Holocene History of the El Niño Phenomenon As Recorded in Flood Sediments of Northern Coastal Peru

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ABSTRACT: The Holocene history of flooding in northern coastal Peru is believed to be a proxy record for the El Niño phenomenon. A recently completed set of 30 radiocarbon dates on overbank flood deposits and a tsunami deposit from the Casma region (Figure 1 and Table 1) establishes a chronology for the largest events that have occurred during the last 3500 years. The El Niño phenomenon is an episodic event that perturbs the ocean/climate system of the Pacific basin and is believed to be related to anomalous weather patterns worldwide (Rasmusson and Wallace, 1983). An increased understanding of the magnitude variations and the long-term frequency of the El Niño phenomenon will provide a better understanding of the nature and causes of the El Niño/Southern Oscillation phenomenon. The data presented here indicate that events much larger than the one in 1982-1983 may occur with a frequency of about once every 1000 years.

INTRODUCTION

The desert climate of the Peruvian coast is responsible for a direct correspondence between flood events and the El Niño phenomenon. The hyperarid climate is controlled by the location of the South Pacific anticyclone, the rain-shadow effect of the Andes, and the location of the cold Peru/Chile Current. It is only during El Niño events, when the South Pacific anticyclone weakens and the northern boundary of the Peru/Chile current migrates south (Rasmusson and Wallace, 1983), that significant precipitation is able to reach the coastal zone.

At Casma (Figure 1), annual precipitation has averaged 4.2 ±2.0 mm during the last 20 years; during 1983 an annual precipitation of 42.4 mm was recorded here. There is a large orographic gradient to the precipitation during the El Niño events, and most of the flooding is induced by precipitation that falls upstream of the area studied. There is also a latitudinal gradient of rainfall, with more northerly areas receiving more frequent and larger rainfall than areas to the south. At Casma (9.5°S) precipitation data indicates that flooding occurs during all events of the magnitude of 1982-1983 or larger.

FLOOD SEDIMENTS

Flood sediments of the 1982-1983 El Niño event were studied to characterize an El Niño alluvial deposit

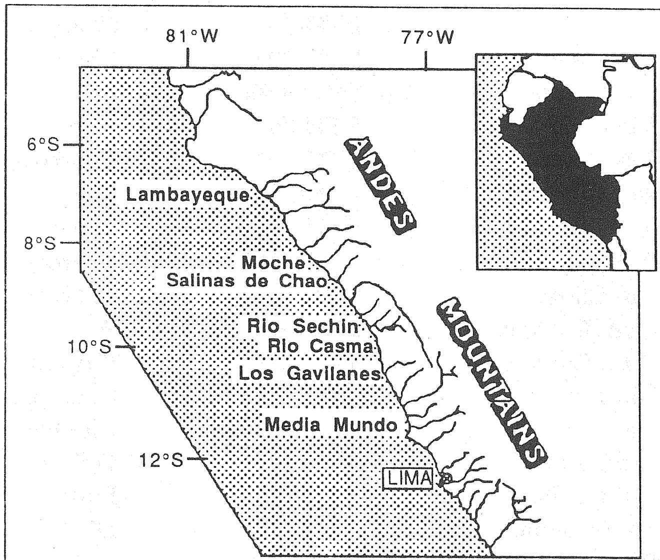

Figure 1. Map showing study area and locations mentioned in the text.

(Wells, 1987). Sedimentary structures indicate that depositional processes ranged from sheet floods to debris flows. The 1982-1983 deposits were recognized by the pristine preservation of surface textures, burial of live trees and plants, and burial and reworking of recent artifacts or of recently plowed fields. Field comparison of the surface geomorphology before and after flooding showed that about 30 percent of the flood plain was reworked during the winter of 1983.

Pre-1982-1983 deposits of the overbank flood plain are sedimentologically identical to 1982-1983 deposits, indicating similar depositional origins (Wells, 1987, 1988). Individual flood deposits are typically fining-upward silty-sand beds separated by mud-cracked silt layers, agricultural soils, and/or eolian sand sheets. The sediments bury archaeological sites and include reworked prehistoric artifacts and abundant charcoal. Deposits were tentatively dated in the field on the basis of the included artifacts and the inset stratigraphy of the fluvial terraces. Conventional and atomic mass spectrometer radiocarbon dates, together with field relationships, resulted in the stratigraphy presented in Table 1 and Figure 2. The radiocarbon dates have been corrected for δC^{13} variations and calibrated using the dendrochronologic time scale.

In J.L. Betancourt and A.M. MacKay, editors, 1990. Proceedings of the Sixth Annual Pacific Climate (PACLIM) Workshop, March 5-8, 1989: California Department of Water Resources, Interagency Ecological Studies Program Technical Report 23.

Table 1. Radiocarbon-dated El Niño events.

Location	Laboratory Number	Material	Calibrated Age[1]	Event Date
Rio Casma	SMU-1861	Wood	139.2% Modern	1957-1958[2]
Rio Casma	ETH-3483	Charcoal	136.6% Modern	1957-1958[2]
Rio Casma	SMU-1955	Peat	129.2% Modern	1957-1958[2]
Que. Tomeque	ETH-3924	Charcoal	101.8% Modern	1957-1958[2]
Rio Sechin	ETH-3919	Charcoal	100.3% Modern	1957-1958[2]
Rio Casma	ETH-3922	Charcoal	AD 1880-1980	AD 1925[2]
Rio Casma	SMU-1860	Wood	AD 1813-1919	AD 1891[2]
Rio Casma	ETH-3920	Charcoal	AD 1680-1880	AD 1828 or 1878[2]
Rio Casma	ETH-3917	Charcoal	AD 1660-1860	AD 1791[2]
Rio Casma	ETH-3921	Charcoal	AD 1640-1840	AD 1791[2]
Rio Casma	ETH-3484	Charcoal	AD 1631-1810	AD 1728[2]
Rio Casma	ETH-3918	Charcoal	AD 1670-1870	AD 1728[2]
Rio Casma	SMU-1938	Charcoal	AD 1665-1808	AD 1728 or 1791[2]
Que. Rio Seco	SMU-1694	Wood	AD 1662-1801	AD 1728 or 1791[2]
Que. Rio Seco	SMU-1696	Wood	AD 1638-1810	AD 1728 or 1791[2]
Rio Sechin	ETH-3485	Charcoal	AD 1651-1813	AD 1728 or 1791[2]
Rio Sechin	ETH-3482	Charcoal	AD 1651-1886	AD 1728 or 1791[2]
Salinas de Chao	A-3279	Driftwood	AD 1508-1655	AD 1618[2]
Los Gavilanes	SMU-1752	Driftwood	AD 1470-1627	AD 1618[2]
Media Mundo	SMU-1753	Driftwood	AD 1521-1658	AD 1618[2]
Rio Sechin	ETH-3486	Charcoal	AD 1486-1668	AD 1578[2,3]
Rio Casma	SMU-1693	Wood	AD 1434-1474	~AD 1450
Rio Casma	SMU-1935	Charcoal	AD 1441-1483	~AD 1450
Rio Sechin	SMU-2002	Charcoal	AD 1296-1453	~AD 1450
Rio Casma	ETH-3916	Charcoal	AD 1270-1390	AD 1325[4]
Rio Casma	SMU-1940	Charcoal	AD 1282-1389	AD 1325[4]
Que. Rio Seco	SMU-1669	Wood	AD 1220-1460	AD 1325[4]
Rio Casma	SMU-1963	Charcoal	130 BC-AD130	~AD 0
Que. Rio Seco	SMU-1692	Wood	1211-1315 BC	~1200 BC[5]
Rio Casma	ETH-3915	Charcoal	1140-1400 BC	~1200 BC[5]

[1] Post-modern radiocarbon dates calibrated according to curve in Baker et al. (1985). Other radiocarbon dates corrected for δC^{13} variations and calibrated according to the dendrochronologic time scale.
[2] Corresponds to event dated by Quinn et al. (1987).
[3] Corresponds to event dated by Rowe (1948).
[4] Corresponds to event dated by Pozorski (1987).
[5] Corresponds to event dated by Wells (1987, 1988).

FLOOD STRATIGRAPHY AND EL NIÑO HISTORY

A total of 34 samples were submitted for radiocarbon dating. Samples included detrital charcoal and wood, buried plant material from between individual flood sheets, and organic material from buried agricultural soil horizons. Three of the radiocarbon dates are from driftwood samples, collected over 3° of latitude (8-11°S). These samples were deposited by a tsunami during the 1618 AD El Niño (Wells and DeVries, 1987). Four of the 31 fluvial samples were determined to yield inappropriate dates, demonstrated by stratigraphic reversals. The anomalously old dates probably result from inclusion of old detrital carbon.

Event dates for historical times (post-AD 1578) were determined by comparing the precision of the calibrated radiocarbon ages with the historical dates compiled by Quinn (1987) and then choosing the largest event that occurred within the 1σ error range. Five of these eight events yielded multiple dates from samples collected at different locations within the flood plain. Four prehistoric events are dated, three of which yielded multiple dates. The AD 1325 event is probably the same event recorded ethnohistorically and referred to as Nyamlaps flood (Rowe, 1945; Pozorski, 1987). Multiple dates from widely separated regions of the flood plain and the close correspondence of these dates with the historical record indicate that radiocarbon dating is a valid way of determining dates for prehistoric El Niño events.

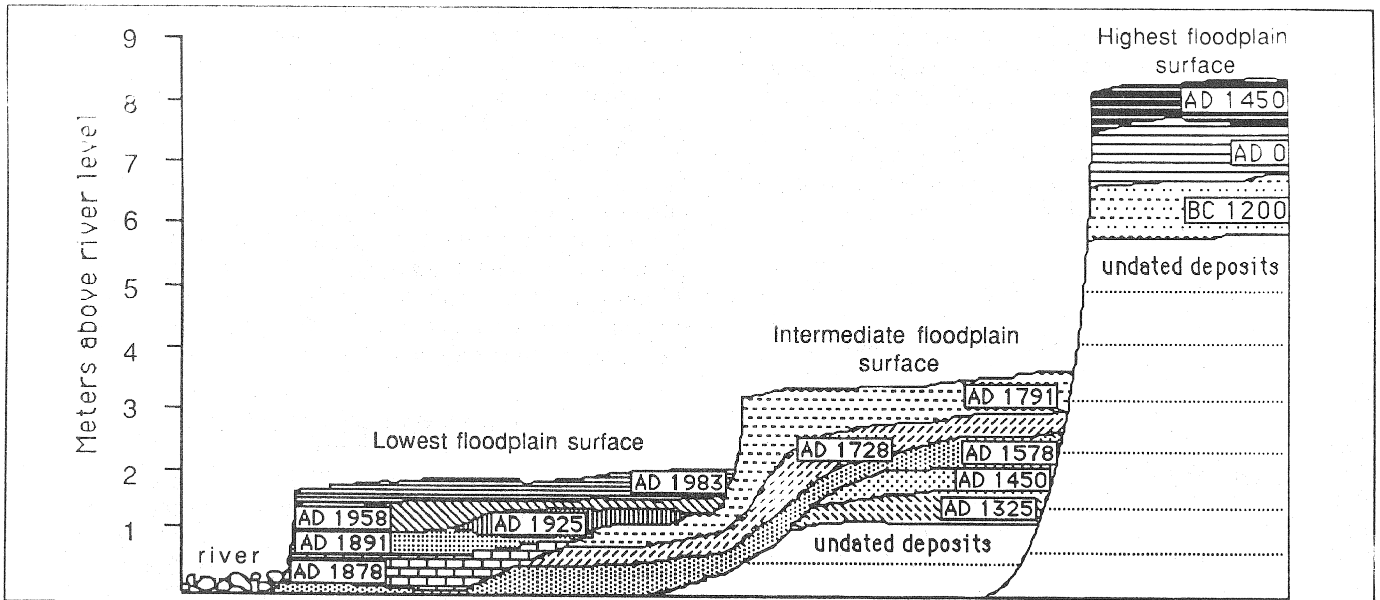

Figure 2. Flood plain surfaces and deposits of the Rio Casma area. The dates shown are hypothesized event dates (see Table 1) for individual flood events. Note overlapping stratigraphy for lowest to intermediate surface. Base of the section below highest flood plain surface is believed to be ~7500 years old (Wells, 1988).

The apparent change in the frequency of El Niño events (Figure 3) is most likely due to the nature of the stratigraphic record rather than to an actual frequency change. Three distinct flood plain levels have been identified on the Holocene flood plain (Figure 2):

- The youngest surface (average height 2.0 m) includes sediments of the eight most recent flood events and yields a frequency of one event every 36 years.
- The middle surface (average height 3.5 m) records events 6 through 11 (sans event 10) and yields a frequency of one event every 100 years.
- The oldest surface (average height 7.5 m) records events 10 through 12 (sans event 11), and yields a frequency of one event every 1060 years.

The difference in the height of the flood plain surfaces indicates that a threshold water level must be reached before new deposition takes place on each progressively higher surface. We are looking, therefore, through a geomorphologic filter that separates the stratigraphic record of events with different magnitudes. The largest events (1/1000 years) probably destroy the record of younger events. The basal and undated stratigraphy of the highest flood plain surface includes a minimum of seven large flood events prior to AD 1450. The base of the section is believed to correspond to Holocene stabilization of sea level that initiated backfilling of river valleys at c. 7500 YBP. This sequence, therefore, further indicates an average recurrence interval of about once every 1000 years for the largest Holocene flood events.

The cause of these large flood events is not clear. The 1982-83 El Niño event was the largest during recorded history. It left deposits on only the youngest flood plain surface. Two scenarios can be envisioned that could explain the frequency of the largest events:

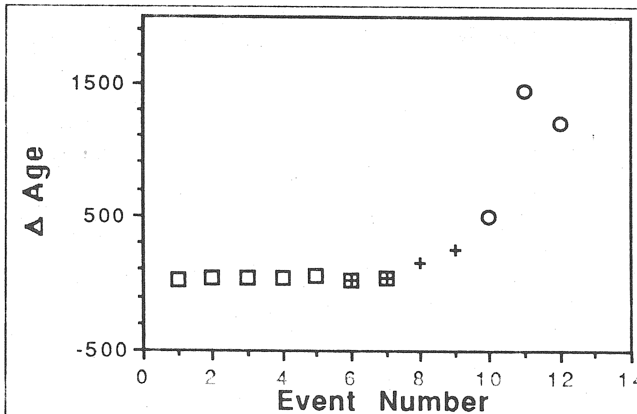

Figure 3. Change in frequency of flood events with time. Change in event frequency from c. 1/1000 years to c. 1/36 years is believed a result of the geomorphologic filter that separates events of various magnitudes. Events represented with: (o) are preserved on the highest terrace; (+) are on the intermediate terrace; (□) are on the lowest terrace (see text and Figure 2). Δ age refers to difference in years between sequential flood events. Event numbers are used rather than actual age dates on the abscissa: event 1 represents time difference between the two most recently dated events (AD 1983 and AD 1958); event 12 represents the time between the two oldest events (AD 0 and 1200 BC).

- "Mega El Niño events" exist that cause major devastation in coastal Peru and perhaps worldwide, and
- Once every 1000 years rainfall associated with El Niño events concentrates in the Casma area, causing large-scale flooding.

If the largest El Niño events recorded at Casma are global-scale events, they would have caused major societal impacts. These events would result in a loss of most of the agricultural area in coastal Peru as well as any human development on the flood plain. In comparing the flood date list (Table 1) with archaeological record, it appears the two oldest El Niño events occur at about the times of the transitions between major archaeological periods:

- The 1200 BC event occurs during the transition from the Initial Period to the Early Horizon (c. 900-1400 BC) (Lanning, 1967; Rowe and Menzel, 1948) when the Chavin culture spread its influence from the highlands into the coastal zone.
- The AD zero event occurs near the estimated transition from the Early Horizon to the Early Intermediate Period (c. 200-400 BC) Lanning, 1967; Rowe and Menzel, 1948); during this time a large coherent culture broke down and the coastal zone became controlled by small political entities.
- The AD 1325 event is believed to correspond to Nyamlaps flood (Rowe, 1945; Pozorski, 1987). This ethnohistorically recorded flood caused the breakdown of the Dynasty of Nyamlap and the subsequent invasion of the Lambayeque region by the Chimu Dynasty, a large power base centered to the south, in the Moche valley.

All of these societal changes record a region outside the area of flood devastation gaining political control over regions affected by the floods or in the breakdown of a large political entity in the flooded zone. These data indicate that the flood events recorded here are large-scale disasters that affected the entire northern coastal zone of Peru and that, if repeated, may have global implications. A crucial test will be the dating of a sequence of flood deposits from other coastal valleys in Peru to document the regional nature of contemporaneous flooding and the correlation of these large events with extreme climate events, as recorded historically or geologically, in other regions of the globe.

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