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Former El Niño events: records from western South America

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ABSTRACT

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The quasi-periodic alterations of the climate in South America and of the oceanographical conditions in the eastern Pacific Ocean, referred to as the "El Niño" phenomenon, are part of a global anomaly in the ocean–atmosphere interactive system (the El Niño-Southern Oscillation, ENSO). As this phenomenon is responsible for the major interannual climatic variability and has a great potential to document links between the atmospheric and oceanic circulations, it is important to understand its mechanism, its boundary conditions and the causes of the variations of its intensity. Many answers to such questions can be sought in the historical and geological record of El Niño occurrences.

Former impacts of the El Niño phenomenon along the western coast of South America are documented by remnants of catastrophic rainfalls and associated river floods, records of lake salinity variations, beach ridge sequences and numerous evidences of alterations in the biotic and physical coastal environment. For the last millennium or so, relatively precise (although discontinuous) archaeological and historical data are available. Continuous, high-resolution, proxy records are provided by glaciological data (last 1500 yr) from the Quelccaya ice cap of southern Peru and are potentially available from coral cores from the Galapagos Islands. No marine varves that would permit a detailed and sequential study of El Niño-related oceanographic anomalies during the late Quaternary have yet been obtained off western South America. The reconstruction of the sequence of the main ENSO events during the last millennia is thus hampered by the fact that there are too few continuous records and that these have not necessarily registered every El Niño occurrence and/or the relative intensity of each event. The discontinuous records of major El Niño events are more numerous, but often lack the required chronological accuracy. Obviously, both series of data need to be cross-checked and compared with information (e.g. dendroclimatology and marine varves) from other regions of the globe where climate teleconnections with the ENSO phenomenon can be assessed.

Introduction

El Niño, ENSO and the ocean–atmosphere interaction

The El Niño-Southern Oscillation (ENSO) system is commonly considered as the best example of ocean/atmosphere interaction and one of the most relevant manifestations of interannual variability in the global climate system. Although the ENSO phenomenon is primarily observed in the equatorial Pacific Ocean and the bordering land areas, it has been shown that it induces worldwide climatic anomalies (teleconnections) in tropical and extra-tropical areas (Walker and Bliss, 1932; Bjerknes, 1969; Barnett, 1981; Horel and Wallace, 1981; Rasmusson, 1985; Ropelewski and Halpert, 1987; Kiladis and Diaz, 1989). These characteristics and the fact that many impacts and consequences of the ENSO/El Niño anomalies are catastrophic, explain that the phenomenon has received a particular attention in major current research programs (IGBP-"Global Change", Research Program on the World Climate, Tropical Ocean–Global Atmosphere project, etc.).

In the last few decades, progress has been made in the monitoring of the oceanic and atmospheric conditions in the intertropical areas and in the understanding of some of the typical ENSO processes and interactions (Rasmusson, 1984; Enfield, 1987; Philander, 1989), as well as in the modeling of the phenomenon (Cane and Zebiak, 1985; Vallis, 1986; Zebiak and Cane, 1987; Sperber et al., 1987; Graham and White, 1988; Philander et al., 1989). However, numerous questions about the mechanisms and parameters involved in the ENSO/El Niño anomalies remain to be answered. For instance, we still do not know the ultimate causes of the ENSO phenomenon and which fundamental process drives the system. There are still discussions about the theory of a closed, internal, system that would mainly rely on feedback mechanisms. The role of lithospheric processes, such as variations in the earth rate of rotation or volcanic activity, that may trigger and enhance major ENSO events, needs to be better defined. Similarly, it is necessary to assess the importance of the extra-terrestrial, astronomical, forcing on ENSO. Finally, there is much practical interest in determining the processes and factors that control the variability in the intensity of ENSO events and more generally in improving our forecast capability.

The term "ENSO" is commonly used for large scale (intertropical, inter-oceanic, or global) features related to the Southern Oscillation "seesaw" system, while the term "El Niño" refers more specifically to the regional manifestations of the oceano-climatic phenomenon centered on the eastern Pacific and western South America. Here, we are mainly concerned with the former manifestations of El Niño activity, as the eastern component of the ENSO phenomenon. As El Niño impacts on landforms, sediments, fauna and flora of many regions of South America, notably in its birthplace in the Piura region of northern Peru and distinct kinds of historical/archaeological records of former El Niño events have been investigated in recent years (see: Devries, 1987; Enfield, 1989; Ortlieb and Macharé, 1989, 1992; Macharé and Ortlieb, 1992), it may be useful to review the most significant results obtained and try to delineate future directions of research.

Manifestations of the El Niño anomaly

The main climate anomalies that characterize the El Niño phenomenon in South America are related to a modification of the Walker circulation and to a southern shift of the Intertropical Convergence Zone. They include the following manifestations:

- exceptional precipitations in the normally arid/semi-arid coastal regions of northwestern Peru and southernmost Ecuador (Eguiguren, 1894; Petersen, 1935; Murphy, 1925, 1926; Waylen and Caviedes, 1986);
- increased precipitations in central Chile, Paraguay and northern Argentina (Walker and Bliss, 1932; Berlage, 1966; Quinn et al., 1978; Pittock, 1980; Quinn and Neal, 1983; Kousky et al., 1984; Ruttlant, 1985; Ropelewski and Halpert, 1987; Depetris and Kempe, 1990; Rutllant and Fuenzalida, 1991);
- significant rainfall deficits in the Altiplano of southeastern Peru and Bolivia, the Brazilian Nordeste, northernmost South America and southern Central America (Caviedes, 1973, 1975, 1984; Hastenrath and Heller, 1977; Francou and Pizarro, 1985; Ropelewski and Halpert, 1987; Aceituno, 1987, 1988; Rogers, 1988; Quinn and Neal, 1992).

From an oceanographic point of view, the ENSO phenomenon is characterized by an elevation of the sea surface temperature (SST) in the equatorial Pacific Ocean (east of 130°W) and along the South American coast, an important lowering of the thermocline accompanied by an alteration of the upwelling system and a decrease in the primary productivity. The biological impacts of these anomalous conditions are numerous, especially along the Peruvian coast: high mortality at all levels of the trophic chain, displacement of pelagic species and ecological stress on most marine organisms (Barber and Chavez, 1983; Arntz, 1986; Arntz and Tarazona, 1990). The main markers of these short-term oceanographic alterations, of varying intensity, include the presence/absence of organisms in sedimentary sequences and biochemical modifications recorded by skeletal marine organisms like corals, molluscs, foraminifera, dinoflagellates (Druffel, 1985; Rollins et al., 1987; Ochoa and Gomez, 1987; Shen et al., 1988, 1992; Earley et al., 1991; Juillet et al., 1991; Perrier et al., 1992).

Variability in the frequency and intensity of the El Niño phenomenon

The recurrence of the El Niño/ENSO phenomenon is about 3–7 years. The major effects of ENSO events typically last several months, centered on the austral summer, but may encompass two years, like in 1982–1983. One of the main characteristics of the phenomenon is its large variability in intensity. The classical intensity scale comprises four levels: very strong, strong, moderate and weak (Quinn et al., 1978, 1987). Even for modern El Niño events, this classification is not always easy, depending on the site of observation and the oceanographic or climatic component considered. At the lower end of the variability range, the occurrence/non-occurrence of an El Niño event may be debatable. The intensity of strong (e.g. 1991–1992) and very strong (1982–1983) events is generally easier to establish.

A better understanding of the mechanisms, boundary conditions and rhythm of the ENSO system, requires that the periodicity of the phenomenon in the last centuries/millennia and the evolution of this periodicity (Trenberth and Shea, 1987), be determined with some accuracy. For instance, precise reconstructions of the recurring ENSO events in the recent past can determine the influence on the El Niño system of oscillatory phenomena like the Quasi-Biennial Oscillation (Van Loon and Labitzke, 1987; Rasmusson et al., 1990), different types of luni-solar variations (Anderson, 1990; Fairbridge, 1990; Barnett, 1990; Labitzke and Van Loon, 1990; Lowrie, 1992), or shorter-term, intraseasonal, rhythms like the Madden-Julian Oscillation (Lau and Chan, 1988; Rasmusson, 1990; Weickmann, 1991).

From a palaeoclimatic point of view there is much interest in establishing the relationship between El Niño and longer-term climate phases like the Little Ice Age (AD 1500–1900) or the Medieval Warm episode (AD 1000–1300), notably to determine variations in frequency and intensity of the El Niño phenomenon. At a longer time scale, it remains to establish whether the ENSO system is strictly linked to interglacial conditions and how it behaved during glacial maxima. In an another way, it has been hypothesized that climatic variations with durations of the order of decades/centuries represented "El Niño-like conditions", or "super-ENSOs" (DeVries, 1987; Martin, 1992a, b; Mörner, 1989, 1992), but such concepts still need to be substantiated (Markgraf et al., 1992).

Beside, precise studies on former occurrences of the phenomenon are most useful to test the forcing of geodynamic agents and processes. A detailed chronological reconstruction of former El Niño events (including evaluation of intensities) correlated with a historical study of volcanic eruptions should help in determining the respective influences of volcanic activity and El Niño anomalies (Angell, 1988; Quinn, in press b). Detailed studies on the El Chichón (1982) and Agung (1963) eruptions could not firmly establish whether large volcanic ash emissions are able to trigger and/or intensify El Niño events (Handler, 1984, 1986; Hirono et al., 1985; Hirono, 1988; Handler et al., 1990). The recent (June 1991) Pinatubo eruption, which produced aerosols with an optical depth about twice that of El Chichón, is expected to modify the climate of the next few years and to influence the modality of the next El Niño manifestations (Hansen, 1991; Handler and Andsager, 1991).

For many reasons, then, the study of former occurrences of El Niño events is compulsory, beginning with the key area of the western coast of South America.

Records of El Niño events in South America

Last millennium events

Documentary historical sources

Quinn et al. (1987) developed a chronological series of the major El Niño events that probably occurred in the last 450 years. This was done through a compilation of historical evidence of meteorological anomalies in Peru and neighbouring countries. The Quinn et al. (1987) chronology included estimates of event intensity (very strong,

strong +, strong and also: moderate + and moderate for the last two centuries) and a confidence rating (5–2) of the evaluation of the event reconstruction. This chronological sequence of the main El Niño events recorded in western South America has been for several years the most detailed and most complete data set available. The sequence was accepted as standard by numerous authors working on palaeo-ENSO records and has been largely used for recurrence studies and for calibration purposes (e.g.: Enfield, 1988; Hanson et al., 1989; Michaelsen, 1989; Enfield and Cid, 1990, 1991; Fairbridge, 1990; Nicholls, 1990; Thompson, 1990; Pulwarty and Diaz, 1991).

Through critical readings of the historical sources listed by Quinn et al. (1987) and by taking into account a few additional texts, Hocquenghem and Ortlieb (1990, 1992) suggested that the first two events of the sequence (AD 1525–1526 and 1531–1532) as well as some other episodes should be eliminated and that for a series of other historical events the intensities

TABLE 1

Chronological sequences of strong El Niño events since early 16th century, reconstructed from historical data, according to diverse sources: Eguiguren (1894) (period 1791–1891), Hamilton and Garcia (1986) (period 1525–1982), Quinn et al. (1987) (period 1525–1986), Hocquenghem and Ortlieb (1992) (period 1525–1891), Quinn (in press b) (period 1525–1992).

Abundant rains in northern Peru (Eguiguren, 1984)	Major events in Peru Hamilton and Garcia, 1986)	Very strong and strong events in W South America (Quinn et al., 1978)	Confirmed strong and very strong events in Peru (Hocquenghem and Ortlieb, 1992)	Very strong and strong "regional" El Nino events (Quinn, in press b)
↑		1525–26		
		1531–32		
	1541			
				1546–47
		1552		1552
		1567–68		1567–68
		1574		1574
	1578	* 1578 *	* 1578 *	* 1578–E79 *
		1591–92		
			1593	
			1596	
				1600
		1607		1607–08
	1614	1614		1614
N		1618–19		1618–19
	1624	1624	1624	1624
O		1634		
				1635
	1652	1652		1652
		1660		
				1661
		1671		1671
D		1681		1681
			1686	
A		1687–88		1687
				1692
T		1696		
	1701	1701	1701	1701
A		1707–08		
		1714–15		
				1715–16
↓	1720	1720	1720	* 1720 *

TABLE 1 (continued)

Abundant rains in northern Peru (Eguiguren, 1984)	Major events in Peru Hamilton and Garcia, 1986)	Very strong and strong events in W South America (Quinn et al., 1978)	Confirmed strong and very strong events in Peru (Hocquenghem and Ortlieb, 1992)	Very strong and strong "regional" El Nino events (Quinn, in press b)
N	1728	* 1728 *	* 1728 *	* 1728 *
O				1737
	1747	1747	1747–48	1747
		1761		1761
D	1763			
A	1770			
T		1775		
A				1776–E78
				1782–83
		1785–86		
1791	1791	* 1791 *	1791	* 1791 *
1804	1804	1803–04		1803–04
1814	1814	1814		1814
1828	1828	* 1828 *	1828	* 1828 *
1845		1844–45		1844–E46
1864		1864		1864
1871		1871	1871	1871
1877–78		* 1877–78 *	1877–78	* 1877–78 *
1884		1884	1884	1884
* 1891 *	1891	* 1891 *	* 1891 *	* 1891 *
		1899–1900		1899–E1900
		1911–12		
N		1917	N	
O	1925	* 1925–26 *	O	* 1925–26 *
		1932		1932
D		1940–41	D	L1940–41
A		1957–58	A	1957–58
T		1972–73	T	1972–E73
A	1982	1982–83	A	* L1982–M83 *
	←——— NO DATA	———→		1992

* (year) *: Very strong events.
E: early, M: middle, L: late.

evaluated by Quinn et al. (1987) should be questioned. The discussion bears upon: (1) the validity of some historical sources, (2) the criteria used for the identification of some El Niño events and, (3) the general problem of evaluation of event intensity. A major point that requires further investigation concerns all the cases for which there are no indication in historical documents of precipitation in northern Peru and instead only sparse information from the central or southern Peruvian coast. The Quinn et al. (1987) chronology includes several so-called "El Niño events" that were only identified on the basis of a notice of a flood of the Rimac River at Lima, or of a small rain (at any time of the year, including in austral winter), or even some lightnings, in south-central Peru. But floods of the Rimac River do not seem to be linked to El Niño conditions (and rather to high Andes thunderstorms fed by Atlantic air masses) and small rains are not uncommon during anti-El Niño episodes in southern Peru.

Thus, according to Hocquenghem and Ortlieb (1992), the number of well-identified El Niño events should be lower than interpreted by Quinn et al. (1987) and the intensity of the events was in many cases minor than previously evaluated (Table 1). The lack of anomalous rainfalls in northern Peru during the Conquest by Pizarro (AD 1531–1532) seems now well established (see also: Petersen, 1935 and Hamilton and Garcia, 1986). It is suggested here that most of the discrepancies observed in cross-correlations between the classical historical chronology of El Niño and other proxy records, such as tree-ring data or the Quelccaya ice core records (e.g. Michaelsen, 1990), heavily depend on the utilization of the over-estimated number (and over-rated intensity) of El Niño events listed by Quinn and co-workers.

Recently, Quinn and Neal (1992) and Quinn (in press a, b), extended the chronology of ENSO occurrences back to AD 622, by adding records from the Nile floods (low floods, due to deficits in monsoonal rainfall in Ethiopia, are correlated with ENSO episodes). This longer chronology, based upon data from a much wider geographical area and involving several sets of teleconnected climatic anomalies, may be viewed of global significance. However, it should be noted that this new chronology relies on a very limited number of historical sources (much less than the El Niño record in Peru).

Tree ring record

Another approach to reconstruct annual records of El Niño chronologies lies upon dendroclimatic analyses. For several reasons, though, there are no dendrochronological records from the regions in western South America most directly affected by El Niño impacts. On one hand, tree growth in tropical regions has proved to be too irregular to provide reliable palaeoclimatic signals (Fritts, 1976; Bormann and Berlyn, 1981; Norton, 1988; Lough and Fritts, 1990). On another hand, it has been shown that wood from these areas presented a reduced accuracy in radiocarbon dating, thus hampering precise age determination (Norton, 1988). Moreover, the center of the region affected by the El Niño phenomenon, in northern Peru, is arid and may be devoid of trees suitable for dendrochronologic analysis (although preliminary studies are being conducted in the area, see: Rodriguez, 1992; Rodriguez et al., 1992).

The tree ring information extracted from South America remains largely incipient and up to now has been of little help for the record of El Niño past events (LaMarche et al., 1979a, b; Boninsegna and Holmes, 1985; Lough and Fritts, 1985; Norton, 1988; Prieto and Boninsegna, 1992). Actually, tree ring data that are being used for the reconstruction of former ENSO events come from temperate (mid-latitude) regions, particularly western North America. The well-developed tree ring studies in the western US tend to indicate that dendrochronological data on the last 400 yr satisfactorily record the Southern Oscillation extremes (Michaelsen, 1989) and even allow a reconstruction of the Southern Oscillation Index (Lough and Fritts, 1990). In fact, tree rings studies of ENSO-related climatic features constitute a good example of the teleconnections which link some extra-tropical areas and the equatorial Pacific in the course of ENSO forcing conditions.

Glaciological record

Ice sheets and ice caps offer a reliable documentation on annual changes in the atmosphere composition and circulation pattern. The Quelccaya ice cap, in the high Andes of southern Peru (13°56′S, 70°50′W), has become a classical source of information for climate variability in the last 1500 yr (Thompson et al., 1985, 1986, 1988; Thompson and Mosley-Thompson, 1989). The conspicuous annual ice layers and the inclusion of historically well-dated markers (i.e. volcanic ashes of the AD 1600 Huaynaputina eruption) provide a solid chronological scale for this type of high-resolution palaeoclimatic record. The Quelccaya ice cap is located in the high Andes area where El Niño events are characterized by droughts. Annual rain deficits and lower levels of Lake Titicaca correlate with minor amounts of snow in the Quelccaya area (Newell, 1949; Thompson and Mosley-Thompson, 1989). Thus, cores from this ice cap may be of great help to reconstruct, in a continuous manner, a sequence of hydrological parameters.

In the Quelccaya ice cores, the Little Ice Age (LIA) period (Fig. 1) is identified by an increase in the dust content (from AD 1490 to 1880), a decrease in the $^{16}O/^{18}O$ values (from AD 1520

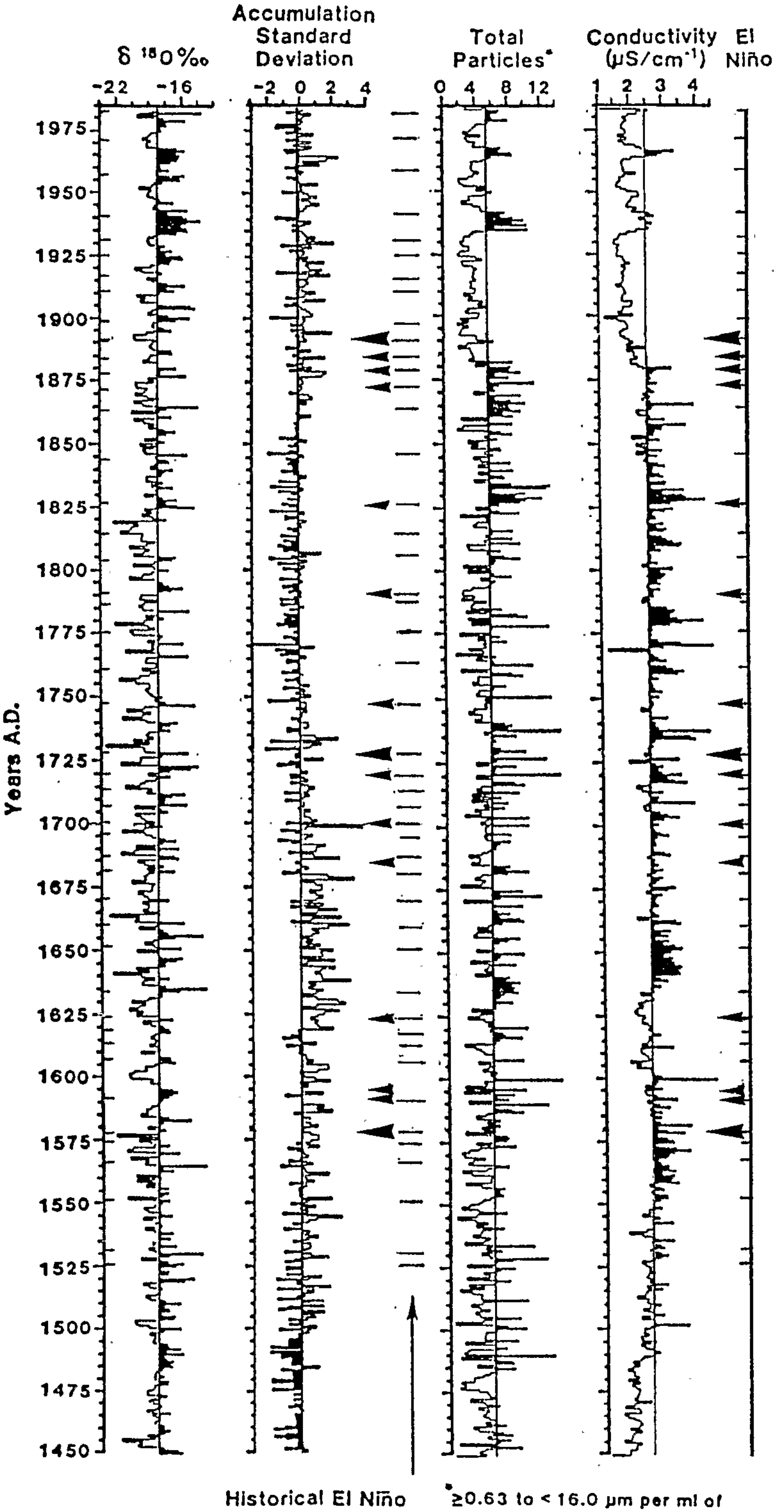

Fig. 1. Upper part of the Quelccaya ice core (southern Peruvian Andes) covering the period AD 1450–1983: Comparison between the historical chronologies of strong and very strong El Niño events, according to Quinn et al. (1987) (horizontal ticks) and Hocquenghem and Ortlieb (1992) for the period 16–19th centuries (small arrows for strong events and large arrows for very strong events), with annual fluctuations in oxygen-isotope, ice accumulation (standard deviation), microparticle content, and conductivity (modified from Thompson, 1990). The Little Ice Age period covers the span 1490–1880 (see text).

to 1900) and an initial increase in net ice accumulation (AD 1500–1720) followed by a dry period (AD 1720–1860) (Thompson et al., 1986). As an illustration of the ice core chronological accuracy, it may be mentioned that the onset and termination of the LIA were determined at, respectively, AD 1486–1489 and AD 1880 (Thompson and Mosley-Thompson, 1987, 1989). The ice cores seem to record strong and very strong El Niño events during the whole LIA (Fig. 1), thus suggesting that the two types of climatic anomalies pertain to distinct, relatively independent, systems.

The main expressions of the El Niño climatic anomaly as recorded in the Quelccaya ice core involve a less negative $^{16}O/^{18}O$ composition, a reduced ice accumulation, a high concentration in particles and a high conductivity level (Thompson, 1990), but these combined indications are not sufficient *per se* to identify former occurrences of the phenomenon (Fig. 1). On the other hand, a comparison of the Quinn et al. (1987) and Hocquenghem and Ortlieb (1992) historical series of El Niño with the Quelccaya summit ice core data does not show a strong year-to-year correlation (Fig. 1). The ice record suggests instead the existence of relatively long-lasting "El Niño-like conditions" in the course of the last few centuries. We interpret that the Quelccaya ice cap data may not register perfectly El Niño atmospheric anomalies because the area is primarily under the influence of the Atlantic system (from which it receives the precipitations), even if it is also affected by alterations of the Pacific system. The high resolution of the Quelccaya data yields a most valuable year-to-year information that we may not be ready to use until we understand better atmospheric circulation patterns over South America.

Coral reef record

Because of their high sensitivity to environmental changes combined to a regular growth pattern, coral reefs from the equatorial Pacific constitute an appropriate material for the recognition of El Niño effects in the past. Long-lived reef corals from SE Asia, central Pacific islands and NW South America currently provide 50–300 yr records with a resolution that can be monthly at best. Seasonal banding patterns generally allow a better than annual accuracy in core studies. Corals provide palaeoclimatic and palaeoceano-

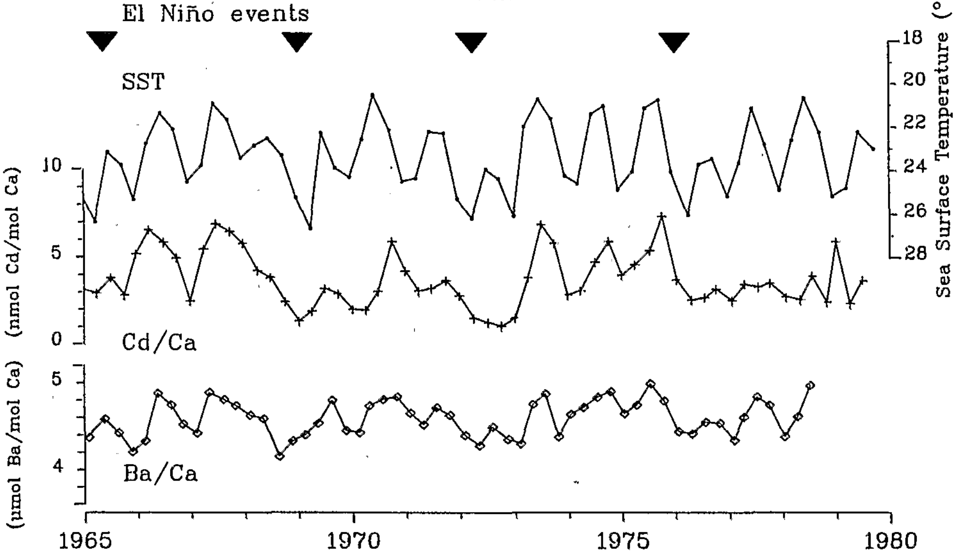

Fig. 2. Barium and cadmium concentrations in modern scleractinian corals (*Pavona clavus*) from Punta Pitt, Galapagos Is., compared with sea-surface temperature measured at Academy Bay (Galapagos Is.) (redrawn from Lea et al., 1989, and Shen and Sanford, 1990). El Niño (warmer) years are: 1965 (moderate), 1969 (weak), 1972 (strong) and 1976 (moderate)(black triangles).

graphic information through distinct methodological approaches: stable isotope geochemistry (Weber and Woodhead, 1972; Dunbar and Wellington, 1981; Carriquiri et al., 1988; Cole and Fairbanks, 1990; Cole et al., 1992, in press), study of growth parameters such as density and band width, fluorescence banding (Isdale, 1984) and trace elements (Cd, Ba, Mn, Sr) content (Shen et al., 1987, 1991; Lea et al., 1989; Linn et al., 1990; Shen and Sanford, 1990; Beck et al., in press) (Fig. 2). Oxygen isotope ratios provide records of sea water temperature and salinity and also of changes in evaporation and rainfall precipitation, whereas trace metals record productivity and upwelling conditions (Cd, Mn) or enrichment in freshwater (Ba). Sr/Ca ratios measured through thermal ionization mass spectrometry record mean monthly SST with an accuracy of better than 0.5°C.

Reef coral cores are particularly suitable for the study of global ENSO records because this material register distinct and complementary environmental parameters in the western, central and eastern equatorial Pacific region. In Central America and in the Galapagos Islands, a combination of the distinct tracers, particularly the stable isotopes and Cd/Ca ratio, allows the identification of El Niño occurrences of the last 50 years through departures from normal SST and upwelling conditions (Linsley et al., 1991; Shen et al. 1992a, b; Cole et al., 1992). After the reliability of this type of record has been carefully established, there is much expectation for correlation of coral cores spanning several centuries and obtained from widely separated localities across the whole Pacific basin. Actually, long cores from reef corals on both sides of the equatorial Pacific may provide in a near future the key proxy record of ENSO in the last few centuries.

Holocene and late Quaternary events

Marine varves and sedimentary records

Marine depositional processes may record with a good accuracy short-term oceanic/climatic alterations, provided that there is a combination of a high and stable sedimentation rate, a significant climatic signal and a subsequent preservation of the sequence. Such exceptional conditions have not yet been found offshore western South America, although laminated sediments of Plio-Quaternary age observed on the Peruvian margin are currently studied (Kemp and Brodie, 1992). Marine varves that comply with the above mentioned requisites are reported from off-California (notably the Santa Barbara Basin) and in the Gulf of California (Guaymas Basin) (Soutar and Crill, 1977; Anderson et al., 1987; Baumgartner et al., 1985, 1991a, b). In these two favorable regions, calibration studies carried on the upper part of hydraulic piston cores showed that the high-resolution sedimentary sequences record environmental changes indirectly related to El Niño episodes (Baumgartner et al., 1985, 1989; Weinheimer et al., 1986; Anderson et al., 1989; Gorsline and Christensen, 1992). In these sequences, the ENSO events are recognized by indicators of reduced productivity (^{13}C-depleted phytoplankton: Schimmelmann and Tegner, 1991), or variations in radiolarian (Ciccateri and Casey, 1991; Weinheimer et al., 1986; Weinheimer, 1991) and planktonic foraminiferan assemblages (Earley et al., 1991).

Another recently developed method that is able to provide an annually resolved record of oceanic temperatures is based on the degree of alkenone unsaturation (U^{K}_{37} values) (McCaffrey et al., 1989, 1990). According to studies offshore California (Santa Barbara Basin) and preliminary work on the Peruvian shelf, alkenone concentrations in recent sediments record SST variations of the order of 1°C that correlate with El Niño events during the 20th century (Farrington et al., 1984; Kennedy and Brassell, 1992).

Flood deposits

In the valley of Río Casma (9°S, 400 km NNW of Lima), where current precipitation does not exceed 5 mm/yr, Wells (1987, 1990) distinguished 18 Holocene flood events and a few late Pleistocene flood remnants. Thirteen out of the 18 Holocene flood deposits were formed in the last 3200 yrs. Wells (1990) correlated two flood events (radiocarbon-dated AD 1750 ± 34, mean value of ten clustered results) and the 1728 and 1791 events of the historical sequence of El Niño

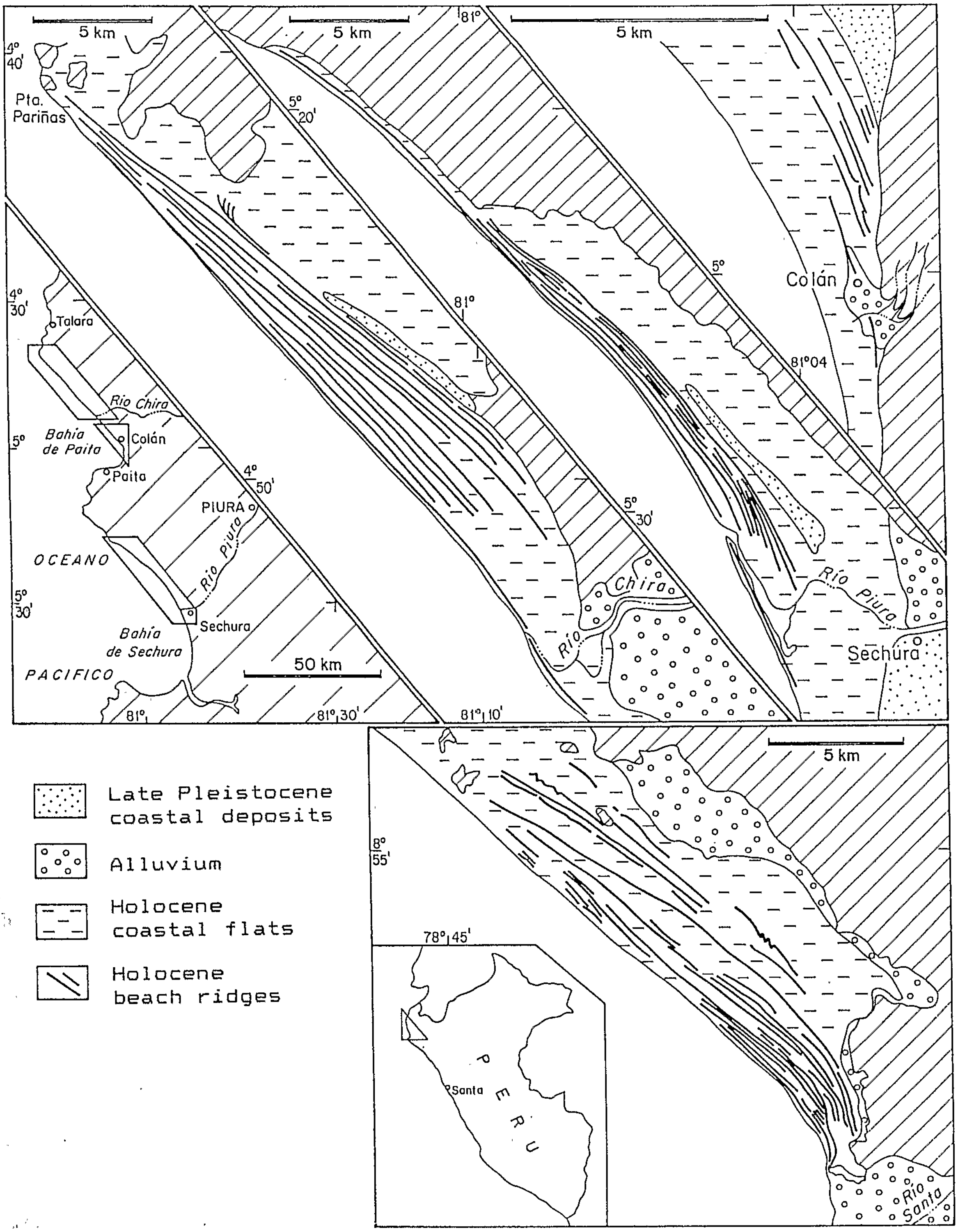

Fig. 3. Location of the major sequences of Holocene beach ridges in northern Peru. The three northernmost sequences, that all comprise 8–10 ridges, record the high runoff and large sediment supply of the Chira and Piura rivers provoked by particularly heavy rains that occurred during very strong El Niño events, in the second half of the Holocene. See Fig. 4 for more details on the Chira and Colan sequences. The Santa beach ridge sequence is less directly related to El Niño effects (see text).

(Quinn et al., 1987) (Table 1). Another correlation was attempted between a flood deposit dated AD 1330 ± 35 and the historical Naylamp flood (Nials et al., 1979; Craig and Shimada, 1986; Pozorski, 1987). Two other flood deposits (AD 16 ± 163, 1240 ± 45 BC) were tentatively correlated with transitions between archaeological periods. The exceptional heavy rains and large floods which occurred during past El Niño events provoked much damage in the irrigation systems of the Peruvian coastal desert and thus played a major role in the land use and political history of the region (Kosok, 1965; Nials et al., 1979; Moseley et al., 1981, 1992; Pozorski, 1987). Consequently, the archeology played also an important role in the identification of former climatic anomalies in coastal Peru.

According to Wells' (1990) study, the mean frequency of major El Niño events during the last 7000 yrs (i.e. since the Holocene high sealevel maximum) is of the order of one episode every 1000 yr, although many more flooding events were registered in the last few thousand years. For the last 40,000 yrs, Wells (1987) had estimated a total number of about a hundred El Niño events, based on the number of flood deposits preserved in the arid north central Peruvian coast.

The evaluation of relative intensity of past El Niño events on basis of flood evidence is certainly not straightforward, but may be attempted in some cases. Combined geomorphological, geological and archaeological data from coastal Peru seem to indicate that three or four unusually strong events (= as strong, or stronger, than the 1925 and 1982–1983 episodes) occurred in the last 2500 yr or so. Similar preliminary results are obtained from stratigraphic studies in the lower Magdalena Basin of northern Columbia (Dueñas, 1992) and in eastern Amazonia (Absy, 1979; Perota, 1992; Martin et al., 1992a, 1992b) but in these regions El Niño major events are recorded as drought episodes. Undoubtedly, it would be most useful to firmly establish (or disclose) this kind of teleconnections based on river floods/droughts within South America, with the help of precise radiochronological determination. It would be of much value to determine the time scale (a few years or decades/centuries?) of these short-term major climatic anomalies.

Lacustrine cores

The absence of lakes in the arid northwestern Peru is unfortunate since it prevents us from obtaining lacustrine core data in the most sensible area. However, a preliminary study in the Ecuadorian Lake Yambo, located in an intra-andean semi-arid depression, that is affected by the large rainfalls accompanying strong El Niño events showed major salinity variations during the last 2500 yr (Steinitz-Kannan et al., 1992). The diatom record is interpreted to register the strongest historical El Niño events and about 15 older episodes (pre-AD 1578) (Steinitz-Kannan et al., 1992). Other lakes from western South America may yield comparable data and should be investigated (Markgraf, 1989; Markgraf et al., 1992).

The High Andes and altiplano lakes, like Titicaca, may record level lowering during strong El Niño events. Holocene fluctuations of Bolivian lake levels are currently studied, notably through detailed ostracod analysis (Mourguiart, 1987; Mourguiart and Roux, 1990).

Beach ridge sequences of northern Peru

Along the northern coast of Peru, Holocene beach-ridge sequences may record major El Niño events that occurred in the last few thousands years. Heavy rainfalls, exceptional runoff, largely increased sediment supply of coastal rivers, together with rough sea conditions and short-lived sea-level elevation, all processes that characterize strong El Niño events in northern Peru, are also favorable to the formation of beach ridge sequences. Three of these coastal features are located at the mouth of the three major rivers of northern Peru (Santa, Chira and Piura), downdrift from the northbound longshore drift (Fig. 3) (Richardson, 1983; Sandweiss, 1986; Rollins et al., 1986; Wells, 1988; Macharé and Ortlieb, 1990; DeVries and Wells, 1990; Moseley et al., 1992). In a fourth case, at Colan (5°S, 10 km NW of Paita), a sequence of 8 ridges is preserved at the foot of a 70-m high abandonned seacliff. The ridges are formed by shingles derived from a conglomerate unit that crops out in the upper part of the dead seacliff (Ortlieb et al., 1989, 1992; Macharé and Ortlieb, 1990). In this particular case, the erosion of the pebbles, their transport to former shorelines and, finally their accumulation as beach-ridges above the sandy strandplain, imply the co-occurrence of heavy rains (strong enough to erode the conglomerate bed) and of nearshore energetic conditions and higher sealevel that is only met during very strong El Niño events (Ortlieb et al., 1989, 1992).

Chronological analyses of fossil shells and archaeological charcoal in the two northernmost Peruvian beach-ridge sequences (Fig. 4, Table 2),

TABLE 2

Radiocarbon dates from northern Peru sequences of beach ridges, at Colan and north of the Chira River mouth (simplified from Ortlieb et al., 1992), for location see Figs. 3 and 4. In the beach ridges at Colan, the dated material are shells and reworked small charcoal remains that were sedimented in the ridges: thus they pre-date the ridge formation. In the Chira sequence, the geochronological data are from midden shells and archaeological hearth material (associated shells and charcoal, coming from the same hearth, and thus supposedly contemporaneous, are in bold) that post-dates the ridge formation (see discussion in Ortlieb et al., 1992).

TABLE 2A
Chira sequence of beach-ridges

Beach-ridge#		Nature of sample	Measured ^{14}C age (B.P.)	Normalized ^{14}C age (yr B.P.)
Ortlieb et al. 1992	Richardson, 1983			
"J"	IX	**shells**	4210 ± 40	4630 ± 40
		charcoal	4570 ± 50	4540 ± 50
		shells	3230 ± 40	3640 ± 40
		charcoal	4485 ± 80	
		charocal	4255 ± 65	
		charcoal	3985 ± 80	
"K"	VIII	**shells**	3310 ± 40	3720 ± 40
		charcoal	3520 ± 50	3490 ± 50
		shells	3060 ± 30	3480 ± 30
		charcoal	3490 ± 80	
Interridge		in situ shells	3410 ± 40	3840 ± 40
		in situ shells	3370 ± 40	3790 ± 40
"L"	VII	**shells**	3210 ± 35	3620 ± 35
		charcoal	3190 ± 45	3160 ± 45
		shells	2610 ± 35	3020 ± 35
		shells	2600 ± 150	3030 ± 150
		shells	3500 ± 160	
"M"	VI	**shells**	2540 ± 40	2950 ± 40
		charcoal	2760 ± 40	2730 ± 40
		charcoal	2685 ± 105	
		charcoal	2485 ± 70	
	V	charcoal	1955 ± 100	
	IV	shells	1550 ± 110	
	III	charcoal	1405 ± 75	
		charcoal	1305 ± 100	
	II	charcoal	805 ± 60	
Last ridge	I	**shells**	460 ± 40	870 ± 40
		charcoal	380 ± 40	350 ± 40

TABLE 2B
Colan sequence of beach-ridges

Beach-ridge#	Nature of sample	Measured ^{14}C age (B.P.)	Normalized ^{14}C age (B.P.)
#8	charcoal	3170 ± 300	3130 ± 300
	shells	2890 ± 250	3300 ± 250
	shells	3020 ± 250	3450 ± 250
#8N	charcoal	3340 ± 45	3310 ± 45
	shells	3210 ± 40	3630 ± 40
	shells	3210 ± 50	3640 ± 50
#7	shells	2760 ± 210	3190 ± 210
#5	charcoal	2550 ± 490	2520 ± 490
	shells	2510 ± 250	2920 ± 250
#4	shells	2150 ± 170	2560 ± 170
#3	charcoal	2080 ± 540	2050 ± 540
	charcoal	2040 ± 380	2010 ± 380
	shells	2170 ± 300	2600 ± 300
#3a	shells	1660 ± 180	2090 ± 180
#2	shells	1450 ± 180	1880 ± 180
#1N	shells	960 ± 230	1390 ± 230
#1S	shells	790 ± 210	1200 ± 210
N flat	in situ shells	730 ± 190	1150 ± 190
shell-line	shells	180 ± 160	590 ± 160
and site C	charcoal	620 ± 290	590 ± 290

in the core of the El Niño region, strongly suggest that these coastal features formed at the same time in the course of the last 4500 yr, with an approximate recurrence of 400–500 yr (Ortlieb et al., 1989, 1992; Macharé et al., 1992). Limitations of the radiocarbon method (involving problems of reservoir effect possibly related to upwelling anomalies) unfortunately prevented a precise ^{14}C age determination of the formation of each ridge. The long sandy beach ridges that formed north of the Chira River mouth and the smaller shingle ridges of Colan are interpreted to constitute two types of coastal features associated with very strong El Niño episodes: the Chira ridges reflect episodes of exceptional sand discharge of the Chira River following heavy inland rains, while the Colan ridges result from episodes of sudden availability of pebbles fallen downcliff also related to very strong rains. We infer that, in both cases, the ridges record the strongest El Niño events of the second half of the Holocene (Macharé and Ortlieb, 1990; Ortlieb et al., 1992). The duration of such episodes and their strength with respect to the historical intensity scale (very strong *vs.* "super" or "mega" El Niños) are still under debate (Macharé et al., 1992; Martin et al., 1992a, 1992b; Mörner, in press).

The relationship between former El Niño occurrences and the beach ridge sequence formed at the mouth of the Santa River, on the central coast of Peru, are more controversial (Sandweiss et al., 1983; Sandweiss, 1986; Wells, 1988; DeVries and Wells, 1990; Moseley et al., 1992; Macharé et al., 1992). No clear indication was obtained that the ridges formed during El Niño events: the cobble ridges indicate discrete episodes of high energy in the nearshore area during the last 4000 yr, but there may be no direct time-correlation between the pulses of coarse-grained sediment supply at the river mouth

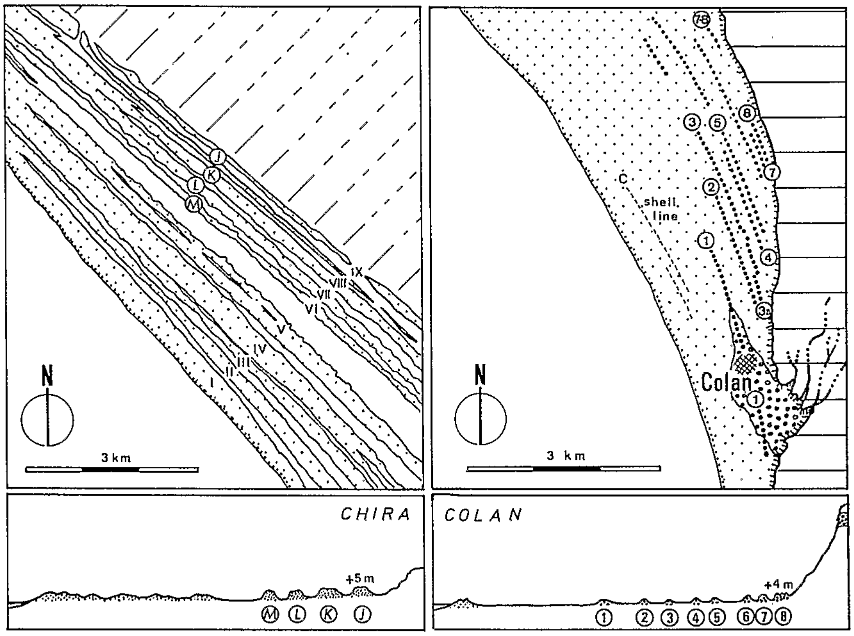

Fig. 4. Beach ridge sequences on both sides of the Chira River mouth, northern Peru (for location see Fig. 3): sketch maps and cross-sections, with identification of the ridges indicated in Table 2. At Chira, north of the river mouth, the ridges are made of reworked fluvial sand, and were protected from erosion by a cover of midden shells (see chronological data, Table 2). At Colan, the ridges are largely made of pebbles inherited from a conglomerate bed that crops out at about +50 m up the abandonned seacliff. Although the beach ridges differ by their size (length, height, width), sediment nature, and formation processes, it is interpreted that they were formed coevally, during the strongest El Niño events of the last 4500 yrs.

and El Niño events. The Santa River regime is much less controlled by El Niño precipitation than the northern Peru rivers of Chira and Piura.

Plio-Pleistocene events

The modern oceanic circulation of the Pacific Basin has existed for about the last 3 m.y., namely since the final closure of the Isthmus of Panama (Keigwin, 1978; Romine, 1982; Keller et al., 1989) and after the thermal gradients were set up across the Pacific (Romine, 1982; Hays et al. 1979). On paleogeographical grounds, then, the Southern Oscillation may have been active since the late Pliocene. On another hand, radiolarian data from the US Pacific coast suggested that El Niño-like episodes may have existed since 8 m.y. and that proper (?) El Niño events were apparently registered off California for the last 5.5 m.y. (Nelson, 1989). Pre-late Quaternary ENSO activity still remains to be assessed with high-resolution sedimentary records.

What happened with the ENSO cycle during the glacial/interglacial climatic fluctuations of the Pleistocene? Some authors hypothesized that during glacial sea-level lowstands, the ocean/atmosphere conditions in the Indonesian region prevented the functioning of the ENSO system (Quinn, 1971; Salinger, 1981). Several oceanographic and palaeoclimatic indicators from the inter-tropical Pacific Ocean and surrounding areas seemed to confirm that the last glacial period was characterized by a reduction of the monsoonal rains, a decrease of the upwelling, drier atmospheric conditions and more generally a reduction of the Southern Oscillation (Colinvaux, 1972, 1984; CLIMAP members, 1981; Romine and Moore, 1981; Rea et al., 1986; COHMAP members, 1988). Off California, late Quaternary marine varves in the oxygen-minimum zone (at ca. −700 m depth), that suggest increased upwelling and high productivity, were interpreted as indicative of an anti-El Niño regime (Anderson et al., 1990). From 25,000 yrs records of silicoflagellate assemblages of laminated sediments in the Gulf of California, it has been inferred that El Niño events were stronger and/or more frequent in the last 8000 yr (Murray, 1992).

Limited data exist from the Peruvian continental margin. At sites 680, 681 and 686 of ODP Leg 112 off central Peru, advanced hydraulic piston cores were obtained and provided a productivity and coastal upwelling record of the last 400,000 yrs on decadal and centennial time-scales; according this record, upwelling activity was maximal during interglacial stages 1, (late) 5 and 7 and during the interstadial 3, but also partly during glacial stages 6 and 8 (Oberhänsli et al., 1990). Nevertheless, the greater than decadal resolution of the record and the fact that no data is available for the last 100 yr (thus impeding proper calibration), hamper a positive recognition of El Niño activity.

It seems reasonable to infer from these sparse data that the ENSO system was probably operative during middle–late Pleistocene interglacials and warm interstadials and inversely that it was largely reduced, or totally lacking, during glacial maxima (Colgan, 1989; Ortlieb and Macharé, 1989; Anderson et al., 1990; Mörner, 1992, in press; Markgraf et al., 1992).

Conclusion

Historical, archaeological and geological studies documenting past El Niño events have greatly increased during the last years, as a result of growing interest in this major oceano-climatic anomaly. Recent occurrences of the El Niño phenomenon, including the very strong 1982–1983 episode, provided the opportunity to appreciate the range of variability of the biological and physical (not to mention societal) impacts of oceanic and meteorologic alterations along the Pacific coast of South America.

In the case of sedimentary or ice cores, recent work concentrated on the identification of the physical, chemical and bio-geochemical variables that reflect characteristic El Niño alterations of the environment. This was done through comparisons and "calibrations" with instrumental records of climatic and oceanographic parameters available for the last few decades, before the data could be extrapolated in the past. For the relatively short duration of the El Niño phenomenon (from a geological point of view) and because of the variability in the intensity of the phenomena and processes from one event to the other, the task is uneasy and requires records with a high (seasonal) resolution and very sensitive variables. Necessarily, these prerequisites limit the search to some types of record, namely: ice cores, tree rings, coral reefs and varved sediments and furthermore imply that only a small number of sampling locations are suitable.

The western coast of South-America is the area of the globe where the El Niño anomaly was first defined and where the intensity of modern events is currently determined. Quite naturally, thus, it is viewed as an appropriate area for recurrence and palaeo-intensity studies of the ENSO phenomenon. Nevertheless, this short review indicates that, for diverse methodological reasons, marine varves and dendroclimatic records from western North America have yielded up to now more reliable results than South America. In South America and in the eastern Pacific, it seems that the glaciological and coral reef records present the best potential for the reconstruction of palaeoclimatic and palaeoceanographic anomalies on a century scale. A combination of these sets of records should constitute a solid basis for a chronological sequence of El Niño events. The establishing of a standard sequence will still require substantial efforts, since the coral data for the last few centuries only begin to be available and because we need to improve our understanding of the atmospheric circulation patterns over South America in relationship with the Quelccaya ice cap formation.

The unraveling of interferences between climate anomalies at distinct time scales, like the Little Ice Age and El Niño, still requires further investigation. Available proxy records provide contradictory indications regarding changes in the recurrence and strength of the El Niño events during the LIA, with respect to the last century: some data suggest that the variability of El Niño remained unchanged during and after the LIA, while other proxies seem to indicate that it differed significantly. We consider that this important point should be resolved through a close scrutinization of biological and physico-chemical records, followed by cross-correlations of these data.

It was stressed here that the classical El Niño chronology of the last 450 yr based on documentary sources (Quinn et al., 1987) apparently involved more numerous and stronger, events than those that really occurred (particularly in the 16–18th centuries) and thus that it biased earlier calibrations of other types of ENSO records. The El Niño chronology published in 1987 should not be accepted any more at face value, without some caution, especially for recurrence studies of the phenomenon, or for straightforward calibration of other proxies.

For the time span of the late Quaternary–Holocene, relevant palaeoclimatic data are still very fragmentary. The available information comes from flood deposits, beach ridges, short sequences of laminated sediments, lake level fluctuations or faunal associations. This kind of discrete record is useful but needs to rely on precise dating, so that special efforts should be made in this direction (AMS radiocarbon dating and other isotopic methods). Catastrophic events related to intense precipitation, or to important alterations of the nearshore (or offshore, or inland) environment and which left geological remnants, offer opportunities to evaluate paleo-intensities of El Niño events. Evidences on short term climate/environmental alterations are also of special interest in establishing former teleconnections between areas of South America which registered in distinct manners the El Niño phenomenon.

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References

Absy, M.L., 1979. A palynological study of Holocene sediments in the Amazonas Basin. Thesis. Univ. Amsterdam, 103 pp.

Aceituno, P., 1987. On the interannual variability of South American climate and the Southern Oscillation. Thesis. Univ. Wisconsin, Madison, 128 pp.

Aceituno, P., 1988. On the functioning of the Southern Oscillation in the South American sector. Part 1: Surface climate. Mon. Weather Rev., 116: 505–524.

Allan, R.J., Nicholls, N., Jones, P.D. and Butterworth, I.J., 1991. A further extension of the Tahiti–Darwin SOI, early ENSO events and Darwin pressure. J. Climate, 4: 743–749.

Anderson, R.Y., 1990. Solar cycle modulations of ENSO: A possible source of climatic change. In: J.L. Betancourt and A. McKay (Editors), Proc. 6th Pac. Climate (PACLIM) Workshop. Calif. Dep. Water Resour. Tech. Rep., 23: 77–82.

Anderson, R.Y., Gardner, J.V. and Hemphill-Haley, E., 1987. Persistent late Pleistocene–Holocene upwelling and varves off the coast of California. Quat. Res., 28: 307–313.

Anderson, R.Y., Gardner, J.V. and Hemphill-Haley, E., 1989. Variability of the late Pleistocene–Holocene oxygen-minimum zone off northern California. In: D.H. Peterson (Editor), Aspects of Climate Variability in the Pacific and Western Americas (Geophys. Monogr., 55). Am. Geophys. Union, Washington, DC, pp. 75–84.

Anderson, R.Y., Linsley, B.K. and Gardner, J.V., 1990. Expression of seasonal and ENSO forcing in climatic variability at lower than ENSO frequencies: evidence from Pleistocene marine varves off California. Palaeogeogr., Palaeoclimatol., Palaeoecol., 78: 287–300.

Angell, J.K., 1988. Impact of El Niño on the delineation of troposheric cooling due to volcanic eruptions. J. Geophys. Res., 93 (D4): 3697–3704.

Arntz, W.E., 1986. The two faces of El Niño 1982–83. Meeresforschung, 31: 1–46.

Arntz, W.E. and Tarazona, J., 1990. Effects of El Niño 1982–83 on benthos, fish and fisheries off the South American Pacific coast. In: P.W. Glynn (Editor), Global Ecological Consequences of the 1982–83 El Niño-Southern Oscillation (Oceanogr. Ser., 52). Elsevier, Amsterdam, pp. 323–360.

Barber, R.T. and Chavez, F.P., 1983. Biological consequences of El Niño. Science, 222: 1203–1210.

Barnett, T.P., 1981. Statistical relations between ocean/atmosphere fluctuations in the Tropical Pacific. J. Phys. Oceanogr., 11: 1043–1058.

Barnett, T.P., 1990. A solar–ocean relation: Fact or fiction? Geophys. Res. Lett., 16: 803–806.

Baumgartner, T.R., Ferreira-Bartrina, V., Schrader, H. and Soutar, A., 1985. A 20-year varve record of siliceous phytoplankton variability in the central Gulf of California. Mar. Geol., 64: 113–129.

Baumgartner, T.R., Michaelsen, J., Thompson, L.G., Shen, G.T., Soutar, A. and Casey, R., 1989. The recording of interannual climatic change by high-resolution natural systems: Tree-rings, coral bands, glacial ice layers, and marine varves. In: D. Peterson (Editor), Aspects of Climatic Variability in the Pacific and Western Americas (Geophys. Monogr., 55). Am. Geophys. Union, Washington, DC, pp. 1–14.

Baumgartner, T.R., Ferreira-Batrina, V., Cowen, J. and Soutar, A., 1991a. Reconstruction of a 20th century varve chronology from the central Gulf of California. In: J.P. Dauphin and B. Simoneit (Editors), The Gulf and Peninsular Province of the Californias. Am. Assoc. Pet. Geol. Mem., 47: 603-616.

Baumgartner, T.R., Ferreira-Batrina, V. and Moreno-Hentz, P., 1991b. Varve formation in the central Gulf of California: a reconsideration of the origin of the dark laminae from the 20th century record. In: J.P. Dauphin and B. Simoneit (Editors), The Gulf and Peninsular Province of the Californias. Am. Assoc. Pet. Geol. Mem., 47: 617–635.

Beck, J.W., Edwards, R.L., Ito, E., Taylor, F.W., Récy, J., Rougerie, F., Joannot, P. and Hénin, C., in press. Sea surface temperature from coral skeletal Sr/Ca ratios. Science.

Berlage, H.P., 1966. The Southern Oscillation and world weather. K. Ned. Meteorol. Inst. Meded. Verh., 88: 1–52.

Bjerknes, J., 1969. Atmospheric teleconnections from the equatorial Pacific. Mon. Weather Rev., 97: 163–172.

Boninsegna, J.A. and Holmes, R.H., 1985. *Fitzroya cupressoides* yields 1534-year long South American chronology. Tree-Ring Bull., 45: 37–41.

Bormann, F.H. and Berlyn, G. (Editors) 1981. Age and growth rate of tropical trees: New directions for research. School Forest. Environ. Stud., Yale Univ. Bull., 94.

Cane, M.A. and Zebiak, S.E., 1985. A theory for El Niño and Southern Oscillation. Science, 228: 1085–1087.

Carriquiri, J.D., Risk, M.J. and Schwarcz, H.P., 1988. Timing and temperature record from stable isotopes of the 1982–83 El Niño warming event in eastern Pacific corals. Palaios, 3: 359–364.

Caviedes, C.N., 1973. Secas and El Niño: Two simultaneous climatical hazards in South America. Proc. Assoc. Am. Geogr., 5: 44–49.

Caviedes, C.N., 1975. El Niño 1972: its climatic ecological, human and economic implications. Geogr. Rev., 65: 494–509.

Caviedes, C.N., 1984. El Niño 1982–83. Geogr. Rev., 74: 267–290.

Ciccateri, A.J. and Casey, R.E., 1991. Phaeodarian radiolarian evidence for bottom water oxygen concentration fluctuations during El Niño and anti-El Niño periods. Geol. Soc. Am. Abstr. Progr., 23, p. A36.

CLIMAP Project Members, 1981. Seasonal reconstruction of the earth's surface at the last glacial maximum. Geol. Soc. Am. Map Chart Ser., MC–36.

COHMAP Project Members, 1988. Climatic changes of the last 18,000 yrs: Observations and model simulations. Science, 241: 1043–1052.

Cole, J.E. and Fairbanks, R.G., 1990. The Southern Oscillation recorded in the $\delta^{18}O$ of corals from Tarawa Atoll. Paleoceanography, 5: 669–683.

Cole, J.E., Fairbanks, R.G. and Shen, G.T., 1992. Annual–decadal climate variability monitored by equatorial Pacific corals. In; Am. Quat. Assoc., 12th Biennial Meet., Davis, CA, Aug. 1992 Progr. Abstr., pp. 8–9.

Cole, J.E., Shen, G.T., Fairbanks, R.G. and Moore, M., in press. Coral monitors of El Niño/Southern Oscillation dynamics across the Equatorial Pacific. In: H.F. Diaz and V. Markgraf (Editors), El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation.

Colinvaux, P.A., 1972. Climate and the Galapagos Islands. Nature, 240: 17–20.

Colinvaux, P.A., 1984. The Galapagos climate: Past and present. In: R. Perry (Editor), Key Environments, Galapagos. Pergamon Oxford, pp. 55–70.

Craig, A.K. and Shimada, I., 1986. El Niño flood deposits at Batán Grande, northern Peru. Geoarcheology, 1: 29–38.

Depetris, P. and Kempe, S., 1990. The impact of the El Niño 1982 event on the Parana River, its discharge and carbon transport. Palaeogeogr., Palaeoclimatol., Palaeoecol. (Global Planet. Change Sect.), 89: 239–244.

Deser, C. and Wallace, J.M., 1987. El Niño events and their relation to the Southern Oscillation: 1925–86. J. Geophys. Res., 92 (C13): 14,189–14,196.

Devries, T.J., 1987. A review of geological evidence for ancient El Niño activity in Peru. J. Geophys. Res., 92(C13): 14,471–14,479.

Devries, T.J. and Wells, L.E., 1990. Thermally-anomalous Holocene molluscan assemblages from coastal Peru: evidence for paleogeographic, not climate change. Palaeogeogr., Palaeoclimatol., Palaeoecol., 81: 11–32.

Druffel, E.R.M., 1985. Detection of El Niño and decade time scale variations in sea surface temperature from banded coral records: Implications for the carbon dioxide cycle. In: The Carbon Cycle and Atmospheric CO_2: Natural Variations, Archean to Present (Geophys. Monogr., 32). Am. Geophys. Union, Washington, DC, pp. 111–122.

Dueñas, H., 1992. The paleo ENSO record in the lower Magdalena Basin, Colombia. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 81–85.

Dunbar, R.B. and Wellington, G.M., 1981. Stable isotopes in a branching coral monitor seasonal temperature variation. Nature, 293: 453–455.

Earley, P.J., Sturz, A., Lowery, M.S., Ciccateri, A.J. and

Casey, R.E., 1991. Radiolarian, planktonic foraminiferan and physical and chemical evidence in support of the initiation of the anticipated 1991 El Niño off Southern California. Geol. Soc. Am. Abstr. Progr., 23, p. A36.

Eguiguren, V., 1894. Las lluvias en Piura. Bol. Soc. Geogr. Lima, 4: 241–258.

Enfield, D.B., 1987. Progress in understanding El Niño. Endeavour, 11: 197–204.

Enfield, D.B., 1988. Is El Niño becoming more common? Oceanography, 1: 23–27.

Enfield, D.B., 1989. El Niño, past and present. Rev. Geophys., 27: 159–187.

Enfield, D.B. and Cid, L., 1990. Statistical analysis of El Niño/Southern Oscillation over the past 500 years; low frequency in El Niño/Southern Oscillation. TOGA Notes, 1: 1–4.

Enfield, D.B. and Cid, L., 1991. Low-frequency changes in El Niño/Southern Oscillation. J. Climate, 4: 1137–1146.

Fairbridge, R.W., 1990. Solar and lunar cycles embedded in the El Niño periodicities. Cycles, May: 66–72.

Flohn, H., 1986. Indonesian droughts and their teleconnections. Berl. Geogr. Stud., 20: 251–256.

Francou, B. and Pizarro, L., 1985. El Niño y la sequía en los altos Andes Centrales (Perú y Bolivia). Bull. Inst. Fr. Etud. Andines, Lima, 14: 1–18.

Fritts, H.C., 1976. Tree Rings and Climate. Academic Press, New York, 567 pp.

Gorsline, D.S. and Christensen, C., 1992. El Niño-Southern Oscillation signals in primary sediment laminae sequences in Santa Monica Basin, California Continental Borderland. In: Am. Geophys. Union 1992 Ocean Sci. Meet. EOS, 72 (51 suppl.), p. 53 (abstract).

Graham, N.E. and White, W.B., 1988. The El Niño cycle: a natural oscillator of the Pacific Ocean–atmosphere system. Science, 240: 1293–1302.

Hamilton, K. and García, R.R., 1986. El Niño/Southern Oscillation events and their associated midlatitude teleconnections 1531–1841. Bull. Am. Meteorol. Soc., 67 (11): 1354–1361.

Handler, P., 1984. Possible association of stratospheric aerosols and El Niño type events. Geophys. Res. Lett., 11: 1121–1124.

Handler, P., 1986. Possible association between the climatic effects of stratospheric aerosols and sea surface temperature in the eastern tropical Pacific ocean. J. Climatol., 5: 31–41.

Handler, P., Andsager, K., Spencer, M.J., Mayewski, P., Lyons, W.B., Taylor, K. and Holdsworth, G., 1990. The El Niño events of 1939, 1941, and 1943–44 and their relationship to acidity peaks in the Greenland ice cores. EOS, 71, p. 1232 (abstract).

Handler, P. and Andsager, K., 1991. Pinatubo, El Niño and California rainfall. EOS, 72, p. 65 (abstract).

Hansen, J.E., 1991. Potential climate impact of Mount Pinatubo eruption. EOS, 72, p. 65 (abstract).

Hanson, K., Brier, G.W. and Maul, G.A., 1989. Evidence of significant non random behavior in the recurrence of strong El Niño between 1525 and 1988. Geophys. Res. Lett., 16: 1181–1184.

Hastenrath, S. and Heller, L., 1977. Dynamics of climatic hazards in northeast Brazil. Q.J. R. Meteorol. Soc., 10: 77–92.

Hays, P.E., Pisias, N.G. and Roelofs, A.K., 1979. Paleoceanography of the eastern equatorial Pacific during the Pliocene: a high-resolution radiolarian study. Paleoceanography, 4: 57–73.

Hirono, M., 1988. On the trigger of El Niño-Southern Oscillation by the forcing of early El Chichón volcanic aerosols. J. Geophys. Res., 93 (D5): 5365–5384.

Hirono, M., Shibata, T. and Fujiwara, M., 1985. A possible relationship of volcanic aerosol variations with El Niño Southern Oscillation—Lidar observations of volcanic aerosols in the stratosphere. J. Meteorol. Soc. Jap., 63: 303–310.

Hocquenghem, A.M. and Ortlieb, L., 1990. Pizarre n'est pas arrivé au Pérou durant une année El Niño. Bull. Inst. Fr. Etud. Andines, Lima, 19 (2): 327–334.

Hocquenghem, A.M. and Ortlieb, L., 1992. Eventos El Niño y lluvias anormales en la costa del Perú: siglos XVI–XIX. Bull. Inst. Fr. Etud. Andines, Lima, 21 (1): 197–278.

Horel, J.D. and Wallace, J.M., 1981. Planetary-scale atmospheric phenomena associated with the Southern Oscillation. Mon. Weather Rev., 109: 813–829.

Isdale, P., 1984. Fluorescent bands in massive corals record centuries of coastal rainfall. Nature, 310: 578–579.

Juillet-Leclerc, A., Labeyrie, L.D. and Reyss, J.L., 1991. Temperature variability in the Gulf of California during the last century: a record of the recent strong El Niño. Geophys. Res. Lett., 18: 1889–1892.

Keigwin, L.D., 1978. Pliocene closing of the Isthmus of Panama based on biostratigraphic evidence from nearby Pacific Ocean and Caribbean Sea cores. Geology, 6: 630–634.

Keller, G., Zenker, C.E. and Stone, S.M., 1989. Late Neogene history of the Pacific-Caribbean gateway. J. South Am. Earth Sci., 2: 73–108.

Kemp, A.E.S. and Brodie, R.A., 1992. The record of variability from laminated sediments of the Peru coastal upwelling zone. In: Am. Geophys. Union 1992 Ocean Sci. Meet. EOS, 72 (51 suppl.), p. 53 (abstract).

Kennedy, J.A. and Brassell, S.C., 1992. Molecular records of twentieth-century El Niño events in laminated sediments from the Santa Barbara Basin. Nature, 357: 62–64.

Kiladis, G.N. and Diaz, H.F., 1989. Global climatic anomalies associated with extremes in the Southern Oscillation. J. Climate, 2: 1069–1090.

Kosok, P., 1965. Life, Land and Water in Ancient Peru. Long Island Univ. Press, New York, 264 pp.

Kousky, V.E., Kagano, M.T. and Cavalcanti, I.F.A., 1984. A review of the Southern Oscillation: Oceanic–atmospheric circulation changes and related rainfall anomalies. Tellus, 36A: 490–504.

Labitzke, K. and Van Loon, H., 1990. Associations between the 11-year solar cycle, the Quasi Biennial Oscillation and the atmosphere: A summary of recent work. Philos. Trans. R. Soc. London, A330: 577–589.

LaMarche, V.C., Holmes, R.L., Dunwiddie, P.W. and Drew, L.G., 1979a. Tree-ring chronologies of the Southern Hemisphere. 1. Argentina (Chronol. Ser., 5). Lab. Tree-Ring Res., Univ. Arizona, Tucson, AZ, 69 pp.

LaMarche, V.C., Holmes, R.L., Dunwiddie, P.W. and Drew, L.G., 1979b. Tree-ring chronologies of the Southern Hemisphere. 2. Chile (Chronol. Ser., V). Lab. Tree-Ring Res., Univ. Arizona, Tucson, 43 pp.

Lau, K.M. and Chan, P.H., 1988. Intraseasonal and interannual variations of tropical convection: Possible link between the 40–50 day oscillation and ENSO? J. Atmosph. Sci., 45: 506–521.

Lea, D.W., Shen, G.T. and Boyle, E.A., 1989. Coralline barium records temporal variability in equatorial Pacific upwelling. Nature, 340: 373–375.

Linn, L.J., Delaney, M.L. and Druffel, E.R.M., 1990. Trace metals in contemporary and seventeenth-century Galapagos coral: Record of seasonal and annual variations. Geochim., Cosmochim. Acta, 54: 387–394.

Linsley, B.K., Dunbar, R.B., Mucciarone, D.A. and Wellington, G.M., 1991. Seasonal to decadal-scale oceanographic variability recorded by eastern Pacific corals over the last 200+years. EOS, 72: 66–67 (abstract).

Lough, J.M. and Fritts, H.C., 1985. The Southern Oscillation and tree rings: 1660–1961. J. Climatol. Appl. Meteorol., 24: 1069–1090.

Lough, J.M. and Fritts, H.C., 1990. Historical aspects of El Niño/Southern Oscillation: Information from tree rings. In: P.W. Glynn (Editor), Global Ecological Consequences of the 1982–83 El Niño–Southern Oscillation (Oceanogr. Ser., 52). Elsevier, Amsterdam, pp. 285–321.

Lowrie, A., 1992. Sunspot and El Niño correlation. In: Am. Geophys. Union 1992 Ocean Sci. Meet. EOS, 72 (51 suppl.), p. 56 (abstract).

Macharé, J. and Ortlieb, L., 1990. Global change studies in northwestern Peru: a high potential for records of former El Niño events. Rev. Geofís., 32: 153–171.

Macharé, J. and Ortlieb, L., 1992. Recent research on records of former El Niño events in Peru. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 177–183.

Macharé, J., Ortlieb, L., Guevara, J. and Díaz, A. (Editors), 1992. Impacts of the 1982–83 and earlier El Niño events on the coast of northern Peru. In: Guidebook Fieldtrip Int. Symp. Former ENSO Phenomena in Western South America: Records of El Niño Events, Lima, 4–7 March 1992. ORSTOM-CONCYTEC, Lima, 181 pp.

Markgraf, V., 1989. Palaeoclimates in Central and South America since 18,000 BP based on pollen and lake level records. Quat. Sci. Rev., 8: 1–24.

Markgraf, V., Dodson, J.R., Kershaw, A.P., McGlone, M.S. and Nicholls, N., 1992. Evolution of late Pleistocene and Holocene climates in the circum-South Pacific land areas. Climate Dyn., 6: 193–211.

Martin, L., Absy, M., Fournier, M., Mourgiart, P., Sifeddine, A., Turcq, B. and Volkmer Ribeiro, M., 1992a. Some climatic alterations recorded in South America during the last 7000 years may be expounded by long-term El Niño-like conditions. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 187–192.

Martin, L., Absy, M.L., Flexor, J.M., Fournier, M., Mourguiart, P., Sifeddine, A. and Turcq, B., 1992b. Enregistrements de conditions de type “El Niño”, en Amérique du Sud, au cours des 7000 dernières années. C.R. Acad. Sci. Paris, 315: 97–102.

McCaffrey, M.A., Farrington, J.W. and Repeta, D.J., 1989. The impact of El Niño conditions on the geochemistry of Peru margin surface sediments. Geol. Soc. Am. Abstr. with Programs, 21(6): A5.

McCaffrey, M.A., Farrington, J.W. and Repeta D.J., 1990. The organic geochemistry of Peru margin surface sediments. J. Geochim. Cosmochim. Acta, 54: 1671–1682; 55: 483–498.

Meehl, G.A., 1989. Coupled GCM Simulations of ENSO: Implications for ENSO in the paleoclimatic record. In: H.F. Diaz and V. Markgraf (Editors), Workshop on Paleoclimatic aspects of El Niño/Southern Oscillation, Boulder, May 1990, NOAA & INSTAAR Abstr. Vol. Univ. Colorado, Boulder, pp. 38–41.

Michaelsen, J., 1989. Long-period fluctuations in El Niño amplitude and frequency reconstructed from tree-rings. In: D.H. Peterson (Editor), Aspects of Climatic Variability in the Pacific and Western Americas (Geophys. Monogr., 55). Am. Geophys. Union, Washington, DC, pp. 69–74.

Michaelsen, J., 1990. A comparison of proxy records of ENSO. In: H.F. Diaz and V. Markgraf (Editors), Workshop on Paleoclimatic aspects of El Niño/Southern Oscillation, Boulder, May 1990, NOAA & INSTAAR Abstr. Vol. Univ. Colorado, Boulder, pp. 52–54.

Mörner, N.-A., 1989. Changes in the Earth's rate of rotation on an El Niño century basis. In: F.J. Lowes et al. (Editors), Geomagnetism and Paleomagnetism. Kluwer, Dordrecht, pp. 45–53.

Mörner, N.-A., 1992. Present El Niño-ENSO events and past super-ENSO events effects of changes in the earth's rate of rotation. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 201–206.

Mörner, N.-A., in press. Present El Niño-ENSO events and past super-ENSO events. In: J. Macharé and L. Ortlieb (Editors), Registros del fenómeno El Niño y de eventos ENSO en América del Sur. Bull. Inst. Fr. Etud. Andines, Lima, 22 (1).

Moseley, M.E., Feldman, R.A. and Ortloff, C.R., 1981. Living with crises: human perception of process and time. In: M. Nitecki (Editor), Biotic Crises in Ecological and Evolutionary Time. Academic Press, New York, pp. 231–267.

Moseley, M.E., Tapia, J., Satterlee, R. and Richardson III, J.B., 1992. Flood events, El Niño, and tectonic events. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 207–213.

Mourguiart, P., 1987. Les ostracodes lacustres de l'Altiplano bolivien. Le polymorphisme, son intérêt dans les reconstitutions paléohydrologiques et paléoclimatiques de l'Holocène. Thesis. Univ. Bordeaux I, 263 pp.

Mourguiart, P. and Roux, M., 1990. Une approche nouvelle du problème posé par les reconstructions des paléoniveaux lacustres: utilisation d'une fonction de trnsfert basée sur les faunes d'ostracodes. Géodynamique, 5: 57–71.

Murphy, R.C., 1925. El Niño. Comp. Admin. Guano Bol. Lima, 10: 365–372.

Murphy, R.C., 1926. Oceanic and climatic phenomena along the western coast of South America during 1925. Geogr. Rev., 16: 26–54.

Murray, D.W., 1992. Decadal-to millennial-scale ENSO variations recorded in Gulf of California sediments. EoS, 72, p. 154 (abstract).

Nelson, C.O., 1989. California El Niños and related shifts in the California Current system from recent and fossil radiolarian records. Geol. Soc. Am. Abstr. Progr., 11, p. A228.

Newell, N.D., 1949. Geology of the Lake Titicaca Región, Perú and Bolivia. Geol. Soc. Am. Mem., 36111 pp.

Nials, F.L., Deeds, E.R., Moseley, M.E., Pozorski, S.G., Pozorski, T. and Feldman, R.A., 1979. El Niño: the catastrophic flooding of coastal Peru. Field Mus. Nat. Hist. Bull., 50 (7): 4–14 (part 1); 50 (8): 4–10 (part 2).

Nicholls, N., 1990. Historical ENSO variability in the Australasian region. In: H.F. Diaz and V. Markgraf (Editors), Workshop on Paleoclimatic Aspects of El Niño/Southern Oscillation, Boulder, May 1990, NOAA & INSTAAR Abstr. Vol. Univ. Colorado, Boulder, pp. 29–31.

Norton, D.A., 1988. Historical development of Southern Hemisphere dendrochronology. In: E.R. Cook and L. Kairiukstis (Editors), Methods of Tree-ring analysis: Applications in the Environmental Sciences. IIASA, Laxenberg, Reidel, Dordrecht.

Oberhänsli, H., Heinze, P., Diester-Hass, L. and Wefer, G., 1990. Upwelling off Peru during the last 430,000 yr and its relationship to the bottom-water environment, as deduced from coarse grain-size distributions and analyses of benthic foraminifers at holes 679D, 680B, Leg 112. In: E. Suess, R. von Huene et al. (Editors), Proc. Ocean Drilling Progr. Sci. Res., 112: 369–383.

Ochoa, N.F. and Gomez, O., 1987. Dinoflagellates as indicators of water masses during El Niño, 1982–1983. J. Geophys. Res., 92 (C13): 14,355–14,368.

Ortlieb, L. and Macharé, J., 1989. Evolución climática al final del Cuaternario en las regiones costeras del Norte peruano: breve reseña. Bull. Inst. Fr. Etud. Andines, Lima, 18: 143–160.

Ortlieb, L., Macharé, J., Fournier, M. and Woodman, R., 1989. La secuencia de cordones litorales de Colán, Piura: un registro del fenómeno "El Niño" en el Holoceno superior. Bol. Soc. Geol. Perú, Lima, 80: 107–121.

Ortlieb, L. and Macharé, J., Editors, 1992. Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, 336 pp.

Ortlieb, L., Fournier, M. and Macharé, J., 1992. Sequences of Holocene beach ridges in northern Peru: Chronological framework and possible relationships with former El Niño events. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO Records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 215–222.

Perota, C., 1992. Cambios climáticos y la ocupación prehistórica en la Amazonia. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 235–236.

Perrier, C., Hillaire-Marcel, C. and Ortlieb, L., 1992. Isotopic record of recent and paleo-El Niño events on mollusk shells from NW Peru. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO Records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 245–250.

Petersen, G., 1935. Estudios climatológicos del noroeste peruano. Bol. Soc. Geol. Perú, Lima, 7 (2): 1–142.

Philander, S.G.H., 1989. El Niño, La Niña and the Southern Oscillation (Int. Geophys. Ser.). Academic Press, San Diego, 293 pp.

Philander, S.G.H., Lau, N.C., Pacanowski, R.C. and Nath, M.J., 1989. Two different simulations of Southern Oscillation and El Niño with coupled ocean–atmosphere general circulation models. Philos. Trans. R. Soc. London, A329: 167–178.

Pittock, A.B., 1980. Patterns of climatic variation in Argentina and Chile. I: Precipitation, 1931–60. Mon. Weather Rev., 108: 1347–1361.

Pozorski, T., 1987. Changing priorities within the Chimu state: The role of irrigation agriculture. In: J. Haas, J. Pozorski and T. Pozorski (Editors), The Origins and Development of the Andean State. Cambridge Univ. Press, pp. 111–120.

Prieto, M.R. and Boninsegna, J., 1992. Dendrochronological and historical evidences of climatic anomalies related to ENSO in south South America during the XVIII and XIX centuries. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, p. 263.

Pulwarty, R.S. and Diaz, H.F., 1991. Frequency changes in El Niño occurrence during and after the Little Ice Age. EOS, 72, p. 70 (abstract).

Quinn, W.H., 1971. Late Quaternary meteorologic and oceanographic developments in the equatorial Pacific. Nature, 229: 330–331.

Quinn, W.H., in press a. A study of Southern Oscillation-related climatic activity for A.D. 622–1990 incorporating Nile River flood data. In: H.F. Diaz and V. Markgraf (Editors), Paleoclimatic Aspects of El Niño-Southern Oscillation.

Quinn, W.H., in press b. The large scale ENSO event, the El Niño and other important regional features. In: J. Macharé and L. Ortlieb (Editors), Registros del fenómeno El Niño y de eventos ENSO en América del Sur. Bull. Inst. Fr. Etud. Andines, Lima, 22 (1).

Quinn, W.H. and Neal, V.T., 1983. Long-term variations in the Southern Oscillation, El Niño, and Chilean subtropical rainfall. Fish. Bull., 81: 363–374.

Quinn, W.H. and Neal, V.T., 1992. The historical record of El Niño events. In: R.S. Bradley and P.D. Jones (Editors), Climate since A.D. 1500. Routledge, London, pp. 623–648.

Quinn, W.H., Zopf, D.O., Short, K.S. and Kuo Yang, R.T., 1978. Historical trends and statistics of the Southern Oscillation, El Niño, and Indonesian droughts. Fish. Bull., 76: 663–678.

Quinn, W.H., Neal, W.T. and Antunez de Mayolo, S.E., 1987. El Niño occurrences over the past four-and-a-half centuries. J. Geophys. Res., 92 (C13): 14,449–14,461.

Rasmusson, E.M., 1984. El Niño: the ocean/atmosphere connection. Oceanus, 27: 5–12.

Rasmusson, E.M., 1985. El Niño and variations in climate. Am. Sci., 73: 168–177.

Rasmusson, E.M., 1990. Intraseasonal and interannual climate variability. Clim. Change, 16: 153–171.

Rasmusson, E.M., Wang, K. and Ropelewski, C.F., 1990. The biennial component of ENSO variability. J. Mar. Syst., 1: 71–96.

Rea, D.K., Chambers, L.W., Chuey, J.M., Jenecek, T.R., Leinen, M. and Pisias, N.G., 1986. A 420,000-year record of cyclicity in oceanic and atmospheric processes from the eastern equatorial. Paleoceanography, 1: 577–586.

Richardson, J.B., 1983. The Chira beach ridges, sea level change, and the origins of maritime economies on the Peruvian coast. Ann. Carnegie Mus., 52(11): 256–275.

Rodriguez, R., 1992. Estudio dendrocronológico en la costa norte del Perú, Región Grau. In: J. Macharé, L. Ortlieb, J. Guevara and A. Díaz (Editors), Impacts of the 1982–83 and earlier El Niño events on the coast of northern Peru, Guidebook Fieldtrip Int. Symp. Former ENSO Phenomena in Western South America: Records of El Niño events, Lima, 4–7 March 1992, pp. 45–66.

Rodriguez, R., Mabres, A., Woodman, R., Balsley, B. and Phipps, R., 1992. Avances sobre estudios dendrocronológicos en la región costera norte del Perú, para obtener un registro pasado del fenómeno El Niño. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 275–280.

Rogers, J.C., 1988. Precipitation variability over the Caribbean and tropical Americas associated with the Southern Oscillation. J. Climate, 1: 172–192.

Rollins, H.B., Richardson, J.B. and Sandweiss, D.H., 1986. The birth of "El Niño": geoarcheological evidence and implications. Geoarcheology, 1(1): 3–15.

Rollins, H.B., Sandweiss, D.H., Brand, U. and Rollins, J.C., 1987. Growth increment and stable isotope analysis of marine bivalves: implications for geoarcheological record of El Niño. Geoarcheology, 2(1): 181–197.

Romine, K., 1982. Late Quaternary history of atmospheric and oceanic circulation in the eastern equatorial Pacific. Mar. Micropaleontol., 7: 163–187.

Romine, K. and Moore, T.C., 1981. Radiolarian assemblage, distribution and paleoceanography of the eastern equatorial Pacific Ocean during the last 127,000 years. Palaeogeogr., Palaeoclimatol., Palaeoecol., 35: 281–314.

Ropelewski, C.F. and Halpert, M.S., 1987. Global and regional scale precipitation patterns associated with El Niño/Southern Oscillation. Mon. Weather Rev., 115: 1606–1626.

Ruttlant, J., 1985. Algunos aspectos de la influencia climática, a nivel mundial y regional, del fenómeno El Niño. Invest. Pesquera, Santiago, 32: 9–17.

Rutllant, J. and Fuenzalida, H., 1991. Synoptic aspects of the central Chile rainfall variability associated with the Southern Oscillation. Int. J. Climatol., 11: 63–76.

Salinger, M.J., 1981. Palaeoclimates north and south. Nature, 291: 106–107.

Sandweiss, D.H., Rollins, H.B. and Richardson, J.B., 1983. Landscape alteration and prehistoric human occupation on the north coast of Peru. Ann. Carnegie Mus., 52: 277–298.

Sandweiss, D.H., 1986. The beach ridges at Santa, Peru: El Niño, uplift and prehistory. Geoarcheology, 1(1): 17–28.

Schimmelmann, A. and Tegner, M.J., 1991. Historical oceanographic events reflected in $^{13}C/^{12}C$ ratio of total organic carbon in laminated Santa Barbara Basin sediments. Global Biochem. Cycles, 5: 173–188.

Shen, G.T. and Sanford, C.L., 1990. Trace element indicators of climate change in annually-banded corals. In: P.W. Glynn (Editor), Global Ecological Consequences of the 1982-83 El Niño. Elsevier, New York, pp. 255–283.

Shen, G.T., Boyle, E.A. and Lea, D.W., 1987. Cadmium in corals as a tracer of historical upwelling and industrial fallout. Nature, 328: 794–796.

Shen, G.T., Dunbar, R.B., Colgan, M. and Glynn, P.W., 1988. Equatorial upwelling at Galapagos: Cd record in corals since the 17th century. EOS, 68: 1744.

Shen, G.T., Campbell, T.M., Dunbar, R.M., Wellington, G.M., Colgan, M.W. and Glynn, P.W., 1991. Paleochemistry of manganese in corals from the Galapagos Islands. Coral Reef, 10: 91–101.

Shen, G.T., Linn, L.J., Price, M.T., Cole, J.E., Fairbanks, R., Lea, D.W. and McConnauguey, T.A., 1992a. Paleochemistry of reef corals: Historical variability of the Tropical Pacific. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 287–294.

Shen, G.T., Linn, L.J., Campbell, T.M., Cole, J.E. and Fairbanks, R.G., 1992b. A chemical indicator of trade wind reversal in corals from the western tropical Pacific. J. Geophys. Res., 97: 12,689–12,697.

Soutar, A. and Crill, P.A., 1977. Sedimentation and climatic patterns in the Santa Barbara Basin during the 19th and 20th centuries. Geol. Soc. Am. Bull., 88: 1161–1172.

Sperber, K.R., Hameed, S., Gates, W.L. and Potter, G.L., 1987. Southern Oscillation simulated in a global climate model. Nature, 329: 140–142.

Steinitz-Kannan, M., Nienaber, M.A. and Riedinger, M.A., 1992. The fossil diatoms of Lake Yambo, Ecuador. A 2500 year record on intense El Niño events. In: L. Ortlieb and J. Macharé (Editors), Paleo-ENSO records, Int. Symp. Ext. Abstr. ORSTOM-CONCYTEC, Lima, pp. 295–298.

Stuiver, M., Kromer, B., Becker, B. and Ferguson, C.W., 1986. Radiocarbon age calibration back to 13300 years BP and the ^{14}C age matching of the german oak and US bristlecone pine chronologies. Radiocarbon, 28: 969–979.

Stuiver, M. and Polach, H., 1977. Reporting of ^{14}C Data. Radiocarbon, 19(3): 355–363.

Thompson, L.G., 1990. Reconstructing the history of interannual climate variability from the Tropical and Subtropical Ice Core Records. In: H.F. Diaz and V. Markgraf (Editors), Workshop on Paleoclimatic Aspects of El Niño/Southern Oscillation, Boulder, May 1990, NOAA & INSTAAR,Abstr. Vol. Univ. Colorado, Boulder, pp. 46–51.

Thompson, L.G. and Mosley-Thompson, E., 1987. Evidence of abrupt climatic change during the last 1,500 years recorded in ice cores from the tropical Quelccaya ice cap, Peru. In: W.H. Berger and L.D. Labeyrie (Editors), Abrupt Climatic Change Evidence and Implications. Reidel, Dordrecht, pp. 99–110.

Thompson, L.G. and Mosley-Thompson, E., 1989. One-half millennia of tropical climate variability as recorded in the stratigraphy of the Quelccaya ice cap, Peru. In: D.H.

Peterson (Editor), Aspects of Climate Variability in the Pacific and the Western Americas (Geophys. Monogr., 55). Am. Geophys. Union, Washington, DC, pp. 15–31.

Thompson, L.G., Mosley-Thompson, E., Bolzan, J.F. and Koci, B.R., 1985. A 1500-year record of tropical precipitation in ice cores from the Quelccaya ice cap, Peru. Science, 229: 971–973.

Thompson, L.G., Mosley-Thompson, E., Dansgaard, W. and Grootes, P.M., 1986. The "Little Ice Age" as recorded in the stratigraphy of the tropical Quelccaya Ice cap. Science, 234: 361–364.

Thompson, L.G., Davis, M.E., Mosley-Thompson, E. and Liu, K.B., 1988. Pre-Incan agricultural activity recorded in dust layers in two tropical ice cores. Nature, 336: 763–765.

Trenberth, K.E. and Shea, D.J., 1987. On the evolution of the Southern Oscillation. Mon. Weather Rev., 115: 3078–3096.

Vallis, G.K., 1986. El Niño: A chaotic dynamical system?. Science, 231: 243–245.

Van Loon, H. and Labitzke, K., 1987. The Southern Oscillation. Part V: The anomalies in the lower stratosphere of the northern hemisphere in winter and a comparison with the Quasi-Biennial Oscillation. Mon. Weather Rev., 115: 357–369.

Walker, G.T. and Bliss, E.W., 1932. World weather, V. Mem. R. Meteorol. Soc., 4: 53–84.

Waylen, P.R. and Caviedes, C.N., 1986. El Niño and annual floods on the north Peruvian littoral. J. Hydrol., 89: 141–156.

Weber, J.N. and Woodhead, P.M.J., 1972. Temperature dependence of oxygen-18 concentration in reef coral carbonates. J. Geophys. Res., 77: 463–473.

Weickmann, K.M., 1991. El Niño Southern Oscillation and Madden-Julian (30–60 day) oscillations during 1981–82. J. Geophys. Res., 96: 3187–3196.

Weinheimer, A.L., 1991. Effect of basin-wide and local conditions on radiolarian fluxes in the Santa Barbara Basin. Geol. Soc. Am. Abstr. Progr., 11: A228.

Weinheimer, A.L., Carson, T.L., Wigley, C.R. and Casey, R.E., 1986. Radiolarian responses to Recent and Neogene California El Niño and anti-El Niño events. Palaeogeogr., Palaeoclimatol., Palaeoecol., 53: 3–25.

Wells, L.E., 1987. An alluvial record of El Niño events from northern coastal Peru. J. Geophys. Res., 92 (C13): 14,463–14,470.

Wells, L.E., 1988. Holocene fluvial and shoreline history as a function of human and geologic factors in arid northern Peru. Thesis. Stanford Univ.,CA, 381 pp.

Wells, L.E., 1990. Holocene history of the El Niño phenomenon as recorded in flood sediments of northern coastal Peru. Geology, 18: 1134–1137.

Zebiak, S.E. and Cane, M.A., 1987. A model El Niño-Southern Oscillation. Mon. Weather Rev., 115: 2262–2278.