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BEACH-RIDGE SERIES IN NORTHERN PERU: CHRONOLOGY, CORRELATION, AND RELATIONSHIP WITH MAJOR LATE HOLOCENE EL NIÑO EVENTS

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Abstract

It has previously been hypothesized that the sequences of beach ridges observed at the mouth of the major rivers of the northern coast of Peru (Santa, Chira and Piura Rivers) might record the most intense events of the El Niño phenomenon that occurred in the second half of the Holocene. The purpose of this paper is to reexamine this interpretation through a comparative study of the two sequences preserved north and south of the Chira River mouth. The beach ridges of the two sequences are different sedimentologically and geomorphologically but in both cases required, for their formation, particular meteorologic and oceanic conditions that correspond to very strong El Niño events. Special attention is paid to the radiochronologic data available for these two sequences.

Radiocarbon data from marine shells and from charcoal remains, collected either within or upon the ridges, suggest that the two sequences were formed coevally in the course of the last 4,500 yrs. The ridges appear to have been formed at time intervals varying from 100 to 600 yrs. The comparison of the geomorphologic characteristics of the beach ridges, their geometric disposition, and the entire radiocarbon data finally led to construct a ridge-to-ridge chronological correlation between the two series. This correlation tends to confirm that the formation of these coastal features was closely related with the strongest ocean/climate El Niño anomalies that occurred in the last few millennia.

Key words: *El Niño, Peru, Holocene, beach ridges, radiocarbon.*

SECUENCIAS DE CORDONES LITORALES EN EL NORTE DEL PERÚ: CRONOLOGÍA, CORRELACIÓN Y RELACIONES CON MAYORES EVENTOS EL NIÑO DEL HOLOCENO TARDÍO

Resumen

Las secuencias de cordones litorales observadas cerca de la desembocadura de los mayores ríos de la costa norte del Perú (Santa, Chira, Piura) podrían reflejar los mayores eventos El Niño de la segunda mitad del Holoceno. Con el objetivo de averiguar esta interpretación, se reexamina aquí las principales características de las dos secuencias de cordones observadas en ambos lados de la desembocadura del río Chira, y en particular el conjunto de datos radiocronológicos obtenidos sobre estos cordones. Se confirma que los cordones de las dos secuencias difieren entre sí tanto por el tipo de sedimento como por su morfología, pero que en los dos casos su formación implicó condiciones meteorológicas y procesos oceanográficos que caracterizan eventos El Niño muy fuertes.

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Los fechamientos por radiocarbono de conchas marinas y carbón muestreados dentro y sobre los cordones sugieren que las dos series se fueron formando paralelamente en los últimos 4500 años. Los cordones se habrían formado a intervalos de tiempo de 100-600 años. La comparación geomorfológica de las dos series de cordones, su disposición geométrica y el conjunto de datos geocronológicos llevan a establecer una correlación cronológica entre las dos secuencias. Esta correlación tiende a confirmar que la formación de estas construcciones litorales fue ligada a los más violentos trastornos oceano climáticos de tipo El Niño que ocurrieron en los últimos milenios.

Palabras claves: *El Niño, Perú, Holoceno, cordones litorales, radiocarbono.*

SÉRIES DE CORDONS LITTORAUX DANS LE NORD DU PÉROU: CHRONOLOGIE, CORRÉLATION ET RELATION AVEC DES ÉPISODES EL NIÑO INTENSES DE L'HOLOCÈNE SUPÉRIEUR

Résumé

Les séquences de cordons littoraux observés à proximité de l'embouchure des principaux fleuves de la côte nord du Pérou (rios Santa, Chira et Piura) pourraient être des témoins des événements El Niño les plus intenses de la seconde moitié de l'Holocène. Pour vérifier cette hypothèse, nous ré-examinons les principaux traits des deux séquences de cordons préservés de part et d'autre de l'embouchure du rio Chira, et en particulier l'ensemble des âges radiocarbone disponibles. Les cordons de ces deux localités diffèrent notamment par le type de sédiment, leurs dimensions et leur forme. Néanmoins, dans les deux cas, les processus de formation impliquent des conditions météorologiques et océanographiques particulières qui caractérisent les épisodes El Niño les plus intenses.

Les datations par radiocarbone de coquilles marines (soit incluses dans le sédiment des cordons, soit recouvrant ces derniers) et de charbons d'origine anthropique suggèrent que les deux séquences sont contemporaines et couvrent les derniers 4 500 ans. Les cordons se seraient formés à des intervalles de temps de l'ordre de 100-600 ans. La comparaison géomorphologique des deux séries de cordons, ainsi que leur disposition géométrique et l'ensemble des données radiochronologiques conduisent à proposer une corrélation chronologique des deux séquences. Cette corrélation tend à confirmer que ces constructions littorales sont liées aux anomalies océan/climat les plus intenses de type El Niño qui se soient produites durant les derniers milliers d'années.

Mots clés: *El Niño, Pérou, Holocène, cordons littoraux, radiocarbone.*

1. INTRODUCTION

Along the northern coast of Peru four sequences of Holocene beach ridges have been preserved (Fig. 1). According to several authors these coastal remnants may record major El Niño events, or series of events, that occurred in the last few thousands years (Richardson, 1983; Sandweiss, 1986; Rollins *et al.*, 1986; Ortlieb *et al.*, 1989a; 1989b; Macharé & Ortlieb, 1990). As the El Niño phenomenon is characterized in northern Peru by heavy rainfalls, exceptional river runoff, rough seas and a temporary sea-level elevation, it has been suggested that a combination of these climatic and oceanographic effects was responsible for the formation of beach ridges close to major river estuaries. The sediment that constitutes the ridges would have been carried to the coastal zone by flooded rivers and the beach ridges would have formed in response to the higher than normal energetic conditions observed in the nearshore area during El Niño years. But, on another hand, it can be noted that the recent 1982-1983 El Niño event, one of the strongest ever observed during the last centuries, did not produce any new beach ridge in northern Peru. Actually, the question of the precise relationship between northern Peru beach ridges and strong El Niño events is still actively debated (Craig, 1992; Martin *et al.*, 1992a; 1992b; 1992c; Moseley *et al.*, 1992a; 1992b; Woodman & Mabres, 1993).

We reexamine here the complete geochronological data obtained from the two beach-ridge sequences preserved on both sides of the Chira River mouth: the so-called "Chira" and Colan sequences (Fig. 1). Limitations of the radiocarbon dating method (through the traditional, not AMS, measurement technique) hinder a straightforward and precise age determination of the episodes of formation of each beach ridge. However, we shall try to establish a chronological correlation of the two sequences, partly based upon the geomorphological characteristics of the ridges and their geometric disposition. This approach should determine whether the ridges were formed coevally, and should document the frequency of occurrence of exceptionnal hydrologic conditions that led to the formation of these coastal features.

2. THE BEACH-RIDGE SEQUENCES OF NORTHERN PERU

2.1. Beach ridges: Conditions of formation and preservation

Beach ridges are common features along sandy coasts that experience depositional progradation. They often form downdrift from river mouths, where large sediment supply is made available. Series of beach ridges reflect repetitive processes that may be of varying nature and origin such as tectonic pulses, isostatic motions, intermitent sediment supply, and repeated climatic, or oceanographic, phenomena. Sequences of beach ridges are observed in the cases where ridge-forming processes are unable to destroy the previously built beach ridges. The preservation of a beach-ridge series is favored by two kinds of circumstances: a relative lowering of sea-level (*e.g.* regressive pulses following Pleistocene high sea-stands, or repeated vertical relative land/sea motions), or a rapid progradation of coastal areas where sediment supply is large enough so that each newly formed ridge protects the older ones from subsequent coastal erosion. In Peru, the Holocene beach-ridge sequences pertain to the second category, although a slight relative fall of sea-level probably occurred since the mid-Holocene maximum highstand (Wells, 1988; Ortlieb & Macharé, 1989a).

2.2. The four Peruvian sequences

Along the arid coast of Peru, only three rivers (Santa, Chira, Piura) carry enough sediment to sustain the development of beach-ridge sequences. The northward longshore drift that characterizes the Peruvian coast explains that the ridges normally extend north of the estuaries of these major rivers (Fig. 1).

The northernmost sequence of beach ridges is located immediately north of the Chira River mouth (Fig. 1, Fig. 2). It consists in nine ridges which measure up to 20 km long, 100-300 m wide and 3-4 m high (Fig. 2, Fig. 3) (see description *in*: Chigne, 1975, and Richardson, 1983). These ridges are made of unfossiliferous sands directly derived from the Chira River. The ridges resisted erosion (particularly deflation) thanks to a wide sheet of midden shells. The shells which correspond to only two species of bivalves (*Tivela hians* and *Donax peruvianus* = *D. obesulus*), were accumulated in large quantities and spread over the ridges by prehistoric Indian populations.

The Sechura sequence also consists of about eight, wide and 10-km-long, sandy ridges that extend north of the Piura (=Sechura) River estuary (Fig. 1). The Sechura sequence of beach ridges resembles the Chira sequence in several ways. However, it has not yet been

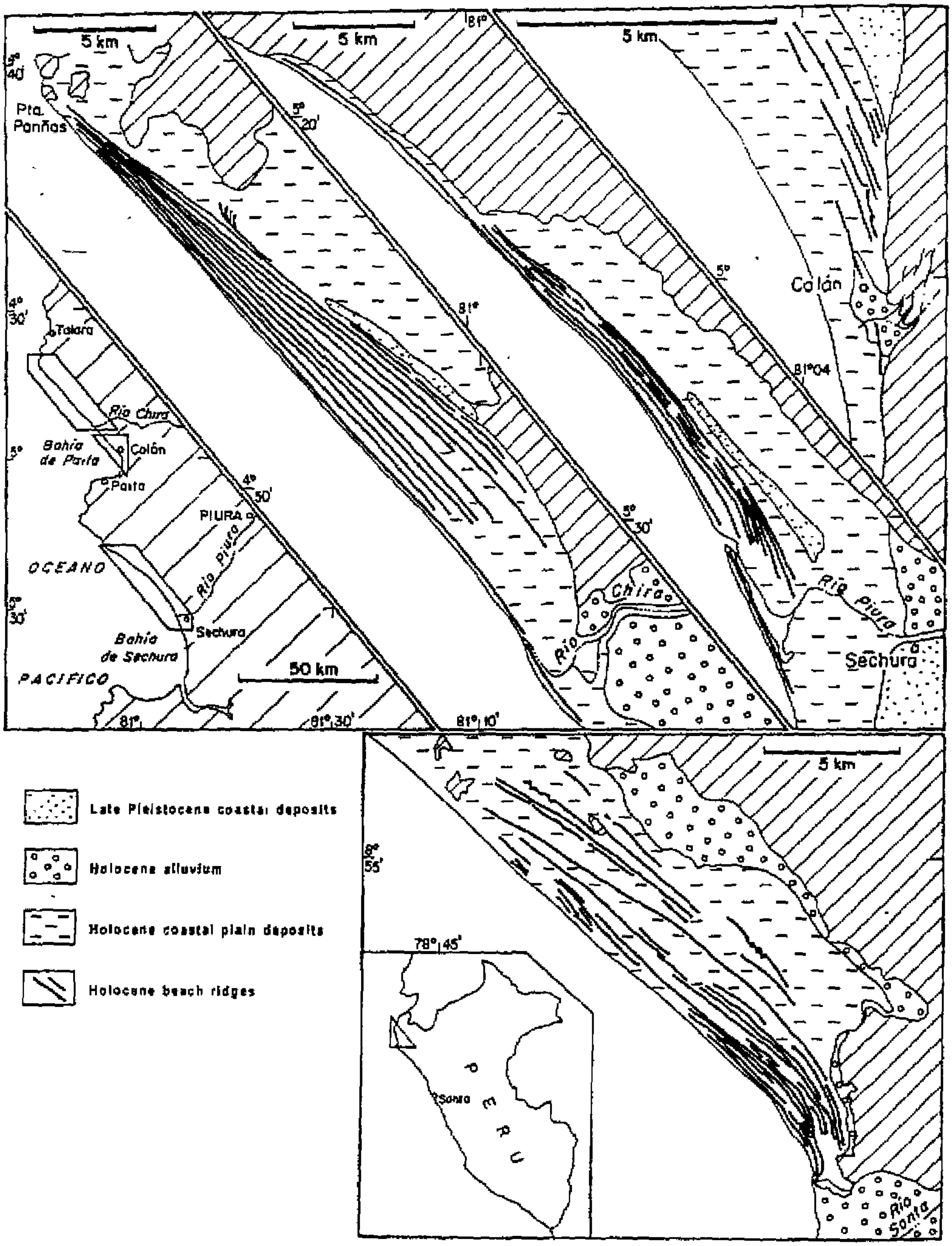

Fig. 1 - The sequences of Holocene beach ridges in northern Peru: Location and simplified geological setting.

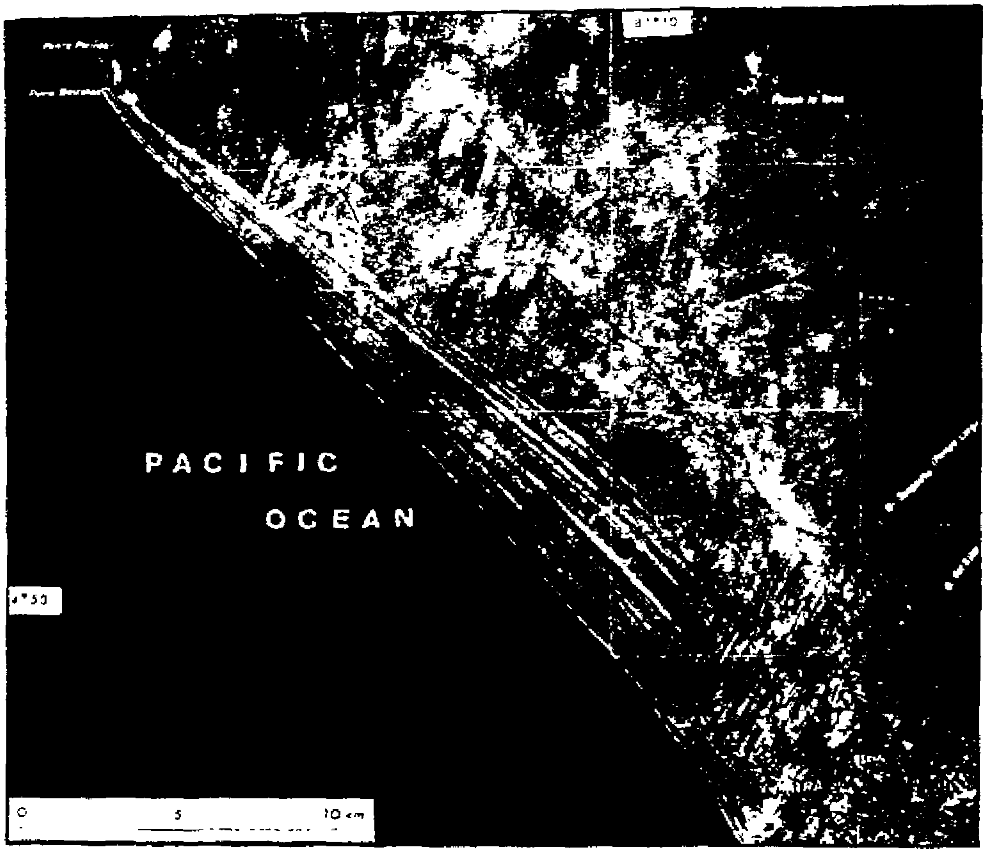

Fig. 2 - Beach-ridge sequence of Chira, north of Chira River estuary (lower right corner). Chira beach ridges measure more than 20 km long, and are up to 100-300 m wide. (Photomap from Instituto Geográfico Nacional).

thoroughly studied (Lanning, 1963; Richardson & McConaughy, 1987), and only yielded a few preliminary ^{14}C results. Donax shells from the oldest Holocene ridge indicate an apparent ^{14}C age of 4320 ±170 BP, while the third youngest ridge provided a 2270 ±170 BP age (authors'unpublished data).

The beach-ridge sequence located north of the Santa River mouth (Fig. 1) is a complex coastal feature that developed in the last 4,000 yrs (Sandweiss, 1986; Wells, 1988; DeVries & Wells, 1990; Perrier *et al.*, 1992). The well-developed Santa ridges are made of gravel and pebbles supplied by the largest of the permanent rivers of Peru. The hydrological regime of the Santa River is dominated by the glacier system and the precipitation of the High Andes (Cordillera Blanca and Cordillera Negra) and seems to be only secondarily affected by El Niño meteorological anomalies. Through studies of distinct sets of aerial photographs and satellite imagery, it previously has been inferred that a poor correlation existed between the El Niño events that occurred in the last few decades and the most recent beach ridges formed at Santa (Wells, 1988; Moseley *et al.*, 1992a; 1992b). Thus, it seems that the beach-ridge sequence formed at Santa cannot constitute a reliable record of El Niño climatic anomalies during the last few millennia (Ortlieb & Macharé, in press).

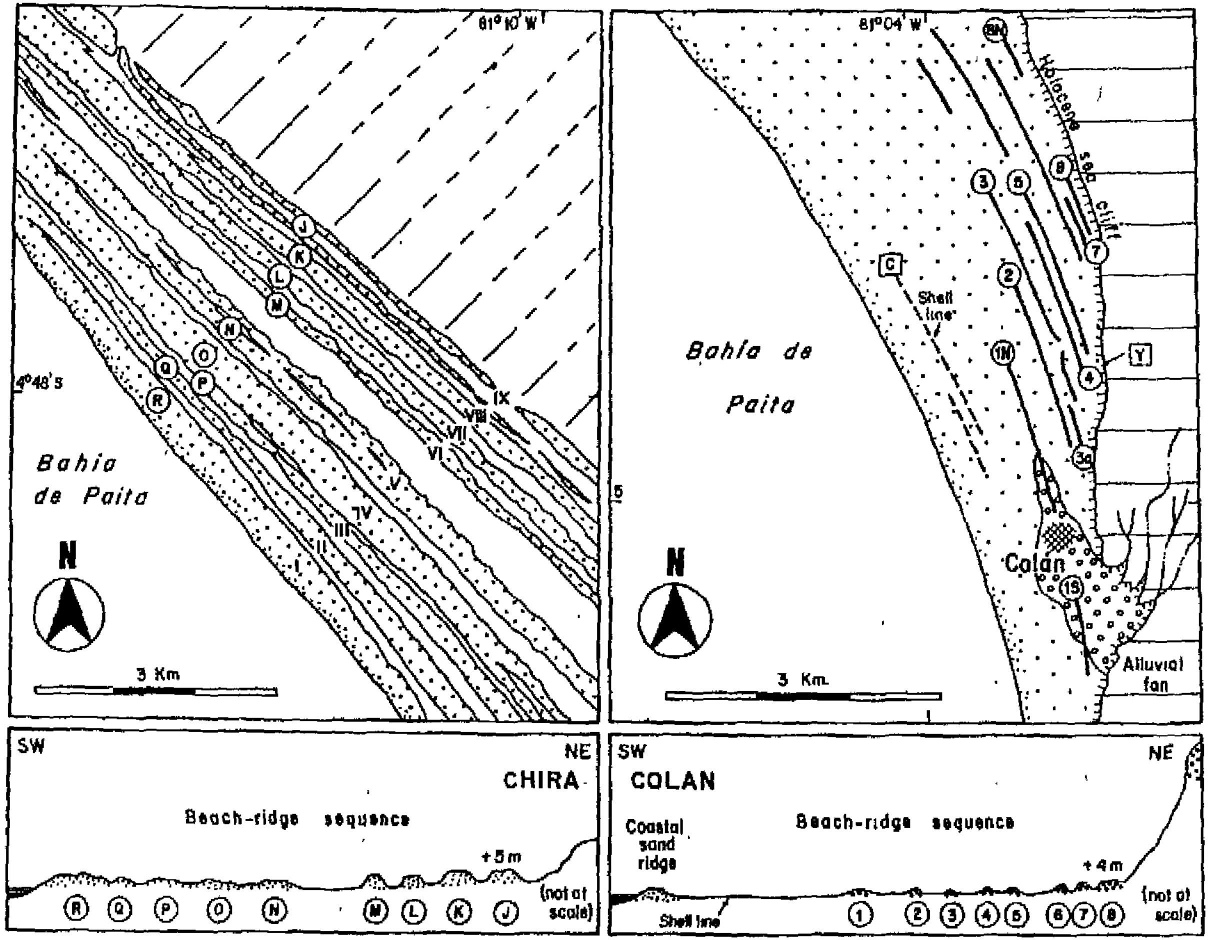

Fig. 3 - Comparison of the Chira and Colan beach ridge sequences: location sketch and schematic cross section, with identification of the ridges (at Chira, roman numerals refer to the work of Chigne, 1975 and Richardson, 1983). Observe difference of ridge size between the two sequences.

Fig. 4 - Beach ridge sequence of Colan (aerophoto from Servicio Aerofotográfico Nacional, Lima, taken in 1946), with identification and numbering of individual ridges.

In the last case, at Colan, the sequence of ridges is located south of the Chira River mouth (Fig. 1, Fig. 3, Fig. 4). This singular situation is related to the fact that the beach ridges are built upon the same coastal plain as the Chira sequence, but are not predominantly formed by Chira River sands (Fig. 3). The ridge sediments essentially consist of pebbles eroded from conglomerate beds that crop out in an overhanging paleo-seacliff. This lithologic composition indicates that the beach-ridge forming processes involved erosion of the Plio-Pleistocene conglomerate units, and a subsequent supply of the shingle and gravel to the prograding Holocene shorelines. The conglomerate erosion and the concentration of shingle at the foot of the cliff were interpreted as closely related to the exceptional rainfalls that occur in the area during strong El Niño events (Ortlieb *et al.*, 1989b; Macharé & Ortlieb, 1990; Ortlieb & Macharé, in press). The redistribution of the shingles along the coastline in the form of successive supratidal ridges was probably controlled by temporarily higher-than-normal sea-levels (which should compare with the +0.50 m anomaly observed during the 1982-1983 El Niño event).

At Colan, the gravelly ridges are of smaller size than in the other sequences. They measure at most a few kilometres long, 15-50 m wide, and are 1.5 to 3.5 m high over the deltaic plain (see description in Woodman & Polia, 1974, and Ortlieb *et al.*, 1989b) (Fig. 3). The sediment composition varies slightly from one extremity of the ridges to the other, and also from one ridge to the other; the grain-size of the largest clasts diminishes progressively northward, and from the oldest ridges to the more recent ones. These gradients clearly indicate that the source of the pebbles was located at the foot of the seacliff, and in the case of the youngest ridges, at the base of the small alluvial fan of Colan. The beach ridges of the Colan sequence are numbered according to the pioneer work of Woodman & Polia (1974), from the youngest (ridge 1) to the oldest (ridge 8)(Fig. 3).

It may be noted that the modern coastal ridge (Fig. 3, Fig. 4) is sedimentologically and genetically different from the Holocene beach ridges. It is essentially made of wind-blown sand. This coastal ridge does not have any relationship with the El Niño phenomenon and, on the contrary, has been largely eroded during the very strong 1982-1983 El Niño event (as a combined result of increased storminess, sea level elevation and strong rainfall). The fact that the 1982-1983 event did not induce the formation of a gravelly beach ridge is clearly due to the lack of any available coarse material. The source of pebbles had been totally eliminated after the formation of ridge 1, as a direct result of the coastline progradation. This geographical situation and the recent coastal evolution of the Colan area should, of course, be taken into consideration when correlations are attempted with other sequences of beach ridges.

2.3. A record of major El Niño events

In the three northernmost localities (Chira, Colan and Sechura), between eight and ten beach ridges were preserved (Fig. 1). This coincidence strongly suggests that the successive ridges were formed coevally. As it has been disproven that tectonic motions (previously envisaged in the case of Colan by Woodman & Polia, 1974) were involved in the formation of the ridges, it is logical to infer an external geodynamic control in the genesis of these features (Ortlieb & Macharé, 1989b; Ortlieb *et al.*, 1989b, Macharé & Ortlieb, 1990). Such recurrent conditions might be a series of major episodes of oceanic/climatic alterations.

The relative disposition of the ridges in each sequence, and their geological characteristics, support the interpretation that these features were formed episodically, during short time periods, and in a context of continuous progradation of the coastal plain. The strong difference in the sedimentologic composition of the ridges, between the two sequences of Colan and Chira, is not opposed to the hypothesis that the ridges were formed simultaneously; quite on the contrary, it constitutes a sound argument in favor of our interpretation. Unusually strong rainfalls able to erode pebbles in the Colan seacliff were the same that could induce tremendous and sudden increases in the Chira River runoff and sediment supply. And such rainfalls are closely and unambiguously linked to El Niño conditions.

To be completely established this interpretation needs a chronological framework as precise as possible. A perfect test of this hypothesis would be to assess chronological correlations between every beach ridge of the two sequences of Colan and Chira. We shall thus re-examine the geochronological data available on these coastal features.

3. CHRONOLOGICAL DATA FROM THE CHIRA AND COLAN SEQUENCES

3.1. The dated material

In northernmost Peru, where the nearshore fauna is more abundant and varied than along the cool central coast, marine shells are found imbedded in coastal ridge sediments. This biogenic carbonate material can be most useful for dating purposes. As a secondary consequence of the locally abundant marine resources, the coastal area was inhabited by prehistoric Indians who left many archaeological remains (midden shells, charcoal, ceramic and lithic artefacts) associated to former successive shorelines. Radiocarbon dating was thus performed on marine shells and charcoal fragments sampled either within the ridge sediment, or atop the ridges.

Colan samples

Unlike most Peruvian beach ridges, the Colan ridges are fossiliferous (Díaz & Ortlieb, 1991; Díaz, 1992): they contain beach-worn and reworked mollusc, barnacle and echinoid shells which may be older than the ridges, and also well-preserved small shells (*Donax peruvianus* = *D. obesulus* and *Olivella columellaris*) that we consider as penecontemporaneous to the ridge formation. In the few cases where the well-preserved bivalve shells were found in anatomic connection, we are reasonably confident that they lived immediately before the ridge were formed. It should be stressed that this kind of shell material was not found in the ridges of the other Peruvian sequences (Sandweiss, 1986; Wells, 1988; DeVries & Wells, 1990; Perrier, 1992). The shells sampled within the Colan ridges were obtained from trench cutting across the ridges (Ortlieb *et al.*, 1989b).

A few charcoal fragments were also collected within the ridge sediment, under the surface: these small remains of anthropic activity along the coastal area had been reworked by the waves and deposited together with the pebbles, sand and shell material during the episode of ridge formation. The charcoal samples are necessarily older than the episode of ridge formation: for this reason, charcoal apparent ages in the Colan sequence should be considered as maximum ages of the beach ridges (Table 1).

Chira samples

In the Chira area, the beach ridges are unfossiliferous. All the dated material from the ridges consists of midden shells and associated charcoal fragments (hearths) that clearly postdate the episodes of ridge formation. The shells that cover the ridges were abandonned

Beach-ridge #	Sample (field) #	Lab. analysis # (1)	Nature of sample (2)	Measured C-14 age (BP)	delta C-13 (/PDB)	Normalized C-14 age (BP) (3)	Corrected age (for reservoir effect) (4)	Maximum age of beach-ridge (BP) (5)	Calibrated (BC/AD) max. age of beach-ridge (6)
8N	P.393 P.394 P.395	By 688 By 690 By 686	charcoal *Tivela hians* *Donax* + spp	3340±45 3210±40 3210±50	-26.6 +0.75 +1.34	3310±45 3630±40 3640±50	3410±90 3420±100	3310±45	1675- 1542 BC
8	P.176 P.174 P.175	By 316 By 331 By 345	charcoal several spp several spp	3170±300 2890±250 3020±250	-27.8 +0.51 +1.26	3130±300 3300±250 3450±250	3080±300 3230±300	3130±300	1776- 1030 BC 1697- 955 BC
7	P.187	By 380	*Donax* + spp	2760±210	+1.62	3190±210	2970±260	(2970±260)	1510- 904 BC
5	P.189 P.190	By 324 By 350	charcoal *Tivela hians*	2550±490 2510±250	-27.05 +0.47	2520±490 2920±250	2700±300	>2520±490	> 1270- 68 BC
Locality Y	P.237 P.238	By 410 By 402	*Donax* *Tivela hians*	2430±240 2280±200	+1.16 +0.89	2860±240 2700±200	2640±290 2480±250	<(2480±250)	< 901 - 295 BC
4	P.194	By 382	*Donax* + spp	2150±170	+0.49	2560±170	2340±220	(2340±220)	727- 173 BC
3	P.199 P.200 P.197	By 323 By 322 By 349	charcoal charcoal *Olivella* + spp	2080±540 2040±380 2170±300	-26.7 -27.01 +1.56	2050±540 2010±380 2600±300	2380±350	2010±380	533 BC- 364 AD
3a	P.209	By 381	*Donax*	1660±180	+1.29	2090±180	1870±230	(1870±230)	161 BC- 376 AD
2	P.202	By 379	*Donax* + spp	1450±180	+1.24	1880±180	1660±230	(1660±230)	88- 578 AD
1N	P 207	By 351	*Donax* + spp	960±230	+1.34	1390±230	1170±280		
1S	P.214	By 383	*Donax* + spp	790±210	+0.05	1200±210	980±260	(980±260)	768- 1235 AD
flat *	P.235	By 441	*Donax*	730±190	+0.83	1150±190	930±240		
shell-line & site C	P.181 P.170	By 424 By 320	*Tivela hians* charcoal	180±160 620±290	+0.15 -26.6	590±160 590±290	370±210	(370±210)	1393- 1803 AD

(1) # of analysis from ORSTOM-Bondy geochronological laboratory.
(2) *Donax*: *D. peruvianus* (=*D. obesulus*); *Olivella*: *O. columellaris*; spp: distinct genus and species of molluscs.
(3) Correction for isotopic fractionation (delta C-13= -25 per mil/PDB), according to Stuiver and Robinson (1974) corrected activity= measured activity x $[0.975^2/1 + (\text{delta C-13}/1000)^2]$.
(4) Correction for so-called "reservoir effect", with factor R= 220±50 yr (according to Stuiver *et al.*, 1986); *results and sigmas are rounded off to the nearest multiple of ten* (Stuiver & Polach, 1977).
(5) Maximum age of beach ridges is given by the youngest available date *from charcoal sample* collected within the ridge sediments. When no charcoal data are available, the (youngest) shell date is used (results in parenthesis).
(6) Calibrated ages are calculated *according the software "CALIBETH", ver. 1.5b (1991)* from Stuiver & Becker, 1986.
BC= Before Christ; AD= Anno Domini (after Jesus-Christ).
* In situ shells *cored below* the surface of the coastal plain, between beach-ridge 1 and modern coastline.

Table 1 - Available C-14 data from the sequence of beach-ridges of Colan, with estimates of maximum age of the ridges.

by early inhabitants who lived extensively on this marine resource. Two species of pelecypods (*Tivela hians* and *Donax peruvianus*) represent more than 95 % of the shells (these species are still the most abundant species living in the nearshore today). The time elapsed between the beach-ridge formation and its human occupation is assumed to have been short because prehistoric Indians probably ate shellfish on the last-formed beach ridge, close to the shoreline.

At Chira, our data complement a set of radiocarbon analyses obtained during previous archeological studies (Chigne, 1975; Richardson, 1983) (Table 2). Most of our samples from the Chira sequence were collected at a few centimetres below the surface of the sandy ridges, in individual hearths. Thus, it can be expected a similar age for the shells and the wood used to cook the shellfish.

3.2. Global comparison of the Chira and Colan radiocarbon data

In both cases, at Colan and north of the Chira River mouth, the radiocarbon results (Tables 1, Fig. 2) show an internal consistency of the data so that the successive ridges, from the oldest ones located inland to the more recent ones near the modern shoreline (Fig. 2), yield progressively younger ages. This observation somewhat validates the assumption that the archeological material collected on the Chira beach ridges is a useful indicator of the ridge formation.

On the other hand, in situ shells collected below the Chira deltaic plain between beach ridges K and L provide an apparent ^{14}C age (ca. 3,600 BP, corrected) slightly older than that of ridge K (ca.3,500 BP) (Table 2). These data involving shells in their natural nearshore environment and midden shells brought by early inhabitants on top of the ridge confirm that the midden material may be used as a proxy for the age determination of the ridges. Similarily, at Colan, in situ shells were collected beneath the wide coastal flat extending between ridge 1 and the present-day coastal ridge (Fig. 2, Table 1); apparent ages of the shells are, as expected, a little younger (930 BP, corr.) than ridge 1 material (1170 and 980 BP, both corr.).

Chronological discrepancies between distinct samples from a given ridge exist but are of limited amount in most of the cases (Tables 1, Fig. 2). Typical variability within a ridge is of the order of 150 years at Colan, and a little more at Chira. In the Chira sequence, the variability of apparent ages provided by the charcoal fragments (including the previous data of Richardson, 1983) may reach 500 years: these large ranges probably reflect longer episodes of human occupation on the ridges. From another point of view, it must be emphasized that quite homogeneous results were obtained, by distinct laboratories, for charcoal fragments sampled in separate localities along ridges J, K and M in the Chira sequence (Table 2).

At first glance, a general comparison of the apparent ages obtained in the two sequences does not point out direct and clear-cut ridge-to-ridge correlations. The radiocarbon ages provided by distinct sorts of samples (charcoal *vs.* shells, archeological *vs.* geological material) do not show unambiguous correlations between a given ridge at Colan and a Chira ridge. Furthermore, the standard deviations are commonly so large that it appears difficult to assess any ridge-to-ridge correlation.

Beach-ridge # this study	Richardson, 1983	Sample (field) #	Lab. analysis # (1)	Nature of sample (2)	Measured C-14 age (BP)	delta C-13 (/PDB)	Normalized C-14 age (3)	Shell/charcoal data: forced correlation	Shell/charcoal data: factor "S" (4)	Corrected age (for reservoir effect) (5)	Minimum age of beach-ridge (BP) (6)	Calibrated (BC/AD) min. age of beach-ridge (7)
J		P.293	By 667	*Tivela*	4210±40	+0.6	4630±40	4540±90	90±90	4410±90	4540 ± 50	3337-3140 BC
		P.294	By 693	charcoal	4570±50	-26.6	4540±50	4540±50				
		P.264	By 562	*Tivela*	3230±40	+0.42	3640±40			3420±90		
	IX		SI-1450	charcoal	4485±80							
			SI-1420	charcoal	4255±65							
			SI-1456	charcoal	3985±80							
K		P.295	By 668	*Tivela*	3310±40	+0.31	3720±40	3490±90	230±90	3500±90	3490 ± 50	1895-1767 BC
		P.296	By 648	charcoal	3520±50	-26.6	3490±50	3490±50				
		P.269	By 549	*Tivela*	3060±30	+0.58	3480±30			3260±80		
	VIII		SI-1421	charcoal	3490±80							
Inter-ridge		P.300A	By 671	*Donax* *	3410±40	+1.15	3840±40			3620±90		
		P.300B	By 672	*Tivela* *	3370±40	+0.72	3790±40			3570±90		
L		P.298	By 669	*Tivela*	3210±35	+0.04	3620±35	3160±80	460±80	3400±90	3160 ± 45	1499-1408 BC
		P.299	By 691	charcoal	3190±45	-26.6	3160±45	3160±45				
		P.268	By 670	*Tivela*	2610±35	+0.06	3020±35			2800±90		
		P.267	By 525	*Donax*	2600±150	+1.3	3030±150			2810±200		
	VII		GX-1565	*Tivela*	3500±160							
M		P.305	By 678	*Tivela*	2540±40	+0.23	2950±40	2730±80	220±80	2730±90	2730 ± 90	942-846 BC
		P.306	By 689	charcoal	2760±40	-26.6	2730±40	2730±40				
	VI		SI-1422	charcoal	2685±105							
			SI-3184	charcoal	2485±70							
N	V		SI-1423	charcoal	1955±100						(1955 ± 100)	97 BC-151 AD
O	IV		GX-1566	*Tivela*	1550±110		(ca.1990)			(ca.1770)	(1770 ± 110)	(57-417 AD)
P	III		SI-1424A	charcoal	1405±75						(1405 ± 75)	550-682 AD
			SI-1424B	charcoal	1305±100							
Q	II		SI-1457	charcoal	805±60						(805 ± 60)	1130-1252 AD
R	I	P.301	By 673	*Tivela*	460±40	+0.48	870±40	350±80	520±80	650±90	350 ± 90	1477-1607 AD
		P.303	By 647	charcoal	380±40	-26.6	350±40	350±40		350±90		

(1) Analysis # of geochronology lab of ORSTOM-Bondy (By), Cambridge, Mass. (GX) and Smithsonian Inst. (SI).
(2) *Tivela*: *T. hians*; *Donax*: *D. peruvianus* (=*D. obesulus*). Shaded data concern samples from archeological hearths, in which charcoal and shells may be considered as penecontemporaneous.
(3) Correction for isotopic fractionation (delta C-13= -25 per mil/PDB), according to Stuiver & Robinson, 1974). corrected activity= measured activity x [0.975 ²/1 + (delta C-13/1000)²].
(4) Associated charcoal and shell samples from single hearths, thus of similar ages, should provide useful data for the evaluation through time of the reservoir effect that affected the nearshore shells. An empirical factor "S" is thus determined by the difference between the shell normalized age and the charcoal normalized age "S" varies from 90 to 520 years.
(5) Correction for the "reservoir effect", with factor R= 220±50 yr (according to Stuiver *et al.*, 1986). Results (and sigmas) are rounded off to the nearest multiple of ten (Stuiver & Polach, 1977).
(6) The minimum age of the beach-ridges is given by the (most significant or youngest) C-14 age of charcoal fragments collected atop the ridge The selected data are indicated by "]". When no charcoal data are available, shell dates are used (data in parenthesis).
(7) Calibrated C-14 ages, according calculation with software "CALIBETH", ver. 1.5b (1991) from Stuiver & Becker, 1986. BC = Before Christ; AD = Anno Domini (after Jesus-Christ).
* In situ shells cored, below the surface, in inter-ridge swale.

Table 2 - Available C-14 data from the sequence of beach-ridges of Chira, with estimates of minimum age of the ridges.