series 452), pp. 303–335.

Soressi, M., McPherron, S.P., Lenoir, M., Dogandžić, T., Goldberg, P., Jacobs, Z., Maigrot, Y., Martisius, N.L., Miller, C.E., Rendu, W., et al. (2013). Neandertals made the first specialized bone tools in Europe. Proc. Natl. Acad. Sci. *110*, 14186–14190. https://doi.org/10.1073/pnas.1302730110.

Staff, R.A., Ditchfield, P., Rhodes, E., Schwenninger, J.-L., Clark-Balzan, L., Lee, S., and Barton, R.N.E. (2019). Chronology. In Cemeteries and Sedentism in the Later Stone Age of NW Africa: Excavations at Grotte des Pigeons, Taforalt, Morocco, R.N.E. Barton, A. Bouzouggar, S.N. Collcutt, and L.T. Humphrey, eds. (Mainz, Verlag des Römisch-Germanischen Zentralmuseums), pp. 143–154.

Stammers, R.C., Caruana, M.V., and Herries, A.I.R. (2018). The first bone tools from Kromdraai and stone tools from Drimolen, and the place of bone tools in the South African Earlier Stone Age. Quat. Int. *495*, 87–101. https://doi.org/10.1016/j.quaint.2018.04.026.

Steele, T.E., and Álvarez-Fernández, E. (2011). Initial investigations into the exploitation of coastal resources in North Africa during the Late Pleistocene at Grotte des Contrebandiers, Morocco. In Trekking the Shore (Springer), pp. 383–403.

Sutcliffe, A.J. (1970). Spotted Hyaena: crusher, gnawer, digester and collector of bones. Nature *227*, 1110–1113. https://doi.org/10.1038/2271110a0.

Sutcliffe, A.J. (1973). Similarity of bones and antlers gnawed by deer to human artefacts. Nature *246*, 428–430. https://doi.org/10.1038/246428a0.

Tartar, E. (2012). The recognition of a new type of bone tools in Early Aurignacian assemblages: implications for understanding the appearance of osseous technology in Europe. J. Archaeological Sci. *39*, 2348–2360. https://doi.org/10.1016/j.jas.2012.02.003.

Tartar, É. (2009). De l'os à l'outil: caractérisation technique, économique et sociale de l'utilisation de l'os à l'Aurignacien ancien: étude de trois sites: l'Abri Castanet (secteur nord et sud), Brassempouy (Grotte des Hyènes et Abri Dubalen) et Gatzarria (Paris 1).

Toups, M.A., Kitchen, A., Light, J.E., and Reed, D.L. (2011). Origin of clothing lice indicates early clothing use by anatomically modern humans in Africa. Mol. Biol. Evol. *28*, 29–32. https://doi.org/10.1093/molbev/msq234.

Villa, P., and d'Errico, F. (2001). Bone and ivory points in the lower and middle paleolithic of Europe. J. Hum. Evol. *41*, 69–112. https://doi.org/10.1006/jhev.2001.0479.

Vogel, J.C. (2001). Radiometric dates for the middle stone age in South Africa. In Humanity from African Naissance to Coming Millennia: Colloquia in Human Biology and Palaeoanthropology., P.V. Tobias, M.A. Raath, J. Moggi-Cecchi, and G.A. Doyle, eds. (Firenze: Firenze University Press; Witwatersrand University Press), pp. 261–268.

Wood, W.R., and Johnson, D.L. (1978). A survey of disturbance processes in archaeological site formation. Adv. Archaeological Method Theor. *1*, 315–381.

Yellen, J.E., Brooks, A.S., Cornelissen, E., Mehlman, M.J., and Stewart, K. (1995). A middle stone age worked bone industry from Katanda, Upper Semliki Valley, Zaire. Science *268*, 553. https://doi.org/10.1126/science.7725100.

STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Fossilized vertebrate archaeofaunal remains from Contrebandiers Cave, Morocco, raw and analyzed data	This paper	Table S3
Fossilized bone tools from Contrebandiers Cave, raw and analyzed data	This paper	Tables S2, and S4
Software and algorithms		
R Studio	RStudio Team https://www.rstudio.com/	RStudio version 1.2.5033
R	R Core Team https://www.r-project.org/	R version 3.6.2

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Emily Y. Hallett (hallett@shh.mpg.de).

Materials availability

All of the bone tools and vertebrate faunal remains from Contrebrandiers Cave that were analyzed in this study are curated in the Institut National des Sciences de l'Archéologie et du Patrimoine in Rabat, Morocco under the site code CB.

Data and code availability

- All data reported in this paper will be shared by the lead contact upon request.
- All data reported in the paper are available within the main text and Supplemental Information.
- All data necessary to interpret and replicate results are available in the main text and Supplemental Information, Supplemental Figures, and Supplemental Tables.
- This paper does not report original code.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

EXPERIMENTAL MODEL AND SUBJECT DETAILS

The fossilized non-human bone samples used in this study were recovered from archaeological excavations at the site of Contrebandiers Cave, Morocco. All necessary permits for archaeological excavation and analysis were obtained from the Institut National des Sciences de l'Archéologie et du Patrimoine in Rabat, Morocco. All archaeological samples were curated in Rabat, Morocco, in sterile plastic bags and given unique specimen identifiers.

METHOD DETAILS

Excavation methods

A total of 11,702 macrofaunal bone fragments were excavated between 2007 and 2010 following the methodology described in Dibble et al. (1995) and McPherron and Dibble (2002). All 11,702 macrofaunal bone fragments were analyzed in this study, as part of a complete zooarchaeological and taphonomic analysis of the Contrebandiers Cave bone assemblage (Hallett, 2018). Bones larger than 25 mm and all teeth were point-provenienced using a Total Station. Bones smaller than 25 mm were treated as aggregated data collected in 7-L buckets and screened with 1 cm and 2 mm mesh. All bone fragments were cleaned in a water bath to remove adhering sediment from bone surfaces, then allowed to dry completely before being placed in unused and new individual plastic specimen bags. Each bucket received a unique identifier and provenience at the center of the area from where the sediments were excavated. Aggregated bone from the 7-L buckets screened with 1 cm mesh was included in this study. Bones smaller than 1 cm that were screened using 2 mm mesh were not included in this study, as this division typically only includes microfaunal and macrofaunal bone fragments too small for confident identification. Each aggregate of bone from buckets was analyzed to remove bone fragments identifiable to skeletal element and/or taxonomic group, and fragments with signs of burning and/or surface modification were also removed, then assigned new unique identifiers, while retaining the original provenience information from the 7-L bucket. Also removed from the 1 cm division of aggregate bone and given unique identifiers were bone fragments displaying evidence of manufacture. Each bone tool analyzed in this study has a unique identifier.

Zooarchaeological methods

Surface modification and other taphonomic variables were recorded for all 11,702 macrofaunal bones (Hallett, 2018). Cut marks, carnivore tooth marks, and hammerstone percussion marks were identified using a 40-10X Olympus® zoom binocular microscope and bright incident light. This method of surface modification recording has shown 95% accuracy in a blind test (Blumenschine et al., 1996). Biochemical marks and trampling were also recorded, following the criteria outlined in Domínguez-Rodrigo and Barba (2006) and Domínguez-Rodrigo et al. (2009). Each layer at Contrebandiers Cave contains bones with evidence of cutmarks and hammerstone percussion marks. While the frequencies of human-accumulated large mammal bones vary according to layer, there are no layers where an absence of human accumulation was observed (Figure S7). Carnivore-accumulated bone is less frequent than human-accumulated bone at Contrebandiers Cave, in contrast to neighboring sites such as El Harhoura 2 and El Mnasra where carnivore accumulation dominates the assemblages (Campmas, 2012). In addition to each layer containing evidence for the predominantly human accumulation of bone, nearly all MSA layers at Contrebandiers Cave contain at least one bone tool.

Methods for identifying bone tools

Experimental and actualistic studies by others have established criteria for identifying bone tools. Natural processes can alter bones to the extent that their appearance resembles human modification and/or use. As such, a range of natural processes that can create "pseudo-bone tools" was considered in this study. Bone surface striations, sheen, polish, and breakage are criteria commonly used to identify human modification of bone. However, many non-human processes can produce similar modification. Striations can appear on bone surfaces as a result of rockfall (Fisher, 1995; Oliver, 1989), sedimentary abrasion (Andrews and Cook, 1985; Behrensmeyer et al., 1986; Fisher, 1995; Haynes, 1988; Olsen and Shipman, 1988; Shipman and Rose, 1983), trampling (Andrews and Cook, 1985; Behrensmeyer et al., 1986; Haynes, 1988; Olsen and Shipman, 1988), root etching (Andrews and Cook, 1985; Haynes, 1988), vascular grooves (Shipman and Rose, 1984), bone remodeling during the life of the animal (d'Errico, 1993), carnivore gnawing (Behrensmeyer, 1978; Binford, 1981; Blumenschine, 1988; Fisher, 1995; Shipman and Rose, 1983), herbivore gnawing (Sutcliffe, 1973), rodent gnawing (Andrews and Cook, 1985), insect burrowing (Shipman, 1981), and snail, beetle, and larvae damage (Dirks et al., 2015), among others. Sheen and polish can appear on bone surfaces through natural processing including water transport (Behrensmeyer, 1982; Jalvo and Andrews, 2003), sediment freezing/thawing or clay shrinking/swelling (Wood and Johnson, 1978), carnivore gnawing and repeated licking (Haynes, 1982; Sutcliffe, 1970), digestion by carnivores and raptors (Andrews, 1990; Fisher, 1981, 1995; Marean, 1991; Sutcliffe, 1970), and use as a juvenile carnivore play item (Haynes, 1982), among others.

In this study, criteria for identifying human modification and/or use of bone were based on experimental and archaeological studies that took natural processes into consideration, including striations on bone surfaces resulting from scraping with a lithic edge during manufacture (Campana, 1989; d'Errico, 1993; d'Errico and Backwell, 2003; Newcomer, 1974); striations from grinding bone against a fine or rough-grained surface during manufacture (Campana, 1989; d'Errico et al., 1984; Newcomer, 1974); striations from use (d'Errico and Backwell, 2003; d'Errico et al., 2012a; Tartar, 2012; Tartar, 2009); hammerstone percussion marks and notches from shaping during manufacture (d'Errico et al., 2012a; Henshilwood et al., 2001; Tartar, 2012; Tartar, 2009); and step-fractures from shaping and/or use (Henshilwood et al., 2001), and polish and sheen from use as a tool (Backwell and d'Errico, 2001; Campana, 1989; d'Errico et al., 2012a; Frison, 1982; Shipman and Rose, 1988; Tartar, 2009).

Following the methodology for bone tool recording presented in Henshilwood et al. (2001), a typological approach that incorporates manufacturing was used to analyze the Contrebandiers Cave bone tools. This approach was selected to allow for detailed descriptions of the steps taken in the manufacture and use of each piece. Each bone that displayed evidence of manufacture or use was recorded using the same criteria in order to reconstruct the sequences of actions taken. In addition, we recognize that similarly shaped bone tools might have been used for different tasks.

Identification of the raw material selected to manufacture or use each bone tool includes, when possible, taxonomic identification, size class, skeletal element, and skeletal element side (Table S4). Shaping techniques and use-wear were recorded for each piece using bright incident light coupled with an Olympus binocular 10x-40x zoom microscope, as well as a Leica EZ4 HD stereo 8x-35x zoom microscope with an integrated high-definition digital camera for photography. The manufacture of each piece was recorded using the following categories: Localization and extent of worked areas, manufacturing technique used, occurrence of wear, presence and location of breakage, burning, ochre or mineral staining, cut-marks, and post-depositional traces of damage. Shaping techniques were recorded according to the following categories: Scraping bone blank with stone tool, shaping by flake removal, holding the bone and abrading it against a fine-grained surface, and shaping by polishing. Length, width, and thickness were recorded for each bone, as well as width and thickness at 5 mm intervals from the tip. Possible reasons for discard were noted for each piece by analyzing breakage patterns, amount of retouch, and size.

Only adult bone was selected for manufacture. Adult long bones are distinguishable from juvenile long bones when epiphyseal fusion is visible, and cortical bone has a spongy, flaky appearance in juveniles. As most of the worked bones from Contrebandiers Cave were manufactured on long bone shafts where epiphyseal fusion is not visible, these bones were identified to age class with the aid of a comparative collection of bovid skeletons from individuals of known age class. A comparative collection was also used to identify the skeletal element that each worked bone was made from. Bone tools were made on long bone shafts, rib shafts, mandibular bodies, teeth, and unknown skeletal elements (Table S4). Bone tools that were made from unknown skeletal elements are heavily shaped through manufacture, making identification difficult, as diagnostic landmarks are not present. The skeletal elements most frequently used as blanks for manufacture are shafts from ribs, femora, humeri, radii, and metapodials. Adult long bone shafts were likely selected for bone tool manufacture because cortical bone provides a thick and strong material ideal for use. Taxonomic identifications were made when possible.

The majority of worked bones were made on shaft fragments from bovids belonging to size class 2 or 3 (Table S4). Brain's (Brain, 1981) bovid size class descriptions were modified for the study of the Contrebandiers Cave faunal assemblage, as the majority of bovid species from the Maghreb belong to size classes that border I and II, II and III, and III and IV. In addition, size classes were broken into subclasses, represented by a and b. For example, Brain's (Brain, 1981) bovid size class I (4.5–19 kilograms [kg]) is divided into class 1a (1–12 kg) and class 1b (12–23 kg). The remaining body size classes were subdivided as: 1b/2a (12–53 kg); 2a (23–53 kg); 2b (53–84 kg); 2b/3a (53–190 kg); 3a (84–190 kg); 3b (190–246 kg); 3b/4a (190–598 kg); 4a (296–598 kg); 4b (598–900 kg); 5 (900–1,500 kg); and 6 (1,500 + kg). Selection of long bone shafts from bovids belonging to either size class 1a/2a or size class 3 reflects the abundance of bone from these size classes and taxa within the site.

Four categories of manufacturing technique were identified: Shaping by scraping the bone blank with a stone tool (Figures 2 and 3) shaping by flake removal using percussion (Figure S4); shaping by direct abrasion against a fine-grained surface (Figure S6); and what is potentially shaping by polishing (Figure S4). Of these, shaping by polishing is the most difficult to distinguish from polish through use. In this study, intentional shaping by polish was distinguished from polish through use based on the extent of polish. If a bone tool had polish over the entire surface, then this was likely due to intentional polish. However, we are cautious in assigning bone tools with polish covering the entire surface as formal tools, as we are not yet able to confidently assign these to a known tool type. Polish restricted to tool tips, butts, edges, or elevated areas was likely the result of tool use (Figure 2).

Criteria for distinguishing striations left by scraping versus those left by abrasion are outlined in d'Errico and Backwell (2003), Newcomer (1974), and Campana (1989). Campana (1989) conducted experiments with fresh cattle bone, flint and sandstone to determine which manufacturing technique was used by the

Natufian and Zagros Proto-Neolithic cultures: scraping with a stone tool or abrasion. These experiments showed that it is possible to distinguish bone that was shaped by stone tool scraping (flint) from bone that was abraded against a sharp-grained surface (sandstone) (Campana, 1989). Both methods leave striations visible to the naked eye. However, when viewed with at least 24x magnification, differences are visible between the two techniques. When scraping a bone blank with a flint stone tool, in a manner similar to sharpening a pencil with a knife, striations are parallel to one another and often parallel to the long axis of the bone blank (Campana, 1989). Striations are also somewhat wavy, rather than straight, due to the unevenness of retouched lithic edges and lateral movement of the lithic edge against the bone blank, as shown in Figure 2. Striations produced with lithic scraping are also shallow and have curving cross sections, and striations overlap one another because of repeated shaving strokes, as shown in Figure 2. In contrast, shaping a bone blank with sandstone leaves striations that are straight (Campana, 1989). Striations from grinding are parallel to one another, overlapping, and v-shaped in cross section (Campana, 1989).

Spatules or "spatulas" (Figures 2, 3, and 4) are synonymous in form with the formally recognized tool type *lissoir*, following Tartar (2009). Tartar (2009) groups *spatules* or "spatulas" and *brunissoirs* (thicker than *lissoirs* and mostly made on deer antler) into sub-types within lissoirs. We agree with this sub-type designation and hope that comparison between MSA spatulates (also referred to as *spatules* in other literature) and Middle/Upper Paleolithic lissoirs can proceed in future studies with clarified terminology. As Tartar's (Tartar, 2009) study of bone tools from the Upper Paleolithic in France found that lissoirs are often made on split-rib shafts, the spatulates from Contrebandiers Cave are also often made on split-rib shafts (Figure 4).

Techniques for experimentally manufacturing split-rib shafts have been described elsewhere (Tartar, 2009). Generally, as shown in Figure 4, this process consists of first removing the head, neck and tubercle of the rib, then preparing the cranial (upper) and caudal (lower) edges with a lithic edge to create a flat surface for subsequent wedge insertion. After the edges have been prepared, a wedge is hammered into the length of the piece until the rib splits at the midline running between the cranial and caudal edges. This process produces two blanks (either the internal face of the rib or the external face) that can then be shaped using hammerstone percussion, scraping with a lithic edge, or abrasion against a sharp-grained surface. Tartar (2009) notes that the initial process of splitting the rib in half rarely leaves marks on lissoirs, as subsequent shaping and use modify the surface such that marks from blank production are not preserved. This was true for the Contrebandiers Cave spatulates. One piece (K7-707) more closely resembles the shape and use wear of a *lissoir*. K7-707 (Figure S6) is thicker at the end than the other Contrebandiers Cave *lissoirs*, and has sheen restricted to the tip. However, the tip curves away from the body, unlike other known *lissoirs*.

Burning extent and severity were also recorded for each bone tool. In sum, 6 pieces showed complete (100% coverage) burning, 8 pieces showed partial (10–75% coverage) burning, 6 pieces showed burning on the tip only, and 42 pieces were not burned (Table S2). It is possible that some pieces were heated to get a hardened tip. As Campana (1989) discusses, moderate heating of bone will harden it considerably. However, intense heating will result in the breakdown of the tensile strength of bone through the loss of its organic fraction.

Methods for recording use wear

Short, deep, non-parallel striations and polish restricted to limited areas of a bone tool were interpreted as resulting from use after manufacture (Figure 2). While specific uses of bone tools are difficult to determine, extensive experimental research on bone tool use and wear has been published by others (Backwell and d'Errico, 2001; Campana, 1989; d'Errico and Backwell, 2003; d'Errico et al., 1984; Henshilwood et al., 2001; Newcomer, 1974; Soressi et al., 2013; Tartar, 2009) and these studies were used as reference during analyses of the Contrebandiers Cave bone tools. The published reference collections and microscopic mark analyses from Backwell and d'Errico (2004), d'Errico and Backwell (2009) and Backwell et al.(2008) were also used in the Contrebandiers Cave bone tool analyses. The use wear recorded on the Contrebandiers Cave spatulates is consistent with experimental, ethnographic, and use-wear studies of leather-working tools (Semenov, 1964; Soressi et al., 2013; Tartar, 2009), as sheen and polish are restricted to the ends and sides but do not cover the entirety of the pieces. However, while our study used 40X magnification to identify use wear traces, others have used 100X-500X magnification to identify polish from use (see (Almeida Évora, 2015) for review and discussion of various magnification strengths). This is a possible limitation to our study, and future analyses of the Contrebandiers bone tool assemblage should use 100X-500X magnification to verify that the bone tools were used on skin, as has been suggested here.

Pressure flakers experimentally produced by d'Errico et al. (2012a) resemble three pieces at Contrebandiers Cave (Figures 6, and S3). When experimentally producing and using pressure flakers, d'Errico et al. (2012a) observed "crushing and flake removals originating from the tip [that] appeared when the broad aspect of the tool was applied perpendicular to the lithic edge and the tool was held almost upright during use." Mourre et al. (2010) identified stone tools at Blombos Cave, South Africa that suggest pressure flaking technology was used by ~75 ka in the final stages of Still Bay bifacial point manufacture, however, tools that were used as pressure flakers were not identified at Blombos Cave. d'Errico et al. (2012a) identified bone tools used as pressure flakers at Sibudu Cave, South Africa that support the presence of pressure flaking technology by ~64–57 ka in South Africa. While it is possible that hand-held pressure flaking was used in the manufacture of Aterian bifacial foliates—which have been identified at Contrebandiers Cave (Dibble et al., 2012)—further experimental studies must be completed to support this implication.

Bone tool imaging methods

Color photographs of bone tools and 5 cm scales were taken with a Canon EOS 10D Digital camera using a Canon Ultrasonic 100 mm macro lens. Photographs were then imported into Adobe Lightroom 5, where white balance was corrected for using the white portion of the scale in each photograph. Images were then imported into Adobe Photoshop CS6, where the same methods were used to remove the background in each image. These methods are: 1) open images in 6,000 x 8,000 pixels with 240 pixels per inch and in 16 bit color on 50% gray background, 2) use Magic Wand Tool at level 10 tolerance to select bone tool from background, then remove background, 3) refine edge with feather set at 1.5 pixels, and 4) draw rectangle over 1 cm portion of 5 cm scale to create 1 cm scale bar. Microscope photographs of bone tools were taken with a Leica EZ4 HD stereo 8x-35x zoom microscope with an integrated high definition digital camera. Microscope photographs were then imported into Adobe Photoshop CS6, where the same methods were used to convert each color to grey scale and remove the background in each photo. The methods are: 1) open images in 6,000 x 8,000 pixels with 240 pixels per inch and in 16 bit color on 10% or 50% grey background, 2) use Magic Wand Tool at level 10 tolerance to select bone tool from background, then remove background, 3) refine edge with feather set at 1.5 pixels, 4) convert each photo to grey scale and set auto contrast, and 5) scale each grey scale microscope photo to color photo taken with macro lens. The final microscope and bone tool photographs were composed and finaliz ed into Figures 2, 3, 5, and 6 using Adobe Photoshop 2021. Figure 2 illustrations G, H, I and J were drawn and composed using Adobe Photoshop CC 2019. The methods are: 1) import base layer with original bone tool photographs and scale set to 50% opacity, 2) use Jazza's Signature Photoshop Brushes (JSPB) Fineliners 0.3 and 0.5 to trace outline and major features of bone tool, 3) use JSPB Fineliner 0.1 to draw lateral breakage and irregular surfaces of bone tool, 4) draw dotted lines with Photoshop Hard Round Brush at 215% spacing, 5) draw bone tool shaping marks with ruler guides and JSPB Fineliner 0.1, 6) use JSPB Ink Brush to draw irregular marks, 7) trace darkened area of bone tool with Lasso Tool then fill with 50% grey, and 8) trace 1 cm scale bar then fill with black and white rectangles. Figure 4 illustrations were created using Adobe Illustrator CC 2020.

Stratigraphy methods

Contrebandiers Cave is carved into a Middle Pleistocene calcarenite (calcareous sandstone) formation and is located along the Atlantic Coast of Morocco in the town of Témara. The cave is currently ~250 m from the ocean with an entrance facing northwest. The top of the cave is ~14 m above current sea level. The basal deposits are archaeologically sterile beach sands (Aldeias et al., 2014) with a weighted mean OSL age of 126 ± 9 ka (Jacobs et al., 2011). This OSL age is concordant with widespread age estimates for Marine Isotope Stage (MIS) 5e high sea-level stand (Hearty et al., 2007). Anthropogenic inputs (in the form of stone tools, ash, charcoal and bones) are visible in deposits directly above the basal beach sands, indicating the onset of human occupation following the MIS 5e marine regression (Aldeias et al., 2014).

There are three stratigraphic sectors in the cave: the central excavation area (CEA), sector IV in the front of the cave, and sector V in the rear of the cave (Figure S1). Roche's previous excavations removed all of the uppermost Neolithic deposits and nearly all of the Iberomaurusian (Later Stone Age) deposits. As for the latter, Roche reported that the Iberomaurusian was spatially restricted within the site and never reached the back of the cave (Roche, 1976). A very small amount of sediment associated with Iberomaurusian occupations remains below the current dripline in sector IV, and unconformably overlies the uppermost MSA deposits of layer IV-2. Both field and micromorphological analyses attest to the lack of significant mixing between the Iberomaurusian layers and the underlying MSA deposits; the sedimentary contact between layer IV-2 and the overlying Iberomaurusian layers is sharp and clear. All of the stone tools associated with layer IV-2 are also consistent with MSA technocomplexes.

Sector V only contains Aterian MSA deposits; the base of the deposit was not reached in the rear of the cave. According to evidence from previous excavations, there were no Iberomaurusian occupations in this area of the cave. Presumably, the MSA deposits in sector V must, therefore, have been directly overlain by the distinct strong brown Neolithic sediments, which completely in-filled the cave at the time of its discovery (Roche, 1976). The MSA deposits in sector V (layers V-1a, V-1b and V-2) are composed of reddish brown silty sands, commonly incorporating combustion remains and discrete features (hearths).

The CEA contains Aterian and Maghrebian Mousterian MSA deposits, as well as MIS 5e beach sands at the base of the sequence. Within the ~3 m thick MSA sequence, the stratigraphical contacts between the different layers are clear and occasionally associated with calcium carbonate crusts (Aldeias et al., 2014). Within the CEA, 27 bone tools were identified in six MSA archaeological layers (Layers 4, 5A, 5B, 5C, 5D, and 6B). Fourteen bone tools were identified from one MSA archaeological layer in sector IV (Layer IV-2). Twenty-two bone tools were identified from three MSA archaeological layers in sector V (Layers V-1a, V-1b and V-2). Only one bone tool was identified in one archaeological layer associated with the Iberomaurusian in sector IV. In total, 62 MSA bone tools, and one Iberomaurusian bone tool were identified. Detailed descriptions of the geology (Aldeias et al., 2014; Dibble et al., 2012), stratigraphy (Aldeias et al., 2014; Dibble et al., 2012), and archaeological content (Dibble et al., 2012, 2013) of the Contrebandiers Cave sequence have previously been published.

Methods for dating the deposits

A large number of samples have been dated to construct a chronology for the MSA deposits at Contrebandiers Cave (Dibble et al., 2012). A multi-method dating approach was used, involving electron spin resonance (ESR), thermoluminescence (TL) and optically stimulated luminescence (OSL) techniques (Dibble et al., 2012). All three techniques are based on the same physical principles, but are applied to different minerals, namely hydroxyapatite in tooth enamel for ESR, microcrystalline quartz in flint or other rock types for TL, and sand-sized grains of quartz in sediment for OSL. Ages are obtained by measuring the cumulative effect of ionizing radiation on the crystal structure of these minerals. The greater the amount of energy stored in the crystal lattice, the longer the duration since first exposure to radiation and, consequently, the greater the age of the material being dated (Aitken, 1985). A series of OSL ages were first published in Schwenninger et al. (2010) for samples collected from a profile left by the Roche excavation. The OSL chronology associated with the latest excavations was first reported in Jacobs et al. (2011) and again in Dibble et al. (2012), and also together with the ESR and TL ages, in Dibble et al. (2012). No further dating of the MSA deposits has since been reported. Measurement and analytical details for all the samples are provided in these publications. In this article we will look more closely at the ages so far obtained for deposits that contain bone tools. Results relevant to the age of the bone tools presented in this article are summarized in Table S1 and the weighted mean ages for each of the Layers are shown in Figure S8.

Dating the central excavation area (CEA)

In Figure S1 the provenience of each of the bone tools is provided. Twenty-seven bone tools were discovered in deposits from the CEA, of which most (N = 20) come from Layer 5 (A, B and C) and are associated with the "Maghrebian Mousterian" of the MSA. The Maghrebian Mousterian is similar to the Aterian but without the diagnostic tanged artifacts, which are the *fossil directeur* of the Aterian Industry (Dibble et al., 2013). OSL ages for Layer 5 range between 124 $\pm$ 9 ka (SC19) and 112 $\pm$ 7 (SC13) (Table S1). Jacobs et al. (2011) calculated a weighted mean OSL age of 115.3 $\pm$ 3.4 ka for this layer. Preliminary TL ages for 4 individual burnt stone samples were reported in Dibble et al. (2012). These ages range between 116 $\pm$ 13 and 89 $\pm$ 14 ka. Preliminary ESR ages were also reported for 4 tooth samples. The ages range between 123 $\pm$ 10 ka and 90 $\pm$ 2 using the recent uptake (RU) model. The range of TL and ESR ages are almost identical and overlap with the OSL ages; all three sets of ages are statistically consistent at the 1σ level within the CEA and at the 2σ level for Layer 4 in the CEA, Layer V-1 in Sector V, and Layer IV-2 in Sector IV (Dibble et al., 2012). One bone tool was also collected from Layer 6B, which has a low artifact abundance and for which a weighted mean OSL age of 112.2 $\pm$ 4.2 ka was calculated. The youngest bone tools (N = 6) in the CEA were collected from Layer 4D which is associated with the Aterian with tanged pieces (Dibble et al., 2013). Three OSL ages of 104 $\pm$ 7 (SC20), 108 $\pm$ 9 (SC8) and 117 $\pm$ 9 ka (SC7) were calculated for Layer 4D and are similar to, and slightly younger than, those for Layer 5. The earliest occurrence of bone tools in the CEA can best be dated by the grand weighted mean OSL age for the archaeological units in Layers 5 and 6 of 116.1 ± 2.9 ka (see Table 3 in Jacobs et al. (2011)) and the mean TL age of 97 ± 7 and the mean ESR age of 111 ± 7 ka (weighted mean = 94 ± 8 ka), both for Layer 5.

Dating sector V

A large number of bone tools (N = 21) were also recovered from the MSA levels in Sector V (-1a, -1b and −2), all associated with the Aterian Industry. No TL ages were obtained from this Sector, but Dibble et al. (2012) reported ESR ages for 4 teeth collected from Layer V-1a and obtained ages that ranged between 109 ± 7 ka and 86 ± 2 using the linear uptake (LU) model or between 132 ± 9 ka and 108 ± 4 using the recent uptake (RU) model. Their respective weighted mean ages are 91.4 ± 7.7 and 110.5 ± 8.3 ka. A single OSL age was reported for each of Layer V-1b and V-2, and ages of 113 ± 7 (SC23) and 107 ± 9 ka (SC34) were calculated, respectively. Archaeologically, these deposits are similar to that of Layer 4D in the CEA for which comparable OSL ages were obtained.

Dating sector IV

A further 14 bone tools were also recovered from the Aterian deposits at the front of the Cave in Sector IV, in Layer IV-2. TL ages for 6 burnt stone samples were reported in Dibble et al. (2012) and 5 of the ages range between 115 ± 11 ka and 80 ± 11; there is a single outlier with an age of 179 ± 14 ka. No ESR ages have been reported for these deposits. Three OSL samples were collected from this Layer and these posed a number of issues. We were unable to obtain a reliable age for one of the samples (SC30) because of evidence for extensive sediment mixing (Jacobs et al., 2011); small-scale (mm-sized) bioturbation by wasps and other insects are pervasive in these sediments (Aldeias et al., 2014). We were able to obtain ages for the other two samples, but these two samples also showed evidence for mixing, both from the overlying Iberomaurusian deposits and incorporation of grains from the roof rock. The erosional boundary between the Aterian and Iberomaurusian deposits in this sector is sharp and easy to identify macroscopically in the field. The boundary, however, is not horizontal and undulates; this is probably due to erosion by water (see Aldeias et al. (Aldeias et al., 2014)). When we collected the OSL samples with ~15 cm long tubes, we likely cross-cut the boundary and sampled a mixture of both deposits. It is important to emphasize that the Aterian and Iberomaurusian deposits are not mixed here, rather the mixing is most likely the result of the sampling procedure. The best-estimate OSL ages for Layer IV-2 are 96 ± 8 (SC39) and 101 ± 9 ka (SC37). These ages are also supported by dating of 2 samples from the adjacent squares in the old excavation area of Roche that gave consistent ages of 92 ± 6 (SC31) and 97 ± 7 ka (SC32). Together, these samples gave a weighted mean OSL age of 95.9 ± 4.1 ka (Jacobs et al., 2011) that is statistically consistent with the range of TL ages for burnt stones collected from these sedimentary deposits, and provides an age for the youngest MSA bone tools at Contrebandiers Cave.

Checking the reliability of the OSL chronology

Most of the chronology is based on the large number of OSL ages provided in Jacobs et al. (2011). However, Guérin et al. (2013) recently critiqued the use of the beta dose correction procedure of Jacobs et al. (2008) to deal with scatter in equivalent dose (D_e) data sets for the samples from Contrebandiers Cave, among other sites. Quartz grains deposited at the same time but situated within a few mm or cm of each other can have experienced different beta dose rates, depending on their relative proximity to materials of high or low radioactivity, resulting in a range of different D_e values. Jacobs et al. (2011) explained in detail their reasons for applying this model at this site based on the heterogeneous distribution of organic and inorganic materials, and also described, with a worked-example, how it was implemented. To test the effect of the use of this model, we present in Figure S9, as filled circles, the individual ages reported in Jacobs et al. (2011) for samples from layers in which bone tools were recovered, together with ages (shown as open squares) for the same samples but for which we did not use the beta dose adjustment procedure (i.e., we used the central age model (CAM) of Galbraith et al. (1999) to obtain a weighted mean D_e, that is then divided by the bulk beta dose rate for the sample). From here it can be seen that the model, when applied to samples from this site, had a systematic effect and that ages are on average 5 ± 1% younger when the beta dose rate is not adjusted. The change in age, however, is well within the 1σ age uncertainty of the individual OSL samples (Figure S9), and also within the range of ages obtained from other independent methods that are statistically consistent with the OSL ages. Thus, the difference in age is insignificant and does not change the antiquity of the bone tools recovered from the MSA deposits at Contrebandiers Cave.

The weighted mean OSL age of 116.1 ± 2.9 ka, therefore, best constrains the age of the oldest bone tools found in Layers 5 and 6 in the CEA, and the weighted mean age of 95.9 ± 4.1 ka best constrain the age of the youngest MSA bone tools found in Layer IV-2 in Sector IV at the top of the MSA deposits. Bone tools are also found in layers between these oldest and youngest bone tool bearing deposits, so an age range of ~120–90 ka obtained by all three dating techniques captures the ages of all MSA bone tools at Contrebandiers Cave.

Other Contrebandiers cave bone tools

Other bone tools from MSA layers at Contrebandiers Cave include scaled pieces (see Figure S4) and possible awls (see Figure S4), as well as other bone tools that do not conform to a yet-known type (see Figure S4). Future experimental studies are aimed at providing descriptions of the manufacturing stages for these bone tools, and at determining their function and typology.

MSA stone artifacts

As previously reported in Dibble et al. (Dibble et al., 2012, 2013), assemblages with MSA lithics at Contrebandiers were traditionally divided into two groups. The lower one (Layers 5A-5D and 6A-6C in the CEA), referred to as the Maghreb Mousterian, does not contain stemmed (tanged) implements, while the upper assemblage (Aterian) from Layers 4A-4E (CEA), Layer IV-2 (Sector IV near the front of the cave), and Layers V-Ia, V-Ib, and V-2 (Sector V near the back of the cave) does have stemmed pieces. Some stemmed pieces are pointed, but most are not, suggesting that these artifacts are not functional points but rather indicate the hafting of lithic artifacts, likely as scrapers and knives (Iovita, 2011). The Aterian occupation also produced one bifacial foliate. In other respects, these two MSA components are quite similar. Typologically, both have sidescrapers (primarily single sidescrapers) and notch/denticulates. All other tool types are rare, but include truncated-facetted, endscrapers, and various retouched pieces. A similar situation exists for the lithic technology, with Levallois technique present in low frequencies (ca. 3% overall) throughout, along with some examples of Kombewa cores and flakes (suggesting small flake production). Plain platforms are typical on flake debitage indicating that, with the exception of Levallois technique, no extensive core preparation or maintenance of cores was undertaken. Levallois cores are rare, while most other cores are single surface. Based on this combination of features, Dibble et al. (2013) suggested the possibility that the lower and upper occupations may not represent two distinct industries. Instead, they may reflect somewhat different activity profiles at the site over time, which might be supported by the fact that the identified spatulate bone tools are associated with the upper (Aterian) deposits (Table S1; but note that many bone tools have not been identified to type).

QUANTIFICATION AND STATISTICAL ANALYSIS

The ages are given as mean ± SEM (Table S1, Figures S8 and S9) as reported in Jacobs et al. (2011) and Dibble et al. (2012). Data were analyzed with RStudio version 1.2.5033 (RStudio Team, 2019) running R version 3.6.2 (R Core Team, 2020).