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### *Age and context of the oldest known hominin fossils from Flores*

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1    **Stratigraphic context and age of hominin fossils from Middle Pleistocene Flores**

2

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44

45 **Recent excavations at the early Middle Pleistocene site of Mata Menge in the So'a**  
46 **Basin of central Flores, Indonesia, have yielded fossils of hominins<sup>1</sup> attributed to**  
47 **a population ancestral to Late Pleistocene *Homo floresiensis*<sup>2</sup>. Here we describe**  
48 **the context and age of the Mata Menge hominin specimens and associated**  
49 **archaeological findings. The fluvial sandstone layer from which the *in situ* fossils**  
50 **were excavated in 2014 was deposited in a small valley stream around 700**

51 thousand years (kyr) ago, as indicated by  $^{40}\text{Ar}/^{39}\text{Ar}$  and fission track dates on  
52 stratigraphically bracketing volcanic ash and pyroclastic density current  
53 deposits, in combination with coupled Uranium-series (U-series) and Electron  
54 Spin Resonance (ESR) dating of fossil teeth. Palaeoenvironmental data indicates  
55 a relatively hot and dry climate in the So'a Basin during the early Middle  
56 Pleistocene, while various lines of evidence suggest the hominins inhabited a  
57 savannah-like open grassland habitat with a strong wetland component. The  
58 hominin fossils occur alongside the remains of an insular fauna and a simple,  
59 'Mode 1'-like stone technology that is markedly similar to that of *H. floresiensis*.

60

61 Mata Menge is located near the northwestern margin of the So'a Basin, a  $\sim 400 \text{ km}^2$   
62 geological depression in the interior highlands of central Flores (Fig. 1). The basement  
63 substrate consists of the Ola Kile Formation (OKF), a  $>100 \text{ m}$ -thick sequence of  
64 indurated volcanoclastic deposits dominated by andesitic breccia and locally  
65 alternating with lava flows, tuffaceous sandstones, and siltstones<sup>3,4</sup>. Zircon fission-  
66 track (ZFT) age determinations date the upper part of the OKF to  $1.86 \pm 0.12$  million  
67 years ago (Ma) (ref. 4). The OKF is unconformably overlaid by the Ola Bula  
68 Formation (OBF)<sup>3,4</sup>. The latter is up to  $120 \text{ m}$  thick, and comprises an intra-basinal  
69 fossil- and stone artefact-bearing sequence deposited between  $1.8$  to  $0.5 \text{ Ma}$ . The  $\sim 5^\circ$   
70 southward dipping volcanic breccias of the OKF are associated with a former volcanic  
71 centre located on the northwestern edge of the basin. Inside the remnant of this  $10 \text{ km}$   
72 diameter caldera structure, known as the Welas Caldera, are well-formed intra-caldera  
73 lake sediments punctuated by two intra-caldera basaltic cones that were the major  
74 sources of primary and secondary basaltic volcanoclastic deposits within the OBF.

75



76 Since the 1950s, palaeontological and archaeological research in the So'a Basin has  
77 focused on the OBF<sup>5-14</sup>, which is composed largely of undistorted volcanic, fluvial,  
78 and lacustrine sediments<sup>3,4</sup>. The volcanoclastic aprons that entered the central  
79 depression from various directions, at times debouching into a lake, or series of small  
80 lakes, were incised by erosional gullies during periods of volcanic quiescence, but  
81 became sites of enhanced accretion following major volcanic influxes. Well-developed  
82 paleosols and pedogenically altered fine-grained fluvial deposits intervening  
83 between variably textured pyroclastic (primary) and fluvio-volcanoclastic (secondary)  
84 deposits document intermittent periods of landscape stability that alternated with rapid  
85 depositional events triggered by major volcanic eruptions, generating airfall tephra,  
86 ignimbrites, and associated mass-flow deposits (see SI Table 1). A basin-wide, thinly-  
87 bedded lacustrine sequence, consisting of an alternation of thin-bedded micritic  
88 freshwater limestones, clays, and with numerous basaltic tephra inter-beds – the 'Gero  
89 Limestone Member' (GLM) – caps the basin infill and registers the formation of a  
90 basin-wide lake<sup>3,4</sup>, which formerly extended into the Welas Caldera.

91  
92 The total preserved thickness of the OBF at Mata Menge, up to the top of an adjacent  
93 hill northwest of the site, is 40 m (Fig. 1). The uppermost interval of the GLM, with a  
94 thickness of 9 m, outcrops at the summit of a hill 600 m west (Excavation #35, or E-  
95 35). The main fossil-bearing intervals at Mata Menge form part of a roughly NNW-  
96 SSE trending palaeovalley dominantly occupied by a sequence of cut-and-fill  
97 fluvial and clay-rich mass-flow deposits. The hominin-bearing sedimentary layer  
98 lies at the head of a modern dry stream valley at the base of a hill (ht = 397m). A slot-  
99 trench excavated into the eastern side of this hill revealed an 18 m-thick sequence of  
100 planar bedded lacustrine clays and micritic limestones containing oogonia and

101 diatoms, fluvial sandstone beds, massive tuffaceous clay-rich mass-flow (mudflow)  
102 deposits, fine-grained well-developed clay-textured paleosols, and numerous  
103 centimetre-thick basaltic tephra inter-beds, pertaining to the middle upper part of the  
104 OBF. At the base of this slot-trench, a thin (<30 cm-thick) fossil-bearing fluvial  
105 sandstone layer was exposed underlying a sequence of mudflow deposits (Layers Ia-f)  
106 up to 6.5 m thick. This fossiliferous sandstone, named Layer II, represents the deposit  
107 of a small stream channel that has an irregular lower bedding plane and was incised  
108 into a well-developed, consolidated paleosol with prominent root traces (Layer III).  
109  
110 We conducted a 50 m<sup>2</sup> excavation (E-32) into Layer II in 2013 (Fig. 1 and Extended  
111 Data Figs. 1-2). The sandstone layer yielded fossils of the dwarfed proboscidean  
112 *Stegodon florensis*<sup>8</sup>, and numerous well-preserved dental and skeletal remains of giant  
113 rat (*Hooijeromys nusatenggara*)<sup>15</sup>, as well as teeth of Komodo dragon (*Varanus*  
114 *komodoensis*) and crocodiles, and flaked stone artefacts (Fig. 2). In 2014, we exposed  
115 Layer II over a larger area by extending the initial trench (E-32A) to the south (E-  
116 32B/C) and west (E-32D/E). A separate excavation was also opened upstream of the  
117 palaeo-channel to the north (E-32F). These excavations recovered six hominin teeth  
118 and a hominin mandible fragment from Layer II (ref. 1). Another less diagnostic  
119 hominin fossil comprises a 60 mm<sup>2</sup> piece of a cranial vault. The hominin fossils  
120 occurred at the stratigraphic interface between Layer II and the overlying mudflow  
121 deposit, spread over a maximum linear distance of 15 m. The flow direction in the  
122 sinuous stream tributary in which Layer II was deposited was from NNW to SSE,  
123 based on the slight decrease in elevation of the top of this layer in the same direction  
124 (i.e., 20 cm over a horizontal distance of 17 m). The fine- to medium-grained fluvial  
125 sandstone has a maximum thickness of 30 cm, contains scattered pebbles, and occurs

126 13 m stratigraphically above the main (lower) fossil-bearing beds at Mata Menge,  
127 which have a combined thickness of up to two metres (Fig. 1).  
128

129 The mudflow sequence (Layers Ia-f) sealing in Layer II can be clearly related to  
130 phreatomagmatic to magmatic eruptive activity occurring within the confines of the  
131 Welas Caldera (then occupied by a lake). The formation of these multiple mudflow  
132 events either relates to intermittent displacement of lake waters down adjacent  
133 tributaries during cone construction, or, alternatively, failure of a lake outlet barrier  
134 during and/or following intra-caldera eruptive activity. Four articulated thoracic  
135 vertebrae of *S. florensis* were recovered from Layer II (Fig. 2k) near a concentration  
136 of other vertebrae, ribs, and postcranial remains of a *Stegodon* carcass. These are the  
137 only articulated stegodont elements so far recovered at Mata Menge, indicating  
138 relatively limited post-mortem modification prior to burial by mudflows. We infer  
139 that the artefacts and faunal remains, including the hominin elements, were exposed  
140 to weathering on the ground surface, and could have been transported short distances  
141 by the small stream, before a series of mudflows originating from the intra-caldera  
142 lake system were channelized within adjacent stream tributaries, inundating these  
143 valleys with metre-thick muddy debris. It is conceivable that the presence of elements  
144 from multiple hominin individuals, including two juveniles, and several individual  
145 stegodonts, could be the result of a volcanic event. However, other explanations are  
146 also possible and more research into taphonomic factors is needed.  
147

148 A total of four new radiometric determinations, with ages in sequential order and in  
149 accordance with the stratigraphic sequence, as well as previously published estimates,  
150 provide a robust chronological framework for the hominin fossils (Fig. 1; see also

Supplementary Information). Near the base of the OBF at Mata Menge, a widespread ignimbritic marker bed (the Wolo Sege Ignimbrite; T-WSI) with an  $^{40}\text{Ar}/^{39}\text{Ar}$  age of  $1.01 \pm 0.02$  Ma (ref. 13; and see Fig. 1) is recognised on the combined basis of its stratigraphic association, unique depositional architecture, and glass-shard major element chemistry (see Extended Data Fig. 3). In addition, the hominin find-locality in E-32 is situated 12.5 m stratigraphically above a ZFT date of  $0.80 \pm 0.07$  Ma from Mata Menge<sup>4</sup>. To verify this prior estimate<sup>4</sup>, we conducted Isothermal Plateau Fission-Track (ITPFT) dating of glass shards from an inter-regional tephra marker (T3) identified at several So'a Basin localities, including just above the T-WSI at Mata Menge (in E-34/34B), returning a weighted mean age of  $0.90 \pm 0.07$  Ma (based on two independent age determinations) (see Extended Data Fig. 3). Moreover,  $^{40}\text{Ar}/^{39}\text{Ar}$  single crystal dating of hornblende from the Pu Maso Ignimbrite (T-Pu) located just above T3 in E-34/34B yielded a weighted mean age of  $0.81 \pm 0.04$  Ma, which is stratigraphically consistent with that of underlying T3 (Extended Data Fig. 4). These ages demonstrate that Layer II was deposited after  $\sim 0.80$  Ma.

To further constrain the age of the hominin fossils, we carried out  $^{40}\text{Ar}/^{39}\text{Ar}$  dating on one basaltic tephra and one rhyolitic tephra from the GLM above Layer II (E-12 and E-35). The GLM contains at least 85 crystal-rich tephra inter-beds of basaltic composition, collectively named the Piga Tephra (the lower 56 tephra are sequentially numbered PGT-1 to PGT-56). At Mata Menge, PGT-2 occurs 13.5 m above Layer II, and produced a  $^{40}\text{Ar}/^{39}\text{Ar}$  weighted mean age of  $0.65 \pm 0.02$  Ma from single crystal dating of hornblende (Extended Data Fig. 5). This is in accordance with the published ZFT age of a basaltic tephra inter-bed from the lower part of the GLM ( $0.65 \pm 0.06$  Ma)<sup>4</sup>. Finally, a biotite-bearing vitric-rich ash of distinctive rhyolitic

176 composition (T6; see Extended Data Fig. 3) from the top of the GLM has an  $^{40}\text{Ar}/^{39}\text{Ar}$   
177 age of  $0.51 \pm 0.03$  Ma, based on the weighted mean of single grain feldspar analyses.  
178 Thus, the hominin fossils constrained by the lowermost of these two radiometric dates  
179 within the GLM have an established minimum age of  $\sim 0.65$  Ma.

180

181 In order to demonstrate that the hominin fossils and associated faunal assemblage do  
182 not reflect vertical displacement of chronologically more recent finds into older  
183 sediments, we conducted laser ablation U-series analysis of a hominin tooth root  
184 fragment from Layer II (specimen SOA-MM6), and combined U-series/ESR-dating  
185 of two *S. florensis* molars excavated *in situ* from the same sedimentary context (see  
186 Extended Data Fig. 7 and Supplementary Information). U-series dating of the hominin  
187 tooth root independently confirms this specimen was deposited at least 0.55 Ma,  
188 whereas combined U-series/ESR indicates minimum and maximum ages of around  
189 0.36 Ma and 0.69 Ma, respectively, for the *Stegodon* molars. In sum, therefore, we  
190 have used multiple dating methods to establish a secure age of  $\sim 0.70$  Ma for the Layer  
191 II hominin fossils.

192

193 Our systematic, high-volume excavations ( $\sim 560$  m<sup>2</sup>) at Mata Menge between 2010–15  
194 have yielded a wealth of fossil vertebrate remains (see Supplementary Information).  
195 To date, 75% of the  $>7000$  vertebrate fossils recovered from E-32 have been  
196 analyzed, and include *S. florensis* (23.7% of the number of identified specimens, or  
197 NISP), *V. komodoensis* (0.6% of NISP), freshwater crocodiles (3.7% of NISP), frogs  
198 (0.3% of NISP), murine rodents (15.6 % of NISP), and birds (0.5% of NISP), the  
199 remainder comprising unidentifiable bone fragments. From the lower fossil-bearing  
200 interval (E-1 to 8 and E-11 to 31D) the remains of least 120 *S. florensis* individuals

201 are represented by dental elements spanning all ontogenetic stages<sup>16</sup>. The age profile  
202 of the Mata Menge lower level death assemblage corresponds to that of a living  
203 population, suggesting a mass death event. The lack of age-selective mortality does  
204 not fit a pattern of hominin predation, such as in the *H. floresiensis* type-locality,  
205 Liang Bua<sup>17</sup>. In Layer II, remains of juvenile, sub-adult, intermediate-aged, and very  
206 old *Stegodon* individuals are also present, but the Minimum Number of Individuals is  
207 too low to allow for the construction of a reliable age profile.

208

209 We conducted carbon and oxygen isotope analysis of tooth enamel samples collected  
210 from several *S. florensis* and murine rodent individuals from the two fossil-bearing  
211 levels at Mata Menge (Extended Data Fig. 8). The results indicate a diet heavily  
212 dominated by C<sub>4</sub> grasses, suggesting both animals were grazers, and implying that  
213 open grasslands were the major vegetation type in the So'a Basin. The recovery of  
214 rare fossils of rails, swans, ducks, eagles, and eagle owls from the lower trenches  
215 (~0.80 to 0.88 Ma) further evidences the presence of a savannah-like biome with a  
216 strong wetland component, as well as scattered patches of forest<sup>18</sup>. Fossil pollen and  
217 phytoliths from both fossil levels, while poorly preserved, offer additional evidence  
218 that grasses dominated the Middle Pleistocene vegetation (SI Table 9). Abundant  
219 moulds and casts of two species of freshwater gastropods (Cerithioidea) were  
220 recovered from Layer II and the base of the overlying mudflow sequence, pointing to  
221 the existence of permanent freshwater bodies in the ancestral stream valley.

222

223 Our excavations uncovered 149 *in situ* stone artefacts in E-32, including 47 artefacts  
224 from Layer II, in direct association with the hominin remains (Fig 2; Extended Data  
225 Fig. 9). Some of the artefacts from E-32 are lightly to heavily abraded from low-

energy water transport<sup>19</sup>, but 74.5% are in fresh, as-struck condition, suggesting minimal dislocation from nearby stone-flaking areas. Hominins gathered coarse- to fine-grained rounded volcanic cobbles from local fluvial gravels and struck them with hammerstones to create sharp-edged flakes and cores. Reduction was mostly bifacial, with blows struck to two faces of the stone from one platform edge (Fig 2a). Two cores were rotated and a second bifacial platform edge was established, resulting in multi-platform cores. Core platform surfaces or edge-angles were unprepared, and core reduction was not intensive. The edges of flakes struck from these cores were sometimes retouched for use, or possibly to produce additional flake tools. One heavily abraded core was scavenged and further flaked. Overall, the E-32 assemblage reflects a technologically straightforward core-and-flake approach to stoneworking<sup>20</sup>. The function of the implements is unknown; as yet, no butchery marks have been conclusively identified on the faunal remains at Mata Menge, and the tools may have been used for modifying other organic materials.

240

Notably, the tools and flaking technology in E-32 are nearly identical in size and nature, respectively, to the assemblage dating some 110 kyr earlier at Mata Menge<sup>12,21-23</sup>, including 1186 analysed stone artefacts from E-23 and E-27 excavated between 2011–14 (Table S6). The E-32 assemblage is also technologically similar to the artefacts from Liang Bua, dating ~600 kyr later<sup>12,24</sup> and associated with *H. floresiensis*<sup>25,26</sup>. The long persistence of this technical approach to stone-flaking on Flores<sup>12</sup>, together with the close anatomical similarities between the Mata Menge and Liang Bua hominins<sup>1</sup>, suggests remarkable stability in the behaviour of the *H. floresiensis* lineage. In contrast, the only lithic assemblage thus far recovered *in situ* below the T-WSI, which has a minimum age of  $1.01 \pm 0.02$  Ma and is therefore the

earliest known stone technology from Flores<sup>13</sup>, whilst also ‘Mode 1’ in character,  
features a typologically distinct element: large Acheulean pick-like implements<sup>27</sup> that  
in Lower Palaeolithic industries of Africa and western Eurasia are emblematic of  
cognitively advanced tool-making<sup>20,28-29</sup>. The reason for the absence of these more  
sophisticated components from the later technology of Flores remains unknown;  
however, possible explanations include: i) a reduction in the behavioural flexibility of  
*Homo erectus* due to island-dwarfing<sup>1</sup>; ii) by ~880 Ma the hominin population size  
had dropped below a minimum threshold required to maintain cultural complexity<sup>30</sup>;  
iii) the older, Acheulean-like artefacts were made by a separate hominin lineage.

260

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361

362 **Supplementary Information** is available in the online version of the paper.

363

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388 data used in Fig. 1b. Geodetic surveys and measurements were conducted by E.E.  
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394 measurements.

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#### 397 **Author contributions**

398 A.B., G.D.v.d.B., I.K. and M.J.M. directed the Mata Menge excavations. M.S., B.A.  
399 and R.S. collected tephra samples and M.S. undertook  $^{40}\text{Ar}/^{39}\text{Ar}$  dating.  
400 G.D.v.d.B. described the site stratigraphy, with R.S., D.Y. and B.V.A.. J.A.W.

401 conducted ITPFT-dating of T3 with B.V.A. and comparative trace element analyses  
402 of interregional markers (with N.J.P. & B.V.A.). E.S., F.A. and T.S. oversaw key  
403 aspects of the field project. M.W.M. analysed the stone assemblage, and G.D.v.d.B.,  
404 H.I., I.S., M.R.P. U.P.W. and H.J.M.M. analysed the fauna. M.P. conducted isotopic  
405 analyses, R.G. and M.D. undertook U/Th and ESR analyses of faunal remains, and  
406 S.v.d.K. carried out the palynological analysis. A.B. and G.D.v.d.B. prepared the  
407 manuscript, with contributions from other authors.

408

409 **Figure legends (main text)**

410

411 **Figure 1:** Context and chronology of the hominin fossils at Mata Menge. **a-b**,  
412 location of Flores and the So'a Basin; **c**, Digital Elevation Map of the So'a Basin,  
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study (1.185 Ma; see SI ref. 25), T-WSI becomes  $1.01 \pm 0.02$  Ma.

**Figure 2:** Stone artefacts and fossils from Mata Menge. All specimens are from the  
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core (chlorite); **b-c**, chert flakes; **d**, chalcedony flake; **e**, rhyolite flake; **f**, right maxilla  
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**j**, right coracoid of a duck (cf. *Tadorna*); **k**, *Stegodon florensis* thoracic vertebrae in  
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**Figure legends (extended data)**

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slope visible in the background is the eastern flank of the Welas Caldera, which was

451 the source for many of the volcanic products deposited in the So'a Basin; **b**, E-32A-E  
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460 boundary is sharp; **f**, West baulk of E-32C. Large *Stegodon florensis* bones occur at  
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463 **Extended Data Figure 2: Plan and baulk profiles of Excavation 32A-F showing**  
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471 dotted line indicates the western margin of the ancient streambed.

472

473 **Extended Data Figure 3: ITPFT dating and glass chemistry analysis. a-c,**  
474 Selected major element compositions (weight percent FeO vs. K<sub>2</sub>O and CaO and SiO<sub>2</sub>  
475 vs. K<sub>2</sub>O) of glass shards from key rhyolitic pyroclastic density current (PDC) and



476 airfall deposits at Mata Menge; **d-h**, Weight percent FeO versus CaO composition of  
477 glass shards from key rhyolitic pyroclastic density current (PDC) and airfall deposits  
478 at Mata Menge (in stratigraphic sequence – youngest to oldest) compared with  
479 correlatives from adjacent So’a Basin sites. While the major element glass  
480 compositions of T-WSI, T-T and T-Pu are all geochemically indistinguishable (i.e.,  
481 they are most likely from the same eruptive source) the major element data for each of  
482 the tephra consistently occupies different overlapping fields. Moreover, while subtle  
483 geochemical differences exist between T-WSI, T-T and T-Pu, these tephra can also be  
484 readily distinguished in the field by a combination of stratigraphic position and  
485 association, as well as by morphological expression; **i-j**, Selected trace element  
486 compositions Sr versus Th and Zr, and **(k-m)** Y versus Nb, Ce and Th of glass shards  
487 from T3 correlatives at Mata Menge, Lowo Mali and Kopowatu as well as T6  
488 (uppermost inter-regional marker) from Mata Menge. All trace element  
489 concentrations are in ppm unless otherwise stated. This data is plotted against  
490 equivalent elemental mean and standard deviation (represented as  $\pm 1\sigma$  error bars)  
491 reference data from potential distal tephra correlatives (i.e. Youngest Toba Tuff  
492 [YTT], Middle Toba Tuff [MTT], Oldest Toba Tuff [OTT] and Unit E from ODP-  
493 758) acquired on the same instrument using the same standards and under the same  
494 analytical conditions<sup>31,32</sup>. Trace element data indicates that the upper (T6) and lower  
495 (T3) inter-regional marker beds occurring at Mata Menge cannot be geochemically  
496 related to any known Toba-sourced tephra. On this basis, the eruptive sources of T6  
497 and T3 currently remain unknown. However, this absence of eruptive source certainly  
498 does not diminish their importance within the overall So’a Basin stratigraphy.

499

500 **Extended Data Figure 4:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating results. a**, Age probability plot for single

crystal laser fusion data for hornblende from the Pu Maso ignimbrite (sample FLO-15-15; SI Table 5); the vertical scale is a relative probability measure of a given age occurring in the sample<sup>33</sup>. We applied an outlier-rejection scheme to the main population to discard ages with normalized median absolute deviations of  $>1.5$  (ref. 34) and these are shown as open circles. % $^{40}\text{Ar}^*$  refers to the proportion of radiogenic  $^{40}\text{Ar}$  released for individual analyses. The weighted mean age of the filtered hornblende data for the Pu Maso ignimbrite is  $0.81 \pm 0.04$  Ma ( $1\sigma$ ; msd = 0.59, prob = 0.93;  $n = 23/29$ ). An inverse isochron plot (**b**) for these 23 analyses gives a statistically overlapping age of  $0.78 \pm 0.07$  Ma ( $1\sigma$ ; msd = 0.6, prob. = 0.92). The  $^{40}\text{Ar}/^{36}\text{Ar}$  intercept of  $303 \pm 10$  is statistically indistinguishable from the atmospheric ratio of  $298.6 \pm 0.3$  (ref. 35), thus supporting the more precise weighted mean age result.

**Extended Data Figure 5:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating results.** **a**, Age probability plot for single crystal laser fusion data for hornblende from the PGT-2 tephra (sample T XII 252-261; SI Table 5).  $^{40}\text{Ar}^*$  ranges from  $< 10\%$  to nearly  $60\%$ . The weighted mean age of the filtered hornblende data for the PGT-2 tephra is  $0.65 \pm 0.02$  Ma ( $1\sigma$ ; msd = 0.78, prob = 0.71;  $n = 17/24$ ). An inverse isochron plot (**b**) gives a statistically overlapping, but less precise age of  $0.61 \pm 0.04$  Ma ( $1\sigma$ ; msd = 1, prob. = 0.19).

**Extended Data Figure 6:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating results.** **a**, Age probability plot for single crystal laser fusion data for anorthoclase from the T6 upper inter-regional rhyolitic tephra (sample FLO15-09/2; SI Table 5).  $^{40}\text{Ar}^*$  ranges from  $20\%$  to nearly  $100\%$ . The weighted mean age of the filtered feldspar data for the T6 tephra is  $0.51 \pm 0.03$  Ma ( $1\sigma$ ; msd = 0.20, prob = 0.94;  $n = 5/8$ ). An inverse isochron plot (**b**) gives a

526 statistically overlapping, but less precise age of  $0.45 \pm 0.04$  Ma ( $1\sigma$ ;  $\text{mswd} = 0.8$ ,  
527  $\text{prob.} = 0.54$ ).

528

529 **Extended Data Figure 7: U-series and ESR samples and dating results. a,**  
530 Hominin tooth root samples (#3543A and #3543B) from Layer II, Mata Menge; **b, d,**  
531 U-series laser tracks for *Stegodon* molar samples from Layer II; **e, f,** Dose response  
532 curves obtained for the two powder enamel samples from #3541 and #3544,  
533 respectively. Fitting was carried out with a SSE function through the pooled mean  
534 ESR intensities derived from each repeated measurement. Given the magnitude of the  
535  $D_E$  values, the correct  $D_E$  value was obtained for  $5 > D_{\text{max}}/D_E > 10$  (ref. 36).

536

537 **Extended Data Figure 8. Carbon and oxygen isotope analysis of dental enamel. a,**  
538  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values of *Stegodon florensis* and murine rodent tooth enamel. All but  
539 one of the  $\delta^{13}\text{C}$  ratios corresponds with a  $\text{C}_4$  diet, indicating that both *Stegodon* and  
540 murine rodents were predominantly grazers in both fossil-bearing horizons. The  
541 positive shift observed in  $\delta^{18}\text{O}$  of the younger *Stegodon* samples (from the hominin-  
542 bearing Layer II) is more difficult to interpret with the limited data available, but  
543 could mean a distinct source of drinking water (run-off versus lacustrine) and/or  
544 warmer conditions; **b,** Benferroni corrected p values for a pairwise Mann-Whitney  
545 statistical analysis to test for similarity of  $\delta^{13}\text{C}$  between subsamples; **c,** Benferroni  
546 corrected p values for a pairwise Mann-Whitney statistical analysis to test for  
547 similarity of  $\delta^{18}\text{O}$  between subsamples; p values showing significant differences in  
548 median values are in bold.

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552 **Extended Data Figure 9:** Analytical data for the Mata Menge stone technology. **a**,  
553 Artefact counts and provenance, Trench E-32 (artefact definitions after ref. 37); **b**,  
554 raw materials used to manufacture the stone tool assemblage, Trench E-32; **c**,  
555 Platform types on flakes and modified flakes, E-32. Cortical: the blow was struck  
556 onto the cortical surface of a cobble. Single-facet: the blow was struck on a scar  
557 produced by previous reduction. Dihedral: the blow was struck on the ridge between  
558 two scars produced by previous reduction. Multifacet: the blow was struck on the  
559 surface of multiple small scars produced by previous reduction. Edge: the blow was  
560 struck on the edge of the core and a platform surface is not retained on the flake; **d**,  
561 Cortex coverage on the dorsal surface of complete unmodified flakes, E-32. Percent  
562 cortex coverage refers to the proportion of the dorsal surface covered in cortex; **e**,  
563 Artefact counts, Trenches E-32 and E-23/27 (artefact definitions after ref. 37); **f**, Sizes  
564 of artefacts and attributes, E-32 and E-23/27; **g**, Raw materials used to manufacture  
565 the stone tool assemblage, E-32 and E-23/27; **h**, Scatterplot of complete flake sizes,  
566 E-32 (total sample size [N] = 68 complete flakes) and E-23/27 (N=443). With regards  
567 to raw materials, coarse- and medium-grained materials include andesite, basalt,  
568 rhyolite, and tuff. Fine-grained materials include silicified tuff, chalcedony, and opal.  
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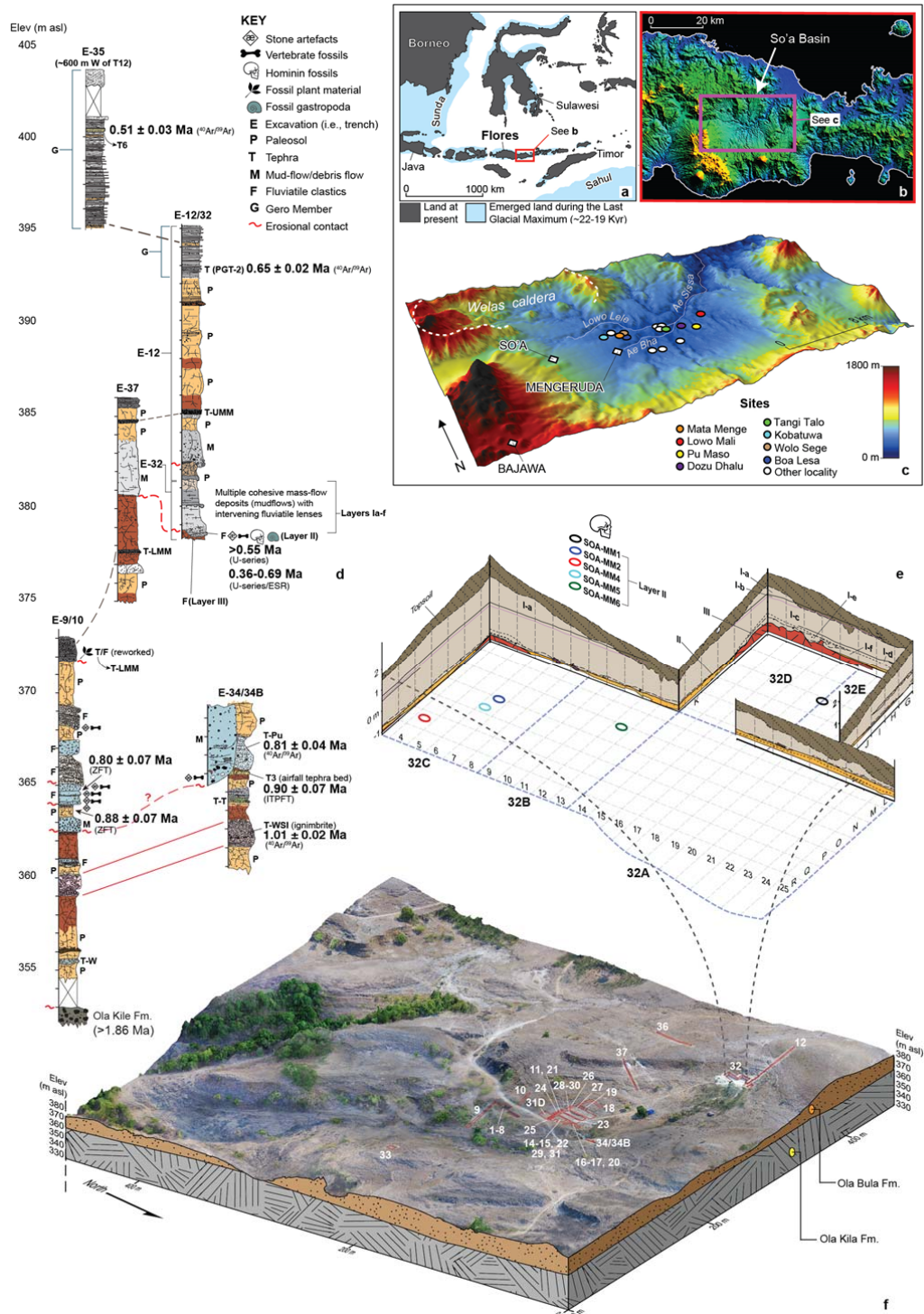
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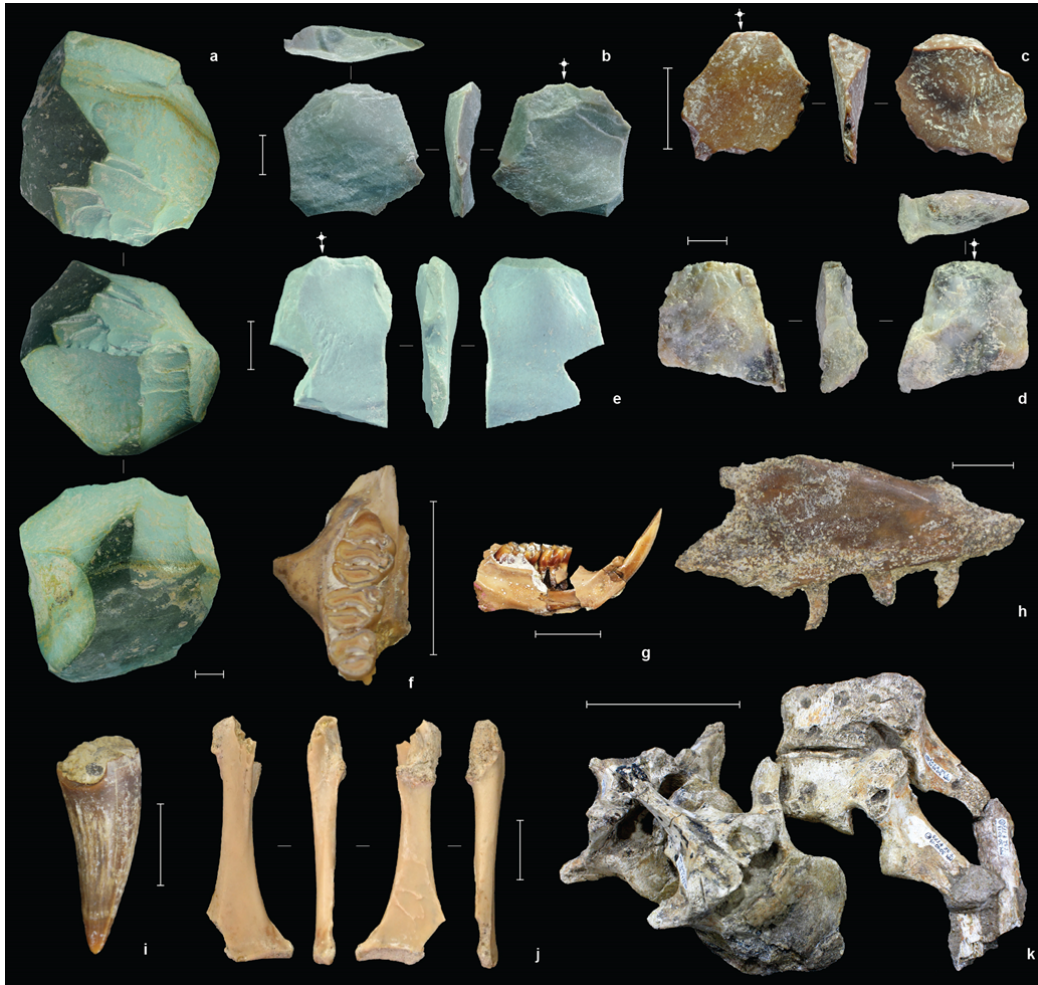
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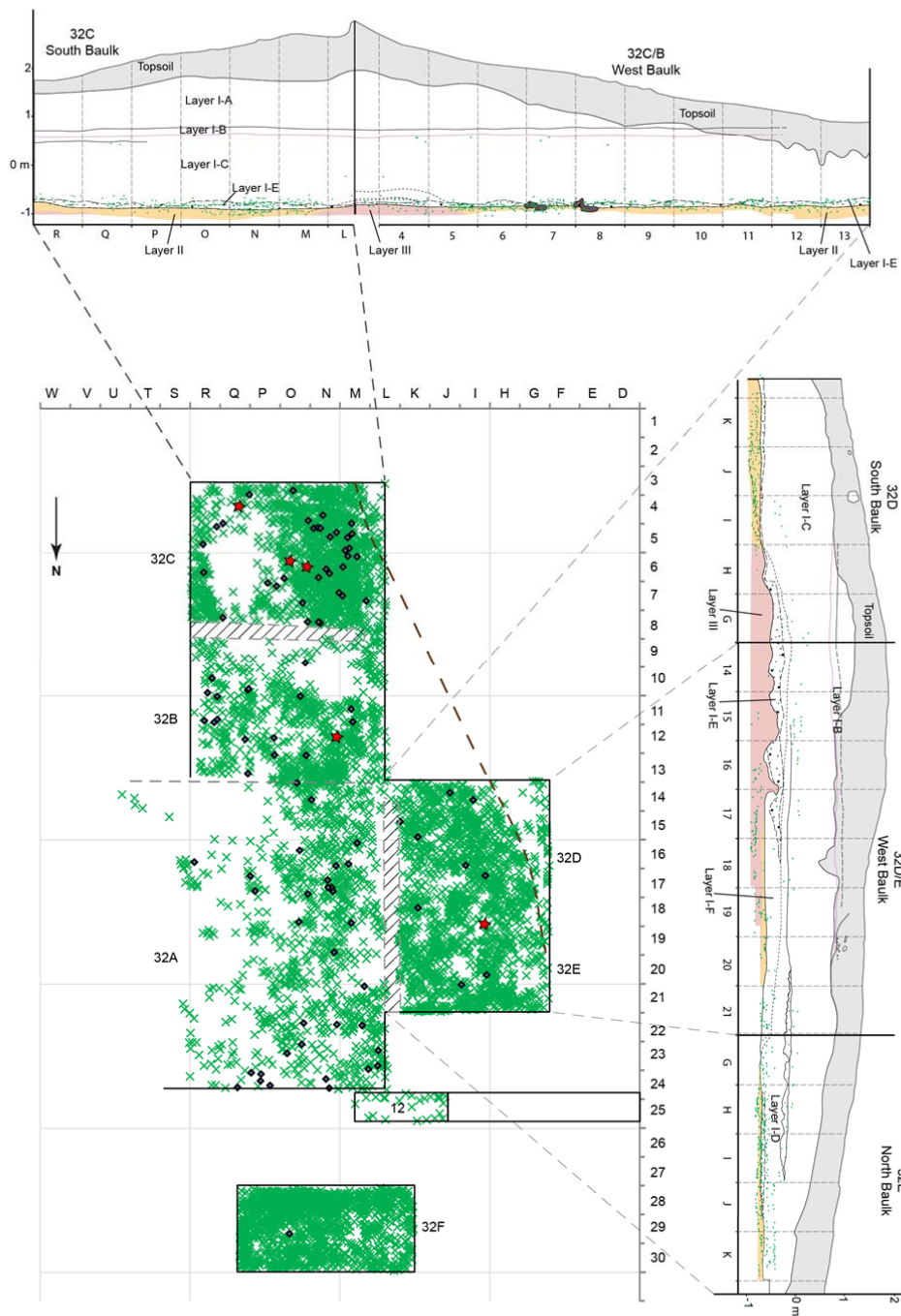
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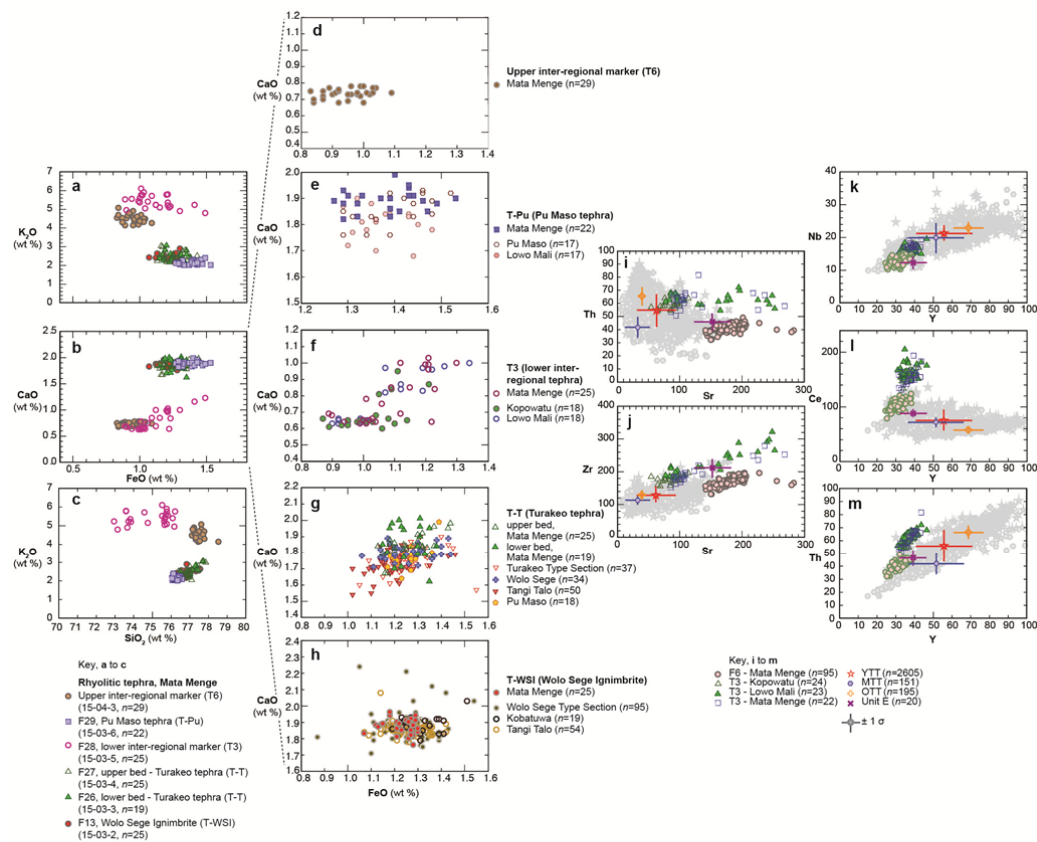
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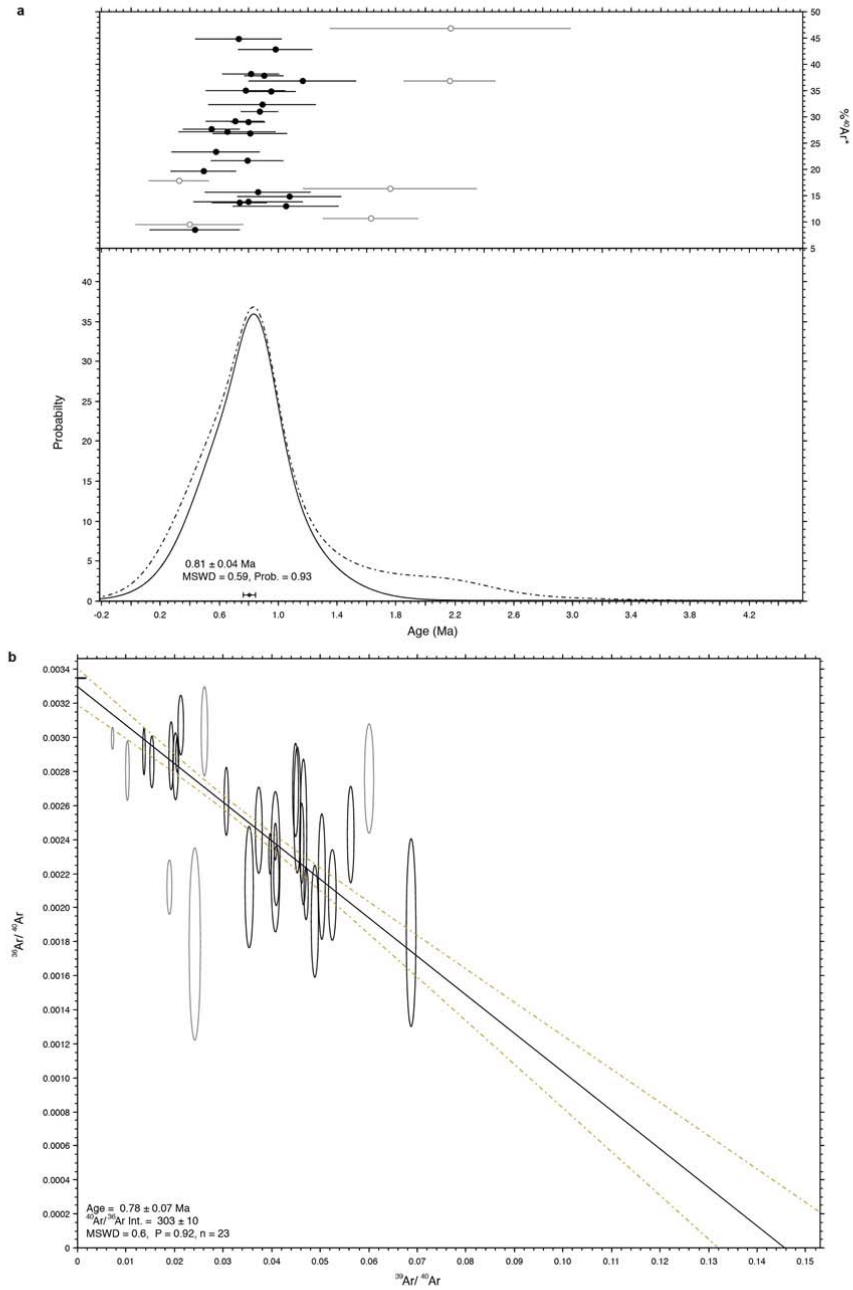
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685 airfall deposits at Mata Menge; **d-h**, Weight percent FeO versus CaO composition of

686 glass shards from key rhyolitic pyroclastic density current (PDC) and airfall deposits  
687 at Mata Menge (in stratigraphic sequence – youngest to oldest) compared with  
688 correlatives from adjacent So'a Basin sites. While the major element glass  
689 compositions of T-WSI, T-T and T-Pu are all geochemically indistinguishable (i.e.,  
690 they are most likely from the same eruptive source) the major element data for each of  
691 the tephra consistently occupies different overlapping fields. Moreover, while subtle  
692 geochemical differences exist between T-WSI, T-T and T-Pu, these tephra can also be  
693 readily distinguished in the field by a combination of stratigraphic position and  
694 association, as well as by morphological expression; **i-j**, Selected trace element  
695 compositions Sr versus Th and Zr, and **(k-m)** Y versus Nb, Ce and Th of glass shards  
696 from T3 correlatives at Mata Menge, Lowo Mali and Kopowatu as well as T6  
697 (uppermost inter-regional marker) from Mata Menge. All trace element  
698 concentrations are in ppm unless otherwise stated. This data is plotted against  
699 equivalent elemental mean and standard deviation (represented as  $\pm 1\sigma$  error bars)  
700 reference data from potential distal tephra correlatives (i.e. Youngest Toba Tuff  
701 [YTT], Middle Toba Tuff [MTT], Oldest Toba Tuff [OTT] and Unit E from ODP-  
702 758) acquired on the same instrument using the same standards and under the same  
703 analytical conditions<sup>31,32</sup>. Trace element data indicates that the upper (T6) and lower  
704 (T3) inter-regional marker beds occurring at Mata Menge cannot be geochemically  
705 related to any known Toba-sourced tephra. On this basis, the eruptive sources of T6  
706 and T3 currently remain unknown. However, this absence of eruptive source certainly  
707 does not diminish their importance within the overall So'a Basin stratigraphy.  
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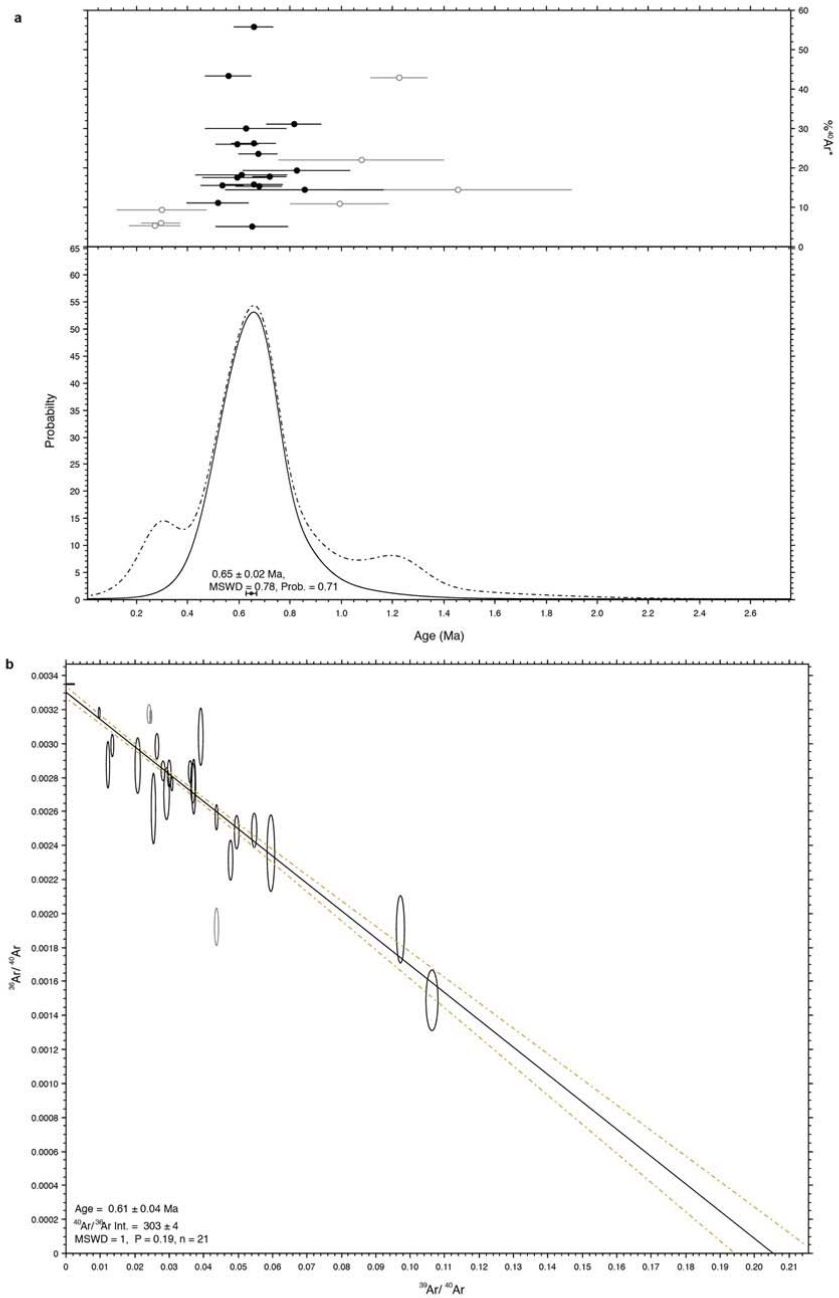
712 **Extended Data Figure 4:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating results. a,** Age probability plot for single

713 crystal laser fusion data for hornblende from the Pu Maso ignimbrite (sample FLO-

714 15-15; SI Table 5); the vertical scale is a relative probability measure of a given age

715 occurring in the sample<sup>33</sup>. We applied an outlier-rejection scheme to the main  
716 population to discard ages with normalized median absolute deviations of >1.5 (ref.  
717 34) and these are shown as open circles. %40Ar\* refers to the proportion of  
718 radiogenic 40Ar released for individual analyses. The weighted mean age of the  
719 filtered hornblende data for the Pu Maso ignimbrite is  $0.81 \pm 0.04$  Ma ( $1 \square \square \square$ mswd =  
720 0.59, prob = 0.93; n = 23/29). An inverse isochron plot (**b**) for these 23 analyses gives  
721 a statistically overlapping age of  $0.78 \pm 0.07$  Ma ( $1\sigma$ ; mswd = 0.6, prob. = 0.92). The  
722  $^{40}\text{Ar}/^{36}\text{Ar}$  intercept of  $303 \pm 10$  is statistically indistinguishable from the atmospheric  
723 ratio of  $298.6 \pm 0.3$  (ref. 35), thus supporting the more precise weighted mean age  
724 result.  
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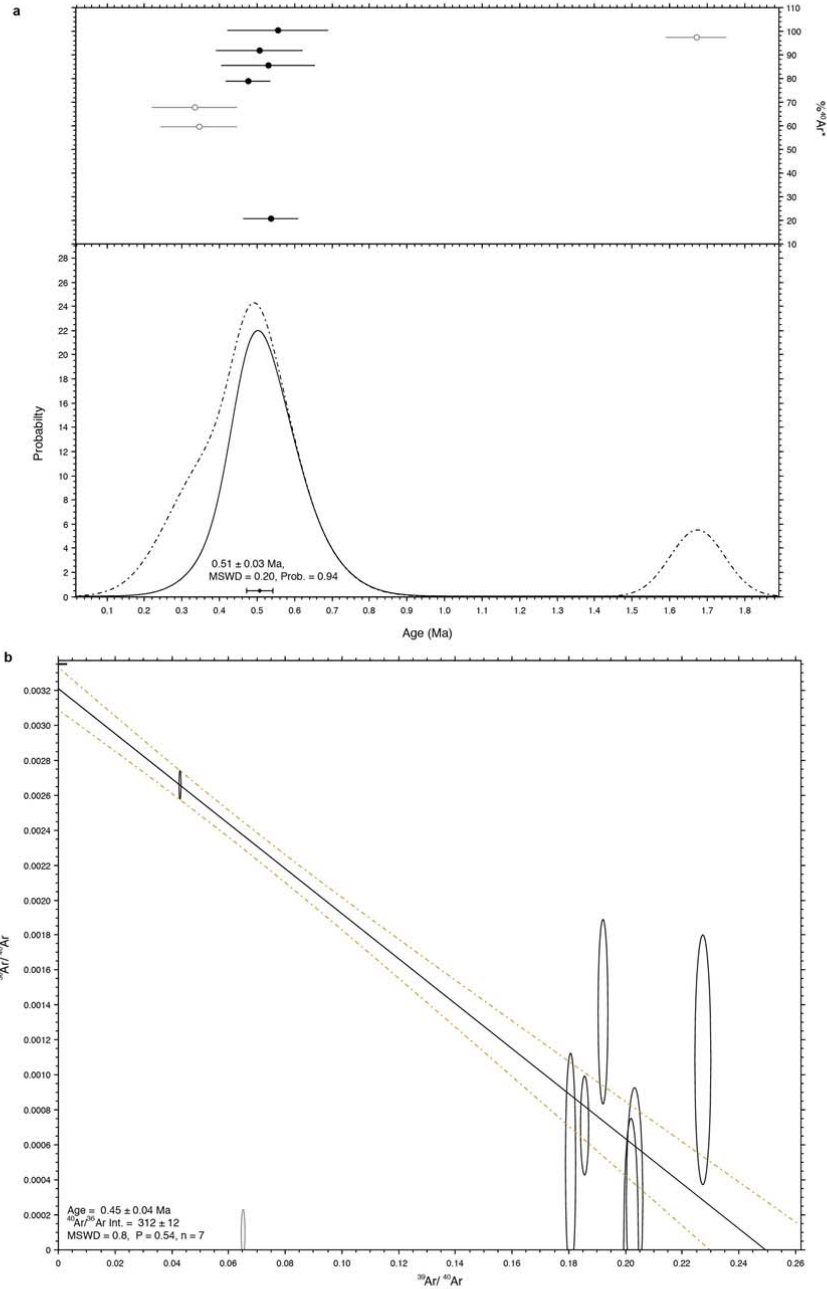
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728 **Extended Data Figure 5:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating results. a,** Age probability plot for single

729 crystal laser fusion data for hornblende from the PGT-2 tephra (sample T XII 252-

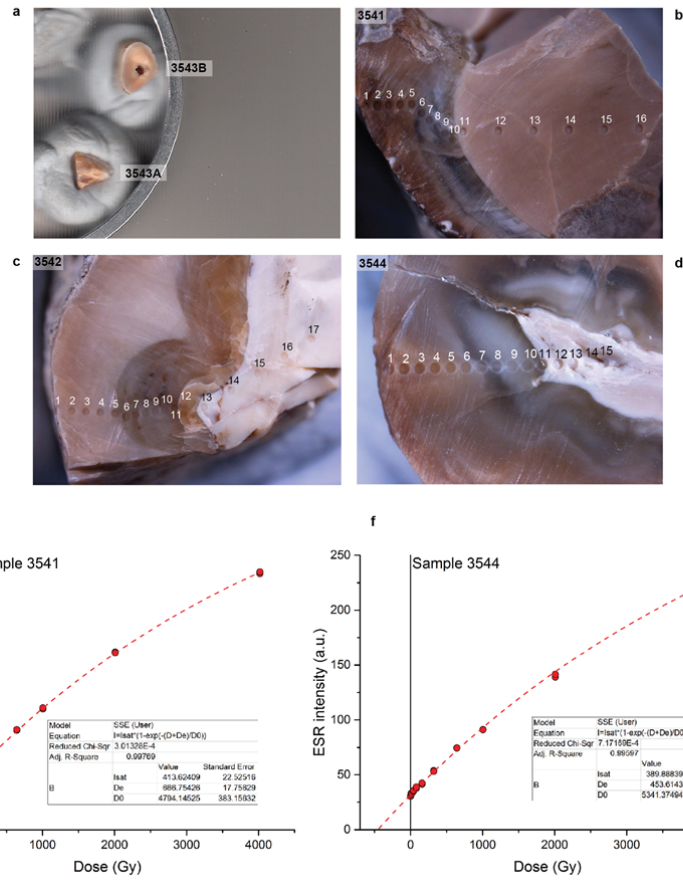
730 261; SI Table 5).  $^{40}\text{Ar}^*$  ranges from < 10% to nearly 60%. The weighted mean age of  
731 the filtered hornblende data for the PGT-2 tephra is  $0.65 \pm 0.02$  Ma ( $1\sigma$ ;  $\text{mswd} = 0.78$ ,  
732  $\text{prob} = 0.71$ ;  $n = 17/24$ ). An inverse isochron plot (**b**) gives a statistically overlapping,  
733 but less precise age of  $0.61 \pm 0.04$  Ma ( $1\sigma$ ;  $\text{mswd} = 1$ ,  $\text{prob.} = 0.19$ ).  
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737 **Extended Data Figure 6:  $^{40}\text{Ar}/^{39}\text{Ar}$  dating results.** **a**, Age probability plot for single  
 738 crystal laser fusion data for anorthoclase from the T6 upper inter-regional rhyolitic  
 739 tephra (sample FLO15-09/2; SI Table 5).  $^{40}\text{Ar}^*$  ranges from 20% to nearly 100%. The

740 weighted mean age of the filtered feldspar data for the T6 tephra is  $0.51 \pm 0.03$  Ma  
741 ( $1\sigma$ ; mswd = 0.20, prob = 0.94; n = 5/8). An inverse isochron plot (**b**) gives a  
742 statistically overlapping, but less precise age of  $0.45 \pm 0.04$  Ma ( $1\sigma$ ; mswd = 0.8,  
743 prob. = 0.54).  
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746 **Extended Data Figure 7: U-series and ESR samples and dating results. a,**

747 Hominin tooth root samples (#3543A and #3543B) from Layer II, Mata Menge; **b, d,**

748 U-series laser tracks for *Stegodon* molar samples from Layer II; **e, f**, Dose response

749 curves obtained for the two powder enamel samples from #3541 and #3544,  
750 respectively. Fitting was carried out with a SSE function through the pooled mean  
751 ESR intensities derived from each repeated measurement. Given the magnitude of the  
752  $D_E$  values, the correct  $D_E$  value was obtained for  $5 > D_{\max}/D_E > 10$  (ref. 36).

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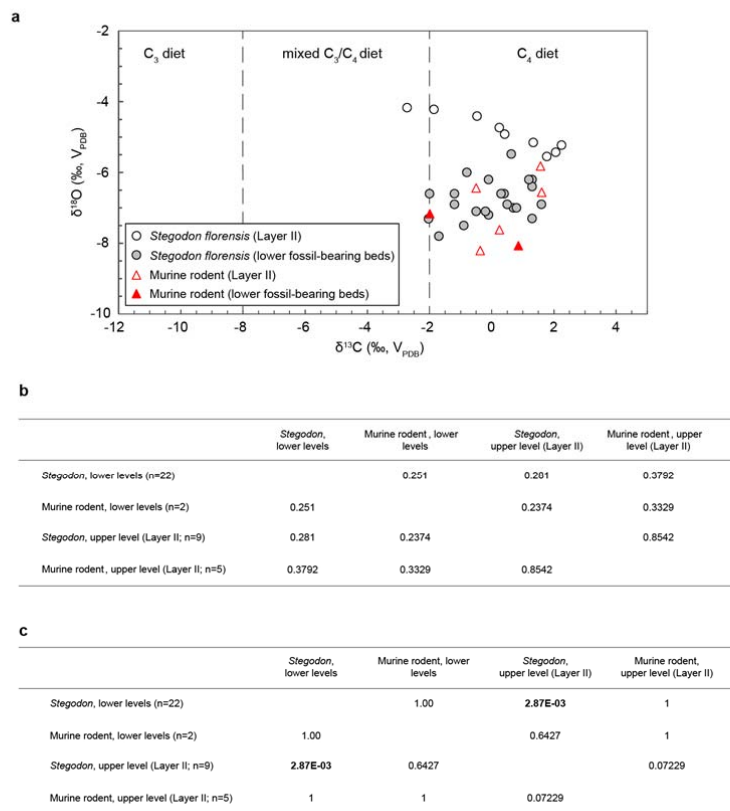
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764 **Extended Data Figure 8. Carbon and oxygen isotope analysis of dental enamel. a,**

765  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values of *Stegodon florensis* and murine rodent tooth enamel. All but

766 one of the  $\delta^{13}\text{C}$  ratios corresponds with a  $\text{C}_4$  diet, indicating that both *Stegodon* and

767 murine rodents were predominantly grazers in both fossil-bearing horizons. The

768 positive shift observed in  $\delta^{18}\text{O}$  of the younger *Stegodon* samples (from the hominin-

769 bearing Layer II) is more difficult to interpret with the limited data available, but

770 could mean a distinct source of drinking water (run-off versus lacustrine) and/or

771 warmer conditions; **b**, Benferroni corrected p values for a pairwise Mann-Whitney

772 statistical analysis to test for similarity of  $\delta^{13}\text{C}$  between subsamples; **c**, Benferroni  
773 corrected p values for a pairwise Mann-Whitney statistical analysis to test for  
774 similarity of  $\delta^{18}\text{O}$  between subsamples; p values showing significant differences in  
775 median values are in bold.

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782 raw materials used to manufacture the stone tool assemblage, Trench E-32; c,

783 Platform types on flakes and modified flakes, E-32. Cortical: the blow was struck  
784 onto the cortical surface of a cobble. Single-facet: the blow was struck on a scar  
785 produced by previous reduction. Dihedral: the blow was struck on the ridge between  
786 two scars produced by previous reduction. Multifacet: the blow was struck on the  
787 surface of multiple small scars produced by previous reduction. Edge: the blow was  
788 struck on the edge of the core and a platform surface is not retained on the flake; **d**,  
789 Cortex coverage on the dorsal surface of complete unmodified flakes, E-32. Percent  
790 cortex coverage refers to the proportion of the dorsal surface covered in cortex; **e**,  
791 Artefact counts, Trenches E-32 and E-23/27 (artefact definitions after ref. 37); **f**, Sizes  
792 of artefacts and attributes, E-32 and E-23/27; **g**, Raw materials used to manufacture  
793 the stone tool assemblage, E-32 and E-23/27; **h**, Scatterplot of complete flake sizes,  
794 E-32 (total sample size [N] = 68 complete flakes) and E-23/27 (N=443). With regards  
795 to raw materials, coarse- and medium-grained materials include andesite, basalt,  
796 rhyolite, and tuff. Fine-grained materials include silicified tuff, chalcedony, and opal.  
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