Centennial Oscillation of the Climatic Crescendo During the Last Glacial Maximum: Evidence from Lake Estancia, Central New Mexico

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Abstract: Sediments deposited in late Pleistocene Lake Estancia, central New Mexico, contain a paleoclimatic record that includes the last glacial maximum and deglacial episode. Stratigraphic reconstruction of an interval representing the highstand of the lake that occurred during the last glacial maximum reveals ~2000-, ~600-, and ~200-year oscillations in lake level and climate. Shifting position of the polar jetstream in response to expansion and contraction of the North American ice sheet may be partly responsible for the millenial-scale changes in Lake Estancia but probably does not explain the centennial-scale oscillations.

Introduction

Estancia Valley in central New Mexico contains a sequence of lake sediments and shoreline features that reflect the last great expansion of "pluvial" lakes in the western United States. Lake Estancia existed as a perennial lake during the Wisconsin glacial episode, and meter-scale changes in the lacustrine sediments indicate large, millenial-scale fluctuations in lake-level occurred in response to changes in the glacial-age climate. A continuous source of ground water recharge maintained the lake with a surface area greater than ~400 km^2 until about 12,000 years BP, preventing desiccation in the central part of the basin and preventing loss of continuity of the stratigraphic and climatic record.

In addition to preserving information about climatic changes over time intervals comparable to the advance and retreat of the North American ice sheet, the Estancia hydrologic system was responsive to climatic forcing at higher frequencies, including decadal- through millenial-scale changes (Allen and Anderson 1989; Allen 1991). This contribution identifies high-frequency (millennial- to centennial-scale) changes in hydrology and climate during a highstand of Lake Estancia coinciding with the last glacial maximum and early deglacial interval.

Sediments and History of Highstands

The upper part of the lacustrine sequence is exposed in the walls of numerous deflation basins that dot the Estancia valley floor (Figure 1) and includes sediments ranging in age from the time of the last glacial maximum in North America to the desiccation of the lake just prior to the Holocene. Major oscillations in the extent of Lake Estancia during the

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latest Pleistocene are recorded in the central part of the basin as alternating intervals of bioturbated and thinly-bedded to laminated sediment. Two major highstands of Lake Estancia are represented in the upper ~5 meters of the basin-center sequence. Radiocarbon dates obtained from organic material deposited in the central part of the basin (Bachhuber 1989; Allen 1991) provide time control for this part of the lacustrine sequence. A "glacial maximum" highstand occurred from about 20,000 years BP until about 15,600 years BP (uncorrected ^{14}C years), resulting in the highest set of well-developed shorelines on the valley floor. Following a relatively brief, sudden drop in lake level, centered at about 15,000 years BP, the perennial lake expanded again at about the same time that lakes in the Great Basin experienced their highest levels in the latest Pleistocene (Benson *et al* 1990).

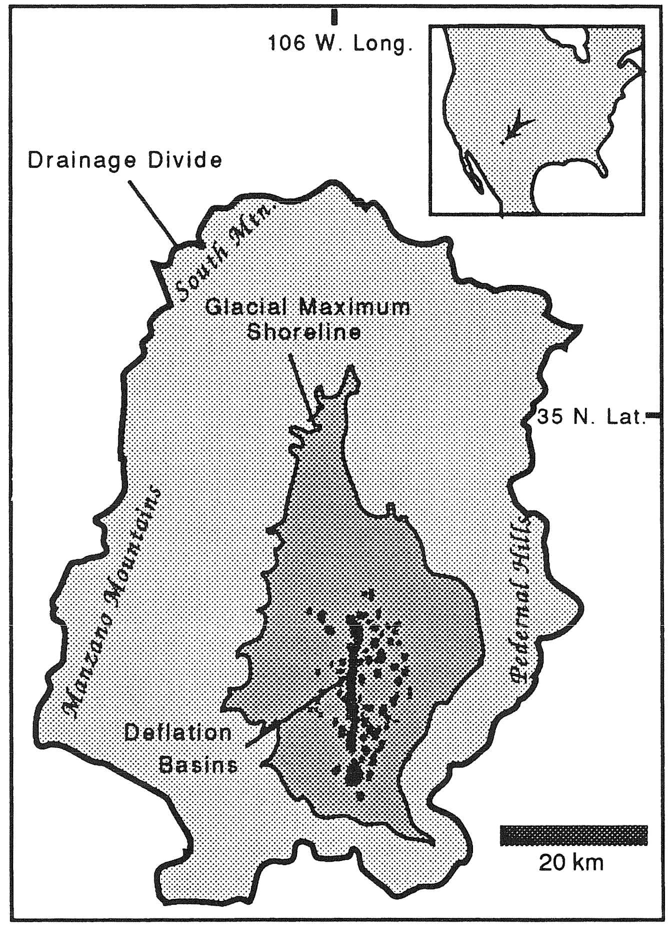

Figure 1. Index map of Estancia Valley showing drainage area, modern deflation basins, and largest extent of Lake Estancia during the glacial maximum highstand.

The sediment deposited in Lake Estancia is a marly clay rich in silt- and sand-sized gypsum. Ostracode valves are extremely abundant in most of the glacial maximum highstand sequence, as are a variety of other biotic components (Bachhuber 1971). Although the sediments deposited during the glacial maximum highstand are bioturbated, the degree of mixing is small and closely spaced samples reveal variability in several components that reflect freshening and expansion and contraction of the lake. Time series for detrital quartz, relative percent gypsum, and relative abundance of various ostracode species illustrate the century-scale oscillations recorded in Estancia sediments.

Detrital Quartz

Relative abundance of detrital quartz was determined from grain counts of the medium sand-sized fraction. A plot of the detrital quartz time series shows three episodes of increased quartz content, each consisting of two peaks in abundance. The average period for major episodes is about 2000 years, with about 200 years elapsing between separate events within the same major episode (Figure 2).

The first two episodes of increased quartz abundance coincide with a marked increase in abundance of the ostracodes *Cytherissa lacustris* and *Candona caudata* (first episode) and *Limnocythere ceriotuberosa* (second episode). Appearance of these ostracode species suggests freshening of the lake relative to intervening periods when *Limnocythere staplini* and *Candona rawsoni*, more saline-tolerent species (Delorme 1989, Figure 2), dominate the ostracode assemblage.

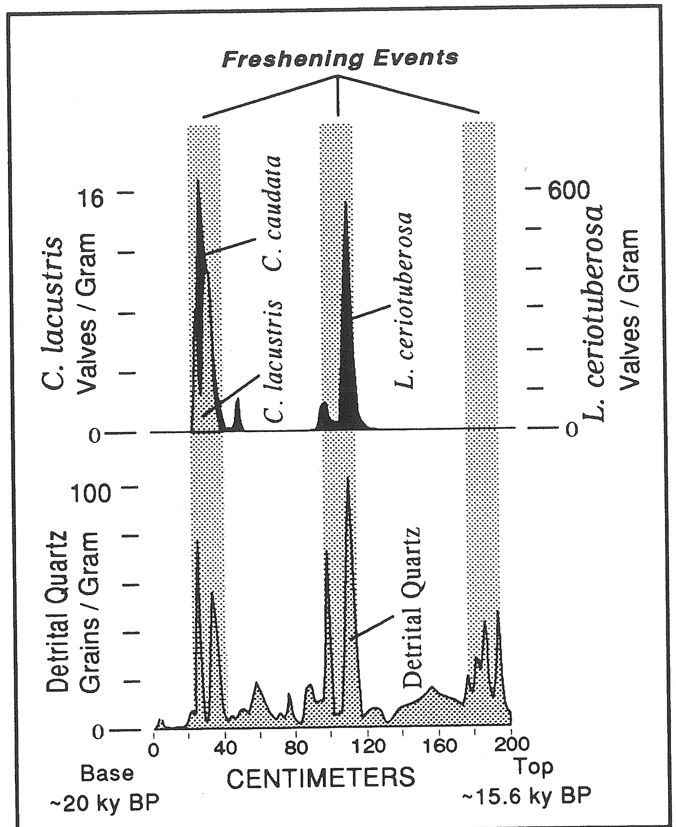

Figure 2. (Top) Relative abundance of ostracode species that indicate events of freshening.
(Bottom) Relative abundance of detrital quartz grains, believed to reflect brief episodes of runoff from the drainage.

Gypsum

Sand- and silt-sized gypsum deposited in Lake Estancia originated as gypsum crystals growing in shallow muds around the margins of the lake (Allen 1991). These crystals were transported to the central part of the lake by currents and winds. This interpretation is supported by comparison of gypsum abundance between laterally equivalent basin-center and near-shore samples. For example, sediments from the *C. lacustris* zone in the central part of the basin contain virtually no gypsum, whereas the sand-sized fractions from the biostratigraphically near-shore equivalent are domi-

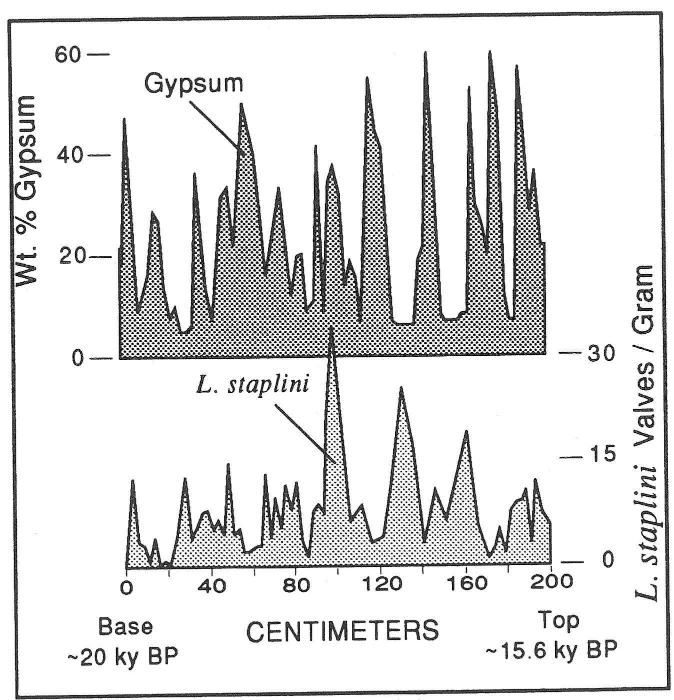

Figure 3. (Top) Relative abundance of detrital gypsum.
(Bottom) Relative abundance of *Limnocythere staplini*.
Note: ~600-year cycles in abundance of gypsum and *L. staplini*.

nated by gypsum. Stratigraphic variations in the percentage of gypsum contained in the glacial maximum highstand sediments are, thus, thought to reflect the proximity of marginal mudflats (gypsum source area) to the depositional site.

A time series for the weight percent of gypsum in the sediments (Figure 3) reveals repeated pulse-like increases in concentration of detrital gypsum in the central part of the basin. Spectral analysis of the gypsum time series (Figure 4) reveals a strong cycle with a period of ~600 years, with weaker periodicity between ~250 to ~350 years. The ~600 year period is especially noticeable in the younger part of the time series (Figure 3, 100 to 200 cm), and higher frequencies appear in the older half (Figure 3, 0 to 100 cm).

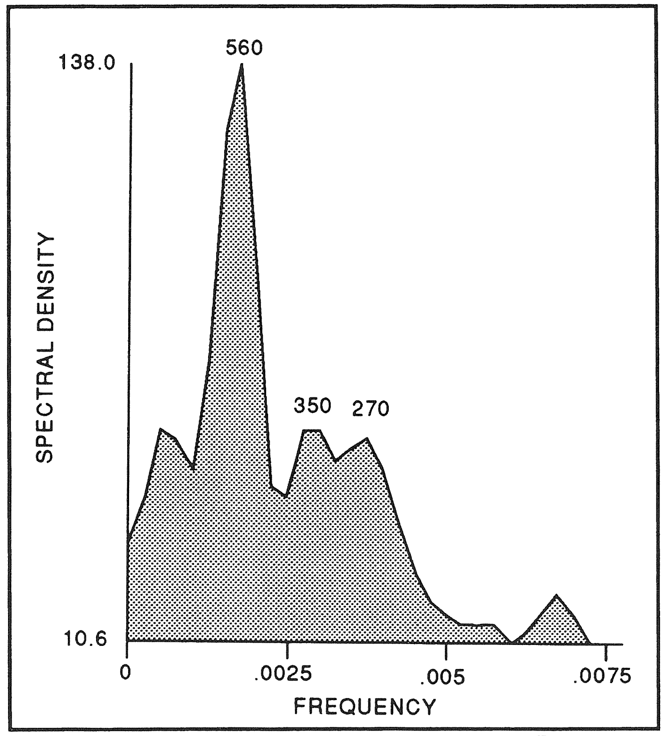

Figure 4. Power spectrum for gypsum time-series shown in Figure 3.

Ostracodes — *Limnocythere staplini*

Cycles of about 600 years, reflected in the abundance of gypsum, can also be recognized in the abundance of the ostracode *L. staplini* (Figure 3). Comparison of *L. staplini* abundance with the percent gypsum time series (Figure 3) shows a nearly inverse relationship between 100 and 190 cm, suggesting that increases in abundance of the ostracode species reflect, in part, lower sedimentation rates between episodes of gypsum influx (dilution effect). Episodes of more favorable water chemistry in the lake also may have contributed to relative increases in abundance of *L. Staplini*, as suggested by its independence from gypsum in the older half of the record.

Discussion

The association between detrital quartz and ostracode abundance (Figure 2) indicates the large pulses in detrital quartz correspond to periods of freshening. We attribute the freshening events that introduced quartz grains into the basin to episodes of surface runoff from the surrounding drainage basin. Major episodes of detrital quartz influx are separated by ~2000 years, suggesting millenial-scale climatic cycles were responsible for maintaining highstands in Lake Estancia during the last glacial maximum. Our reconstruction shows that, within these larger ~2000-year episodes, freshening occurred in brief pulses separated by ~200 years.

Because flux of detrital gypsum is related to proximity of the sampling locality to the near-shore environment it implies that fluctuations in the gypsum time series record similar oscillations in lake level. Although gypsum content cannot yet be used to quantitatively determine the magnitude of these oscillations, the record reveals ~600-year changes in lake-level in addition to the ~200- and ~2000-year cycles that are reflected in detrital quartz and ostracode abundance. Although changes in abundance of *L. staplini* may reflect either dilution effects or absolute abundance, both responses imply changes in the extent and volume of the lake, but these changes were not accompanied by freshening events of the same magnitude as those responsible for the introduction of detrital quartz.

The timing of major, millenial-scale changes in lake level in Estancia Valley is similar to the record from other paleo-lakes at comparable latitudes (Allen and Anderson 1989) and supports the hypothesis that southerly displacement of the polar jetstream by the North American ice sheet brought increased precipitation and "pluvial" conditions to the western United States (Benson and Thompson 1987). The major high-stand of lakes in the northern Great Basin at ~14,000 years BP (Benson *et al* 1990) is matched by a highstand at Estancia, although not as high as its glacial maximum highstand. The highest stand of Lake Estancia during the glacial maximum suggests the mean position of the jetstream may have been positioned over the Estancia basin during the last glacial maximum and then may have migrated north with the decay of the North American ice sheet.

Although positioning of the polar jetstream over the Estancia basin may be explained by the growth and decay of the ice sheet, it is not clear that the expansion and contraction of Lake Estancia in cycles of ~2000 years is directly related to the ice sheet. It is even less likely that the centennial-scale oscillations are directly related to the growth and decay of the ice sheet, and these cycles suggest there are other controls on the routing of moisture from the Pacific Ocean. Additional high-resolution paleoclimatic reconstructions from climatically sensitive sites will be needed to test the regional extent of the centennial- and millenial-scale changes in the Estancia record.

Acknowledgments

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