LATE HOLOCENE PALEOHYDROLOGY, LAKE-LEVEL FLUCTUATIONS, AND ANDEAN CIVILIZATIONS IN THE LAKE TITICACA BASIN

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ABSTRACT

Studying the interactions between pre-Columbian Andean civilizations and their biophysical environment not only provides deep insights into how humans cope with their environment, but can also contribute to basic studies in both social and natural sciences. One barrier to productive interchange among disciplines that may surprise physical scientists is that while social scientists often use theoretical justification to reject hypotheses, the underlying theory in social sciences is poorly developed, often contradictory, and usually short-lived. The consequence is that all too often the results of studying the human dimensions of natural systems are not useful to understanding the whole system. Again in a statement that may seem a truism to physical scientists, we maintain that empirical studies pertaining both to human and physical processes are necessary for adequate understanding of whole systems, and that theoretical perspectives are not sufficient to test hypotheses about environmental variation and human activity. In this vein, we report the results of integrated paleolimnological and archaeological work from 1986-1998 on the Bolivian side of Lake Titicaca basin that allowed us to develop a lake-level curve for the past 3500 years, and then to correlate the curve with cultural activities. The lake-level curve was also used as input to the Hastenrath and Kutzbach climatonomy model[1] to calculate paleoprecipitation. The modeled precipitation decrease of about 15-20% resulted in insufficient water availability to maintain raised agricultural fields, a widespread and very productive technology that provided the food resources necessary to sustain exponential human population growth. Consequently, the end of Tiwanaku IV, the final cultural period of the civilization, was coincident with, and in combination with the large human population, caused by the drought.

For the paleolimnological analyses, sediment cores were collected from the southern basin of Lake Titicaca (Bolivia/Peru) along a depth transect from 4.6 m above overflow level (3804 m) to 15.1 m below overflow level. Lithologic and geochemical analyses of the cores were used to identify and date century-scale lake-level changes. Detailed sedimentary analyses of sub-facies and radiocarbon dating were conducted on 4 representative cores. A chronology based on 60 accelerator mass spectrometer (AMS) radiocarbon measurements constrains the timing of water-level fluctuations. Core studies establish the timing and magnitude of five periods of low lake level, implying negative moisture balance for the northern Andean altiplano over the last 3500 Cal ^{14}C yr. Between 3500 and 3350 Cal ^{14}C yr B.P., a transition from massive, inorganic-clay facies to laminated organic-matter-rich silts in each of the four cores signals a water-level rise after a prolonged mid-Holocene dry phase. Evidence of other significant low lake levels

occurs between 2900-2800, 2400-2200, 2000-1700, and 900-500 Cal ^{14}C yr B.P. These studies are reported in Abbott et al.[2]

Archaeological evidence established spatial and temporal patterns of agricultural field use and abandonment, and demonstrates that the emergence of agriculture (ca. 1500 B.C.) and the collapse of the Tiwanaku civilization (ca. A.D. 1100) coincided with the periods of the abrupt, profound climate change. Prior to 1500 B.C., aridity in the altiplano precluded intensive agriculture. During a wetter, but climatically variable period from 1500 B.C. to A.D. 1100, the Tiwanaku civilization and its immediate predecessors developed specialized agricultural methods that stimulated population growth and sustained large human settlements. Several of the other periods of low lake levels, and by extension low precipitation, coincided with cultural transitions in the region. A prolonged drier period (ca. A.D. 1100-1500) caused declining agricultural production, field abandonment, and cultural collapse. These studies are reported in Binford et al.[3], and archaeological and paleoclimate data from that paper are summarized in Figure 1.

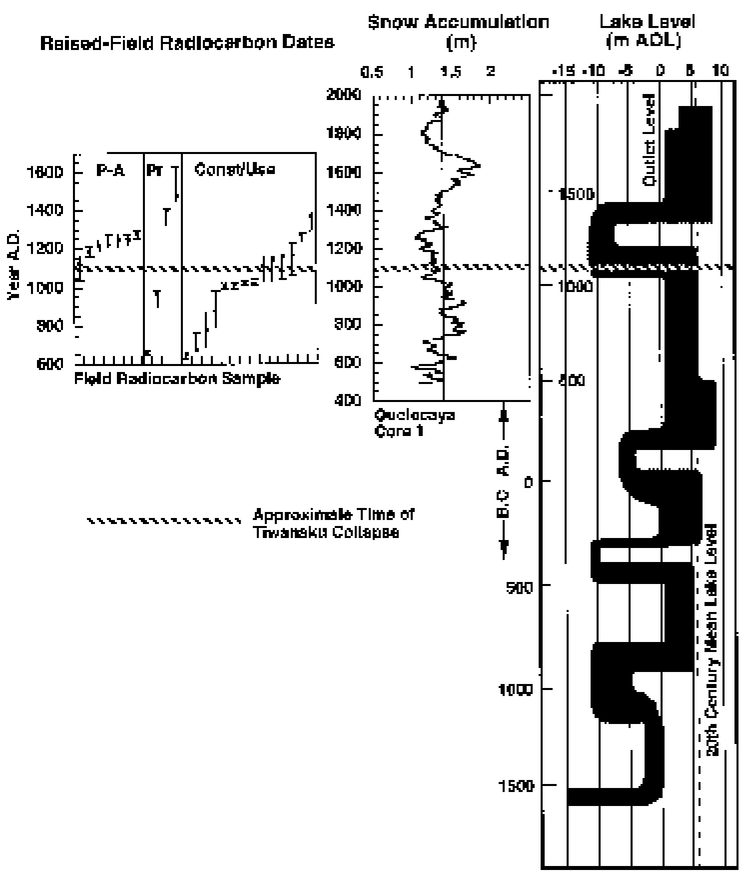

Figure 1. Calibrated radiocarbon dates, snow accumulation on the Quelccaya ice cap (redrawn from Thompson et al.[4] and smoothed with a 10-yr moving mean), and proposed lake-level curve redrawn from Abbott et al.[2]. P-A, Pr, and Const/Use denote material taken from postabandonment, problematic, and construction/use contexts, respectively[5]. The crosshatched line at A.D. 1100 denotes the approximate beginning of reduced precipitation at the Quelccaya ice cap and the beginning of the collapse of the Tiwanaku

civilization. The lake-level line is drawn thickly to illustrate century-scale variability, e.g., the 20th-century variation has been about 6 m, so the line is 6 m thick[2].

Thus we have shown that while the Tiwanaku were able to create and sustain a highly productive, water-dependent form of intensive cultivation, the agricultural system was unable to function when its fundamental resource was somewhat less available during an extended period. These extended periods of low lake level may have corresponded to periods of more frequent El Niño-like climatic conditions, implying a direct link between ENSO and the civilization. The Tiwanaku did actively shape their physical environment, as many organisms do, but there were periods of abrupt and profound climatic change that, when coupled with the very large human population, were beyond the ability of the civilization to continue to provide for its own requirements. The lessons for our current civilization should not be lost: we must understand the patterns and causes of climate variation, and how the variation can affect our own ability to sustain ourselves. We argue that these studies of "Human Dimensions" cannot be overemphasized.

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