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RECENT RESEARCH ON RECORDS OF FORMER EL NIÑO EVENTS IN PERU

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Investigaciones recientes sobre registros de antiguos eventos El Niño en el Peru

Luego del evento, excepcionalmente fuerte, de El Niño en 1983, en el Perú se han realizado varios estudios tendientes a identificar las ocurrencias de este fenómeno en el pasado. Todos estos estudios tratan de identificar alguna "señal" de El Niño que pueda quedar grabada en archivos naturales o humanos. Entre los primeros se cuentan los testigos de hielo, sedimentos lacustres y aluviales, construcciones litorales, árboles del desierto, composición isotópica y distribución de moluscos marinos, etc. Entre los registros asociados a la intervención del hombre destacan los instrumentales, que dan parámetros meteorológicos y oceanográficos; los históricos, basados en fuentes escritas y los arqueológicos. Aquí, revisamos brevemente las bases conceptuales, los métodos utilizados y los problemas de interpretación de los resultados obtenidos.

OCEANIC AND ATMOSPHERIC EXPRESSIONS OF EL NIÑO PHENOMENON

El Niño, the regional component of the ENSO (El Niño-Southern Oscillation) phenomenon in South America, involves changes in the atmospheric and oceanic conditions of the northern Peruvian coast. The following expressions are as summarized by Enfield (1987) and Aguilar (1990). In the atmospheric aspect, strong rainfalls strike this normally arid land producing an increased runoff erosion; this is thought to be associated to a southward shift of the Inter-tropical Convergence Zone ITCZ. Along the usually dry short valleys (quebradas), water runs and generates sheet flows that are deposited on the adjacent coastal plain, sometimes upon former alluvial fans. The water discharge and the amount of sediments transported by the major rivers (Piura, Chira) also increase, and may produce overbank flood deposits. Part of these sediments are carried in the coastal area and into the sea. In the coastal ocean, the El Niño conditions include a temporary sea-level rise and frequent storms. Nearshore, the sea surface temperature increases by several degrees centigrades which in turn produces marine and littoral faunal migration along the coast. Meanhwile, the southern Peruvian Andes undergo a deficitary precipitation, as discussed below.

EL NIÑO IN MAN-MADE ARCHIVES

Instrumental data and analysis

Direct measurements of the oceanographic and meteorological parameters in Peru began in the second decade of this century; therefore, they are useful to identify and analyse the contemporaneous oceano-atmospheric anomalies, with better-than-annual resolution.

As a consequence of the prosperous fishing activities along the north-central Peruvian coast, sea surface temperature (SST) is recorded in the Chicama station since 1924. The other coastal stations used for the definition of El Niño events (Paita, Talara and Chimbote) have all approximately 30-year of SST records.

Concerning precipitation, seven coastal meteorological stations provide records of rainfall exceding 50 years, and at least three Andean stations recorded data during the last 40 years.

General relationships linking high SST, high sea level, reversal of wind direction, heavy rainfall on the northern coast, cordilleran drought, and Lake Titicaca low level are statistically proved and widely accepted. Nevertheless, detailed studies of these distinct records show ambiguous correlations and several complications in the interactions of the oceanic and atmospheric phenomena in the Peruvian territory (see for example: Philander, 1983; Francou & Pizarro, 1985; Caviedes & Waylen, 1987).

Historical research

For the period between the Spanish conquest and the beginning of instrumentation (nearly 4 centuries), several kinds of written sources have been used to identify El Niño events, assess their intensities and document their periodicity. This approach allows also a better-than-annual resolution. The important compilation of Quinn et al. (1978 and 1987) and the El Niño chronological sequence of Hamilton & García (1986) were scrutinized by Hocquenghem & Ortlieb (1990, and this volume) and Ortlieb & Hocquenghem (1991), who objected that some events were probably less strong than assumed previously, and that a few reported events (1925-26, 1531-32) did not occur at all. Huertas (1987a, b, and this volume) analyzed the information about repeated destruction of Saña, and interpreted some socio-economic disturbances as closely related to El Niño events between the XVIIth and XVIIIth centuries.

Archaeological approach

Extending the record back beyond the historical sources, the archaeological research has successfully identified evidences of catastrophic rainfalls in the pre-historical record. Nials et al. (1979) first described the effects of a very large flood (the Chimu flood, ca. 1,000 AD) in the Quebrada Río Seco and in the Moche valley, and related it to a great El Niño event. Moseley & Feldman (1982) stressed the effects of El Niño on the behavior and development of pre-hispanic populations. Craig & Shimada (1986) characterized a big flood (ca. 600 AD) and other undated events in Batán Grande. More recently, it has been observed that several monuments display breaks in their use, and closer examination shows runoff erosion of exposed buildings and accumulation of sediments in protected

parts, as in Huaca de la Luna (Uceda, this volume). Changes in the architectural styles are being used to identify breakdowns in the Sipán site, and to relate them to El Niño events (W. and S. Alva, pers. comm. 1992). The relative ("cultural") dating, frequently used in archaeological studies, limits the resolution of this approach to a century, at best.

SIGNATURES OF EL NIÑO IN NATURAL ARCHIVES

Several of the above cited effects of El Niño on land and in coastal environments, as well as on the associated life, are able to remain registered in different natural and man-made archives (Macharé et al., in press). Therefore, the reconstruction of EN chronologies in the past depends on two factors: 1) The capability to identify a series of occurrences of a given El Niño-related effect, and 2) the accuracy in the age determination precision in dating of these signatures. Among the parameters deduced from these effects, precipitation has been by far the most frequently mentioned. The following review mentions only some of the numerous works related to the issue. Two extensive lists of references may be found in Ortlieb (1991 a & b).

Ice cores

Ice-coring is one of the most fruitful methods used in paleoclimatic research, and presents high potential in paleoENSO reconstructions, as mentioned by L.G. Thompson in several recent papers (references included in Thompson & Mosley-Thompson, 1989). The best record, presently available in Peru, comes from the Quelccaya ice cap located in the southern Peruvian Andes, where El Niño phenomenon is expressed by a deficit in the annual precipitation (Francou & Pizarro, 1985). The low temperature (-3°C) related to the high altitude (more than 5,600 m) of the site, prevents melting and percolation. Therefore, the summer snowfalls accumulate continuously on the summit of the glacier, as annual ice layers. Mass balances are obtained from analyses of microparticles concentration, oxygene isotope ratios, and β activity. Precipitation variation with annual resolution is obtained for the last decades, and signals of droughts proved to correlate well with El Niño events known from historical data (Thompson et al, 1984). Although the resolution decreases toward the basal layers, the 10-yr average in the precipitation curve is still very useful to identify the dry and wet events produced in the last 1,500 yr.

Littoral geological features

The existence of prograding coasts, with beach ridges sequences, in several places of northwestern Perú had once been associated to tectonic phenomena. It is now regarded as a probable evidence of major El Niño events (Sandweiss, 1986; Ortlieb et al., 1990). The assumption is based on the fact that, during El Niño events, an increased amount of sediments released by coastal rivers into the ocean and is redistributed by coastal drift currents onto the shoreline. The distances (tens of meters) between the individual ridges of a sequence, favor the interpretation of an episodic, rather than continuous, phenomenon.

Radiocarbon dating has been performed on marine shells included in the ridge sediments, on midden shells covering up the ridges, and on charcoals, from the Chira and Colán sequences (Richardson, 1983, Ortlieb et al., this volume). The ^{14}C results give a chronological framework, according to which, both sequences are younger than ca. 4,500 BP, and the time elapsed between the formation of two successive ridges is about 400 to

500 yr. Owing to problems inherent to the radiocarbon method applied to marine carbonates, the resolution of this approach to major El Niño cyclicity is of 10^2 yr.

However, alternative points of view have arisen concerning the interpretation of the Peruvian beach ridges. Craig (this volume) believes that the ridges may have been formed by strong wave dynamics unrelated to El Niño events, and rather associated to distant storm systems. On another hand, Martin et al. (this volume) envisage ridge formation during long-time spans (several decades to few centuries), which would have been characterized by "El Niño-like" oceano-atmospheric conditions.

Sedimentary record of onshore coastal depressions

During the 1972 and 1982-83 El Niño events, it was noted that several closed depressions and ponds, located in the Sechura Desert, received the runoff water, and were converted in temporal lakes for several months, until their complete evaporation. Sediments carried into those basins may thus record El Niño events. Recently, an IGP-ORSTOM drilling program was established to obtain undisturbed cores of the some 15 m-thick infill of the Salina Grande depression. The drilling operations, using a ligh-weight vibro-corer, encountered technical problems, mainly due to the presence of hard gypsum and halite layers. In addition, the upper part of the sedimentary column appears badly disturbed by near-surface salt dynamics. Other sites are being identified as targets for future drilling ;a combined vibro-corer plus auger system should be useful in Salina Grande, which remains the main objective.

Alluvial geological record

The increased precipitation received by the Pacific watershed of the northern Peruvian rivers, during El Niño events, has produced flooding in several valleys between 3° and 10° lat. S (Caviedes & Waylen, 1987). Wells (1987) studied the sedimentary characteristics of the 1982-83 flood deposits, in the Casma valley, and defined a typical El Niño-sedimentary unit. More recently, she was able to identify in this valley 18 flood events during the Holocene, giving a minimum number of occurrences of mega El Niño events (Wells, 1990). The report of several El Niño-sedimentary units of late Pleistocene age, would implies that this archive may contain the longest record of El Niño in the past. However, dating of the individual alluvial units will be always the major problem to face in determining a credible periodicity of the Late Quaternary. Nevertheless, other river valleys should be investigated in order to correlate time-equivalent units.

A probable correlation between floods in the middle part of the Río Rimac watershed, east of Lima, and El Niño events has been suggested (Ibañez & Gómez, 1990; Martínez, 1991). Analyses of the precipitation in several stations of the high Andes of central Peru, during the most recent El Niño events revealed a very high variability, with a sligh predominance of deficit (drought) (García & Fernandez, 1984; Francou & Pizarro, 1985). However, the Rimac valley stations still need to be studied from this point of view to verify the relationship between catastrofic floods and El Niño. This data would be also of great help to assess the historical chronology of El Niño events proposed by Quinn et al. (1987) and discussed by Hocquenghem & Ortlieb (this volume, in prep.).

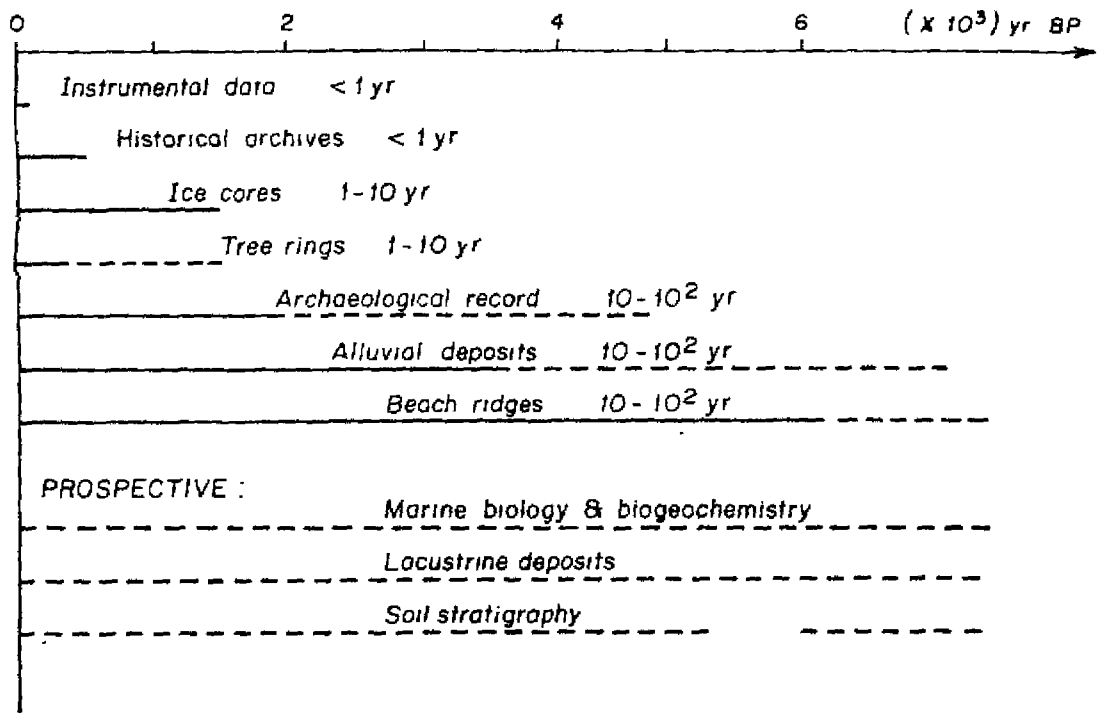

Figure 1.- Natural and man-made archives recording former occurrences of El Niño phenomenon in Peru. Line lengths indicate proved (continuous) and probable (dashed) extents of each record. The present-day resolution is also indicated.

Coastal marine biological changes and biogeochemical signatures

The nearshore marine fauna shows different kinds of responses when exposed to environmental changes associated with El Niño phenomenon. In function of their ability to adapt themselves to variations of sea-water temperature, salinity, dissolved oxygene, currents, sediment influx, food availability, etc., the distinct species may survive, migrate or die. These behaviors have been reported during the last events of El Niño (Arntz et al., 1985; Barber & Chávez, 1983). An analysis of mollusk shells from archaeological sites led Rollins et al. (1986) to propose a major reorganization of the coastal environments by 5,000 BP, and the start of El Niño occurrences since that date. Recent studies on Holocene mollusks contained in natural marine deposits, and in shell middens address the problem of long-term environmental changes versus El Niño effects in the northern and central coast of Peru (Díaz & Ortlieb, 1991; this volume). On another hand, comparisons between the isotopic composition of present-day and Holocene mollusk shells, and their relationship with El Niño have been investigated by Perrier et al. (1991, and this volume). Finally, the organic geochemistry of surface sediments off Peru is also considered to register effects of El Niño phenomenon, and to present a high potential as marker of its occurrence (Mc Caffrey et al., 1989). At the present time, biological and biogeochemical research should be regarded as prospective line to approach new types of past El Niño record.

Tropical tree-ring record

The recognition of ENSO signals in tree rings of temperate North America, Australia, and Indonesia (Meko, 1990; Cook, 1990; D'Arrigo, 1990; Lough, 1990) shows that short-

lived episodes of both increased rainfall and droughts are able to be recorded by tree trunks. During the last few years, a team from the Universidad de Piura has been exploring the probable presence of El Niño-related rainfall signals on growth rings of several trees which are common in the Sechura Desert, northwestern Peru. The first results should be presented during this "Paleo ENSO records" meeting (Rodriguez et al., this volume).

Soil development

There exist few reports about ongoing research concerning identification of El Niño evidences in soil sequences. Noller et al. (1990) summarizes the main characteristics of soils developed on alluvial terraces of the central Peruvian coast, and proposes that some features be explained by the effect of El Niño-related water into the geochemistry of the soils. More work appears to be needed to clearly identify El Niño signal in soils, and use these data in the reconstruction of former occurrences of the phenomenon in the area.

CONCLUSION

Peru is probably the most appropiated place on earth to study former occurrences of the El Niño phenomenon. The atmospheric and oceanographic anomalies and disturbances that characterize this global phenomenon are registered by a series of archives offshore, along the coast, in the foothills, in the high cordillera and on the altiplano. Some work has been performed in the last few years, but much more remains to be done, especially regarding the correlation of the distinct records observed up to now. One of the objectives of this Paleo ENSO Records meeting is precisely to encourage the multidisciplinary studies on this topic.

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REFERENCES

Aguilar P., 1990. *Boletín de Lima*, 70, 69-84.
Arntz W., Landa A., Tarazona J. (Eds), 1985. *Bol. extraord. Inst. Mar del Perú*,
Barber R.T. & Chávez F., 1983. *Science*, 222, 1203-1210
Caviedes C. & Waylen P.R., 1987. *Bull. Inst. Fr. Etudes Andines*, 16 (1-2), 1-19.
Cook E.R., 1990. Workshop Paleoclimatic aspects of El Niño/Southern Oscillation, NOAA-INSTAAR, Boulder, 6 p.
Craig A.K. & Shimada I., 1986. *Geoarchaeology*, 1 (1), 29-39.
D'Arrigo R., Workshop Paleoclimatic aspects of El Niño/Southern Oscillation, NOAA-INSTAAR, Boulder, 1 p.
Díaz A. & Ortlieb L., 1991. VII Congr. Peruano Geol., Lima, 2, 407-411.
Enfield D.B., 1987. *Endeavour*, 11 (4), 197-204.
Francou B. & Pizarro L., 1985. *Bull. Inst. Fr. Etudes Andines*, 14 (1-2), 1-18.
García A. & Fernández I., 1984. *In:* Ciencia, tecnología y agresión ambiental: El Fenómeno El Niño, CONCYTEC, 521-550.
Hamilton K. & R.R. García, 1986. *Bull. Am. Meteor. Soc.*, 67 (11), 1354-1361.
Hocquenghem A.M. & Ortlieb L., 1990. *Bull. Ins. Fr. Etudes Andines*, 19 (2), 327-334.
Huertas L., 1987a. *Ecología e historia. Probanzas de Indios y Españoles referentes a las catastróficas lluvias de 1578, en los corregimientos de Trujillo y Saña, por Francisco Alcocer (escribano receptor)*. Centro de estudios Sociales "Solidaridad", Chiclayo, 208 p.

Huertas L., 1987b. *Saña, análisis histórico*, unpublished ms., 165 p.
Ibáñez M. & Gómez W., 1990. *Boletín de Lima*, 68, 43-62.
Lough J.M., 1990. Workshop Paleoclimatic aspects of El Niño/Southern Oscillation, NOAA-INSTAAR, Boulder, 4 p.
Macharé J. & Ortlieb L. Global Change studies in northwestern Peru: a high potential for records of former El Niño events. *Revista Geofísica*, Mexico, *(in press)*.
Martínez A., 1991. 5to. Simp. Nac. Prevención de Desastres, CISMID, Lima, 22 p.
Meko D. Workshop Paleoclimatic aspects of El Niño/Southern Oscillation, NOAA-INSTAAR, Boulder, 1p.
Moseley M.E. & Feldman R.A., 1982. *Rev. Museo Nacional*, 46, 267-287.
Mc Caffrey R. A., Farrington J. W. & Repeta D. J., 1989. *Geol. Soc. Am. Abstr. Progr.*, 21 (6), A5.
Nials F.L., Deeds E.R., Moseley M.E., Pozorski S.G., Pozorski T.& Feldman R.A., 1979 *Field Museum Nat. Hist. Bull.*, 50 (7), 4-14, and 50 (8), 4-10.
Noller J.S., Wells L. & Birkeland P., 1987. *Geol. Soc. Amer. Abstr. Progr.*, 19 (7), 790.
Ortlieb L., 1991 (a & b). 3ra. Reunión An. PICG 281 Climas cuaternarios de América del Sur, Res. y Contrib., 83-112 & 113-156.
Ortlieb L., Macharé J., Fournier M. & Woodman R., 1990. *Bol. Soc. Geol. Perú*, 80, 107-121.
Perrier C., 1991. Mém. Maîtr. Sc. Terre., Univ. Québec, Montréal, 80 p.
Philander S.G.H., 1983. *Nature*, 302, 291-301.
Quinn W.H., Zopf D.O., Short K.S. & Kuo Yang R.T.W., 1978.*Fishery Bull.*, 76. 363-378.
Quinn W.H., Neal V.T. & Antunez de Mayolo S., 1987. *J. Geophys. Res.*, 92 (C13), 14449-14461.
Richardson J.B., 1983. *Ann. Carnegie Museum*, 52 (11), 265-275.
Rollins H.B., Richardson J.B. & Sandweiss D.H., 1986. *Geoarchaeology*, 1 (1), 3-15.
Sandweiss D.H., 1986. *Geoarchaeology*, 1 (1), 17-28.
Thompson L.G., Mosley-Thompson E., Morales Arnao B., 1984. *Science*, 223, 50-53.
Thompson L.G. & Mosley-Thompson E., 1989. *In:* Aspects of climate variability in the Pacific and the western Americas. Am. Geophys. Un., Geophys. Monogr., 55, 15-31.
Wells L.E., 1987. *J. Geophys. Res.*, 92 (C13), 14463-14470.
Wells L.E., 1990. *Geology*, 18, 1134-1137.

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EL NIÑO/SOUTHERN OSCILLATION CLIMATE VARIABILITY IN SOUTH AMERICAN PALEO-ENVIRONMENTAL RECORDS

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In trying to understand the long-term behavior of ENSO over the range of thousands of years and under boundary conditions substantially different from today, pollen records offer a unique opportunity because of their time depth, continuity, and regional cover. Using the climate patterns that have been linked to ENSO events world-wide, pollen records from specific regions sensitive to El Niño and La Niña events were analyzed for their past climate patterns. In South America, El Niño is characterized by substantially drier conditions over the northeastern part of the continent, in Venezuela and Brazil, but wetter conditions over the south-central part of South America, Chile and Argentina. The opposite signal holds true for La Niña events. During the early Holocene (10 to 8 kyr) climates were wetter and cooler than today over northeastern South America, but drier than today over the south-central part of southern South America, suggesting climates resembling La Niña conditions. However, over the western Pacific land areas, Australia and New Zealand, climates instead suggested El Niño conditions. This indicates that probably the ENSO system at that time did not operate as today. During the late Holocene, on the other hand, especially after 3 kyr, northeastern South America turned drier, and south-central South America wetter than before. In addition, in the southern parts of the continent, vegetation was dominated by a mixed plant community of taxa adapted to droughts and fire, as well as mesic taxa. Charcoal in sediments increased also at that time, indicating greater fire frequency. All this suggests that climate had become much more variable, with a pattern that indicates greater frequency and/or amplitude of El Niño events. Similar climate condition is reported from the Australia/New Zealand sector, that also experienced substantial increase in climate variability, droughts, and fires, characteristic of El Niño events only during the late Holocene, suggesting that in fact only during the late Holocene ENSO was operating in a fashion similar to today.