# Reports

## Great Sand Sea and Selima Sand Sheet, Eastern Sahara: Geochronology of Desertification

Abstract. *The relation of playa sediments and associated archeological sites with longitudinal dunes allows estimation of ages for the two uppermost strata of the Great Sand Sea. Active dune formation corresponds with interpluvial periods of hyperaridity; dune stability corresponds with semiarid pluvial periods. Archeological sites associated with truncated paleosols in the Selima Sand Sheet suggest a similar climatic relation and indicate that the isohyets of central Sudan shifted at least 400 kilometers northward during the peak of pluvials.*

From Siwa Oasis on the north to the Gilf Kebir plateau on the south, the Great Sand Sea covers approximately 150,000 km$^2$ of eastern Libya and western Egypt (Fig. 1). Since the beginning of recorded history the Sand Sea has been considered a treacherous area because it is a seemingly unending expanse of active windblown sand and no water (*1*). In 1874 the German explorer Rohlfs (*2*) led the first scientific expedition through 450 km of the eastern part by following the "streets" between the dune ridges after a providential rain allowed the expedition to replenish their disastrously low water supply (*2*).

By 1932, when the Sand Sea was first traversed from east to west, several parties had ventured into it with motor vehicles (*3*). During such desert trips Bagnold (*4*), a British signals officer, began to accumulate observations that became the basis for his classic study of the physics of sand dunes, but the age of this giant mass of windblown sand has, until now, remained unknown. The maximum age and origin still remain unknown. Landsat imagery shows ancient drainage networks, extending northward under the Sand Sea from the Gilf Kebir highlands (Fig. 2), which could have provided some of the fluvial sands that were subsequently reworked by wind during periods of hyperaridity (*5*, *6*).

The Great Sand Sea is characterized by a series of nearly continuous, remarkably parallel longitudinal dune ridges up to 1 km or more wide extending downwind from north-northwest to south-southeast and separated by streets up to 5 km wide. In the southern part the desert floor of wind-abraded bedrock and gravelly alluvium is exposed in the streets (Fig. 2), but northward these are covered by increasing thicknesses of aeolian sand. The sand thickness to the north reaches 200 to 300 m, according to recent seismic surveys for the Continental Bahariya Oil Company, whose Foram-1 test well (Fig. 1) penetrated at least 120 m of sand (*7*). It appears, therefore, that the dune ridges, which can exceed 70 m in height, override a giant wedge of sand in the north and extend southward beyond where the wedge feathers out.

The investigation reported here is the result of an expedition organized primarily to examine the occurrence of Libyan Desert glass (LDG) (*8*). The location of our camp in a small deflated playa basin on the east side of dune ridge B-C (*9*) 5 km from its southern terminus (Fig. 2) provided an excellent opportunity to observe the stratigraphic relation between the ephemeral pond muds and the dune sands. In transverse section each dune ridge consists of a basal segment or plinth, unit C, supporting one or more sharp-crested ridges of active dune sand, unit F (Fig. 3a), in the form of longitudinal ridges or coalesced barchans. The plinths or whaleback dunes are composed of laminated, very weakly consolidated sand having a bimodal size distribution and covered by a surface armor of very pale yellow, fine pebbles or coarse sand (*4*, pp. 157 and 229). The steeper

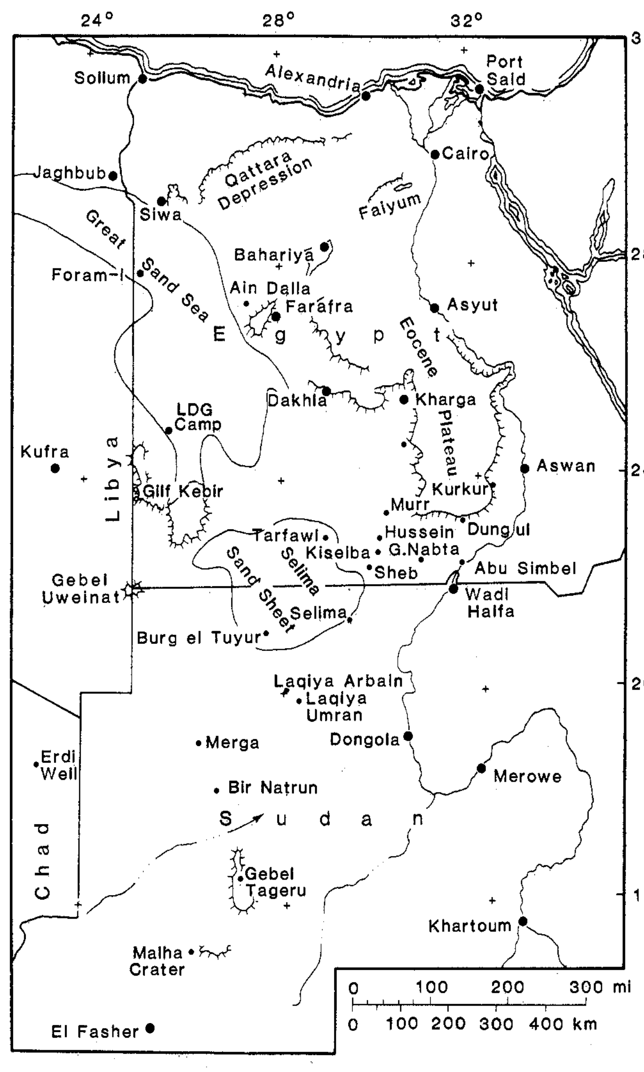


Fig. 1. Map of Egypt showing the Great Sand Sea and the Selima Sand Sheet. Much of the intervening area is discontinuous sand sheets. The borders of the Selima Sand Sheet are currently being remapped.


0036-8075/82/0813-0629$01.00/0 

sided, yellow to reddish-yellow dune ridges are composed of loose, more active, fine to medium-grained sand riding along the tops of the whalebacks. The transition from plinth to ridge is therefore marked, in most cases, by (i) a textural change, (ii) a subtle color change, and (iii) a break in slope from gentle to relatively steep, and steeper yet (31° to 33°) where a slip face is encountered. The stratigraphic contact also varies from sharp to interfingering, similar to the hypothetical internal stratigraphy shown by Bagnold [figure 84 in (4)]. However, there is evidence for a more significant age difference than this might imply.

At our dune ridge B-C camp, pale reddish-brown, firm, sandy playa muds alternating with weakly cemented reddish-brown, reworked dune sands with foreset bedding are inset into an eastward barblike projection of the dune ridge complex (Fig. 3b). From the few test pits that could be excavated in the limited time available it appears that these deposits, unit D, formed from slope wash from the adjacent whaleback, unit C, during a time of greater precipitation. The red and brown hues are presumably due to pedogenic clays winnowed from soil development on the whaleback as well as on the desert floor.

Dune sand, unit E, makes up part of the sandy hook enclosing the southern and eastern sides of the playa basin and is probably partly interbedded with playa facies. Neolithic artifacts and camp debris occur over all surfaces except active dune sand (unit F), but surface concentrations indicate that units D and E were the host sediments. A few flakes and a fire hearth were observed in situ in the playa sediments. Radiocarbon dates on individual lag concentrations of ostrich egg shell indicate at least two separate occupations, one about 4780 ± 50 years ago (A-2517) at the end of or after unit D deposition, and another about 6660 ± 320 years ago (A-2516) near the top of unit E (10). Without more stratigraphic testing it is not possible to be certain of the relative ages of units D and E, but it is reasonable to assume that the occupation at the top of unit E coincided with a playa phase about 6600 years ago during which dune E was at least partly inundated. The occupation about 5000 years ago was either at the time of the latest playa or possibly later, with hand-dug wells being the final source of water for human sustenance.

The beginning of the Neolithic pluvial phases in the immediate area is not known, but these data suggest that it was before 6600 years ago. From the investigations of major Neolithic sites associated with playas near Gebel Nabta, 600 km to the southeast, and other sites elsewhere in the Western Desert, we find that there were three playa phases between 9500 and 5500 years ago (11). The dated phase at our dune camp playa probably corresponds to the last of these, but the data are too sparse to determine whether basal unit D is as old as the first playa phase of the Nabta sequence.

The deflated floor of the playa is made up of low outcrops of quartzite bedrock and a compact pebbly, silty sand (unit B) that may be either alluvium or an older playa deposit transitional to alluvium. In addition to Neolithic artifacts and LDG, the surface lag on the playa floor includes Acheulean artifacts in distinct concentrations (12). A few hand axes show undersides that are only slightly wind-abraded (eolized), suggesting that they have not been let down very far. The Acheulean artifacts occur under unit D and appear to be associated with the C-B contact.

Unit A is a complex of sand and gravel alluvial deposits with varying degrees of red paleosol development, which indicate several ages as great as and greater than that of unit B. Unit B is lighter in color, presumably due to bleaching or calcification when it was saturated by water percolating down from the overlying playa. The chunks of LDG occur, apparently as clasts, in unit A. Exposed portions of LDG in situ show sandblasting and wind faceting from predominantly northerly winds and to a degree equal to and in excess of that on some Acheulean artifacts in the surface lag. Buried portions show varying degrees of pitting and etching, obviously by pedogenic processes. No LDG artifacts, including an Acheulean hand axe (13), show the degree of soil etching seen on the chunks observed in situ, which must therefore have experienced a period of pedogenesis considerably longer than the 200,000 years or so since the Late Acheulean artifacts were manufactured (14). The climatic regime under which the silica was taken into solution appears to have been different from that of Acheulean time or any since then.

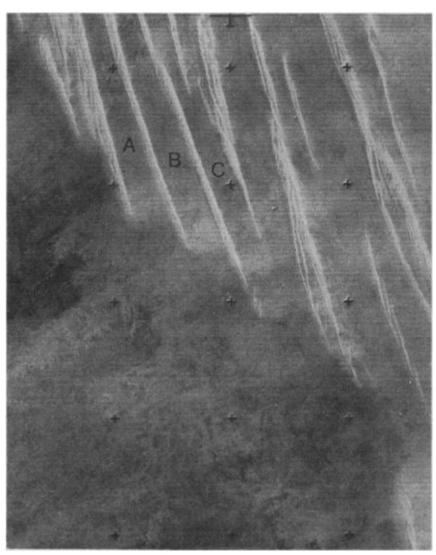


Fig. 2. Landsat (F-30871-07581-B) return beam vidicon image of the southwestern edge of the Great Sand Sea, where prominent dune ridges up to 70 m high are separated by relatively dune-free streets labeled A, B, and C from west to east. Interbedded playa deposits occur in the barblike projection near the southern terminus of dune ridge B-C separating streets B and C. Drainages from the Gilf Kabir highlands (lower left) may have supplied sand to the sand sea. Vertical alignment of crosses is approximately N10°E. Distance between crosses is approximately 11 km.

From the archeological geology of the Western Desert we infer three major periods of prehistoric human occupation associated with pluvial periods and separated by hyperarid periods at least as dry (less than 1 mm of annual rainfall) and windy as today (11). Occupation around springs 300,000 ± 100,000 years ago was at the end of what I will refer to as the Late Acheulean pluvial period; it was followed by hyperarid conditions under which the area was abandoned and basins were deepened by wind until Mousterian-Aterian peoples occupied lakes and springs at various places over the desert during the Middle Paleolithic pluvial period. From 35,000 years ago or earlier to the beginning of the Neolithic pluvial 10,000 years ago, there is again no evidence of human occupation, but abundant evidence of aeolian activity and lowered water tables. The climate was again hyperarid. Evidence of Neolithic occupation of the eastern Sahara from 10,000 to 5000 years ago is commonly associated with playa lakes and weak to moderate paleosols, commonly truncated by wind erosion. Thus the Neolithic pluvial is inferred to have been at least as wet, arid to semiarid (100 to 300 mm of annual rainfall), as northern Kordofan is today (15).

The playa occupation at our dune ridge camp is typical of playa-related archeology to the south, and the numerous other concentrations of Neolithic artifacts that we observed at various places along the basal portions of the dune ridges suggest that there may have been many other playa deposits which were blown away where not protected by dunes. Similar playa deposits were observed near the terminus of the next ridge (A-B) to the west.

The whaleback dunes (unit C), which appear to be earlier than Neolithic and later than Late Acheulean in the area studied, were probably active dune ridges during the hyperarid period preceding the Neolithic pluvial period. During their southward prolongation from the continuous part of the Sand Sea they may have overridden older plinths, in which case the internal stratigraphy of the whalebacks is more complex and may contain pre-Mousterian aeolian strata, especially to the north, where the wedge of older sand thickens.

If this picture is correct, the whaleback dunes were active dune ridges from the end of the Middle Paleolithic pluvial period (sometime before 35,000 years ago) to the beginning of the Neolithic pluvial period 10,000 years ago. They were presumably stabilized by vegetation under a semiarid climate from 10,000 to 5000 years ago, during which period there were probably hyperarid intervals such as those indicated elsewhere (*11*) and at our dune ridge camp by the foreset layers of aeolian sand interbedded with the playa muds.

The low, rounded to flattened transverse profile of the typical whaleback is probably the combined result of bioturbation, human occupation, pedogenesis, and slope wash. The reddish-brown color of the playa muds is most likely due to the displacement of pedogenic clays and soil-reddened sands by slope wash from the adjacent dunes and red soils on the alluvial gravels (unit A). Subsequent aeolian erosion as the post-Neolithic hyperarid phase ensued would further degrade dunes, truncate paleosols, and disperse artifact concentrations to the nearly equal spacing of artifacts commonly observed and so eloquently described by Bagnold (*4*, p. 158).

Unlike the Great Sand Sea, the Selima Sand Sheet, 130 km to the south (Fig. 1), is a remarkably flat continuous expanse of wind-sorted sand covering approximately 60,000 km$^2$ of southern Egypt and northern Sudan. In most areas the sand grains are compacted enough to allow easy motor travel at speeds in excess of 100 km per hour. As one approaches the edges of the Selima Sand Sheet the first sighting of rock outcrops can ony be likened to a landfall at sea. The effect is sometimes heightened by a mirage.

In places the Selima Sand Sheet is absolutely flat, in others, especially in the southwestern part, it is gently undulating with a subtle low relief of 10 m or more (Fig. 4a). The higher places are on low mounds of sand that coalesce and merge imperceptibly with the flat expanses. In a few places processions of active barchan dunes are moving south-southwest over the compound surface of the sand sheet, which is armored with a lag of coarse sand or fine pebbles. The lowest areas are commonly flat surfaces with a coarser armor of pebbles commonly forming a reticulate pattern (relict ripples), and low outcrops of quartzite bedrock occur in some of these small depressions.

Subtle differences in color and texture can be discerned within a few hundred meters in parts of the sand sheet. A stratigraphic succession appears to be present. On several occasions over the past few years small test pits excavated into the Selima Sand Sheet, as well as smaller sand sheets nearby, revealed several variations ranging from unweathered laminations of coarse and medium sand to pronounced paleosols invariably truncated by wind erosion. In several cases the unweathered laminations overlie a truncated paleosol developed in older laminated sands (*16*), where laminations have been destroyed by pedogenesis and bioturbation. In two places west and southwest of Bir Tarfawi (Fig. 1), Neolithic artifacts have been associated with a moderately strong reddish-brown paleosol, and a radiocarbon date on pieces of ostrich egg shell from one of these sites indicates that pedogenesis occurred at or before about 8170 ± 120 years ago (A-1966) (*17*).

During this field season similar pits were excavated on several sand-sheet surfaces in the vicinity of Burg el Tuyur, a remote "island" of rock in the southern part of the Selima Sand Sheet (Fig. 4a). At least three separate ages appear to be represented, based on the paleosols (Fig. 4b). The youngest stratum (unit Z) consists of unweathered, light brown to yellow (7.5 YR hues) (*18*), laminated, medium to coarse, aeolian sands commonly making up the higher surfaces. The oldest (unit X) underlies the relatively flat, pebble-armored surfaces in the lowest areas where moderately strong, yellowish-red (5 YR 5/6, 4/6) eroded paleosols occur on sandy, fine-pebble alluvium. Intermediate strata (unit Y) are lithologically similar to unit Z but have several weak to moderately well developed brown (7.5 YR hues) paleosols, which are probably related to the climatic oscillations known to have occurred

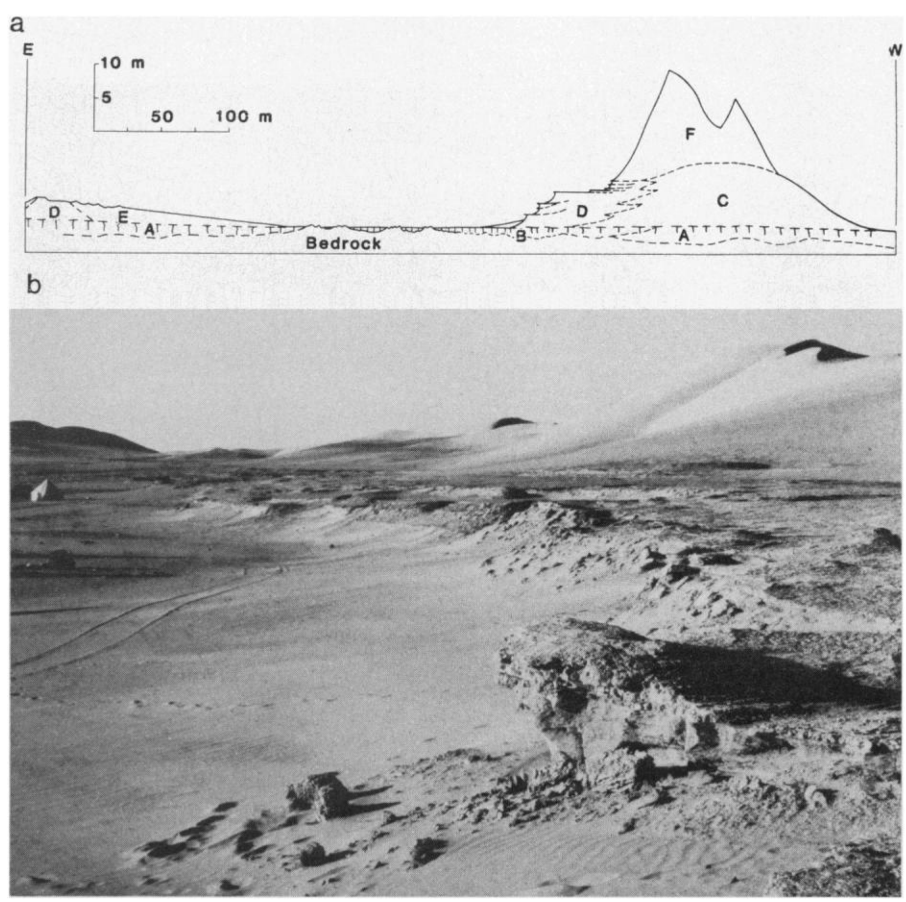


Fig. 3. (a) Generalized geological cross section of dune ridge B-C and interbedded playa (unit D) showing compound nature of dune strata (units C, E, and F) resting on a desert floor composed of Cretaceous bedrock and Pleistocene alluvium (units A and B). (b) Dune ridge B-C camp in basin from which playa deposits, right foreground, interbedded with linear dunes have been removed by wind action since 5000 years ago.

during Neolithic time (*11*). These youngest and intermediate portions of the sand sheet are therefore correlated with the whaleback dunes of the Great Sand Sea. Unit Z may be correlated with the uppermost part of the whalebacks because the active barchans on the Selima Sand Sheet are the most likely correlatives of the active dune ridges of the Great Sand Sea.

The older red soils therefore represent pre-Neolithic pluvial periods, some of which may be coeval with Mousterian and Acheulean occupations because such artifacts with relatively unabraded undersides have been observed in lagged position on these deflated surfaces (Fig. 4b).

Within a markedly reddened (2.5 YR 5/8, 4/6) soil on the sand sheet 30 km northeast of Burg el Tuyur we found geode-like nodules, up to 10 cm in diameter, in the surface lag and in situ at least 30 cm deep. These had black, quartzitic, manganiferous shells up to 8 mm thick filled with the same red, poorly sorted, pebbly alluvium that surrounds them. These large clasts were probably derived from a nearby outcrop that has been covered by the sand sheet. The paleosol is the oldest one observed in the Selima Sand Sheet and is undoubtedly very old, perhaps Middle Pleistocene.

The maximum depth of the sand sheet is not known, but Said (*19*) mentions that water test wells drilled by the Egyptian General Petroleum Company went through 22 m of sand before encountering bedrock in the Bir Tarfawi area. It may not be much deeper than this, because the Bir Tarfawi area is a pre-Acheulean depression filled with aeolian sand (*11*). The edges of the sand sheet appear to feather out against a relatively flat floor of bedrock.

From these investigations I conclude that the Selima Sand Sheet is made up of a sequence of degraded dune patterns over Quaternary alluvium and was, at several times in the past, vegetated much as the Sudanese Qoz is today (*20*). It appears to be a truncated Qoz and, like the rest of the Western Desert, is a product of Quaternary climatic change (*15*).

As a substrate for plant growth, the pebble-armored sand sea and sand sheets appear to be well suited for some grasses because, unlike active sand dunes, the surface is relatively stable and is disturbed by only the severest storms. Significant rains, separated by perhaps 30 years or more (*21*), can produce patches of grass, commonly *Stipagrostis* spp., over tens of square kilometers (Fig. 4a). If this occurs close enough to the southern fringe of the desert, it will attract animals to gizzu grazing—that is, that typically exploited in northern Sudan—which will last for only a year or so. But as the recurrence frequency increases we can visualize the eventual creation of a vegetated savanna as the height of a pluvial period is reached. When dunes stabilized and soils formed, the Sudanese Qoz appears to have shifted to the latitudes of the Selima Sand Sheet, that is, at least 400 km northward (*15*). A similar shift may have occurred southward from the Mediterranean coastal zone to stabilize the Great Sand Sea during past pluvials, but until adequate data are obtained from northern deposits we cannot be sure of the interplay of these two climatic zones (*22*).

From the results presented here it is apparent that both the Great Sand Sea and the Selima Sand Sheet contain complex sequences of strata separated by paleosols that will allow more precise correlations as the geochronology and archeology are better understood. These investigations will eventually provide a better understanding of natural desertification in relation to climatic change. A significant conclusion based on these studies is that the sensitive belt for Quaternary climatic oscillations across the southern Sahara is at least 800 km wide (*20*). Compared to the grand scale of Quaternary climatic change, the Sahelian drought of the early 1970's was but a minor perturbation (*23*). Future perturbations, both better and worse for human occupation, are quite likely. Ongoing chronostratigraphic studies may provide a basis for predicting recurrence intervals.

C. Vance Haynes, Jr.
*Department of Anthropology and Geosciences, University of Arizona, Tucson 85721*

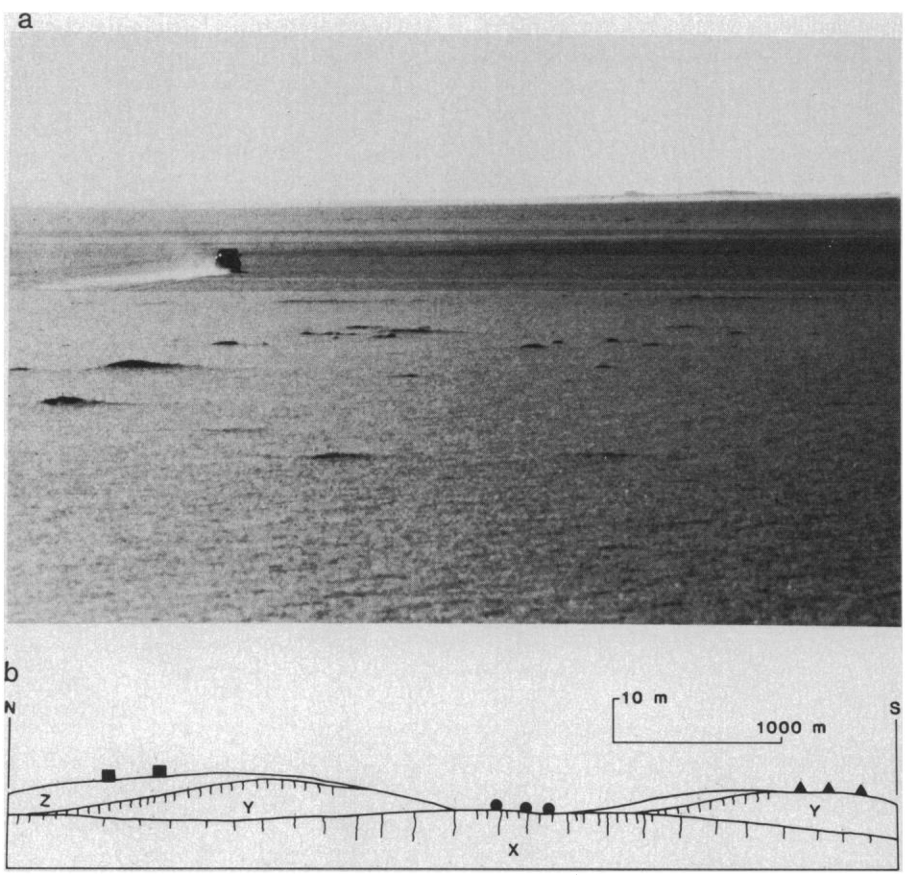


Fig. 4. (a) Remote rock outcrop of Burg el Tuyur, the only prominent landmark within the Selima Sand Sheet. Subtle differences in color and texture of the sand sheet reflect stratigraphic differences. Small hummocks of dead grass (*Stipagrostis* spp.) were probably germinated by a single rain shortly before the nuclear addition of radiocarbon to the atmosphere. Dust from the moving vehicle is caused by disturbance of a vesicular horizon on a paleosol protected by an armor of coarse sand. (b) Diagrammatic cross section of the Selima Sand Sheet showing a generalized stratigraphy based on test pits and surface archeology. Vertical hachures indicate two generations of paleosols truncated by wind erosion. Exposed concentrations of Acheulean (●), Middle Paleolithic (▲), and Neolithic (■) artifacts can be correlated with the stratigraphy and indicate approximate ages of the strata. Unit X is alluvium, unit Z is aeolian sand, and unit Y can be of either aeolian or fluvial origin.

## References and Notes

1. A 50,000-man army, of the Persian general Cambyses, is reported by Herodotus [H. Carter, *The Histories of Herodotus* (Heritage, 1958), book 3, chapter 26] to have perished in a sand storm in 525 B.C. while trying to reach and destroy the temple of Jupiter Amun by crossing the Sand Sea presumably from Dakhla Oasis. In more recent times a camel caravan route from Kufra Oasis in Libya to Abu Mungar Well in Egypt crossed the southern end by winding its way through gaps in the longitudinal (seif) dunes.
2. G. Rohlfs, *Drei Monate in der Libyschen Wüste* (Theodor Fischer, Cassel, 1875).
3. P. A. Clayton and L. J. Spencer, *Mineral. Mag.* **23**, 501 (1934); R. A. Bagnold, *Libyan Sands* (Hodder and Staughton, London, 1935), chap. 7; L. de Almasy, *Publications Speciale de la Societe Royale de Geographie d'Egypte* (Schindler, Cairo, 1936), p. 43.
4. R. A. Bagnold, *The Physics of Blown Sand and Desert Dunes* (Methuen, London, 1941).
5. The concept of a fluvial origin for the sand grains of the Western Desert has been stated by C. Squyres (personal communication); R. Said in (*6*), p. 281; C. S. Breed, J. F. McCauley, M. J. Grolier, *J. Geophys. Res.*, in press; B. Issawi, *Geol. Soc. Am. Abstr. Programs*, in press.
6. F. Wendorf and R. Schild, Eds., *Prehistory of the Eastern Sahara* (Academic Press, New York, 1980).
7. C. Squyres and S. E. Whitten, personal communication.
8. Originally called Libyan Desert silica glass, the chunks of clear pale greenish glass have eluded unequivocal explanation [L. J. Spencer, *Mineral. Mag.* **25**, 425 (1939)]. My investigation of the Sand Sea began with a preliminary trip to the area 80 km west of the remote well of Ain Dalla (Fig. 1) in 1978 in an effort to find playa deposits within the Sand Sea while en route to the LDG area (C. V. Haynes, Jr., *Natl. Geogr. Soc. Res. Rep., 1978 Proj.*, in press). Although one playa deposit was believed to have been seen at a distance, it was not visited because of mechanical difficulties. It was with great pleasure, therefore, that I accepted an invitation to visit the southwestern edge of the Sand Sea in March 1981. The expedition, organized by B. Issawi, Geological Survey of Egypt, and R. E. Giegengack, University of Pennsylvania, consisted of specialists in aeolian processes, stratigraphy, physics, archeology, and Quaternary geochronology (R. F. Giegengack *et al.*, in preparation). My function was to attempt to date the linear dunes by studying the stratigraphic relations of the playa deposits and artifacts described to me by R. F. Giegengack on the basis of a trip to the area in 1980 [R. F. Giegengack and J. R. Underwood, Jr., *NASA Tech. Memo. 82385* (1980), pp. 314–316].
9. The streets between the linear dunes were given letter designations during the pioneering study of the LDG by P. A. Clayton and L. J. Spencer [*Mineral. Mag.* **23**, 501 (1934)]. Dune ridge B-C is therefore between streets B and C.
10. Radiocarbon date A-2517 is on shell carbonate, as are dates of 6290 ± 150 (A-2518) and 6270 ± 50 (A-2515) years ago, but the latter sample was large enough to allow analysis of the organic carbon to provide A-2516 after pyrolysis and hydrolysis. Because carbonates are subject to exchange with atmospheric $CO_2$, A-2516 is considered to be the most accurate of the three values closest to it in apparent age.
11. F. Wendorf, R. Schild, R. Said, C. V. Haynes, A. Gautier, M. Kobuseiwicz, *Science* **193**, 103 (1976); B. Issawi, *Ann. Geol. Surv. Egypt* **8**, 295 (1978); F. Wendorf and R. Schild, (*6*); C. V. Haynes, Jr., in *ibid.*, p. 353. The term pluvial is used here in the general sense of a period of greater effective moisture for vegetation, soil development, and ground water recharge whether due to increased precipitation, decreased evaporation, or both.
12. J. W. Olsen, unpublished manuscript.
13. D. A. Roe, J. W. Olsen, J. R. Underwood, Jr., R. F. Giegengack, *Antiquity*, in press.
14. Absolute dates pertaining to the end of the Early Paleolithic are few and unknown for Egypt; 300,000 ± 100,000 years is a minimum estimate based on potassium-argon dates for the Middle Paleolithic in Ethiopia. See F. Wendorf, R. L. Laury, C. C. Albritton, R. Schild, C. V. Haynes, P. E. Damon, M. Shafiqullah, R. Scarborough, *Science* **187**, 740 (1975); C. E. Stearns, *ibid.* **190**, 809 (1975); R. G. Klein, *ibid.* **197**, 115 (1977).
15. C. V. Haynes, Jr., in preparation; G. E. Wickens, *Boissiera* **24**, 43 (1975); H.-J. Pachur and G. Braun, in *Palaeoecology of Africa and the Surrounding Islands*, E. M. Van Zinderen Bakker, Sr., and J. A. Coetzee, Eds. (Balkema, Rotterdam, 1980), p. 351.
16. C. V. Haynes, Jr., in (*6*), p. 353.
17. ——, *Geogr. J.* **146**, 59 (1980).
18. Soil colors are indexed according to the Munsell system. Where specified, the first value/chroma ratio is for dry soil, the second for moist soil.
19. R. Said, in (*6*), p. 281.
20. The Qoz is an area of ancient dunes and red soils, between 10° and 16°N, stabilized by vegetation [A. Warren, *Z. Geomorphol. Suppl.* **10**, 154 (1970)].
21. The recurrence interval is not known, but R. A. Bagnold [in *Biology of Deserts*, J. L. Cloudsley-Thompson, Ed. (Institute of Biology, London, 1954), p. 7] estimates 30 to 50 years. We are probably still a long way from learning the actual value because, as he points out, "it is against human nature to look conscientiously at an empty rain gauge for several years on end. By the time rain does come the gauge has probably been put to some other use, or the observer is elsewhere."
22. P. J. Mehringer, Jr., *Natl. Geogr. Soc. Res. Rep., 1976 Proj.*, in press; C. V. Haynes, P. J. Mehringer, Jr., El S. A. Zaghloul, *Geogr. J.* **145**, 437 (1979). Mehringer is currently analyzing fossil pollen samples from a Holocene sequence of laminated, organic lake beds at Selima Oasis, Sudan, and from lake sediment cores from Birqet Qarun, Faiyum depression, Egypt.
23. N. Wade, *Science* **185**, 234 (1974); S. W. Matthews, *Natl. Geogr. Mag.* **150**, 576 (1976).


24. Investigations supported by grants from the Smithsonian Foreign Currency Program (grant FC-10215300), the National Science Foundation (grant EAR-7926362), and the National Geographic Society (grant 2258) in cooperation with the Geological Survey of Egypt, and the Geological and Mineral Resources Department, Ministry of Energy and Mining, Sudan. Radiocarbon samples were pretreated by J. Quade and analyzed under the auspices of A. Long. Participation in the Libyan Desert Glass expedition was made possible by R. F. Giegengack and B. Issawi. Participation of P. J. Mehringer, Jr., is appreciated. Reading of preliminary versions of the manuscript by C. C. Albritton, Jr., R. F. Giegengack, and M. Grolier is appreciated.

16 November 1981; revised 1 April 1982


# Fossil Birds from the Hawaiian Islands: Evidence for Wholesale Extinction by Man Before Western Contact


Abstract. *Thousands of fossil bird bones from the Hawaiian Islands collected since 1971 include remains of at least 39 species of land birds that are not known to have survived into the historic period; this more than doubles the number of endemic species of land birds previously known from the main islands. Bones were found in deposits of late Quaternary age; most are Holocene and many are contemporaneous with Polynesian culture. The loss of species of birds appears to be due to predation and destruction of lowland habitats by humans before the arrival of Europeans. Because the historically known fauna and flora of the Hawaiian Islands represent only a fraction of natural species diversity, biogeographical inferences about natural processes based only on historically known taxa may be misleading or incorrect.*


Since 1971, tens of thousands of fossil bird bones have been found in various geological settings on five of the main Hawaiian islands (*1*). At least 39 endemic species of land birds and one species of seabird are now known only from fossil remains (*2*); only three of these have been named previously (*3*). We have completed a general overview of the fossil deposits and their faunas (*1*), but systematic revisions and descriptions of new taxa are not completed (*4*). We now report on the role of Polynesians, who colonized the Hawaiian Islands by A.D. 600, and perhaps as early as A.D. 400 (*5*), in the disappearance of native birds.

The largest collections of fossil birds were found on the islands of Molokai, Oahu, and Kauai (*6*) (Fig. 1), and a few remains were found in lava tubes on Maui and Hawaii. Bones of prehistorically extinct birds (that is, extinct before Europeans arrived to keep written records, beginning in 1778) have also been recovered from archeological midden sites on Hawaii, Molokai, and Oahu.

The endemic species of land birds (*7*) that survived into the historic period on the main Hawaiian Islands include a goose, a hawk, a flightless rail, a crow, two thrushes, a flycatcher, five honeyeaters, and 27 Hawaiian finches (Drepanidini, previously called "Hawaiian honeycreepers"). To these, the fossil record now contributes the following additional endemic taxa: at least seven species of geese (many of them flightless), two species of flightless ibises, a sea eagle (*Haliaeetus*), a small hawk (*Accipiter*), seven flightless rails (Rallidae), three species of owls belonging to an extinct genus, two large crows (*Corvus*), one honeyeater (*Chaetoptila*), and at least 15 Hawaiian finches (Drepanidini). Thus, the number of species of endemic land birds known for the main islands has been more than doubled by the fossil taxa. The number of colonizations by birds that are known to have produced endemic species in the main islands has likewise now been doubled (*1*).

In addition to providing evidence of the extinction of many species, the fossil record shows that numerous taxa with restricted ranges in the historic period were formerly more widely distributed. For instance, certain species that are known historically only from the Hawaiian Leeward Islands (*Pterodroma hypo-*


0036-8075/82/0813-0633$01.00/0  