A 100,000-Year-Old Ochre-Processing Workshop at Blombos Cave, South Africa

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The conceptual ability to source, combine, and store substances that enhance technology or social practices represents a benchmark in the evolution of complex human cognition. Excavations in 2008 at Blombos Cave, South Africa, revealed a processing workshop where a liquefied ochre-rich mixture was produced and stored in two *Haliotis midae* (abalone) shells 100,000 years ago. Ochre, bone, charcoal, grindstones, and hammerstones form a composite part of this production toolkit. The application of the mixture is unknown, but possibilities include decoration and skin protection.

Grinding or scraping ochre to produce a powder for use as a pigment was common practice in Africa and the Near East after 100,000 years ago (ka) (*1*–*4*). Ochre is the colloquial term used by archaeologists to describe an earth or rock containing red or yellow oxides or hydroxides of iron (for example, ferruginous siltstone). Ochre may have been applied with symbolic intent as decoration on bodies and clothing during the Middle Stone Age (MSA) (*2*). Archaeological evidence for the procedures that MSA people followed during their handling, preparation, storage, and application of ochre is limited (*2*, *3*, *5*). Here, we report on the in situ discovery and subsequent analysis of two coeval, spatially associated toolkits (Figs. 1 and 2) used for the production and storage, in shell containers, of an ochre-rich compound at Blombos Cave, South Africa, 100 ka. Other pigment workshops and containers date to about 60 ka [e.g. (*6*)], although older grindstones and hammerstones used for ochre processing have been recovered [e.g. (*7, 8*)].

Blombos Cave is situated on the southern Cape coast, 300 km east of Cape Town. The MSA levels at the site are divided into three phases: M1, M2 (upper and lower), and M3 (*9*) (Fig. 2). The M1 and upper M2 phases (78 to 72 ka) contain Still Bay–type bifacial foliate points, engraved ochre and bone, bone tools, and *Nassarius kraussianus* shell beads (*2*). The M3 phase contains many shellfish, in situ hearths, faunal remains, stone tools, and many modified ochre pieces. The ochre-processing toolkits were recovered in the lower M3 phase. They were found within layer CP, composed mainly of aeolian dune sand, and lay on a thin orange sand layer, CPA (Fig. 2 and fig. S1A). Within layer CP, there are few artifacts apart from the toolkits. Using single-grain optically stimulated luminescence (OSL) dating (*10*), we estimated the time of deposition of the quartz sediments in which the ochre containers were buried to be 101 ± 4 ka (weighted mean and standard error for all three samples collected from layer CP). This age is stratigraphically consistent with younger ages for the overlying sediments estimated by OSL dating and by thermoluminescence (TL) dating of burnt lithics (*11*, *12*) (Fig. 2 and table S4). We also dated calcium carbonate concretions formed within the layer-CP sediments, using uranium-series methods and an isochron approach to deal with detrital thorium contamination (*13*, *14*) (figs. S43 to S45 and tables S5 and S6). The most reliable isochron age estimate of >92 ka is consistent with carbonate formation after sediment deposition, and should be regarded as a minimum age for layer CP and its associated artifacts. The most accurate estimate of age for the ochre toolkits is ~100 ka.

Toolkit Tk1 comprises a stack of artifacts (Figs. 1A and 3) above and below a *Haliotis midae* (abalone) shell (Tk1-S1) (figs. S2 and S3). A quartzite cobble (Tk1-L1), tightly fitted within

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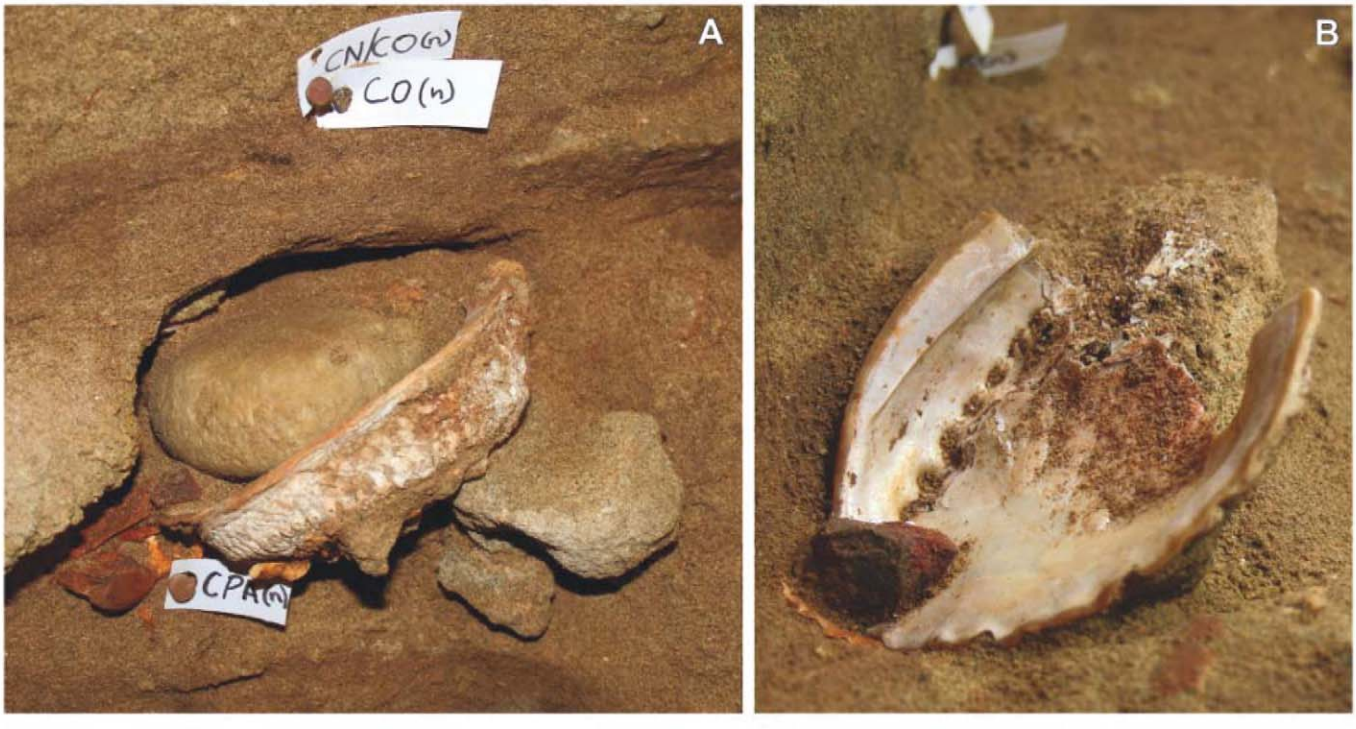

Fig. 1. Ochre-processing toolkits in situ showing Tk1 (**A**) and Tk2 (**B**). [Images: G. Moéll Pedersen]

the shell aperture, has use-wear marks consistent with its application as a percussor and grinder. The upper face is stained with red ochre and encrusted with fragments of trabecular bone (figs. S7 and S8). Removal of the cobble revealed a 5-mm-thick red compound adhering to the shell nacre, overlain by a khaki-colored aeolian sand (fig. S1C). Microscopic and chemical analysis (*15*) of the red compound (figs. S5, S6, S36, and S37 and table S3) shows that it is composed of: (i) microflakes and microchips of two ferruginous siltstone (ochre) types (FS1 and FS2) that are predominantly present inside the shell, with only minute quantities in the CP layer matrix; FS1 and FS2 are composed of quartz, hematite, muscovite/illite, and goethite but differ in their petrographic structure and elemental composition; (ii) fragments, some apparently burnt, of crushed trabecular (spongy) bone, once rich in fat and marrow, that may have acted as a binder in the compound, and of crushed compact bone; (iii) charcoal fragments; (iv) quartz and quartzite microflakes with ochre on some of the striking platforms; and (v) quartz grains coated with ochre powder and in some instances coated with a micrite containing hematite, illite/muscovite, quartz, and calcium phosphate (figs. S40 and S41).

A khaki-colored aeolian sand (figs. S2 and S3), overlying the red compound, consists of quartz grains, glauconitic grains, vertebrate microfauna

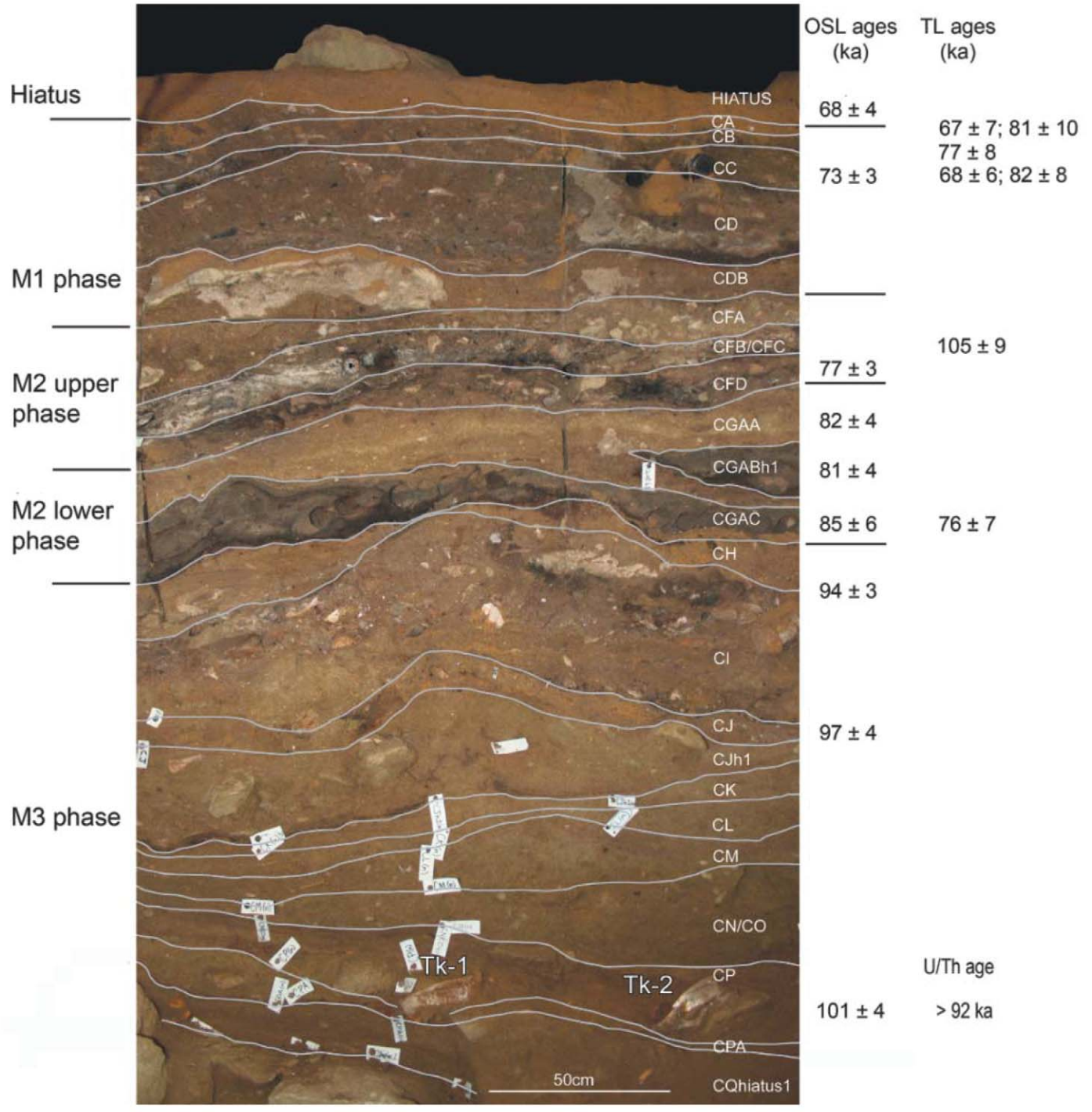

Fig. 2. South section of Blombos Cave showing layers, phases, and ages. The ages shown here were determined with the OSL, TL, and uranium/thorium (U/Th) methods. The ochre-processing toolkits (Tk1 and Tk2) came from layer CP in the M3 phase and are shown in situ. [Image: G. Moéll Pedersen and K. van Niekerk]

remains, marine gastropods, ostracods, foraminifera, urchin spines, lamellibranches, and calcitic worm tubes from annelids (fig. S34). The CP layer matrix (fig. S1) corresponds to this upper sand layer (figs. S33 and S35 and tables S1 and S2), and the aeolian quartz grains within the red compound originally derive from the CP layer matrix. When the red and aeolian sand layers were removed, an orange ring-stain residue consisting of calcium phosphate mixed with traces of hematite and calcite was visible on the shell's inner lip, base (fig. S3D), and outer lip (figs. S3C and S6). The calcium phosphate may result from diagenetic microbial activity (fig. S41). A small piece of FS1 red ochre (Tk1-P1), rubbed on one face, was found on the inner lip of the shell (figs. S9 and S10). A quartzite flake fragment (Tk1-L2), with ochre powder on all faces, was adhering to it (figs. S11 and S12). A small quartzite flake (Tk1-L3) with red ochre on the striking platform lay above the cobble and below the quartzite slab (Tk1-L4) (figs. S13 to S15). Longitudinal streaks of red ochre are visible on one face of this slab. The coarse surface of the slab contains microscopic traces of ochre powder, suggesting that it was used as a grinder.

Lying below the *Haliotis* Tk1-S1 were (i) the distal portion of a canid ulna (Tk1-B1) with ochre residues on the broken tip and close to the epiphysis (fig. S16); (ii) a seal scapula (Tk1-B2) with numerous microspots of red ochre on its lateral surface (fig. S17); (iii) a broken bovid vertebra (Tk1-B3) (fig. S18); (iv) a quartz flake (Tk1-L5) with red ochre residues and a microchipped edge indicating its use as a grinder (fig. S19); and (v) two quartzite flakes (Tk1-L6 and Tk1-L7) (figs. S20 to S22). The striking platform of the first flake is covered with red ochre powder and is microchipped on one edge, suggesting its use as a grinder (fig. S21). The same ochre powder is present on the cortical face of the second flake (fig. S23). The quartz and quartzite microchips found in the red compound in the *Haliotis* shell Tk1-S1 are of the same raw material as Tk1-L5, Tk1-L6, and Tk1-L7.

The second toolkit (Tk2), located 16 cm west of Tk1 (Figs. 1B and 2), comprises a *Haliotis midae* shell (Tk2-S1) (fig. S24), broken postdepositionally, with a red compound on the nacre of the inner surface of the *Haliotis* (Fig. 1B and fig. S24). The components of this red compound (fig. S26) are the same as described for Tk1-S1, with the addition of fragments of coarse silcrete probably originating from a grindstone. The ferruginous siltstone FS2 was not detected in this red compound (table S2). On the ventral side and close to the outer lip of Tk2-S1, ancient striations are present on the nacre (fig. S25). Microscopic observation suggests that they were produced when quartz or ochre grains were gently moved across the nacre surface during mixing.

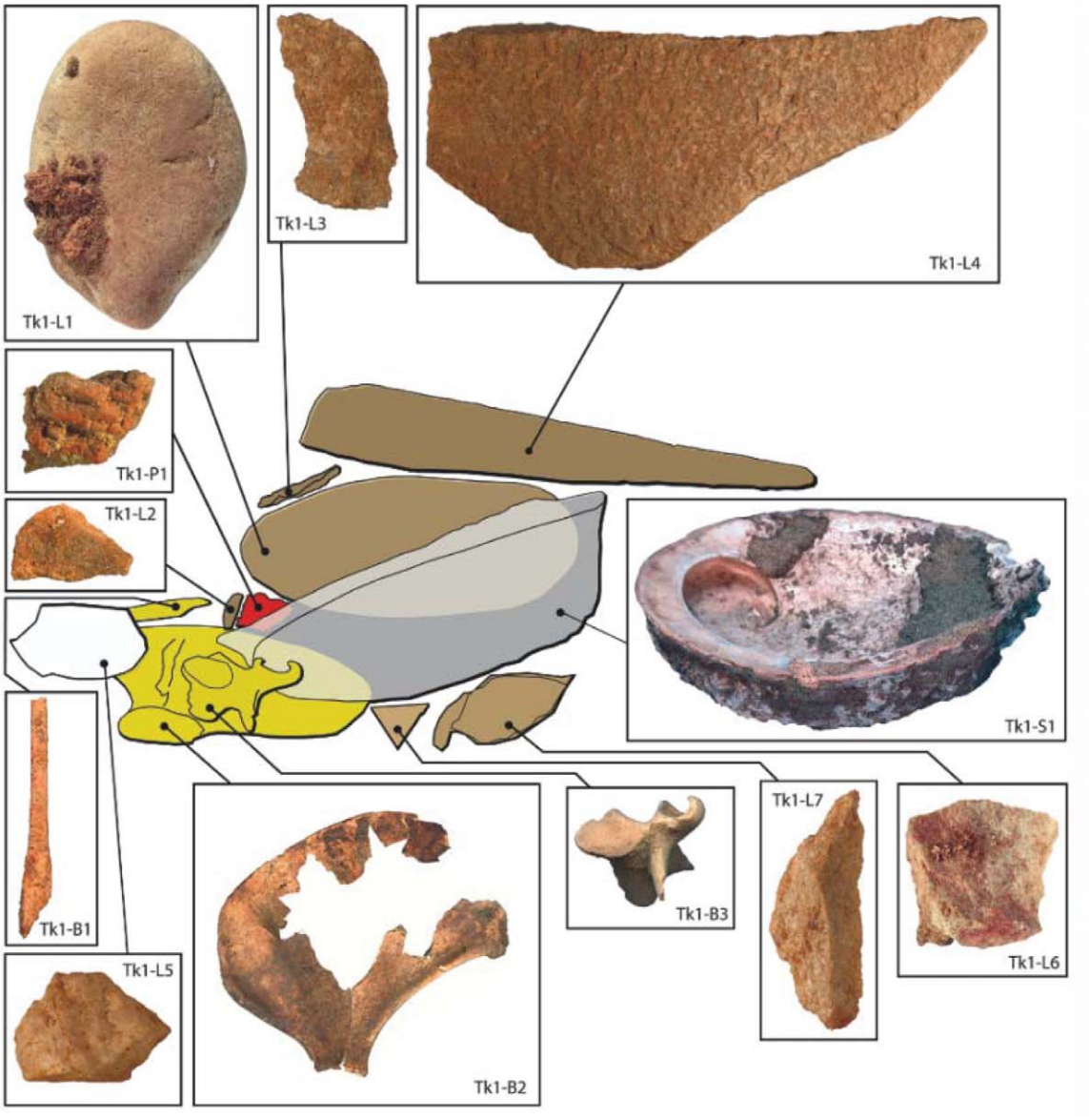

Fig. 3. Artifacts making up Tk1 and their relative spatial locations. [Image: C. Henshilwood and F. d'Errico]

After the shell containing the red compound was abandoned, it was covered with aeolian dune sand derived from layer CP, as was the case for Tk-S1.

A small quartzite core (Tk2-L1) rested on the shell nacre close to the anterior edge (figs. S24 and S27). The core was used first to grind ferruginous lutites, composed in one case of goethite, calcite, and quartz, and in the other of hematite, calcite, and quartz (figs. S28 and S29 and table S2). Several flakes were then removed from the utilized area, and the object was again used to grind a type FS1 red ferruginous siltstone. A large fragment of ochre (Tk2-P1) composed of ferruginous siltstone FS1 lay 5 cm southwest of the shell (fig. S30). It was knapped to produce small flakes, similar to those in the red compound from Tk1-S1 and Tk2-S1. The piece was also rubbed against a hard stone to produce ochre powder (figs. S31 and S32).

The two *Haliotis* shells derive from the infratidal zone, at that time a few hundred meters from the cave (*16*). Before their use as containers, the respiratory holes of the *Haliotis* were possibly plugged. When recovered, these holes were filled with detritus (fig. S6), but this could have occurred postdepositionally. The ochre and silcrete were sourced from at least several kilometers away (*9*), and the rest of the objects that make up the toolkits were available in the immediate environment.

We infer that manufacturing proceeded as follows: Pieces of ochre (FS1 and FS2) were rubbed on quartzite slabs to produce a fine red powder, and some were knapped with large lithic flakes. The ochre chips resulting from the latter were crushed with quartz, quartzite, and silcrete hammerstones/grinders. Quartzite grinders were used to crush goethite or hematite-rich lutite. Medium-sized mammal bone was crushed, probably with a stone hammer. The red or reddish brown color and cracked, flaky texture of some of the trabecular bone suggest that it was heated before crushing, probably to enhance the extraction of the marrow fat. The hematite powder, charcoal, crushed trabecular bone, stone chips, and quartz grains and a liquid were then introduced into the *Haliotis* shells and gently stirred (figs. S5, S25, and S26). Charcoal is rare in the layer-CP matrix, suggesting that it was a deliberate addition to the mix. The quartz and quartzite chips, produced during the action of crushing the ochre, and the quartz grains may have been incidentally incorporated.

The application or use of the compound is not self-evident. No resins or wax were detected that might indicate it was an adhesive for hafting. Possible uses could include painting a surface in order to decorate or protect it, or to create a design. Ochre residues on the bone Tk1-B1 show that it was possibly used as a stirrer and also to transfer some of the compound out of the shell. At least some of the components of the toolkit were reused, suggesting that production was not a one-time event. An example is the first use of the grinder Tk2-L1 to grind yellow goethite, its subsequent reduction by flaking, and then its reuse to grind red ochre. The ochre FS2 is present only in Tk1, and the stone tools found in close association with each shell may have been exclusive to the processing related to that shell. However, the close proximity of the two toolkits suggests that they were used contemporaneously. Because both toolkits were left in situ, and because there are few other archaeological remains in the CP layer, it seems that the site was used primarily as a workshop and was abandoned shortly after the compounds were made. Aeolian sand then blew into the cave from the outside, encapsulating the toolkits (Fig. 2).

Recent support for a southern African origin for *Homo sapiens* comes from genomic and phenomic diversity studies (*17*, *18*). The recovery of these toolkits at Blombos Cave adds evidence for early technological and behavioral developments associated with *H. sapiens* and documents their deliberate planning, production, and curation of a pigmented compound and the use of containers. *H. sapiens* thus also had an elementary knowledge of chemistry and the ability for long-term planning.

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Supporting Online Material

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Materials and Methods
SOM Text
Figs. S1 to S45
Tables S1 to S6
References (*19*–*50*)

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The Dynamic Architecture of *Hox* Gene Clusters

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The spatial and temporal control of *Hox* gene transcription is essential for patterning the vertebrate body axis. Although this process involves changes in histone posttranslational modifications, the existence of particular three-dimensional (3D) architectures remained to be assessed in vivo. Using high-resolution chromatin conformation capture methodology, we examined the spatial configuration of *Hox* clusters in embryonic mouse tissues where different *Hox* genes are active. When the cluster is transcriptionally inactive, *Hox* genes associate into a single 3D structure delimited from flanking regions. Once transcription starts, *Hox* clusters switch to a bimodal 3D organization where newly activated genes progressively cluster into a transcriptionally active compartment. This transition in spatial configurations coincides with the dynamics of chromatin marks, which label the progression of the gene clusters from a negative to a positive transcription status. This spatial compartmentalization may be key to process the colinear activation of these compact gene clusters.

During mammalian development, *Hox* genes are activated sequentially relative to their positions along the four genomic clusters (*HoxA* to *HoxD*). As a result, this process leads to a corresponding distribution of transcripts along the rostral-to-caudal body axis. This process of