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The Prehistory of the Egyptian Sahara

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The Western Desert of Egypt is one of the driest and least hospitable areas on Earth. It is characterized by almost total lack of rainfall (less than 1.0 millimeter per year), extremely high temperatures during much of the year (daily average more than 24°C between April and October), and is seemingly devoid of life except near widely scattered wells or oases and in the lowermost portion of rare, large, internally drained basins. The area is also poorly known; much of it has rarely been entered in modern times (*1*, *2*).

It has long been known, however, that the Western Desert was not always so inhospitable. Substantial evidence has existed since the mid-1930's that rich prehistoric remains occur there. The major sources of this information were the studies at Kharga Oasis (*3*) and the Fayum (*4*), at the Gilf El Kebir (*2*), at Gebel Uweinat (*5*), and at Dungul and Kurkur Oases (*6*). These reports suggested that the area might offer an ideal laboratory for the study of climatic change in the Sahara during the late Pleistocene and perhaps provide an unusual opportunity for the study of long-term cultural adaptive behavior in a variety of arid to hyperarid environmental situations. These attractions led the Combined Prehistoric Expedition to begin a systematic study of the area in 1972. We give a brief description of the results thus far and provide a comparison with Nilotic data (*7*).

Since 1972, four field seasons have been completed in the desert and 18 prehistoric sites, clustered in five widely separated localities, have been excavated. These sites range in age from Upper Acheulean to Old Kingdom, and they have yielded rich complexes of artifacts, associated faunal remains, and many radiocarbon dates from which the following conclusions have been drawn. (i) This portion of the Sahara was occupied only during specific and sharply restricted time intervals that closely coincide with episodes of significantly increased moisture. (ii) The Western Desert did not experience a period of increased moisture coeval with the last major episode of glaciation in northern Europe (main Würm). (iii) Most of the archeological industries are significantly different from those of the same age known from along the Nile. (iv) It is unlikely that the Sahara was a significant contributor to the archeological diversity evident along the Nile during the Late Paleolithic.

Geological Framework

The Western Desert of Egypt (or the Libyan Desert) can be conveniently divided into two major physiographic provinces separated by an impressive Eocene scarp that is approximately 300 to 400 meters high. The northeastern province, the portion above the scarp, is known as the Libyan Plateau. It is underlain by Eocene limestone and is characterized by numerous pans and basins formed by deflation or solution, or both. Below the Eocene scarp, the southwestern portion of the area is known as the Nubian Desert. The landscape is dominated by Nubia sandstone, which has been eroded to leave numerous inselbergs and extensive erosional surfaces of low relief with sandy or pebble-strewn surfaces.

Almost all of the work so far has been limited to the Nubian Desert. Except at Dakhla and Kharga, both located on the northern edge of this vast region, the area is uninhabited and lacks surface water. However, water is present at shallow depths in several places and can be obtained by digging wells.

The key stratigraphic sequence was developed at the Bir Sahara–Bir Tarfawi area (Fig. 1) (*8*), which is located some 350 kilometers west and slightly north of Abu Simbel and is surely one of the most isolated and desolate places on Earth. The landscape around Bir Tarfawi–Bir Sahara is almost flat except for three depressions, one of which is Bir Sahara. Another, located 14 km to the east, is Bir Tarfawi (*9*) and the third, about 10 km northwest of Bir Sahara, is unnamed and is considerably smaller than the other two. The flat area surrounding the *birs* (wells) is an extremely large sand plain occupying a synclinal basin that is blocked on the east by the Precambrian massif of El Tawila (*10*). This basin is filled with eolian sands older than the Upper Acheulean that occurs on its slightly lowered surface. Carbonate nodules and crusts, all probably of pedogenic origin, occur on the surface and seem to define the extent of the basin, which measures some 70 km in diameter.

Both the Bir Sahara and Bir Tarfawi subbasins were formed by deflation, have an elongated oval shape (maximum dimensions, 8 and 15 km, respectively), and are oriented northeast to southwest. The two basins are cut about 10 m below the level of the surrounding flat plain. At Bir Sahara the initial deflation of the subbasin probably precedes the very lat-

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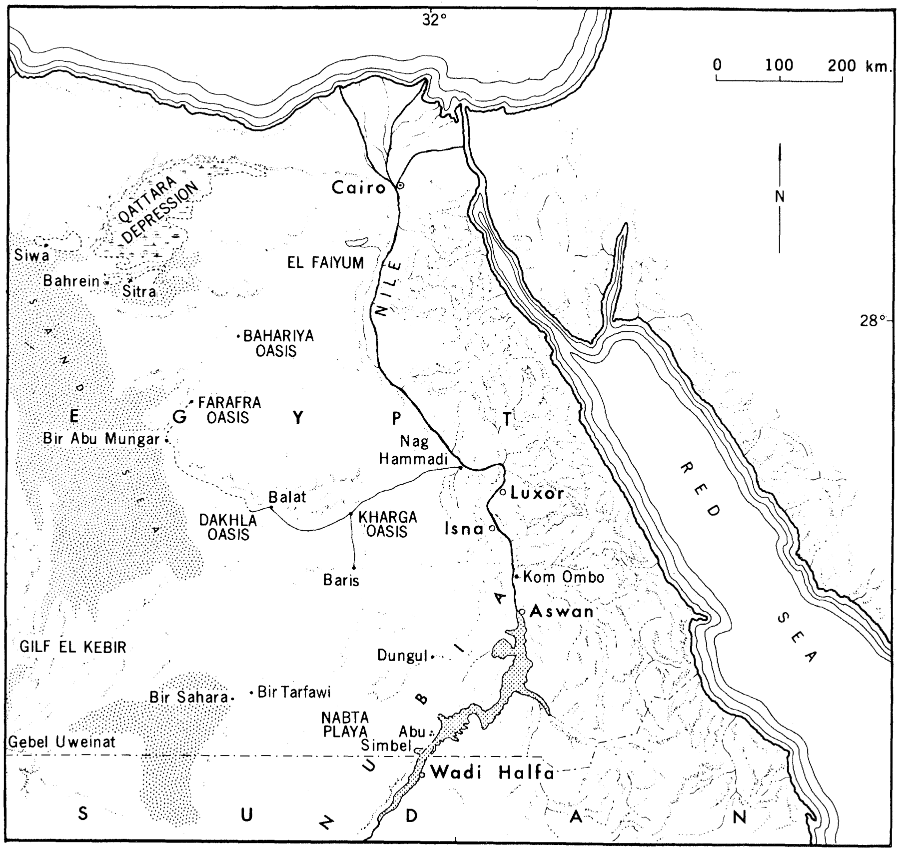


Fig. 1. Map of Egypt showing positions of various localities discussed in text.

est Acheulean (Fig. 2). Along the southern margin of the basin are several spring vents whose firmly cemented tops are about 2 m below the carbonate plain. These numerous spring vents on the floor of the depression, together with the gross geological setting of the Bir Sahara depression and the absence of a distinct peripheral drainage net, strongly suggest that the lake was fed by artesian springs associated with the aquifer in the underlying sandstone. One of the vents (site BS-14) was excavated; it yielded a group of evolved Acheulean bifaces, fragments of ostrich eggshell, and bone scraps of an equid, probably *Equus asinus*. The archeological assemblage has typological features generally regarded as characteristic of the Final Acheulean.

The episode of spring discharge was followed by a major period of deflation to a level below that of the modern water table. During the final phase of this erosion, dunes were deposited in the basin and the earliest Mousterian occupation occurred. The formation of the dunes was followed by the formation of the first of two lakes in the basin, as recorded by a series of lacustrine and nearshore sediments. Associated with this first lake are three, possibly four, levels of Mousterian occupation. Subsequent deflation has destroyed most of these lacustrine sediments and many of the associated archeological sites; however, numerous remnants are preserved in the floor of the basin and along its northern and western edges. These remnants, together with several hundred meters of carefully profiled trenches, provide the evidence for the reconstruction of the sequence of events and their associated archeology.

The lacustrine sediments yielded a rich molluscan fauna containing *Melanoides tuberculata*, *Lymnea natalensis*, *Biomphalaria alexandrina*, *Gyralus costulatus*, *Hydrobia* sp., and *Bulinus truncatus*, all occurring in silts and marl units. These, as well as the numerous unidentified aquatic plant remains associated with evaporites, suggest a rich lacustrine freshwater environment with dense plant growth. Unfortunately, almost nothing can be inferred about the vegetation during this period because none of the several hundred palynological samples yielded fossil pollen, despite the fact that the lacustrine sediments would seem to have provided an ideal environment for their preservation (*11*).

Almost all of the Mousterian sites contain faunal remains of similar composition that is limited to a few species. These species are: white rhinoceros (*Ceratotherium sinum*), extinct camel (*Camelus thomasi*), ass (*Equus asinus*), buffalo (*Homoioceras antiquus*), an unidentified large antelope, and warthog (*Phacochoerus aethiopicus*).

The first lacustrine sequence at Bir Sahara terminates with an arid episode

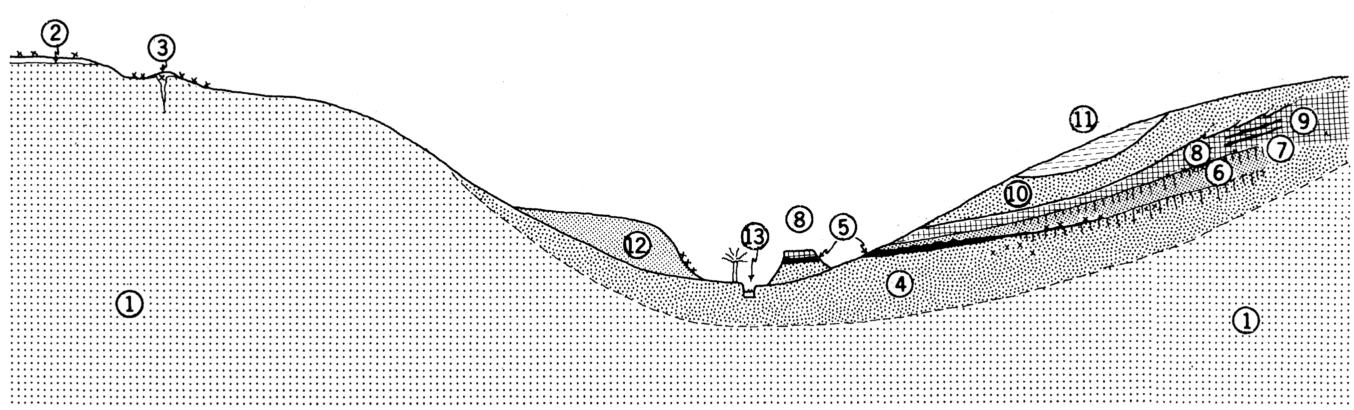


Fig. 2. Generalized profile across Bir Sahara depression, based on profiles from several hundred meters of excavated trenches. (1) Old basin fill; (2) plateau carbonate crust with Late Acheulean artifacts in lag position on surface; (3) spring vent with Final Acheulean artifacts in situ; (4) oldest dune sand with first Mousterian settlement in upper part; (5) gray to black swamp layer with several Mousterian settlements in situ; (6) gray sand unit; (7) soil at top of gray sand unit with latest Mousterian settlement in situ; (8) highly calcareous light-gray silt; (9) two lenses of burned silt; (10) Eolean sand interfingering with top of (8), terminates lower ponding sequence; (11) upper pond silts (two units); (12) recent dune with Old Kingdom settlement; (13) dug well at Bir Sahara.

marked by the formation of a new dune over the lake sediments. Two units of marl overlie this dune, marking another rise in the water table and the formation of another lake. The development of a soil in the upper marl marks the termination of the second lake. The marls of this second lake contain a molluscan assemblage similar to that in the lower lake, except for *Corbicula*, the land snail *Pupoides coenopictus*, and numerous examples of the land snail *Zootecus insularis* in the upper portion. The sediments of the upper lake were archeologically sterile; however, the preserved sedimentary remnants were extremely limited in areal extent.

A series of radiocarbon dates on shells facilitates the chronological placement of the two lakes. Several of these dates are absolute but are possibly contaminated, and two others were beyond the extreme limits of the laboratory capability.

1) Lower lake: 32,780 ± 900 years ago (SMU-80), site BS-13, surface, *Melanoides* shells; 40,710 ± 3,270 years ago (SMU-82), site BS-16, excavated, small *Melanoides* shells; > 41,450 years ago (SMU-81), site BS-16, excavated, large *Melanoides* shells.

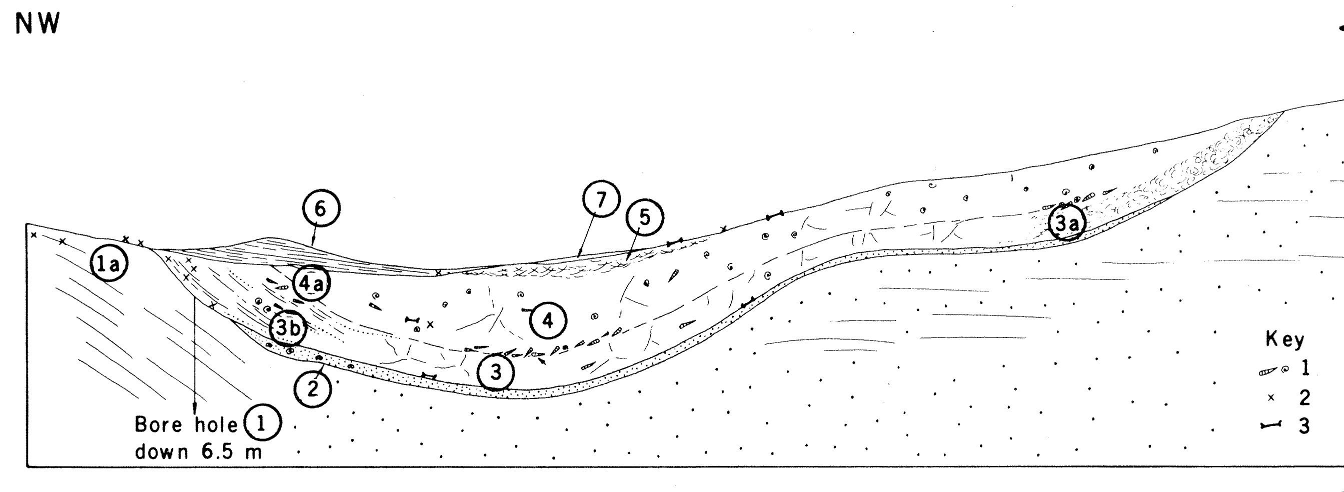
2) Upper lake: 30,870 ± 1,000 years ago (SMU-75), site BS-15, upper marl, bivalve shells; > 44,700 years ago (SMU-79), site BS-15, upper marl, large *Melanoides* shells.

It is of interest to note that samples SMU-81 and SMU-82 were collected from the same spot and from the same unit, while SMU-80 was collected nearby from the surface of what is almost certainly the same unit. Because great care was taken in cleaning all of the samples, we attribute the variation in age to recent carbonate contamination for the surface sample and to the difficulty in removing minute carbonate particles from the smaller shells (*12*). The date of greater than 44,000 years ago from the upper marl of the last lake indicates that the whole sequence at Bir Sahara is well beyond the reach of radiocarbon techniques.

The nearby subbasin at Bir Tarfawi provides additional data on late Pleistocene climatic events in this area. The stratigraphic sequence at Bir Tarfawi begins at a slightly earlier date than can be demonstrated for Bir Sahara. The south end of the Bir Tarfawi subbasin contains a series of shallow basins that are filled with thick (about 50 centimeters) freshwater limestone. These basins are less than 2 m below the level of the surrounding carbonate plains. Several fresh Late Acheulean hand axes were found embedded in the limestone, indicating their contemporaneity with the formation of the sediment, while numerous deflated remains of Late Acheulean sites were recorded on the topographically lower surfaces of the dunes around the edges of the limestone remnants.

The next recorded event at Bir Tarfawi is the deflation that formed the main depression, a narrow elongated trench some 12 km long. As at Bir Sahara, the Tarfawi basin was then invaded with sand dunes containing rare, heavily eolized, and unclassifiable artifacts.

Subsequently, in the interdunal lows at the north end of the basin, a series of small, partially isolated ponds developed (Fig. 3). These ponds left a complex series of lacustrine sediments and beach



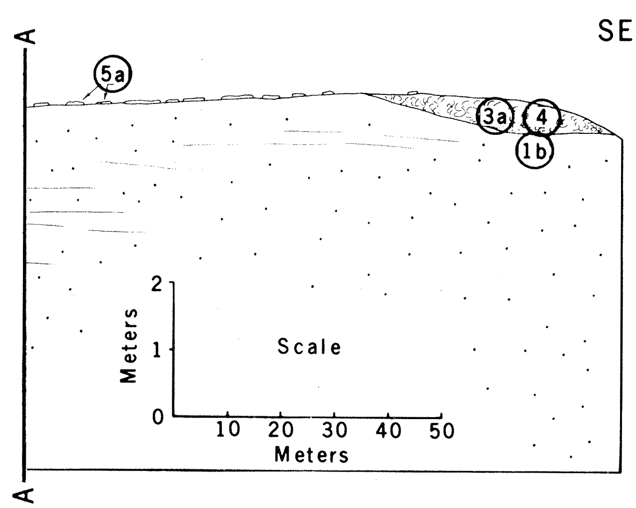


Fig. 3. Generalized profile through playa at Bir Tarfawi, based on 17 trenches excavated along both north-south and east-west axes. (1) White dune sand with bioturbation at top; (1a) dune with inconspicuous foreset and topset bed stratification, Aterian artifacts near top; (1b) consolidated dune sand; (2) dark silty sand; (3) white consolidated silt with $CaCO_3$ concentrations, occasional snails, and bones (^{14}C date comes from top of this unit); (3a) cavernous evaporite developed in silt with pockets of snails and bones; (3b) beach, grayish silty sand, mottled, with snails and Aterian artifacts; (4) cemented light-gray silt containing large animal bones and Aterian artifacts; (4a) same as (4) but with laminations; (5) white carbonaceous silt with numerous concretions and abundant fauna with Aterian artifacts; (5a) plates of $CaCO_3$; (6) brown to olive-yellow silt; (7) modern sand sheet. Key symbols: 1, shells; 2, artifacts; 3, bones.

features composed of silts, stratified sands, and evaporites. Rich accumulations of *Melanoides tuberculata* occur within the highly calcareous silts deposited in the lakes, while land snails (*Pupoides coenopictus*) often occur in the nearshore laminated sands. The whole complex of pond sediments now stands from 2 to 3 m higher than the surrounding eolian sands, displaying a typical inverted geomorphic situation.

The inverted small lakes and ponds at Bir Tarfawi are literally framed by a mass of Aterian artifacts dropped from the now almost completely deflated shores that surrounded the ponds. In addition, the lacustrine sediments within the basins contain extensive remains of human occupation and/or activity. The oldest recognized evidence of Aterian activity occurs at the very base of the lake sediments in the black bottom layer. Much more extensive traces of occupation occur in the near beach locations, grading up into the extensive clusters of deflated settlements (site BT-14, area B).

The whole thickness of gray lacustrine silts and shallow water evaporites contains numerous concentrations of animal remains, composed mainly of the bones that surround the thoracic cavity. Associated with these concentrations of bones are Aterian artifacts with a high frequency of tools (more than 50 percent) and of a very restricted typological composition (site BT-14, area A). Within the uppermost part of the preserved gray lacustrine silts, but closer to the ancient beach, is a tight small concentration containing a significantly different tool assemblage (site BT-14, area C). The most recent traces of Aterian occupation are associated with an olive-yellow silt that overlies the gray silt. The olive-yellow silts are preserved only in patches but contain a few large mammal remains as well as a freshwater molluscan fauna, of which *Melanoides tuberculata* is the most numerous.

The recovered faunal assemblage, mostly from the silts of the butchering area of site BT-14, area A, contains white rhinoceros, extinct Pleistocene camel, a large bovid (probably *Homoioceras antiquus*), wild ass, red-fronted gazelle (*Gazella rufifrons*), a small gazelle (probably *G. dama*), rare remains of fox (*Vulpes ruppeli* ?), jackal (*Canis aurenus lupaster* ?), warthog, unknown large and middle-sized antelopes, and ostrich. Turtle and bird remains are also present. A sample of *Melanoides tuberculata* shells from the midpoint of the gray lacustrine silt yielded a radiocarbon date of 44,190 ± 1,380 years ago (SMU-177), which is regarded by the laboratory as radiometrically dead because of the almost certain admixture of small traces of later carbonate that could not be completely removed from the shells.

Although the sequence at Bir Tarfawi cannot be directly related to that at Bir Sahara, the simplest correlation calls for the comparison of the second lake at Bir Sahara with that at Bir Tarfawi, a correlation which is reinforced by the repeated occurrence of Mousterian below Aterian elsewhere in North Africa (*13*). The lithostratigraphic sequences at Bir Tarfawi and Bir Sahara demonstrate at least three wet events, all associated with lakes, one of which is of Late and Final Acheulean age, and two that are contemporaneous with Middle Paleolithic. These two are almost certainly more than 45,000 years old and could be correlated with the early Würm glaciation of Europe. The environmental reconstruction based on fauna suggests the existence of a savanna landscape supporting large herbivores around the lakes.

Younger Pleistocene sediments postdating the Aterian occupation were not observed at either Bir Sahara or Bir Tarfawi. The next event is a pronounced deflation which cut through the accumulated lacustrine and preceding eolian sediments to a level that must have been very close to the modern water table. It seems likely that the present morphology was developed during this period because there are several sites of Old Kingdom age that are located close to the modern wells and are only 2 m above the present water level. These sites are only partially in situ but they clearly display preserved occupational patterning (*14*). A radiocarbon assay on ostrich eggshell from one of these sites (BT-20) gave a date of 2560 B.C. ± 70 years (SMU-74).

The long break in the stratigraphic record after the Aterian is not confined to the Bir area. Nowhere in the Nubian Desert was any evidence seen to suggest the presence of surface water occurring after the Aterian and before the onset of another wet episode at about 7000 to 8000 B.C. The evidence for this next wet episode is best preserved at Nabta Playa, a huge (more than 100 km^2), irregular, shallow, internally drained deflation basin located about 250 km southeast of Bir Sahara and 100 km west of Abu Simbel. It is situated near the foot of the southernmost projection of the Eocene scarp. The playa is filled with fossil dunes and clays, with numerous associated Terminal Paleolithic and Neolithic settlements. The exact dimensions of the playa are unknown because modern sand sheets and dunes mask its margins.

At Nabta Playa the Quaternary sequence overlies the truncated surface of the Nubia Formation (shales and sandstones) and begins with the deposition of extensive sand dunes with numerous troughs between the dunes. The beginning of a more moist episode is recorded by the stabilization of the dunes and the growth of vegetation over the dune surface. Traces of this unidentified vegetation are preserved as a mat of silicified root casts in the uppermost part of the dunes. During the same interval, pond sediments accumulated in the deeper part of the interdunal troughs and the first Terminal Paleolithic occupation occurred. This episode was succeeded by the deposition of sheetwash sand with occasional lenses of playa clay, which in turn was succeeded by a period of stabilization with another Terminal Paleolithic occupation. A thin layer of sheetwash sand covers the stabilized surface, and above it is evidence of the first Neolithic occupation. The earliest Neolithic sites are covered by more sheetwash sand, lenses of silt that apparently record seasonal bodies of water, and then by the main body of playa clay. These playa sediments reach a maximum thickness of more than 3 m with several minor fluctuations evident within the deposits. Around the margins of the playa is an extensive series of later Neolithic settlements that were contemporaneous with the main playa sedimentation. One of the largest of these sites (E-75-8) is situated on the highest beach of the playa; the cultural and beach sediments interfinger.

Extensive faunal remains were recovered from the Neolithic horizon at site E-74-6, including numerous hare (*Lepus capensis*) and red-fronted gazelle (*Gazella rufifrons* ?) accompanied by rare carnivores, including mongoose (*Herpetes ichneumon*), wildcat (*Felis libyca*), and hedgehog. All of these species still occur in Egypt along the Nile or slightly farther south in the Sahara. Ostrich eggshells, often worked into beads, are common in all of the sites. More surprising in view of the radiocarbon age of the site is the presence of a few bones tentatively identified as cattle that were probably domestic. Other bones of cattle that are also believed to have been domestic occurred at site E-75-8, together with the remains of caprovin (goat/sheep). Domestic animals were presumably part of the subsistence economy of the Nabta Neolithic settlements; however, hare and gazelle were much more common. The Terminal Paleolithic horizon contained only hare, gazelle, and ostrich.

While pollen was not preserved in the playa sediments, the ash deposits of the Neolithic settlements contained abundant plant remains. So far, ten species have been identified, including *Acacia* and *Salsola*, both dom and date palm, barley, and four weeds common in cultivated and similar disturbed moist areas. The botanical analyses are still under way and it is not yet possible to determine whether the barley was wild or domestic (*15*).

A series of radiocarbon samples yielded the following dates from these sites.

1) Terminal Paleolithic: 7410 B.C. ± 70 years (SMU-200), site E-74-6, on charcoal; 6630 B.C. ± 80 years (SMU-257), site E-74-6, on ostrich eggshell.

2) Earliest Neolithic settlement: 6250 B.C. ± 110 years (SMU-189), site E-74-6 on ostrich eggshell; 5760 B.C. ± 70 years (SMU-191), site E-74-6 on ostrich eggshell; 6170 B.C. ± 100 years (SMU-199), site E-74-6 on charcoal; 6060 B.C. ± 80 years (SMU-203), site E-74-6 on charcoal; 6068 B.C. ± 100 years (SMU-240), site E-74-6 on charcoal.

3) Latest Neolithic settlement: 5200 B.C. ± 130 years (SMU-242), site E-75-8 on charcoal.

Other Areas Studied

Dakhla Oasis. The basin of Dakhla extends for more than 80 km along the foot of the Eocene scarp. Its floor is covered by shales of the Nubia Formation with patches of playalike silts and clays in the lowermost portions. Most of the clays appear to be very recent and none yielded in situ Paleolithic materials. Just west of the village of Mut, near Balat, was an extensive area with numerous fossil spring remnants and associated tufas. Two of these fossil spring vents yielded very rich Upper Acheulean assemblages.

The spring vents are located in the mouth of a highly deflated wadi cut in the shale and descending from the foot of the Eocene scarp. Upstream from the mouth are large remnants of the preerosional surface with a thick bed of chert and limestone boulders in a reddish pebbly sand matrix unconformably overlying the shale. We examined more than 50 of the numerous local spring vents, but only the two we excavated showed traces of occupation. Also, no artifacts were found associated with the tufas, although many pieces, mostly of Mousterian or Aterian affiliations, occurred on the floor of the wadi near the spring vents.

The two Acheulean vents are located at the southern and lower edge of an elongated mound of shale capped by gravels of the preerosion surface. Site E-72-1 is indicated by a thin cluster of artifacts around a single vent, while site E-72-2, immediately to the west of it, consists of a similar, adjoining cluster around four separate and smaller vents (*16*).

The best stratigraphy within the vents occurs at site E-72-1, where the base of the vent has a thin lens of rewashed shale overlain by a sterile layer of white clay. Toward the sides, the fill of the vents consists of gravels in a coarse sand matrix with abundant iron oxides, sulfates, and jarosite (potassium iron hydroxy sulfate). The center is an unstratified, loose, white to light-gray sand that forms the largest quantity of the fill.

We interpret the fill in the vent to suggest a greater discharge and velocity at the beginning of the activity, with considerable sorting of the archeological materials that worked down through the sands made fluid by ascending water. The central portion of the fill probably represents a somewhat declining discharge, while the presence of iron oxides, sulfates, and jarosite suggests that the ascending water had a mineral content and temperature similar to that of the Dakhla springs today.

The Dyke area. South of the Dakhla basin, the surface of the desert slowly rises to one enormous, generally flat to slightly undulating plain that is covered here and there with sand sheets and extends southward beyond Bir Sahara–Bir Tarfawi. Some 140 to 160 km south of the village of Balat is an extensive area of dykes (*9*). In the same area but not clearly associated with the dykes are numerous large shallow basins excavated in the Nubia sandstone and filled with sand. Inconspicuous drainage lines appear only in the immediate vicinity of the basins. Two of the most promising of several prehistoric sites found with these sand pans were excavated: one was Mousterian and the other was Terminal Paleolithic. There are no known traces of fossil spring activity closer than Dakhla Oasis, which is also the nearest available source of water today. A markedly different climate must have prevailed during the periods when the sand pans were used by man.

The Gilf Kebir. The Gilf is an extensive series of Nubia sandstone mesas covering an area of around 15,000 km^2, with near-vertical sides rising from 200 to 300 m above the surrounding plain. The eastern side is cut by numerous deep wadis. The floors of these wadis are choked with sheetwash, and at the mouth of each is a huge alluvial fan. The nearest surface water now is at Gebel Uweinat, 150 km to the south.

A brief visit to the Gilf during the 1974 season led us to reexamine two sites reported by Myers (*2*). The first is located near Bagnold's camp and may be classified as Upper Acheulean. The bifaces are slightly eolized and occur in the upper part of an alluvial fan at the front of a major wadi. Although not strictly in situ, the occupation is probably contemporaneous with the accumulation of the fan. The second site is located near the upper end of Wadi Bakht, near the southern end of the Gilf. A falling dune formed a dam across the wadi and a large pond developed behind it. Eventually, the pond sediments completely filled the depression and the water overflowed the dune and broke the dam. Cultural debris occurs through the upper 2 m of the pond sediments. Although the material has not yet been studied in detail, the pottery is frequently decorated with cord-impressed and incised designs that are different from the Early Khartoum ware at the Nabta Playa sites. A sample of ostrich eggshell from this site yielded a radiocarbon date of 5330 B.C. ± 90 years (SMU-273). No other sites were found in the vicinity of the Gilf.

Archeology

The Paleolithic materials recovered from the Western Desert of Egypt represent seven distinct episodes of occupation: Upper Acheulean, Final Acheulean, Mousterian, Aterian, Terminal Paleolithic, Neolithic, and Old Kingdom. Each of these episodes, except for the Terminal Paleolithic and Neolithic, appears to be separated from the others by periods of aridity, a lower water table, and deflation.

Upper Acheulean. Traces of Upper Acheulean occupation occur throughout the area surveyed, almost always on deflated surfaces, and are heavily eolized. We studied two sites of this period in detail: E-72-1 and E-72-2, both in fossil spring vents at Dakhla Oasis.

An impressive collection of 7002 pieces was recovered from site E-72-1 and 2847 pieces were recovered from E-72-2. The collection includes 910 bifaces, of which 784 are from E-72-1. Both collections are highly homogeneous in their quantitative and qualitative content as well as in preferred materials. More than 99 percent of all artifacts in both sites are made from the local Eocene chert that occurs nearby, redeposited over the prespring surface.

The general structure of these two assemblages is closely similar, with fairly high frequencies of primary flakes but relatively few flakes overall (many of which were from changed orientation cores), very few blades, and a high frequency of tools. The presence of numerous bifaces and the relatively few biface trimming flakes could imply that the bifaces were manufactured elsewhere. Alternatively, this may reflect a depositional selection in which the lighter pieces were concentrated in the upper part of the vent and then removed or destroyed when that portion was deflated. The non-Levallois cores were exploited by the hard hammer technique; most were of the changed orientation variety. A few Levallois cores also occur, but the Levallois indices are negligible.

Among the tools the bifaces are the most common, representing 80.5 percent of the tools at site E-72-1 and 64.3 percent at site E-72-2. The most frequent form is amygdaloid; many of these bifaces have thick unworked butts. Backed bifaces, including both natural and worked backs, are also common. Double-backed and triangular forms are next in importance, followed by cordiforms that generally have thick butts. The rarer varieties include discoidal, lanceolate, limande, rostrocarinate, amygdaloid with cleaverlike tip, and atypical Micoquian. The non–hand axe tools are mostly denticulates and sidescrapers. The extreme richness of both collections, perhaps initially deposited around a single spring pool, suggests that the pool was used repeatedly over a long period of time and possibly throughout its existence.

The closest analogy among other North African assemblages is seen with the material from Kharga Oasis site K-10, which is also from a spring conduit (*3*, p. 60). These artifacts show a similar emphasis on double-backed hand axes, amygdaloids, and thick butts. However, the Khor Abu Anga variety of Acheulean from along the Nile in Nubia (*17, 18*) is significantly different, with greater emphasis on ovates, disks, lanceolates, and Micoquian bifaces in the Middle and Upper Acheulean and on primitive forms in the assemblages that are, presumably, Lower Acheulean. The Upper Acheulean at Bir Tarfawi and Bir Sahara seems to have greater similarity to the Nilotic Nubian material than to the Dakhla and Kharga assemblages. None of these groups appears to have a close resemblance to other Acheulean assemblages from North Africa, such as that at Sidi Zin in Tunisia (*19, 20*) or that from the central Sahara at Erg Tihodaine and Tabelbalat-Tachenghit (*21*).

Final Acheulean. Several Final Acheulean sites have been discovered but only one, site BS-14, a fossil spring vent just below the southern rim of the Bir Sahara basin, has been worked thus far. The raw material used to make tools was almost entirely quartzitic sandstone with rare pieces of quartz. The assemblage contains only six cores and biface trimming flakes are the most frequent element in the débitage (lithic waste products). The assemblage includes 110 bifaces that represent 88 percent of the tools recovered. Two groups of bifaces were emphasized: triangular (40.4 percent) and cordiform (35.3 percent). Most of the bifaces are fine, elongated examples with thinned butts. Amygdaloids are the third most common form, followed by discoidals. Other tools (15 specimens) include several spheroids and sidescrapers, a bifacial edged piece, a chopping tool, and a denticulate.

The assemblage from BS-14 is clearly different from those at sites E-72-1 and E-72-2 at Dakhla. The only close analogy to site BS-14 is seen at El-Ma el-Abiod in Algeria (*20*), which has a similarly elegant biface trimming, a high frequency of elongated cordiforms, and no cleavers.

Mousterian. There were four, or possibly five, consecutive Mousterian horizons associated with the lower lacustrine series at Bir Sahara.

1) The first horizon, in the top of the dune below the lower lacustrine series, is recorded only at one site (BS-12, lower level) and is known only from a small collection (86 pieces) of highly abraded artifacts. There are, however, six tools and three recognizable cores, one of which is for Levallois flakes. Five of the tools are denticulates and the other is a notch.

2) The second Mousterian horizon is represented by several extensive settlements in a black layer at the beginning of the lower lacustrine series. A typical example from this period is site BS-11, a long, low-density assemblage that is still mostly in situ just below the black layer and is without statistically significant concentrations of débitage or tool clusters. Most of the artifacts are made of gray quartzitic sandstone that probably came from one of the outcrops around the edge of the carbonate plain 30 to 40 km away. A few pieces are made of Eocene chert. The analysis of the assemblage indicates the presence of a workshop with lumps of rock brought to the site and shaped there. High values for initial flakes and Levallois preparation flakes, plus a low Levallois index (1.4), suggest that many of the Levallois cores were not exploited at the site but were made there and taken elsewhere to be used. The débitage is mainly based on changed orientation cores. Blades are rare and possibly accidental. Flaking was done with heavy hammerstones. The tool kit is characterized by a heavy dominance of denticulates (nearly 70 percent) that occur in a number of varieties, of which bilateral, transverse, lateral, triangular, and converging are the most common. All of these are made on flakes and elongated bladelike flakes. Notches are also important (20 percent), while sidescrapers are less common (only 7 percent). Several large spheroids were also present. Tools of the Upper Paleolithic group are extremely rare.

3) The third horizon occurs in the sands just above the black zone and is represented only at site BS-13. The concentration at this site was thin, with an elongated oval outline measuring 18 by 7 m. It was largely in situ but was partially exposed on the surface of a small sedimentary remnant. The raw material used for making tools was essentially the same as that at BS-11; however, there were significantly fewer primary and Levallois preparation flakes and Levallois pieces were more numerous (Levallois index, 14.3). There were few cores of any kind. This suggests that most of the Levallois flakes and points, as well as other blanks, must have been brought to the site in finished form. The tool assemblage is dominated by denticulates (55 percent) as is site BS-11; however, sidescrapers are nearly twice as numerous here (Fig. 4). Tools of the Upper Paleolithic type are not common although they occur more often here than at site BS-11. A probable activity area in the site is indicated by a cluster within a 2-m square, of three Levallois points, three converging sidescrapers, one Mousterian point, one bifacial triangular point, one notched flake, and two denticulates. This activity cluster has particular significance because it is a Typical Mousterian tool group in a concentration that is otherwise dominated by denticulates.

4) Two large adjoining concentrations were recorded from the fourth horizon, both almost entirely embedded within the beach sediment of the upper vegetation horizon just before the maximum aggradation of the lower lacustrine series. Both concentrations were oval in outline, about 30 m in diameter, and displayed much denser accumulations of artifacts than the other living floors. No significant clustering or activity areas were evident. All the raw material used for making tools at this site was a brownish quartzite. The assemblage contains only a few primary or early stage preparation flakes, while the frequency of occurrence of Levallois core preparation flakes is high (more than 50 percent of

the total restricted count). However, there are very few cores (*8*), only one of which is Levallois, and the Levallois index (14.3) is only moderate. This structure indicates that cores tended to be blocked out elsewhere, brought to the site to be completed, and then taken to another site to be used. The tool kit is significantly smaller in size than those of the previous sites. However, it is also dominated by denticulates (77.0 percent). Sidescrapers are not frequent, and tools of the Upper Paleolithic type are again very rare. Slightly over 36 percent of the tools are made on Levallois flakes. One of the recovered tools is pedunculated, marking the first appearance of this technology within the Middle Paleolithic sequence of the Western Desert.

5) The fifth level, at the maximum of the lower lacustrine series, is suggested only by faunal material at one locality where the nearby beach was completely removed by deflation. A Mousterian affiliation seems likely since, apparently, only a short time gap separates the assemblage from site BS-1 and the maximum aggradation of the lake.

In summary, artifacts at all of the Bir Sahara Mousterian settlements are dominated by denticulates and are classified as Denticulate Mousterian. Within the series there are no evident evolutionary trends, and the quantitative dissimilarities, particularly those touching the Levallois group, may be explained by slightly divergent raw material economies and variations in the workshop activities. Significantly, there were no traces of clustering that could suggest smaller homogeneous occupation units within the extensive settlement areas. This is in marked contrast to Upper and Late Paleolithic sites in Europe and North Africa, where patterning often indicates small social units, generally identified with families, within larger groups. Their absence at Bir Sahara suggests a radically different social or functional structure (or both) for these settlements.

The Denticulate Mousterian at Bir Sahara is generally comparable to the denticulate-oriented assemblages reported from Nubia, Syria, southwestern France, or along the northwestern Mediterranean (*22*); however, only some of the so-called Mousterio-Tayacian sites from southern Russia, such as Kiyk-Koba and Krouglik, contain similarly high indices of denticulates (*23*).

Elsewhere in the Western Desert a significantly different variety of Mousterian occurs. The Mousterian site found near the center of a sand pan in the Dyke area, far removed from any available surface water, was presumably occupied during a more moist interval and possibly was contemporary with the deposition of the lower lacustrine series at Bir Sahara and the Mousterian settlements there.

The artifacts at this site were fresh on the underside, but wind-faceted on the upper surface. There were only 371 artifacts, including 41 tools. They were made of three varieties of locally available raw material: a brown quartzitic sandstone; a dark brown, almost black, ferruginous grit sandstone; and, rarely, a light-colored petrified wood. There is a low emphasis on Levallois technology (Levallois index, 0.9), a dominance of sidescrapers (64.1 percent of all tools), and, in contrast to the Bir Sahara sites, low values for denticulates and notches (11.1 percent). It is classified as Typical Mousterian of non-Levallois facies.

Aterian. Three Aterian sites, all clustered around a large pond that was the scene of numerous kills and related butchering activities, were studied at Bir Tarfawi. One site (BT-14, area B) was on the dune at the edge of the pond; another site (BT-14, area C) was a small tight concentration within the pond sediments and presumably was occupied during a seasonal low water phase of the pond; and the third (BT-14, area A) was the extensive (6800 m^2 was scatter-patterned) kill and butchering area in the central portion of the pond. All of these sites share low Levallois indices (8.9 to 10.9), very low blade frequencies (1.7 to 2.7 percent), and low values for occurrence of tools of the Upper Paleolithic type. In this respect they recall the preceding Mousterian settlements at nearby Bir Sahara. Other characteristics are reminiscent of the Typical Mousterian. The Levallois tool indices are high in the living areas (B and C) but low in the butchering area (A). Areas A and B both

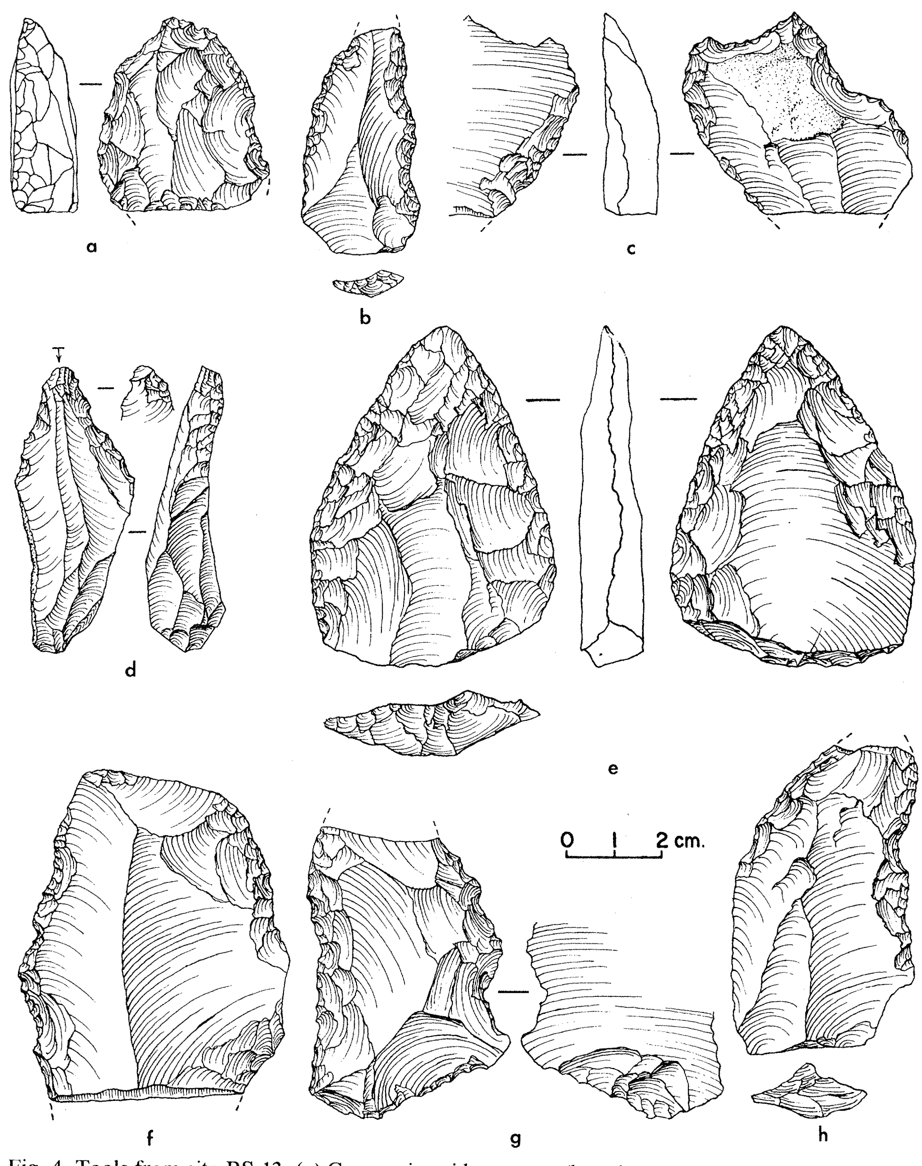


Fig. 4. Tools from site BS-13. (a) Converging sidescraper; (b and g) converging denticulate; (c) bec; (d) borer; (e) Mousterian point; (f) bilateral denticulate; (h) bilateral sidescraper.

have very high frequencies of denticulate occurrence (44.4 and 62.9, restricted), while area C has relatively few denticulates (14.1) and more sidescrapers and other Mousterian group tools. Pedunculates and bifacial foliates are unusual; they comprise only 2.8 to 5.9 percent of the total tools.

The butchering area (A) stands out in contrast to the two other areas in an extremely high tool to débitage ratio (almost 50 percent as opposed to 15 and 11 percent) and by its high frequency of occurrence of large denticulates. Areas B and C share a strong emphasis on Levallois core preparation, but the difference in the tool kits suggests a difference in functional emphasis.

These Aterian sites appear to differ significantly from the Aterian assemblage from the spring vent of site KO6E at Kharga Oasis (*3*, p. 86). That industry is dominated by the Levallois in both the cores and tools, with numerous retouched and unretouched Levallois points. Biface foliates are also much more common at Kharga Oasis; they represent 22 percent of the tool group.

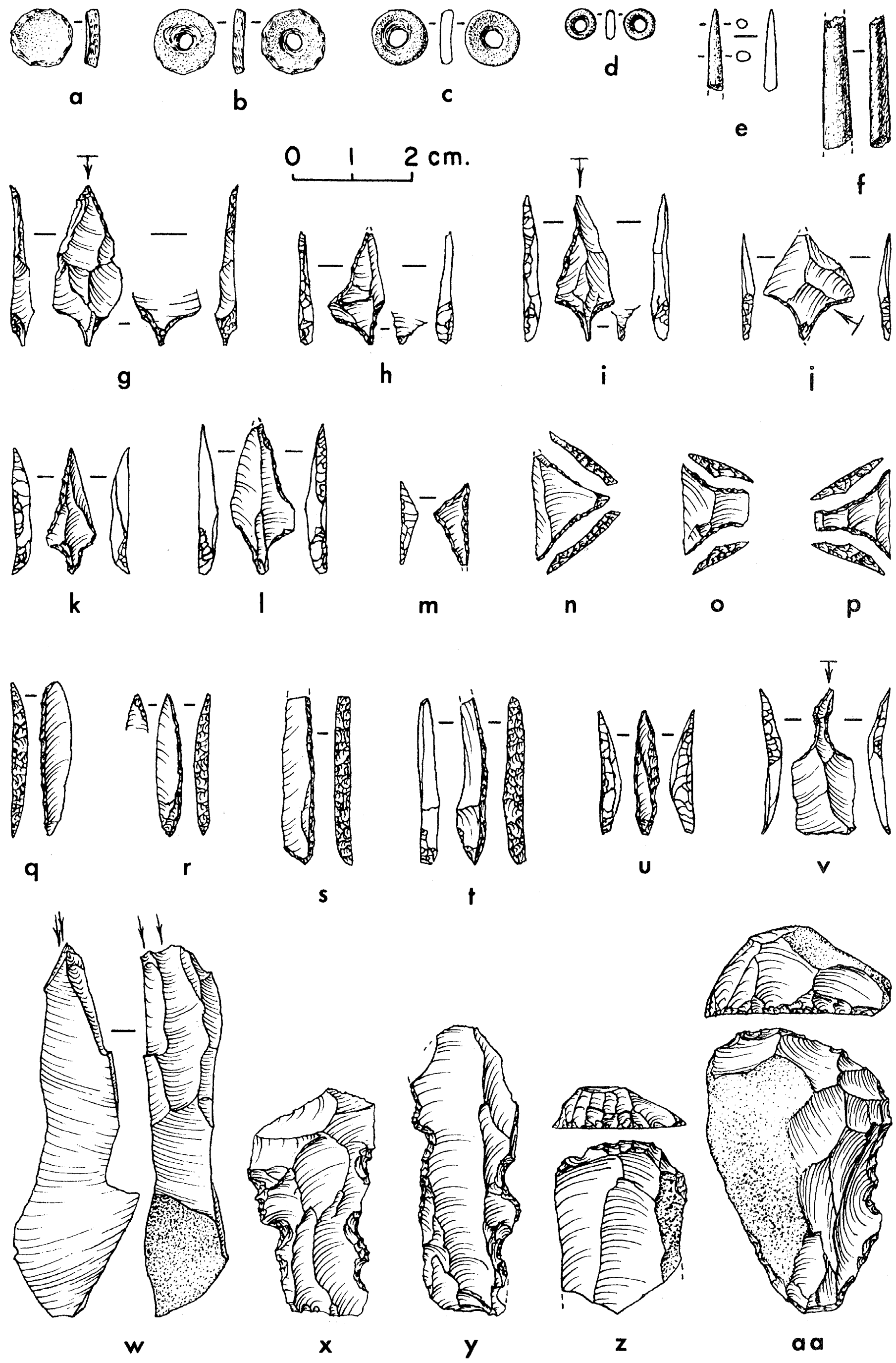


Fig. 5. Artifacts from Terminal Paleolithic cultural layer, site E-74-6 at Nabta Playa. (a) Worked ostrich eggshell; (b to d) eggshell beads; (e and f) worked bone; (g to l) Ounan points; (m) scalene triangle; (n) isosceles triangle; (o and p) trapeze; (q to t) straight-backed bladelets, slightly arched [(r) with inverse retouched tip; (s and t) with retouched bases]; (u) double-backed perforator with both ends pointed; (v) *zinken* perforator with developed curved point; (w) multifaceted single-faced burin; (x and y) denticulates; (z and aa) endscrapers.

Along the Nile in Nubia are several sites that seem to be related to the Aterian. They have been classified as Nubian Middle Paleolithic, but some yielded strong Levallois components, numerous biface foliates, and occasional pedunculates. These include Gebel Brinikol, Arkin 5, and Arkin 6A, sites 400, 401, and 415 (*17, 24*). Although they are most often compared to the Sangoan and Stillbay of sub-Saharan Africa, they could well be considered a close parallel or variety of the Aterian in the adjacent Sahara.

Terminal Paleolithic. Sites of this period were found in several areas in the Nubian Desert and were studied in detail at two separate localities. The best data come from Nabta Playa where three sites were excavated. Although all are closely related, each of the sites differs from the others by the emphasis within the tool kit. Unfortunately, only one of the sites is dated; therefore, we cannot determine whether these differences in the tool kits are the result of changes through time.

All of the sites of this period at Nabta Playa are generally microlithic in character and share a similar technology that emphasizes changed orientation and single platform cores. One site (E-74-6) shows a strong emphasis on pointed bladelets with straight to slightly arched backs. Geometrics are usually isosceles triangles with two concave and markedly convergent sides. Ounan points occur in several varieties (Fig. 5). The second site (E-75-7) contains many straight-backed bladelets, but elongated scalene triangles with small short sides are the most common geometric shape. The third site (E-75-9) is dominated by fully arch-backed bladelets and lunates. All sites revealed frequent notches and denticulates on both flakes and blades. Endscrapers, burins, and grinding stones are rare.

Another Terminal Paleolithic site (E-72-5) was excavated at the Dyke area about 18 km south of the Mousterian site discussed above. Site E-72-5 is situated on the floor of a sand pan and consists of six concentrations, two of which are adjacent to each other. Only one of these was excavated. It appeared to be an almost circular, very dense cluster of artifacts about 7 m in diameter. Numerous heavy sandstone slabs were scattered around the perimeter of the cluster. The patterning of the artifacts and the slabs suggests a large tent or enclosure with its floor covered by tools and débitage. There is no conclusive evidence for special activity areas or clustering within the concentration.

The preferred raw material at E-72-5 was a local dark brown quartzitic sandstone. Chert, probably also local, was next in order of preference. Blade cores are heavily dominant; the most numerous type is the single platform variety, which is elongated with a flat or rounded flaking surface and full or almost full precore preparation of the backs, preflaking surfaces, and sides. Opposite platform elongated blade cores are also common. All were exploited by punch flaking. Flake cores are less numerous and are mostly of the changed orientation variety. The assemblage contained very few primary and core preparation flakes of quartzite, suggesting that the precores of this material were prepared elsewhere. However, primary flakes of the local chert were more numerous, indicating that the preparation of these cores was done at the site.

The tool kit has high frequencies of denticulates, notches, and retouched pieces, followed closely by geometrics in the form of elongated scalene triangles and elongated scalene triangles with short, often concave, sides. Backed bladelets are unusual; many of these are shouldered and are probably unfinished triangles. Endscrapers and burins also occur, but are not numerous. Microburins are common.

The relationship of the Terminal Paleolithic at Nabta and the Dyke area to the "Bedowin Microlithic" at Kharga is not clear, in part because the Kharga collections are all from the surface and appear to be mixed with strong Neolithic elements (*3*). However, the presence of elongated scalene triangles suggests that a similar Terminal Paleolithic occupation may have occurred.

Comparisons with contemporary Nilotic materials suggest statistically significant dissimilarities between the two areas. The Shamarkian from Sudanese Nubia (*25*, *26*) and from near Idfu, Egypt, emphasizes backed bladelets, while triangles, notches, and denticulates are very rare or absent. There are also differences in methods of core preparation, in core form, and in raw material preferences. The Qarunian from the Fayum in northern Egypt (*27*) has a technology similar to that of the Shamarkian and is also heavily dominated by backed bladelets with few geometrics.

Conversely, surprisingly close parallels to the desert Terminal Paleolithic are found in Tunisia, particularly with the inland Chacal and Aïn Aachena varieties or the Setifian facies of the Upper Capsian (*28*). Similarities are reflected in high frequencies of notched and denticulated blades and bladelets and in high concentrations of geometrics, particularly elongated scalene triangles.

Although there is a clear dichotomy between the Nilotic sites and those deep in the desert, it is also evident that a technomorphological unity exists within the Terminal Paleolithic of northern Africa, as demonstrated by the repetition of types, techniques, and methods of stone work which are shared by the Upper Capsian, Shamarkian, Qarunian, and several Western Desert assemblages. The differences shown between the Nilotic industries, which were associated with an economy where fishing was important, and those of the same age found deep in the desert probably reflect, at least in part, different systems of procurement. Environmental patterning seems to be reflected in the structure of the tool kits, in the raw material preferences, and in the flint working methods.

Neolithic. At Nabta, the Neolithic sites are associated with the same epi-

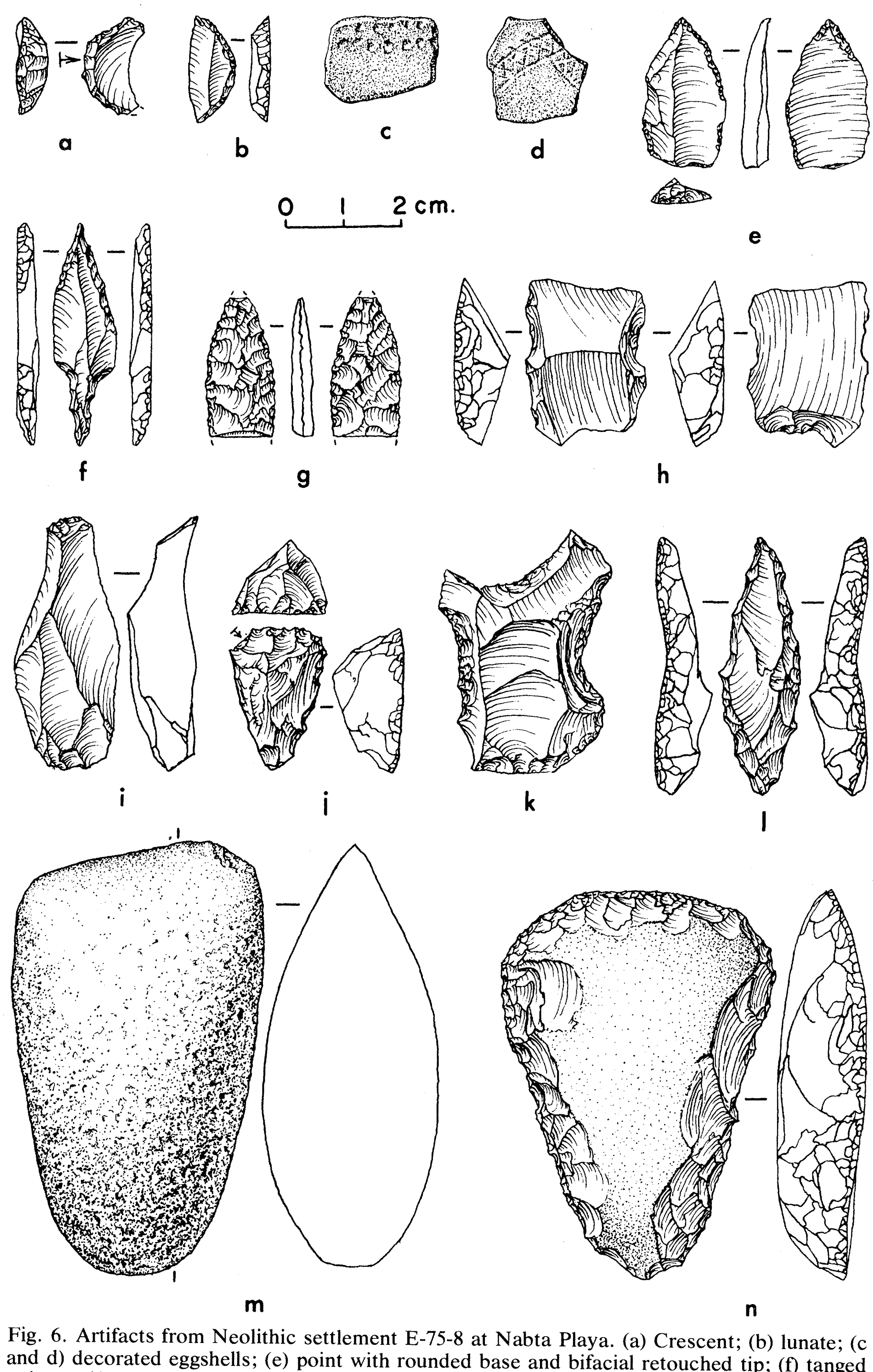


Fig. 6. Artifacts from Neolithic settlement E-75-8 at Nabta Playa. (a) Crescent; (b) lunate; (c and d) decorated eggshells; (e) point with rounded base and bifacial retouched tip; (f) tanged point, unifacial; (g) bifacial point; (h) transverse arrowhead on thick flake; (i and j) endscrapers; (k) multiple-notched piece; (l) double-backed perforator; (m) pecked and polished celt; (n) celt or adze, plano-convex, unifacial.

sode of playa sedimentation as the Terminal Paleolithic, and the radiocarbon dates indicate that 1000 years or less may separate the two occupations. The Neolithic settlements at Nabta Playa represent a radically different exploitation strategy from that of the Terminal Paleolithic. The social units were undoubtedly larger, sites were occupied for longer intervals, formal structures were dug for storage, well-made pottery was in common use, the villages may have contained houses (indicated by alignments of post holes), deep walk-in wells were dug during intervals of low water, domestic animals (including cattle and sheep/goat) were maintained, and there was extensive use of ground grains that have not yet been identified as domestic or wild. Hunting of gazelle and hare was still important, but nonetheless, these sites reflect a new type of society.

Three sites of the Neolithic period were excavated at Nabta Playa and yielded closely similar lithic assemblages. The predominant raw material was Eocene chert. Quartz was also extensively used, and there were a few pebbles of Nile chert and agate. Most of the cores are changed orientation flake cores. Blades are not common in the débitage, although a few blade tools are present. The tool kit includes microlithic elements (mostly crescents, short lunates, and J-lunates) and a nonmicrolithic group that includes perforators, notches, denticulates, bifacial stemmed arrowheads, fine elongated bifacial pieces, ground and pecked celts, chipped adzes, and transverse sidescrapers on side-blow flakes (Fig. 6). Nearby sites that were not excavated yielded several concave-base arrowheads identical to those from Fayum A in northern Egypt.

The pottery was sand-tempered, well made, and usually had densely stamped surfaces in the typical Early Khartoum style. There were also a few undecorated sherds, which were otherwise similar to the Khartoum ware.

The beginning of the Neolithic occupation at Nabta is firmly dated to around 6000 B.C., nearly 1000 or more years earlier than the oldest known Neolithic settlements along the Nile 100 km to the east. Terminal Paleolithic settlements at DIW-51, Catfish Cave, El Kab, and the Fayum (*26, 27, 29*) are placed between 5000 and 6000 B.C. Together with several dates around 4000 B.C. or slightly later for the Neolithic occupation at DIW-50 and Fayum A (*30*), these dates suggest that the Neolithic complex along the Nile did not begin much before 4000 B.C. This situation poses a very interesting problem of cultural conservatism.

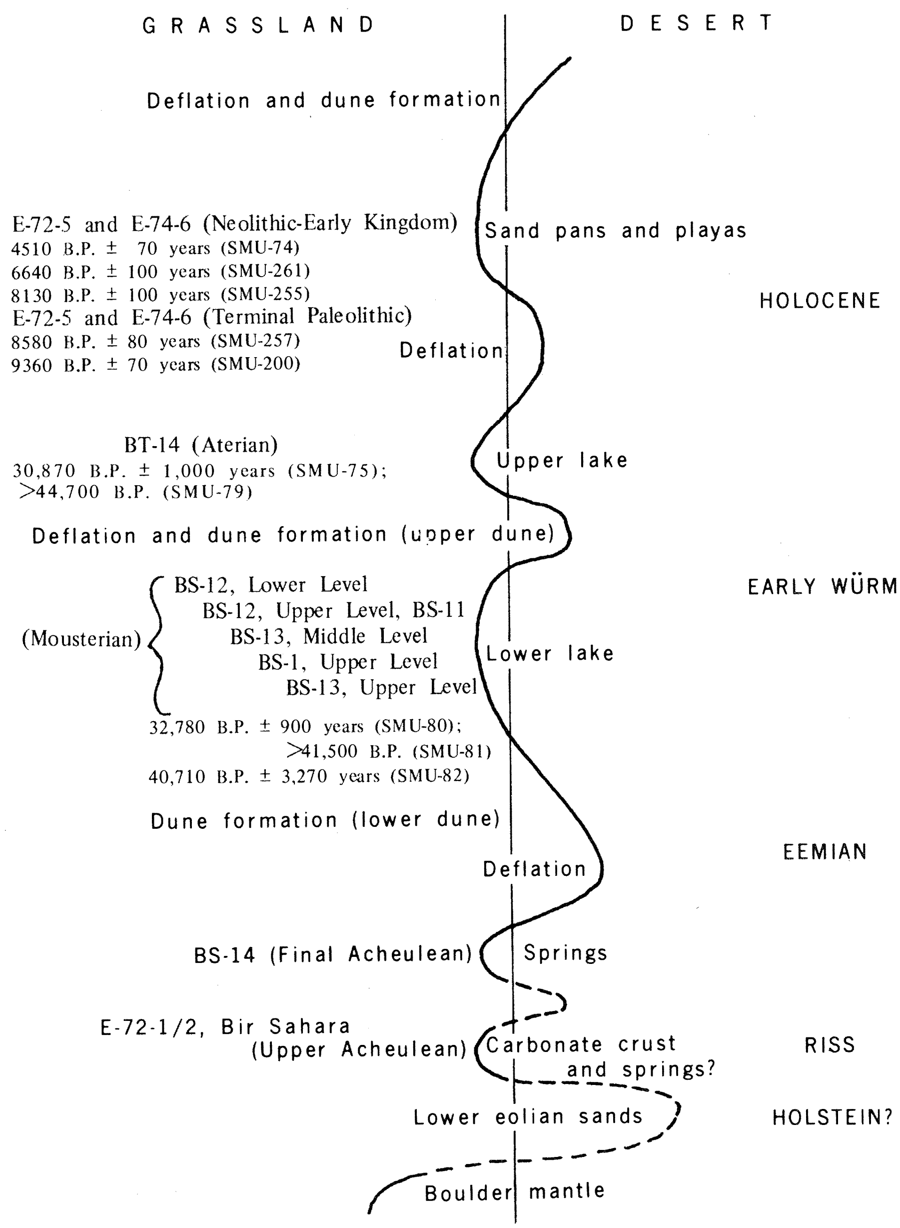


Fig. 7. Schematic climate curve of the Egyptian Sahara and two tentative correlations with Europe. Abbreviation: B.P., years before present.

Conclusions

The recent research in the Western Desert of Egypt has provided significant new data on climatic pulsations in the eastern Sahara (Fig. 7). The base of the sequence begins at Dakhla with the deposition of the boulder and pebble mantle, a deposition that almost certainly preceded the Upper Acheulean spring at sites E-72-1 and E-72-2 near Balat (Fig. 1). A high-velocity stream with torrential rains and relatively steep and hard depositional surfaces is indicated for this sedimentation.

The deposition of the oldest sands under the carbonate crust in the Bir Sahara–Bir Tarfawi area also precedes the Upper Acheulean. Preliminary studies of the grains indicate eolian transportation as the main source, which signifies a long period of desert environment during which the Bir Sahara–Bir Tarfawi basin was filled to a level slightly higher than that today.

The formation of the carbonate bed on the surface of the oldest sands at Bir Sahara is presumably connected with the beginning of spring discharge and an associated high groundwater table. The origin of the springs at Kharga and Dakhla, as well as those at the birs and the ponds at the southern end of Bir Tarfawi, was undoubtedly connected with a much greater hydrostatic pressure associated with an increased water supply to the aquifer. The upthrown granite massif of El Tawila caused groundwater to approach the surface several times in the Bir area during the Pleistocene, so that ponds and marshes occupied the deflation basins. A short period of deflation seems to separate the Upper Acheulean springs and ponds from the Final Acheulean spring at site BS-14; however, this event is not well documented.

A pronounced period of deflation occurred after the Acheulean occupation. During this time a deep basin was scoured out at Bir Sahara, indicating a huge drop in the water level. Subsequently, the Bir Sahara basin was partially filled with dunes, the upper part of which may be associated with a slightly rising water table as suggested by traces of the oldest Mousterian occupation left during the time the dune was still forming. Succeeding Mousterian sites at Bir Sahara relate to a rising water table and, conceivably, to increasing moisture in the area. The thick sandy beaches, however, indicate that eolian sand continued to enter the basin throughout this period.

A dry grassland environment apparently prevailed during the period of rising water table and the Mousterian occupation at Bir Sahara. An Ethiopian fauna, including rhino, ass, camel, buffalo, and several varieties of gazelle existed in the vicinity of the lakes. At some point during this period, possibly when the lake reached its maximum stand, the Mousterian population spread over the desert and the sand pan at site E-72-4 was occupied. We assume that the revival of spring activity at Bir Sahara was contemporaneous with the development of new springs at Kharga, such as the Levalloisian conduit of KO8A (*3*, pp. 75–80). An increase in local rainfall is indicated also by the wadi silts and tufas containing Levallois elements at Refuf Pass, near Kharga (*3*, pp. 103–105).

Deterioration of the climate was recorded by the receding lake and invading dunes, with an occasional better year marked by thin streaks of silt and crusts of cemented sand in the basal part of the younger dune at Bir Sahara. The depth to which the water table receded is unknown, but the thickness of the sand under the Aterian ponds at Bir Tarfawi and the absence of any traces of human occupation suggest a level close to that of the present, accompanied by true desert conditions.

This was followed, once again, by a considerable rise of the water table and increased spring discharge that caused the formation of lakes at both Bir Tarfawi and Bir Sahara. This increased moisture may also have caused a renewal of spring activity at Kharga Oasis (*3*, pp. 86–90). At both Kharga and Bir Sahara the Mousterian groups were replaced by Aterian hunters who shared many of the artifactual traits of the earlier Mousterian. A few refinements appeared in the addition of bifacial foliates and pedunculates to the tool kit. A dry grassland probably existed again around the ponds; an Ethiopian fauna, closely similar to that of the Mousterian moist period, returned to the area and was extensively hunted by Aterian man.

The Aterian moist interval was succeeded by a long period of desert conditions accompanied by a drop in the water table and pronounced deflation to a level not more than 2 to 4 m above the modern water table. The current morphology of the Bir area was formed at that time. It is significant that, after the Aterian ponds dried up, an event which apparently occurred more than 44,000 years ago, there are no traces anywhere in the Nubian Desert of any occupation, spring, or lacustrine sediments that are between the Aterian sites and the Terminal Paleolithic in age. For this period of more than 30,000 years' duration the Western Desert of Egypt was apparently devoid of surface water and of any sign of life. The Ethiopian fauna disappeared. We have no direct evidence on the environment during this period, but it could well have been hyperarid and cold. This interpretation is in agreement with other indications of great aridity in the Sahara during the last glacial maximum, in particular the increase in wind-blown sand off the West African coast and the changes in the foraminifera of the Red Sea and the Gulf of Aden (*31*).

The moist episode when the Terminal Paleolithic and Neolithic playa developed at Nabta and elsewhere where the sand pans were occupied is not recorded at Bir Sahara or Bir Tarfawi. This suggests that the period of increased rainfall was of such limited duration as to be inadequate to cause a substantial rise of the water table around the Birs. There was an increase in precipitation around 7500 B.C. which, with minor fluctuations, persisted at least until around 5000 B.C. The evidence is not adequate to determine whether this was followed by a brief period of aridity, but in any event, another widespread occupation occurred around both the Birs and the sand pans at around 2500 B.C., suggesting another episode of increased moisture.

A comparison of the climatic sequence in the Egyptian Sahara with that of Europe is hazardous in the absence of firm, absolute dates, particularly since there is an extremely complex series of recognized oscillations associated with the Würm glaciation. There are, however, several possibilities. For example, the Upper Acheulean spring activity may be correlated with the Riss glaciation, and the pronounced deflation responsible for the formation of the basins at Bir Sahara may have occurred during the Eemian interglacial. The Mousterian and Aterian occupations and their associated ponds would, consequently, correlate with early and lower middle Würm and thus would be contemporary with the Mousterian of Europe. On the other hand, the Final Acheulean and the Mousterian might possibly be placed in early Würm. We favor the first sequence. With either correlation the long period of desert conditions that succeeds the Aterian wet phase is almost certainly contemporary with the main Würm glaciation in northern Europe. The absence of any evidence for pluvial conditions during that time in the Sahara is a serious complication for simplistic correlations of pluvial and glacial phenomena.

The Early Holocene wet phases are closely comparable to the two wet fluctuations indicated for the central and western Sahara, including Tchad (*32*). During the early part of the first of these wet phases, the Sahara was reoccupied for the first time since the Middle Paleolithic. However, Terminal Paleolithic hunters and gatherers were soon replaced by fully developed Neolithic societies.

It is clear that the Western Desert could not have been a significant source for the numerous and highly diverse Late Paleolithic complexes that occur along the Nile during the latter part of the late Pleistocene. The two areas, the Nile Valley and the Sahara, seem to have developed along largely independent lines, much as they have even until the present time.

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Electrotonic Processing of Information by Brain Cells

Recent research augurs an important role for neuronal local circuits in higher brain function.

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Great advances have been made in major areas of neuroscience over the years, but strikingly lacking are unifying conceptual principles capable of relating brain cell activities to psychological processes such as learning, memory, perception, consciousness, and other "higher brain functions." Essential to the development of such principles will be a more profound understanding of the bioelectrical and other processes of neuronal interaction that are implicated in higher brain functions.

The last two decades have seen a revolution in concepts of information processing and transfer in and between brain cells, concepts that have dominated neurological thinking for many years (*1–5*). One significant change is in the concept of the dynamic functional polarization of the neuron, according to which the neuron is a one-way, information-transmitting, cellular system with a sometimes vast but passive receptive dendritic surface, with integrative capabilities focused at the axon hillock, and with an axonal self-regenerative mechanism for rapid transmission of the message to axonal terminals. The new view of the neuron, based primarily on recent electron microscope evidence (*6*) and supported by intracellular electrical recording, holds that the dendrite, far from being only a passive receptor surface, may also be presynaptic, transmitting information to other neurons through dendrodendritic synapses. Such neurons may simultaneously be the site of many electrotonic current pathways, involving components as small as dendritic membrane patches or individual dendrites. Electrotonic currents, originating in various loci, flow through a vast network; the information-processing product of these currents is transmitted to other brain regions by projection neurons—that is, neurons with long axons.

The second significant recent change has been modification of the concept that transmission of information between neurons requires the propagation of "spike" action potentials. Evidence is accumulating that small graded changes in potential in one neuron can synaptically influence electrical activity in other neurons (*1, 3, 7, 8*). In dendritic networks, distances between interactive sites are measured in micrometers, as contrasted with the millimeter or centimeter distances characteristic of spike propagation. Attenuation of a passively conducted electrical signal is correspondingly less significant in such localized dendritic networks, and thus obviates the need for spikes. That some neurons characteristically interact without the benefit of spikes has been repeatedly demonstrated. In such neurons, changes in membrane potential of less than a millivolt may suffice to alter synaptic transmission (*7, 9*).

Paralleling the evolution of a new view of electrical information processing in neurons has been the emergence of knowledge of fast bidirectional transport and biochemical signaling between brain cells. Such molecular exchange may function not only to provide metabolic

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