Border Cave and the beginning of the Later Stone Age in South Africa

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

[a]University of Colorado Museum, Boulder, CO 80309-0265; [b]School of Geography, Archaeology and Environmental Studies, [i]Bernard Price Institute for Palaeontological Research, School of Geosciences, and [j]Institute for Human Evolution, University of the Witwatersrand, Wits 2050, South Africa; [c]Centre National de la Recherche Scientifique (CNRS)–Unité Mixte de Recherche 5199 De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie (PACEA), Université Bordeaux 1, 33405 Talence, France; [d]Archéologies et Sciences de l'Antiquité, Université Paris Ouest, CNRS, 92023 Nanterre, France; [e]Max-Planck-Institute for Evolutionary Anthropology, D-04103 Leipzig, Germany; [f]Dipartimento di Chimica, Università di Pisa, 56126 Pisa, Italy; [g]Research Laboratory for Archaeology and the History of Art, University of Oxford, Oxford OX1 3QY, England; [h]Institute for Archaeology, History, Cultural and Religious Studies, University of Bergen, 5020 Bergen, Norway; and [k]Archaeology Department, McGregor Museum, Kimberley 8300, South Africa

Edited* by Richard G. Klein, Stanford University, Stanford, CA, and approved June 26, 2012 (received for review February 14, 2012)

The transition from the Middle Stone Age (MSA) to the Later Stone Age (LSA) in South Africa was not associated with the appearance of anatomically modern humans and the extinction of Neandertals, as in the Middle to Upper Paleolithic transition in Western Europe. It has therefore attracted less attention, yet it provides insights into patterns of technological evolution not associated with a new hominin. Data from Border Cave (KwaZulu-Natal) show a strong pattern of technological change at approximately 44–42 ka cal BP, marked by adoption of techniques and materials that were present but scarcely used in the previous MSA, and some novelties. The agent of change was neither a revolution nor the advent of a new species of human. Although most evident in personal ornaments and symbolic markings, the change from one way of living to another was not restricted to aesthetics. Our analysis shows that: (*i*) at Border Cave two assemblages, dated to 45–49 and >49 ka, show a gradual abandonment of the technology and tool types of the post-Howiesons Poort period and can be considered transitional industries; (*ii*) the 44–42 ka cal BP assemblages are based on an expedient technology dominated by bipolar knapping, with microliths hafted with pitch from *Podocarpus* bark, worked suid tusks, ostrich eggshell beads, bone arrowheads, engraved bones, bored stones, and digging sticks; (*iii*) these assemblages mark the beginning of the LSA in South Africa; (*iv*) the LSA emerged by internal evolution; and (*v*) the process of change began sometime after 56 ka.

human behavior | hafting pitch | hunting weapons | gathering equipment

The period between *ca.* 40,000 and 20,000 y ago in South Africa is poorly known, and the timing of the Middle Stone Age (MSA) to Late Stone Age (LSA) transition is debated. In 1999 the LSA was defined (1) as a culture-stratigraphic unit that includes all assemblages dated within the last 20,000 y, characterized by artifacts such as hafted microlithic tools; bored stones used as digging-stick weights; bows and arrows; polished bone tools, such as awls, linkshafts, and arrowheads; fishing equipment; beads of shell and ostrich eggshell; and engraved decoration on bone and wood items.

The earliest technological expression of the LSA would be the Robberg Industry dated *ca.* 22–21 to 12 ka BP (1–3).

In the 1970s Beaumont and colleagues described the Border Cave stratigraphic sequence (*SI Appendix, The Site*) ranging from *ca.* 200 ka to the present (4–8). In the upper part of the sequence two layers, 1WA and 1BS Lower B+C, now dated 44–42 ka cal BP, contain evidence of some remarkable changes in stone and organic tool manufacture and in the making of decorated objects and personal ornaments. Some of these innovations have antecedents in the preceding Howiesons Poort (HP) and Still Bay periods (1), but they disappear or are extremely scarce in the following post-HP period, *ca.* 60–40 ka (9). According to Beaumont, the appearance of new tools and ornaments [bored stones, digging sticks, ostrich eggshell (OES) beads, bone points, engraved bone, and wood objects], together with high frequencies of microliths made by the bipolar technique and hafted with pitch, and of scaled pieces mark the beginning of the LSA (early LSA or ELSA) at Border Cave.

Some scholars have accepted this interpretation (10); others have rejected it (11), expressed doubts about the association of organic artifacts (11–13), or suggested that the transition MSA–LSA took place between 32 and 22 ka, setting the beginning of the LSA at 22 ka (14, 15). The temporal boundary between the MSA and the LSA and how the transition took place in the region remain controversial. New data are warranted.

Results

The Sequence. The post-HP is subdivided into four main layers: 2WA, 2BS Lower C, 2BS Lower A+B, and 2BS UP. ELSA layers are 1WA and 1BS Lower B+C (Table 1 and *SI Appendix, Dating*, Fig. S1, and Table S1). We have done a comprehensive study of three post-HP layers and of the two ELSA layers. Our focus is on the technology of stone artifacts and the analysis of hafting adhesives and bored stones. We discuss the origins of bow and arrow technology. The organic materials (Table 2) are the subject of another article (9) in PNAS.

Lithic Raw Materials. Several varieties of raw material were used at Border Cave; their frequencies change through time (*SI Appendix*, Table S2). The most common variety is a porphyritic rhyolite with plagioclase phenocrysts in a fine-grained glassy matrix; less common is aphanitic rhyolite of better knapping quality. Other materials are chalcedony, which occurs as small nodules not larger than 6 to 7 cm in diameter, and small nodules or pebbles of milky quartz. Crystal quartz is rare or absent in the MSA but becomes more frequent in ELSA. Quartzite, dolerite, and hornfels occur in negligible quantities. Rhyolite is the local bedrock; the cave itself was formed by differential weathering of a less-resistant agglomerate within the Lebombo rhyolites (16). Chalcedony and quartz occur in vesicles within the rhyolite; these seem to be most common 40 km from the site (4). In the ELSA layers the outer surface of some quartz and chalcedony artifacts show alluvial cortex, suggesting that they were collected from the Ingwavuma river gravels (2.4 km south of the site), together with few cobbles of quartzite and dolerite.

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

The authors declare no conflict of interest.

*This Direct Submission article had a prearranged editor.

[1]To whom correspondence should be addressed. E-mail: villap@colorado.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1202629109/-/DCSupplemental.

ANTHROPOLOGY

Table 1. Border Cave: Lithic assemblage composition of layers 2WA to 1BS Lower

Categories	2WA	2BS LR A+B	2BS UP	1WA	1BS LR B+C
n	766	406	369	4,729	722
Flakes and flake proximal fragments	61.4	64.5	60.4	27.1	66.9
Blades and all blade fragments	31.9	21.7	12.2	2.5	2.2
Cores and core fragments	0.8	1.7	3.0	0.7	2.5
Bipolar cores and fragments	0.0	1.5	5.4	12.6	5.8
Bipolar flakes and bladelets	0.5	6.2	18.4	53.8	16.3
Scaled pieces	0.3	1.0	0.0	2.7	6.0
Retouched pieces	5.2	3.4	0.5	0.6	0.3

Values are percentages except where noted.

MSA 3/Post-HP

2WA is a white ash layer *ca.* 14 cm thick, dated to 60 ± 3 ka by electron spin resonance (ESR) (7) and directly overlying 3BS, the last HP layer (*SI Appendix*, Fig. S1*B*). Blades and elongated flakes with parallel sides are the main objective of the debitage. Core exploitation proceeded with bidirectional removals from two opposed striking platforms using the wide face of the core, as is common in the European Middle Paleolithic (17). This gives rise to a variety of end-products, mainly pointed forms (*SI Appendix*, Fig. S6). Many flakes with unidirectional or bidirectional scars probably come from the same reduction sequences. There is, however, an independent production of flakes, as indicated by the rare presence of centripetal Levallois flakes and one centripetal Levallois core. Moreover, 36% of the retouched pieces are on flakes. Production of flakes as tool blanks is a pattern that also occurs in the post-HP of Klasies, Rose Cottage, and Sibudu (18–20). Unifacial points, pointed blades, and a variety of flake tools are characteristic of this period, replacing segments and other backed pieces of the HP. At Border Cave and other post-HP sites the knapping technique is direct percussion by stone hammer, and the blow is away from the platform edge, marking a clear discontinuity with the preceding HP assemblages, for which blade production was based on the use of marginal percussion with a soft stone hammer. Layer 2BS Lower C dated to *ca.* 56 ka (8) has not been studied in detail. Preliminary observations indicate an industry similar to 2WA.

The 2BS Lower A+B and 2BS UP are dated by ^{14}C to >49 and 49–45 ka cal BP, respectively (*SI Appendix, Dating*). They show an incremental evolution of techniques and tool forms: decline of blade production, disappearance of unifacial points, drastic reduction in the number of traditional retouched pieces (scrapers, denticulates), and rise of bipolar knapping associated with increase in the use of chalcedony, milky quartz, and crystal quartz. There is also a decrease in the use of aphanitic rhyolite, often used for formal tools and blades, and a decline in the quality of blades, which reaches its maximum in layer 1WA. Reduction sequences are simpler. Cores have a discoid morphology but are organized in short, successive, unidirectional sequences without any visible preparation (*SI Appendix*, Fig. S8). The strong increase in bipolar cores and flakes in 2BS UP indicates change toward LSA technology (Fig. 1). A similar increase in bipolar cores, bipolar flakes, and scaled pieces and a decline in the production of blades has been observed in the post-HP at Rose Cottage in layer THO dated by thermoluminescence (TL) to 47.1 ± 10.2 ka (19). Post-HP assemblages directly above THO show almost complete absence of blade cores, and the blades present are less standardized. The similarities in technological changes between Border Cave and Rose Cottage (575 km apart) suggest an open system of cultural transmission.

Table 2. Border Cave: Organic artifacts from the post-HP and ELSA layers

Categories	2WA	2BS LR	1WA	1BS LR B+C
OES beads	0	0	11	3
Perforated marine shells (*Nassarius*)	0	0	1	1
Notched bones	1	0	2	1
Bone points	0	0	1	3
Bone awls	0	0	2	0
Ground warthog or bushpig tusks	2	3	1	2
Digging stick	0	0	1	0
Lump of beeswax	0	0	0	1
Bone tool fragment	0	0	1	0

See ref. 9. The three worked tusks of 2BS Lower come from 2BS Lower C. Dating was attempted by the Oxford Radiocarbon Laboratory on one of the suid tusks from 2WA, but it failed due to no yield. Values are number.

Early Later Stone Age

Dating. *SI Appendix*, Table S3 lists ^{14}C dates by Pretoria and Australian National University Accelerator (ANUA) on charcoal

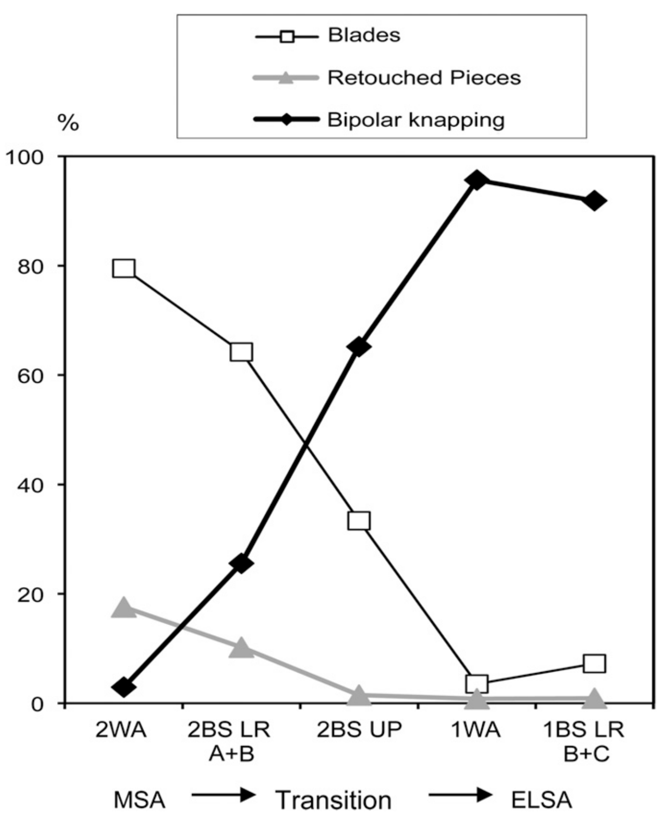

Fig. 1. Border Cave. Changes in the frequencies of main artifact classes in layers 2WA (307), 2BS Lower A+B (137), 2BS UP (135), 1WA (3418), and 1BS B+C (221). Bipolar knapping includes bipolar cores, bipolar flakes and bladelets, and scaled pieces.

samples from excavation 4 (5, 8) and accelerator mass spectrometry (AMS) dates by the Oxford and Kiel laboratories on digging stick wood, OES bead, pitch, and beeswax from 1BS Lower B+C. Bayesian analysis of the ^{14}C dates (9) shows an age of 44.2–43.0 ka cal BP for layer 1WA and 43.0–42.5 ka for 1BS Lower B+C. The AMS dates confirm the association of the organic artifacts with the lithic materials.

Lithic Technology. The 1WA and 1BS Lower B+C lithic assemblages are characterized by the production and use of unretouched blanks with sharp edges, made from unorganized cores, without standardized reduction strategies (*SI Appendix*). The technology is expedient and wasteful of material, resulting in high numbers of flake fragments, shatters, and minute debris. Changes in debitage patterns away from more controlled flaking and with focus on the detachment of expedient products were already apparent in the transitional assemblages, but now these trends dominate. There are two major kinds of products done on different raw materials: (*i*) bipolar flakes, bipolar bladelets, and scaled pieces, done with the bipolar technique using small blanks of chalcedony, milky quartz, and crystal quartz; and (*ii*) larger flakes (3–7 cm on average) and a small number of blades obtained by direct stone hammer percussion from unstandardized rhyolite cores. Small blades/bladelets obtained by direct percussion are a minor debitage objective; bladelets (<3 cm in length) are more commonly obtained from bipolar cores (*SI Appendix*, Table S1 and *Assemblage Components*).

This pattern of change is not unusual in South African prehistory. The HP technocomplex at Rose Cottage and Klasies was characterized by a gradual evolution of knapping techniques, accompanied by some changes in the typological composition of the assemblages and by an increasing disregard for the regularity of the morphology of tools and debitage products (18, 19). The changes we observe at Border Cave also reflect internal evolution. A decline in the standardized technology of the final MSA is followed by dominance of an expedient technology without structured reduction sequences. This pattern of simplification seemingly runs counter to the increasingly sophisticated developments in other aspects of material culture. 1WA and 1BS Lower have provided a variety of bone tools, OES beads, engraved and decorated bones, a digging stick, worked suid tusks, and bored stones (Table 2) (9). Is there a relationship between this shift to expedient technologies and other aspects of the LSA way of life?

Interpreting the Scaled Pieces. Fig. 1 and *SI Appendix*, Table S6 show a significant increase in the proportion of scaled pieces. Scaled pieces are a common artifact in the South African LSA, although they also occur in low frequencies in MSA layers. They overlap in morphology and are often lumped with bipolar cores (20–22).

A strong increase in the production of scaled pieces is documented in Western Europe at about the same time [e.g., in the Protoaurignacian of Arcy and the Aurignacian of Brassempouy in France (23, 24) and in the Uluzzian and Protoaurignacian of Castelcivita in Italy (25)]. In these industries bone tools are a significant part of the assemblage. As in the South African MSA, some Mousterian assemblages contain scaled pieces but in low proportion (20).

The increase in scaled pieces at Border Cave may be related to the increase in the production of bone and wood items. Interestingly, suid tusks, either complete or longitudinally split and abraded (three at Border Cave), were used for planing wood in the French Neolithic and by the New Guinea agriculturalists (26). Microwear analysis of the scaled pieces has not been done but may not provide a definitive answer. Intensive exploitation as pieces were turned 180° to be reused is likely to obliterate any polish or other traces of use, except on the last used edge (27). The ELSA scaled pieces are very small, with a mean length of 1.7 cm. A great majority have two or more axes of percussion. Many are broken (59–69%). Chalcedony and quartz with their sharp cutting edges were the preferred raw material.

Microliths and Hafting Pitch

The ELSA assemblages are characterized by the systematic production of microliths, used unretouched (*SI Appendix, Lithic Technology*). In 1BS Lower two bladelet fragments of chalcedony (BC48 and 49) adhered to a thick lump of dark-brown material (Fig. 2). A fresh break in this material was analyzed under an optical microscope and was found to have the characteristics of amorphous organic material. A third piece, BC50, is a scaled piece originally covered by a lump of brown material; however, the lump was removed and given to a specialist before our study. The analysis was never published, and only traces of the original material remain visible on the stone. Three more microliths [a debris from bipolar knapping (BC1), a short flake (BC2), and a bipolar flake (BC3)] have traces of organic material along their sides and on both faces. These microliths, all from 1BS Lower, appear to have been hafted laterally.

Microliths embedded in adhesive or with traces of it have been reported from LSA sites in Southern Africa (28–30). Adhesives made from red ochre mixed with resin have also been reported in the HP and post-HP (31, 32). In these cases the identification of

ANTHROPOLOGY

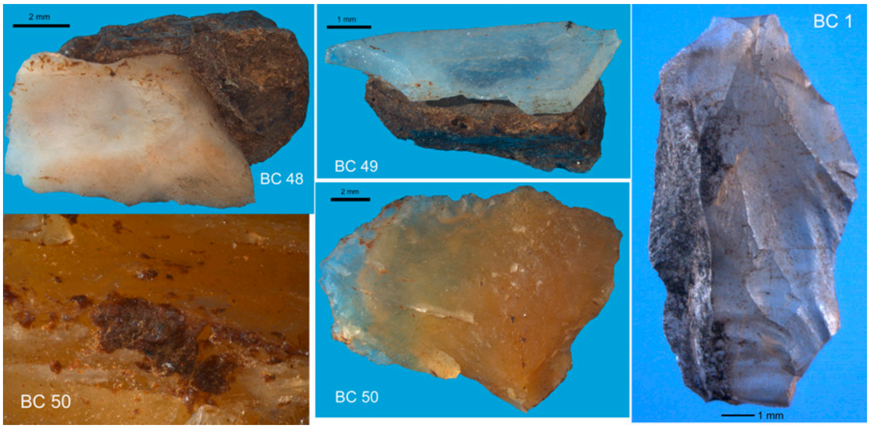

Fig. 2. Border Cave, layer 1BS Lower. Chalcedony microliths with lumps or traces of adhesive: a portion of bladelet (BC 48), a flake or bladelet fragment (BC49), a scaled piece (BC50), and a debris of bipolar knapping (BC1). Their length is 9.8, 6.0,13, and 11.5 mm, respectively. The pitch of BC 48 was dated by AMS (*SI Appendix, Dating*).

resin was achieved by visual inspection and optical microscopy. Microscopic examination, if not substantiated by chemical analysis, cannot be considered conclusive for the identification of resinous materials (33, 34). We used a combined analytical procedure based on gas chromatography–mass spectrometry for the identification of lipids, waxes, proteins, resinous materials, and saccharides in the same microsample (35, 36).

Chemical Analysis of the Adhesive. Microsamples were collected from BC48 (0.6 mg), 49 (1.5 mg), and 50 (less than 0.1 mg). The analytical results (*SI Appendix*, *Chemical Analysis*) revealed the absence of proteins or polysaccharides in all samples, whereas it indicated the presence of lipid-resinous materials. The identification of linear, monocarboxyilic even- and odd-number carbon acids (ranging from 14 to 18 atoms and showing a maximum with palmitic acid) and α,ω-dicarboxylicacids (ranging from 7 to 22 atoms and showing a maximum with α,ω-hexanedienoic acid and α,ω-docosanedioic acid) suggests the presence of a bio-polyester. This is confirmed by the detection in samples 48 and 49 of phenolic compounds, such as 3-methoxy and 3-hydroxy cinnamic acids. Moreover, the three samples contained known and unknown diterpenes (sugiol, totarol-7-one and unknown oxidation products).

The detection of long chain dicarboxylic acids can be related to the occurrence of a biopolyester, whose presence can be due to the use of a pitch produced by processing a suberin-containing bark (37). Suberin is a bio-polyester mainly composed of a poly(phenolic) domain and a poly(aliphatic) one consisting in hydroxy, epoxy, and dicarboxylic acids (38). The alkaline hydrolysis in the sample pretreatment frees the monomers, which are determined in the gas chromatogram. The identified terpenes are oxidation products of ferruginol and totarol, which are characteristics of *Cupressaceae* and *Podocarpaceae* species (39). The occurrence of both sugiol and totarol-7-one suggests the use of the bark of a species belonging to the *Podocarpaceae* family, and in particular of *Podocarpus elongatus* (40). This hypothesis is confirmed by the analysis of reference materials of bark and sapwood of *P. elongatus* and *Podocarpus falcatus* and of a reference pitch prepared with the bark of *P. elongatus*. The latter material showed high percentages of ferruginol and totarol, with traces of their expected oxidation products (sugiol and totarol-7-one), together with α,ω-dicarboxylic acids and long chain hydroxy-fatty acids. Nowadays *P. elongatus* occurs only in the winter-rainfall Western Cape, but pollen and charcoal archives indicate that *Podocarpus* forests were more widespread in the past (41, 42).

The amount of organic material detected in sample 50 is extremely reduced with respect to the other samples. Nonetheless, the biomarker of a suberin-containing pitch was detected, together with some sterols, both of plant and animal origin (sitosterol, stigmasterol, and cholesterol).

Ground Stone Artifacts

Bored stones are implements with no parallel in the MSA. Two fragments are from layer 1WA (*SI Appendix*, Figs. S17 and S18). According to ethnographic observations, the best attested use of bored stones was as weights for digging sticks (1). They are not limited to South Africa. One of the oldest examples known is from Matupi Cave (Democratic Republic of Congo) dated to *ca.* 20,000 BP (43).

The perforation of the Border Cave measurable fragment is 1.5 cm, which is considered too small for a digging stick weight (44). In fact archaeological bored stones can have perforation diameter <2 cm; the maximum thickness of archaeological and ethnographic digging sticks can also be <2 cm (*SI Appendix*, Table S13) (9). The wooden implement from layer 1BS Lower interpreted as a digging stick (9) has a maximum thickness of 1.6 cm, which corresponds to the diameter of the 1WA bored stone. The Border Cave specimen is the oldest artifact of this kind known in South Africa.

Slab with Rubbed Edges

A small slab of red hematite (*SI Appendix*, Fig. S19) comes from 1BS Lower. The edges are rounded, and under the microscope the rounding seems to be the result of rubbing the edge in a longitudinal motion, as indicated by long grooves. The purpose seems to be to make red marks on a soft material (possibly human skin or animal hide). Ochre lumps are common in the South African MSA and LSA, and they also occur at Border Cave in all layers. Lumps of oxidized iron were broken in smaller pieces, and some were ground to produce a red powder, as indicated by numerous parallel grooves on their flat surfaces. This slab was not used to extract powder but for marking (45).

Discussion

The 2BS layers at Border Cave show abandonment of the post-HP technological style and a rise of bipolar knapping and microlith production. The recognition of this trend raises a number of questions.

Which Hunting Weapon Replaced the Stone Spearheads of Post-HP Times, Used for Killing Large and Medium Mammals? It has been suggested that some of the HP backed pieces at Klasies River Main site and at Sibudu were so small that they may have been used as arrowheads (46–48). Small quartz segments ≤2.5 cm could have been used as transverse arrowheads, whereas larger pieces could have been used as axially or diagonally mounted spear tips. A small bone point from the Sibudu HP has been tentatively interpreted as an arrowhead (49). According to this evidence the bow and arrow technology would predate 60,000 BP. This claim is poorly supported owing to (*i*) the very small number of possible arrowheads compared with the total of backed pieces, (*ii*) the fact that equally small or smaller pieces were used as barbs on spears in the Upper Paleolithic, and (*iii*) the total lack of evidence for arrowheads in post-HP assemblages of the following 20,000 y (18, 50) (more in *SI Appendix, Quartz-Tipped Arrows*). Bow and arrow are generally recognized as a successful weapon, widely adopted on most continents, except Australia (51), used for hunting a wide range of game in forested as well as grassland areas. The loss of this successful technology is explained as a historical contingency (52), that is, a chance historical event, due to undetermined factors. Even if the idea of bow and arrow in the HP is accepted, the record shows that it was a short-lived experiment. In contrast, the bone points of Border Cave are very similar in width and thickness to the LSA and San poisoned arrowheads, and thinner than the MSA bone points (9).

Bone points can penetrate thick hides and muscles but have less knock-down power than spears and may need thrusting or a powerful delivery system (53). The ethnographically documented bows of the San are very light, and without poison the arrows would have little effect on any but the smallest animal (54). The ELSA faunal remains (55) include a variety of mammals, from large (e.g., the Cape buffalo) to medium (e.g., zebra), and even dangerous mammals (such as the bushpig and warthog). We believe that the use of poison made the bone points an effective hunting weapon (49, 56, 57). Knowledge of a wide variety of plants with medicinal, adhesive, and poisonous properties is well documented by ethnographies of modern Bushmen (54). This kind of knowledge goes back to at least 77 ka in South Africa (58).

Were the Border Cave Microliths Used Primarily as Cutting Edges, or Were They also Inserted with Mastic on Arrow Shafts as Tips and Barbs, to Be Used in Hunting in Addition to the Bone-Tipped Arrows? Our data do not allow us to answer this question. The Border Cave microliths are unretouched. There are no geometric or pointed forms, unlike the triangles and the pointed backed pieces inserted into wooden shafts as barbs and tips in the Mesolithic of Northern Europe (59). In South Africa backed microliths are common only in the Wilton industry [7,000–4,000 BP; (3)].The bipolar bladelets of the Robberg industry were unretouched and hafted as cutting edges (30).

Do Some Elements of Continuity in Lithic Components Prove That the Border Cave ELSA Assemblages Are MSA in Nature? The significance of stone artifacts as specific indicators of certain industries depends on their frequencies. Lower and Middle Paleolithic tool types are not unusual in Upper Paleolithic industries (*SI Appendix, Lithic Technology*). Levallois cores and flakes can be found in the Upper Paleolithic and even in more recent industries (60). The retention of a few "MSA" pieces is not a significant factor.

Do the Lithic and Organic ELSA Assemblages of Border Cave Mark the Beginning of the LSA in South Africa? The Border Cave ELSA lithic assemblages have been considered undiagnostic or "transitional," but their assessment as MSA or transitional MSA/LSA seems to rest mainly on the absence of Robberg components, such as thin prismatic cores, "punch-struck" bladelets, and the retention of a few "MSA" pieces.

The Border Cave record clearly indicates that after 56 ka technology started to take a different direction from the MSA traditions. This agrees with the East African evidence from Mumba Cave (61, 62). The investment in lithic technology documented in the HP and post-HP by complex and standardized reduction sequences was then directed to the manufacture of tools of bone and wood, ornaments, decorated items, and bored stones, all of which require several manufacturing stages and a variety of techniques of shaping, drilling, perforating, and polishing. The post-20,000-y record shows the continued success of those technologies.

Did MSA Technology Survive Until 26–20 ka in South Africa? Several sites in South Africa Lesotho and Swaziland are dated to the interval between 40 and 20 ka and defined as MSA or transitional MSA–LSA (11–15, 63). However, many assemblages have uncertain stratigraphy or small and undiagnostic inventories or are poorly dated or unpublished. A few have only preliminary descriptions.

At Rose Cottage three layers (DY, DC, and RU) dated between *ca.* 30.8 and 27 ka are defined as final MSA (64). They are described as having bladelets produced by the bipolar technique but also having "MSA" types of formal tools (11).

Strathalan Cave B (Eastern Cape) has two main layers dated between 29 and 25.7 ka. Their inventory, defined as late MSA, includes single and multiplatform cores, some blades, many irregular flakes, and very few retouched blades and flakes (65). At Boomplas Cave (Western Cape) the uppermost MSA level (BP), dated to 34–32 BP, is unpublished. Layer LPC contains an assemblage classified as LSA, with two bone points and few bladelets, dated to *ca.* 21 ka (2, 14). Systematic technological analyses and more dates are needed to break the impasse (63).

Conclusion

The Border Cave ELSA assemblages are the earliest known occurrence of the LSA in South Africa. The process of change began after 56 ka (date of 2BS Lower C) (8) and included the decline and abandonment of the complex reduction sequences of the MSA, a tendency to simplification of stone artifact production, emphasis on microlithic elements, disappearance of stone spear points in favor of the adoption of bow and (probably poisoned) bone arrows, and new forms of personal ornaments and gathering equipment. Fig. 3 models the interactions between elements of continuities and discontinuities in *ca.* 65–40 ka assemblages showing that the LSA emerged in South Africa by internal evolution. Changes in technology constructed an environment in which new forms of sociality could prosper. However,

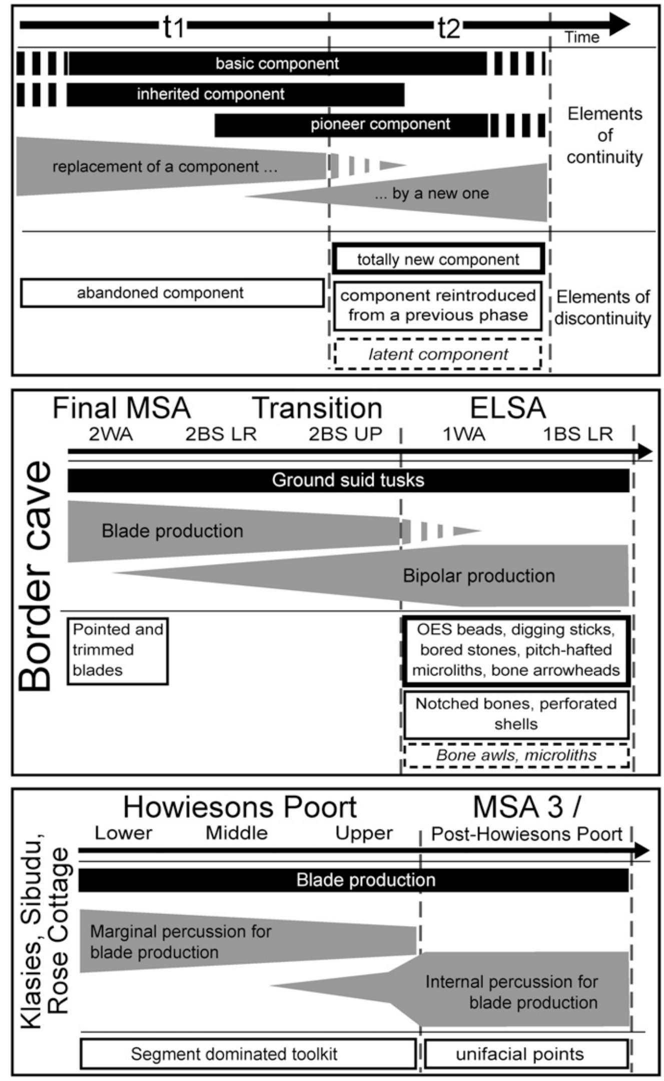

Fig. 3. Trajectories of change in technology between 65 and 40 ka in South Africa. "Reintroduced" components are elements occurring at the site in previous phases. Notched bones are in 2WA; a perforated *Conus* shell occurs in the Border Cave BC3 burial dated to 74 ka by electron spin resonance (ESR) (see ref. 7). "Latent" components are artifacts occurring at other sites in older phases. A small number of microliths occurs in the HP of Klasies and Sibudu. MSA III and post-HP are equivalent terms.

available data are insufficient to trace the spread of the new features and the survival of MSA lithic traditions in South Africa. More research is needed to answer these questions.

Materials and Methods

Analytical procedures were designed to study changes of techniques and reduction sequences over long periods of time and were exactly the same for all assemblages. Thus, no distortion is introduced by the use of different typologies or different approaches by different authors (details in *SI Appendix*). Microscopic images were made by L.B. and F.dE. with an Olympus SZX16 Stereo microscope and a Leica Z6 APO with multifocus module. Detailed results and equipment used in chemical analyses are in the *SI Appendix*.

ACKNOWLEDGMENTS. We thank D. Morris for access to the McGregor Museum collections and facilities during analysis; B. Wilson for identification of the suid tusks; M. Bamford for data on sources of resin; M. Bamford, C. Sievers, and L. Wadley for collecting botanical specimens; and K. Sadr for useful discussions and financial support. Research at Border Cave was funded by National Science Foundation Grant BCS 0613319; the Paleontological Scientific Trust; the School of Geography, Archaeology and Environment, University of the Witwatersrand; and the Centre National de la Recherche Scientifique (Unité Mixte de Recherche 5199, De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie (PACEA), University of Bordeaux). Research by S.S. was funded in part by Institut Français d'Afrique du Sud. F.d. and L.B. received financial support from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC Grant agreement no. 249587, South Africa/France Scientific Co-operation Agreement, National Research Foundation of South Africa, University Research Council, University of the Witwatersrand, Institut Français d'Afrique du Sud, and the Project Origine II, Aquitaine Region.

1. Deacon HJ, Deacon J (1999) *Human Beginnings in South Africa* (David Philip, Cape Town, South Africa).
2. Deacon HJ (1995) Two Late Pleistocene-Holocene archaeological depositories from the southern Cape, South Africa. *S Afr Archaeol Bull* 50:121–131.
3. Bousman BC (2005) Coping with risk: Later Stone Age technological strategies at Blydefontein Rock Shelter, South Africa. *J Anthropol Archaeol* 24:193–226.
4. Beaumont PB (1978) *Border Cave* (Univ of Cape Town, Cape Town, South Africa).
5. Beaumont PB, Miller GH, Vogel JC (1992) Contemplating old clues to the impact of future greenhouse climates in South Africa. *S Afr J Sci* 88:490–498.
6. Miller GH, et al. (1999) Earliest modern humans in southern Africa dated by isoleucine epimerization in ostrich eggshell. *Quat Sci Rev* 18:1537–1548.
7. Grün R, Beaumont P, Tobias PV, Eggins S (2003) On the age of Border Cave 5 human mandible. *J Hum Evol* 45:155–167.
8. Bird MI, et al. (2003) Radiocarbon dating from 40 to 60 ka BP at Border Cave, South Africa. *Quat Sci Rev* 22:943–947.
9. d'Errico F, et al. Earkt Evidence of San material culture represented by organic artifacts from Border Cave, South Africa. *Proc Natl Acad Sci USA*, 10.1073/pnas.1204213109.
10. Klein RG (2008) Out of Africa and the evolution of human behavior. *Evol Anthropol* 17:267–281.
11. Clark AMB (1999) *A Technological and Behavioral Interpretation of the Change from the Middle Stone Age to the Later Stone Age in South Africa* (Univ of the Witwatersrand, Johannesburg).
12. Wadley L (1993) The Pleistocene Later Stone Age south of the Limpopo River. *J World Prehist* 7:243–296.
13. Mitchell PJ (2002) *The Archaeology of Southern Africa* (Cambridge Univ Press, Cambridge, UK).
14. Vogel JC (2001) *Humanity from African Naissance to Coming Millennia—Colloquia in Human Biology and Palaeoanthropology*, eds Tobias PV, Raath MA, Moggi-Cecchi J, Doyle GA (Florence Univ Press, Florence), pp 261–268.
15. Deacon HJ (2001) *Guide to Boomplaas and Cango Caves. AZEF Meeting Excursion* pp 1–14. Available at http://www.docstoc.com/docs/121988654/GUIDE-TO-BOOMPLAAS-CAVE. Accessed July 11, 2012.
16. Cooke HBS, Malan BD, Wells LH (1945) Fossil man in the Lebombo Mountains, South Africa: The Border Cave, Ingwavuma district, Zululand. *Man (Lond)* 45:6–13.
17. Révillion S (1994) *Les Industries Laminaires du Paléolithique Moyen*, ed Tuffreau A (Editions CNRS, Paris).
18. 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.
19. Soriano S, Villa P, Wadley L (2007) Blade technology and tool forms in the Middle Stone Age of South Africa: The Howiesons Poort and post-Howiesons Poort at Rose Cottage Cave. *J Archaeol Sci* 34:681–703.
20. Villa P, Delagnes A, Wadley L (2005) A late Middle Stone Age artifact assemblage from Sibudu (KwaZulu-Natal). Comparisons with the European Middle Paleolithic. *J Archaeol Sci* 32:399–422.
21. Barham L (1987) The bipolar technique in Southern Africa: A replication experiment. *S Afr Archaeol Bull* 42:45–50.
22. Hayden B (1980) Confusion in the bipolar world: Bashed pebbles and splintered pieces. *Lithic Technology* 9:2–7.
23. Perpère M, Schmider B (2002) *L'Aurignacien de la Grotte du Renne. Les Fouilles de Leroi-Gourhan à Arcy-sur-Cure*, ed Schmider B (Editions CNRS, Paris), pp 107–196.
24. Bon F (2002) *L'Aurignacien entre Mer et Océan (Mémoire Société Préhistorique Française XXIX)* (Société Préhistorique Française: Nanterre, France).
25. Gambassini P (1997) *Il Paleolitico di Castelcivita* (Electa, Napoli, Italy).
26. Petrequin AM, Petrequin P (1988) *Le Néolithique des Lacs* (Errance, Paris).
27. Hays MA, Lucas G (2007) *Tools Versus Cores: Alternative Approaches to Stone Tool Analysis*, ed McPherron ShP (Cambridge Scholars, Newcastle, UK), pp 107–126.
28. Deacon HJ, Deacon J (1980) The hafting, function and distribution of small convex scrapers with an example from Boomplas Cave. *S Afr Archaeol Bull* 35:31–37.
29. Phillipson DW (1976) *The Prehistory of Eastern Zambia* (British Institute Eastern Africa, Nairobi).
30. Binneman J, Mitchell PJ (1997) Usewear analysis of Robberg bladelets from Sehonghong Shelter, Lesotho. *S Afr Field Archaeol* 6:42–49.
31. Lombard M (2005) Evidence of hunting and hafting during the Middle Stone Age at Sibidu Cave, KwaZulu-Natal, South Africa: A multianalytical approach. *J Hum Evol* 48: 279–300.
32. Wadley L, Hodgskiss T, Grant M (2009) From the Cover: 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.
33. Burger P, Charrié-Duhaut A, Connan J, Albrecht P (2011) Taxonomic characterisation of fresh Dipterocarpaceae resins by gas chromatography–mass spectrometry (GC–MS): Providing clues for identification of unknown archaeological resins. *Archaeol Anthropol Sci* 3:185–200.
34. Langejans GHJ (2012) Middle Stone Age pièces esquillées from Sibidu Cave, South Africa: An initial micro-residue study. *J Archaeol Sci* 37:971–985.
35. Lluveras A, Bonaduce I, Andreotti A, Colombini MP (2010) GC/MS analytical procedure for the characterization of glycerolipids, natural waxes, terpenoid resins, proteinaceous and polysaccharide materials in the same paint microsample avoiding interferences from inorganic media. *Anal Chem* 82:376–386.
36. Andreotti A, et al. (2006) Combined GC/MS analytical procedure for the characterization of glycerolipid, waxy, resinous, and proteinaceous materials in a unique paint microsample. *Anal Chem* 78:4490–4500.
37. Mazza PPA, et al. (2006) A new Palaeolithic discovery: Tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed. *J Archaeol Sci* 33:1310–1318.
38. Bernards MA (2002) Demystifying suberin. *Can J Bot* 80:227–240.
39. Otto A, Wilde V (2001) Sesqui-, di-, and triterpenoids as chemosystematic markers in extant conifers: A review. *Bot Rev* 67:141–238.
40. Cox RE, Yamamoto S, Otto A, Simoneit BRT (2007) Oxygenated di- and tricyclic diterpenoids of southern hemisphere conifers. *Biochem Syst Ecol* 35:342–362.
41. Allott LF (2006) Archaeological charcoal as a window on paleovegetation and wood-use during the Middle Stone Age at Sibudu Cave. *Southern Afr Hum* 18:173–201.
42. Bamford MK, et al. (2010) Botanical remains from a coprolite from the Pleistocene hominin site of Malapa, Sterkfontein Valley, South Africa. *Palaeont Afr* 45:23–28.
43. Van Noten F (1977) Excavations at Matupi Cave. *Antiquity* 51:35–40.
44. Deacon J (1982) *The Later Stone Age in the Southern Cape* (Univ of Cape Town, Cape Town, South Africa).
45. Hodgskiss T (2010) Identifying grinding, scoring and rubbing use-wear on experimental ochre pieces. *J Archaeol Sci* 37:3344–3358.
46. Singer R, Wymer J (1982) *The Middle Stone Age at Klasies River Mouth in South Africa* (Univ of Chicago Press, Chicago).
47. Wadley L, Mohapi M (2008) A segment is not a monolith: Evidence from the Howiesons Poort of Sibudu, South Africa. *J Archaeol Sci* 35:2594–2605.
48. Lombard M (2008) Finding resolution for the Howiesons Poort through the microscope: Microresidue analysis of segments from Sibudu Cave, South Africa. *J Archaeol Sci* 35:26–41.
49. Backwell L, d'Errico F, Wadley L (2008) Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. *J Archaeol Sci* 35:1566–1580.
50. Villa P, Soriano S (2010) Hunting weapons of Neanderthals and early modern humans in South Africa. *J Anthropol Res* 66:5–38.
51. Cattelain P (1997) *Projectile Technology*, ed Knecht H (Plenum, New York), pp 213–240.
52. Lombard M, Parsons I (2011) What happened to the human mind after the Howiesons Poort? *Antiquity* 85:1–11.
53. Waters MR, et al. (2011) Pre-Clovis mastodon hunting 13,800 years ago at the Manis site, Washington. *Science* 334:351–353.
54. Shaw EM, Woolley PL, Rae FA (1963) Bushman arrow poisons. *Cimbebasia* 7:2–41.
55. Klein RG (1977) The mammalian fauna from the Middle and Later Stone Age (Later Pleistocene) levels of Border Cave, Natal Province, South Africa. *S Afr Archael Bull* 32: 14–27.
56. Hitchcock R, Bleed P (1997) *Projectile Technology*, ed Knecht H (Plenum, New York), pp 345–368.
57. Robbins LH, Campbell AC, Brook GA, Murphy ML, Hitchkock RK (2012) The antiquity of the bow and arrow in the Kalahari desert: Bone points from White Paintings rock shelter, Botswana. *J Afr Archaeol* 10:7–20.
58. Wadley L, et al. (2011) Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa. *Science* 334:1388–1391.
59. Larsson L, Sjöström A (2011) Early Mesolithic flint-tipped arrows from Sweden. *Antiquity*, 85: Project Gallery. Available at http://antiquity.ac.uk/projgall/larsson330/. Accessed July 10, 2012.
60. Inizan ML, Reduron-Ballinger M, Roche H, Tixier J (1999) *Technology and Terminology of Knapped Stone* [Cercle de Recherches et d'Etudes Préhistoriques (CREP), Nanterre, France].
61. Díez-Martin F, et al. (2009) The Middle to Later Stone Age technological transition in East Africa. New data from Mumba rockshelter Bec V (Tanzania) and their implications for the origin of midern human behavior. *J Afr Archaeol* 7:147–173.
62. Gliganic LA, Jacobs Z, Roberts RG, Domínguez-Rodrigo M, Mabulla AZP (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.
63. Mitchell P (2008) Developing the archaeology of Marine Isotope Stage 3. *S Afr Archaeol Soc Goodwin* 10:52–65.
64. Wadley L (2004) *Settlement Dynamics of the Middle Paleolithic and Middle Stone Age*, ed Conard N (Kerns Verlag, Tübingen, Germany), Vol II, pp 23–36.
65. Opperman H (1996) *Aspects of African Archaeology*, eds Pwiti G, Soper R (Univ of Zimbabwe, Harare, Zimbabwe), pp 335–342.