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The First Geologists?

Stone Tools and Hominin Brain Development in the East African Rift System

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The First Geologists?

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ABSTRACT

The rate of evolutionary brain growth (encephalization) in African human ancestors increased dramatically at ca. 3.5 Ma. Crude stone tools first appear in fluvial sediments in eastern Africa at about this time, as does evidence for tool-assisted butchery that left scrape marks on animal bones. Early hominins were selective in their choice of rock types for tool production, preferring rocks that, when broken, yielded planar or conchoidal fractures with sharp and durable edges. In addition to butchery, early stone tools might have been used to process roots and tubers, while abrasive stones might have been used to sharpen spears and digging sticks. Regardless of specific tool use, evolutionary pressures for the cognition and dexterity necessary for effective stone selection and stone-tool fabrication and use were relevant only in areas with rocks with appropriate mechanical properties, as with areas of geologically young volcanic rocks associated with the east African rift system. The first geologists, aware of different rock types, their mechanical properties, and their distributions within natural landscapes, were also products of a specific geologic environment.

INTRODUCTION

The Great Acceleration in human population growth and anthropogenic environmental modification in the mid-twentieth century represents the beginning of a proposed Anthropocene Epoch. This was preceded at ca. 3.5 Ma by a great acceleration in the rate of evolutionary brain growth (encephalization) in human ancestors (hominins) that coincided with initiation of the earliest archaeological evidence for fabrication and use of stone tools (McPherron et al., 2010; Harmand et al., 2015; Du et al., 2018). The association of encephalization with stone-tool fabrication and use is consistent with the concept that the benefits of stone-tool use contributed to evolutionary selective pressures for greater cognitive abilities. Increasing cognitive abilities and associated creation of increasingly sophisticated tools led eventually, and perhaps inexorably, to the Anthropocene.

Early stone-tool fabrication and use marked the beginning of a suite of behavioral and anatomical changes associated with encephalization, but the nature and timing of these changes and their relative significance for encephalization are poorly understood. Increased cognitive abilities applied toward stone-tool use appear to have led to additional behaviors and skills that conferred additional survival advantages. This article is an attempt to evaluate the origins of stone-tool use and the significance of associated changes, both as causes and consequences of early encephalization.

HOMININ BRAIN GROWTH AND TOOL USE

The late Miocene African hominin *Sahelanthropus tchadensis,* from the Lake Chad region of central Africa and dated at ca. 7 Ma, is the oldest known hominin with evidence for upright posture as indicated by the morphology of a partial femur and a digitally reconstructed fossil skull (Daver et al., 2022). Endocranial volume (inside of the skull), at 360–370 cm^3, is similar to that of chimpanzees (Zollikofer et al., 2005). Two partial skulls of the younger Pliocene hominins *Ardipithecus ramidus* and *Australopithecus anamensis* have similar brain volume (Suwa et al., 2009; Haile-Selassie et al., 2019). At ca. 3.5 Ma, the rate of brain growth accelerated dramatically from near zero to an average rate of ~4.2%/10^5 yr, reaching a modern volume of ~1350 cm^3 that is almost quadruple its early Pliocene value (Fig. 1; Du et al., 2018). Numerous skeletal features indicate that the transition to rapid encephalization occurred after adaptation to upright posture, although some of these features have been interpreted to indicate a mix of arboreal and terrestrial locomotion.

From its beginning at ca. 3.5 Ma, rapid encephalization was associated with stone-tool production and use in eastern Africa. The subtle beginnings of tool use are represented by 3.4-Ma animal bones with scrapes and cut marks interpreted as products of stone-tool butchery (McPherron et al., 2010) and by crude, 3.3-Ma stone tools that were likely used for chopping, scraping, and/or crushing animal and/or plant matter (Harmand et al., 2015). The oldest known stone tools, at Lomekwi 3 on the west side of Lake Turkana in northwestern Kenya (Fig. 2), consist of locally available basalt and alkalic basaltic rocks. Compared to more abundant and younger stone artifacts, the Lomekwi 3 cores are unusually massive and were broken with a low level of skill, perhaps by block-on-block percussion (Fig. 3A; Harmand et al., 2015).

OLDOWAN TOOLS

Oldowan tools are simple stone tools produced at ca. 1.6–2.6 Ma by impact removal of rock chips from a "core" to

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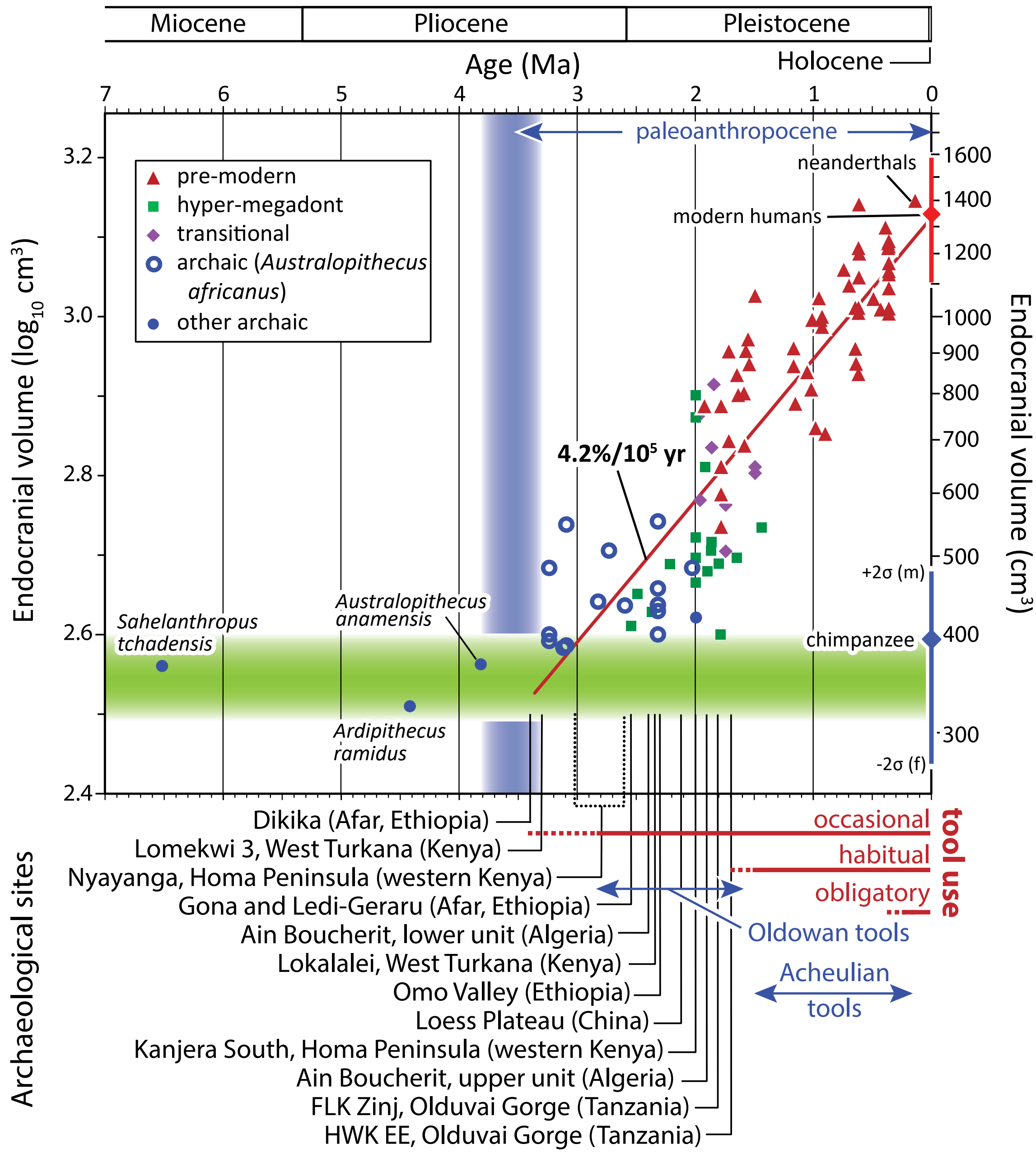

Figure 1. Endocranial volume vs. fossil age for hominins over 0–7 Ma and the chronology of early hominin archaeological sites. Endocranial volume data from compilation of Du et al. (2018), with additional points for the older hominins *S. tchadensis* (Zollikofer et al., 2005), *A. ramidus* (Suwa et al., 2009), and *A. anamensis* (Haile-Selassie et al., 2019). Least-squares linear regression of data points <3.5 Ma reveals an average volume increase of 4.2%/10^5 yr (~0.001% per generation; coefficient of determination $r^2 = 0.78$). Green indicates background hominin endocranial volume before ca. 3.5 Ma acceleration and is projected forward to the present, where it encompasses the average brain volume of modern chimpanzees. Note that various data points do not necessarily represent human ancestors and could be now-extinct branches from the human ancestral lineage (e.g., Du et al., 2018; Diniz-Filho et al., 2019). Estimated times of occasional, habitual, and obligatory stone-tool use are from Shea (2017a).

produce sharp but generally irregular edges. These tools are not as sophisticated as younger Acheulian stone tools produced, for example, by coarse knapping to yield an approximately shaped tool followed by fine chip removal to produce straight, or more evenly curved, sharp edges. (Attaching sharpened stones to wood to make axes or stone-tipped spears occurred much later [<300 ka].) Oldowan tools appear to have been made by hitting a stone held in one hand with a stone held in the other (pebble-core reduction), hitting or throwing a stone at another stone or stone surface (anvil percussion), or placing the target stone on a stone surface and hitting the target stone with another stone held in the other hand (bipolar-core reduction; e.g., Shea, 2017b). The rock chips themselves may have been desired products.

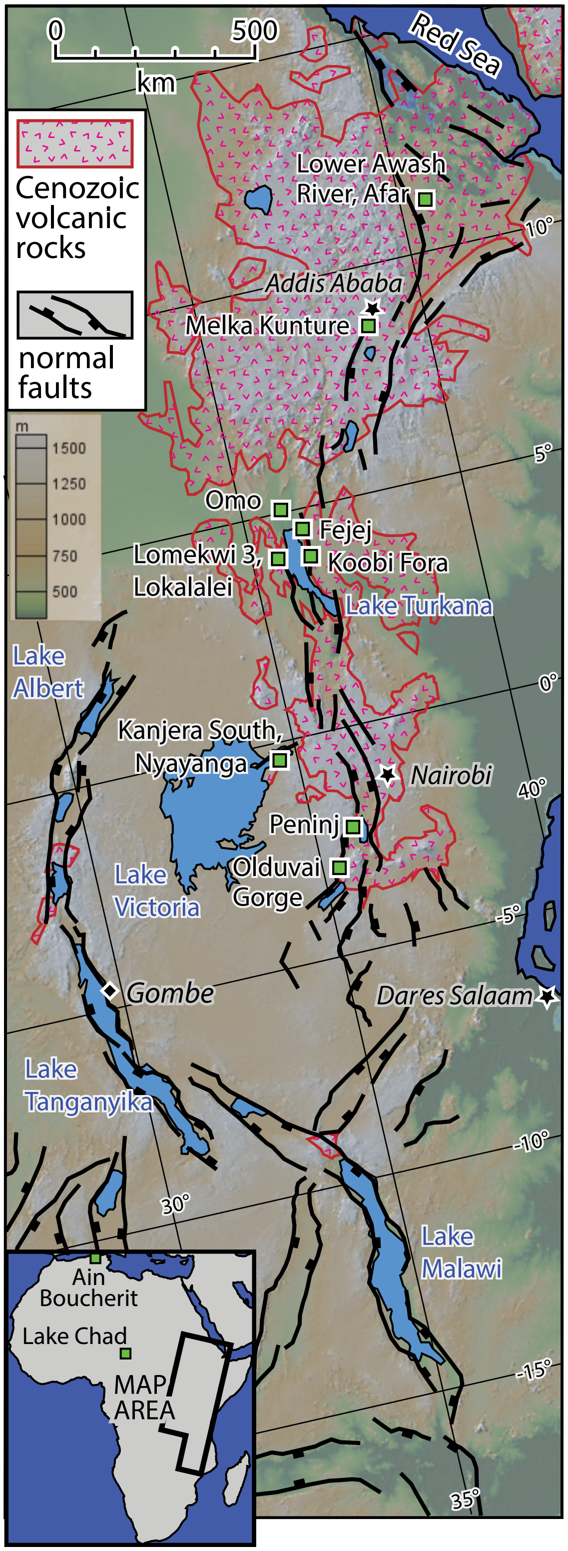

Figure 2. Relief map of the east African rift system, with rectangular symbols on the downthrown side of normal faults. Also shown are the distribution of volcanic rocks associated with the rift system and areas where significant numbers of hominin-related stone tools and/or bones have been recovered (green squares). These areas include all 22 stone-tool sites included in the compilation of stone-tool dimensions by Braun et al. (2019).

Tools made by these methods are not generally distinctive of tool-making cultures or geographic areas and are simple enough that cultural transmission might not have been necessary, leading to the inference of occasional rather than habitual fabrication (Fig. 1; Shea, 2017a).

A compilation of measurements of rocks interpreted as cores (targets of tool fabrication) by hominins at 21 eastern African archaeological sites, all dated to between 1.4 and 2.6 Ma, includes the average of the maximum dimension of the cores from each site (Braun et al., 2019). The average of the averages from all 21 sites, 6.5 ± 3.7 cm (2σ) (equivalent to 2.5 ± 1.5 in.), indicates that these cores are generally small, consistent perhaps with the small size and less developed thumbs of early hominins (Grabowski et al., 2015; Karakostis et al., 2021). These small tools are inferred to have been used for butchery because cut and scrape marks on associated animal bones have been found at some of the sites (e.g., de Heinzelin et al., 1999, *Bouri, Afar, Ethiopia, 2.5 Ma*; Domínguez-Rodrigo et al., 2005, *Gona, Afar, Ethiopia, 2.1–2.6 Ma*; Ferraro et al., 2013, *Kanjera South, Kenya, ca. 2.0 Ma*). Stone tools from many of these sites include subangular to subrounded pebbles and cobbles that are partially knapped (Figs. 3A–3B) so that a hominin could hold at least some of the smoother side or end of the tool while chopping, sawing, or scraping with the sharp edge of the other side or end ("pebble tools"; e.g., Leakey, 1971; Stout et al., 2010; Harmand et al., 2015; Shea, 2017b). Some clasts may have been selected for their planar surfaces that would provide natural targets for percussive removal of chips at the edges (Goldman-Neuman and Hovers, 2012).

Regardless of the general simplicity of Oldowan stone tools, some tools were crafted with significant skill. Reassembly of stone tools and chipped debris at the 2.34 Ma Lokalalei site west of Lake Turkana in western Kenya indicates skill and consistency in exploiting the edges and faces of cores during tool fabrication (Roche et al., 1999). Reassembly and analysis of artifacts from three of the oldest known Oldowan tool sites (ca. 2.6 Ma) at Gona in the Afar region of eastern Ethiopia indicates that cores "were efficiently reduced through the production of large, invasive flakes, using a range of strategies comparable to that seen in later Oldowan times" (Stout et al., 2010, 488). Two-handed pebble-core reduction with good manual dexterity was inferred, with the suggestion of cultural transmission of knapping technique that influenced core-reduction strategies (Stout et al., 2010).

ROCK-TYPE SELECTIVITY

Production of stone tools requires selection of rock types with appropriate mechanical properties, as most rocks would not make good cutting or scraping tools and some are difficult to break. Stone tools were likely intended for some purpose that the stone knapper had in mind, thus requiring forethought, although the specificity of forethought might have been only of a generally sharp object with multiple potential uses.

A variety of hominin preferences can be discerned from stone artifact assemblages from different geologic environments. An early example of rock selectivity is apparent for 2.5–2.6 Ma stone tools from sites in Gona, Afar, in which the

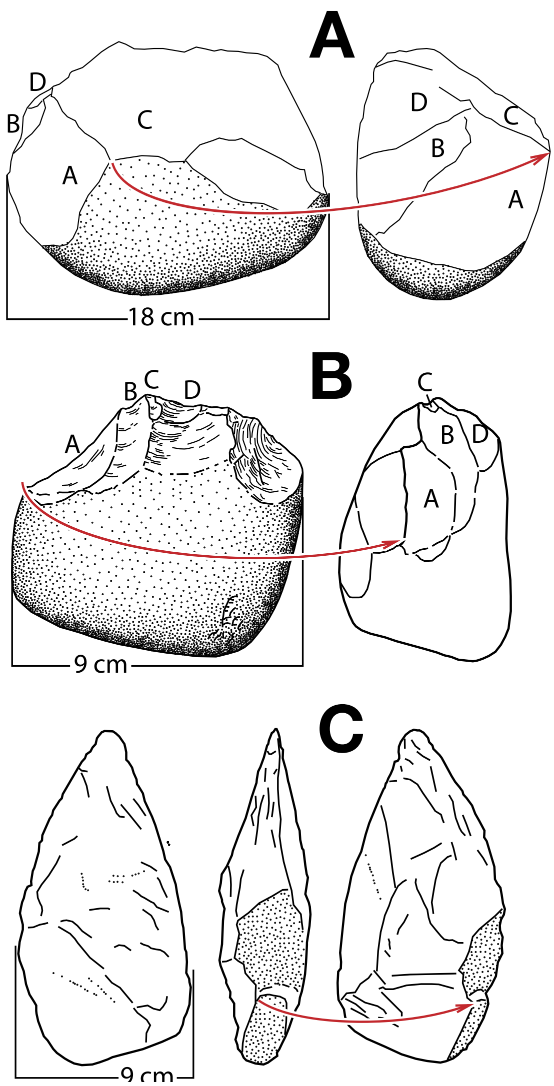

Figure 3. Examples of stone-tool artifacts. Red arrows and lettered faces show correlation between features with different view direction. (A) Lomekwian (3.3 Ma) core from the west of Lake Turkana, Kenya (simplified from Harmand et al., 2015). (B) Oldowan core (1.7 Ma) from Olduvai Gorge, Tanzania (redrawn from Leakey, 1971). (C) Middle to late Pleistocene Acheulian core from Santa Ana Cave, Spain (simplified from García-Vadillo et al., 2022).

stone tools were derived from local conglomerate or streambed gravel containing a variety of clast types. Hominins preferred aphanitic and vitreous volcanic rocks and avoided basalt (Stout et al., 2005). At another archaeological site near the lower Awash River, ca. 2.6 Ma hominins preferred rhyolite, dacite, and cryptocrystalline silica and avoided basalt (Braun et al., 2019). Durability of stone tools rather than fracture predictability appears to have influenced rock selection at Kanjera South in western Kenya (Braun et al., 2009). At Olduvai Gorge, late Oldowan and early Acheulian artifact assemblages (ca. 1.7–1.4 Ma) include large fractions made of quartzite, which was apparently preferred because angular fragments from nearby bedrock outcrops presented attractive faces and angles for flake removal, unlike the generally rounded shapes characteristic of volcanic rocks forming streambed pebbles and cobbles (McHenry and de la Torre, 2018).

TOOL USE

The uses of Oldowan tools for purposes other than butchery are not apparent from the tools themselves, but perhaps can be discerned from inventories of vertebrate bones from areas of hominin butchery. At Kanjera South in western Kenya (Fig. 2), three excavations of ca. 2.0 Ma fluvial and lacustrine strata near the shore of Lake Victoria yielded several thousand bones, bone fragments, and lithic artifacts (Ferraro et al., 2013). An inventory of the bones indicates that hominins butchered small herbivores generally as whole or nearly whole carcasses, whereas medium-sized herbivore bones are disproportionately overrepresented by skulls and long limb bones. This was interpreted to indicate that small herbivores were hunted and whole carcasses brought to sites of butchery, while medium-sized herbivores were scavenged for parts that contain nutritious marrow and brain. Demographic profiles of bovid bones at the 1.8 Ma FLK Zinj archaeological site at Olduvai Gorge, Tanzania (Fig. 2), approximate natural herd demographics rather than the greater abundance of the old and young that characterize lion kills and scavenged remains (Bunn and Gurtov, 2014). Ambush hunting, most likely with wooden spears sharpened with abrasive stones, was inferred for these Olduvai bones.

Hunting small- to medium-size mammals with wooden spears seems likely in eastern Africa by 2 Ma, regardless of the lack of direct evidence for spear fabrication and use. Evidence of hominin wood use is indirect or inferential as wood does not survive burial under generally warm, oxidizing soil conditions and so is absent in fluvial, paleosol, and subaerially exposed lake-margin strata that contain African hominin fossil and bone matter. Wooden spears are preserved in 300 ka anoxic lake sediments deposited under temperate to arctic conditions in northern Europe (Schoch et al., 2015), but similar preservation is unknown at African hominin fossil sites. Important points here are that ambush hunting with wooden spears would have led to more consistent meat-rich diets and, with sufficient hunting success, habitual rather than occasional fabrication and use of stone tools for carcass butchery.

ENVIRONMENTAL CONSEQUENCES

The appearance in eastern Africa of hominins armed with wooden spears and butchery tools, whenever it occurred, might be expected to have had ecological consequences. Gradual drying and the spread of C_4 grasses since ca. 4 Ma in eastern Africa (Cerling et al., 2011) was associated with declining megaherbivore diversity (Faith et al., 2018; Bibi and Cantalapiedra, 2023). These changes began, however, before the archaeological appearance of the oldest known stone tools at 3.3 Ma and well before evidence of hominin hunting of small herbivores at Kanjera South at ca. 2.0 Ma (Ferarro et al., 2013) and larger bovids at the 1.8 Ma FLK Zinj archaeological site at Olduvai Gorge (Bunn and Gurtov, 2014).

The fossil record of carnivores, however, is different than that of herbivores. Statistical analysis of bone and tooth remains from eastern Africa indicates that a major reduction in the diversity of large carnivores (>21.5 kg) began at ca. 2.0 Ma (Werdelin and Lewis, 2013). Another analysis determined that extinction rates of large carnivores began to increase at ca. 4 Ma and occurred at increasing rates up to the present (Faurby et al., 2020). Smaller carnivores, however, did not experience increased extinction rates during this time interval. Early extinction of large carnivores was attributed to loss of carcasses due to direct confrontation with hominins, potentially wielding spears (kleptoparasitism), and to hominin scavenging of undefended carcasses (Faurby et al., 2020). The increasing rate of extinction over time was attributed to progressive reduction of available prey because of increasingly effective hunting and scavenging by hominins.

A NEW DIET AND A NEW BODY

A variety of anatomical and behavioral changes accompanied encephalization. The size of hominin teeth began shrinking at ca. 2 Ma, roughly at the transition from *Australopithecus* to *Homo*. Using stone tools to process animal and plant matter into smaller fragments, tenderize meat, and remove animal tissues that are mechanically resistant to chewing could all contribute to evolution of smaller teeth and chewing muscles (Zink and Lieberman, 2016). Dental reduction has been linked to cooking, which softens food, destroys pathogens and toxins, and increases nutritional value (Gowlett and Wrangham, 2013). Evolution toward a less flared rib cage indicates less space for a smaller gut, consistent with digestion of cooked rather than raw foods (Andrews and Johnson, 2019). Combined with encephalization, dental reduction changed skull shape, leading eventually to a short mouth and greater capacity to shape sounds with the tip of the tongue (Lieberman, 2011), which likely facilitated language development. Changes in the hominin body that reflect a new and changing lifestyle include a longer and stronger thumb more capable of tool fabrication and use (Karakostis et al., 2021) and greater adaptation to walking and running.

DISPERSAL

Regardless of crude fabrication skills and the possibility of only occasional tool use, early stone-tool–using hominins dispersed out of tropical and subtropical Africa into temperate environments. Stone tools at Ain Boucherit near the town of Beni Fouda in northeastern Algeria, dated at ca. 2.4 Ma and located less than 100 km from the Mediterranean Sea, are ~4500 km away from eastern African hominin fossil sites (Fig. 2; Sahnouni et al., 2018). By 2.12 Ma, hominins had reached the Loess Plateau near Xi'an in central China (Zhu et al., 2018). Hominins at this time had developed the capacity to live in and disperse through diverse environments that were increasingly temperate at more northern latitudes. Use of stone tools for butchery, wooden spears for hunting and defense, sharpened sticks for digging for roots and tubers, and fire for warmth and cooking would have enabled dispersal and survival in diverse environments, but it is uncertain if any or all of these factors were particularly relevant to long-distance dispersals.

ENCEPHALIZATION WITHOUT TOOLS?

The crude nature of Oldowan tools, and the minuscule improvement in fabrication in the first ~1.5 m.y. of tool use, allows for the possibility that early encephalization was only marginally related to tool fabrication and use. Another likely cause of early hominin encephalization is an increasingly complex social environment with larger social-group populations, as indicated by positive correlations between brain size and social group size in primates (Dunbar, 2009). In other words, it takes a lot of brain power to form and maintain long-term social bonds that generally provide mutual benefits to all parties. In this context, evolutionary development of the extensive and uniquely complex kinship relations of human societies (Chapais, 2017) provided survival benefits and selective pressures that contributed to encephalization. More recent (post-Oldowan) and more sophisticated stone-tool use might have contributed more effectively to selective pressures for greater cognition and brain growth.

THE FIRST GEOLOGISTS?

The east African rift system is a divergent plate boundary that is gradually accommodating tectonic breakup of eastern Africa and its separation from the rest of the continent (e.g., Martin, 2023). Volcanic activity associated with rifting produced generally basaltic lava flows and alkalic volcanic and shallow intrusive rocks, and locally produced volcanic rocks with a wide range of silica content, as is characteristic of continental rifts. Where these volcanic rocks were nonvesicular and fresh (unaltered by weathering, diagenesis, or hydrothermal processes), and hard but not too tough, they were commonly the dominant material selected by hominins for tool fabrication. Toughness is a mechanical property that can make a rock difficult to break, even with a steel rock hammer and a strong human arm. In contrast, glassy rocks such as obsidian are not very tough but yield sharp edges when broken and are hard enough to sustain a sharp edge during light to moderate use. Other types of volcanic rock, quartzite, quartz (probably vein quartz), and amorphous silica such as chert have also been used, as they are typically hard and can yield sharp edges upon impact, but are not so tough as to greatly inhibit breakage by stone-wielding hominins.

If earliest hominin use of sharp-edged stone tools resulted from use of chipped debris generated when breaking bones or nuts, then areas underlain by suitable rock units would be necessary to foster the behavioral transition from breaking with stones to cutting or scraping with broken stones. The east African rift system south of Ethiopia consists of western and eastern branches, with abundant volcanic rocks associated only with the eastern branch (Fig. 2). Sediment accumulation and erosional incision occurred along both branches, but major early hominin sites are located almost entirely within or near the eastern branch. This spatial relationship suggests that early hominin tool use was associated specifically with areas of geologically young volcanic rocks. Thus, even if it is a stretch to think of tool-fabricating, small-brain hominins as geologists, such a hominin appears to have been a product of a specific geologic environment.

There are other reasons why hominin fossils and tools from the western branch of the east African rift system might be largely unknown, including more rainfall and vegetation that would conceal fossil-bearing strata, and more adverse political and societal environments for archaeological fieldwork. The western branch is also characterized by deep grabens with abundant lakes, perhaps concealing evidence of hominin tool use, while rift shoulders could have been sites of persistent erosion rather than erosion with occasional sediment accumulation and preservation. This would contrast with the eastern branch, where volcanic activity was associated with more complex and varied structural and topographic changes that led in many areas to exhumation of Pliocene and Pleistocene, fossil- and tool-bearing strata (e.g., Quade et al., 2004). The fact remains, however, that Lomekwi 3 and most Oldowan stone tools were derived from volcanic and shallow intrusive rocks in an environment of abundant and geologically young volcanic rocks associated with the eastern rift.

CONCLUSION

Hominin encephalization began at about the same time as stone-tool production and carcass butchery with sharp stone tools. This is consistent with the concept that early encephalization was triggered by the survival benefits of making and using stone tools. The advantages of stone-tool–assisted butchery, however, seem inadequate as the primary driver of early encephalization. A variety of other changes were associated with encephalization, but the relative significance and timing of these changes in producing evolutionary selective pressures for greater cognitive abilities and fine motor skills are poorly known. These changes include (1) use of stone-sharpened wooden spears for hunting and defense; (2) use of stone-sharpened sticks to dig for roots and tubers; (3) use of fire for cooking; (4) development of a stronger and more dexterous thumb; (5) development of language; and (6) development of increasingly complex social relationships with increasing social-group size.

Regardless of these uncertainties, stone tools appear to have been foundational in triggering 3.5 m.y. of rapid evolutionary brain growth. I suggest that sharp rock fragments produced inadvertently by bone and/or nut cracking at sites located on hard and brittle volcanic rocks within the east African rift system provided a setting where hominins learned to use the sharp edges of broken rocks for butchery and then gradually transitioned to deliberate fabrication of stone tools. Effective tool production was then based partially on increasing recognition of the variable mechanical properties of rocks relevant to stone-tool fabrication and knowledge of the color, texture, and distribution of useful rock types. Increasingly complex communication among hominins would have led to expressions for relevant rock properties and distributions, eventually leading to exchanges of knowledge crudely resembling discussions among geologists.

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