PERSPECTIVES: PALEOCLIMATE

Hydrological Changes in Africa

Françoise Gasse

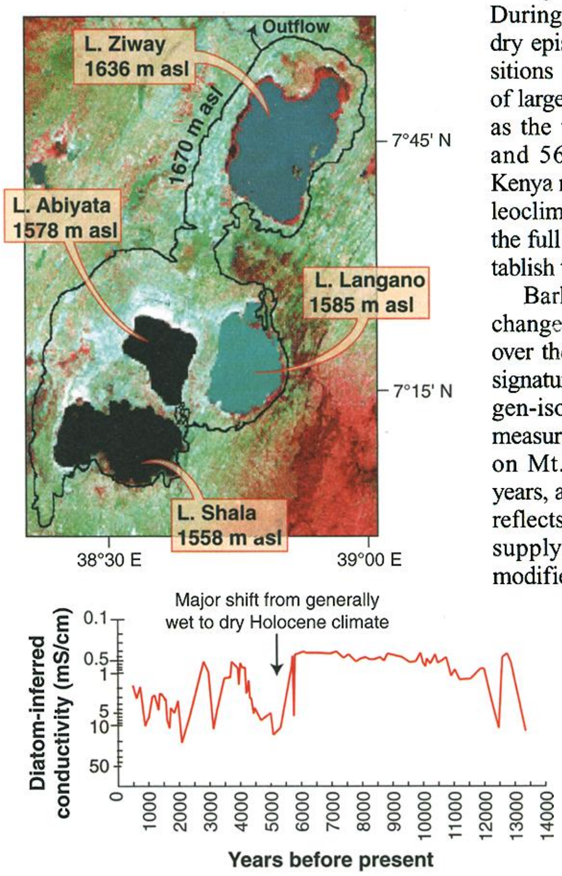
During the past 10,000 years or so—the Holocene—climate in high-latitude regions has been relatively stable compared to glacial times, but the tropics underwent dramatic hydrological shifts. On page 2307 of this issue, Barker *et al.* (*1*) report new evidence for such shifts in tropical Africa.

Moisture is brought to tropical Africa primarily by the highly seasonal rainfalls of the African and/or Indian monsoons. The monsoon circulation responds to the annual cycle of solar heating in the atmosphere, in the ocean, and on land, in interaction with other global circulation systems (*2*). It transfers water vapor and energy from the subtropical oceans across the equator to the "summer" hemisphere.

The monsoon, and thus the hydrology of the African continent, exhibit considerable variability at different time scales and for different reasons. Interannual rainfall fluctuations correlate with sea surface temperature and pressure anomalies and with the zonal circulation in the tropical oceans (*3*), in particular the El Niño–Southern Oscillation (*4*).

Rainfall also fluctuates at decadal to centennial time scales. The Sahel drought in the 1970s to 1980s is not a unique event in Subsaharan Africa. An 1100-year sediment record from Lake Naivasha, Kenya, shows three periods of severe drought (*5*), the longest one at the same time as the European Medieval Warm Period (circa AD 1000 to 1270). Solar variability may have been responsible for these droughts, which coincide with phases of high solar radiation, whereas phases of low solar radiative output—for example, the Maunder minimum (AD 1645 to 1715) during the European Little Ice Age—match periods of enhanced moisture (*5*).

On a millennial scale, much larger and more persistent wet and dry episodes took place in response to periodic changes in Earth's orbit around the Sun (*6*). The orientation of Earth's orbit and its eccentricity (how elliptical it is) precess slowly. The direction of its rotation axis in space also changes slowly. From about 11,500 to 5500 years ago, the precession cycle led to higher Northern Hemisphere summer insolation, thereby strengthening the Indian and African monsoonal circulation. A climate much wetter than today prevailed in northern and equatorial Africa (*7*). Verdant landscapes and shallow lakes extended over the Sahara, where rainwater filled deep groundwater reservoirs. Large deep lakes stored huge volumes of freshwater in presently semiarid or arid areas of East Africa (see the figure).



Changes in water balance in the Ziway-Shala basin, Ethiopia. Map: Today, four small lakes lie in the closed Ziway-Shala basin, a region of semi-arid climate. Around 7000 to 5500 years ago, in response to increased precipitation in the catchment area, the four lakes merged and formed a large, single, open lake extending 122 m above the present-day Lake Shala (*1, 16*). Black curve, ancient shoreline; asl, above sea level. Graph: A 13,500-year record of diatom-inferred electric conductivity in the presently closed, shallow, saline Lake Abiyata. Changes in lake water depth and volume during the Holocene were associated with large and rapid shifts in water salinity, from drinkable to strongly saline, which may have had serious impact on the inhabitants of the region.

CREDITS: MAP, ADAPTED FROM (16); GRAPH, ADAPTED FROM (17)

Climate models show that feedback processes, associated with changes in sea surface temperature and vegetation cover, amplified the climatic response to gradually changing insolation (*8*). Such feedbacks may explain the abrupt termination of the generally humid period about 5500 years ago in the northern tropics (see the figure) (*9*). However, the complexity of African climate during the Holocene is far from understood. During this period, successive humid and dry episodes were separated by abrupt transitions and punctuated by very brief events of large magnitude (*7*) (see the figure), such as the wet pulses observed between 6700 and 5600 years ago in the record from Kenya reported by Barker *et al.* (*1*). Such paleoclimate series are essential to document the full range of monsoon variability and establish the underlying mechanisms.

Barker *et al.* (*1*) attempt to understand changes in the moisture transport patterns over the continent by exploring the isotopic signature of past rainfall. They use the oxygen-isotope composition of diatom silica, measured in sediment cores from two lakes on Mt. Kenya spanning the past 14,000 years, as a proxy. The diatom isotopic record reflects the isotope composition of rainfall supplying the lake, although it has been modified by a series of surface and biogeochemical processes. Taking into account the processes that control the isotopic composition of atmospheric water vapor, and consequently of precipitation, in the regions submitted to the monsoon circulation (*10*), the authors (*1*) conclude that the centennial- to millenial-scale fluctuations in their oxygen-isotope record primarily reflect variations in moisture balance and cloud height, driven by sea surface temperature anomalies in the southern subtropical Indian Ocean.

The report by Barker *et al.* highlights that, in contrast with high-latitude and temperate regions (*10*), isotopic rainfall compositions in the tropics cannot be interpreted in terms of temperature only but correlate well with precipitation amounts. A temperature-oriented view of climate change in the tropics (*11*) therefore biases the interpretation of the isotope signal. In line with the development of global circulation climate models that integrate isotopic tracers (*12*), innovative steps such as that taken by Barker *et al.* should be taken to infer isotopic compositions of rainfall waters in the past to identify the water vapor source and trajectory and understand changes in regional and global hydrological cycles.

Indeed, because of the sparse and rapidly deteriorating archives in tropical glaciers,

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other data sources should be promoted in tropical Africa. Groundwater archives can provide direct access to water isotopic composition (*13*) and thus to deuterium excess, which helps detect the recycling of water vapor on the continent (*10*), but because of mixing and diffusion they cannot provide decadal- or centennial-scale resolution. Silica from lake diatoms is a promising proxy. However, as for other potential proxies such as lake or speleothem carbonates, its full potential will not be reached until the processes that modify the signal are identified, their effects are quantified, and a robust calibration is established between the measured signal and the isotopic composition of the host water. Annually laminated, diatom-rich sediments—for example, at Lake Malawi—could then help explore the isotope signal at the seasonal scale, so characteristic in the regions submitted to the monsoon circulation. Such archives often provide an acceptable chronology of hydrological changes. But to derive amplitude estimates, they must be complemented by a multiproxy approach and hydrological modeling of individual systems because records are site specific and proxies are not univocal. Global climate models must also be improved to simulate precipitation more reliably.

Until recently, climate change investigations focused on temperate and polar regions, with particular emphasis on past temperatures and on the North Atlantic region commonly thought to be the prime mover of climate. The tropics—about 40% of Earth's surface—were neglected despite their central role in global climate (*14*). Indeed, they are the very place where the bulk of solar heat enters Earth's climate system and the primary source of atmospheric water vapor. In tropical countries, life and economy have been (*5*, *7*, *15*), and still are, most vulnerable to changes in continental hydrology. Forecasting changes in hydrology at low latitudes is thus essential. It should integrate not only the effects of future anthropogenic greenhouse gas emissions but also the full range of natural variability that can be inferred from paleoclimatologic data.

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PERSPECTIVES: ARCHAEOLOGY

On Maize and the Sunflower

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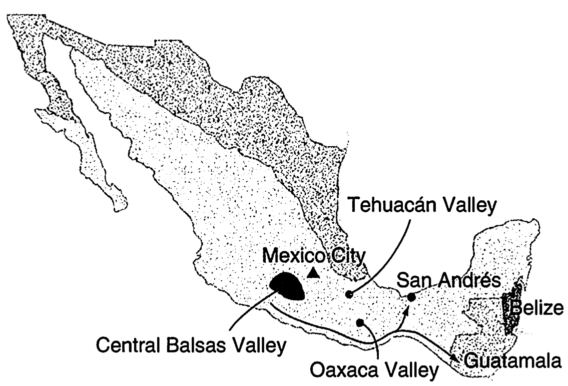
The study of agricultural origins has been equated to the search for the Holy Grail, such is the importance granted to it by members of diverse scientific communities, from archaeology to botany to molecular biology. There are good reasons for this belief: food surpluses made possible by agricultural economies have fueled major cultural developments during the past 10,000 years, culminating in the emergence of urban societies and advanced civilizations around the world.

The current consensus is that agriculture arose independently in six to eight regions of the world, including both hemispheres of the Americas, after the termination of the last Ice Age 12,000 years ago (*1*, *2*). Mexico is one of the primary centers of agriculture. Maize (*Zea mays* L.) was domesticated here, and new evidence suggests that it was also a birthplace of another important American crop plant, the sunflower (*Helianthus annuus* L.).

The earliest macrofossils (cobs) of maize have been found in the arid, highland Tehuacán and Oaxaca valleys (see the figure) (*3*). It has been argued on the basis of these macrofossils that corn was domesticated much later, about 6000 years ago, than other major cereals such as wheat and rice (*4*, *5*). Recently, a team led by K. Pope and M. Pohl recovered 7100-year-old maize pollen from the site of San Andrés, on the tropical Gulf coast of Mexico (see the figure), in association with indicators of land clearance resulting from slash-and-burn cultivation (*6*). This is the oldest evidence for maize in Mexico, predating the earlier macrofossil evidence by 1000 years. It is now apparent that well before 6000 years ago, maize spread out from its cradle in the seasonally dry tropical forest of southwestern Mexico (*3*) and was incorporated into lowland tropical food producing economies elsewhere. An earlier genesis from its genetically fingerprinted wild ancestor, teosinte, remains to be documented.



The origins of mesoamerican agriculture. This map of Mexico shows the location of the sites discussed in the text and the probable cradle of maize domestication in the Central Balsas River Valley. Arrows indicate likely diffusion routes of early maize out of the Balsas Valley through lowland areas to San Andrés and south out of Mexico. Shaded area: location of wild Mexican sunflowers.

The study by Pope *et al.* (*6*) strengthens the already strong case made on the basis of plant microfossils (pollen, phytoliths, and starch grains) for the appearance of maize in southern Central and northern South America between 7700 and 6000 years ago and for the existence of horticultural systems using both seed and root crops during this period (*2*, *7*, *8*). Much of the data from countries south of Mexico fits comfortably into the chronological framework of early maize dispersals established by Pope *et al.* (*6*).

The other intriguing aspect of Pope *et al.*'s study is their discovery of the earliest fully

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