Age of the oldest *Homo sapiens* from eastern Africa

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Abstract

Efforts to date the oldest modern human fossils in East Africa, from Omo-Kibish and Herto in Ethiopia, have drawn on a variety of chronometric evidence, including 40Ar/39Ar ages of stratigraphically-associated tuffs. The generally-accepted ages for these fossils are ca. 196 thousand years (ka) for the Kibish Omo I and ca. 160-155 ka for the Herto hominins. However, stratigraphic relationships and tephra correlations that underpin these estimates have been challenged. Here, we report new geochemical analyses that link the Kamoya Hominin Site (KHS) Tuff, which conclusively overlies the Kibish Formation member containing Omo I, with a major explosive eruption of Shala volcano in the Main Ethiopian Rift. By dating the proximal deposits of this eruption, we obtain a new minimum age for the Omo fossils of 212±16 ka. Contrary to previous arguments, we also show that the KHS Tuff does not correlate with another widespread tephra layer, the Wadaido Vitric Tuff (WAVT), and therefore cannot anchor a minimum age for the Herto fossils. Shifting the age of the oldest known Homo sapiens fossils in eastern Africa to before ~200 ka is consistent with several independent lines of evidence for greater antiquity to the modern human lineage.

Main Text

Only eight sites in Africa have yielded possible early anatomically modern *H. sapiens* fossils from the African Late Middle Pleistocene (350–130 ka)[10]. Most of these have significant age uncertainty or debatable *H. sapiens* apomorphy[10]. A principal method for constraining the fossil ages is the use of single-crystal $^{40}Ar/^{39}Ar$ isotope dating applied to stratigraphically-associated volcanic ash (tephra) beds[11–13]. Some tephra deposits consist largely of glass and lack suitable crystals for dating. In this case, geochemical fingerprinting can be used to match a tephra layer to more readily dated proximal deposit with larger and more abundant phenocrysts. The most widely accepted fossils interpreted as possessing unequivocal modern cranial apomorphies (i.e. a tall cranial vault and a chin) and classified as *H. sapiens* are two Ethiopian fossils[10,14,15], namely the Omo I[1] and Herto specimens[4]. Accordingly, the evidence that constrains their ages assumes particular importance and is a topic of considerable geochronological controversy[3,6,7].

The Omo I remains were discovered in the late 1960s in the Lower Omo valley of southern Ethiopia[1,14], at the surface of a siltstone at the top of Member I of the Kibish Formation (Figures 1a and 1b). Omo I was dated to 196±8 ka (2σ)[3,6,17] based on $^{40}Ar/^{39}Ar$ ages obtained for alkali feldspar phenocrysts from the three youngest pumice clasts sampled from an heterogeneous tuffaceous deposit correlated with the Nakaa'kire Tuff[3], reported to lie 'near, but probably slightly below', the fossils[3] (Figure 1b). Recalculated using a more widely adopted age for the irradiation monitor used (sanidine from the Fish Canyon Tuff of Colorado)[17], the Nakaa'kire Tuff age shifts marginally to 197±8 ka . Owing to the uncertain stratigraphic relationship between this tuff and the hominin fossils[2], much attention has been focused on dating the KHS Tuff, a widespread >2-m-thick fallout deposit of fine ash at the base of Member II of the Kibish Formation (Figure 1b). The KHS tuff overlies Member I where Omo I was retrieved, and is demonstrably younger than the fossils[3,8]. Although the Nakaa'kire Tuff was identified in several sections below the KHS Tuff, the latter was not found in the same section from which the pumice clasts correlated to the Nakaa'kire Tuff were sampled and dated. The dated pumice clasts share the same major element composition as recorded in other Nakaa'kire Tuff outcrops[3]. The fine grain size of the KHS Tuff has precluded direct $^{40}Ar/^{39}Ar$ dating, and no correlation to a source volcano, or proximal pyroclastic unit, has previously been made. However, drawing on published major element glass compositions, it has been correlated both with tephra TA-55[18,19] from the Konso formation and the directly $^{40}Ar/^{39}Ar$ dated 191±4 ka Unit D[20] (recalculated age) of the Gademotta formation[6] (Figure 1b). Relating the sediment flux in the Kibish basin with high lake levels that correspond to Mediterranean sapropel deposition[21], a slightly earlier date for the KHS of ca. 172 ka has also been proposed[6]. Either of these dates (191 or 172 ka) would be consistent with the age of 197±8 ka for Omo I, which lie stratigraphically below the KHS.

The Herto *H. sapiens* fossils were recovered in the late 1990s in the Middle Awash (Afar Region, Figure 1a)[4,5]. They were preserved in a sandstone within the Upper Herto Member (UHM) of the Bouri Formation (Figure 1b). This sandstone is capped by the Waidedo Vitric Tuff (WAVT, Figure 1b), which is widespread in western Afar, and has also been identified at Gona[22], 50 km north of Herto. Direct dating of the WAVT has remained inconclusive due to crystal contamination but dating of pumice and obsidian clasts in the fossiliferous sandstone yielded a maximum age of ca. 160 ka (ref. [5]). The WAVT was identified as a distal correlative of tephra TA-55 (Figure 1b), based on major and trace element analysis of purified bulk separates[5,23]. In Konso, Unit TA-55 lies below the ca. 155±14 ka Silver Tuff[5] (SVT, recalculated age, Figure 1b), suggesting a date for the Herto fossils of ca. 160–156 ka (ref. [4]). This finding was challenged, however, in a study[6] that attempted to correlate the Kibish KHS with Konso TA-55, and therefore with the Herto WAVT (Figure 1b). This argument suggested an age of ca. 172 ka for the WAVT, contradicting the established Herto stratigraphy. The Herto research group[7] subsequently corroborated their original stratigraphy, with the WAVT above the Herto fossils, thus challenging the ca. 172 ka age for the KHS. They concluded that the ca. 172 ka KHS[6], Konso unit TA-55[5], ca. 191 ka Gademotta Unit D[20] and WAVT[5] could all represent a single tephrostratigraphic marker lying above the Omo-Kibish and Herto *H. sapiens* fossils[7] (Figure 1b). Given the lingering uncertainties of the stratigraphic relationship of the Nakaa'kire Tuff to Omo I, the age of the KHS tuff becomes critical to the chronostratigraphy of these sites.

We have re-sampled the KHS tuff and other pertinent ash deposits at Kibish, Konso and Gademotta to assess the geochemical correlations from which the ages of the oldest modern human fossils are inferred. While revisiting the sampling locality of the KHS tuff (KS type section)[8] at Kibish, we identified a previously unreported tephra layer in Member II (Figure 1c) in an outcrop ~ 100 m from the KS type section. Unit ETH18-8 is a ~15 cm thick, very well-sorted crystal-rich fine sand grey tephra that occurs 40 cm above the KHS tuff (Figure 1c). This deposit is ubiquitous in a radius of one kilometre around the KHS section.

Our dataset also includes samples from ignimbrite deposit Qi2 of Shala volcano[24], located in the central Main Ethiopian Rift (Figure 2a), which consist of a >20 m-thick unwelded ignimbrite[24] (Figures 2b and 2c), exposed southwest of lake Shala in Labusuka village, at the centre of the MER, 350 km northeast of Omo-Kibish (Figure 2a). We also analysed glass from a welded ignimbrite (COI2E) attributed to the caldera formation of Corbetti, dated 177±8 ka (ref. [25]). One of the challenges of geochemical correlations between proximal and distal tephra deposits in the region is the compositional similarity between pyroclastic products not only of the same volcano but of different volcanoes in the Main Ethiopian Rift (MER)[26]. Accordingly, correlations are ideally based on a detailed suite of major, minor and trace element single-grain glass shard or pumice glass analyses.

The KHS glass shards are homogeneous pantelleritic rhyolite in composition (77.0±0.3 wt% SiO_2, 9.7±0.1 wt% Al_2O_3, 5.0±0.1 wt% FeO*, and 7.1±0.4 wt% Na_2O+K_2O, Supplementary Table 1). Incompatible oxide abundances, including FeO, CaO, Al_2O_3 and TiO_2 (Figure 3, Supplementary Table 1), correspond closely with those of glasses from the proximal products of the Qi2 eruption of Shala volcano (samples ETH17-14A1, B1, B5 and C, Figures 2b, 2c and 3, Supplementary Table 1). These correlations are corroborated by comparing incompatible trace element ratios for Qi2 and KHS glasses (Figure 3).

The COI2E glass from the 177±8 ka[25] Corbetti ignimbrite has a pantelleritic rhyolite composition (74.3±0.2 wt% SiO_2, 9.1±0.1 wt% Al_2O_3, 5.6±0.2 wt% FeO*, 10.1±0.2 wt% Na_2O+K_2O, Figure 3, Supplementary Table 1), with incompatible oxides and trace abundances similar to those of Kibish unit ETH18-8 and Konso TA-56 (Figure 3, Supplementary Table 1), indicating both tephra units originated from the 177±8 ka (ref. [25]) Corbetti eruption.

We used the $^{40}Ar/^{39}Ar$ dating method to analyse 113 individual sanidine crystals extracted from pumice samples ETH17-14A1 (base, 68 crystals) and ETH17-14C (top, 45 crystals) collected from the Qi2 deposits (Figure 2). The resulting data were filtered to exclude grains with low gas yields, at or below blank level, and xenocrysts with ages significantly older than the mean of the dataset (six grains with ages exceeding 1 million years). The distributions of ages from each sample were indistinguishable at 2σ uncertainty (Figure 2d). Combining analyses from both pumice samples yields a weighted mean of 212±16 ka (2σ), which represents a robust estimate of the age of Shala's Qi2 eruption yet available (Figure 2d, Supplementary Table S2).

An age of 212±16 ka for KHS is consistent with the 177±8 ka age we have associated with the overlying ETH18-8 tephra in Member II of the Kibish Formation (Figure 1b). The identification of the 212±16 ka Qi2 eruption of Shala as the source of the KHS tuff thus provides a new stratigraphically-robust minimum age for the Omo I *H. Sapiens*.

Further, our glass compositional data, source-correlation and age estimate for KHS allow us to re-assess identification of this tuff in the Kibish Formation and at other archaeological sites in Ethiopia. New lithological examination of the pedogenically-altered TA-55 unit at Konso (Figure S1) in grain size fractions of >125 μm, >80 μm and >25 μm, after density separation, failed to identify glass shards in the deposit previously correlated with the WAVT at Herto. This precluded evaluation of the reported correlation with the KHS tuff[6]. However, with the underlying unit TA-56 now correlated to Kibish unit ETH18-8 and to the source, the 177±8 ka Corbetti ignimbrite (Figure 3), we can affirm that TA-55 is younger than 177±8 ka and cannot be correlated with the KHS.

While the 191±4 ka Unit D of Gademotta appears geochemically close to KHS in major element content, neither major nor trace element abundances overlap (Figure 3), precluding a match. Unit D also differs from TA-56 in all incompatible elements except TiO_2; however TiO_2 abundances of ~3.5 wt% are very typical of the products of the major eruptions of the central MER[26].

The correlation of the Herto WAVT to Konso Unit TA-55[5], ~800 km south of Herto, led earlier investigators to accept the 155±14 ka age of SVT at Konso as the *terminus ante quem* of the Herto fossils. This correlation has been debated[27], but later reinforced by additional geochemical data[23]. However, this correlation was based on major and some trace element compositions of purified bulk samples, rather than grain-discrete single-point glass analyses as used in this study[7]. As we have noted, glass compositions of Middle Pleistocene pyroclastic rocks of the MER are remarkably similar[26], limiting the reliability of attributions based on major element abundances alone. We were unable to find preserved glass in our TA-55 sample but our results undermine the tephrostratigraphic correlations proposed between Kibish, Gademotta and the Konso formations[6] and bracket the age of the Konso TA-55 tuff between 177±8 ka (TA-56) and 155±14 ka (SVT). Considering its correlation with the WAVT at Herto, this is consistent with the underlying ~160 ka Herto fossiliferous sandstone[5], and confirms that the Herto *H. sapiens* are significantly younger than Omo I at Kibish.

Our new age constraints are congruent with most models on the evolution of modern humans which estimate the origin of H. sapiens and its divergence from archaic humans at the end of the Middle Pleistocene at ~350-200 ka (ref. [9,15,28]). The challenge remains to obtain a robust maximum age for Omo I. Our revised tephrostratigraphy demonstrates that the Herto specimens postdate the Omo I skeleton from Omo-Kibish, and that they do not lie beneath the same tephra horizon as the Kibish fossils, as has been previously inferred[7]. Further geochemical data are needed to clarify the relationship between WAVT and other MER tephra, and may ultimately identify the WAVT source, promising a more reliable minimum age for the Herto fossils. More generally, continued efforts to develop the tephrochronological framework for eastern Africa will help in addressing a range of interrelated volcanological, palaeoenvironmental and palaeoanthropological questions.

Declarations

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Authors contribution

C.O., C.V., C.L., A.A. and W.H. designed the study. C.V. and C.L. designed and conducted field and lab work, acquired, analysed and interpreted stratigraphic and geochemical data. A.A., G.Y., A.Z.T. and A.D. designed fieldwork, acquired and interpreted stratigraphic data in the field. D.N.B. analysed and interpreted radiometric data. E.T. analysed samples for trace elements. A.M. contributed to the palaeoanthropological discussion of the manuscript. All authors substantively revised the manuscript and approved the submitted version.

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Figures

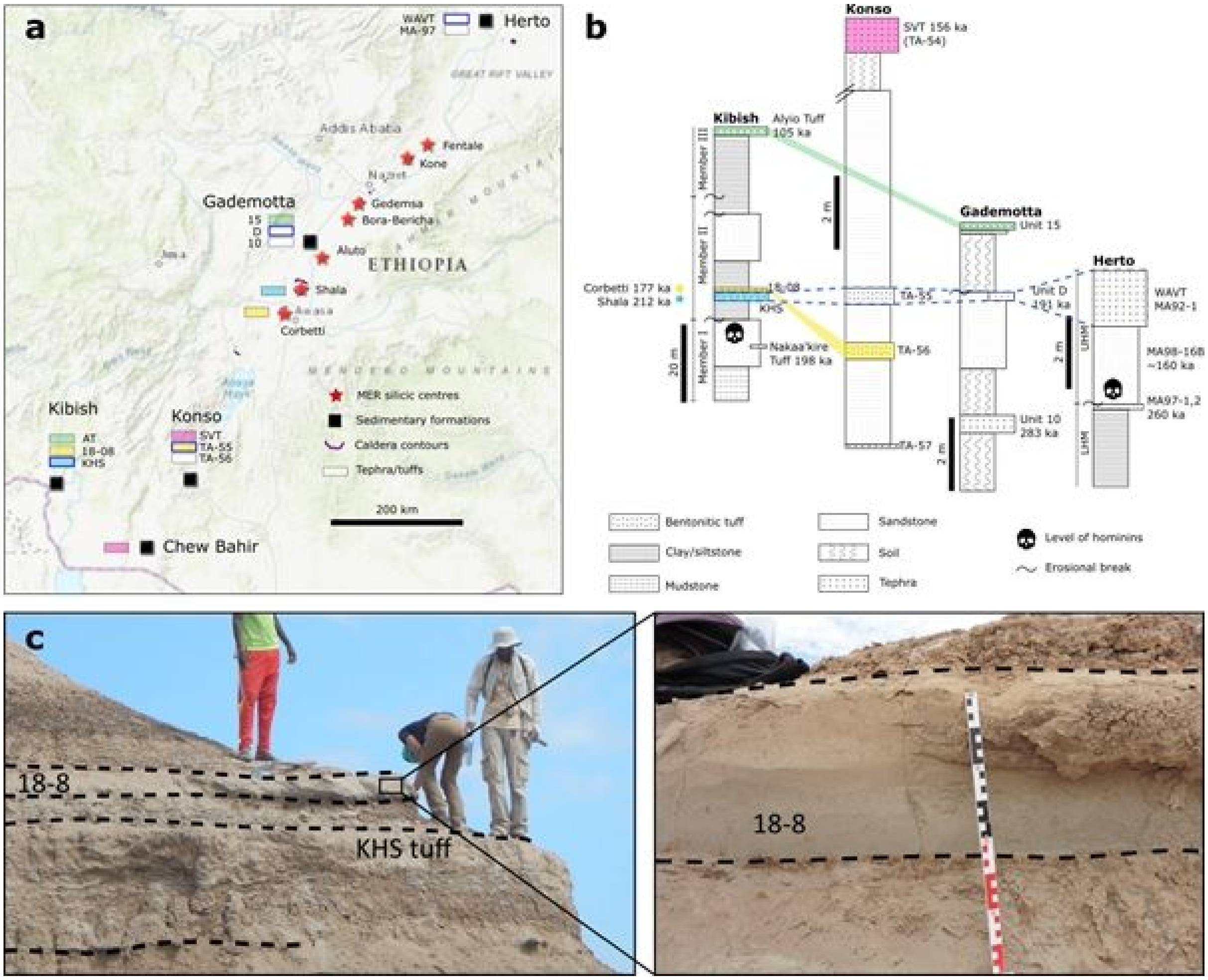

Figure 1

Late Middle Pleistocene tephrostratigraphy of the Main Ethiopia Rift. a Map of the Main Ethiopian Rift (MER) showing silicic volcanoes and the Late Middle Pleistocene sedimentary formations with tuff/tephra units discussed here. b Synthetic stratigraphic logs of the Late Middle Pleistocene formations showing previously suggested correlations6,7 for the Kibish KHS tuff (blue dashed lines) and Alyio Tuff6(green), Konso SVT (pink, also identified in the Chew Bahir sediment29), new correlations for Konso unit TA-56 (yellow), and source eruptions (stars). Key SVT: Silver Tuff, KHS: Kamoya’s Hominid Site tuff, LHM: lower Herto Member, UHM: Upper Herto Member, WAVT: Waidedo Vitric Tuff. c Tephra ETH18-8 above KHS at the KS locality in the Kibish Formation8

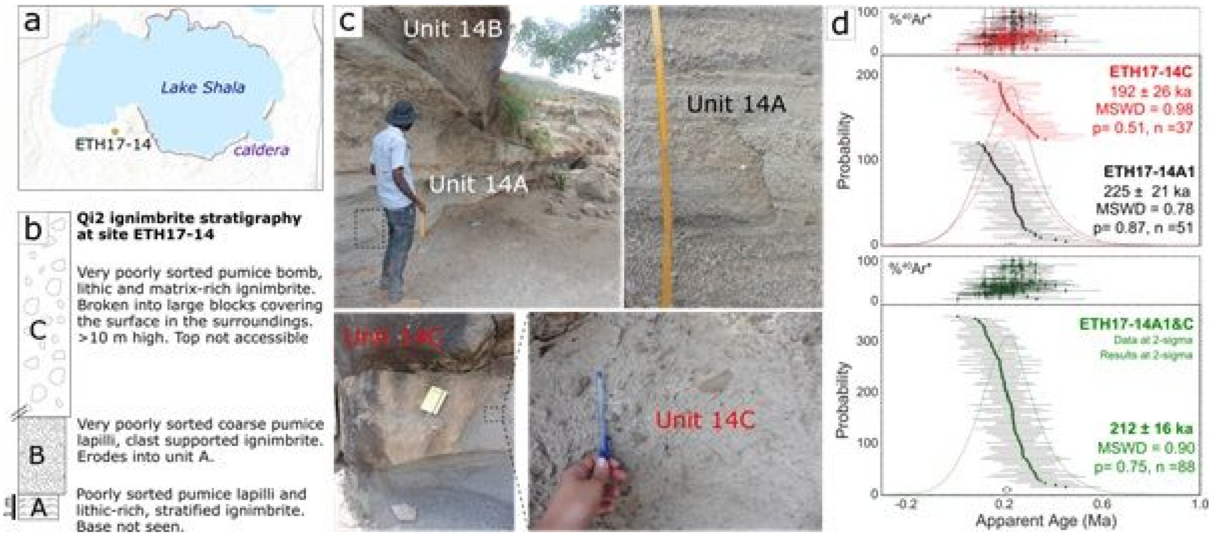

Figure 2

Stratigraphy and age of the Shala Qi2 ignimbrite. a Location of site ETH17-14 near Lake Shala in the MER. b Synthetic stratigraphy of the Qi2 ignimbrite of Shala at location ETH17-14. c Photos of the units 14A, 14B and 14C of the the Qi2 sequence at site ETH17-14. d 40Ar/39Ar age data plotted on ideograms for units 14A and 14C of the Qi2 ignimbrite.

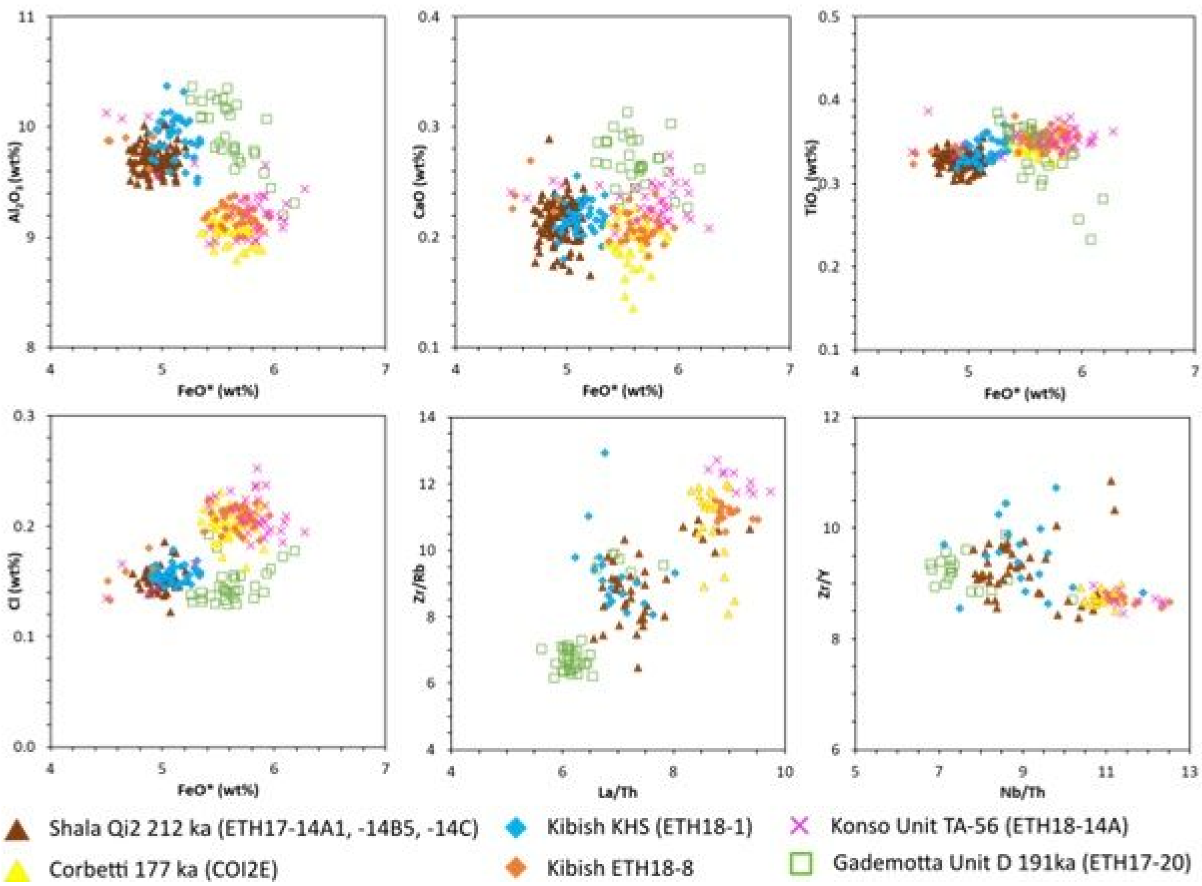

Figure 3

Geochemical fingerprint of MER tephra and their sources Major and trace element abundances of glasses from the ca. 210 ka Shala Qi2 ignimbrite, the ca. 177 ka Corbetti ignimbrite, the ca. 191 ka Gademotta Unit D, the Kibish KHS and ETH18-8 tuffs and Konso TA-56 tuffs (all data from this study).

Supplementary Files

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