# How the Sahara Became Dry

A continuous lake record elucidates how Saharan climate changed gradually from humid to today's desert conditions.

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Around 14,800 years ago, a strengthening of the summer monsoons led to a dramatic increase in North African lakes and wetlands and an extension of grassland and shrubland into areas that are now desert (*1*), creating a "green Sahara" (see the first figure). On page 765 of this issue, Kröpelin *et al.* (*2*) report a lake sediment record that sheds light on how this "African Humid Period" came to an end.

**A different past.** This tropical savanna with freshwater wetland in the Sahel is a possible analog for the "green Sahara."

Current knowledge of the climate history of North Africa comes from three main sources. Lake sediments provide information about the size and distribution of former lakes and preserve pollen from past vegetation (*3*). Marine sediments from the equatorial Atlantic also preserve evidence of environments on the adjacent continent (*4*). Finally, climate models (*5*) allow past patterns of precipitation and vegetation to be reconstructed, helping to elucidate the mechanisms underlying change.

However, lake sediments may have uncertain chronologies and are often discontinuous in the drier parts of North Africa. Ocean sediment sequences are often uninterrupted and well dated, but integrate information from a wide area, making it difficult to reconstruct regional patterns. Models reconstruct past climate and vegetation patterns with variable success, and model results must be validated using the geological records.

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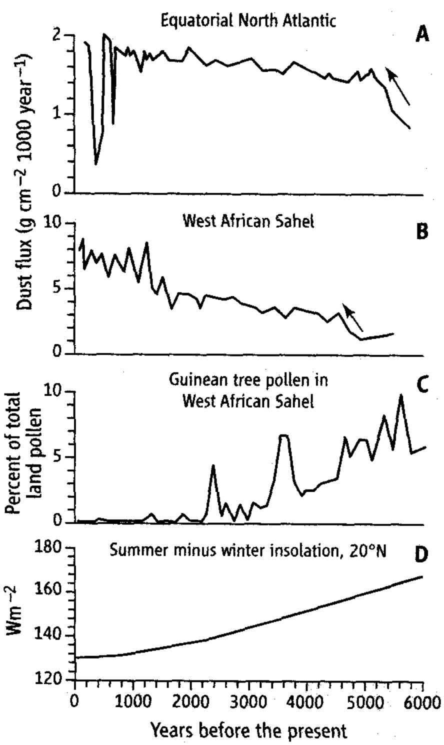
In general, the evidence shows that the African Humid Period came to an end between ~6000 and ~4000 years ago. Beyond this, there is much uncertainty. Kröpelin *et al.* now fill an important gap in our understanding of the past 6000 years of North African climate through their study of a sediment record from Lake Yoa in northern Chad. The record comes from one of the few Saharan lakes in which sediments have accumulated without a break during the Holocene (the past 11,500 years). Despite its hyperarid location, the lake is fed by ancient groundwater and therefore does not dry up. The authors infer the past salinity of the lake—a proxy for effective precipitation—from the remains of diatoms and aquatic invertebrates preserved in its sediments and reconstruct the vegetation history of the surroundings from pollen. Groundwater input has reduced the lake's hydrological sensitivity to climate change, but the reconstructed salinity values still provide a record of changing precipitation. Finally, the authors reconstruct the input of atmospheric dust to the lake using mineral magnetic measurements; dust flux reflects wind regimes and the extent of vegetation cover in the surrounding landscape. The results show that vegetation and dust flux changed gradually over the past 6000 years, accompanied by the slowly weakening monsoon, whereas a rise in lake salinity ~4000 years ago was more abrupt.

Sediments from the equatorial Atlantic suggest that dust export from North Africa increased sharply ~5500 years ago, implying that the end of the African Humid Period was abrupt (see the second figure, panel A) (*4*). This is something of a puzzle, because the reduction in the seasonal contrast in insolation—the fundamental driving force behind the weakening of the African monsoons in the Holocene—has been gradual (see the second figure, panel D). Climate modelers have shown that feedbacks involving changes in vegetation, surface albedo, and sea surface temperature are important in explaining the strong monsoon of the early to mid-Holocene (*5*, *6*). However, the spatial and temporal patterns of change are less faithfully reconstructed by models.

Moreover, there is disagreement about the abruptness of mid-Holocene aridification. Several simulations indicate an abrupt collapse in both vegetation and precipitation




**Evolution of mid- to late-Holocene climate of North Africa.** Saharan dust flux over the Atlantic (*4*) increased sharply 5500 years ago [arrow in (**A**)], suggesting an abrupt end to the African Humid Period, whereas records from the West African Sahel (*10*) show a later rise [arrow in (**B**)]. A reduction in swamp forest in the Sahel (*9*), indicated by Guinean tree pollen (**C**), accompanied the demise of wetlands and broadly followed changes in insolation (**D**).

between ~6000 and ~4000 years ago that is consistent with the marine dust-flux record (*7*). However, various simulations suggest that precipitation changed more gradually, accompanied by vegetation collapse in some models but steadier decline in others (*8*).

Even the continental geological evidence is equivocal. The appearance of abrupt drying of the Sahara might have arisen from the removal of sediments from many basins by the wind following desiccation during the mid-Holocene. Added to this, there is a dearth of well-dated sites in the Sahara, truncated or otherwise (*3*). In the Sahel, the semiarid southern fringe of the present-day Sahara, continuous and well-dated lake-sediment sequences do not support the idea of abrupt drying either; here, changes in vegetation were gradual (*9*) (see the second figure, panel C) and dust flux increased later than 5500 years ago (see the second figure, panel B) (*10*). However, the extent to which these Sahelian records are more widely representative is uncertain.

The evidence from Lake Yoa reported by Kröpelin *et al.* adds a new dimension to the problem. The continuous and well-dated pollen record for this site shows no abrupt change in vegetation in the mid-Holocene. The rise in Lake Yoa's salinity was rapid, but this was almost certainly a response to a local threshold being crossed as the lake changed from hydrologically open to hydrologically closed, rather than to abrupt climatic drying. The relatively smooth rise in dust flux is consistent with the gradual reduction in vegetation cover. Kröpelin *et al.* conclude that the vegetation feedbacks that have preoccupied modelers of the African monsoons must have been weaker than previously thought.

The record does not provide the last word on the tempo of Holocene aridification in North Africa, but it does raise important questions about Holocene environmental changes across the area and about the nature of feedbacks in the climate system. There is little point in calling for further continuous records to help resolve these issues: As Kröpelin *et al.* point out, suitable sites probably do not exist. However, improving existing geological records and using these to refine climate models would go a long way toward furthering our understanding.

### References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