

Mid-Holocene Climate in the South-Central Andes: Humid or Dry?

Betancourt *et al.* (1) recently challenged the prevailing view that the central Andes were a generally arid zone during the mid-Holocene (2–7). This debate has wide implications regarding monsoonal and westerly paleocirculation in this area. The archives used by Betancourt *et al.* (1) are organic and inorganic alluvial deposits that formed in steep valleys along the western slope of the Central Andes between 7 and 3 ¹⁴C kiloyears before present (ky B.P.). Consensus exists about the chronology, the calm wetland depositional environment, and the existence of higher groundwater tables at the deposit locations during that time. Disagreement exists about the interpretation of the high water tables. Whereas Betancourt *et al.* (1) interpret the Tulán and Puripica profiles as a result of wetter conditions and high regional groundwater tables, our studies (2, 3) have concluded that generally drier conditions prevailed.

We argue that wet conditions result in higher river discharge and erosion, whereas accumulation of fine materials in a steep valley requires overall decreased river flow and a low-energy environment. With dry conditions, fine-grained but permeable sediments that accumulate in the valley bottom may form local aquifers and raise the groundwater table, despite a larger cross section in the valley and reduced discharge overall. Modern analogs show that groundwater tables in such wetlands are often self-sustained, very local, and disconnected from their surroundings, and are thus difficult to interpret in terms of climate conditions. Today, the rivers in both the Tulán and Puripica valleys are erosive and have dissected the mid-Holocene sediments down to bedrock. Typically, sediments from between 14 and 9 ky B.P., a period of well-documented, extreme humidity, are missing in these valleys because of strong erosion, whereas, as expected, sediments from this humid period are present in fossil spring complexes [Tilomonte Springs, figure 4 in (1)]. These spring deposits were indeed related to a higher regional groundwater table during the humid period 14 to 9 ky B.P. (8).

Ice accumulation and levels of endorheic lakes (3–6, 8) are most sensitive to large-scale climatic conditions. The Sajama ice core shows that minimal accumulation rates and lake levels on the Altiplano from 16°S to 27°S were mostly low between 7 and <4 ¹⁴C ky B.P., drawing a consistent general picture of multimillennia-scale aridity. The ephemeral salt lake around 5 ky B.P. in the Salar de

Atacama (9) is enigmatic. In that particular location, subsidence in the tectonically active graben must be considered; however, decade- to century-scale ephemeral saline lakes are also recorded in other Altiplano localities around 6 to 5 ky B.P. Missing paleosol formation on undisturbed surfaces after 8.5 ky B.P. speaks against generally humid mid-Holocene conditions, and the significant regional decline of human occupation can be interpreted as a response to extremely arid conditions (2, 10, 11).

The picture of mid-Holocene aridity is more complex, however. Decade- to century-scale humid spells found in lake sediments (2, 3, 7) might offer an explanation for the fossil rodent midden data (1). There does not seem to be a contradiction with the midden data, but we disagree with the interpretation drawn from wetland deposits of generally humid mid-Holocene climates in the Atacama Desert.

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References and Notes

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12. Supported by Swiss NF 20-056908.99. Comments by C. Rigsby, P. Baker, T. Lowenstein, and D. Sandweiss are gratefully acknowledged.

22 February 2001; accepted 21 May 2001

Response: Grosjean does not take issue with the evidence in our study (1) from wetland deposits for elevated water tables or with their dating. Less clear, according to Grosjean, are the causes of the water table rise or how regionally consistent—and therefore climatically driven—the changes in water table elevation have been. These issues were the focus of considerable debate at a recent workshop on the central Andean paleoclimate (2).

The wetland evidence for high water tables during the late Pleistocene and mid-Holocene is more widespread and in more diverse geomorphic settings than is implied in the simple scheme portrayed by Grosjean. In the central Atacama, wetland deposits date from ~8.0 to 3.0 ky B.P. at Rio Tulán; 6.8 to 4.0 ky B.P. at Rio Salado; >4.5 to 3.0 ky B.P. at Rio Loa; and 6.5 to 3.0 ky B.P. at Quebrada Puripica (3). Mid-Holocene deposits are not confined to the canyon narrows at Rio Tulán, as suggested by Grosjean, but occur both within small channels and on interfluvies outside of the mainstem channel. Mid-Holocene deposits are located in open, marshy environments in the Calama depositional basin (Rio Salado and Rio Loa) and around spring vents to the north, such as Zapahuita Springs at 18°S (3). In contrast, late glacial–early Holocene deposits crop out in deep, erosive canyons to the south (Quebrada Chaco, 25°S) and north (Quebrada la Higuera, 18°S). The consistency of the wetland ages across this broad spectrum of geomorphic settings suggests to us that regional hydrology and climate—not the complex local factors suggested by Grosjean—control wetland distribution.

In our view, the height of the water table in these hydrologic systems is the main control on the wetland deposition, and water table height is directly related to groundwater recharge in the Andes. When water tables were high, thick phreatophytic vegetation protected the soft wetland sediments from erosion. When water tables dropped and vegetation died, water and wind quickly eroded the deposits, as occurs in the area today. Channel filling by alluvial sediment cannot be the mechanism for raising water tables across the region, insofar as many wetland deposits are composed of diatomite and organic mats, not alluvium.

The evidence for mid-Holocene aridity in the Atacama is equivocal. Grosjean has proposed that ~30-m-thick diatomites at Quebrada Puripica are lake deposits dammed behind a side-canyon debris flow during the period of mid-Holocene aridity (4). The presence of diatomites for several kilometers above and below the suggested side-canyon dam clearly demands a different explanation for their development (5). The core from Lake Miscanti contains gypsum from a depth of ~2.0 to 3.75 m, but the dating of the core entails large and variable ¹⁴C reservoir corrections, making the true age of the gypsum layer uncertain (6). Those studying the Salar de Atacama core view the shift from salt pan to saline lake during the mid-Holocene as induced by climate (7), not by local tectonic effects as suggested by Grosjean.

In the final analysis, Grosjean accepts

TECHNICAL COMMENT

the evidence from wetlands and middens for increased late Pleistocene and early Holocene wetness, which agrees with his own lake studies, but rejects similar evidence for the mid-Holocene, which conflicts with those studies.

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28 March 2001; accepted 21 May 2001