Lakeside Cemeteries in the Sahara: 5000 Years of Holocene Population and Environmental Change

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Abstract

Background: Approximately two hundred human burials were discovered on the edge of a paleolake in Niger that provide a uniquely preserved record of human occupation in the Sahara during the Holocene (~8000 B.C.E. to the present). Called Gobero, this suite of closely spaced sites chronicles the rapid pace of biosocial change in the southern Sahara in response to severe climatic fluctuation.

Methodology/Principal Findings: Two main occupational phases are identified that correspond with humid intervals in the early and mid-Holocene, based on 78 direct AMS radiocarbon dates on human remains, fauna and artifacts, as well as 9 OSL dates on paleodune sand. The older occupants have craniofacial dimensions that demonstrate similarities with mid-Holocene occupants of the southern Sahara and Late Pleistocene to early Holocene inhabitants of the Maghreb. Their hyperflexed burials compose the earliest cemetery in the Sahara dating to ~7500 B.C.E. These early occupants abandon the area under arid conditions and, when humid conditions return ~4600 B.C.E., are replaced by a more gracile people with elaborated grave goods including animal bone and ivory ornaments.

Conclusions/Significance: The principal significance of Gobero lies in its extraordinary human, faunal, and archaeological record, from which we conclude the following:

1. The early Holocene occupants at Gobero (7700–6200 B.C.E.) were largely sedentary hunter-fisher-gatherers with lakeside funerary sites that include the earliest recorded cemetery in the Sahara.
2. Principal components analysis of craniometric variables closely allies the early Holocene occupants at Gobero with a skeletally robust, trans-Saharan assemblage of Late Pleistocene to mid-Holocene human populations from the Maghreb and southern Sahara.
3. Gobero was abandoned during a period of severe aridification possibly as long as one millennium (6200–5200 B.C.E).
4. More gracile humans arrived in the mid-Holocene (5200–2500 B.C.E.) employing a diversified subsistence economy based on clams, fish, and savanna vertebrates as well as some cattle husbandry.
5. Population replacement after a harsh arid hiatus is the most likely explanation for the occupational sequence at Gobero.
6. We are just beginning to understand the anatomical and cultural diversity that existed within the Sahara during the Holocene.

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**Introduction**

The “greening” and ultimate desiccation of the Sahara rank among the most severe climatic fluctuations during the Holocene [1]. Driven by variation in orbital insolation and magnified by feedback between monsoonal rainfall and vegetation [2], ecosystem succession in the Sahara is well known from many lines of evidence such as pollen spectra [3], paleolake levels [4–6], and, most recently, high-resolution paleolake sediment cores [7].

Human adaptation during this period of climate fluctuation is best known in the Eastern Sahara to the west of the Nile valley. This region witnessed continuous occupation from 8500 B.C.E., when hunter-gatherers using a distinctive Epipaleolithic tool kit expanded across open grass savanna habitats, to about 3500 B.C.E., when aridification drove pastoralists from most areas of the desert [8]. Occupational patterns in low-lying regions elsewhere in the Sahara most closely resemble the Eastern Sahara during the early Holocene (~8000–7000 B.C.E.), when pottery-producing hunter-fisher-gatherers resided beside paleolakes, utilizing a tool kit including microliths and harpoon points and fish hooks of bone [9–11]. By the mid-Holocene, occupational histories diverge in the Central and Western Sahara [12] as a result of distinctive local humid-arid cycles [13–15], diversified economies and lifestyles tied to ephemeral paleolakes [10], upland refugia [16] and rivers [17], and marked variation among the human populations themselves [10,10,19]. Despite increasing knowledge regarding occupational succession in the Sahara from early to late Holocene [9,10,11,16,17], that record is based on individual sites that typically preserve short intervals of occupation, include few if any intact burials, and rely largely on indirect dating of human remains and artifacts [20].

We report here on a new site complex called Gobero located at the western tip of the hyperarid Ténéré Desert in the southern Sahara in Niger (Figures 1A, 2). Approximately 200 burials ranging in age over five millennia are present in the upper level of several paleodunes that are situated adjacent to a paleolake deposit. Gobero preserves the earliest and largest Holocene cemetery in the Sahara, opening a new window on the funerary practices, distinctive skeletal anatomy, health and diet of early Holocene hunter-fisher-gatherers, who expanded into the Sahara when climatic conditions were favorable. The site complex also preserves numerous mid-Holocene burials, some indicating funerary rituals with grave inclusions. Associated middens and an exceptional faunal and pollen record provide a chronicle of episodic human occupation in the Sahara under conditions of severe climatic change.

**Results and Discussion**

**Geologic Setting**

Gobero is located on the northwestern rim of the Chad Basin, approximately 150 km southeast of the Air massif (Figure 1A). Isolated on a vast peneplain of mid-Cretaceous sandstone between fields of migrating harcan dunes (Figure 2), the most important cluster of sites at Gobero is located in low, calcite-fringed paleodunes that are partially surrounded by paleolake deposits [Figure 1B, C]. The paleodunes accumulated at Gobero over a period of at least seven millennia from the Late Pleistocene to the early Holocene (~14,000–7000 B.C.E.), as determined by optically stimulated luminescence (OSL) dating of paleolake sand at various depths (Figure 1F, Table 1). During the best preserved intervals of occupation, the core paleolake sites (G1-3) formed islands that may have been originally partially conjoined as a narrow peninsula into Paleolake Gobero, a shallow, freshwater lake no more than 3 m in depth and 3 km in diameter (Figure 1C, D). The lake occupied a small endorheic basin located on a low rise between drainages southwest to the Niger River and southeast to Paleolake Chad. Fed periodically by surface water from the Air massif that pooled against a low east-west fault scarp (Mazelet) immediately to the south, Paleolake Gobero appears to have been more closely associated with the Chad Basin, as there is no trace of the giant catfish (Arius gigas) common to drainages of the Niger [21]. The archaeological sites were submerged when the lake filled to a depth greater than 5 m (Figure 1D). Over time the human bone in submerged burials darkened and hardened to resemble the pyrolusite (MnO2)-darkened vertebrate bone in the adjacent paleolake deposit.

**Model for the Gobero Sequence**

Based on geochronological data (Tables 1, 2) with input from archaeological, craniometric, zooarchaeological and archaeobotanical analysis, we divide the record preserved at Gobero into four occupation phases (Figure 3).

**Phase 1—Paleolune Accumulation (14,000–7700 B.C.E.).** Phase 1 is predominantly an arid interval at the close of the Pleistocene and beginning of the Holocene, when dune sands accumulated in the Gobero area over Cretaceous bedrock under climatic conditions characterized by weakened monsoons and the spread of aridification across northern Africa [4–6,12–14]. The base of the paleolake deposit at site G1 dates to ~14,000 B.C.E. (Figure 1B, F, section 12; Table 1, dates 3, 4). Although humid intervals are recorded elsewhere in the central Sahara [5,13,14] and may have occurred during phase 1 at Gobero, Paleolake Chad never grew to megalake dimensions until later in the early and mid-Holocene [5,6], and the paleolake sequence at Gobero accumulated without a detectible hiatus. Deflated Ounanian artifacts [22–24] were recovered suggesting that during this phase there were transient hunter-gatherers in the Gobero area who seem not to have left any burial record in the lower portion of the paleolake sequence.

**Phase 2—Early Holocene Occupation (7700–6200 B.C.E.).** During phase 2, wet climatic conditions attracted a population of hunter-fisher-gatherers to Gobero sites, which served both funerary and habitation functions. In one area of site G3 no larger than 50 m², 17 closely interspaced (≥4 m), undisturbed burials contain dark-stained skeletons composing a cemetery (Figure 4A, B). Direct dates for five of these burials indicate an age of ~7500 B.C.E. and range over only ~250 years (Figure 3; Table 2, dates 1–7). This cemetery is considerably larger than a small cluster of burials at a somewhat younger site along the upper Nile (El Damer) [11] and predates by three millennia the oldest cemetery in Egypt’s Western Desert (Gebel Ramlah) [25]. Phase 2 is delimited in time by burials within site G3 with direct dates (Table 2, dates 1, 7), the oldest a subadult individual in the cemetery (7730–7580, midpoint 7655 B.C.E.) and the youngest an adult located nearby (6380–6210, midpoint 6295 B.C.E.).

Phase 2 peoples are tall in stature, approaching two meters for both males and females. Hyperflexed, supine burial postures predominate, their compact configuration and anatomical articulation suggesting that their bodies were tightly bound with animal skin, ligament or basketry binding, although no trace of these perishable materials are preserved (Figure 4C). Their crania are long and low and are characterized by a distinct occipital bun, flattened sagittal profile, pentagonal posterior outline, broad proportions across the zygoma and interorbital region, broad nasal aperture, and negligible alveolar prognathism (Figure 4D), features that are apparent in juveniles as young as four years of age.
Figure 1. Location maps and geologic section across principal sites at Gobero. (A)-Map showing location of the Holocene archaeological site Gobero and the Holocene felsite quarry Alallaka on the border of the Air massif. (B)-Geologic map of main paleodune cemetery sites (G1-3) showing transect line connecting 13 geologic sections (see C, E, F) and a portion of a topographic transect (dashed line; see D). (C)-Stratigraphic profile across sites G1-3 based on 13 sections showing the Cretaceous peneplain of the Elrhaz Formation, the Late Pleistocene to early Holocene paleodune deposit, the early to mid-Holocene paleolake deposit, and Recent sand cover (15 times vertical exaggeration). (D)-Topographic transect (dashed line in B) between site G5 and a spillway on the Mazelet fault scarp located 1.3 km to the south (30 times vertical exaggeration). Habitation (3 m) and maximum (8 m) paleolake levels are shown, the latter resulting in inundation of archaeological sites G1-5. (E)-Stratigraphic section of paleolake deposit between sites G1 and G2 with fossiliferous zone limited to the uppermost 5 cm and location of sediment sample for 14C AMS date 75 (Table 2). (F)-Stratigraphic section of paleodune deposit at site G1 showing human skeletons limited to the uppermost 1 m and the location of three OSL samples (Table 1, dates 2–4). Abbreviations: AMS 75, 14C AMS date 75; OSL, optically stimulated luminescence.
Nine OSL dates on paleodune sand samples taken at varying depth from sites G1-4 at Gobero. OSL samples 2–4 are from a 3.0 m section on the north edge of site G1 (Figure 1F). Abbreviations: BCE, BP dates minus 2000 years to approximate BCE age; BP, before present; UG, Luminescence Dating Laboratory, University of Georgia. doi:10.1371/journal.pone.0002995.t001

Table 1. Optically stimulated luminescence (OSL) dates for paleodune sand.

| No. | Sample Level         | Notes                          | Lab-Date-Number | OSL Age   |
|-----|----------------------|--------------------------------|-----------------|-----------|
|     |                      |                                |                 | BP        | BCE       |
| Site G1 |                       |                                |                 |           |           |
| 1   | mid level            | 1.5 m down from calcrete       | UG-2006-391     | 10,100±700 BP | 8100±700 BCE |
| 2   | upper level (section 12) | 1.0 m down from calcrete; burial level; deep control trench | UG-2007-442     | 10,500±800 BP | 8500±800 BCE |
| 3   | mid level (section 12) | 2.0 m down from calcrete; deep control trench | UG-2007-443     | 16,500±1800 BP | 14,500±1800 BCE |
| 4   | lower level (section 12) | 2.5 m down from calcrete; deep control trench | UG-2007-445     | 15,000±1400 BP | 13,000±1400 BCE |
| Site G2 |                       |                                |                 |           |           |
| 5   | upper level          | 1.0 m down from calcrete       | UG-2007-444     | 8700±800 BP  | 6700±800 BCE |
| Site G3 |                       |                                |                 |           |           |
| 6   | upper level          | 0.35 m down from calcrete      | UG-2006-393     | 8200±600 BP   | 6200±600 BCE |
| 7   | upper level          | 1.0 m down from calcrete       | UG-2007-446     | 10,800±1200 BP | 8800±1200 BCE |
| 8   | upper level          | 0.75 m down from calcrete; thickness of dune 2.0–3.0 m | UG-2006-394     | 11,100±1200 BP | 9100±1200 BCE |
| Site G4 |                       |                                |                 |           |           |
| 9   | G4 upper level       | 1.0 m down from calcrete       | UG-2007-448     | 10,500±1200 BP | 8500±1200 BCE |

Microliths, bone harpoon points and hooks, and ceramics with dotted wavy-line and zigzag impressed motifs were found in the burial fill, in an associated refuse area, and in nearby paleolake deposits (Figure 7C–F). These artifacts exhibit attributes of the Kifli technocomplex, named after the type site Adrar-n-Kifl at Adrar Bous some 500 km to the north [28,29]. Direct dates on bone harpoon points and plant temper in Kifli sherds confirm the association of several of these artifacts with this occupational phase (Figure 3; Table 2, dates 26–28, 64, 65). Nile perch (Lates niloticus) and large catfish dominate the midden fauna, which also includes bones and teeth from hippos, several bovids, small carnivores, softshell turtles and crocodiles (Table 5, refuse area 5). The burial density, tool kit, ceramics, and midden fauna suggest a largely sedentary population with a subsistence economy based on fishing and on hunting of a range of savanna vertebrates.

Pollen from phase 2 burials at site G3 indicates an open, low-diversity savanna with grasses and sedges, and an arboreal component including fig (Ficus) and tamarisk (Tamarix). Hydrophytes and rushes (Juncus) suggest the presence of permanent water and marshy habitats [13,30]. Nevertheless, serophyles including saltbushes (Chenopodiaceae) are significant, indicating that sandy habitats were also present, although perhaps distant, in the region.

Toward the end of phase 2 (~6500–6300 B.C.E.), the level of Paleolake Gobero rose, at least episodically, submerging the paleodunes and forcing the relocation of occupants (Figure 1D). Well-aerated permanent water at depths of 5 m or more are suggested by large vertebrae (up to 5 cm diameter) of the Nile perch (Lates niloticus), which correspond to a body length of up to 2 m [31]. These vertebrae were found in situ in paleolake sediments and directly dated to the end of this phase (Figure 3; Table 2, dates 57, 58, midpoint average 6525 B.C.E.). The darkened bone color of all human skeletons in phase 2 burials is indicative of sustained inundation. Inundation, nevertheless, may have been episodic, as a dark-stained human skeleton (G3B28), Kifli potsherd, refuse area, and hartebeest skeleton (Alcelaphus buselaphus) are also directly dated to this interval (Figure 3; Table 2, dates 8, 28, 40, 41, 56; midpoint range 6540–6295 B.C.E.).
Table 2. Ages and associated data for 78 radiocarbon $^{14}$C AMS dates, which are shown graphically in Figure 3 (bottom to top).

| Date No. | Sample Type | Lab No. | $^{14}$C Age (conventional) Cal BC (95%) (midpoint) Specimen | Notes |
|----------|-------------|---------|----------------------------------------------------------|-------|
| 1        | enamel      | P-587   | 8640 ± 40 BP 7730–7580 (7655 cal BC) G3B7                | Subadult in vertical burial (dark-stained bone) |
| 2        | enamel      | P-590   | 8620 ± 40 BP 7680–7580 (7630 cal BC) G3B17B              | Double juvenile burial (4- & 5-year old); 5-year old (dark-stained bone) |
| 3        | enamel      | P-542   | 8570 ± 40 BP 7600–7550 (7575 cal BC) G3B9                | Adult male (dark-stained bone) |
| 4        | femur (internal) | P-583 | 8470 ± 40 BP 7570–7490 (7535 cal BC) G3B8                | Adult male, tightly hyperflexed, supine; sherd with dotted wavy line decoration under skeleton (dark-stained bone) |
| 5        | enamel      | P-584   | 8420 ± 40 BP 7570–7460 (7515 cal BC) -                   | -     |
| 6        | femur (surface) | P-582 | 8220 ± 40 BP 7350–7080 (7215 cal BC) -                   | -     |
| 7        | enamel      | P-546   | 8330 ± 40 BP 7510–7310 (7410 cal BC) G3B23               | Adult female (dark-stained bone) |
| 8        | enamel      | P-544   | 7390 ± 40 BP 6380–6210 (6295 cal BC) G3B28               | Adult (dark-stained bone) |
| 9        | enamel      | P-595   | 5940 ± 40 BP 4930–4720 (4825 cal BC) G1B11               | Adult male with mud turtle carapace (Pelusios) under skeleton (intermediate-stained bone) |
| 10       | enamel      | P-541   | 5620 ± 40 BP 4530–4360 (4445 cal BC) -                   | -     |
| 11       | femur      | P-581   | 5570 ± 40 BP 4470–4340 (4405 cal BC) -                   | -     |
| 12       | enamel      | P-634   | 5140 ± 40 BP 4030–3810 (3920 cal BC) G2B1                | Adult male (dark-stained bone) |
| 13       | enamel      | P-633   | 4990 ± 40 BP 3940–3660 (3800 cal BC) G5B2                | Adult male (dark-stained bone) |
| 14       | enamel      | P-586   | 5180 ± 40 BP 4040–3950 (3995 cal BC) G3B6                | Adult female |
| 15       | enamel      | P-540   | 4990 ± 40 BP 3940–3660 (3800 cal BC) G3B5                | Adult male |
| 16       | enamel      | P-585   | 4910 ± 40 BP 3770–3660 (3705 cal BC) G3B3                | Adult male |
| 17       | enamel      | P-545   | 4860 ± 40 BP 3700–3540 (3625 cal BC) G3B41               | Adult female with necklace |
| 18       | enamel      | P-543   | 4710 ± 40 BP 3630–3370 (3505 cal BC) G3B36               | Adult male, skull in half ceramic pot; grave goods include croc astragalus, boar tusk |
| 19       | enamel      | P-547   | 4690 ± 40 BP 3630–3360 (3495 cal BC) G3B24               | Adult near Midden 4 |
| 20       | enamel      | P-594   | 4590 ± 40 BP 3500–3130 (3315 cal BC) G1B8                | Adult female in triple burial |
| 21       | femur      | P-589   | 4090 ± 40 BP 2860–2490 (2675 cal BC) -                   | -     |
| 22       | enamel      | P-588   | 4380 ± 40 BP 3100–2900 (3000 cal BC) G1B5                | Juvenile male with frontal osteoporosis |
| 23       | enamel      | P-548   | 4370 ± 40 BP 3090–2900 (2995 cal BC) G1B7                | Adult female |
| 24       | enamel      | P-592   | 4360 ± 40 BP 3090–2900 (2995 cal BC) G1B6                | Adult female, partial toad skeleton found under skull |
| 25       | enamel      | P-593   | 4250 ± 40 BP 2910–2760 (2835 cal BC) G1B2                | Juvenile female with upper arm bracelet |
| 26       | partial pot | P-539   | 8150 ± 40 BP 7300–7060 (7180 cal BC) GA107               | In situ in lakebed between G1 and G2, packed zigzags (Kiffian) |
| 27       | sherd      | P-535   | 8060 ± 40 BP 7080–6840 (6960 cal BC) G3-98               | Under skeleton G3B8 (dark-stained bone), dotted wavy line (Kiffian) |
| 28       | sherd      | P-538   | 7570 ± 40 BP 6470–6390 (6430 cal BC) G3-97               | In ribcage of skeleton GIB3 (light-colored bone), 20 cm down, packed zigzag (Kiffian) |
| 29       | sherd      | P-611   | 6170 ± 40 BP 5220–5000 (5110 cal BC) G1-135              | In burial G1B16 (light-colored bone), level 1, packed zigzag (Kiffian) |
### Table 2. cont.

| Date No. | Sample Type | Lab No. | Δ¹³C Val (PDB) | Δ¹⁴C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|----------------|-------------------------|------------------------|----------|-------|
| 30       | sherd       | P-533   | −17.40         | 5170 ± 40 BP            | 4040–3940 (3990 cal BC) | G3-96    | In burial G3B36 (intermediate-stained bone), level 2, alternating pivoting stamp (Tenerean) |
| 31       | partial pot | P-534   | −15.40         | 5130 ± 40 BP            | 3990–3800 (3895 cal BC) | G3-94    | In burial G3B36 (intermediate-stained bone), level 2, alternating pivoting stamp (Tenerean) |
| 32       | sherd       | P-612   | −24.27         | 5020 ± 40 BP            | 3950–3700 (3825 cal BC) | G3-90    | In burial G3B16 (dark-stained bone), level 1, spaced zigzag (Kiffian) |
| 33       | sherd       | P-536   | −17.26         | 5010 ± 40 BP            | 3940–3700 (3820 cal BC) | G3-95    | In burial G3B36 (intermediate-stained bone), level 2, packed zigzag (Kiffian) |
| 34       | sherd       | P-613   | −21.59         | 4950 ± 40 BP            | 3800–3650 (3725 cal BC) | G3-91    | In burial G3B24 (light-colored bone), level 1, spaced zigzag (Kiffian) |
| 35       | partial pot | P-615   | −15.75         | 3640 ± 40 BP            | 2130–1900 (2015 cal BC) | GB-3     | In situ in lakebed at G8, undecorated (Late Tenerean) |
| 36       | partial pot | P-616   | −13.94         | 2240 ± 40 BP            | 390–200 (205 cal BC)   | GA17     | In situ over charcoal layer on red sandstone west of G3, undecorated (Late Tenerean) |

**Charcoals**

| Date No. | Sample Type | Lab No. | Δ¹³C Val (PDB) | Δ¹⁴C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|----------------|-------------------------|------------------------|----------|-------|
| 37       | charcoal    | UCIAMS 34745 | —  | 3555 ± 25 BP       | 1980–1770 (1875 cal BC) | G1B3     | Particle in G1B3 burial (weak acid-base treatment) |
| 38       | charcoal    | UCIAMS 35600 | −15.70 | 2345 ± 25 BP       | 510–370 (440 cal BC)  | GA17a,b  | Charcoal from a hearth in situ directly under pot GA17, GA17a (date 38) is acid-base-NO₃-treated, GA17b (date 39) is humic acids from pretreatment |
| 39       | charcoal    | UCIAMS 35601 | −14.30 | 2205 ± 25 BP       | 370–190 (280 cal BC)  |          |       |

**Midden**

| Date No. | Sample Type | Lab No. | Δ¹³C Val (PDB) | Δ¹⁴C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|----------------|-------------------------|------------------------|----------|-------|
| 40       | bone        | P-682   | −2.79          | 7700 ± 40 BP            | 6620–6460 (6540 cal BC) | B6N–140E | Refuse area 5, Redunca rubida phalanx (dark-stained bone) |
| 41       | bone        | P-683   | −5.21          | 7480 ± 40 BP            | 6430–6240 (6335 cal BC) | B6N–140E | Refuse area 5, Lates niloticus vertebra, top 5 cm |
| 42       | clam        | UCIAMS 35940 | −3.50 | 5665 ± 20 BP       | 4545–4455 (4300 cal BC) | —        | Midden 4 (HCl-etched nacreous shell), near G3B24 |
| 43       | clam        | UCIAMS 35941 | −0.80          | 5535 ± 20 BP            | 4450–4330 (4390 cal BC) | —        | Midden 4 (chalky exterior shell); midden near G3B24 |
| 44       | sherd       | P-529   | −17.58         | 5240 ± 40 BP            | 4230–3970 (4100 cal BC) | G1-132   | Midden 1, level 1, alternating pivoting stamp (Tenerean) |
| 45       | sherd       | P-531   | −13.77         | 5090 ± 40 BP            | 3970–3790 (3880 cal BC) | G1-131   | Midden 1, level 1, packed zigzag (Kiffian) |
| 46       | sherd       | P-532   | −13.78         | 5030 ± 40 BP            | 3950–3710 (3830 cal BC) | G1-133   | Midden 1, level 2, packed zigzag (Kiffian) |
| 47       | clam        | UCIAMS 35944 | −3.90 | 5065 ± 20 BP       | 3950–3790 (3870 cal BC) | Clam A   | Midden 1 (chalky exterior shell) |
| 48       | clam        | UCIAMS 35946 | −0.40          | 5040 ± 15 BP            | 3950–3780 (3865 cal BC) | Clam B   | Midden 1 (HCl-leached hinge, nacreous shell) |
| 49       | clam        | UCIAMS 35945 | −1.20          | 5005 ± 15 BP            | 3910–3710 (3810 cal BC) | Clam C   | Midden 1 (150 µm thick section, innermost calcite) |
| 50       | bone        | P-549   | 0.45           | 4210 ± 40 BP            | 2900–2670 (2785 cal BC) | G1-136   | Midden 1, level 2, Bos taurus femur found in situ (107N, 132E) on G1; proximal femur with epiphysis |
| 51       | sherd       | P-532   | −15.77         | 4600 ± 40 BP            | 3500–3190 (3345cal BC) | G1-134   | Midden 2, level 1, undecorated (?) tradition |
| 52       | sherd       | P-537   | −13.95         | 4530 ± 40 BP            | 3360–3090 (3345 cal BC) | G1-135   | Midden 2, level 1, packed zigzag (Kiffian) |
| 53       | bone        | UCIAMS 35598 | −6.40         | 4445 ± 25 BP            | 3330–3010 (3170 cal BC) | —        | Midden 2 (humic acids from “decalification supernatant slit-charcoal”) |
| 54       | bone        | UCIAMS 35599 | −8.90          | 4445 ± 25 BP            | 3330–3010 (3170 cal BC) | —        | Midden 2 (humic acids from decalcified burnt bone) |

**Fauna**

| Date No. | Sample Type | Lab No. | Δ¹³C Val (PDB) | Δ¹⁴C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|----------------|-------------------------|------------------------|----------|-------|
| 55       | bone        | P-689   | −1.13          | 8820 ± 40 BP            | 8200–7740 (7970 cal BC) | G1-49    | Bovid astragalus on top of G1, deflated (dark-stained bone) |
| 56       | bone        | P-687   | 1.83           | 7810 ± 40 BP            | 6690–6580 (6635 cal BC) | GF22     | Alcelaphus buselaphus metatarsus midshaft section (2 cm) in situ in lakebed G7 (dark-stained bone) |
| 57       | bone        | P-688   | −0.15          | 7720 ± 40 BP            | 6640–6470 (6555 cal BC) | —        | Lates niloticus vertebra, lakebed G6, deflated |
Table 2. cont.

| Date No. | Sample Type | Lab No. | $^{13}$C %o (PDB) | $^{14}$C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|-------------------|-----------------------------|------------------------|----------|-------|
| 58       | bone        | P-691   | 0.61              | 7210 ± 40 BP                | 6560–6430 (6495 cal BC)| GF11     | Lates niloticus vertebra, 5 cm diameter, in situ between G1–G2, [dark-stained bone] |
| 59       | enamel      | P-607   | −0.53             | 4990 ± 40 BP                | 3940–3660 (3800 cal BC)| GF10     | Bos taurus molar |
| 60       | bone        | P-608   | 1.15              | 4930 ± 40 BP                | 3790–3640 (3715 cal BC)|          | Bos taurus mandible [dark-stained bone] |
| 61       | bone        | P-685   | −1.39             | 4130 ± 40 BP                | 2880–2570 (2725 cal BC)| GF75     | Oryx damnah metatarsal, in situ in lakebed south of G3 |
| 62       | bone        | P-690   | 1.75              | 4050 ± 40 BP                | 2840–2480 (2660 cal BC)| GF13     | Hippotragus equinus astragalus, lakebed, deflated |
| 63       | bone        | P-686   | −4.81             | 3910 ± 40 BP                | 2480–2290 (2385 cal BC)|          | G3–1/SR7290 Crocodylus niloticus scute in lakebed, deflated |

**Artifacts**

| Date No. | Sample Type | Lab No. | $^{13}$C %o (PDB) | $^{14}$C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|-------------------|-----------------------------|------------------------|----------|-------|
| 64       | bone harpoon point | P-694  | −9.00             | 7690 ± 50 BP                | 6590–6470 (6530 cal BC)| G3-86a   | Harpoon, in situ in Refuse area 5 |
| 65       | bone harpoon point | P-695  | −0.90             | 7850 ± 50 BP                | 6770–6600 (6685 cal BC)| G3-86b   | Harpoon, in situ in Refuse area 5 |
| 66       | bone harpoon point | P-692  | −0.20             | 5500 ± 40 BP                | 4450–4270 (4560 cal BC)| GA59     | Harpoon, in situ in G6 lakebed |
| 67       | ostrich eggshell bead | CEDAD  | −6.10             | 5348 ± 55 BP                | 4330–4040 (4185 cal BC)| G3-1a    | Eggshell bead associated with burial G3B4 and encrusted with calcrete |
| 68       | bone harpoon point | P-693  | 3.60              | 5130 ± 50 BP                | 3990–3700 (3895 cal BC)| GA41     | Harpoon, in situ in G6 lakebed |

**Sediments & Molluscs**

| Date No. | Sample Type | Lab No. | $^{13}$C %o (PDB) | $^{14}$C Age (conventional) | Cal BC (95%) (midpoint) | Specimen | Notes |
|----------|-------------|---------|-------------------|-----------------------------|------------------------|----------|-------|
| 69       | snail       | UCIAMS 35937 | 5.00         | 6650 ± 20 BP                | 5625–5535 (5580 cal BC)| GF80     | G1-2 lakebed (HCl-leached gastropods, Melanoides) |
| 70       | clam        | UCIAMS 35597 | −15.50        | 5745 ± 30 BP                | 4690–4500 (4595 cal BC)|         | G1-2 lakebed clam, black particulate carbon from sediment filling shell interior |
| 71       | clam        | UCIAMS 35596 | −14.70        | 5505 ± 25 BP                | 4450–4270 (4360 cal BC)|         | G1-2 lakebed clam, humic acids from sediment filling shell interior |
| 72       | clam        | UCIAMS 35942 | 0.70          | 4955 ± 20 BP                | 3790–3660 (3725 cal BC)|         | G1-2 lakebed clam, chalky exterior, outer shell surface |
| 73       | clam        | UCIAMS 35943 | 0.80          | 4940 ± 20 BP                | 3770–3650 (3710 cal BC)|         | G1-2 lakebed clam, HCl-etched nacreous hinge |
| 74       | calcite     | ISGS     | −3.50          | 5120 ± 30 BP                | 3990–3800 (3895 cal BC)| G3       | G3 calcite, east side; inorganic C from CO$_3$ |
| 75       | lakebed     | ISGS     | −17.50         | 6250 ± 180 BP               | 5550–4750 (5150 cal BC)| G6       | G6 lakebed sediment, 20–25 cm depth; below organic rich layer; low organic C yield |
| 76       | clam        | CEDAD    | 1.70           | 4562 ± 35 BP                | 3490–3100 (3295 cal BC)| G6       | G6 lakebed clam, composite shell (did not isolate organic layer) |
| 77       | clam        | UCIAMS 35939 | 2.00          | 4420 ± 20 BP                | 3270–2920 (3095 cal BC)| G6a,b    | G6 lakebed clam, G6a (date 77) is HCl-leached hinge zone shell, G6b (date 78) is from chalky exterior shell |
| 78       | clam        | UCIAMS 35938 | 0.80          | 4395 ± 20 BP                | 3090–2920 (3005 cal BC)|         | |

Dates from the same specimen or feature are grouped together (shaded or unshaded). For some sherds recovered in burials with Kiffian decorative motifs, dates based on plant temper are older than 6000 B.C.E. [dates 26–28]. Other sherds found in burials and middens with Kiffian decorative motifs and dates based on plant temper are younger than 6000 B.C.E. [dates 29, 32, 34, 45, 46, 52]. Although these younger ages may be aberrant (EAAG), they are concordant with dates based on other materials when found in the same midden [dates 44–54, JFS]. Likewise, two direct dates on bone harpoon points [dates 64, 65] are concordant with other dated material in refuse area 5 associated with the early Holocene occupational phase 2 [dates 64, 65]. An additional pair of direct dates [dates 66, 68] on bone harpoon points found in situ in paleolake sediment, however, are more than 2 kyr younger and date to the middle of the mid-Holocene occupational phase 3. Additional testing of bone harpoon points is warranted to better understand these results.

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Because spillways external to the restricted catchment for Paleolake Gobero may have kept inundation levels under 10 m (Figure 1D), it is possible that floodwaters may not have displaced lakeside occupants by a long distance or over a long temporal span. The inundation history at Gobero is doubtless complex, as the earliest mid-Holocene burials are also variegated or darkly stained (Table 2, dates 9–13; midpoint range 4825–3860 B.C.E.). Resolving additional inundation events of short duration will require further direct dates on paleolake fauna and sediments.

Figure 3. Radiocarbon (¹⁴C AMS) dates for human skeletons, ceramics, charcoals, middens, fauna, artifacts and sediment. Timelines and occupation phases 1–4 are shown at the bottom. Associated chronometric data are compiled in Table 2 using current atmospheric standards [55]. All of the burials that have been dated at Gobero fall within phases 2 and 3, which are shown as green to indicate favorable humid climate conditions; more arid intervals are shown as tan including occupation phases 1 and 4. Multiple dates on individual specimens or features are boxed. A dotted line separates early and mid-Holocene human burials. Abbreviations: B.C.E., before current era (registered to calendar year zero); B.P., before present (1950); G1B8, burial 8 on G1; G1B11, burial 11 on G1; G3B8, burial 8 on G3; K, Kiffian; LT, Late Tenerean; T, Tenerean. doi:10.1371/journal.pone.0002995.g003
Occupational Interruption (6200–5200 B.C.E.). A harsh arid interval separates early and mid-Holocene populations at Gobero, when the paleolake appears to have dried out and the area abandoned. Although we have no means to directly assess aridity, no terrestrial or aquatic vertebrates or lakebed sediment have been dated to this interval, which lasted approximately one millennium (Figure 3). The only specimen dated within this interval were found in the paleolake deposit and consist of a cluster of the small gastropod *Melanoides tuberculata*, a species that prefers periodically flooded habitats to permanent water bodies.

This occupational hiatus correlates well with the “arid interruption” in the central Sahara [12], a somewhat shorter interval (~6400–6000 B.C.E.; ~400 yr) of severe climatic deterioration across the Chad Basin [5,12] linked to cooling events in the North Atlantic [13,14]. This overlaps the early portion of the occupational hiatus at Gobero, the beginning of which is set after the youngest burial dated so far in occupation phase 2 (Figure 3; Table 2, date 8, 6380–6210 B.C.E., midpoint 6295 B.C.E.). The end of the occupational interruption is set just before direct dates that indicate the return of humid conditions, including paleolake sediment 20–25 cm below the fossil-rich zone (Figure 1B, E, section 9; Figure 3; Table 2, date 75, 5550–4750 B.C.E., midpoint 5150 B.C.E.), a ceramic sherd from burial fill in site G1 (Figure 3; Table 2, date 29, 5220–5000 B.C.E., midpoint 5110 B.C.E.), and the oldest burial dated so far from occupation phase 3 (Figures 3, 5A–C; Table 2, dated dates 9, 10, midpoint average 4635 B.C.E.).

Phase 3—Mid-Holocene Occupation (5200–2500 B.C.E.). Phase 3 is a long interval over two millennia in length that witnessed the return of humid conditions and the re-occupation of Gobero by humans that account for approximately one-half of excavated burials (Figure 3; Table 2, dates 9–25). The lower boundary of this phase marks the end of the occupational interruption and, as discussed above, is based on dates on lakebed sediment, a potsherd from burial fill, and the oldest burial in the occupation phase (Figures 3, 5A–C). The oldest skeletons within this phase have variegated or dark-stained bone and appear to have undergone episodes of inundation postdating their internment (Figure 5A–C, Table 2, dates 9–13). Occupational phase 3 at Gobero comes to a close with the youngest dated burial, a subadult approximately 11 years old (Figures 3, 5D; Table 2, date 25, 2910–2760 B.C.E., midpoint 2835 B.C.E.).

Phase 3 humans have more gracile skeletons and shorter stature for both males and females. They are buried most commonly in semi-flexed postures on either left or right sides (Figure 5D, E). Their crania are long, high and narrow, and their faces are taller with considerable alveolar prognathism (Figure 5C). Principal components analysis of craniometric data clearly distinguishes the mid-Holocene population at Gobero (Gob-m) from all other sampled populations, including the early Holocene population at Gobero, Iberomaurusian and Capsian populations from the Maghreb, “Mechtoids” from Mali and Mauritania, as well as much older Aterian samples (Figure 6). The morphological isolation of the mid-Holocene population from Gobero is particularly noteworthy, as several of the other populations sampled (WMG, Mali, Maur) are believed to be mid-Holocene contemporaries.

Grave goods occur in approximately 20% of the burials excavated thus far (7 of 33 burials) and include bones or tusks from wild fauna, ceramics, lithic projectile points, and bone, ivory and shell ornaments (Figures 5B, 7A, B, H, K–M). Although the disc knife that characterizes the mid-Holocene Tenerean industry [28,29] has never been recovered in situ, small projectile points that also characterize the Tenerean tool kit are present in some burials that are directly dated to the mid-Holocene (Figure 7I; Figure 4. Early Holocene cemetery, burials and skulls. (A)-Gobero site G3 showing excavated burials (red dots). (B)-Enlarged map of the early Holocene cemetery showing the location of 17 undisturbed burials of skeletons with dark-stained bone (red dots). Five burials (red dot with outer ring) were directly dated to a narrow range of ~7500±250 years B.C.E. (Figure 2; Table 2). (C)-Skeleton (dark-stained) of an early Holocene adult male (G388; ~7515 B.C.E.) buried in supine, hyperflexed posture with hands over the mouth and feet crossed. Computed-tomography cross-section (below) across the middle of the skeleton (red line) shows the tightly bundled configuration of major limb bones (within a 25 cm × 12 cm rectangle) for an adult with stature approximately 2 m. (D)-Skull of early Holocene adult male (as in C) showing long, low calvarium, broad zygomatic width and relatively flat face. (E)-Skull of an early Holocene juvenile (G3817b; ~7630 B.C.E; estimated age 5 years) already showing long, low cranial proportions. Scale bar in C equals 13.3 cm for skeleton and 10 cm for CT scan; skull length (glabella-opisthocranion) in D and E equals 190.0 mm and 171.0 mm, respectively. Abbreviations: f, femur, fl, fibula; h, humerus; r, radius; t, tibia; ul, ulna. doi:10.1371/journal.pone.0002995.g004
Table 2, date 20, 3500–3130 B.C.E., midpoint 3315 B.C.E.). Burials of particular note include an adult male with his skull resting on a half vessel decorated with an alternately pivoting stamped impression (Figure 7A, B; Table 2, date 18, midpoint 3500 B.C.E). Another adult male was buried in a recumbent posture seated on the carapace of a mud turtle (Figure 5A–C; Table 2, dates 9, 10, midpoint average 4635 B.C.E.). A triple burial, composed of an adult female and two juveniles, has intertwined arms, hands and legs, suggesting that they died nearly simultaneously and were interred in an intimate pose within a short period of time (Figure 5E, F; Table 2, date 20, midpoint 3315 B.C.E). Four hollow-based points lie between their limbs and underneath their skeletons (Figure 7H), and pollen clusters from flower heads of the wool flower (Celosia) were detected in underlying sediment. Like other burials at Gobero, these individuals show no sign of a violent traumatic death.

A conspicuous fine-grained green rock (with tan and brown variants) was often used for points, scrapers and adzes (Figure 7G, I) and always used for the delicate Tenerean disc knives [28,29] at sites east and south of the Air massif. Previously this distinctive rock was identified as microcrystalline quartz, initially as jasper [32] and later as silicified vitric tuff [28]. For some 50 years, its
source has remained a matter of speculation. Along with amazonite, the green rock was cited as evidence of trade over distances of one thousand kilometers or more, in order to link the Aïr with Tibesti (northern Chad-southern Libya) or regions farther afield [28,33,34].

Thin sections of artifacts made from the green rock and its color variants show the near absence of quartz. It is correctly identified as a felsite, a fine-grained volcanic rock composed of microcrystalline feldspar [35]. During reconnaissance a short distance (160 km) north of Gobero on the edge of the Aïr massif, we located a narrow outcrop of green felsite rock near the Alallaka wadi (Figures 1A, 8A). The site is littered with debitage from a longstanding knapping operation (Figure 8B). The frequent use of this rock at Gobero and Adrar Bous and its availability in nearby wadis along the eastern edge of the massif (Takolokouzet highland) suggests there were multiple felsite sources local to the Aïr. Given the absence of thorough geologic reconnaissance in the Aïr or any comparative trace element analysis, neither felsite nor amazonite provides evidence to infer trans-Saharan trade in the early or mid-Holocene.

At least semi-sedentary occupation is inferred from the number and density of undisturbed mid-Holocene burials, lack of evidence from strontium isotope analysis for enhanced mobility, abundance of lithic debitage on site, presence of groundstones, and numerous rodent marks on human bone and ornaments indicative of commensal species (Figure 7L) [36,37]. The prevalence of juveniles of very young age among the interred also favors longer term occupation by family groups over transient visitation of the area as a watering hole or attractive hunting ground.

Clams (Mutela) , small catfish (Clarias) and tilapia dominate the midden fauna (Figure 9), which also includes bones and teeth from hippos, a small antelope, small carnivores, softshell turtles and crocodiles (Table 5; middens 1–4). Domesticated cattle (Bos taurus) are present but unlike Adrar Bous [28,29] comprise only a minor component of the midden and area fauna (Figure 3, Bos partial mandible on chart sidebar; GF10). The scarcity of bones or teeth of domesticated cattle suggests a subsistence economy emphasizing fishing in shallow waters and hunting of a range of savanna vertebrates. The gathering of grain and cattle pastoralism may also have played important nutritional or economic roles; further data relevant to occupancy and subsistence patterns are needed, such as seasonality data from piscine otoliths recovered from middens. Elsewhere in the southern Sahara, diversification of dietary resources that combine gathering, hunting, fishing and pastoralism seems to occur under less certain climatic conditions [34,38,39], a pattern that may well accommodate the emerging archaeological record during the mid-Holocene at Gobero.

Pollen spectra from phase 3 burials indicate a mosaic of habitats. Open savannas with shrubland and grassland vegetation dominated, with sporadic presence of a fairly diversified Sudanian and tropical tree flora (Figure 10). Plants linked to wet environments include hydrophytes, which indicate the presence of shallow freshwater lakes. Xeric and psammophilous plants indicate the presence of sandy soils.

Table 3. Nine human populations sampled for craniometric analysis ranging in age from the Late Pleistocene (ca. 80,000 BP, Aterian) to the mid-Holocene (ca. 4000 BP) and in geographic distribution across the Maghreb to the southern Sahara [18,19,26,27,54].

| No. | Sample Size | Area, Form/Culture (Age) | Acronym or Abbreviation | Sites |
|-----|-------------|--------------------------|------------------------|-------|
| 1   | 6           | Sahara, Aterian (Late Pleistocene) | Ater | Témara, Dar-es-Soltan |
| 2   | 39          | Eastern Maghreb, Iberomaurusian (Late Pleistocene) | EMI | Kef-oum-Touiza, Ali-Bacha, Afalou-bou-Rhummel |
| 3   | 5           | Western Maghreb, Iberomaurusian (Late Pleistocene) | WMI | Taforalt, Taza I, Rachgoun 4, La Mouilah |
| 4   | 14          | Eastern Maghreb, Capsian (early Holocene) | EMC | Ain Dokkara, Khanguet-el-Mouhaad, Medjez II, Ain Mentechem, Aioun Beriche, Grotte des Hyenes, Mechta-el-Arbi, Gambetta |
| 5   | 22          | Western Maghreb, Capsian (early to mid-Holocene) | WMC | Columnata |
| 6   | 69          | Mauritania, “Mechtoid” (mid-Holocene) | Maur | Izriten, Sebkha Lasaila, Sebkha Amtal, Sebkha Maharit, Sebkha Lemheirs, Sebkha Edjaila, Tintan, Chami |
| 7   | 45          | Mali, “Mechtoid” (mid-Holocene) | Mali | Hassi-el-Abiod, Asselar |
| 8   | 6           | Gobero, Kiffian (early Holocene) | Gob-e | Gobero (G3) |
| 9   | 12          | Gobero, Tenerean (mid-Holocene) | Gob-m | Gobero (G1-3, G5) |

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Phase 4—Transient Presence (2500–300 B.C.E.). Phase 4 marks the onset of widespread aridification in the Sahara [4,5,7,8,12–14] and brings to a close the record at Gobero. Several undecorated pots, one with an underlying hearth, have been directly dated to this interval (Figure 3; Table 2, dates 35, 36, 38, 39), suggesting the transient presence of more nomadic cattle herders. As with phase 1, there are no burials at Gobero dating to phase 4.

Conclusions. In a recent (2003) review of Niger’s archaeological record [40], the near absence of human remains across the broad expanse of the hyperarid Ténéré Desert was noted. Like many other regions of the Sahara, humid intervals in the early and mid-Holocene created attractive areas for human settlement in Niger. The Gobero site complex, which includes as many as 200 burials, underscores the scale and complexity of human occupation in a “greener” Sahara as well as the fragility of that record under present conditions. We draw the following major inferences from the rich and relatively continuous Holocene record at Gobero:

1) Early Holocene sedentism. The early Holocene occupants at Gobero (7700–6300 B.C.E.) were largely sedentary hunter-fishers-gatherers with lakeside funerary sites that include the earliest recorded cemetery in the Sahara dating to ~7500 B.C.E.

2) Trans-Saharan craniometry. Principal components analysis of craniofacial variables closely allies the early Holocene occupants at Gobero, who were buried with Kiffian material culture, with Late Pleistocene to mid-Holocene humans from the Maghreb and southern Sahara referred to as Iberomaurusians, Capsians and “Mechtoids.” Outliers to this cluster of populations include an older Aterian sample and the mid-Holocene occupants at Gobero associated with Tenerean material culture.

3) Arid interruption. Early and mid-Holocene occupation phases 2 and 3 at Gobero are separated in time by a barren interval (6200–5200 B.C.E.), which is associated with a period of severe aridification recorded across the Sahara.

4) Dietary diversification. Diversification of dietary resources, perhaps in response to increasing or episodic aridification, characterizes mid-Holocene subsistence strategies at Gobero (5200–2500 B.C.E.), as reflected in dated middens containing clams, fish, wild bovids and domesticated cattle.

5) Population replacement. Population replacement rather than gradual phenotypic evolution best explains the distinctive craniofacial morphology and funerary practices of the human occupants during phases 2 and 3 in the early and mid-Holocene, respectively, particularly considering the relatively short intervening occupational hiatus.

6) Regional differentiation. The timing of population change observed at Gobero may only characterize a restricted area. Other areas in the southern Sahara, even those with comparable environmental conditions such as Hassi-el-Abiod in Mali, appear to show a later transition between human populations. The data from Gobero, when combined with existing sites in North Africa, indicate we are just beginning to understand the complex history of biocultural evolution in the face of severe climate fluctuation in the Sahara, a vast region that was occupied for much of the Holocene by an anatomically diverse series of human populations.

Materials and Methods
Discovery and Excavation
The Gobero site complex was discovered in 2000 during palaeontological reconnaissance in central Niger, briefly revisited in 2003, and noted in the press the following year [41]. The Gobero
Archaeological Project was established to coordinate field work and research by an international, multidisciplinary team. Two field seasons (2005, 2006) have been undertaken, during which 67 burials were excavated and the main paleodune burial sites and adjacent paleolake deposits were mapped and sampled. A minimum of 182 human burials are preserved in the central area of the Gobero site complex (G1-5) buried within paleodunes on the edge of a paleolake. With few exceptions, only those burials that have reached the surface have been mapped and/or excavated thus far, and the total number of burials will very likely exceed 200 when the site complex is fully explored and excavated. The paleodunes and lakebed sites also preserve several sediment samples lighter in color, collagen preservation was poor as well. Darkly-stained specimens that were likely subject to prolonged periods of inundation did not preserve collagen; in bone samples lighter in color, collagen preservation was poor as well. We therefore turned to 14C AMS dating of the carbonate component in bioapatite in bone and enamel. Few publications have reported 14C dates on tooth enamel and bone bioapatite, as the method is destructive and less well established than that utilizing bone collagen as a source of radiocarbon. In pre-treatment of samples from Gobero, the cosmic radiation dose was estimated assuming a sediment water content of 5±2% at an altitude of 560 m. Samples were collected on a moonless night from a newly excavated section of paleodune sediment, with a depth ranging from 1–3 m below the paleodune surface (Table 1).

Optically Stimulated Luminescence Dating of Paleodune Sand

When grains of quartz are hidden from exposure to light, they accumulate trapped charges due to ionizing radiation from radionuclides in the sediment. This energy accumulates predictably over time and is released as luminescence after controlled light stimulation in the lab. The age of the sediment (last exposure to daylight) is a measure of the paleodose (radiation dose to which the crystalline material has been exposed) divided by the total radiation dose for each year [42,43]. For the paleodune samples from Gobero, the cosmic radiation dose was estimated assuming a sediment water content of 5±2% at an altitude of 560 m. Samples were collected on a moonless night from a newly excavated section of paleodune sediment, with a depth ranging from 1–3 m below the paleodune surface (Table 1).

Direct 14C AMS Dating of Enamel and Bone

Bone collagen is usually thoroughly degraded in arid environments, which is true for all skeletal samples from Gobero (human, faunal). Darkly-stained specimens that were likely subject to prolonged periods of inundation did not preserve collagen; in bone samples lighter in color, collagen preservation was poor as well. We therefore turned to 14C AMS dating of the carbonate component in bioapatite in bone and enamel. Few publications have reported 14C dates on tooth enamel and bone bioapatite, as the method is destructive and less well established than that utilizing bone collagen as a source of radiocarbon. In pre-treatment of enamel, we used a vacuum as an alternative to acetic acid [44]. Our sampling strategy for human enamel involved replacing all sampled crowns with exact replicas in their original position. We first took photographs in multiple views of the teeth to be sampled. A silicone mold was made for each crown, from which we made a urethane cast. That cast was fixed in the position of the original enamel, we used a vacuum as an alternative to acetic acid [44]. Our sampling strategy for human enamel involved replacing all sampled crowns with exact replicas in their original position. We first took photographs in multiple views of the teeth to be sampled. A silicone mold was made for each crown, from which we made a urethane cast. That cast was fixed in the position of the original crown, using the photographs of the original tooth row prior to sampling. Using this sampling protocol, we retained all information for subsequent dental anthropological analysis.

General concordance between dates on human burials with similar taphonomic signatures and buried in close proximity suggest that the apatite dating is yielding accurate results and that the burials represent a contemporaneous early Holocene cemetery. Five individuals dated to a narrow range of about 250 years (8640–8330 BP; Table 2, dates 1–7).

To test the reliability of using the carbonate component in bioapatite as a source of radiocarbon, we took multiple samples using different source materials from the same individual or...
Figure 7. Ceramic, lithic, bone and hippo ivory artifacts and ornaments. (A) Mid-Holocene adult male (G3B36; ∼3500 B.C.E.) buried with skull resting in a partial ceramic vessel (see B). (B) Side and magnified view of ceramic vessel (G3-94) under skull (see A) showing rocker stamp decoration. Kifian tool kit (C–F). (C) Biserial bone harpoon point with perforated butt (GA154) made from a crocodile dentary. (D) Uniserial fixed barbed point with notched butt (GA130) made from an artiodactyl long bone. (E) Bone hook (GA31a). (F) Crescent-shaped microlith (G1-71b) from site G1 (deflated). Tenerean tool kit (G–I). (G) Felsite bifacial point (G3-1b) associated with an adult male burial (G3B4). (H) One (G1-134) of four hollow-based points associated with a mid-Holocene adult female (G1B8; ∼3315 B.C.E.) in a triple burial (Figure 3E, F). (I) Anterior and magnified view of a felsite adze (GA110c) showing the green color and vesicles common to this source rock. (J) Amazonite pendant (GA124). (K) Upper arm bracelet (G1-7) carved in hippo ivory near the distal end of the left humerus in a juvenile burial (G1B2; ∼2835 B.C.E.). (L) Bead (G3-6 necklace, bead 9) made of hippo ivory showing the paired bite mark from the incisors of a rodent (top, arrow) on a divot removed from the bead margin (bottom). (M) Anterior and magnified lateral views of a pendant (part of G3-6 necklace) carved in hippo ivory and found in situ on a mid-Holocene adult female (G3B41; ∼3620 B.C.E.). Scale bars equal 5 cm in B and 2 cm in L. Ages given above are from 14C AMS dates on enamel bioapatite and represent the midpoint of the calibrated radiocarbon confidence interval (Table 2). Maximum artifact length is 11.9 cm in C, 13.2 cm in D, 2.0 cm in E, 2.3 cm in F, 2.04 cm in G, 2.0 cm in H, 8.2 cm in I, 4.4 cm in J, 8.4 cm in K, and 8.8 cm in M.

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Table 5. Faunal list at Gobero showing taxa recorded at archaeological sites (G1-3), in early and mid-Holocene middens (middens 1–4, refuse area 5), and in the Gobero area (in paleolake deposits or on deflation surfaces).

| Higher Taxon Tribe, Genus, Species | Sites G1-3 | Mid-Holocene Middens 1–4 | Early Holocene Refuse Area 5 | Gobero Area |
|-----------------------------------|------------|--------------------------|-----------------------------|-------------|
| **MOLLUSCA**                      |            |                          |                             |             |
| Gastropoda **Melanoides tuberculata** | +          | x                        |                             | +           |
| Pelecypoda **Murex sp**            | x          | x                        | +                           | +           |
| ?Aspatharia sp                     | +          | +                        | +                           |             |
| **ACTINOPTERYGIA**                 |            |                          |                             |             |
| Polypteridae **Polypterus sp.**    | +          | +                        |                             |             |
| Mormyridae                         | +          | +                        |                             |             |
| Gymnarchus niloticus               |            |                          |                             |             |
| Cyprinidae                         | +          | +                        |                             |             |
| Osteoglossidae **Heterotis niloticus** | +    | +                      |                             |             |
| Siluriformes                       | x          | +                        | x                           | x           |
| Bagridae                           | x          | +                        | +                           |             |
| Auchenoglanis sp.                 |            |                          |                             |             |
| Claridae                           | +          | x                        | x                           | +           |
| Mochocidae                         |            |                          |                             |             |
| Centropomidae **Lates niloticus**  | +          | x                        | x                           | x           |
| Cichlidae                          | x          | x                        | x                           | +           |
| **AMPHIBIA**                       |            |                          |                             |             |
| Bufonidae                          | Gen. et sp. indet. | +                          |                             |             |
| **REPTILIA**                      |            |                          |                             |             |
| Testudines                         | +          | +                        |                             |             |
| Pelomedusidae **Pelusios adansonii** | +        | x                        | +                           | +           |
| Trionychidae                       | +          | +                        | x                           | +           |
| Cyclanorbis senegalensis           |            |                          |                             |             |
| Trionyx trianguis                  |            |                          |                             |             |
| Varanidae                          |            |                          |                             |             |
| Pythonidae                         |            |                          |                             |             |
| Crocodylidae **Crocodylus niloticus** | +        | +                        | x                           | +           |
| **AVES**                           |            |                          |                             |             |
| Palaeognathae **Struthio camelus** | +          | +                        | +                           | +           |
| Neognathae                         | +          | +                        | +                           |             |
| **MAMMALIA**                       |            |                          |                             |             |
| Rodentia                           | +          | +                        | +                           |             |
| Thryonomys swinderianus            | +          | +                        |                             |             |
| Felidae                            |            |                          |                             |             |
| Felis sylvestris                   | +          | +                        |                             |             |
| Panthera leo                       | +          | +                        |                             |             |
| Herpestidae                        | +          | +                        |                             |             |
| Lutrinae                           | +          | +                        |                             |             |
| Canidae                            |            |                          |                             |             |
| Canis aureus                       | +          |                          |                             |             |
| Lycaon pictus                      |            |                          |                             |             |
| Hyaeana hyaeana                    |            |                          |                             |             |
| Elephantidae **Loxodonta africana** | +          |                          |                             |             |
| Suidae                             |            |                          |                             |             |
| Phacochoerus aethiopicus           | +          | +                        | +                           |             |
| Hippopotamidae **Hippopotamus amphibius** | x    | +                        | +                           |             |
| Giraffidae                         | **Giraffa camelopardalis** | +                          |                             | +           |
| Bovidae                            |            |                          |                             |             |
| Gazella sp.                        | +          | +                        | +                           |             |
| Gazella rufifrons                  |            |                          |                             |             |
| Gazella dama                       |            |                          |                             |             |
feature (Table 6). The general concordance of dates validates the method, as seen in three dates from an early Holocene skeleton (Table 6, dates 1–3). The enamel sample, the crystalline structure of which makes isotopic exchanges more difficult, and the core of the femur, which is especially porous after hydrolysis of collagen, still provide concordant dates. This demonstrates the near absence of isotopic exchange under arid conditions. The third estimate of age (Table 6, dates 4–6) is more likely to be the most accurate.

A second multiply-sampled individual (G1B11) is mid-Holocene in age (Table 6, dates 4–6). The discrepancy between dates from this individual is slightly greater and may be due to insufficient purification during pre-treatment. The enamel for one of these samples may have been imperfectly separated from the dentine. Under arid conditions, carbon isotope exchange almost always involves rejuvenation, during which total inorganic dissolved carbon (TIDC) from surface waters tends toward equilibrium with atmospheric CO2. This process results in an average decrease in age of 250 years, a minor correction results in an average decrease in age of 250 years, a minor difference for dates in the early and mid-Holocene. The isotopic exchange of carbon, in addition, does not seem to be linked to time (e.g. 8420 and 8470 BP), but rather to local variation in inundation of surface waters. This result in a younger date. Excluding other complicating factors, the older date (5940 ± 40 BP) suggests slightly greater sensitivity to exchange in bone compared to enamel as expected.

A third human skeleton was sampled twice, using enamel and bone, and also yielded concordant results (Table 6, dates 7, 8). A concordant pair of dates was also obtained using enamel and bone from a cattle mandible (Bos taurus, GF10), which was found deflated on the surface of the paleolake deposit (Table 6, dates 9, 10).

The differences that are apparent between enamel and bone samples from the same individual suggests that bone shows some isotopic exchange with the TIDC surface waters. This rejuvenation results in an average decrease in age of 250 years, a minor difference for dates in the early and mid-Holocene. The isotopic exchange of carbon, in addition, does not seem to be linked to time (e.g. 8420 and 8470 BP), but rather to local variation in inundation of surface waters. The δ13C from bones that experienced early diagenesis remains slightly more positive (e.g. G1B8), but this criterion is too tenuous to be reliable.

Convergence of dates based on multiple sources was also used to evaluate the age of features such as the middens or lakebed fauna. Clam shell from middens or the lakebed that was sampled in multiple ways (leached; chalky exterior shell; dense opalescent, unaltered inner shell) yielded generally concordant results.

In conclusion, dating of the bone and enamel bioapatite has provided the backbone for our chronology (Figure 2). If significant diagenesis were a confounding factor, the dates would show greater dispersion.

Comparative Craniometric Analysis

Craniometric measurements were selected to provide maximum correspondence with previous work on North African Late Pleistocene and Holocene human remains [18,26,27]. Seven chronospatial sample units were defined in accordance with published radiometric dates and allocation of specific sites to particular North African cultures (Table 3, numbers 1–7). The principal components analysis includes all individuals for which data were available and the maximum number of craniometric variables. After individuals were allocated to one of the sampling units, variable means were calculated from the raw data for the following variables: LGO, BPX, LBN, HBB, AFR, APA, AOC, CFR, COC, HNP, HNZ, BNZ, BZY, BF, BF, HRC, AOC, LGO, BPX, LBN, HBB, AFR, APA, AOC, CFR, COC, HNP, HNZ, BNZ, BZY, BF, BF, HRC.

The resulting matrix of means was subjected to principal components analysis to capture the correlations among variable means in a more manageable number of dimensions (Figure 6). The strength of this approach is that it allows maximum inclusion of individuals and variables and thus captures the greatest possible genotypic structure. This approach, however, does not consider within-sample variability, and population affinity is based solely on mean differences.

Three of the loadings from the principal components analysis returned eigenvalues greater than 1.0 (Table 7). Factor loadings transparently reflect anatomical or functional units. The first principal component appears to most closely approximate a size vector, but the loadings are not uniformly positive. The pattern of positive and negative loadings for principal components 2 and 3 are not interpretable.

Strontium Isotope Analysis

In order to investigate residential mobility and sedentism at the Gobero site complex, strontium isotope analysis was performed on archaeological human tooth enamel as well as modern baseline soil and faunal samples. At the Archaeological Chemistry Laboratory at Arizona State University (ASU), the teeth and

| Higher Taxon | Tribe, Genus, Species | Sites G1-3 | Mid-Holocene Middens 1–4 | Early Holocene Refuse Area 5 | Gobero Area |
|--------------|----------------------|-----------|--------------------------|-----------------------------|------------|
| Tragelaphus scriptus | + | + | | | |
| Tragelaphus spekei | + | | | | |
| Tragelaphus strepsiceros | | | | | |
| Taurotragus derbianus | | | | | |
| Redunca reduca | + | + | + | + |
| Kobus ellipsiprymnus | + | | | |
| Kobus kob | + | + | + |
| Hippotragus equinus | | | | | |
| Onyx dammah | | + | | | |
| Alcelaphus buselaphus | | | | | |
| Syncerus caffer | + | | | + |
| Bovini (domestic) | + | | | + |

Abbreviations: +, species present; x, species very common.

1As eggshell beads.

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Table 5. cont.
bone samples were first mechanically cleaned by abrasion with a Dremel 3956-02 Variable Speed MultiPro drill equipped with an engraving cutter to remove the outermost layers of tooth enamel, which are most susceptible to diagenetic contamination. Eight milligrams of tooth enamel powder were dissolved in 0.50 mL of twice-distilled 5 M HNO₃. Bone and soil samples were ashed at 800°C for 10 hours, and then soil samples were digested in concentrated HF and HNO₃.

The strontium, uranium and neodymium concentrations were separated from the sample matrix in the W.M. Keck Foundation Laboratory for Environmental Biogeochemistry (ASU). The strontium was separated using EiChrom SrSpec resin, a crown-ether-selective resin (100–15 μm diameter) loaded into the tip of a glass column. The SrSpec resin was pre-soaked and flushed with H₂O to remove strontium present from the resin manufacturing process. The resin was further cleaned in the column with repeated washes of deionized H₂O and conditioned with 750 μL of HNO₃. The dissolved sample was loaded in 250 μL of 5 M HNO₃, washed in 500 μL of 5 M HNO₃, and then the strontium was eluted with 1000 μL of H₂O. Samples were analyzed using the Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS). Recent ⁸⁷Sr/⁸⁶Sr analyses of strontium carbonate standard SRM-987 yield a value of ⁸⁷Sr/⁸⁶Sr = 0.710261 ± 0.000020 (2σ), which is in agreement with analyses of SRM-987 using a thermal ionization mass spectrometer (TIMS), where ⁸⁷Sr/⁸⁶Sr = 0.710263 ± 0.000016 (2σ) [45].

Uranium and neodymium concentrations were obtained on a quadrupole inductively-coupled plasma mass spectrometer (Q-ICP-MS) to monitor diagenetic contamination in the samples. Since biogenic enamel and bone should have very low concentrations of these elements, elevated concentrations of uranium and neodymium can be used as proxies for the presence of diagenetic contamination of trace elements such as strontium. The mean U/Ca and Nd/Ca ratios are low and within the range of published uncontaminated U/Ca ratios from enamel samples (U/Ca = 1.08 ± 1.33×10⁻⁶, n = 7, 1σ; Nd/Ca = 3.73 ± 3.94×10⁻⁷, n = 7, 1σ).

Baseline strontium isotope data from soil samples soil samples collected from burial sites show that ⁸⁷Sr/⁸⁶Sr = 0.71290 ± 0.00064 (n = 7, 1σ), and modern faunal samples exhibit ⁸⁷Sr/⁸⁶Sr = 0.71261 ± 0.00116 (n = 21, 1σ) (Table 8). The area around Gobero consists of Cretaceous sandstones that are likely to exhibit ⁸⁷Sr/⁸⁶Sr = 0.709–0.710, based on strontium isotope signatures from similar bedrock and archaeological human remains in Egypt and Libya [46,47].

Our preliminary archaeological human enamel data from Gobero (Table 8, ⁸⁷Sr/⁸⁶Sr = 0.71189 ± 0.00039, n = 28, 1σ) closely matches the baseline data outlined above, which suggests that the sampled individuals were not moving between, or migrating from, areas with much lower strontium isotope signatures, such as the Cenozoic volcanic terrain of the Air highlands in northern Niger and Hoggar in southern Algeria (⁸⁷Sr/⁸⁶Sr = 0.703) [48–51].
Figure 10. Pollen composition in mid-Holocene burials. (A) Percentage pollen spectra from three mid-Holocene burials on sites G1 and G3 showing low diversity vegetation and the prevalence of Sahelian phytogeographical character. (B) Arboreal pollen. (C) Non-arboreal pollen. Long distance transport is low, as indicated by the paucity of Mediterranean taxa [15]. Crushed or damaged pollen grains that could be identified were summed in the relevant taxa. Only pollen that could not be identified were included in the deteriorated sum. Abbreviations: CONISS, constrained incremental sum of squares; p/g, pollen per gram.

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Cornulaca half of the spectra with a significant amount of Cyperaceae and samples are sterile. Most pollen is crumpled. Poaceae comprise seven samples from three burials on site G3 (G3B17, G3B8, (Figure 10). were performed at 400 concentration (pollen grains per gram = p/g), and pollen analyses were performed at 400 m (pollen grains per gram = p/g), and pollen analyses were performed at 400 x 1000 x with immersion oil for critical determinations. Graphs are drawn with Tilia and TGView [52], and results are presented using pollen sums of 300–400 grains (Figure 10).

Preliminary data on early Holocene pollen were obtained from seven samples from three burials on site G3 (G3B17, G3B8, G3B9). Concentrations are less than 500 p/g, and two of the samples are sterile. Most pollen is crumpled. Poaceae comprise half of the spectra with a significant amount of Cyperaceae and Cornulaca. ArboREAL pollen includes Ficus, Tamarix and Myrthus. Aquatics include Juncus, Nymphaea and Potamogeton, and many hyphas and fungal spores were observed in G3B17 and G3B8. Microscopic charcoal is present (> 125 µm) in burial in G3B8, suggesting the presence of a hearth in the vicinity of the burial.

Mid-Holocene pollen was analyzed on the basis of 13 samples from burials at sites G1 and G3 (Table 9). Pollen is present in all burials, although concentrations are very low, frequently less than 300 p/g and always less than 600 p/g. The diversity of pollen taxa per sample are also low (minimum 14, maximum 32). When samples from a single burial are combined, diversity remains low in burial G1B18 (53 taxa) but increases in the other two burials (68–78 taxa). Pollen clusters of several taxa are present in sample 3a between the arms of the triple burial (Table 9). Pollen spectra are herb-dominated with prevalence of Poaceae (ca. 60% on average). Cyperaceae and Cornulaca are common with significant percentages in many samples. Cornulaca, for example, is greater than 30% in samples 3a (G1B8-10) and 4b and 5b (G1B18). The ratio D-desert / Sh-Sahelian elements was less than 1.0, the only exception being sample 4b from burial G1B18. ArboREAL pollen, which is always less than 5% of total pollen, includes the ubiquitous Sudanian Ficus plus Moraceae undiff. and the Sahelian Salvadora and Zigiphas (Figure 10B). The Sahelian Capparis is present in burials G1B18 and G3B36. Desert trees such as Acacia are rare, occurring only in sample 1a of the triple burial G1B8-10. Sudanian alluvial or riverine vegetation, such as Celtis, Ficus, Salvadora persica and Hyphaene thebaica, is more common in G1B8-10 (1.5%) than in the other two burials (0.5–0.8%). Saharo-Sindian shrubs and herbs, such as Cornulaca, Cichorae undiff., Ephedra, Plantago, Heliotropium, Zygophyllum, are widespread in the spectra. Pioneer elements, such as Compositae, Polycarpaea and Plantago, are present especially in burial G1B8-10. Bauhavia-type pollen that characterizes a semidesert environment is significant (3.1%) in sample 1b from burial G1B18. Celosia-type trigyna (wool flower) was unusually common (32.4%) in sample 3a from burial G1B8-10, where it occurred in clusters.

Herb plants of wet environments, which measured 0.6–0.7% excluding Cyperaceae, were found in the majority of samples and were slightly more common in burial G3B36. The hydrophytes Lemna and Potamogeton, both of which have submerged and floating leaves, were present in G1B18 and G3B36 (Figure 10C). Typha (cat tail) was found only in trace amounts in sample 2c (G3B36). Algal elements were observed in G1B8-10 and G1B18 (here also including Concentricystis which are algal spores of Zignemataceae [53]. On the other hand, graminoid-type phytoliths, which are silicate or ossalate inclusions of plant epidermids, were abundantly observed in sample 1b from burial G1B18.

Pollen data from the burials are fairly concordant for biopapatite radiocarbon from different materials from the same individual.

### Table 6. Convergence of multiple 14C AMS dates based on bioapatite radiocarbon from different materials from the same individual.

| No. | Material Sampled | 14C AMS Date |
|-----|-----------------|---------------|
| Burial G3B8 | | |
| 1 | enamel | 8420±40 BP |
| 2 | bone (femur interior) | 8470±40 BP |
| 3 | bone (femur surface) | 8220±40 BP |
| Burial G1B11 | | |
| 4 | enamel | 5940±40 BP |
| 5 | enamel | 5620±40 BP |
| 6 | bone (femur) | 5570±40 BP |
| Burial G1B8 | | |
| 7 | enamel | 4590±40 BP |
| 8 | bone (femur) | 4090±40 BP |
| Bos taurus GF10 | | |
| 9 | enamel | 4990±40 BP |
| 10 | bone (mandible) | 4930±40 BP |

### Table 7. Principal component loadings for human samples extracted from matrix of means for North African samples.

| Measurement Acronym | PC1 | PC2 | PC3 |
|---------------------|-----|-----|-----|
| LGO                 | 0.963 | 0.129 | 0.227 |
| BPX                 | 0.873 | 0.463 | -0.140 |
| LBN                 | 0.792 | -0.055 | 0.392 |
| HBB                 | 0.704 | -0.607 | 0.167 |
| AFR                 | 0.901 | -0.373 | -0.010 |
| APA                 | -0.210 | 0.403 | 0.885 |
| AOC                 | 0.497 | 0.850 | -0.169 |
| CFR                 | 0.857 | -0.469 | -0.098 |
| COC                 | 0.609 | 0.678 | -0.182 |
| HNP                 | 0.763 | -0.089 | -0.327 |
| HNZ                 | -0.289 | 0.445 | -0.025 |
| BNZ                 | -0.209 | -0.114 | 0.916 |
| BZY                 | 0.496 | -0.748 | 0.027 |
| BFW                 | 0.853 | -0.433 | 0.256 |
| BFX                 | 0.418 | 0.842 | 0.222 |
| HORC                | 0.760 | 0.645 | 0.077 |

Percent Variance: 46% 27% 13%
Table 8. Strontium isotope \(^{87}\text{Sr}/^{86}\text{Sr}\) results from human enamel in burials at Gobero and baseline samples from modern fauna and soil.

| Laboratory Number | Burial or Specimen Number | Material (acronyms identify tooth sampled) | \(^{87}\text{Sr}/^{86}\text{Sr}\) |
|-------------------|----------------------------|------------------------------------------|--------------------------|
| ACL-0305          | G1B2                       | ULM1                                     | 0.71222                  |
| ACL-0306          | G1B2                       | LRM2                                     | 0.71220                  |
| ACL-0307          | G3B3                       | RC                                       | 0.71160                  |
| ACL-0308          | G1B5                       | ULM2                                     | 0.71293                  |
| ACL-0314          | G3B1                       | LLC                                      | 0.71143                  |
| ACL-0340          | G1B11                      | URM1                                     | 0.71123                  |
| ACL-0341          | G1B11                      | URM2                                     | 0.71147                  |
| ACL-0342          | G1B11                      | URM3                                     | 0.71153                  |
| ACL-0442          | G1B7                       | LRM3                                     | 0.71171                  |
| ACL-0443          | G3B5                       | LLM2                                     | 0.71202                  |
| ACL-0444          | G3B5                       | LLM1                                     | 0.71235                  |
| ACL-0445          | G3B5                       | LLM3                                     | 0.71193                  |
| ACL-0446          | G3B23                      | LLM1                                     | 0.71197                  |
| ACL-0447          | G3B23                      | LLM2                                     | 0.71174                  |
| ACL-0448          | G3B23                      | LLM3                                     | 0.71182                  |
| ACL-0449          | G3B24                      | LLM1                                     | 0.71204                  |
| ACL-0450          | G3B24                      | LLM2                                     | 0.71204                  |
| ACL-0451          | G3B24                      | LLM3                                     | 0.71217                  |
| ACL-0452          | G3B28                      | ULM1                                     | 0.71184                  |
| ACL-0453          | G3B28                      | ULM2                                     | 0.71266                  |
| ACL-0454          | G3B36                      | LLM1                                     | 0.71221                  |
| ACL-0456          | G3B36                      | LLM3                                     | 0.71156                  |
| ACL-0457          | G3B9                       | ULM1                                     | 0.71180                  |
| ACL-0458          | G3B9                       | ULM2                                     | 0.71188                  |
| ACL-0459          | G3B9                       | ULM3                                     | 0.71214                  |
| ACL-0460          | G3B41                      | LLM1                                     | 0.71151                  |
| ACL-0461          | G3B41                      | LLM2                                     | 0.71142                  |
| ACL-0462          | G3B41                      | LLM3                                     | 0.71146                  |
| ACL-0545          | GOB-BCS1                   | bone (Capra hircus)                      | 0.71470                  |
| ACL-0546          | GOB-BCS2                   | enamel (Camelus dromedarius)             | 0.71308                  |
| ACL-0547          | GOB-BCS3                   | enamel (Camelus dromedarius)             | 0.71225                  |
| ACL-0548          | GOB-BCS4                   | enamel (Antilopini sp.)                  | 0.71157                  |
| ACL-0549          | GOB-BCS5                   | bone (rodent)                            | 0.71152                  |
| ACL-0550          | GOB-BCS6                   | bone (rodent from Bubo sp. pellet)        | 0.71261                  |
| ACL-0551          | GOB-BCS7                   | bone (rodent from Bubo sp. pellet)        | 0.71217                  |
| ACL-0552          | GOB-BCS8                   | bone (rodent from Bubo sp. pellet)        | 0.71238                  |
| ACL-0553          | GOB-BCS9                   | bone (rodent from Bubo sp. pellet)        | 0.71444                  |
| ACL-0554          | GOB-BCS10                  | bone (rodent from Bubo sp. pellet)        | 0.71160                  |
| ACL-0555          | GOB-BCS11                  | bone (rodent from Bubo sp. pellet)        | 0.71477                  |
| ACL-0556          | GOB-BCS12                  | bone (rodent from Bubo sp. pellet)        | 0.71080                  |
| ACL-0557          | GOB-BCS13                  | bone (Antilopini sp.)                    | 0.71354                  |
| ACL-0558          | GOB-BCS14                  | bone (caprine or ovine)                  | 0.71371                  |
| ACL-0559          | GOB-BCS15                  | bone (caprine or ovine)                  | 0.71176                  |
| ACL-0560          | GOB-BCS16                  | shell (snail)                            | 0.71120                  |
| ACL-0561          | GOB-BCS17                  | enamel (Hippopotamus sp.)                | 0.71122                  |
| ACL-0562          | GOB-BCS18                  | bone (Antilopini sp.)                    | 0.71251                  |
| ACL-0563          | GOB-BCS19                  | bone (Antilopini sp.)                    | 0.71252                  |
| ACL-0566          | GOB-BCS2                   | enamel (Camelus dromedarius)             | 0.71306                  |
| ACL-0567          | GOB-BCS2                   | enamel (Camelus dromedarius)             | 0.71334                  |
Table 8. cont.

| Laboratory Number | Burial or Specimen Number | Material (acronyms identify tooth sampled) | Sr^60/Sr^80 |
|--------------------|--------------------------|-----------------------------------------|-------------|
| ACL-0643           | GOB-SOI-03                | soil (from burial G1B17)               | 0.71326     |
| ACL-0644           | GOB-SOI-04                | soil (from burial G1B18)               | 0.71347     |
| ACL-0645           | GOB-SOI-05                | soil (from burial G1B6)                | 0.71384     |
| ACL-0655           | GOB-SOI-16                | soil (from burial G3B23)               | 0.71258     |
| ACL-0660           | GOB-SOI-21                | soil (from burial G3B4)                | 0.71245     |
| ACL-0665           | GOB-SOI-26                | soil (from burial G3B7)                | 0.71204     |
| ACL-0667           | GOB-SOI-28                | soil (from burial G3B9)                | 0.71269     |

Abbreviations: ACL, Archaeological Chemistry Laboratory, Arizona State University; c, deciduous canine; l, lower (or left); m, molar; r, right; u, upper.

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Table 9. Pollen sampling for three mid-Holocene burials.

| Sample No. | Description |
|------------|-------------|
| G1B18      | (not dated)        |
| 1          | under the skull   |
| 2          | under the ribs    |
| 3          | inside the stomach|
| 4          | near and inside left hand |
| 5          | under the ribs after removal of skeleton |
| G1B8-10    | (2860–2490 cal BC) (triple burial, Figure 5E, F) |
| 6          | behind thorax of adult G1B8 |
| 7          | between ribs and pelvis to the left of adult G1B8 |
| 8          | between arms of juveniles G1B9 and G1B10 |
| G3B36      | (3630–3370 cal BC) (male with vessel, Figure 7A) |
| 9          | under the skull   |
| 10         | under the femur   |
| 11         | near warthog tusk |
| 12         | between left arm and ribs |
| 13         | inside pot containing skull |

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9. a Saharan environment, with increasing Poaceae and Chenopodiaceae including alophylous shrubs largely spread in salt-rich soils. Chenopodiaceae are common and associated with Poaceae and Cyperaceae. On the other hand, several pollen and other sporomorphs suggest wet environments. For example, Cyperaceae, which includes both aquatic and dune herb species, may sporomorphs suggest wet environments. For example, Cypera-
