Chapter 2
Age Ranges of *Australopithecus* Species, Kenya, Ethiopia, and Tanzania

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Abstract *Australopithecus anamensis, Australopithecus afarensis, Australopithecus bahrelghazali, Australopithecus garhi,* and *Kenyanthropus platyops* have all been described from eastern Africa and Chad. Principal results presented are the age of specimens assigned to these taxa that derive from sedimentary formations of the Omo Group in the Omo-Turkana Basin of Kenya and Ethiopia. Also included are ages of relevant fossils from various sites in sediments of similar age preserved in the Ethiopian Rift Valley (e.g., Hadar, Asa Issie, Aramis, Maka, Bouri), and at Laetoli in Tanzania. All $^{40}Ar/^{39}Ar$ ages were recalculated to a common age for the Fish Canyon sanidine fluence monitor (FCs) to eliminate small differences in age caused by different choices for this value. The value chosen for the age of the Fish Canyon sanidine monitor (28.10 Ma) is that of Spell and McDougall (2003). The overall effect is to increase ages computed using 27.84 Ma for the age of the monitor by 0.93 %, and to increase ages computed using 28.02 Ma for the age of FCs by 0.29 %. An age of 4.000 Ma using the 27.84 Ma age for FCs is thus increased to 4.037 Ma; whereas the same age computed using 28.02 Ma is increased to 4.011 Ma. Thus the differences in the stated ages are on the order of 0.02 Ma–up to about twice the length of a precessional orbital cycle. Excellent age information is available on most specimens principally due to the efforts of Paul Renne and coworkers at the Berkeley Geochronology Center (BGC), and Ian McDougall and coworkers at the Research School of Earth Sciences, Australian National University; some other information (e.g., Walter and Aronson 1993) is also useful, but less extensive than the results obtained by the workers mentioned above.

Keywords Hominin evolution • Geology • Tephrostratigraphy • Radiometric dating • Turkana Basin • Omo Group

Introduction

The principal formations of interest are those of the Omo Group in the Omo-Turkana Basin of northern Kenya and southern Ethiopia, the Sagantole, Hadar, and Bouri formations of northeast Ethiopia, and the Laetoli Formation of northern Tanzania (Fig. 2.1). At other localities, such as that at Bahr al Ghazal (KT-12), Chad, australopith fossils are dated by faunal comparison and $^{10}Be/^{9}Be$ determinations; in some cases it is not evident what area or thickness of strata is included in the fauna being compared.

For the present chapter, we use ages for magnetostratigraphic boundaries given in Table 2.1. These generally follow Gradstein et al. (2004) and Horng et al. (2002), with those of Kidane et al. (2007) used for the Reunion I and Reunion II subchrons. Although stated without error estimates, in many instances errors of up to 0.03 Ma are associated with each of these ages. Further, we use ages given in Table 2.2 for dated volcanic materials in the Omo-Turkana Basin, and ages listed in Table 2.3 are for dated volcanic materials at sites in Ethiopia and Tanzania, recomputed where necessary, so that the Fish Canyon Tuff sanidine reference age is identical to that used for ages in the Omo-Turkana Basin (i.e., 28.10 Ma).

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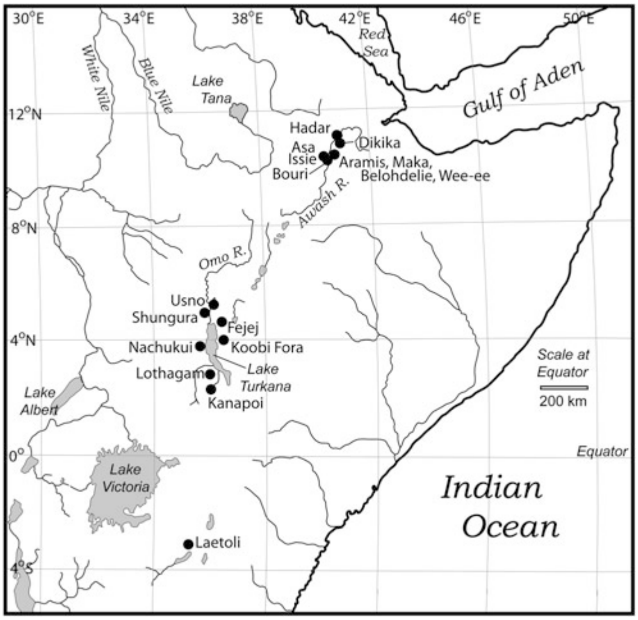


Fig. 2.1 Map of eastern Africa showing locations of most of the fossil sites mentioned in the text. Locations are generalized because some formations (e.g., Koobi Fora Formation; Shungura Formation) extend over large areas

Table 2.1 Ages of magnetostratigraphic and stratigraphic boundaries

Designation	Age (Ma)	Alternate name[a]
C1n	0.000–0.781	Brunhes
C1r	0.781–2.581	Matuyama
C1r.1n	0.988–1.072	*Jaramillo Normal*
C1r.2n	1.173–1.185	*Cobb Mt. Normal*
C2n	1.778–1.945	*Olduvai Normal*
C2r.1n	2.06–2.08[b]	*Reunion II Normal*
C2r.2n	2.15–2.20[b]	*Reunion I Normal*
C2An.1n and C2An.3n	2.581–3.596	Gauss
C2An.1r	3.032–3.116	*Kaena Reversed*
C2An.2n	3.116–3.207	
C2An.2r	3.207–3.33	*Mammoth Reversed*
C2An.3n	3.33–3.596	
C3r	3.596–6.033	Gilbert
C3n.1n	4.187–4.3	*Cochiti Normal*
C3n.2n	4.493–4.631	*Nunivak Normal*
C3n.3n	4.799–4.896	*Sidufjall Normal*
C3n.4n	4.997–5.235	*Thvera Normal*

Sources Gradstein et al. (2004) and Horng et al. (2002)
[a] Subchrons in italics
[b] Age estimates based on Kidane et al. (2007)

Table 2.2 $^{40}Ar/^{39}Ar$ ages of dated units in the Omo-Turkana Basin

Unit	Age and standard deviation (Ma)	
Silbo	0.751 ± 0.022	Anorthoclase[a]
U. Nariokotome	1.230 ± 0.020	Anorthoclase[a]
M. Nariokotome	1.277 ± 0.032	Anorthoclase[a]
L. Nariokotome	1.298 ± 0.025	Anorthoclase[a]
Gele	1.326 ± 0.019	Anorthoclase[a]
Chari	1.383 ± 0.028	Anorthoclase[a]
Ebei	1.475 ± 0.029	Anorthoclase[a]
Karari Blue	1.479 ± 0.016	Anorthoclase[a]
Koobi Fora	1.485 ± 0.014	Anorthoclase[a]
Lower Koobi Fora	1.476 ± 0.013	Anorthoclase[a]
Morte	1.510 ± 0.016	Anorthoclase[a]
Lower Ileret	1.527 ± 0.014	Anorthoclase[a]
Morutot	1.607 ± 0.019	Anorthoclase[a]
Malbe	1.843 ± 0.023	Anorthoclase[a]
KBS	1.869 ± 0.021	Anorthoclase[a]
Kangaki	2.063 ± 0.032	Anorthoclase[b]
G-3	2.188 ± 0.036	Anorthoclase[b]
Kalochoro	2.331 ± 0.015	Anorthoclase[b]
Tuff F	2.324 ± 0.020	Anorthoclase[b]
Tuff D-3-2	2.443 ± 0.048	Anorthoclase[b]
Lokalalei	2.526 ± 0.025	Anorthoclase[b]
Burgi	2.622 ± 0.027	Anorthoclase[b]
B-10	2.965 ± 0.014	Anorthoclase[b]
Ninikaa	3.066 ± 0.017	Anorthoclase[b]
Toroto	3.308 ± 0.022	Anorthoclase[b]
Tulu Bor	3.438 ± 0.023	Anorthoclase[b]
Lokochot	3.596 ± 0.045	Anorthoclase[b]
Moiti	3.970 ± 0.032	Anorthoclase[b]
Topernawi	3.987 ± 0.025	Anorthoclase[b]
Kanapoi Tuff	4.108 ± 0.029	Anorthoclase[b]
Upper pumiceous siltstone, Kanapoi	4.147 ± 0.019	Anorthoclase[b]
Lower pumiceous siltstone, Kanapoi	4.195 ± 0.033	Anorthoclase[b]
Pumice clasts, Apak Mb., Lothagam	4.244 ± 0.042	Anorthoclase[b]
Lothagam Basalt	4.23 ± 0.03	Whole rock[c]

All ages calculated relative to a reference age of 28.10 Ma for the Fish Canyon Tuff sanidine fluence monitor. All results on anorthoclase are arithmetic mean ages with uncertainties the standard deviation of the population. Most pooled ages are based on multiple single crystal total fusion measurements
[a] McDougall and Brown (2006)
[b] McDougall and Brown (2008)
[c] McDougall and Feibel (1999, 2003)

Table 2.3 K/Ar and $^{40}Ar/^{39}Ar$ ages of dated units at Ethiopian sites other than Omo, and at Laetoli standardized to a value of 28.10 Ma for the Fish Canyon sanidine fluence monitor

Unit	Age and standard deviation (Ma)	
Sagantole, Hadar, and Bouri formations		
Maoleem vitric tuff (MOVT)	2.519 ± 0.008	Sanidine[a]
Bouroukie tuff 3 (BKT-3)	2.35 ± 0.07	Alkali feldspar[b]
Bouroukie tuff 2 (BKT-2U)	2.978 ± 0.038	Alkali feldspar[c]
Bouroukie tuff 2 (BKT-2L)	2.971 ± 0.017	Alkali feldspar[c]
Kada hadar tuff (KHT)	3.205 ± 0.012	Alkali feldspar[d]
Triple Tuff (TT-4)	3.250 ± 0.010	Alkali feldspar[d]
Kadada moumou basalt (KMB)	3.311 ± 0.040	Whole rock[e]
Sidi hakoma tuff (SHT)	3.430 ± 0.030	Anorthoclase[f]
Wargolo tuff (VT-3)	3.783 ± 0.023	Alkali feldspar[g]
Cindery tuff (CT)	3.883 ± 0.083	Plagioclase[h]
Moiti tuff (VT-1)	3.925 ± 0.030	Sanidine[h]
Unnamed tuff, Sagantole Fm. (94–55 °C)	4.052 ± 0.060	Sanidine[g]
Unnamed basaltic tuff (MA02-13)	4.128 ± 0.074	Basaltic glass[i]
Marker tuff sibabi	4.303 ± 0.019	Alkali feldspar[h]
Kullunta basaltic tuff (KUBT)	4.329 ± 0.055	Basaltic glass[g]
Igida tuff complex (IGTC)	4.344 ± 0.011	Plagioclase[g]
Gaala tuff complex (GATC)	4.430 ± 0.031	Mainly sanidine[g]
Daam aatu basaltic tuff (DABT)	4.429 ± 0.053	Volcanic glass[g]
Unnamed tuff, Sagantole Fm. 94–58	4.605 ± 0.121	Plagioclase[g]
Abeesa tuff (ABCT)	4.863 ± 0.073	Plagioclase[g]
Unnamed tuff, Sagantole Fm. 94–32	4.895 ± 0.083	Plagioclase[g]
Gawto basalt	5.234 ± 0.083	Whole rock[g]
Upper unit Laetolil beds		
Yellow marker tuff	3.614 ± 0.018	Alkali feldspar[j]
Tuff 8	3.46 ± 0.12	Biotite[k]
Tuff 8	3.618 ± 0.018	Alkali feldspar[j]
Between tuffs 7 & 8 (MM25)	3.49 ± 0.11	Biotite[k]
Between tuffs 7 & 8 (75-7-7E)	3.56 ± 0.02	Biotite[k]
Tuff 7A	3.65 ± 0.02	Biotite[j]
Tuff 7	3.56 ± 0.19	Biotite[k]
Tuff 6	3.77 ± 0.05	Biotite[j]
Tuff 5	3.61 ± 0.19	Biotite[j]
Tuff between 4 & 5	3.78 ± 0.11	Biotite[j]
Tuff 4	3.80 ± 0.04	Alkali feldspar[j]
Tuff 4	3.85 ± 0.02	Biotite[j]
Tuff 3	3.71 ± 0.04	Biotite[j]
Tuff 2	3.78 ± 0.04	Alkali feldspar[j]
Tuff 2	3.85 ± 0.03	Biotite[j]
Tuff 1	3.74 ± 0.02	Biotite[j]
Base of upper unit, Laetolil beds	3.76 ± 0.03	Biotite[k]
Lower unit Laetolil beds		
Uppermost lower Laetolil beds	3.84 ± 0.02	Alkali feldspar[j]

Most results on alkali feldspar are based upon single crystal total fusion measurements, whereas most whole rock or glass measurements are from step heating experiments. In most cases the age and uncertainty are based upon a weighted mean calculation

[a] de Heinzelin et al. 1999
[b] Kimbel et al. 1996
[c] Dimaggio et al. 2008
[d] Walter 1994
[e] Renne et al. 1993
[f] Walter and Aronson 1993
[g] Renne et al. 1999
[h] White et al. 1993
[i] White et al. 2006
[j] Deino 2011; preferred ages
[k] Drake and Curtis 1987

Pliocene Formations of the Omo-Turkana Basin (the Omo Group)

Hominin taxa described from sedimentary deposits of the Omo Group in northern Kenya and southern Ethiopia include *Australopithecus anamensis*, *Australopithecus afarensis*, *Paranthropus aethiopicus*, *Paranthropus boisei*, and *Kenyanthropus platyops*. The Omo Group was defined originally by de Heinzelin (1983) as a general term to include tilted and faulted sedimentary strata of Pliocene and Pleistocene age in the Lower Omo Valley. Within the Omo Group, de Heinzelin (1983) included the Mursi, Nkalabong, Usno, and Shungura formations, and also what he termed the Loruth Kaado and Naiyena Epul beds, which are now included within the Nachukui Formation. By extension, the Koobi Fora Formation (Brown and Feibel 1986), and the Nachukui Formation (Harris et al. 1988a, b) are now included in the Omo Group. These formations consist dominantly of sands, silts and clays, deposited in fluvial, deltaic and lacustrine, environments. The Omo River, which drains the Ethiopian highlands, transported much of the sediment to the basin but there are also important contributions from lateral streams along the basin margin in many places. Two lacustrine intervals are especially prominent, one between ~4.3 and 4 Ma, and a second between ~2.0 and 1.6 Ma. Two of the formations of interest are located in the Lower Omo Valley of Ethiopia—the Shungura and Usno formations. Chronological control on formations of the Omo Group derives principally from $^{40}Ar/^{39}Ar$ ages measured at the Australian National University, Canberra. Directly measured ages are now available for 33 individual volcanic ash layers (Table 2.2). Because of the reasonably closely spaced direct age measurements, additional control can be added by knowing the levels of transition from normal to reversed paleomagnetic polarity and assigning the transitions to previously established chrons and subchrons of the Geomagnetic Polarity Time Scale.

Shungura Formation

The 766 m thick Shungura Formation is beautifully documented by de Heinzelin and coworkers (see de Heinzelin and Haesaerts 1983a, b). It crops out in a long (~65 km), narrow (1–9 km), north–south trending belt west of the Omo River in southern Ethiopia, and it is faulted, with most blocks having been dropped down on the east and strata dip ~10°W. de Heinzelin and Haesaerts (1983a) divided the formation into a Basal Member, followed upward by members A to L (omitting I). The base of the formation is taken as the lowest strata exposed below Tuff A; nowhere is the contact with underlying rocks exposed. A silicic tuff lies at the base of each member except for the Basal Member, which is defined as those strata which lie beneath Tuff A. Tuff A lies at the base of Member A. de Heinzelin and Haesaerts (1983a) divided each member into submembers on the basis of fining upward sequences and/or erosional surfaces, and labeled them numerically from the base upward within each member (e.g., D-3); some submembers are divided internally, and these too are numbered from the base upward within each submember (e.g., D-3-2). Tuffs not used to define members are designated by the submember or unit in which they occur (i.e., D-3-2). Fossils are abundant from Member A to Member L, and have provided an important set of fossil mammals useful for biochronology in East Africa. Below submember G-14, the formation consists principally of fluvial sediments arranged in fining upward cycles, commonly with a paleosol at the top of each. Many fossils derive from sandstones at the base of each fining upward sequence, but others come from less energetic conditions representing ancient floodplains. Chronological control is provided by direct determinations on materials from the Shungura Formation, and also by tephrostratigraphic correlations to dated units in other formations of the Omo Group. For example, Tuff C-4 of the Shungura Formation correlates with the Ingumwai Tuff of the Koobi Fora Formation, and lies below the Burgi Tuff which has been dated at 2.62 Ma. Hence C4 is somewhat older than 2.62 Ma. Other correlations provide still additional information.

Usno Formation

de Heinzelin and Haesaerts (1983b) described the 172 m thick Usno Formation that is exposed ~20 km northeast of the Shungura Formation in several small (named) patches. Fossils come principally from two of these exposures—White Sands and Brown Sands—at stratigraphic levels near the middle of the formation above tuffs U-10 and U-11, which correlate with tuffs B-α and B-β. Like the Shungura Formation, the fossils derive from fluvial deposits.

Koobi Fora Formation

Bowen and Vondra (1973; see also Bowen 1974) first provided a stratigraphy of Pliocene and Pleistocene deposits in the Koobi Fora region east of Lake Turkana. Brown and Feibel (1986) revised the stratigraphy, and defined all Pliocene and Early Pleistocene strata as part of the 525 m thick Koobi Fora Formation. The latter authors divided the

Koobi Fora Formation into eight members based on chemically distinct tephra marker horizons. From bottom to top the member names are: Lonyumun, Moiti, Lokochot, Tulu Bor, Burgi, KBS, Okote, and Chari. A major discontinuity occurs within the Burgi Member, which has a duration of ~0.5 Ma. This separates the informal lower Burgi Member (which extends upward to Lokalalei Tuff; 2.52 ± 0.03 Ma), from the informal upper Burgi Member (for which deposition begins approximately 2 Ma ago; McDougall and Brown 2008). Part of the interval missing in the Koobi Fora region is preserved in exposures of the Koobi Fora Formation at Loiyangalani (Gathogo et al. 2008), where deposits include the Kokiselei Tuff, and the depositional break occurs after eruption of flows of the Lenderit Basalt (2.02 ± 0.02 to 2.51 ± 0.03 Ma). The Koobi Fora Formation records a variety of fluvial, lacustrine, and deltaic environments, but fossils of *Australopithecus* sp. are principally known from fluvial channel deposits (see Coffing et al. 1994).

Kanapoi Formation and Nachukui Formation

These units lie disconformably above Miocene volcanic rocks. In other locations in the Omo-Turkana Basin deposition of Omo Group sediments began shortly before or after eruption of basalts of the Gombe Group (Watkins 1983; Haileab et al. 2004).

The Kanapoi Formation, located southwest of Lake Turkana in the Kerio River Valley is 37.3 m thick in its type section (Feibel 2003a). It records both lacustrine deposition and deltaic deposition by a river entering the basin from the south or southwest. Specimens recovered from this locality led Leakey et al. (1995) to propose a new species of hominin—*A. anamensis*.

At Lothagam, also located southwest of Lake Turkana ~65 km north of Kanapoi, the 37–113 m thick Apak Member of the Nachukui Formation disconformably lies above fluvial strata of the Nawata Formation (7.4 ± 0.1 to 6.5 ± 0.1 Ma; McDougall and Feibel 1999; Feibel 2003b), and below the 59 m thick Muruongori Member. The 94 m thick Kaiyumung Member lies above the Muruongori Member (McDougall and Feibel 1999). The Apak Member records rapid deposition by a meandering river on a floodplain, perhaps related to that at Kanapoi (Feibel 2003b). It is succeeded by lacustrine strata of the Muruongori Member, and then a return to fluvial conditions recorded in the Kaiyumung Member. Despite considerable effort, hominin fossils from Lothagam remain scant. A mandible recovered in 1967 is said to be from the Apak Member, and Leakey and Walker (2003) assigned four dental specimens from the Kaiyumung Member to *Australopithecus* cf. *A. afarensis*.

Where exposed west of Lake Turkana between ~3.75 and 4.25°N latitude (i.e., between the towns of Kataboi and Lowarengak), the Nachukui Formation has an aggregate thickness of 730 m (Harris et al. 1988a, b). The formation in this region is divided into the Lonyumun (4.2–4 Ma), Kataboi (3.9–3.4 Ma), Lomekwi (3.4–2.5 Ma), Lokalalei (2.5–2.3 Ma), Kalochoro (2.3–1.9 Ma), Kaitio (1.9–1.6 Ma), Natoo (1.6–1.3 Ma), and Nariokotome (1.3–0.6 Ma) members. Remains of *Australopithecus* sp. are known from the Lomekwi Member, and those of *Kenyanthropus* are known from the Kataboi Member. Facies variations occur over short lateral distances in some parts of the Nachukui Formation, and it records lacustrine, fluvial, and alluvial fan environments as described in previous publications (e.g., Harris et al. 1988a, b). Remains of *Australopithecus* sp. were recovered from alluvial plain environments, and those of *Kenyanthropus* were recovered from lacustrine margin deposits.

Pliocene Formations in Ethiopia Outside the Omo-Turkana Basin

Along the Awash River in Ethiopia several paleontological sites have yielded specimens ascribed to *Australopithecus*. Geological units include the Sagantole Formation, the Hadar Formation, and the Bouri Formation.

Sagantole Formation

With important fossils, a thickness over 200 m, and a quasi-continuous temporal record extending over ~1.5 Ma, the Sagantole Formation has received special attention. A complete section shown in Fig. 2.2 demonstrates that sedimentary units extending back well over 5 Ma in age exist in the region. Renne et al. (1999) have reviewed the geology, dating, and magnetostratigraphy of this unit, which is very well controlled, and later White et al. (2006) added still more temporal information. The Sagantole Formation has been divided into seven members (Renne et al. 1999). From the base upward these are the Kuseralee, Gawto, Haradaso, Aramis, Beidareem, Adgantole, and Belohdelie members. The Kuseralee Member consists of gypsiferous siltstones and claystones with interbedded bentonite layers and sandstones. A sandstone with a rich vertebrate fauna is succeeded by the lowermost flow of the Gawto Member. Basaltic lava flows and an agglomerate make up the Gawto Member. Fine-grained strata of the overlying Haradaso Member are succeeded by thick, cross-bedded sandstones,

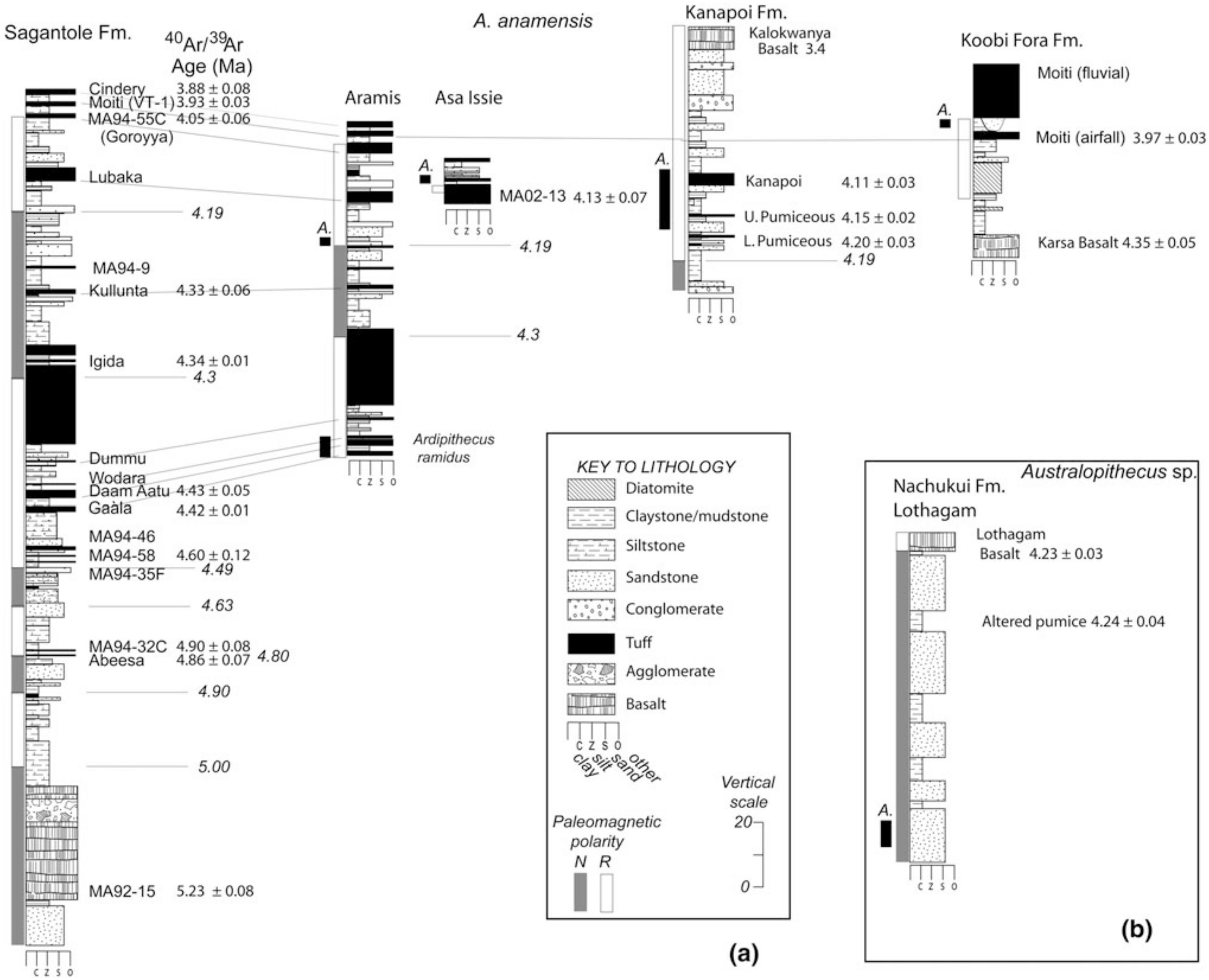


Fig. 2.2 **a** Schematic stratigraphic columns for localities from which fossils ascribed to *Australopithecus anamensis* have been recovered. The column for the Sagantole Fm. is after Renne et al. (1999); those for Aramis and Asa Issie are after White et al. (2006); that for the Kanapoi Fm. is after Leakey et al. (1998) and Feibel (2003a); and that for Koobi Fora is after Coffing et al. (1994). To the left of each stratigraphic column is a column showing paleomagnetic polarity (if known). Left of that is a *small solid bar* capped with "*A.*" showing the known range of fossils in each section. Dated units are identified by name, or if a name is lacking, by sample number; ^{40}Ar/^{39}Ar ages shown with error are recalculated to an age of 28.10 Ma for the Fish Canyon sanidine fluence standard (FCs) so that ages on all columns are comparable. Ages assigned from paleomagnetic transition boundaries are shown without error and italicized. **b** Position of the Lothagam mandible (KNM-LT 329), and the dated tuff at Lothagam using information from McDougall and Feibel (2003)

and conglomerate lenses near the top. Vertebrate fossils are abundant in the silty sandstones and coarser sandstones. The Haradaso Member contains at least seven tephras (mainly altered), including the Abeesa Tuff. At the base of the Aramis Member is the Gàala Tuff Complex, which is overlain by silt, clay, and sand with calcareous layers some of which contain vertebrate fossils and fossilized seeds and dung. A coarse-grained cross-bedded sandstone at the top of the Aramis Member contains vertebrate fossils, but the member also includes gastropod-bearing limestones. Most of the Aramis Member probably records fluvial sedimentation with shallow lacustrine environments represented near the top. The Beidareem Member consists of altered basaltic tephra and locally 2–4 m of silts and silty clays between the basaltic tuffs enclose the Igida Crystal Tuff. Some 80 m of strata comprise the Adgantole Member, which is dominated by silt, clay, and sand, but also has coarse sandstone and conglomerate near the top. It contains several tuffs (e.g., Kullunta Basaltic Tuff, Lubaka Vitric Tuff, Goroyya Tuff Complex). The Goroyya Tuff Complex crops out ∼3 m below Tuff VT-1 (=Moiti Tuff) which defines the base of the Belohdelie Member. The Moiti Tuff was defined in the Omo-Turkana Basin (Cerling and Brown 1982; Haileab and Brown 1992). Extending upward to the base of the Cindery Tuff, the Belohdelie Member consists of clay, silt, and fine sand with a few thin, coarser-sand horizons, several laterally extensive vitric tephra, and a gastropod-bearing limestone beneath the Cindery Tuff. Deposition in a fluctuating shallow- to deep-lacustrine system, including swamp and lake-margin facies is suggested for this member (Renne et al. 1999). White et al. (2006) report on specimens of *A. anamensis* from this formation at Aramis, and also at Asa Issie.

Hadar Formation

The Hadar Formation, a minimum of 280 m thick, is exposed along the Awash River adjacent to the eastern escarpment of the Ethiopian Plateau (Johanson et al. 1982). The principal area (~ 10 km^2) from which fossils of *Australopithecus* were collected is located north of the Awash River. The strata are essentially flat lying, and have been divided into four members, the Basal, Sidi Hakoma, Denen Dora, and Kada Hadar members from the base upwards. The sedimentary strata are generally similar to those of the Sagantole Formation, but lack basaltic tephra that are so prominent in the former. Like the Sagantole Formation, the Hadar Formation contains several vitric tuffs (e.g., the Sidi Hakoma Tuff (SHT), the Kada Hadar Tuff (KHT), the Triple Tuff (TT), the Bouroukie Tuffs (BKT), etc.), which have provided material for ^{40}Ar/^{39}Ar dating. Lacustrine, lake margin, fluvial and flood plain environments are well represented, and described elsewhere (e.g., Taieb et al. 1972, 1976; Johanson et al. 1982). Near the base of the formation is the Sidi Hakoma Tuff, which correlates with the β-Tulu Bor Tuff of the Omo-Turkana Basin (Brown 1982; Walter and Aronson 1993). The site is justly famous for the discovery of many fossils now ascribed to *A. afarensis* (e.g., Taieb et al. 1976; Johanson et al. 1978; Johanson and White 1980). At Dikika, the Hadar Formation has a maximum thickness of ~ 160 m, and many of the units defined at Hadar itself are still recognizable (SHT, KHT, TT-4, etc.; see Wynn et al. 2006). Below the Sidi Hakoma Tuff, lacustrine clays resting on older basalts give way to shoreline facies with gastropod bearing sandstones. These are transitional to delta plain facies that contain the splendid juvenile skeleton attributed to *A. afarensis* described by Alemseged et al. (2005, 2006). Still higher in the section, lacustrine deposition resumes, and is then once again replaced by predominantly fluvially deposited strata in the upper part of the formation. In addition to the juvenile hominin, a partial mandible with associated dentition has been recovered from the area which is also attributed to *A. afarensis* (Alemseged et al. 2005).

Bouri Formation

de Heinzelin et al. (1999) named the Bouri Formation for its location on the Bouri Horst, and divided it into three members (the Hata, Daka, and Herto members) with a combined thickness of 80 m. Of interest here is the Hata Member, which is 40 m thick in its type locality. The lower part of this member is made up of silty claystones, tuffs, and mudstone, with sandstones and mudstones in the upper part. These units are interpreted as having been deposited in fluvial settings close to a shallow fluctuating lake (de Heinzelin et al. 1999). Three tuffs were recognized—the Maoleem Vitric Tuff (MOVT), a yellow-green zeolitized unit, a diatomaceous tuff 14 m higher in the section, and a bentonitic tuff with accretionary lapilli 4 m above that. This is the site from which Asfaw et al. (1999) described the new taxon *Australopithecus garhi*.

Laetolil Beds

Hay (1987) described a representative section of the Laetolil Beds exposed in northern Tanzania, and divided it into a lower unit (64 m), and an upper unit (59 m). His lower unit consists principally of aeolian tuff interbedded with air-fall and water-worked tuffs, and in some sections also contains conglomerates and a mudflow. His upper unit consists largely of aeolian tuff, but also contains air-fall tuffs and several horizons of angular rock fragments, or xenoliths. As subaerial deposits, probably on a grassland savanna, the Laetolil Beds differ sharply from other units discussed previously. K/Ar age measurements along with one ^{40}Ar/^{39}Ar age determination, principally on biotite from airfall tuffs within the sequence are the basis for the chronology of these beds (Drake and Curtis, 1987). More recent detailed 40Ar/39Ar age measurements on biotite and alkali feldspar by Deino (2011) are now the basis for the age assignments. Hominin fossils derive from the upper unit of the Laetolil Beds from levels 7 m below Tuff 3 to 9 m above Tuff 8 (Leakey, 1987).

Temporal Distribution of *Australopithecus* Species

Australopithecus anamensis

Chronologic information on this taxon is summarized in Fig. 2.2, where all columns are drawn, insofar as possible, to a standard format for ease in comparison. The position of *Ardipithecus ramidus* is also shown on this figure where it is apparent that this taxon predates the earliest occurrences of *A. anamensis* by at least 100 ka.

Representative fossils of *A. anamensis* at Kanapoi, southwest of Lake Turkana, come principally from a lower channel sandstone and overbank mudstone complex, and a distributary channel associated with the Kanapoi Tuff (4.108 ± 0.029 Ma; McDougall and Brown 2008). Altered pumiceous clasts occur in two siltstones in the lower levels of the Kanapoi sequence, and alkali feldspar crystals from them yielded ages of 4.195 ± 0.033 and 4.147 ± 0.019 Ma (Leakey et al. 1995, 1998; McDougall and Brown 2008). The oldest dated level (4.195 ± 0.033 Ma) is below the lowest *A. anamensis* specimen yet recovered. Most hominins from Kanapoi occur in strata between the lowest dated level and the Kanapoi Tuff. Fossils of *A. anamensis* have also been recovered from the Koobi Fora Formation in paleontological collecting Area 261 of the Allia Bay region. In the latter locality the specimens lie ~5 m below the Moiti Tuff (Coffing et al. 1994), within the Lonyumun Member as currently defined. However, an airfall equivalent of the Moiti Tuff lies lower in the section in Area 260 (Brown unpublished) to which the age of 3.970 ± 0.032 Ma should most likely be attributed.

Australopithecus anamensis is also known from Aramis and Asa Issie, Ethiopia, probably from the Adgantole Member of the Sagantole Formation. A single specimen from Aramis, Ethiopia, from near the base of paleomagnetic chron C2Ar (4.18 Ma) is attributed to *A. anamensis* (White et al. 2006). At Asa Issie specimens of *A. anamensis* derive from strata above a basaltic tephra layer for which the weighted mean of two plateau ages is 4.128 ± 0.074 Ma (recomputed from 4.116 ± 0.074 in White et al. 2006). These strata are of reversed paleomagnetic polarity, and assigned to chron C2Ar (4.19–3.61 Ma). The younger age limit is more difficult to assess, but White et al. (2006) suggest that the fossils lie below a vitric tuff (VT-3) correlated with the Wargolo Tuff of the Omo-Turkana Basin by Haileab and Brown (1992). White et al. (1993) reported an average age of 3.78 ± 0.02 Ma for this unit. deMenocal and Brown (1999) estimated the age of the Wargolo Tuff at 3.80 ± 0.01 Ma from its correlate in ODP Site 721. Thus, all known specimens attributed to *A. anamensis* lie between 3.8 and 4.2 Ma.

Australopithecus afarensis

Figure 2.3 shows the stratigraphic distribution of this taxon in its principal occurrences: the Hadar region and Laetoli. Some specimens from Koobi Fora, Lothagam and Fejej have also been attributed to *A. afarensis*.

Specimens attributed to *A. afarensis* at Hadar are found in the Sidi Hakoma and Denen Dora members of the Hadar Formation, bounded by the Sidi Hakoma Tuff below, and by BKT-2 above. *Australopithecus* specimens come from a variety of depositional settings; the most famous (A.L. 288-1; "Lucy") derives from a channel fill of a small stream. Site A.L. 333, which has yielded remains of at least 13 individuals, may have been preserved in overbank sediments related to an adjacent channel fill. Hominin fossils have been retrieved from floodplain, delta plain and delta-margin facies in addition to shallow lacustrine deposits in the Sidi Hakoma Member. In the Denen Dora Member, which has shallow lacustrine deposits in the lower part transitional to swamp and floodplain deposits above, hominins have been recovered not only from the sandy units, but also from finer grained deposits. Chronological control is provided not only by K/Ar and $^{40}Ar/^{39}Ar$ dates on intercalated volcanic ash layers, but also by paleomagnetic polarity transitions representing the Mammoth and Kaena subchrons.

K/Ar data reported by Drake and Curtis (1987) establish the general age for the Laetolil Beds, the source of the holotype of *A. afarensis* (L.H. 4; Johanson et al. 1978) but the data set is not as robust as it might be, and additional work would be of interest. In particular, errors on the age determinations are larger than those obtained for materials of comparable age in the Kenyan and Ethiopian materials, partly because biotite normally contains a much smaller fraction of radiogenic argon than feldspars.Recently, Deino (2011) provided new $^{40}Ar/^{39}Ar$ ages on the entire succession at Laetoli that are in general agreement with the earlier results of Drake and Curtis (1987), Harrison and Msuya (2005), and Manega (1993). Deino's preferred ages are shown on the column in Fig. 2.3, and document convincingly that the fossils from the Upper Laetolil Beds lie between 3.63 and 3.8 Ma in age.

Perhaps the best known specimen from Lothagam is a mandible (KNM-LT 329) recovered by Bryan Patterson from the lowest part of the Apak Member of the Nachukui Formation in 1967. It derives from the lowest 3 m of this member, so we only know that it is >4.22 ± 0.03 Ma in age. Leakey and Walker (2003) note that it has affinities to both *A. ramidus* and *A. afarensis*, but attribute the specimen to Hominidae indeterminate. Four dental specimens from the Kaiyumung Member of the Nachukui Formation at Lothagam were assigned to *Australopithecus* cf. *A. afarensis* by Leakey and Walker (2003). On the basis of the known paleomagnetic record, the base of the Kaiyumung Member must be ~3.5 Ma (scaling linearly between 3.58 and 3.33 Ma), but probably greater than 3.11 Ma, as only one reversed magnetozone has been reported (Powers 1980; see also McDougall and Feibel 2003). Details of the stratigraphic placement of the specimens within this

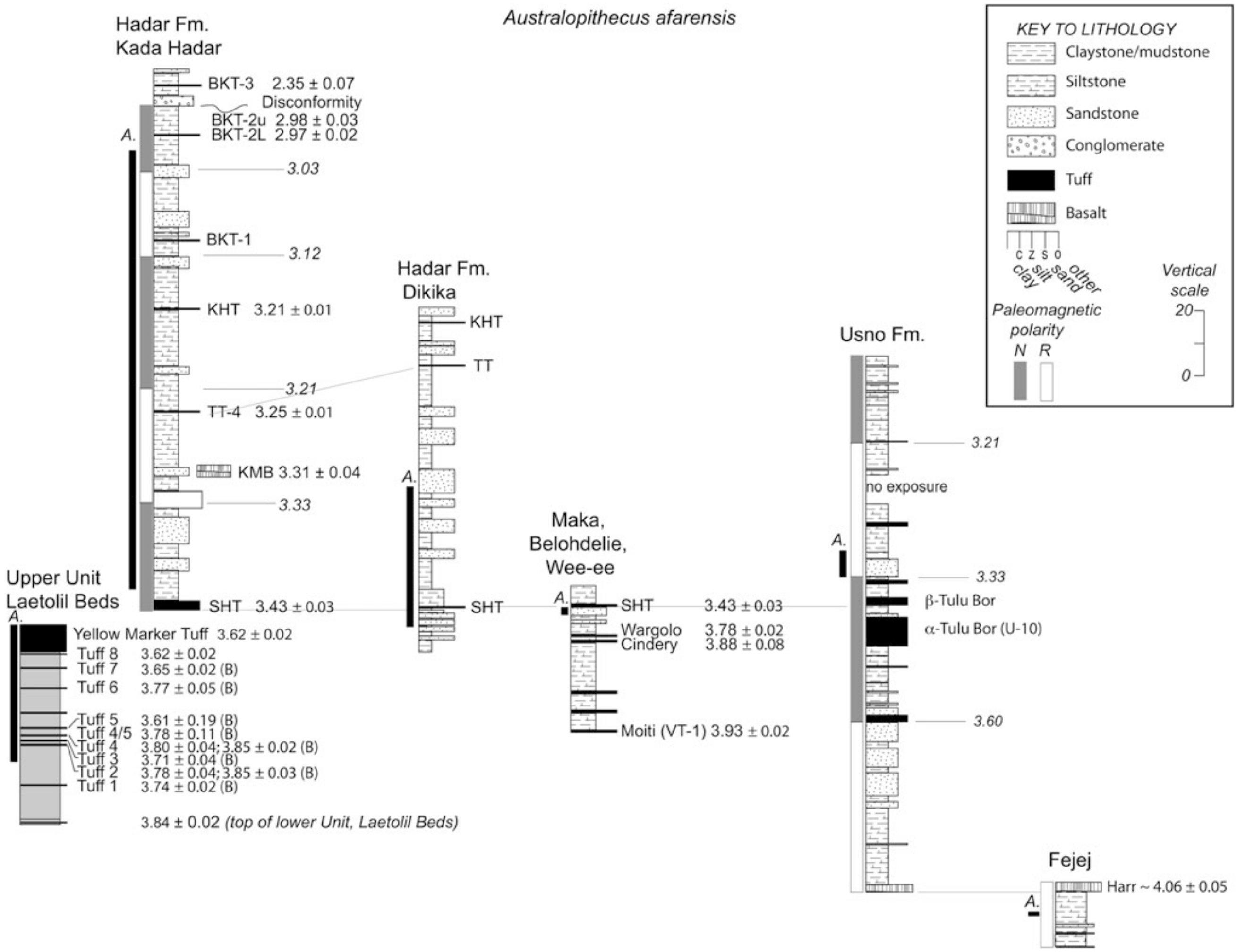
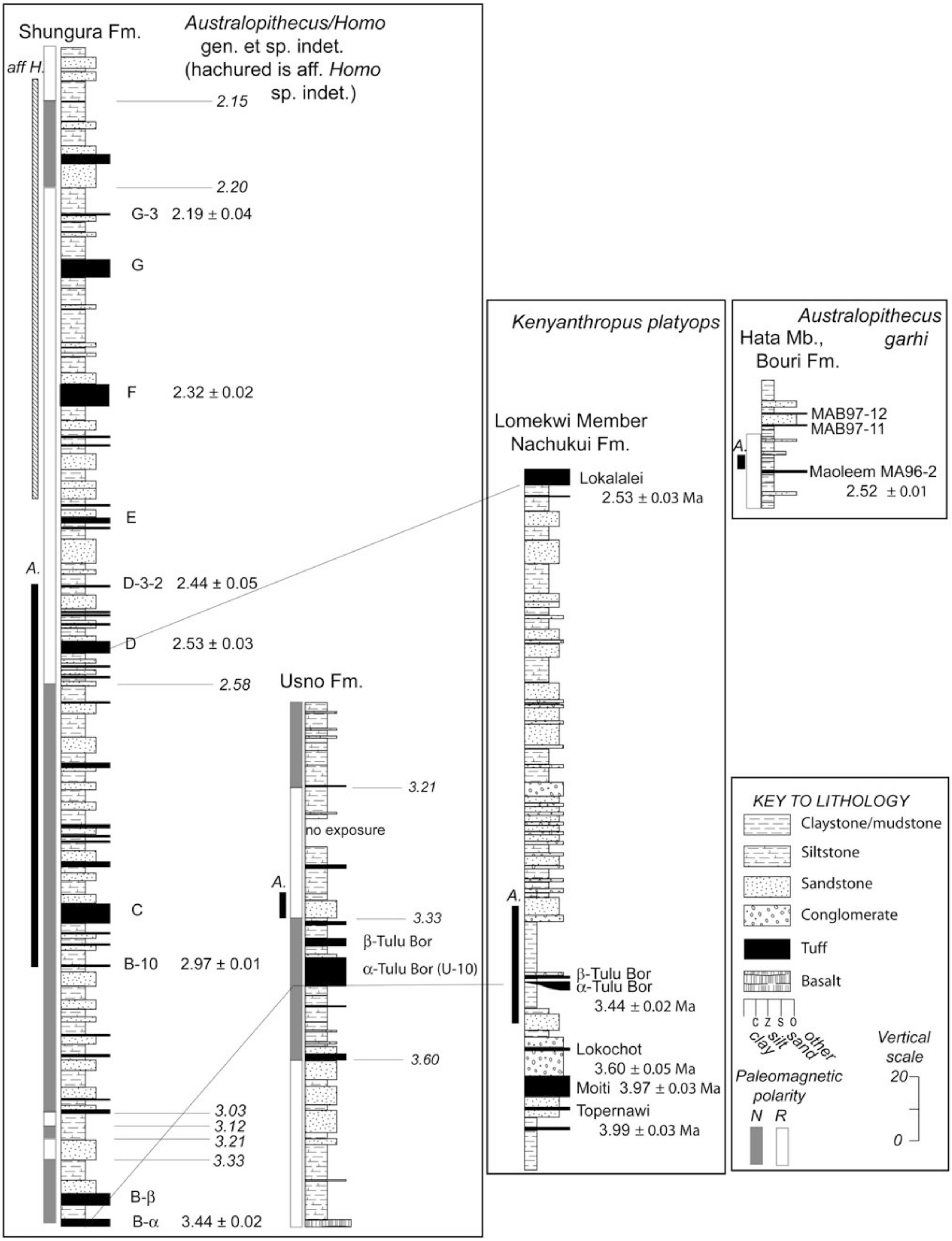


Fig. 2.3 Schematic stratigraphic columns for localities from which fossils ascribed to *Australopithecus afarensis* have been recovered. The column for the Laetolil Beds is after Hay (1987); that for Hadar is after Bonnefille et al. (2004); that for Dikika is after Wynn et al. (2006); that for Maka/Belohdelie/Wee-ee is after White et al. (1993); that for the Usno Formation is after de Heinzelin and Haesaerts (1983b); that for Fejej is after Kappelman et al. (1996). To the left of each stratigraphic column is a column showing paleomagnetic polarity (if known). Left of that is a *small solid bar* capped with "*A.*" showing the known range of fossils in each section. Dated units are identified by name, or if a name is lacking, by sample number; $^{40}Ar/^{39}Ar$ ages shown with error are recalculated to an age of 28.10 Ma for the Fish Canyon sanidine fluence standard (FCs) so that ages on all columns are comparable. Ages assigned from paleomagnetic transition boundaries are shown without error and italicized

member are lacking, so the specimens can only be said to lie between 3.11 and 3.5 Ma.

At Fejej, Ethiopia (Asfaw et al. 1991), there is evidence for the existence of a species of Australopithecus older than 4.0 Ma, but probably not more than 4.2 Ma, based on fossil material from a 25 m section below the Harr Basalt (Fleagle et al. 1991; Kappelman et al. 1996). On the basis of worn and fragmentary teeth they ascribed these specimens to *A. afarensis* following comparison with similar teeth from Hadar. The age of these specimens is nearly 400 ka older than *A. afarensis* at Laetoli. Provided the taxonomic attribution is correct (see Alemseged 2013)—and we stress that this determination should be based on morphology, not age—it would appear that *A. afarensis* overlaps temporally with *A. anamensis*. Thus, the temporal range of *A. afarensis*, insofar as it is currently known is from ~4.1 Ma at Fejej, to ~2.9 Ma at Hadar. On the other hand, Kimbel et al. (2006), and also White et al. (2006), argue for a linear progression from *A. anamensis* to *A. afarensis*. If the former view is correct, it would suggest that the two taxa were not a strictly anagenetic lineage, but overlapped for an extended time (see Kimbel et al. 2006). Therefore it is of the highest importance that the taxonomic identity of the specimens from Fejej be confirmed.


Shungura Fm.
Australopithecus/Homo gen. et sp. indet. (hachured is aff. Homo sp. indet.)
aff H.
2.15
2.20
G-3 2.19 ± 0.04
G
F 2.32 ± 0.02
E
A.
D-3-2 2.44 ± 0.05
D 2.53 ± 0.03
2.58
C
B-10 2.97 ± 0.01
3.03
3.12
3.21
3.33
B-β
B-α 3.44 ± 0.02
Usno Fm.
3.21
no exposure
A.
3.33
β-Tulu Bor
α-Tulu Bor (U-10)
3.60
Kenyanthropus platyops
Lomekwi Member Nachukui Fm.
Lokalalei
2.53 ± 0.03 Ma
A.
β-Tulu Bor
α-Tulu Bor
3.44 ± 0.02 Ma
Lokochot
3.60 ± 0.05 Ma
Moiti 3.97 ± 0.03 Ma
Topernawi
3.99 ± 0.03 Ma
Australopithecus garhi
Hata Mb., Bouri Fm.
MAB97-12
MAB97-11
A.
Maoleem MA96-2
2.52 ± 0.01
KEY TO LITHOLOGY
Claystone/mudstone
Siltstone
Sandstone
Conglomerate
Tuff
Basalt
C Z S O
clay silt sand other
Paleomagnetic polarity
N R
Vertical scale
20
0

◀ **Fig. 2.4** Schematic stratigraphic columns for localities from which fossils ascribed to *Australopithecus/Homo* gen. et sp. indet., *Kenyanthropus platyops*, and *A. garhi* have been recovered. The column for the Shungura Formation (partial) is after de Heinzelin and Haesaerts (1983a); that for the Lomekwi Member of the Nachukui Formation is after Leakey et al. (2001) with additions from Harris et al. (1988b); that for the Hata Member of the Bouri Fm. is after de Heinzelin et al. (1999). To the left of each stratigraphic column is a column showing paleomagnetic polarity (if known). Left of that is a *small solid bar* capped with "*A*." showing the known range of fossils in each section. Dated units are identified by name, or if a name is lacking, by sample number; $^{40}Ar/^{39}Ar$ ages shown with error are recalculated to an age of 28.10 Ma for the Fish Canyon sanidine fluence monitor (FCs) so that ages on all columns are comparable. Ages assigned from paleomagnetic transition boundaries are shown without error and italicized

One specimen from Area 117 at Koobi Fora (KNM-ER 2602) is attributed to *A. afarensis* (Kimbel 1988). As Leakey et al. (1978) describe the specimen as lying just above 117/TIII (the Tulu Bor Tuff) it is thus $<3.438 \pm 0.023$ Ma. No firm minimum age can be placed on this specimen, but it is likely that it lies below the Ninikaa Tuff (3.066 ± 0.017 Ma) exposed $\sim$7 km to the southeast.

Australopithecus bahrelghazali

Brunet et al. (1995) reported an australopith mandible similar in morphology to *A. afarensis* from site KT-12, near Koro Toro in northern Chad. They state that the fauna from KT-12 "shows closest resemblances to collections from Hadar, Ethiopia with an approximate age of 3.0–3.4 Ma." Brunet et al. (1996) later assigned the specimen to a new species, *A. bahrelghazali*. The age estimate seems reasonable, and is consistent with placement of the specimen above a green pelite on which Lebatard et al. (2008) obtained a cosmogenic $^{10}Be/^{9}Be$ age of 3.58 ± 0.27 Ma.

Australopithecus garhi

This taxon was described by Asfaw et al. (1999) on the basis of remains from the Hata Member of the Bouri Formation in the Awash Valley, Ethiopia, lying just above the Maoleem Vitric Tuff (MOVT), with the geology described in an accompanying paper by de Heinzelin et al. (1999). The age of the MOVT is very well constrained at 2.52 ± 0.01 Ma, and strata below and above the MOVT are of reversed paleomagnetic polarity. This polarity agrees with the age determinations and places specimen BOU-VP-112 in the lowest part of the Matuyama Reversed Chron (2.58–2.20 Ma). The age suggested by de Heinzelin et al. (1999; 2.45–2.50 Ma) is well supported by the primary information. Cut marks on contemporary bone suggest that stone tools were in use by this or another creature from this time period.

Kenyanthropus platyops

Specimens collected at LO-6, from the Kataboi Member of the Nachukui Formation in the northern part of the Lomekwi drainage west of Lake Turkana are the only records of this taxon. The holotype is securely bracketed between the Tulu Bor Tuff (3.438 ± 0.023 Ma) and the Lokochot Tuff (3.596 ± 0.045 Ma), and has a probable age of 3.50 ± 0.05 Ma. The paratype lies 17 m above the Tulu Bor Tuff, and scaling on the basis of stratigraphic thickness between the Tulu Bor Tuff and the Lokalalei Tuff, has a probable age of 3.3 ± 0.1 Ma (Leakey et al. 2001). Currently there is no additional age control within the section at Lomekwi between the Tulu Bor Tuff and the Lokalalei Tuff, nor have materials been found that would be of use either for direct age measurement or correlation. Paleomagnetic stratigraphy through this section would be of considerable use in refining the age of the paratype.

Australopithecus/Homo gen. et sp. indet

Suwa et al. (1996) examined 48 mandibular postcanine teeth from members B through G of the Shungura Formation and divided them into robust and non-robust types. They consider the robust specimens from "from Members C through F ($\sim$2.9–2.3 Ma) to represent *A. aethiopicus*." Sometime during lower Member G ($\sim$2.3–2.0 Ma), the derived morphology of *A. boisei* appears. Of course, neither *A. aethiopicus* nor *A. boisei* are even considered to belong to genus *Australopithecus* by many workers, instead being assigned to *Paranthropus*. By contrast, the early non-robust types from the Shungura Formation were considered to be indeterminate to genus or species, but Suwa et al. (1996) consider the non-robust types collected from stratigraphic levels above the base of Member E ($\sim$2.4 Ma) as "aff. *Homo* sp. indet." This may be the material from the Shungura Formation that White (2002) attributed to *A. garhi*. These are included in Fig. 2.4 for the benefit of those workers who may have interest in their age. Grine et al. (2006) consider specimens from the Usno Formation (fossiliferous units are within the Mammoth event; thus

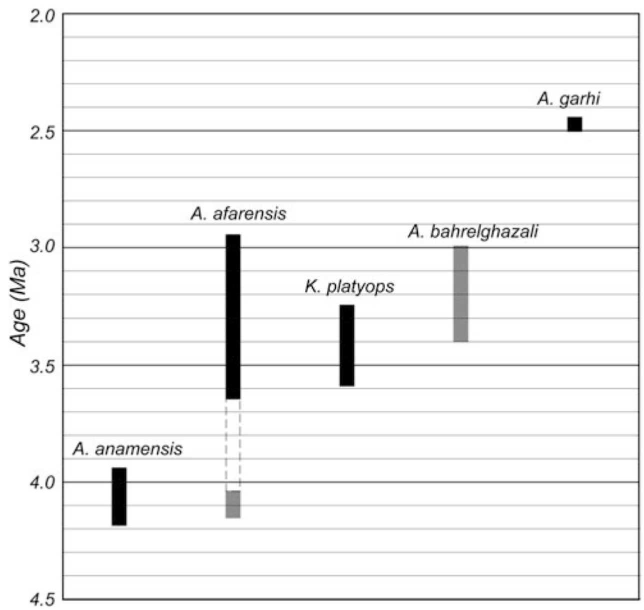


Fig. 2.5 Temporal distribution of *Australopithecus* species. The bar for *A. bahrelghazali* is shown in *gray*; it is based on biochronology and a $^{10}Be/^{9}Be$ age determination. The bottom part of the bar for *A. afarensis* is shown with a *dashed line* for the time interval where no specimens are known, with the record for Fejej filled in *gray* to emphasize the importance of confirming the taxonomic attribution of those specimens

3.207–3.33 Ma in age) and Member B (3.438 ± 0.023 to ~2.9 Ma) of the Shungura Formation as part of the paradigm of *Praeanthropus afarensis*, although one anonymous reviewer is "very skeptical" of these assignments. For this reason we have placed the Usno Formation sections on both Figs. 2.2 and 2.3.

Summary

Of the taxa considered here, *A. anamensis* is known to lie between 3.8 and 4.2 Ma, *A. afarensis* existed from arguably as old as ~4.1 but definitely as old as 3.65–2.97 Ma. Whether the two species were in fact coeval critically depends upon the assignment of the Fejej teeth to *A. afarensis*. *Kenyanthropus platyops*, too, overlaps temporally with part of this time, as does *A. bahrelghazali*, which appears to be reasonably placed in the range of 3.0–3.5 Ma. Finally, an age for *A. garhi* of 2.45–2.50 Ma is quite well supported. The age range for the latter taxon is perhaps artificially restricted because it is known from only a single site. This information is summarized in Fig. 2.5.

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