Climate-Controlled Holocene Occupation in the Sahara: Motor of Africa’s Evolution

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Radiocarbon data from 150 archaeological excavations in the now hyper-arid Eastern Sahara of Egypt, Sudan, Libya and Chad reveal close links between climatic variations and prehistoric occupation during the past 12,000 years. Synoptic multiple-indicator views for major time-slices demonstrate the transition from initial settlement after the sudden onset of humid conditions at 8,500 B.C.E. to the exodus resulting from gradual desiccation since 5,300 B.C.E. Southward shifting of the desert margin helped trigger the emergence of pharaonic civilization along the Nile, influenced the spread of pastoralism throughout the continent, and affects sub-Saharan Africa to the present day.

During the past decade it has become increasingly clear that climate signals extracted from polar ice caps and ocean floor sediments cannot be directly translated into climate and environmental fluctuations on tropical and subtropical continental regions habitable by humans. Contrary to the concept of the Holocene as a climatically stable period (1), all geological and archaeological evidence from the hypercontinental Eastern Sahara indicates dramatic climatic and environmental changes over the past 12,000 years that do often not reflect climate anomalies recorded in high-latitude archives [e.g. (2)]. The Eastern Sahara covers >2,000,000 km² and includes the Western Desert of Egypt, Northwest Sudan and the adjacent parts of Libya and Chad, together about the size of western Europe. Today it is the largest hyper-arid warm desert on Earth, with virtually no rainfall (<2 mm/yr) in its center and maximum precipitation of 30 mm/yr at its peripheries against potential evaporation rates of up to >6000 mm/yr (3).

As a consequence of the extreme aridity and scarceness of wells, the Eastern Sahara, outside the Nile valley and groundwater-supported oases in the Egyptian “New Valley,” Fayum and Siwa, has been completely void of permanent human settlement in recent millennia. For this reason, it is a unique natural laboratory for the reconstruction of the links between changing climate and environments, and human occupation and adaptation, using prehistoric humans as sensitive indicators of past climate and living conditions. Their mere presence there, documented in countless archaeological remains and occupation sites, or their absence, serve as un failing evidence for shifting climatic zones, the development of Neolithic achievements, interregional contacts and innovative strategies that have modeled the socio-cultural evolution on the African continent to the present day.

Understanding the spatial and temporal variations of past rainfall requires integration of geological, archaeological, archaeobotanical and archaeozoological field data into regional chronologies at several time-slices and distinct latitudinal zones. A vast region, stretching 1,800 km from latitudes 15° to 31°N and 1,300 km between longitudes 22° and 34°E, can hardly be treated as a single entity. Such a multi-indicator and supra-regional approach prevents over stressing of local stratigraphies that may not necessarily reflect conditions in the same geographical latitude (4); and the ambiguity of condensing geological and biological evidence from several millennia into a single age loosely defined as “Holocene optimum” (5, 6).

Onset of humid conditions. During the Allerød interstadial (c. 11,900-10,800 B.C.E.) when Northwest Europe witnessed temporarily waning ice-sheets, and the following Younger Dryas, the final cold phase of the Pleistocene, the Eastern Sahara was still as hyper-arid as during the Last Glacial Maximum at 20,000 B.C.E. and void of any aquatic environments. The first signal of a changing climate occurs in the early Preboreal, i.e. the establishment of post-glacial conditions in the mid-latitudes, by a sudden appearance of carbonate lake formations in the Sudanese Sahara and of siliceous mud deposits in the Egyptian Sahara.

Radiocarbon dates of the base levels of these paleolakes and playa-type rain pools reveal the almost contemporaneous onset of pluvial conditions between latitudes 16° and 24°N at circa 8,500 B.C.E. and therefore an abrupt northward shift of the tropical rainfall belts over as much as 800 km within several generations only (7, 8). This decisive climate change can be attributed to tropical summer rains owing to a major extension of the paleomonsoon system while the contribution of Mediterranean winter rain systems north of 24°N remains...
vague. As a result, strikingly improved environmental conditions spread over the entire Eastern Sahara (7–15) with semi-humid climates in its southern part and semi-arid conditions in its center.

**Time transgressive drying of the Eastern Sahara.** The chronology of radiocarbon dates from early and mid-Holocene occupation sites along a north-south oriented transect through the Eastern Sahara provides a spatial and temporal synthesis of the directional trend in shifting human populations (Fig. 1 and fig. S1). It was compiled from almost 500 of our mostly previously unpublished radiometric results from about 150 excavations at non-oasis sites, supplemented by condensed chronologies for Nafta and Kiseiba (4), the Egyptian oases (16, 17) and the Nile valley (18). Salient points are (i) the general array of radiocarbon dates with older dates in the north and the bulk of younger dates in the southern part, clearly indicating a movement of prehistoric populations towards the present-day Sahelian zone; (ii) the dearth of early-Holocene data from the Nile valley at a time when human presence in the Eastern Sahara is well documented; and (iii) a sharp break of settlement in the Egyptian Sahara around 5,300 B.C.E., except for some ecologically favored refuges like the Gilf Kebir Plateau, exactly at a time when Neolithic and predynastic farming communities began flourishing in the Nile valley.

**Phases of human occupation.** Cumulative curves of the archaeological chronological data (Fig. 2) allow the distinction of four major occupation phases. These are (i) the Reoccupation phase (8,500–7,000 B.C.E.) starting with surprisingly early settlement in the Egyptian Sahara; (ii) the subsequent Formation phase (7,000–5,300 B.C.E.) ending abruptly in all areas without permanent water; (iii) the Regionalization phase (5,300–3,500 B.C.E.) featuring retreat to highland refuges with continuing rains and temporary lakes; and finally (iv) the Marginalization phase (3,500–1,500 B.C.E.) with only transient human activities in the Egyptian Sahara and prehistoric occupation restricted to Northern Sudan.

These main occupation phases are discussed against their assumed environmental setting in the following. The climatic background is given in synoptic zones, limited by best-estimate isohyets (lines of equal annual precipitation) on the basis of geological, archaeozoological and archaeobotanical data (7, 9–12, 19). Correlation between the proposed pluviometric pattern and the archaeological evidence produces a coherent scenario for environmental, socio-cultural and economic change in the Eastern Sahara since the terminal Pleistocene.

At that time, the Saharan desert extended about 400 km further south than today, covering more than one third of the African continent (Fig. 3A and fig. S2A). Prehistoric sites along the Nile are overrepresented at Lake Nubia due to the archaeological rescue missions related to the Aswan highdam, but contrast clearly with the complete lack of evidence from the desert. During the terminal Pleistocene “Wild Nile” stage at c. 12,000 B.C.E (20), living conditions along the river became harsh and caused conflicts for land and food as indicated, for example, by the late Paleolithic Nubian cemetery of Jebel Sahaba where many of the buried individuals had died a violent death (21).

**Early Holocene reoccupation (8,500–7,000 B.C.E.).** With the rapid arrival of monsoon rains at 8,500 B.C.E., savannah-like environments turned the Eastern Sahara into a habitable region swiftly used by prehistoric settlers (Fig. 3B and fig. S2B). Groups from the south, already adapted to savannah ecology, extended their traditional way of life following the northward shifting rains while Nile dwellers may have left the inhospitable valley. Their epipaleolithic tool kit as well as archaeozoological evidence from Nafta and Kiseiba define them as hunter-gatherers, possibly already practicing some animal husbandry (4). While this pastro-foraging economy needs further confirmation, “wavy line” decorated pottery – the very first African ceramics – is a key achievement of the 9th millennium B.C.E. (22).

Epipaleolithic camp sites in the Regenfeld area dated to 8,000 – 7,000 B.C.E. demonstrate quick migration of populations over several hundreds of kilometers into the central Great Sand Sea where they encountered satisfactory living conditions in what is today the Libyan Desert’s most barren part (23). Rains had turned the late-Pleistocene dunes into pasture that provided wild grains for the hunters-gatherers and browsing for their game. Most striking is the almost complete lack of settlements in the Egyptian Nile valley, with the exception of El Kab (24). The dearth of archaeological sites along the Nile and in the Wadi Howar region reflects conditions too marshy and hazardous for settlement. During the early Holocene humid optimum, hunters and gatherers obviously preferred the less wooded grassland further north to the regularly flooded and densely wooded environments of the southern Sahara.

**Mid-Holocene formation (7,000–5,300 B.C.E.).** After 7,000 B.C.E. human settlement became well established throughout the Eastern Sahara by way of economical and technological adaptations to regionally different ecological requirements (25) (Fig. 3C and fig. S2C). On the Egyptian Abu Muhariq Plateau, bifacial technology obviously rooted in the Levant caused a complete change in the lithic tool kit that later can be traced into the predynastic cultures of the Nile valley (26). Impression-decorated pottery of Sudan tradition, on the other hand, is represented as far north as the Egyptian oases and the Great Sand Sea (27). The most important achievement of this phase is the introduction of domestic livestock. Sheep and goat, for which an early record also exists in Egypt’s Eastern Desert (28), must have been
introduced from their wild progenitors in western Asia (29) while cattle appear to have been domesticated locally. Livestock keeping, well documented e.g. at Nabta Playa (4), became an essential component of a multi-resource pastoral economy that marks the beginning of African pastoral societies. Depending on local factors, their economic base differed substantially. In the western Abu Ballas area (Mudhams 85/56), for example, rich faunal material from around 6,400 B.C.E. did not reveal any evidence of domestic livestock (30), while in the eastern part (Eastpans 96/2) cattle are well documented, together with a new type of undecorated late Neolithic pottery (25).

The radiocarbon dates do not indicate any rupture in regional climatic development between 7,000 and 5,300 B.C.E. The disparity in ceramics and lithic artifacts at Djara and Mudhams at 6,000 B.C.E. points to a break between the two phases (“A” and “B”), which coincides with the arrival of sheep and goat (26). Some cultural changes may consequently have occurred beyond climate control.

According to the deficiency of occupation sites, regular monsoonal rains have ceased to reach the Egyptian Sahara not later than 5,300 B.C.E. At Djara and on the Abu Muhariq Plateau there is a significant decline in radiocarbon dates (25). Another abrupt end of occupation is observed in the central Great Sand Sea while the few younger dates from Abu Minqar may be linked to local springs and transhumance from the oases depression (27). A comparable pattern of semi-nomadic occupation underlies the evidence for cattle at Eastpans 96/2, when living conditions in the more distant parts of the Abu Ballas region had already deteriorated. With the end of the Formation phase at 5,300 B.C.E., multi-resource pastoralism appears to have become the vital human subsistence strategy in the Egyptian Sahara while at the same time first farming communities developed in the Fayum.

**Mid-Holocene regionalization (5,300-3,500 B.C.E.).** The retreat from desiccating regions into ecological niches such as the Gilf Kebir and the beginning exodus to the Sudanese plains where rainfall and surface water were still sufficient (Fig. 3D and fig. S2D), fostered more regionally differing socio-cultural adaptations. The few dates from the western fringes of the Great Sand Sea, from the Abu Ballas area and the Abu Muhariq Plateau reflect only sporadic occupation, while the eastern Abu Minqar and Abu Ballas areas lie within the range of transhumance from the Farafra and Dakhla oases. Certain ceramic traditions that originated in the Gilf Kebir later occur in the Lajjiya region of Northern Sudan (27), where progressive southwestern movement is reflected, e.g., by the distribution of distinct grinding implements (30). The previously ubiquitous “wavy line” pottery is replaced by more local pottery styles. Of particular significance is the rise of specialized cattle pastoralism (4, 31), which was later to become a basic way of life throughout sub-Saharan Africa.

This Saharan path to a productive economy was the specific African variant of a crucial change in human evolution, contrasting with the traditional Near East model of Neolithization. In place of the transition from nomadic hunter-gatherers to sedentary, pottery-producing farmers and livestock keepers, we see largely sedentary and pottery-producing hunters, fishers and gatherers becoming nomadic cattle herders. Cereal farming does not seem to have been a constituent of this Saharan “Neolithic revolution,” since the mid-Holocene savannah still provided sufficient wild-growing grains, fruits and tubers.

Paradoxically, in certain landscapes the decreasing trend in annual precipitation may have been associated with an increase in the vegetation cover because of a change in seasonality. Geochronological evidence from the Gilf Kebir suggests that the intense day-time summer monsoon rains during the early Holocene pluvial have resulted in less grass growth than the quantitatively lesser winter rains of the terminal humid phase, which presumably fell in the night (32). These favorable circumstances may have maintained the rich culture of cattle keepers depicted in the rock art of the Jebel Ouenat and Gilf Kebir.

The large-scale exodus from the Egyptian Sahara coincides with the rise of sedentary life along the Nile. The first Neolithic communities in Fayum and Merimde, starting around 5,000 B.C.E. with already fully developed cultivation of wheat and barley, are clearly rooted in Near East traditions. At the same time, essential social and cognitive aspects can be traced back to Saharan cattle herders and their spiritual heritage. Neolithic settlements of the Badari culture in the Nile valley recall African livestock enclosures and suggest a rather mobile existence (33). The practice of cattle burials is a presumably religious custom that has been recorded in the Egyptian Sahara from the fifth millennium B.C.E. (4).

Saharan traditions of cattle pastoralism have thus become an essential component of Neolithic life in the Nile valley.

**Late Holocene marginalization (3,500-1,500 B.C.E.).** After 3,500 B.C.E. rains had ceased even in ecological niches such as the Gilf Kebir, and permanent occupation was restricted to southern areas such as Lajjiya (34) and Wadi Howar in Northern Sudan (fig. S2E). For the pharaonic empire, well established after 3,000 B.C.E., the Western Desert obviously played a marginal role. Generally considered a “country of evil and death”, it was thought to bar the Egyptian Nile valley from the Sudanese Sahara, where cattle herders still practiced their Neolithic lifestyle. Sporadic finds of Egyptian pottery near Lajjiya (27) support rare historical reports about desert journeys during the 6th Dynasty, that were considered as daring advances into the unknown.

Recent discoveries, however, throw new light on pharaonic activities in the Egyptian Sahara. Besides an
elaborate desert station of King Khufu, the builder of the great pyramid, 30 outposts between Dakhla and the Gif Kebir indicate the first trans-Saharan trail into the interior continent (35–37). At first related to Ain Azil, Ancient Egypt’s westernmost town in Dakhla (38), and then throughout dynastic times, these desert stations indicate watch-posts concerned with prospecting or trading, or the prevention of smuggling, of African goods to the Nile valley. Since the camel was introduced to Africa only during the first millennium B.C.E., any long-distance travel through waterless desert had to rely on donkeys. Their water needs required extraordinary logistical skills and geographical knowledge — an example of how early societies have coped with the challenges of hyper-arid environments.

Conclusions. While earlier studies have dealt with the response of discrete cultures to climate changes in distant regions during different periods (39, 40), we present here a consistent model of how past climate changes, over a coherent region of sub-continental scale, have affected human societies throughout the Holocene. Contrary to inferences from off-shore marine sediment records and numeric modeling (41, 42), the only supra-regional climate signal in the geological and archaeological archives of the Eastern Sahara is the onset of semi-arid conditions in the north and semi-humid conditions in the south at c. 8,500 B.C.E. Within few centuries only, the desert margin shifted up to 800 km north to latitude 24° N, bringing monsoonal rainfall to most of the former desert. Taking into account the west-east gradient of decreasing humidity from the Atlantic Ocean to the Red Sea, this process apparently applied to the entire Sahara.

This fundamental climatic change from terminal Pleistocene hyper-arid desert conditions to savannah-type vegetation and the formation of lakes and temporary rivers resulted in the rapid dissemination of wild fauna and the swift reoccupation of the entire Eastern Sahara by prehistoric populations. Relatively stable humid conditions prevailed over the following c. 3,200 calendar years between 8,500-5,300 B.C.E. Abrupt drying events stated elsewhere in the Sahara may be explained by fading rainfall at a specific latitudinal position at a certain moment, or by dropping local groundwater.

The roughly parallel southward shift of monsoonal precipitation that set in at 5,300 B.C.E. can be tracked through the following millennia by the discontinuance of the sedimentary record of aquatic deposits at decreasing latitudes. The geological archives in agreement with the archaeological evidence indicate a gradual desiccation and environmental deterioration of the Eastern Sahara, notwithstanding transitory climatic perturbations that are a common feature of all desert margins. This rather linear process culminates in the present extremely arid conditions that, however, have by far not yet reached the extent of the terminal Pleistocene (fig. S2F).

The southward movement of human settlement implied significant changes in the pattern of behavior and land-use as response to regional environmental differences. Most of all, mobility was the key to survival; it has driven prehistoric societies from foraging to a multi-resource economy and specialized pastoralism. The final desiccation of the Egyptian Sahara also had an essential impact on the contemporaneous origin of the pharaonic civilization in the Nile valley. Still today, conflicts in sub-Saharan regions such as Darfur are rooted in environmental deterioration, aggravated by severe demographic growth and man-made desertification. The presented data and conclusions allow suggesting that the climate-controlled desiccation and expansion of the Saharan desert since the mid-Holocene may ultimately be considered a motor of Africa’s evolution up to modern times.

References and Notes
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**Supporting Online Material**
www.sciencemag.org/cgi/content/full/1130989/DC1

**Materials and Methods**
Table S1
Figs. S1 and S2

**References**
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**Fig. 1.** Radiocarbon dates from early and mid-Holocene occupation sites in the Eastern Sahara. The graph is arranged from north to south and based on almost 500 radiometric results from our excavations of non-oasis prehistoric sites, with condensed chronologies for the Egyptian sites of Jebel Nabta and Bir Kiseiba (4), and the Egyptian and Sudanese Nile valley and oases (16-18). It shows the clear trend of southward shifting occupation driven by the retreat of monsoon rainfall, and the contrasting economies in the Nile valley and the Sahara. Green shading marks humid conditions; symbols of domesticated cattle demonstrate the spread of pastoralism. See fig. S2 in the Supporting Online Material for details and site locations.

**Fig. 2.** Major stages of early and mid-Holocene occupation in the Eastern Sahara based on the cumulative curves of calibrated radiocarbon dates from 150 archaeological excavations. Regions are arranged from north to south. The Reoccupation phase (8,500-7,000 B.C.E.) is characterized by early settlements in the northern regions at the beginning of the Holocene humid optimum. Major occupation continues during the Formation phase (7,000-5,300 B.C.E.) until the onset of arid conditions in the Egyptian Sahara. The Regionalization phase (5,300-3,500 B.C.E.) is characterized by the retreat of populations to ecological refuges such as the Gilf Kebir plateau, seasonal or episodic transhumance, and a marked migration into the Sudanese Sahara. During the Marginalization phase (3,500-1,500 B.C.E.), Southwest Egypt receives only passing visits while prehistoric occupation in Northern Sudan persists until the end of humid conditions at 1,500 B.C.E.

**Fig. 3.** Climate-controlled occupation in the Eastern Sahara during the main phases of the Holocene. Dots indicate major occupation areas; rings indicate isolated settlements in ecological refuges and episodic transhumance. Rainfall zones are delimited by best-estimate isohyets on the basis of geological, archaeozoological and archaeobotanical data. (A) During the Last Glacial Maximum and the terminal Pleistocene (20,000–8500 B.C.E.), the Saharan desert was void of any settlement outside of the Nile valley and extended about 400 km further south than today. (B) With the abrupt arrival of monsoon rains at 8,500 B.C.E., the hyper-arid
desert was replaced by savannah-like environments swiftly used by prehistoric settlers. During the early Holocene humid optimum, the southern Sahara and the Nile valley apparently were too moist and hazardous for appreciable human occupation. (C) After 7,000 B.C.E. human settlement became well established all over the Eastern Sahara, fostering the development of cattle pastoralism. (D) Retreating monsoonal rains caused the onset of desiccation of the Egyptian Sahara at 5,300 B.C.E. Prehistoric populations were forced to the Nile valley or ecological refuges, and to exodus into the Sudanese Sahara where rainfall and surface water were still sufficient. The return of full desert conditions all over Egypt at c. 3,500 B.C.E. coincided with the initial stages of pharaonic civilization in the Nile valley.