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Miniaturization and Abstraction in the Later Stone Age

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Abstract
This article offers some hypotheses to explain Later Stone Age lithic miniaturization: the systematic creation of small stone flakes on the finest-grained materials. Fundamentally, this phenomenon appears to represent the prioritization of stone tool sharpness over longevity, and a disposable mode of using stone tools. Ethnographic evidence from Australasia, the Andaman Islands, and Africa is used to suggest some specific functions for miniaturized lithics, as well as their relationship to other aspects of Later Stone Age material culture, including ochre crayons, shell beads, and notched bones. Miniaturized lithic functions are hypothesized to have a common basis in the cognitive capacity for abstraction: having ideas about ideas. The technological and social affordances of abstraction may have given later *Homo sapiens* significant adaptive advantages over other members of our genus.

Keywords Cerebellum · Lithics · Scarification · Sharpness · Shaving · Supergroups

Introduction

In this article we begin with a previously documented empirical phenomenon of the Stone Age archaeological record—that in the second half of the Late Pleistocene in East Africa, hominins began targeting the finest-grained rocks for stone knapping and made very small flakes of those materials, in a way that earlier hominins did not (Shipton et al. 2021c). Ethnographic comparisons from diverse groups living around the Indian Ocean rim are used to suggest an array of functions for these stone tools. One such function is in body ornamentation, which is also attested in other forms of Late Pleistocene archaeological evidence, namely the habitual use of beads and pigment. Combining both ethnographic and archaeological evidence, a particular higher-order function of body ornamentation is argued to be the creation and maintenance of tribal supergroups. The article then moves to a cognitive mechanism that could account for the whole range of functions proposed for small, fine-grained stone tools, namely abstraction. We conclude with a hypothesis that abstraction in general, and tribal supergroups in particular, would have promoted the unparalleled broad and rapid dispersal of our species in the second half of the Late Pleistocene.

The reduction in size of flaked stone tools is a general trend observed from the early Acheulean to the Epipaleolithic (Shea 2013), likely comprised of a series of independent transitions with differing explanations. The reduction in shaped biface size during the Acheulean (Gilead 1970) may reflect increasing knapper dexterity (Shipton 2018), while the reduction in flake blank size from the Acheulean to the Middle Stone Age (MSA) (Tryon et al. 2005) probably reflects the origins of hafting (Barham 2013).

Sporadic instances of systematic small flake (20–30 mm) production are evident during the Oldowan and Acheulean (Early Stone Age) and are usually explained by material scarcity or clast size (Zaidner 2013; Agam and Barkai 2018; Gallotti et al. 2020). At the final Acheulean (Acheulo-Yabrudian) sites of Revadim and Qesem Cave in the Levant, a minority population of very small flakes (< 20 mm) were being used in various tasks including butchery, hide working, and plant processing, demonstrating their utility (Venditti et al. 2019b, 2019a).

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In the African Later Stone Age (LSA), the production of very small flakes (< 20 mm) becomes the dominant mode of knapping, a phenomenon that has been termed miniaturization (Pargeter 2016; Pargeter and Shea 2019). In such assemblages, small flakes are produced on highly siliceous cryptocrystalline rocks even though other stone suitable for knapping may be more readily available, indicating a general hominin preference for such flakes rather than the phenomenon being an incidental result of material scarcity or clast size (Pargeter 2016; Shipton et al. 2021c). This article presents a hypothesis as to what might have been driving that preference.

Miniaturization at Panga ya Saidi

The earliest documented instance of lithic miniaturization as a distinct hominin choice comes from the site of Panga ya Saidi near the coast of Kenya (Shipton et al. 2021c). Here, a record of human occupation begins in late Marine Isotope Stage (MIS) 5, ~ 80 kya (Shipton et al. 2018). This initial occupation phase is typical of the East African MSA (Blinkhorn and Grove 2018) in featuring Levallois technology and retouched flakes, with average flake lengths > 25 mm (Shipton et al. 2021c). At the transition from MIS 5 to MIS 4 (71–67 kya) there appears to be some environmental disruption and very low occupation intensity at the site (Shipton et al. 2021c). When occupation intensity begins to increase again from 67 kya, the character of the stone artifacts is very different. Where previously limestone had been the dominant material used for stone tool production, now highly siliceous (fine-grained) quartz and chert are. And the flakes produced are small (Fig. 1), < 20 mm in mean length.

Several aspects of this reduction in size are noteworthy. It is apparent across a range of artifact sizes including both debitage (complete flakes, broken flakes, and flaked pieces) larger than 5 mm in maximum dimension, and down to 1 mm (Fig. 1), as well as complete flakes longer than 5 mm, and those longer than 20 mm (Shipton et al. 2021c). There is no significant reduction in the size of limestone flakes; it is only apparent in flakes of quartz and chert, so it is directly linked to, but not wholly driven by, the fine-grained material selection.

After this transition, lithic miniaturization then characterizes the entire remainder of the Panga ya Saidi sequence, comprising 16 occupation layers, that, uniquely in East Africa, span the climatic fluctuations of MIS 4, 3, 2, and 1 (Shipton et al. 2021c). Across this sequence there is wide variation in knapping technologies and stone artifact life history lengths, but neither of these factors diverts from the overall signature of miniaturization (Fig. 1). When particular classes of artifact are examined at Panga ya Saidi the reduction in size from the MSA to the LSA is still apparent: Levallois flake median length is 53.3 vs. 33.6 mm, and retouched flake median length is 45.4 vs. 28.2 mm (Shipton et al. 2021c). Bipolar knapping (cracking a stone between hammer and anvil) is associated with knapping small cores and is common in the LSA generally (Tryon and Faith 2013; Blinkhorn and Grove 2018) including at Panga ya Saidi. However, bipolar is one of the oldest and most widespread knapping strategies (Shott 1989; Harmand et al. 2015), and it is also a feature of the MSA at Panga ya Saidi, while conversely

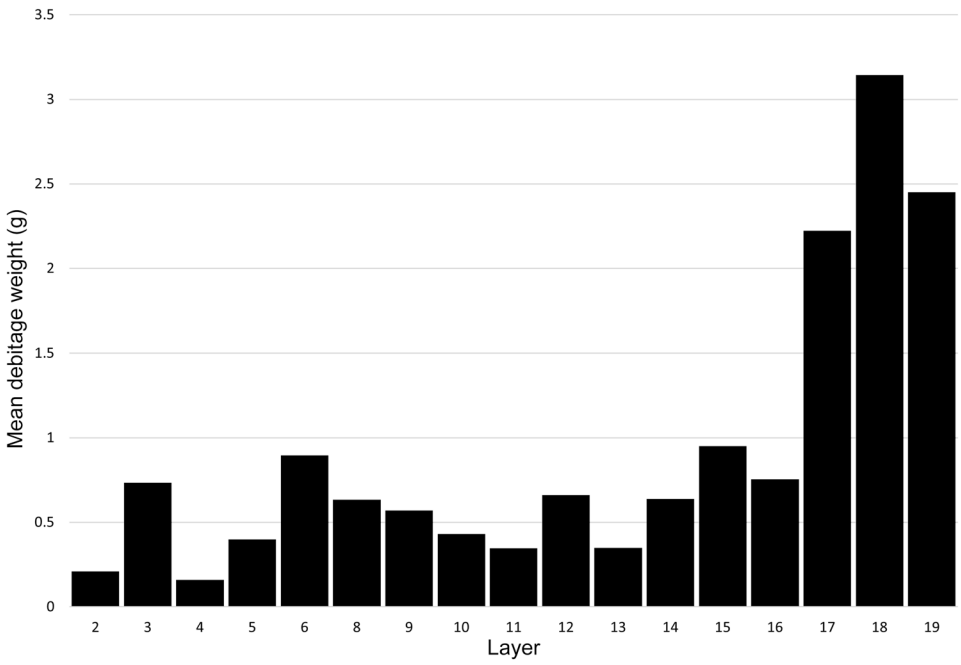

Fig. 1 Mean flaked stone artifact weight (excluding cores) at Panga ya Saidi from 1mm^2 mesh sieved material. Note the abrupt drop between layers 17 and 16 which then characterizes the remainder of the sequence

there are miniaturized LSA layers at the site where it is rare (Shipton et al. 2021c). Therefore it is not bipolar technology driving small lithic size, but the preference for small fine-grained lithics that results in a common, though not ubiquitous, preference for this technology as it is well-suited to knapping small cores (Hiscock 2015; Pargeter and Eren 2017). Rather than any particular technology or tool type, it is the continuity in miniaturization from layer 16 upwards that is the signature of LSA technology at Panga ya Saidi.

Sharpness Over Longevity

The hominin preference for small flakes of siliceous materials at Panga ya Saidi and elsewhere in the LSA begs the question as to what differed from stone tool preference in the MSA. One of the characteristic artifacts of the LSA are backed crescents, tools that have standardized shapes including a straight unretouched cutting edge opposite a steeply retouched (backed) curved edge (Fig. 2), the latter thought to be an adaptation to hafting with glue. Such artifacts may have sporadic earlier appearances in the MSA (Barham 2002), but they are a widespread feature of the African record from MIS4 onwards (Blinkhorn and Grove 2020). At Panga ya Saidi and elsewhere in East Africa backed artifacts are known from around 50 kya (Ambrose 1998; Diez-Martín et al. 2009; Shipton et al. 2021c). It has been suggested that they are the functional equivalent of disposable razors, with their standardized shapes allowing for easy replacement in a hafting arrangement (Ambrose 2010). Miniaturized lithics might be a more general class of disposable tool, whether handheld or hafted, in which edge sharpness is maintained through repeated replacement.

Some support for this disposable razor hypothesis comes from experimental evidence on sharpness. Stone tool sharpness drops off rapidly upon initial use and then stabilizes (Key et al. 2018). So, if you want to maximize sharpness, the optimal strategy is to use a tool for one or two cuts and replace it with a fresh one. Of course, this comes with the cost of the need for a lot of tools, but if flakes are only small then it is possible to make more of them from a given lump of stone.

While finer-grained materials, such as chert and quartz, offer greater sharpness, coarser-grained materials (though still isotropic) offer greater durability (Key et al. 2020). If you want a longer-lasting tool it is better to procure larger clasts of coarser-grained material from which you will be able to make larger tools with more durable edges. But if your priority is sharpness, it is better to procure finer-grained rocks, even though these typically come in smaller clasts.

Ethnographic accounts of the use of fine-grained stone also suggest the prioritization of sharpness over longevity:

> Everywhere on the great western part of New Britain obsidian slivers play a major role as a cutting implement. …When such a knife becomes useless, it is thrown away without any attempt to resharpen the cutting edge, and a new sliver is broken off. (Parkinson 1907, p. 102)

In addition to the experimental and ethnographic affordances of fine-grained materials, a third line of evidence supports the idea that LSA people favored stone tool

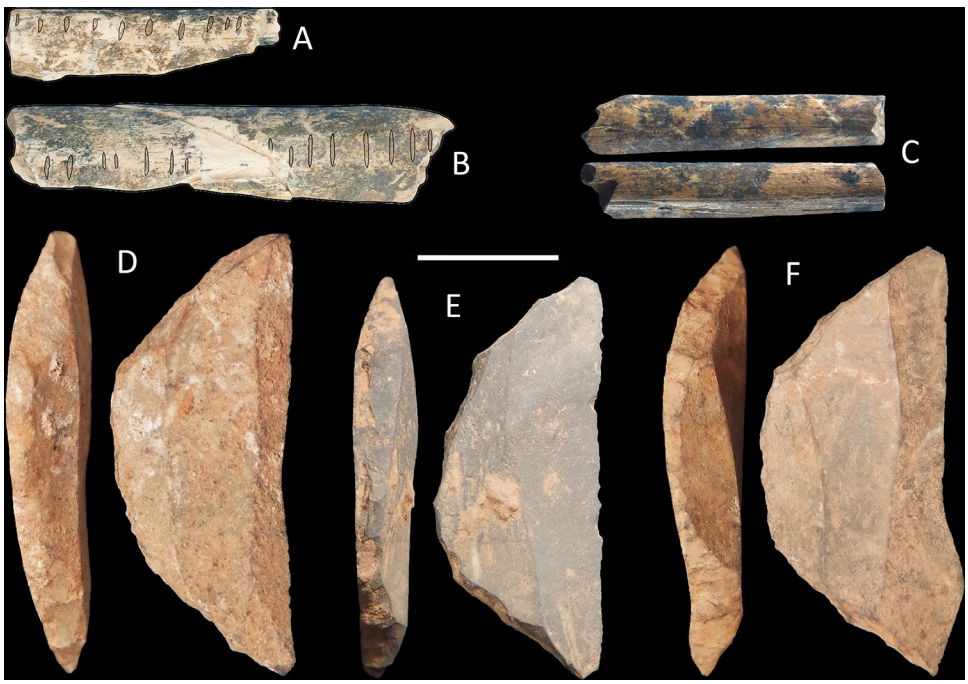

Fig. 2 LSA artifacts from Panga ya Saidi. **A** and **B** are notched bones, **C** is a bone point, and **D–F** are backed crescents. Scale bar is 1 cm. Adapted from d'Errico et al. (2020) and Shipton et al. (2021c)

sharpness over longevity: the low levels of retouch on cutting edges. Retouch, when secondary flakes are removed from the edge of a flake, can be used to resharpen a dulled edge. However, the retouched edge is never as sharp as its unused unretouched counterpart, as retouching typically increases the angle of the edge and gives it a more complex topography resulting in more friction. A notable feature of miniaturized assemblages in the LSA at Panga ya Saidi and elsewhere is the low levels of retouch on the cutting edge (Pargeter 2016; Slater 2016; Blinkhorn and Grove 2020; Shipton et al. 2021c). The majority of LSA retouch was for hafting modifications, particularly backing, rather than to shape or refresh cutting edges, unlike in MSA assemblages where retouch was both more frequent and more commonly on the cutting rather than the hafting edge.

The above lines of evidence suggest that LSA miniaturization at Panga ya Saidi, and more broadly across Africa, was driven by the prioritization of stone tool sharpness over longevity and thus involved creating many small flakes of fine-grained stone, which were rarely resharpened. The following two sections review some potential functional explanations of how LSA stone tools may have differed from those of the MSA.

Utilitarian Miniaturization

A principal function of stone tools throughout human evolution was butchery. Large prey require large butchery tools, but prey smaller than medium-sized ungulates can be dismembered without cutting tools. Despite fluctuations in prey size (Roberts et al. 2020), miniaturized lithics are a consistent feature of the LSA at Panga ya Saidi, suggesting butchery was not one of their principal functions. In southern Africa, Sri Lanka, and Wallacea, miniaturized lithic assemblages are often associated with small prey (Shipton et al. 2019, 2021b; Wedage et al. 2019; Pargeter and Faith 2020), with cut marks sometimes absent on large assemblages of prey bone (Hawkins et al. 2017; Samper Carro et al. 2017), suggesting stone tools were not being used in their butchery.

A missing component of material culture at Panga ya Saidi and at most tropical sites are wooden artifacts. Among the Wonkonguru of central Australia, the final phase of smoothing in making a boomerang was done with twenty or thirty "casual stones": "directly they are blunt, they are thrown away and another picked up" (Horne and Aiston 2009, p. 106). In western New Britain obsidian "slivers" were used to decorate canoes and carve wooden bowls (Parkinson 1907). Among the Warangi of East Africa small quartz flakes were used for smoothing bow staves, handles, and wooden utensils (Masao 1982). Miniaturized lithics may have had such a role in carving elaborate wooden artifacts; however, they do not seem to have been a general class of woodworking tool: wooden artifacts were likely common throughout the Early and Middle Stone Age, with experimental and ethnographic evidence indicating larger and coarser-grained lithics are more effective at general woodworking than smaller finer-grained ones (Hayden 2008, 2015; Gürbüz and Lycett 2021).

In southern Africa, a function suggested for backed crescents is as arrowheads. Local ethnographies demonstrate their use as such in the recent past (Clark 1975; Rudner 1979); experiments show their effectiveness as arrowheads (Lombard and Pargeter 2008); while microscopy indicates archaeological specimens were sometimes hafted in a similar way to ethnographic examples and display the same features of high-velocity impacts (Lombard and Phillipson 2010; Lombard 2011). The earliest appearance of backed arrowheads in southern Africa is in the Howiesons Poort culture of MIS 4 (71–57 kya) (Jacobs and Roberts 2017). The Howiesons Poort is considered MSA rather than LSA, in part because of the large size of the backed artifacts and other stone tools, but notably, it is contemporary with the earliest miniaturized LSA at Panga ya Saidi. While there are no backed artifacts in the early LSA at Panga ya Saidi, unretouched miniaturized flakes could have been used as arrowheads (Odell 1988). Since arrows principally kill by depth of penetration rather than the size of the external wound, sharpness and small size are advantageous in arrowheads (Mika et al. 2020). Backed artifacts appear in the Panga ya Saidi sequence ~ 50 kya (Fig. 2), but then disappear for tens of thousands of years before reappearing in the terminal Pleistocene, ~ 15 kya (Shipton et al. 2021c). During this hiatus, a type of bone artifact occurs in the sequence which may also have functioned as an arrow tip (Fig. 2) (d'Errico et al. 2020) based on ethnographic comparisons with similar artifacts from southern Africa (Backwell et al. 2008).

Rare instances of exceptional preservation indicate that a function of backed lithics was to be hafted in series as compound tools, where the straight cutting edges could either be placed adjacent to one another in a line to form a long continuous edge, or spaced and angled to form barbs (Yaroshevich et al. 2013; Larsson et al. 2017; Tomasso et al. 2018). Ethnographic evidence from Australia shows that such compound hafting need not be restricted to backed artifacts however, and was also done with small unretouched flakes of quartz to make tools like the Death Spear (Etheridge 1890; Davidson 1934) and Taap Knife (Etheridge 1902; Hayden 1973). Indeed, impact damage suggests that unretouched quartz pieces from the Howiesons Poort were sometimes hafted as barbs (de la Peña et al. 2018). Experimental evidence shows that when it comes to replacing inserts in compound tools, it is the absolute rather than relative size variation that determines whether a replacement will fit; so the smaller the inserts, the easier they will be to repair, again suggesting miniaturization may be a correlate

of compound tools (Kuhn and Shimelmitz 2022). Direct archaeological evidence for compound tools is exceedingly rare as it requires extraordinary levels of preservation, but we should entertain the possibility that compound tools were more common than the record allows us to see, and they may explain at least some of the miniaturized lithics of the African LSA. However, even if bow and arrows and compound tools were a feature of LSA technology at Panga ya Saidi, they would still be unlikely to account for the tens of thousands of miniaturized lithics recovered from the excavation, so we must seek further explanations.

In addition to the possible bone arrowheads from Panga ya Saidi, the good preservation conditions have ensured there are several other osseous artifacts. These include notched bones and awls made of suid tusks from the middle part of the sequence (d'Errico et al. 2020) (Fig. 2). The latter are particularly noteworthy as they are an artifact type characteristic of the LSA (d'Errico et al. 2012), with the notches made using an unretouched lithic edge. These notches may be decorative, but elsewhere on the eastern coast of Africa, LSA notched bones have been interpreted as notational objects because the notches were made at different times with different unretouched lithics edges (Langley et al. 2016b; d'Errico et al. 2018). In these instances of potential notational notches at Border Cave and Kuumbi Cave, the notched bones are also associated with assemblages of miniaturized lithics (Villa et al. 2012; Shipton et al. 2016). Ethnographies from across Africa indicate notched artifacts were used for tallying (Lagercrantz 1973), as they were in Europe (Kuchenbuch 2006). In Australia notched sticks were used as symbols of authenticity for the bearer to convey messages over long distances between groups, with notches sometimes indicating numbers of people or days in relation to the message (Howitt 1889; Kelly 2020). However, even if we accept the use of miniaturized lithics in creating notches, the rarity of notched bones and other carved osseous artifacts in general, and their restriction to the middle part of the sequence at Panga ya Saidi in particular, means notching still cannot account for the quantity and distribution of miniaturized lithics in the LSA.

Scarification

Aside from the above utilitarian functions, miniaturized lithics may have had an important role in body ornamentation. Marking the skin through either scarification or tattooing was a nearly universal practice among traditional societies (Hambly 1925; Brain 1979; Gorman 2000). In Tasmania, scarification was "produced by gashes inflicted with sharp stones, into which wood ashes were rubbed, so as to allow healing only under favorable conditions, leaving permanent and elevated cicatrices" (Flower 1881, p. 11). On mainland Australia in the early 20th century stone tools were widely used for scarification. In 1903 around the Musgrave Ranges in central Australia, metal spearheads were employed alongside two types of flaked stone tools (Basedow 2008, p. 26): hafted retouched scrapers (*kuundi*), and "stone knives (*gadord* or *nyilla*) used for the various acts of mutilation that are practised…. They are merely sharp chips of flinty rock (chalcedony) of very variable shape and size…." Sharpness was a noted priority in scarification knives for the Wonkonguru living to the east in central Australia, where the unretouched edge of a pointed foliate flake (called a *yutchawunta*) was used for this and other surgical procedures (Horne and Aiston 2009, p. 102). Among the Jingili of the central Northern Territory, unretouched *djaperi* stone daggers were used to create cicatrices, with the sharp edge needed to create a clean controlled cut (Murgatroyd 1991, p. 49). After their use in such operations the handles of these knives were painted (Spencer and Gillen 1904, p. 649), perhaps to indicate that they were no longer sharp enough for further cicatrizing (Murgatroyd 1991). While *yutchawunta* and *djaperi* are not small tools, the Arunta in central Australia recognized small backed crescents as scarification knives (Horne and Aiston 2009, p. 117). Similarly, the Nakanai of western New Britain wore facial tattoos "scratched with a sharp sliver of obsidian" (Parkinson 1907, p. 96).

On South Andaman Island, cicatrizing was "effected by cutting the skin with sharp pieces of shell or glass" (Brander 1880, p. 14). "The Tribes of the South Andaman Group cut their bodies with small flakes of quartz or glass in patterns of zig-zags or straight lines running up and down the body or limb" (Portman 1899, p. 35). Elsewhere, such tools were described as being "tiny slivers of …quartz" (Cipriani 1966, p. 22), and that "the smallest flakes were obtained" (Man 1932, p. 166).

Centuries after the advent of metal in East Africa, small quartz flakes were used by the Warangi and Wanyisanzu peoples to make bodily incisions (Masao 1982), perhaps because of the greater sharpness of an unretouched siliceous stone edge in comparison to metal. Many flakes were produced using the bipolar technique, with those "found to have sufficiently clean and sharp edges to be used for the purposes of body incision" (Masao 1982, p. 265). Similarly in Namibia, the Nama and other groups were using small quartz flakes for scarification and circumcision in the 19th and early 20th centuries (Hahn 1881; Vedder 1938).

Given the above ethnographic examples where edge sharpness was prioritized and small flakes were used in several regions, even after the availability of metal, the use of LSA miniaturized flakes in scarification seems plausible. However, as scarification is permanent and only carried out on certain occasions it is unlikely to need vast quantities of

lithics, in contrast to another form of body modification: shaving.

Shaving

Due to its flexibility, hair requires the sharpest edges to cut it. In both New Guinea and Aztec society the most widespread use of obsidian, the sharpest of all materials (including steel), was in cutting the hair and beard (MacCurdy 1900; Specht 1981). In early 19th century southwestern Australia on the Swan River, von Hugel (1994, p. 51) observed that the Aborigines used a quartz or glass knife for cutting their hair and beard. In late 19th century New Britain, obsidian was the major material used for cutting tasks, prominent among which was shaving heads and beards (Powell 1883, p. 217; Parkinson 1907, p. 95). Beards and heads were shaved "by means of sharp stone or obsidian splinters" in early 20th century New Britain (Friederici 1912, p. 37). Friederici (1912, p. 37) wrote that,

> From time to time I always had to give my black boys a beer bottle; this was then artfully smashed and made into razors; Then you saw them under the shade of a tree or on the quarterdeck of the *Natuna* busily shaving each other. The hairstyles that result from partial hair removal are also achieved with these razors….

The Kaulong of western New Britain were still using "obsidian chips" alongside metal razor blades to maintain hairlines in the early 1960s, but no longer used any other stone tools (Goodale 1966, p. 25). At the same time, on the Siassi Islands to the west and the adjacent Huon Peninsula of the New Guinea mainland, obsidian was the only stone being flaked, with its functions being hair cutting, shaving, and surgical operations (Harding 1967, p. 42). In Antigua and parts of Africa bottle glass was used to create razor blades at the beginning of the 20th century (Lindblom 1943; Gorman 2000). In the late 19th century the Arusi Galla (Arsi-Oromo) of Ethiopia used obsidian flakes for shaving, with these "mere rough chips, not retouched" (Giglioi 1889). Even in the late 20th century, the Gurage of Ethiopia were making two types of tools out of obsidian rather than metal: retouched hide scrapers and unretouched flakes for shaving (Gallagher 1977).

In the Andaman Islands shaving was the principal function of knapped stone, with scarification being the only other major function (Portman 1899; Man 1932). Of particular note is the disposable use of such lithics, with both quartz and glass flakes on the Andaman Islands (Lapicque 1894, p. 367; Lehmann 1955, p. 110) and obsidian blades in Mexico (Holmes 1919, p. 323) discarded after two or three sweeps. To complete a full haircut with stone flakes thus requires many pieces. In the Andaman islands it was observed that "a woman who is shaving some-one's head may use as many as twenty flakes one after another, and to obtain twenty suitable flakes she probably makes as many as forty or even more" (Radcliffe-Brown 1932, p. 445). The glass flakes used for shaving were described as being "the size of a bean, but as thin as the blade of a penknife" (Portman 1899, p. 283). An assemblage of unretouched glass flakes collected from South Andaman after having been used for shaving averaged 18 mm in length (Gorman 2000).

Ethnographic records indicate that shaving to create hairstyles was a widespread practice across much of the world, particularly among people with afro-textured hair (Gorman 2000). In South Andaman, head shaving began within a few hours of birth, and, with the exception of a period immediately following the onset of menarche in women, continued until after death when the head of the corpse would be shaved (Radcliffe-Brown 1932). The importance of head shaving is indicated by the story of two Andaman islanders who were taken captive by a fishing junk and while on board "the boy shaved the man's head with a broken plate" (Portman 1899, p. 116). Head shaving was done frequently, with reports of every fortnight or more (Man 1883, p. 77). The following description of male and female South Andaman hairstyles reflects the high degree of maintenance required (Man 1932, pp. 77–78):

> The majority of the women every week or ten days shave their heads almost entirely, leaving only two narrow parallel lines of hair, termed *gor-*, from the crown to the nape of the neck. The *gor-* is never allowed to exceed one-eighth of an inch in length; therefore, as they have no means of clipping it, it is constantly shaven off, and a fresh *gor-* is made with the hair which has grown since the last operation. Though many of the men were and are in the habit of having their heads shaved like the women, the style of hairdressing most affected by them before our arrival left only a circular patch of hair, about six or eight inches in diameter, like a skull cap, on the top of the head. Of late, however, they have indulged in many fanciful modes, such as shaving a piece about two or three inches broad between the forehead and the nape of the neck, or making a large tonsure.

As a regular and frequent task involving multiple flakes, the maintenance of hairstyles through shaving in this way can be expected to have contributed a significant quantity of miniaturized lithics to archaeological assemblages where it was practiced. On the Andaman Islands, where shaving was the principal function of stone tools, it was noted that the "heaps of refuse that are found on the sites of old

encampments contain thousands of quartz pebbles that have been used as cores, and thousands of flakes" (Radcliffe-Brown 1932, p. 445). The persistent use of glass and fine-grained stone for shaving when metal was available shows both the effectiveness and centrality of siliceous lithics in this purpose. Notably, the continuous head hair growth that would allow for hairstyles is a relatively recent feature of human biology, estimated on the basis of a particular mutation to have arisen within the last 240 kya (Winter et al. 2001).

Pigment and Beads

Direct archaeological evidence for scarification and shaving with stone tools is rare (Carter 1998; Kononen 2012), perhaps in part because of the disposable way stone tools were used in such activities, so there was little time for microscopic residues and use-wear to accumulate. However, the Paleolithic record does readily preserve other forms of body ornamentation in the form of red pigment (ochre) and shell beads.

Ochre (typically hematite) was used by hominins over the last 500,000 years (Watts et al. 2016). While it can have utilitarian uses such as a binding agent (Lombard 2006; Wojcieszak and Wadley 2018), the selection of the brightest red pieces suggests it was primarily used as pigment (Watts 2002; Hodgskiss 2012). Ethnographies demonstrate the widespread use of red ochre as a body paint in tropical climates (e.g., Hambly 1925; Duarte 2014; Rifkin 2015). MIS 3 burials covered in red ochre from multiple continents suggest this function was also prevalent in prehistory (e.g., Bowler 1998; Jelsma 2000; Einwögerer et al. 2006), with ochre traces found on shell beads, apparently having transferred from the body, from MIS 5 (Bar-Yosef Mayer et al. 2009).

Miniaturized lithics are often found in association with ochre crayons. At Panga ya Saidi ochre crayons occur in the miniaturized part of the sequence (Fig. 3), but not the preceding MSA part (d'Errico et al. 2020). At the Sri Lankan site of Fa-Hien Lena, crayons occur alongside miniaturized quartz lithics from the beginning of occupation in early MIS 3 (48 kya) (Wedage et al. 2019; Langley et al. 2020). Ochre crayons are found with miniaturized lithics throughout the 44,000 years-long occupation sequence of Asitau Kuru on Timor island in Wallacea (Fig. 3) (Langley and O'Connor 2019; Shipton et al. 2019).

The wearing of shell beads by *Homo sapiens* is known from as early as 120 kya (MIS 5) at Skhul cave in the Levant (Vanhaeren et al. 2006), long before miniaturization; but as with ochre crayons, miniaturized lithics are typically found in association with beads. At Panga ya Saidi the earliest bead in the sequence, a perforated *Conus* shell, occurs ~ 67 kya in the same layer as the earliest miniaturized lithic assemblage (Fig. 3) (Shipton et al. 2021c). At Boomplaas cave in southern Africa, an increase in lithic miniaturization occurs alongside an increase in the production of ostrich eggshell beads (Pargeter and Faith 2020). The miniaturized lithic sequence at Fa-hien Lena is associated with *Conus* shell beads from the outset (Langley et al. 2020), and likewise, marine shell beads are found with miniaturized lithics throughout the Asitau Kuru sequence (Fig. 3) (Langley and O'Connor 2016; Langley et al. 2016a).

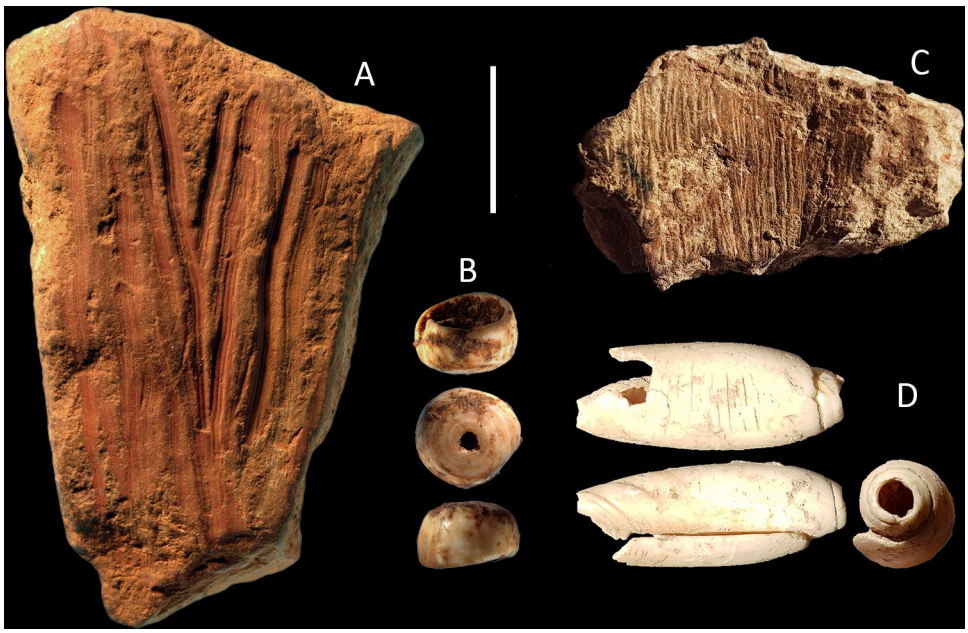

Fig. 3 Examples of crayons and beads from Panga ya Saidi and Asitau Kuru. **A** is an engraved crayon from layer 11 of Panga ya Saidi; **B** is a *Conus* shell bead from layer 16 of Panga ya Saidi; **C** is an ochre crayon from layer 2 at Asitau Kuru; **D** is an *Oliva* shell bead from layer 7 at Asitau Kuru. Scale bar is 1 cm. Adapted from d'Errico et al. (2020) and Shipton et al. (2019)

While both pigment use and bead wearing precede the emergence of miniaturized lithic assemblages, these three traits came to be associated, with body ornamentation a ubiquitous feature of behavior where there is miniaturization. This accords with the ethnographic evidence discussed in the preceding sections, that two of the likely functions of miniaturized lithics were for other forms of body ornamentation—scarification and shaving.

Supergroups

Body ornamentation can have many purposes including decoration, magic, medicine, grieving, and status display, but prominent among these are the signaling of identities and connections. Scarification was frequently used to denote group identity (Hambly 1925). Among the Worora of the Kimberley in northwestern Australia for example, cicatrizing (*burlg*) begins in early adolescence until at the age of maturity:

> almost every part of the body, except the face, hands and feet, is incised. All the adult members of the tribe have same pattern… *Gwola* is a name given in contempt to a man who has not had his complete set of *burlg* cut… the cutting serves a useful purpose in the development of the young boy and girl, by making them realize that membership of their tribe is an honorable distinction, to be won by suffering gallantly borne. (Love 2009, pp. 154–158)

In West Africa tribal affiliation was widely expressed through facial scarification (Nevadomsky and Aisien 1995; Cullivan 1998; Lovejoy 2009), with the Baule, for example, regarding it as essential to societal membership (Vogel 1988).

In the Andamans at the beginning of the 20th century each tribe had its own characteristic hairstyle (Temple 1903, p. 40). The Samburu of East Africa use hairstyles to express tribal affinity, including the application of red ochre to hair and shaved portions of the head (Nyambura et al. 2014). Ovahimba women in Namibia cover their whole bodies including hair, face, and jewelry in red ochre so that, as one woman put it, "all can see that we are real Himba women…. There are no Himba women who are not red, they do not exist" (Rifkin 2015, p. 8). Among San groups in southern Africa beaded headbands denoted group identity, as well as marking connections between individuals in different groups (Wiessner 1984). The *hxaro* system of maintaining reciprocal relationships between individuals in different San groups through gift giving principally involves the exchange of ostrich eggshell beads (Wiessner 1986, 1994; Hitchcock 2012).

The earliest form of body ornamentation seems to have been visually striking paint (Kuhn and Stiner 2007; Watts et al. 2016). A key feature of red ochre as a display symbol is that it is costly, in that sources are rare and it is often procured over long distances (Dayet et al. 2016), so it is a reliable marker (Kuhn and Stiner 2007; Kuhn 2014). Body paint was later supplemented by the use of beads, which though smaller and more subtle are more durable and standardized, so can serve as distant and specific markers of intergroup connections (Kuhn and Stiner 2007), as they do amongst the San (Wiessner 1994).

Strontium isotope analysis of ostrich eggshell beads from sites in the Lesotho highlands of southern Africa indicate spatially distant connections of approximately > 100 km were established by the end of the MSA, 33 kya (MIS 3) (Stewart et al. 2020). A multisite analysis of ostrich eggshell bead form suggests a common cultural repertoire spread between eastern and southern Africa during MIS3 which then diverged into regional traditions (Miller and Wang 2022). By the middle phases of the LSA (late MIS3 to early MIS 2), non-lithic material culture at Panga ya Saidi shares multiple parallels with both the interior of eastern Africa and southern Africa (d'Errico et al. 2020). Ostrich eggshell beads are one such shared item of material culture. Ostriches are not endemic to the coastal forest in which Panga ya Saidi occurs and there is no evidence for on-site bead manufacture, with all beads found as finished items (d'Errico et al. 2020). The beads are made on the shells of two subspecies of ostrich, and there are at least six different types which differ both in their appearance in terms of shape, dimensions, and coloring, and in their methods of manufacture (d'Errico et al. 2020) (Fig. 4). This suggests that the beads were being produced by different groups with different stylistic preferences (Jacobson 1987). Many of the different bead types occur in the same layers, for example in layer 8 (25 kya, MIS 2), where the beads mostly derived from a depression in the southwest corner of the trench and could even be from the same item. These beads represent three different manufacturing traditions (Fig. 4), so not only seem to reflect connections to the interior, but to multiple different groups in the interior.

While the ostrich eggshell bead tradition postdates the beginning of miniaturization at Panga ya Saidi, the earliest marine shell bead coincides with its onset. Miniaturization emerges immediately following the nadir in human occupation intensity in the sequence, and a possible hiatus in sediment deposition (Shipton et al. 2021c) that may represent a drought at the MIS 5–4 transition in this part of East Africa (Schüler et al. 2012). That Panga ya Saidi is in permeable limestone bedrock means water would not have been available in the immediate vicinity during a drought. A short-term crisis such as this could have prompted the initial emergence of intergroup connections to provide access

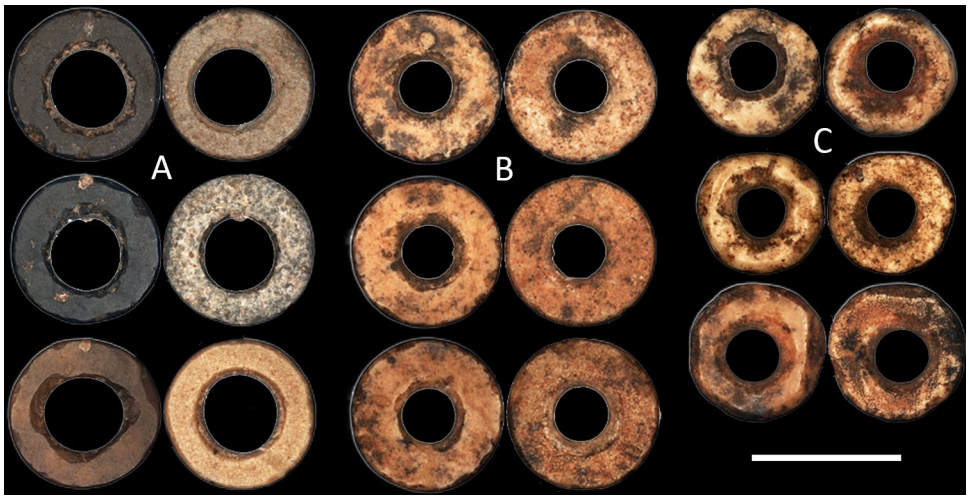

Fig. 4 Three types of ostrich eggshell beads from Panga ya Saidi layer 8. Type A are large circular beads with large subcircular perforations made by drilling from the inner to the outer surface of the eggshell. This type of bead was typically also heated to blacken it. Type B are large circular beads with small circular perforations made by drilling from both surfaces of the eggshell. Type C are small polygonal beads with small polygonal perforations made by cutting the eggshell from both surfaces. Scale bar is 1 cm. Adapted from d'Errico et al. (2020)

to resources in other territories, much as the *hxaro* bead exchange system was used to access distant water sources (Wiessner 2002). In the interior of East Africa, the MSA-LSA transition has also been suggested to reflect the emergence of macroscale groupings, based on the long-distance movement of small standardized backed crescents of obsidian (Ambrose 2002, 2010; Ambrose and Schapiro 2014). A function of unretouched miniaturized lithics may have been to create displays of group identity and connections in both an impermanent high-maintenance form through shaving, and a permanent high-risk form through scarification.

Abstraction

The above evidence indicates a wide range of possible functions for miniaturized lithics, and, given the abundance of these artifacts, those functions are not mutually exclusive. The concurrent emergence of miniaturization in East Africa alongside parallel evidence for diverse behavioral changes from bow and arrows to engraved ostrich eggshell in southern Africa (Texier et al. 2010; Lombard 2011), suggests such multimodal transformations may have a common underlying basis. One hypothesis to account for miniaturization is that it reflects an economic pressure to conserve tool-stone under conditions of high population density (Tryon et al. 2018). However, this does not account for the earliest manifestation of miniaturization at Panga ya Saidi where it occurs following the lowest occupation intensity in the sequence. Levels of reduction intensity might be regarded as a more direct measure of economic pressure on tool-stone, but these vary widely across the Panga ya Saidi sequence and do not explain the differences in artifact size between the MSA and LSA. In sequences of *Homo sapiens* occupation spanning tens of millennia from Wallacea and Australia, miniaturization is a feature of the technology from the outset (when presumably pioneer populations were relatively small), and it is maintained across wide variations in site and regional occupation records (Shipton et al. 2019; Norman et al. 2022), as well as levels of reduction intensity (Shipton et al. 2021b). It may be that the higher occupation intensities associated with miniaturized lithics at some African sites are a consequence rather than a cause of miniaturization.

Several authors have suggested a cognitive transformation to explain the co-emergence of mechanical technology and symbolic material culture at the end of MIS5 and in MIS4 in Africa (Klein 2000; Mellars 2006; Ambrose 2010; Henshilwood and Dubreuil 2011). One such hypothesis is that this transformation is underpinned by abstractive cognition (Shipton 2019). Abstraction refers to the capacity to conceive of multiple theoretical, meaning laden (valenced), or general qualities for an item, independently from its current physical state or specific properties (Coolidge and Overmann 2012; Spunt et al. 2016). It could also be described as meta-representation (Sperber 2000), that is, having extra layers of meanings, or ideas about ideas.

Attributing general theoretical qualities to vocalizations, as in symbolic language, may well have deeper ancestry than our own species (Deacon 1998; Martínez et al. 2013). Similarly, having ideas about the ideas of another individual as in theory of mind, probably predates *Homo sapiens* (at least for lower orders) (Shipton 2010; Cole 2019). However, a

more general capacity for having ideas that are independent of the physical world and can therefore be transferred across contexts, such as from social to technological and natural history, seems to have emerged around MIS4 (Mithen 1996). In this vein, the MIS4 behavioral transition has been characterized as the origin of creating collective fictions: shared meaning-laden ideas that are theoretical (Harari 2014). The following discusses whether the individual traits that characterize the miniaturized LSA from MIS4 may be united by a basis in abstraction.

The concept of an afterlife requires abstraction as it gives the personhood of an individual an independent existence from their physical life (Wynn 2008). The earliest human burials (> 90 kya) at the sites of Skhul and Qafzeh in the Levant contain grave goods (Garrod and Bate 1937; Vandermeersch 1970; Grün et al. 2005), indicating that maintained personhood of the dead was a feature of burial from the outset. These sites significantly predate the MIS4 appearance of miniaturization in the African LSA, but the earliest currently known human burial in Africa occurs at the end of MIS5 in the final MSA at Panga ya Saidi (Martinón-Torres et al. 2021), immediately preceding the onset of miniaturization. Burial in residential sites, such as in this example, is argued to be a public acknowledgment of keeping the personhood of the dead in proximity (Stiner 2017).

Compound tools involve abstraction, as the tool has an existence separate from its component parts, so the overall tool as an idea exists independently from the inserts that are integral to it. Similarly, an interdependent toolset, such as a bow and arrow, requires the conceptual combination of its distinct component parts in order to work. It is very unlikely that the first-ever bow and arrow was particularly effective, but someone must have persisted with the idea, assured by their conception of how it could function, until a useful bow was achieved. Abstract knowledge used in such constructive mental simulations has been suggested to be the key cognitive requirement for bow and arrow technology (Coolidge et al. 2016).

An additional technological signature of abstraction may be found in snares. To invent a snare requires constructive mental simulation that the contraption can work in theory before a functional snare is created, and to use it requires the idea of the tool to be spatially and temporally independent of its operator. Circumstantial evidence for snares, the systematic capture of small prey without age cohort discrimination, first appears in the archaeological record around the MIS5-4 transition in southern Africa (Wadley 2010), with similar evidence also indicating the use of snares throughout the LSA at Panga ya Saidi (Prendergast et al. in prep).

When notched sticks or bones are used as counting devices, the numbers are standing for an abstract transferable idea such as units of time or numbers of people (Coolidge and Overmann 2012). Examples of such abstract ordinal thinking are also common in the meaning of body ornamentation. Scarifications are often added in a particular sequential order to denote the attainment of different stages of life history, for example, among Nuba women of northeast Africa, with body paint having similar connotations for men (Faris 1988, pp. 32–34). In West Africa the Ga'anda biennially added scarifications from betrothal, with each new set requiring increasing bride payments; then when the markings were complete a woman was ready for marriage (Berns 1988, p. 58). Archaeologically, direct evidence for social display comes in the form of beads, with one of their key benefits being that they can be repeatedly added to, thereby showing more and stronger connections between givers and receivers (Wiessner 1982; Kuhn and Stiner 2007).

Belonging to both a proximal residential group and the theoretical entity of a broader tribe is another case of abstractive thinking. This trait seems to emerge in Africa by 33 kya (late MIS 3), but it may have earlier antecedents in bead wearing and in the use of miniaturized lithics for creating tribally distinctive shaving and scarification patterns. A generalized function for body ornamentation may be to make such intangible concepts as the tribe visible (Seeger 1975), with shaving, scarification, and painting forming a bodily script (Zahan 1975). Symbolic vocalizations can arise from intergenerational renewal of the form and meaning of sounds that were initially iconic (Karmiloff-Smith 1992; Tomasello 2008). However, this is different from the relationship between body ornamentation and social identities, as the link between these is arbitrary from the outset, and what is being denoted is often theoretical. For example, particular hairstyles are widely used to denote transitory states such as mourning or initiation. The Fante of West Africa shaped young women's hair into two horn-like projections at the final phase of initiation (Sieber and Herreman 2000, p. 55). When their husbands or husbands' brothers died, Worora women would cut off their hair and paint it black to symbolize the mythological mourning of the black-headed rock python (Love 2009, pp. 189–191). On South Andaman different patterns of body painting were used to signal a variety of transitory states including sickness, mourning, and initiation (Man 1932; Radcliffe-Brown 1932). In eastern New Britain each body painting motif applied for festivities has an individual name, significance, and ownership (Parkinson 1907). Body ornamentation and other explicit symbols may be regarded as a concretized form of abstraction in which marks are not merely decorative but also have explicitly encoded meanings (Coolidge and Overmann 2012).

A further manifestation of abstraction may be rapid innovation itself. As with snares and the bow and arrow, constructive mental simulation allows for much of the iterative design process of complex new technology to be conducted without constructing physical prototypes, thereby reducing the fitness cost of innovation. Furthermore, the flexible

employment of abstract ideas across different domains of knowledge widens the scope of innovation. The end of MIS5 and MIS4 in southern Africa is a period of high innovation (Wadley 2015), while the LSA of East Africa, beginning in MIS4, shows innovations throughout (Shipton et al. 2018). For example, backed lithics are invented in MIS4 in southern Africa (Brown et al. 2012), abandoned, and then reinvented in MIS2; while in East Africa they are invented in early MIS3, then disappear for several millennia before being reinvented in late MIS2 (Shipton et al. 2021c).

The traits discussed above are united by requiring the combination of independent ideas. The earliest manifestations of such abstraction occur in the realm of personhood at the end of MIS5, such as the burials from the Levant, or the bead styles and body paint from southern Africa (Watts 2009; Vanhaeren et al. 2013). From MIS4 there is a more generalized emergence of abstraction across a broad range of human behaviors including compound tools, mechanical devices, notation, and group connectivity, with a unifying correlate of these being lithic miniaturization.

Conclusions

Much of the foregoing has been downright speculative. However, the persistent phenomenon of LSA lithic miniaturization is concrete and in need of hypotheses to account for why there was an apparent prioritization of cutting tool sharpness over longevity from this point in our evolution. The main hypothesis offered here is that, as well as some utilitarian functions, this reflects the emergence of scarification and shaving. Were we to reject this explanation we would still need to account for the near-universal occurrence of scarification and shaving in the ethnographic present somewhere else in the archaeological record. Lithic miniaturization is a pan-African phenomenon (e.g., MacDonald 1997; Mercader and Brooks 2001; Cornelissen 2003; Villa et al. 2012; Bousman and Brink 2018), as well as being associated with early *Homo sapiens* from MIS 3 in Europe (Straus 2002; Slimak et al. 2022), the Levant (Belfer-Cohen and Goring-Morris 2002), the Indian subcontinent (Clarkson et al. 2018; Wedage et al. 2019), the Wallacean islands (Shipton et al. 2019, 2021b), and Australia (Norman et al. 2022), so it is a plausible indicator of a widespread late Paleolithic cutting tool function.

Changes in the shape of the human cranium in the Late Pleistocene may point towards a possible mechanistic explanation for the rise of abstraction. The distinctive parietal bossing of *Homo sapiens* crania evolved to accommodate an expanded cerebellum (Neubauer et al. 2018), with modern *Homo sapiens* suggested to have a particularly large cerebellum even in comparison to similarly large-brained Neanderthals (Weaver 2005). This globularity has arisen relatively recently, with the Skhul and Qafzeh early MIS 5 specimens lacking it, but *Homo sapiens* dating from MIS 3 having this shape (Neubauer et al. 2018; Weber et al. 2020). Remarkably, our cerebellum has four times the number of neurons of the neocortex (Azevedo et al. 2009), perhaps giving it the capacity to take on some of the cognitive load of abstraction. Functional studies point to the role of the cerebellum in representing and controlling mental representations, and in tasks including numerosity and social abstraction (Ito 2008; Stoodley et al. 2012; Buckner 2013; Van Overwalle et al. 2014; Vandervert 2017; Marek et al. 2018).

A late emergence of generalized abstraction may explain another puzzle of recent human evolution; despite fossil evidence for multiple dispersals of *Homo sapiens* out of Africa from MIS 8 onwards (Grün et al. 2005; Groucutt et al. 2018; Hershkovitz et al. 2018; Harvati et al. 2019), over 90% of the genetic ancestry of modern non-Africans is derived from a single late dispersal in MIS 4 or early MIS 3 (Soares et al. 2012; Pagani et al. 2015; Malaspinas et al. 2016; Mallick et al. 2016). Abstraction may have had important adaptative consequences that promoted human dispersal and gave MIS 3 *Homo sapiens* a competitive advantage over incumbent hominin populations, including those of our own species. Compound tools and interdependent technologies such as harpoons and bows and arrows would likely have facilitated faunal resource extraction, perhaps particularly important when entering new environments where edible plant species might be unfamiliar. Reliable crossing of strong ocean currents would have required the interdependent toolset of the raft and paddle. Although an early incursion into northern Australia is dated to MIS4, it is notable that *Homo sapiens* sites first appear on multiple islands on the far side of the Indonesian throughflow current only in MIS 3 (Shipton et al. 2021a), and that these sites are associated with miniaturized lithics (Shipton et al. 2021b). The social aspects of abstraction may also have been important in colonization: belonging to a larger tribal supergroup could facilitate the exploration of new territory through the knowledge and logistical support of a broad social network and the possibility to retreat to friendly country if something goes awry. Notably, our sister species the Neanderthals show low genetic diversity from either end of their range in the second half of the Late Pleistocene, suggesting they did not form such broad social networks (Lalueza-Fox et al. 2011; Skov et al. 2022).

Lithic miniaturization is a key defining trait of LSA behavior, first evident at Panga ya Saidi 67 kya, reflecting the prioritization of stone tool sharpness over longevity. Ethnographic and archaeological evidence indicates diverse functions for miniaturized lithics including in compound tools, arrow tips, scarification, and shaving, the latter requiring numerous pieces. These diverse functions may have a common basis in abstractive cognition.

Technologies reliant on abstractive cognition, such as the bow and arrow or raft and paddle, as well as abstract social structures such as tribal supergroups, could have facilitated the major MIS4–MIS3 dispersal of our species and the extinction or absorption of other members of our genus who lacked this capacity.

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Conflict of interest The author declares no conflicting or competing interest.

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