Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa

Francesco d'Errico[a,b,1], Lucinda Backwell[c,d], Paola Villa[a,e,f], Ilaria Degano[g], Jeannette J. Lucejko[g], Marion K. Bamford[c], Thomas F. G. Higham[h], Maria Perla Colombini[g], and Peter B. Beaumont[i]

[a]Centre National de la Recherche Scientifique, Unité Mixte de Recherche 5199, De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie, Université Bordeaux I, F-33405 Talence, France; [b]Institute for Archaeology, History, Cultural Studies and Religion, University of Bergen, 5020 Bergen, Norway; [c]Bernard Price Institute for Palaeontological Research, School of Geosciences, [d]Institute for Human Evolution, and [f]School of Geography, Archaeology, and Environmental Studies, University of the Witwatersrand, Wits 2050, South Africa; [e]University of Colorado Museum, Boulder, CO 80309-0265; [g]Dipartimento di Chimica e Chimica Industriale, Università di Pisa, 56126 Pisa, Italy; [h]Research Laboratory for Archaeology and the History of Art, University of Oxford, Oxford OX1 3QY, England; and [i]Archaeology Department, McGregor Museum, Kimberley 8300, South Africa

Edited by Richard G. Klein, Stanford University, Stanford, CA, and approved June 6, 2012 (received for review March 11, 2012)

Recent archaeological discoveries have revealed that pigment use, beads, engravings, and sophisticated stone and bone tools were already present in southern Africa 75,000 y ago. Many of these artifacts disappeared by 60,000 y ago, suggesting that modern behavior appeared in the past and was subsequently lost before becoming firmly established. Most archaeologists think that San hunter–gatherer cultural adaptation emerged 20,000 y ago. However, reanalysis of organic artifacts from Border Cave, South Africa, shows that the Early Later Stone Age inhabitants of this cave used notched bones for notational purposes, wooden digging sticks, bone awls, and bone points similar to those used by San as arrowheads. A point is decorated with a spiral groove filled with red ochre, which closely parallels similar marks that San make to identify their arrowheads when hunting. A mixture of beeswax, *Euphorbia* resin, and possibly egg, wrapped in vegetal fibers, dated to ∼40,000 BP, may have been used for hafting. Ornaments include marine shell beads and ostrich eggshell beads, directly dated to ∼42,000 BP. A digging stick, dated to ∼39,000 BP, is made of *Flueggea virosa*. A wooden poison applicator, dated to ∼24,000 BP, retains residues with ricinoleic acid, derived from poisonous castor beans. Reappraisal of radiocarbon age estimates through Bayesian modeling, and the identification of key elements of San material culture at Border Cave, places the emergence of modern hunter–gatherer adaptation, as we know it, to ∼44,000 y ago.

bone artifacts | chemical analysis | modernity | wooden artifacts

A key issue in human evolution is when modern culture, as we know it, emerged. Research conducted in the last decade has made it clear that human populations living in southern and North Africa, as well as the Near East, had developed key cultural innovations by at least 80,000 y ago. These innovations include systematic use of red pigment for utilitarian (1) and perhaps symbolic activities (2); production and storage of pigmented compounds (3); abstract engravings on pieces of ochre and ostrich eggshell (OES) (4, 5); use of marine shells as personal ornaments at coastal and inland sites, some of which were covered with pigment (6); production of bone projectile points and shaped bone tools used in domestic activities (7); complex hafting techniques involving the use of organic and mineral ingredients (1); controlled use of pyrotechnology to facilitate the manufacture of refined lithic projectile points by means of pressure flaking (8); and the use of backed lithics to produce composite tools and to arm spears or arrows (9, 10). These innovations are considered by many as the earliest manifestations of "modern behavior," although the criteria that define behavioral modernity are much debated (11–14). Such innovations are used to support a scenario that postulates a causal connection between the origin of our species in Africa ∼200 ka and a gradual emergence of modern cultures on that continent. This model predicts a gradual accretion of cultural innovations in Africa, which facilitated the spread of our species out of Africa and the replacement of archaic hominin forms (11).

Although the above innovations may reasonably be seen as instances of cultural complexity, the archaeological record alerts us to a number of caveats. First, Neanderthals exhibited many complex behaviors (pigment use, funerary practices, complex hafting techniques, wood-working, personal ornamentation, and bone tool manufacture) before or at the very moment of contact with modern humans (13, 15–18). Second, many of the innovations are only found at a few sites of a given technocomplex, which makes one wonder whether they can be considered as integral features of those cultural systems or just the expressions of local traditions (7, 12). Third, many of the innovations recorded in Africa and the Near East disappear in a staggered manner between 70 ka and 50 ka. In southern Africa, the complex adaptations associated with the Still Bay vanished at the onset of Marine Isotope Stage 4 (∼70 ka), and this event is followed by a possible archaeological hiatus of 6,000 y (19). The subsequent Howiesons Poort (HP) developed new innovative cultural features that disappear at ∼59 ka. These give way, during the post-Howiesons Poort (post-HP), to large unifacial points on flakes that by 40 ka disappear to give rise to the production of microliths obtained with a bipolar knapping technique (10, 20, 21). This disappearance has been attributed to climatic change (22, 23), decrease or lack of population (24), and changes in the mechanisms of cultural transmission (12). Whatever the reason, this pattern evidences major discontinuities in cultural transmission that appear to separate the earliest instances of "modernity" from those that we see associated with historically known hunter–gatherers in southern Africa and their archaeological antecedents.

The truth is that we have little idea about what happened in southern Africa between 40 ka and 20 ka, and it is at present difficult to assess the relationship, if any, between the suite of cultural adaptations recorded before 60 ka and those that emerged with the Later Stone Age (LSA). In light of this reality, making inferences about Middle Stone Age (MSA) societies based on what we know about modern hunter–gatherers from southern Africa is problematic.

San material culture, and its immediate antecedents with which it keeps clear ties, comprises many distinct features, such as hunting with bows and arrows, use of composite poisoned bone arrowheads, relatively short and light spears, organic compounds, digging sticks weighted with bored stones, standardized OES beads finished with grooved stones, and notched sticks used as counting systems (25–27). These elements, which were originally widespread across different geographic and ecological settings, appear inseparable from San social organization, world view, and symbolic systems (28, 29). These practices are based on egalitarianism, fluid band membership, and periods of aggregation

Author contributions: F.d., L.B., P.V., and P.B.B. designed research; F.d., L.B., P.V., I.D., J.J.L., M.K.B., T.F.G.H., and M.P.C. performed research; F.d., L.B., I.D., J.J.L., M.K.B., T.F.G.H., and M.P.C. analyzed data; and F.d. and L.B. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

[1]To whom correspondence should be addressed. E-mail: f.derrico@ipgq.u-bordeaux1.fr.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1204213109/-/DCSupplemental.

during which socializing, ritual intensification, and gift exchange of items such as beadwork and arrow points take place, which help consolidate social bonds (25, 26, 28–30). This observation raises the question of when this recognizably modern cultural system, for which we have a direct link with living people, emerged in the past. Opinions diverge on when and how this emergence happened, mostly because no consensus exists on the classification of lithic industries between 40 ka and 22 ka (21) and when and how distinct LSA tool kits appear in the archaeological record. The dating of key archaeological contexts is also contentious (21, 31, 32).

In addition, most San material culture is made from organic matter that is rarely preserved in the archaeological record. Bone points are known at four southern African sites (Border Cave, Boomplaas, Nelson Bay Cave, and Bushman Rock Shelter) dated to between 39 ka and the Holocene, at which time they become common (30, 32). Poisoned bone arrow points similar to those used by San are thought by most to appear only after 12 ka (33, 34), and perhaps much later (35). Early occurrences of OES beads come from a number of MSA sites in southern and eastern Africa, some of which are >40 ka (35–37), but their low numbers make it difficult to ascertain whether they reflect the emergence of a gift exchange system comparable to the *hxaro* system among the San (30). Personal ornaments become more varied after 13 ka when they incorporate bone beads, pendants, tubes made of bird and mammal bone decorated with spiral incisions, and rare marine shells (30–32). If bored stones are taken as an indicator of the use of digging sticks, the oldest secure occurrences are found at Matupi, Zaire (38), in levels dated to ∼20 ka. Two fragments of bored stone from a level dated 45 ka to 44 ka at Border Cave have been considered too small to have been used to weight a digging stick (refs. 31 and 32, but see ref. 21). The first secure evidence of wooden digging sticks is found in the mid-Holocene at Gwisho Hot-springs, Zambia (39), and later, at a number of sites from South Africa (21, 40).

In sum, most archaeologists believe that the San lifestyle extends back ∼20 ka but that, despite recorded regional and temporal variation within the LSA (30, 32, 40), clear continuity between modern and prehistoric societies in the more intimate aspects of their culture is traceable only from the beginning of the Holocene (32, 33, 40). The Border Cave sequence (*SI Appendix, Archaeological Context*) preserves in the upper layers 1WA and 1BS Lower B-C, attributed to the Early Later Stone Age (ELSA)—evidence supporting the view of an early emergence of San material culture (41). However, the lithic assemblages from the post-HP/MSA3 and the ELSA layers at this site have not been, until now, analyzed in detail. This neglect also applies to the varied collection of organic artifacts, many of which have not been described in depth, despite their possibly being the oldest evidence of recognizably modern culture. Considerable effort has been invested in the last two decades to refine the chronostratigraphic framework of this site (42, 43). The aim of this work, in the context of direct dating of key items, is to make a comprehensive analysis of the organic artifacts from Border Cave upper levels, in conjunction with a companion paper (21) devoted to the lithics, and to discuss the implications of these findings for the origin of modern cultural adaptation as we know it.

Results

Dating. Reappraisal of ESR and ^{14}C age estimates, and Bayesian modeling of calibrated radiocarbon ages conducted in the framework of this study (*SI Appendix, Archaeological Context* and Figs. S1–S4), indicate, from bottom to top, that layer 2WA is dated to 60 ka and 2BS Lower A-B to >49 ka. Layer 2BS UP accumulated between 49 ka and 45 ka, 1WA between 44 ka and 43 ka, 1BS Lower B-C between 43 ka and 42 ka, and 1BS Lower A between 41 ka and 22 ka. The archaeological material analyzed in this study comes from layers 2WA, 2BS Lower C, 1WA, and 1BS Lower B-C.

Worked Tusks. Eight worked tusks come from the post-HP and ELSA layers (Table 1; Fig. 1, *1–8*; and *SI Appendix, Results* and Table S1). They consist of naturally or artificially split warthog (*Phacochoerus aethiopicus*) or bushpig (*Potamochoerus larvatus*) lower canines. They preserve the remains of the occlusal wear facet, indicating a preference for adult individuals. The facets are covered by natural obliquely oriented parallel striations that mimic artificial grinding marks. On the split surface, the dentine is entirely scraped, or scraped and ground (*SI Appendix, Results* and Figs. S5 and S6), to produce a robust tip, triangular in section with sides comprising one worked aspect, the occlusal facet, and unmodified enamel. On a single specimen from layer 1BS Lower B-C, the occlusal facet was modified by scraping, and the split surface was left unworked. On three specimens, grinding

Table 1. Context and description of organic artifacts from Border Cave

Layer	Square	Description (animal source)*	Tech.	Fig.
1BS L.B-C	W16	Bone point	—	2, *7*
1BS L.B-C	Q23	Bone point	S	2, *6*
1BS L.B-C	T18	Notched bone (4)	I	1, *12*
1BS L.B-C	S19	Shell bead	GP	2, *23*
1BS L.B-C	T20	Bone point[†]	S	2, *5*
1BS L.B-C	Q21	Tusk preform (2)	S	1, *8*
1BS L.B-C	R23	OES bead	GP	2, *21*
1BS L.B-C	R24	OES bead	GP	2, *20*
1BS L.B-C	R22	OES bead	GP	2, *19*
1BS L.B-C	Q16	Tusk point (2)	SI	1, *7*
1BS L.B-C	Q21	Wooden stick[‡]	SI	2, *26*
1BS L.B-C	Q21	Wooden stick	SI	2, *26*
1BS L.B-C	Q21	Wooden stick	SI	2, *26*
1BS L.B-C	Q21	Wooden stick	SI	2, *26*
1BS L.B-C	S20	Wood digging stick	—	2, *25*
1BS L.B-C	S19	Lump of beeswax	B	2, *24*
1WA	V21	Notched bone	I	1, *11*
1WA	W16	Notched bone (4)	I	1, *10*
1WA	R18	Shell bead	P	2, *22*
1WA	T22	Worked tusk (2)	SG	1, *6*
1WA	T22	Bone awl	SG	2, *4*
1WA	Q17	Bone awl	S	2, *3*
1WA	S19	Bone point frag.[†]	SE	2, *2*
1WA	S19	Bone-shaped frag.	S	2, *1*
1WA	Q19	OES bead	GP	2, *18*
1WA	Q24	OES bead	GP	2, *17*
1WA	Q24	OES bead	GP	2, *16*
1WA	T18	OES bead	GP	2, *15*
1WA	S23	OES bead	GP	2, *14*
1WA	S23	OES bead	GP	2, *13*
1WA	R20	OES bead	GP	2, *12*
1WA	S19	OES bead	GP	2, *11*
1WA	T19	OES bead	GP	2, *10*
1WA	T19	OES bead	GP	2, *9*
1WA	R19	OES bead	GP	2, *8*
2BS L.C	S21	Worked tusk (2)	S	1, *5*
2BS L.C	R20	Worked tusk (2)	S	1, *4*
2BS L.C	S23	Tusk awl (1)	G	1, *3*
2WA	T19	Notched bone	I	1, *9*
2WA	Q21	Tusk awl (2)	SG	1, *2*
2WA	R18	Worked tusk (2)	S	1, *1*

Tech., technique; L., lower; I, incised; G, ground; B, bound; P, perforated; E, engraved; S, scraped; frag., fragment.

*1, warthog; 2, warthhog or bushpig; 4, baboon fibula.

[†]Ochre residue.

[‡]Residue.

Fig. 1. Implements made on warthog or bushpig lower canines (*1–8*) and notched bones (*9–12*) from Border Cave. (Scale bars: 1 cm.)

marks on the tip are smoothed by wear, suggesting their use as awls to pierce soft material (Fig. 1, *2*, *3*, and *6*; and *SI Appendix, Results* and Fig. S5). After being modified by scraping to create a lanceolate shape, one specimen from layer 1BS Lower B-C was thinned at one end with transverse closely spaced incisions, probably to facilitate hafting (Fig. 1, *7*; and *SI Appendix, Results* and Fig. S6).

Notched Bones. Four bones bear sets of notches produced by the to-and-fro movement of a lithic cutting edge (Table 1; Fig. 1, *9–12*; and *SI Appendix, Results*, Figs. S7–S9, and Table S1). The piece from 2WA displays an incomplete sequence of 12 irregularly spaced notches produced in a single session by the same broad cutting edge (Fig. 1, *9*). The second piece, heavily burnt, from layer 1WA, records an incomplete set of regularly spaced and deeply incised notches produced by the same tool (Fig. 2, *10*). The surface of the object close to the notches preserves residues of red pigment and is highly polished, suggesting long-term manipulation or transport. A rib fragment from 1WA shows two groups of notches along the same edge (Fig. 1, *11*). The first group is composed of two differently oriented subsets incised by the same tool; the second is represented by two notches produced by a different tool. The object from layer 1BS Lower B-C is a diaphysis of a right baboon fibula presenting on the interosseous crest an incomplete sequence of 29 notches, and on the proximal half of the other three aspects are worn oblique shallow incisions (Fig. 1, *12*; and *SI Appendix, Results* and Figs. S8 and S9). The surface of the object is heavily polished, suggesting long-term use. Microscopic analysis identifies four sets of notches, each made by a different tool. Three sets are complete; one is interrupted by bone breakage. (*SI Appendix, Results* and Fig. S9). The widely and irregularly spaced location of the notches from the fourth set, composed of three notches, suggests that they were incised after completion of the first three sets.

Bone Tools. Seven bone tools were found in ELSA layers (Fig. 2, *1–7*; and *SI Appendix, Results*, Figs. S10–S12, and Table S1). Four come from layer 1WA. The first is a long bone fragment, fully shaped by scraping to produce a straight shaft, elliptical in section (Fig. 2, *1*). The second is a broken burnt fragment of a thin point made on a small mammal long bone shaped by scraping and subsequently finely decorated with an incision that spirals around its surface for the length of the piece (Fig. 2, *2*). The incision is still partially filled with red pigment. Energy-dispersive X-ray analysis indicates that the pigment is mainly composed of C, Si, Fe, Mg, Al, and Ti, suggesting the use of an iron-rich clay retaining an organic content (*SI Appendix, Results* and Fig. S10). The elemental composition of the pigment is different from the remainder of the object, and the sediment comprising layer 1WA does not contain clay, indicating that the pigment was intentionally applied. The third worked bone, shaped by scraping, is the mesial portion of a broken bone tool, probably an awl, represented by three fragments (Fig. 2, *3*). The fourth is the burnt working end of a stout awl shaped by scraping, the tip of which was resharpened by grinding, probably after breakage (Fig. 2, *4*; and *SI Appendix, Results* and Fig. S11). The last 4 mm of the tip is highly polished, suggesting intense use wear on a soft material. The tool underwent a final longitudinal break before being abandoned. The three bone tools from 1BS Lower B-C are distal portions of points shaped by scraping (Fig. 2, *5–7*; and *SI Appendix, Results* and Fig. S12). Principal component analysis of the thickness and width of the bone points at 5, 10, and 30 mm from the tip (*SI Appendix, Results*, Fig. S13, and Table S2) identifies a similarity between the Border Cave specimens and those from LSA, Iron Age, and San hunter–gatherer bone arrow points used with poison, and a departure from MSA bone points.

Personal Ornaments. Fourteen OES beads and two perforated *Nassarius kraussianus* shells come from layers 1WA and 1BS Lower B-C (Table 1; Fig. 2, *8–23*; and *SI Appendix, Results*, Figs. S14 and S15, and Table S3). OES beads include two perforated preforms from 1WA that have trimmed but unfinished edges, the product of a stage of manufacture found at LSA sites and observed among San women (44). The finished beads have traces of use. Both conical and cylindrical perforations are recorded in the two layers, suggesting variability in the tip morphology of the perforators and possibly in the drilling techniques used (*SI Appendix, Results* and Fig. S14). A number of beads bear circular, perfectly cylindrical holes, indicating the use of a thin point hafted on a wooden stick to facilitate the drilling motion created by the to-and-fro movement of rubbing hands together. This technique is observed ethnographically among the San (25, 28, 29). Four beads from 1WA are homogeneously blackened by heating (*SI Appendix, Results* and Fig. S14). Analysis of OES beads from LSA sites has shown that burnt beads may be significantly different in size from the unburned ones (45), suggesting that the blackening was intentional. Experimental reproduction of this process by the

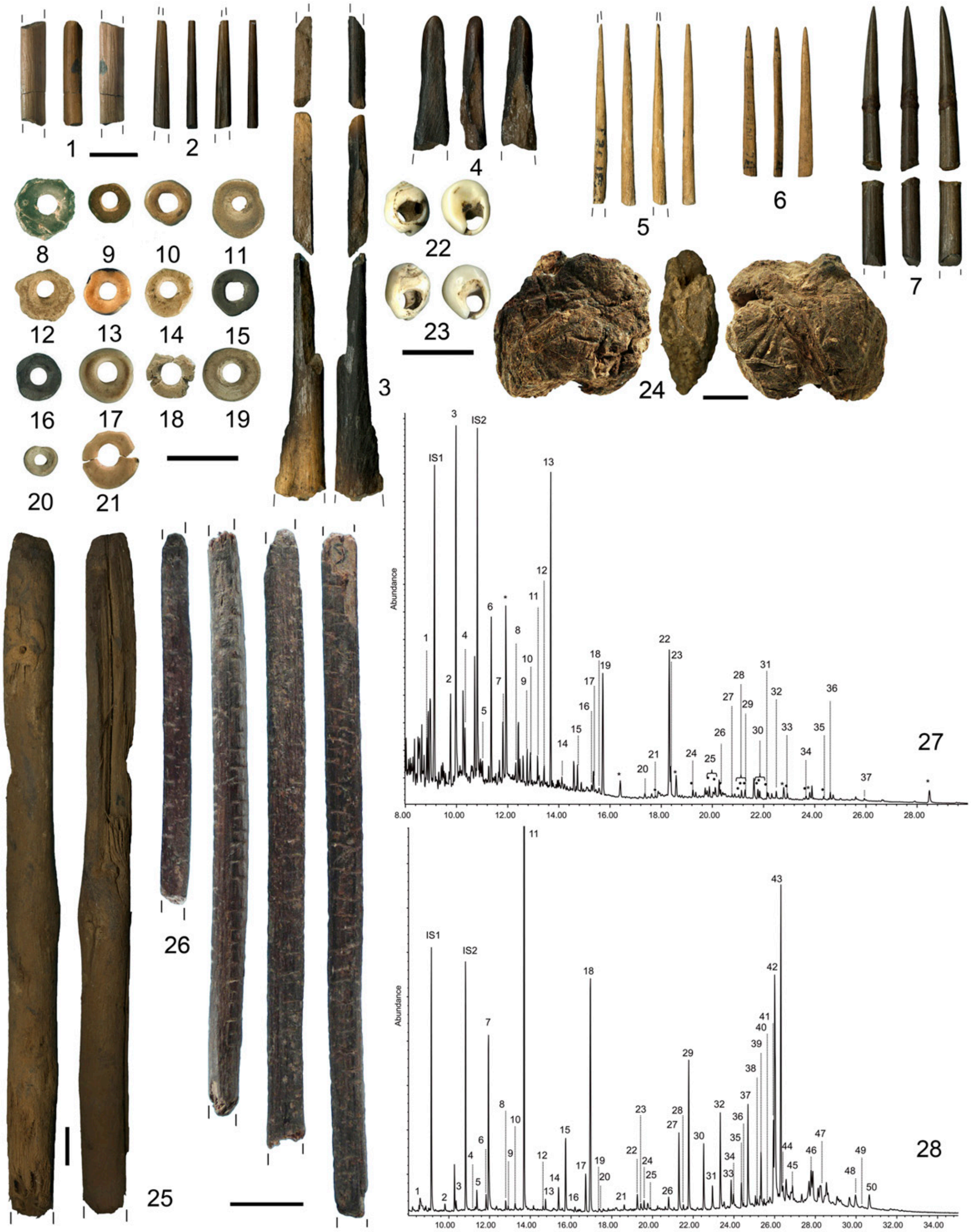

Fig. 2. Bone awls and points (*1–7*), OES beads (*8–21*), *N. kraussianus* beads (*22* and *23*), lump of organic material bound with vegetal fibers (*24*), digging stick (*25*), poison applicator (*26*), and gas chromatograms of the lipid fraction extracted from the residue from one end of the poison applicator (*27*) and from the lump of organic material (*28*). (Scale bars: 1 cm.)

same authors indicates that to obtain homogeneously blackened beads, one needs to heat them at a low to moderate temperature in a reductive environment with the addition of organic material. With the exception of a single specimen, the diameter and aperture of OES beads from Border Cave fall within the size range of large OES beads found at LSA sites (*SI Appendix, Results*, Fig. S16, and Table S4). In the framework of this study, one OES bead from 1BS Lower B-C (Table 1) was directly dated to 38,020 + 1240/−1070 KIA 44423 (44,856–41,010 cal BP). Both *N. kraussianus* shells bear traces of use in the form of smoothing around the perforation and a facet on the parietal wall (*SI Appendix, Results* and Fig. S15). The specimen from 1BS Lower B-C bears, in addition, use wear facets on the lip and two adjacent facets on the body whorl above the perforation. Facets similar to those on the lip are found on the *N. kraussianus* beads from the Still Bay layers at Blombos Cave but are absent on LSA beads studied to date (46). Facets on the body whorl are so far unparalleled and suggest the use of a distinct stringing arrangement.

Digging Stick. Two of the 14 well-preserved pieces of wood recovered from 1BS Lower B-C are similar in diameter and appearance, suggesting that they were originally part of the same object. The longer piece shows at one end evidence of rounding and crushing (Fig. 2, *25*; Table 1; and *SI Appendix, Results* and Fig. S17). On one aspect, an elongated facet almost entirely removed by a longitudinal break emanates from the tip, whereas the opposite aspect bears a short break. San and LSA digging sticks, with a single or double bevel, show similar modifications of their working end, including elongated breaks and crushing of the tip. The thickness of the Border Cave specimen falls at the lower end of the range of San and known LSA digging sticks (*SI Appendix, Results*, Fig. S17, and Table S5), and its size is consistent with the diameter of the hole of the bored stone recovered from layer 1WA (21). The wood is identified as most likely *Flueggea virosa* Roxb. ex Willd. Voight subsp. *virosa* (syn. *Securinega virosa*) Phyllanthaceae (Euphorbiaceae), white-berry bush (*SI Appendix, Results* and Fig. S19), a multistemmed shrub or small tree occurring in deciduous woodland, at forest margins, or on rocky outcrops (47). Its use for making arrow shafts and other implements in widely attested in Africa (48). This object was directly dated in the framework of this study to 34,940 ± 370 OxA-23172 (40,986–38,986 cal BP).

Poison Applicator. A thin wooden stick in four pieces was found in layer 1BS Lower B-C (Fig. 2, *26*; and Table 1). Together, they measure 32 cm. The original object was longer, as they do not refit. After removal of the bark, the stick was entirely covered with perpendicular incisions made by a sharp cutting edge. As with the digging stick, the wood is identified as most likely *F. virosa* (*SI Appendix, Results* and Fig. S19). Efforts to corroborate the taxonomic identification by Py(HMDS)–gas chromatography/mass spectrometry were inconclusive (*SI Appendix, Results*, Fig. S20, and Table S6). Microscopic analysis revealed the presence of a dark orange residue at the end and, to a lesser extent, on the body of one piece (*SI Appendix, Results* and Fig. S21). Gas chromatography of the residue (Fig. 2, *27*; and *SI Appendix, Results* and Table S7) shows the presence of monocarboxylic and dicarboxylic acids (lipid material). The occurrence of both *cis* and *trans* isomers of unsaturated carboxylic acids suggests that the material was heated, and the simultaneous presence of even- and odd-chain-length hydrocarbons points to the presence of cuticular wax (49). Ricinoleic and ricinelaidic acids are present. Ricinoleic acid is found in mature castor beans (*Ricinus communis* L., *Euphorbiaceae*), a species common in this part of Africa. The protein ricin in castor beans is known to be among the most dangerous natural poisons (50). The incised stick may be a broken arrow shaft still retaining poison at one end. However, for aerodynamic reasons, arrow shafts are typically straight and smooth. The Border Cave specimen closely resembles implements used by the Kalahari San to carry and apply poison to arrow points (*SI Appendix, Results*, Fig. S22, and Table S8). On the ethnographic specimens, the notches serve to hold the poison paste and the wax in place. In the framework of this study, the poison applicator was directly dated to 20,420 ± 90 OxA-23173 (24,564–23,941 cal BP).

Lump of Bound Organic Material. A 4-cm-wide piece of organic material, covered with randomly oriented deep grooves, was recovered from 1BS Lower B-C (Fig. 2, *24*; and Table 1). Microscopic analysis revealed that the grooves were produced by binding the material with vegetal twine when the compound was soft. Bundles of vegetal fibers, probably from the inner bark of a woody plant, are imbedded in the grooves (*SI Appendix, Results* and Fig. S23). Gas chromatography of two samples from the piece identifies the main constituent as beeswax, with the addition of a protein-based material (possibly egg), and triterpenoids derived from *Euphorbia tirucalli* resin (*SI Appendix, Results*, Fig. S24, and Table S9). Resins can be exploited as adhesives, but triterpenoids are also used in high concentrations as poisons and in lower concentrations medicinally. *Euphorbia ingens* (naboom or giant euphorbia) and *E. tirucalli* (rubber-hedge euphorbia or Manyara), widely distributed in Africa, have particularly poisonous latex and seeds. Although very poisonous and used as an insecticide or to kill fish, *E. ingens* is also used medicinally, but it can be fatal (47, 51). In the framework of this study, the lump of beeswax was directly dated to 35,140 ± 360 OxA-W-2455-52 (41,167–39,194 cal BP).

Discussion

The highly debated question of the emergence of cultural modernity has generally been approached by analyzing the archaeological record in search of behaviors considered, in one way or another, comparable with our own. Personal ornaments, pigments, engravings, complex technologies, etc. represent in many respects, however, categories that, extracted from their original context of use, may be too broad to assess a degree of modernity. Although they may well have been used in a comparable framework, the possibility exists that such cultural items were in the deep past playing a quite different role from the one attributed to them by archaeologists.

A different way of tackling the issue of modernity—which in a sense raises the threshold of the requirements for modern behaviors—is to analyze the archaeological record in search of evidence that unambiguously parallels, in different domains, those recorded among living or historically known hunter–gatherers. Although this path is not free from pitfalls, it allows one to interpret archaeological evidence in the light of known social and cultural practices. In this respect, the organic artifacts from the upper layers of Border Cave represent arguably the oldest instance of modern culture. Reappraisal of the lithic assemblages from the post-HP and ELSA layers (21), in combination with existing and new radiocarbon dates, supports the view that the LSA emerged in South Africa by internal evolution at ∼44 ka. LSA technology was preceded by a phase of progressive abandonment of the more complex MSA lithic reduction sequences and tool types in favor of a simplification in the production of lithic artifacts.

Our results demonstrate that, with the significant exception of a tusk technology already in place by 60 ka, the suite of complex and varied technical and symbolic items that characterize more recent LSA and historical San material culture was used by Border Cave inhabitants 44 kya. These include bone points identical to San poisoned arrow points, one of which is incised with a mark of ownership. Thanks to the exceptional preservation of organic material, due to the extreme dryness of this cave (52), a notched stick similar to San poison applicators retains residues of a heated toxic compound. Although this piece is clearly intrusive in the 1BS Lower B-C layer, considering its age of 24 ka, it nevertheless represents the oldest known secure evidence of the use of poison for hunting purposes. Kalahari San poison their arrows with beetle larvae, snake venom, and plant extracts (25, 28), which are not available in the tropical KwaZulu-Natal environment. The poisons identified at Border Cave may represent a regional adaptation to exploit local toxic substances. A lump of beeswax mixed with poisonous *Euphorbia* resin and wrapped with vegetal twine was certainly used for hafting purposes. Direct dating of this piece to ∼40 ka makes it the oldest known example of the use of beeswax. This complex hunting kit is complemented by light digging sticks weighted with bored stones (21).

Analysis of Border Cave personal ornaments corroborates previous reports of relatively large OES beads dated to the same period from Boomplaas, Mumba, and Enkapune Ya Muto (35–37), confirming that this typical San personal ornament and exchange medium was already in use at least 45 kya at a number of African sites. In addition, it raises the possibility that some OES beads were intentionally blackened by heating, as attested in the

LSA and ethnographically. The presence of *Nassarius* shell beads also establishes a link with the LSA, in which they are common (53). Symbolic items extend to notched bones. Two of the four notched objects from Border Cave, recovered from 1WA and 1BS Lower B-C, appear to be of particular significance (Fig. 1, *10* and *12*). Contrary to that found in layer 2WA, a simple bone splinter on which unevenly spaced and partially superimposed cuts were made, the two pieces from the more recent layers reveal in one case the intention of producing an object decorated with carefully and regularly made identical notches, and in the other the will of accumulating marks through time, arguably for notational purposes. In addition, both pieces bear clear traces of manipulation or long-term curation.

Contrary to lithic technology, which shows at Border Cave a gradual evolution toward the ELSA starting after 56 ka (21), organic artifacts unambiguously reminiscent of LSA and San material culture emerge relatively abruptly, highlighting an apparent mismatch in rates of cultural change. Our results support the view that what we perceive today as modern behavior is the result of nonlinear trajectories that may be better understood when documented at a regional scale (7, 12–14, 21, 54).

Materials and Methods

Border Cave artifacts were analyzed with reflected light microscopes. Selected items were observed with an environmental scanning electron microscope equipped with an energy-dispersive X-ray analyzer. Chemical analysis of beeswax, wooden artifacts, and residues were conducted by gas chromatography, mass spectrometry, and pyrolysis. An OES bead was AMS ^{14}C dated by the Leibniz Labor für Altersbestimmung und Isotopenforschung (University of Kiel, Kiel, Germany). The poison applicator, digging stick, and lump of beeswax were ASM dated by the Radiocarbon Accelerator Unit at the University of Oxford. More information on methods is given in *SI Appendix, Materials and Methods*.

ACKNOWLEDGMENTS. We thank D. Morris and D. Wall for access to the McGregor Museum and Museum Africa collections, respectively; B. Wilson for identification of the suid tusks; M. Witcomb for assistance with scanning electron microscopy; W. Banks for helpful discussions; and C. Sievers, R. Reddy, and L. Wadley for providing botanical samples. F.d. and L.B. were supported by grants from the European Research Council (FP7/2007/2013, TRACSYMBOLS 249587); South Africa/France Scientific Cooperation Agreement; National Research Foundation of South Africa; University Research Council, University of the Witwatersrand; Ernest Oppenheimer Memorial Trust; Institut Français d'Afrique du Sud; and the Project Origines II, Aquitaine Region. P.V. was supported by National Science Foundation Grant BCS 0613319; Palaeontological Scientific Trust; and the School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand.

1. Wadley L, Hodgskiss T, Grant M (2009) Implications for complex cognition from the hafting of tools with compound adhesives in the Middle Stone Age, South Africa. *Proc Natl Acad Sci USA* 106:9590–9594.
2. Watts I (2010) The pigments from Pinnacle Point Cave 13B, Western Cape, South Africa. *J Hum Evol* 59:392–411.
3. Henshilwood CS, et al. (2011) A 100,000-year-old ochre-processing workshop at Blombos Cave, South Africa. *Science* 334:219–222.
4. Henshilwood CS, d'Errico F, Watts I (2009) Engraved ochres from the Middle Stone Age levels at Blombos Cave, South Africa. *J Hum Evol* 57:27–47.
5. Texier JP, et al. (2010) A Howiesons Poort tradition of engraving ostrich eggshell containers dated to 60,000 years ago at Diepkloof Rock Shelter, South Africa. *Proc Natl Acad Sci USA* 107:7621–7622.
6. d'Errico F, et al. (2009) Out of Africa: Modern human origins special feature: Additional evidence on the use of personal ornaments in the Middle Paleolithic of North Africa. *Proc Natl Acad Sci USA* 106:16051–16056.
7. d'Errico F, Backwell L, Wadley L (2012) Identifying regional traditions in Middle Stone Age bone technology. The case of Sibudu Cave. *J Archaeol Sci*, 10.1016/j.jas.2012.01.040.
8. Mourre V, Villa P, Henshilwood CS (2010) Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. *Science* 330:659–662.
9. Lombard M (2011) Quartz-tipped arrows older than 60 ka: Further use-trace evidence from Sibudu, KwaZulu-Natal, South Africa. *J Archaeol Sci* 38:1918–1930.
10. Villa P, Soriano S (2010) Hunting weapons of Neanderthals and early modern humans in South Africa. *J Anthr Res* 66:5–38.
11. McBrearty S, Brooks AS (2000) The revolution that wasn't: A new interpretation of the origin of modern human behavior. *J Hum Evol* 39:453–563.
12. Hovers E, Belfer-Cohen A (2006) *Transitions Before the Transition: Evolution and Stability in the Middle Paleolithic and Middle Stone Age*, eds Hovers E, Kuhn SL (Springer, New York), pp 295–304.
13. d'Errico F, Stringer CB (2011) Evolution, revolution or saltation scenario for the emergence of modern cultures? *Philos Trans R Soc Lond B Biol Sci* 366:1060–1069.
14. Shea JJ (2011) *Homo sapiens* is as *Homo sapiens* was. *Curr Anthropol* 52:1–35.
15. Zilhão J, et al. (2010) Symbolic use of marine shells and mineral pigments by Iberian Neandertals. *Proc Natl Acad Sci USA* 107:1023–1028.
16. Caron F, d'Errico F, Del Moral P, Santos F, Zilhão J (2011) The reality of Neandertal symbolic behavior at the Grotte du Renne, Arcy-sur-Cure, France. *PLoS ONE* 6:e21545, 10.1371/journal.pone.0021545.
17. Pawlik AF, Thissen J (2011) Hafted armatures and multi-component tool design at the Micoquian site of Inden-Altdorf, Germany. *J Archaeol Sci* 38:1699–1708.
18. Roebroeks W, et al. (2012) Use of red ochre by early Neandertals. *Proc Natl Acad Sci USA* 109:1889–1894.
19. Jacobs Z, et al. (2008) Ages for the Middle Stone Age of southern Africa: Implications for human behavior and dispersal. *Science* 322:733–735.
20. Villa P, Soriano S, Teyssandier N, Wurz S (2010) The Howiesons Poort and MSA III at Klasies River main site, Cave 1A. *J Archaeol Sci* 37:630–655.
21. Villa P, et al. (2012) Border Cave and the beginning of the Later Stone Age in South Africa. *Proc Natl Acad Sci USA* 109:13208–13213.
22. Ambrose SH (1998) Late Pleistocene human population bottlenecks, volcanic winter, and differentiation of modern humans. *J Hum Evol* 34:623–651.
23. Lahr MM, Foley RA (1998) Towards a theory of modern human origins: Geography, demography, and diversity in recent human evolution. *Am J Phys Anthropol* 41(Suppl 27):137–176.
24. Powell A, Shennan S, Thomas MG (2009) Late Pleistocene demography and the appearance of modern human behavior. *Science* 324:1298–1301.
25. Lee R, DeVore I (1976) *Kalahari Hunter-Gatherers: Studies of the !Kung San and Their Neighbors* (Harvard University Press, Cambridge, MA).
26. Wiessner P (1983) Style and social information in Kalahari San projectile points. *Am Antiq* 48:253–276.
27. Lagercrantz S (1973) Counting by means of tally sticks or cuts on the body in Africa. *Anthropos* 68:569–58.
28. Marshall L (1976) *The !Kung of Nyae Nyae* (Harvard University Press, Cambridge, MA).
29. Silberbauer GB (1981) *Hunter and Habitat in the Central Kalahari Desert* (Cambridge University Press, Cambridge, U.K).
30. Wadley L (1993) The Pleistocene Later Stone Age south of the Limpopo River. *J World Prehist* 7:243–296.
31. Barham L, Mitchell P (2008) *The First Africans* (Cambridge University Press, Cambridge, U.K).
32. Deacon J (1984) *The Later Stone Age of Southernmost Africa* (Archaeopress, Oxford).
33. Klein RG (2000) Archaeology and the evolution of human behaviour. *Evol Anthropol* 9:17–36.
34. Inskeep RR (1987) *Nelson Bay Cave, Cape Province, South Africa: The Holocene Levels* (Archaeopress, Oxford).
35. Deacon J (1995) Two late Pleistocene-Holocene archaeological depositories from the southern Cape, South Africa. *South African Archaeol Bull* 50:121–131.
36. Ambrose SH (1998) Chronology of the Later Stone Age and food production in East Africa. *J Arch Sci* 25:337–392.
37. Gliganic LA, Jacobs Z, Roberts RG, Domínguez-Rodrigo M, Mabulla AZ (2012) New ages for Middle and Later Stone Age deposits at Mumba rockshelter, Tanzania: Optically stimulated luminescence dating of quartz and feldspar grains. *J Hum Evol* 62:533–547.
38. Van Noten F (1977) Excavations at Matupi Cave. *Antiquity* 51:35–40.
39. Fagan BM, Van Noten FL (1971) *The Hunter-Gatherers of Gwisho* (Musée Royal de l'Afrique Centrale, Tervuren, Belgium).
40. Deacon HJ, Deacon J (1999) *Human Beginnings in South Africa* (David Philip, Cape Town, South Africa).
41. Beaumont PB (1978) *Border Cave*. PhD Thesis (University of Cape Town, Cape Town, South Africa).
42. Grün R, Beaumont P (2001) Border Cave revisited: A revised ESR chronology. *J Hum Evol* 40:467–482.
43. Bird MI, et al. (2003) Radiocarbon dating from 40 to 60 ka BP at Border Cave, South Africa. *Quat Sci Rev* 22:943–947.
44. Orton J (2008) Later Stone Age ostrich eggshell bead manufacture in the Northern Cape, South Africa. *J Archaeol Sci* 35:1765–1775.
45. Kandel AW, Conard NJ (2005) Production sequences of ostrich eggshell beads and settlement dynamics in the Geelbek Dunes of the Westem Cape, South Africa. *J Archaeol Sci* 32:1711–1721.
46. d'Errico F, Henshilwood C, Vanhaeren M, van Niekerk K (2005) *Nassarius kraussianus* shell beads from Blombos Cave: Evidence for symbolic behaviour in the Middle Stone Age. *J Hum Evol* 48:3–24.
47. Coates Palgrave K (2002) *Trees of Southern Africa* (Struik, Cape Town, South Africa).
48. Tabuti JRS (2007) *PROTA (Plant Resources of Tropical Africa)*, eds Schmelzer GH, Gurib-Fakim A (Wageningen University, Wageningen, The Netherlands).
49. Walton TJ (1990) *Methods in Plant Biochemistry, Lipids, Membranes and Aspects of Photobiology*, eds Harwood L, Bowyer JR (Academic, London), pp 105–158.
50. Harborne JB, Baxter H, Moss GP (1997) *Dictionary of Plant Toxins* (John Wiley & Sons, Chichester, U.K).
51. Wink M, Van Wyk BE (2008) *Mind-Altering and Poisonous Plants of the World* (Timber, Portland, OR).
52. Grün R, Beaumont P, Tobias PV, Eggins S (2003) On the age of Border Cave 5 human mandible. *J Hum Evol* 45:155–167.
53. Mitchell PJ (1996) Prehistoric exchange and interaction in southeastern southern Africa: Marine shells and ostrich eggshell. *Afr Archaeol Rev* 13:35–76.
54. Hovers E (2009) *Sourcebook of Paleolithic Transitions: Methods, Theories, and Interpretations*, eds Camps M, Chauhan P (Springer, New York), pp 455–462.