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EROSION AND ACCRETION PROCESSES DURING EL NIÑO PHENOMENON OF 1982 - 1983 AND ITS RELATION TO PREVIOUS EVENTS

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Abstract

Erosion and accretion are the main processes of coastal line changes. Important morphological processes occurred during El Niño Phenomenon of 1982 - 1983, a great climatological and oceanographic event. The Piura river bed excavation was measured monthly, reaching five meters deep and ninety meters wide at the maximun river discharge. The sediment transport of Jequetepeque river increased in 1983 about twenty times the average of previous years, reaching more than thirty millions of cubic meters. Probably, most rivers in Peruvian northern coast had the same great processes. It seems that it should exist a relation with the biggest El Niño events like that of 1982 - 1983. The Holocene beach ridges, north of Chira, Piura and Santa river mouths and in Colan were formed by maximun supply of fluvial sediments in one great El Niño event. A comparison of transported sediments volumes by Jequetepeque river in ENSO events during last twenty years would indicate a relation betweem the intensity of El Niño Phenomenon and the amount of fluvial transported sediments.

Key words: *Erosion, accretion, El Niño, beach ridges, fluvial sediments.*

LOS PROCESOS DE EROSIÓN Y ACRECIÓN DURANTE EL FENÓMENO EL NIÑO DE 1982 - 1983 Y SU RELACIÓN CON EVENTOS PREVIOS

Resumen

Los principales procesos de cambio de la línea de costa son la erosión y la acreción. Durante el Fenómeno El Niño de 1982-1983, gran evento climatológico y oceanográfico, ocurrieron importantes procesos morfológicos. La socavación del cauce del río Piura se midió mensualmente alcanzando cinco metros de profundidad y noventa metros de ancho durante la máxima avenida del río. El transporte de sedimentos del río Jequetepeque aumentó en 1983 en casi veinte veces el promedio movilizado en años anteriores, llegando a más de treinta millones de metros cúbicos. Probablemente, la mayoría de los ríos de la costa norte peruana sufrieron los mismos grandes procesos. Existiría una relación entre estos procesos y los mayores eventos de El Niño como el de 1982-1983. Los cordones litorales holocénicos que se localizan al norte de las desembocaduras de los ríos Chira, Piura y Santa y en Colán se habrían formado por el aporte máximo de sedimentos fluviales en un solo gran evento El Niño. Una comparación entre los volúmenes de sedimentos transportados por el río Jequetepeque en los eventos ENSO de los últimos veinte años, indicaría una relación entre la intensidad del Fenómeno El Niño y el volúmen de sedimentos transportados.

Palabras claves: *Erosión, acreción, El Niño, cordones litorales, sedimentos fluviales.*

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LES PROCESSUS D'ÉROSION ET D'ACCRÉTION DURANT LE PHÉNOMÈNE EL NIÑO DE 1982-1983 ET LEUR RELATION AVEC DES ÉVÉNEMENTS ANTÉRIEURS

Résumé

Les principaux processus de changement de la ligne de côte sont l'érosion et l'accrétion. Durant le phénomène de 1982-1983, grand événement climatologique et océanographique, d'importants processus morphologiques sont survenus. Le creusement du lit du río Piura a été mesuré mensuellement, atteigant 5 m de profondeur et 90 m de large au cours de la plus forte crue de la rivière. Le transport de sédiments du río Jequetepeque augmente 20 fois plus que la moyenne des années antérieures, dépassant les 30 millions de m^3. Il est probable que la majorité des rivières de la côte nord du Pérou connurent les mêmes grands processus, et il y aurait une relation entre ceux-ci et les événements importants de El Niño comme celui de 1982-1983. Les cordons littoraux de l'Holocène qui se trouvent au nord de l'embouchure des ríos Chira, Piura et Santa et à Colán, se seraient formés grâce à l'apport massif de sédiments fluviaux au cours d'un tel événement important de El Niño. Une comparaison entre les volumes de sédiments transportés par le río Jequetepeque au cours d'événements ENSO dans les 20 dernières années, indiquerait qu'il y aurait une relation entre l'intensité du phénomène El Niño et le volume des sédiments transportés.

Mots clés : *Érosion, accrétion, El Niño, cordons litoraux, sédiments fluviaux.*

1. INTRODUCTION

El Niño Phenomenon represents one of the most significant regional events affecting mainly the Intertropical Pacific and involving a great number of world regions. El Niño Southern Oscillation (ENSO) is a short duration recurrent global phenomenon whose manifestation may seriously affect the regional economy of the western South America countries. The ENSO may give at a limited scale a good idea of global and regional climatological and oceanographic changes. The main processes related to El Niño are the intrusion of warm and low salinity waters into coastal temperate waters, excessive rainfall along the coast and the flooding of rivers (Teves, 1990). It is called El Niño, for the Christ child, because it affects mainly the coast of Ecuador and Peru at christmas time.

Evidences of former El Niño events along the coastal region of western South America are known from geological, archeological and historical records. It is possible that "El Niño" has been occuring for several millions of years since the Miocene, according to some evidence found in Ica Department, south of Lima, in a sequence of diatomites interbedded with conglomerates. Written records indicate that many El Niño events occured since 1541.

Insofar this century is concerned medium and high intensity El Niño phenomena have occurred in: 1902, 1905, 1911, 1914, 1918, 1925, 1929, 1939, 1941, 1953, 1957-1958, 1965, 1972-1973, 1976, 1982-1983 and 1987.

The 1982-83 El Niño was the most severe on record, one of the most destructive climatic-oceanographic events in modern history. The damage related to this event was estimated in almost nine billion dollars. The excessive rainfall on the coast produced great changes in coastal morphology, mass movements, overflowing of rivers, droughts in certain areas, increase in fluvial sediments transport, river bed erosion, sedimentation and accretion along the coastline and on the shelf, and vegetation in the arid zones. These processes had a harmful impact in several sectors including agriculture, transport, housing, industry, ports and piers, public health, education, archeological remains and above all the loss of human life.

The northern coastal belt in Peru shows in great magnitude all these processes. This zone shows a large variety of relief forms and vegetation cover. The landscapes of coastal lagoons and tidal plains in Tumbes change to the south into ondulated topography of

Tertiary rocky hills, marine terraces or "tablazos" between Mancora and Sechura desert and alluvial fans or fluvioalluvial terraces in alternance with rocky massifs south of Chiclayo.

The neotectonics in this zone has been very active during the Quaternary. North of Cabo Blanco predominated the rising and tilting of the Pleistocene terraces up to more than 300 m in the vicinity of Mancora town, or subsidence of the same magnitude in the lower valley of La Leche river.

2. MAIN FEATURES OF 1982-1983 EL NIÑO

The anomalous warming up recorded off the South America coast in 1982-1983 was related to two different water sources: north of 15°S, the warm surface temperature and low salinity water were associated with the tropical waters of Panama Bight and south of 15°S, the warm surface and relatively higher salinity water were associated with an advection of subtropical water toward the coast. As a result of this invasion of abnormally warm water, the sea surface temperature recorded great anomalies throughout the region. Thus, warm temperature anomalies up to 10°C were recorded off the Peruvian coast while off the Ecuadorian and Chilean coasts such anomalies reached up to 5°C.

In 1983, off the Ecuadorian and Peruvian coasts, the sea level reached high elevations up to 30 and 40 cm above normal, respectively, and a maximun of 50 cm in Chilean coastal waters.

The rainfall in the northern coast, from November 1982 to September 1983, was higher than all previous records. The rainfall at Tumbes was 29 times higher than normal, at Talara 226 times, at Piura 62 and at Chiclayo 8. The monthly values were greatly increased, so that in Tumbes instead of the 47 mm average rainfall in March, it rained more than 500 mm in March1983, 557 mm in February and 1242 mm in May. It was similar in Piura where March is normally the rainy month with an average of 17 mm but in 1983, the rainfall was higher than 400 mm and it reached 653 mm in April. The rainfall south of Lambayeque was less intense but the damages were greater because these areas are not well prepared to have neither intense nor moderate rainfall (Vreeland, 1985) (Fig. 1).

In Puerto Pizarro (03°30'S), the maximum rainfall was observed on March 24, 1983, with 166 mm and a return time of more than 4000 years. In Lancones (04°34'S), the maximun rainfall was registered on April 26, 1983, with 193.8 mm and a return time of 200 years. In Morropon (05°11'S) the maximun rainfall was registered on January 26, 1983, with 152.7 mm and a return time of 150 years (Huamán-Carcia Peña, 1985).

3. GEOMORPHOLOGICAL AND STRUCTURAL FEATURES

The Peruvian northern coast presents structural and geomorphological features which are very different from the rest of the coast. At Cabo Blanco, the general orientation of the coastline changes from a NNE-SSW direction to the north, with predominantly parallel faulting, to a NNW-SSE strike, with predominantly oblique faulting toward the south. The Amotapes Mountains, northern extension of the Coastal Cordillera (well-defined from Paracas Peninsula to the north of Chile), are bordering the coastal belt between 3° to 5°S, while the western Andean flank constitutes the eastern boundary of the coastal region between 5° and 18°S (Teves, 1989).

Marine sediments were deposited during Plio-Pleistocene sea regressions. In the northwest of Peru, these sediments constructed large subhorizontal plains with only a few tens of meters of thickness. The terraces were made up of a mixture of both marine and fluvial

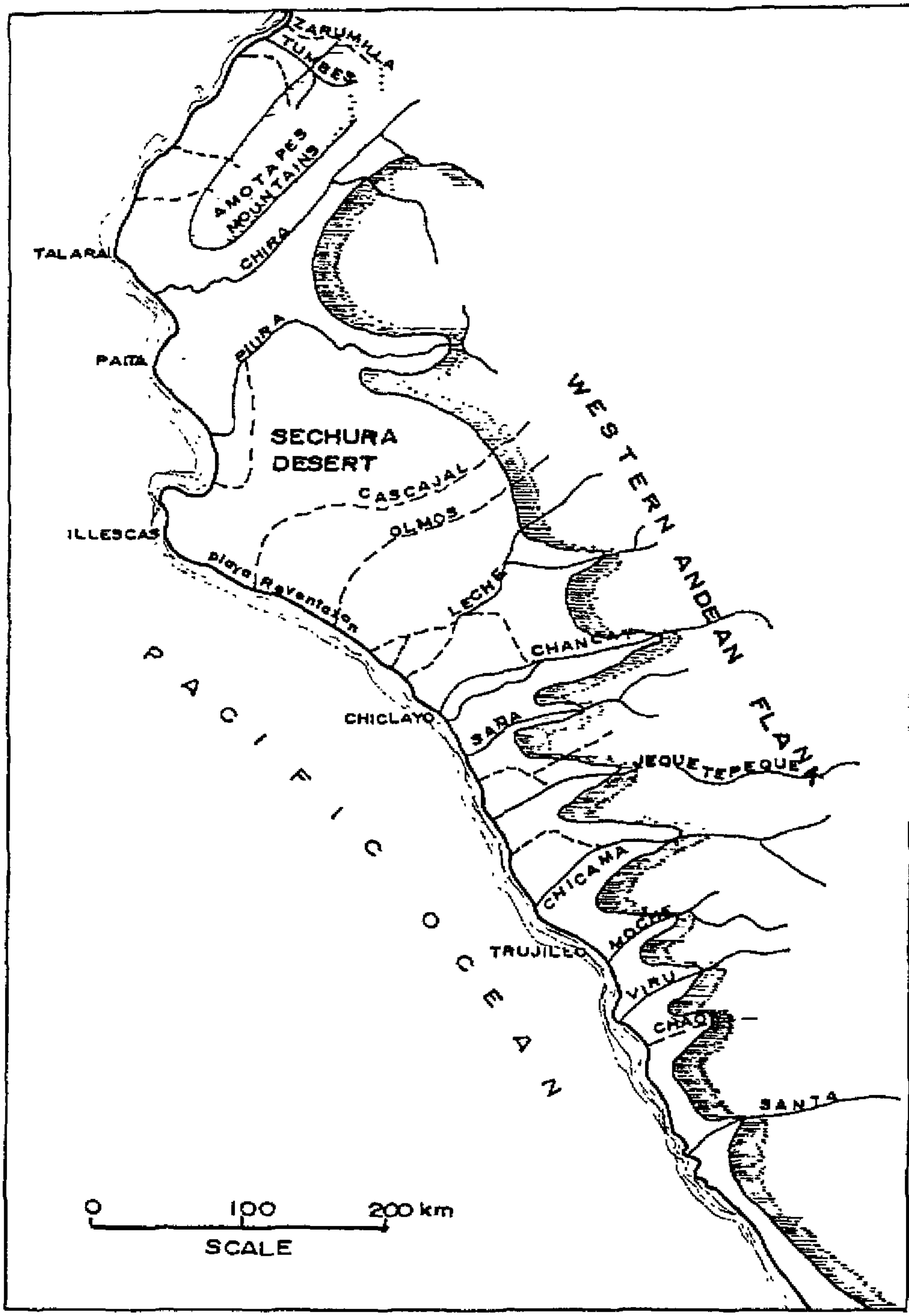

Fig. 1 - Rivers and wadis in the northern peruvian coast.

sediments. Due to the uprising of the coast, these are stepped terraces. The terraces, locally called Tablazos, are made up of conglomerates, bioclastic sands and coquinas. Three older marine terraces and one in formation at present have been recognized. the Mancora Tablazo, reaches a maximum height of 30 m in the vicinity of Mancora town and of only 60 m south of Paita. The Talara Tablazo has been 84 m height toward the north and 40 m toward southwest. The Lobitos Tablazo has uplifted 30 m. The Salinas deposits are constituting a tablazo in formation, which is 3 Km wide from the coastline to the line of abandonned cliffs and was uplifted 3 m. The differential uplifting of the tablazos indicates a tilting of the blocks toward the south.

The area between Bayovar and Morrope experienced an active morphotectonic development during the Cenozoic. A rigid block with intermittent uplifting, the Illescas Massif, constitutes the northwestern border of the subsident Sechura Basin. On the slopes of the Illescas Massif, are observed stepped marine terraces and abrasion platforms of Upper Eocene and Pleistocene age, as a result of the uplifting.

In the area of Sechura desert, there are two well developed marine terraces, which have been correlated with the Talara Tablazo and Lobitos Tablazo. The Talara Tablazo is the highest and most extended level on Sechura desert; it is a plain, slightly sloping toward the southwest and partially covered by alluvial and aeolian deposits. It is 125 m high in Ramon, diminishing to 65 m in Yapato Pampas; near the coastline between Reventazon and Morrope the low cliffs are 10 m high. The Lobitos Tablazo is the lower Pleistocene level, which can be traced along the Sechura Bay at a 10 m height in average.

South of the Illescas Massif, two depressions are observed, the biggest one, Salina Grande Depression, has a diameter between 19 and 14 Km and is more than 30 m deep; important phosphate deposits outcrop near the bottom. A small depression is located toward the South with 2.5 Km of diameter. Both depressions have been developed by aeolian and marine erosion of Talara Tablazo and the Miocene formations.

A beach ridge of concave form outlines the Sechura Bay. The coastline, from Reventazon to Morrope is limited by a straight beach ridge. These beach ridges are 2.5 m high in average. Flood plains extend between these beach ridges and the tablazos, and include marsh zones and river - flood areas, some of them below sea level. The present beaches are narrow.

The coastal piedmonts, south of Chiclayo, are observed as glacis or large alluvial fans and active alluvial plains. Three alluvial fans were distinguished according to the size of the sediments, weathering and age (Collin Delavaud, 1968). The youngest alluvial fan is made up of pebbles, gravels, sand and silts, almost unweathered and yellow colored. The second younger one is made up of pebbles and gravels, is superficially weathered and slightly indurated on surface and covered by a pink and ochre patina. The third alluvial fan, the oldest one, consist of highly weathered boulders, with granite blocks desintegrated to sandy grains; the superficial hardening is strong, and seems to be due to percolation of waters with dissolved gypsum. The regolith has a brown and dark red patina.

Three alluvial terraces are observed in the lower valley of Jequetepeque river (Teves, 1973), with the oldest one reworked by marine action.

The strong waves attack the coastal cliffs, which are made up of conglomerates and consolidated sands. The retreat of the piedmont front is parallel to the coastline, which is controlled by small rocky massifs and isolated hills.

In the nearshore islands, several tombolos where built on former beach ridges, like in Malabrigo, Guañape in Viru, Macabi in Chicama and Cherrepe in Saña (Collin Delavaud, 1968).

4. EROSION AND ACCRETION PROCESSES

Erosion and accretion are the main processes of coastline change. Great morphological changes took place during 1982-1983 El Niño. The joint action of the sea level rise and of the formation of large waves produced a landward retreat of the coastline, the flooding of large sections of the lowlands, the erosion of inmense coastal areas, the wiping out of shrimp cultivation ponds, the destruction of molluscan communities and of coastal civil engineering works as well as the disappearance of some fishing communities. Salinas a seaside resort, was cut off from the rest of Ecuador, meanwhile deluges flooded the streets, and a wind-storm ripped off roofs from hundreds of houses. Deadly diseases developed rapidly, like typhus, salmonella infection and typhoid fever.

The excavation of river beds in the northern zone of the Peruvian coast and the volume of sediment transport were very large. North of Chira, Piura and Santa rivers mouths, a great number of beach ridges were formed during the Holocene (last 10,000 years).

4.1. Accretion in Tumbes Delta

The coastal area between the Ecuador boundary and La Cruz Bay is geodinamically very active. The sediment deposition is very important and provokes a constant morphological change and an accretion of new areas to the continent. In all this coastal area and mainly near Puerto Pizarro, there is a series of beach ridges parallel to coastal line.

Mal Pelo Point is a prominence in the center of Tumbes delta that attenuates the wave force thus favouring the sedimentation on both sides. At Hermosa beach (western side of the point), the sandy sediments accrete along the beach from La Cruz Bay to Mal Pelo Point. This beach has widened 400 m in about thirty years. In Jeli beach (eastern side), the strong waves produce the deposition of coarser sands and other transported materials like trees, during the floods of Guayas, Zarumilla and Tumbes rivers (Fig. 2, 3).

The progradation of the coastline in this area resulted in the incorporation of 190 Km^2 of new territories that correspond for165 Km^2 to the littoral plain, and for 25 Km^2 to the delta (*esteros* and "mangles"). The width of the new land areas varies from 0.5 Km in Las Garzas (Hermosa beach), 4 - 4.5 Km in Tumbes river mouth, 5 Km in Puerto Pizarro and 0.2 Km in Jeli beach (Dávila, 1983).

The process of accretion in the Tumbes delta has occurred in the last few thousand years and continues at present. This process includes the following steps:

- Formation of beach ridges and barrier islands.
- Formation of lagoons and effluent rivers.
- Change of the beach ridges and barrier islands into mangrove trees areas.
- Change of effluent rivers into esteros.
- Filling up of esteros and lagoons with fine sediments, clays and muds.
- Disparition of mangrove trees in areas located behind the coastline, because of ecological changes.

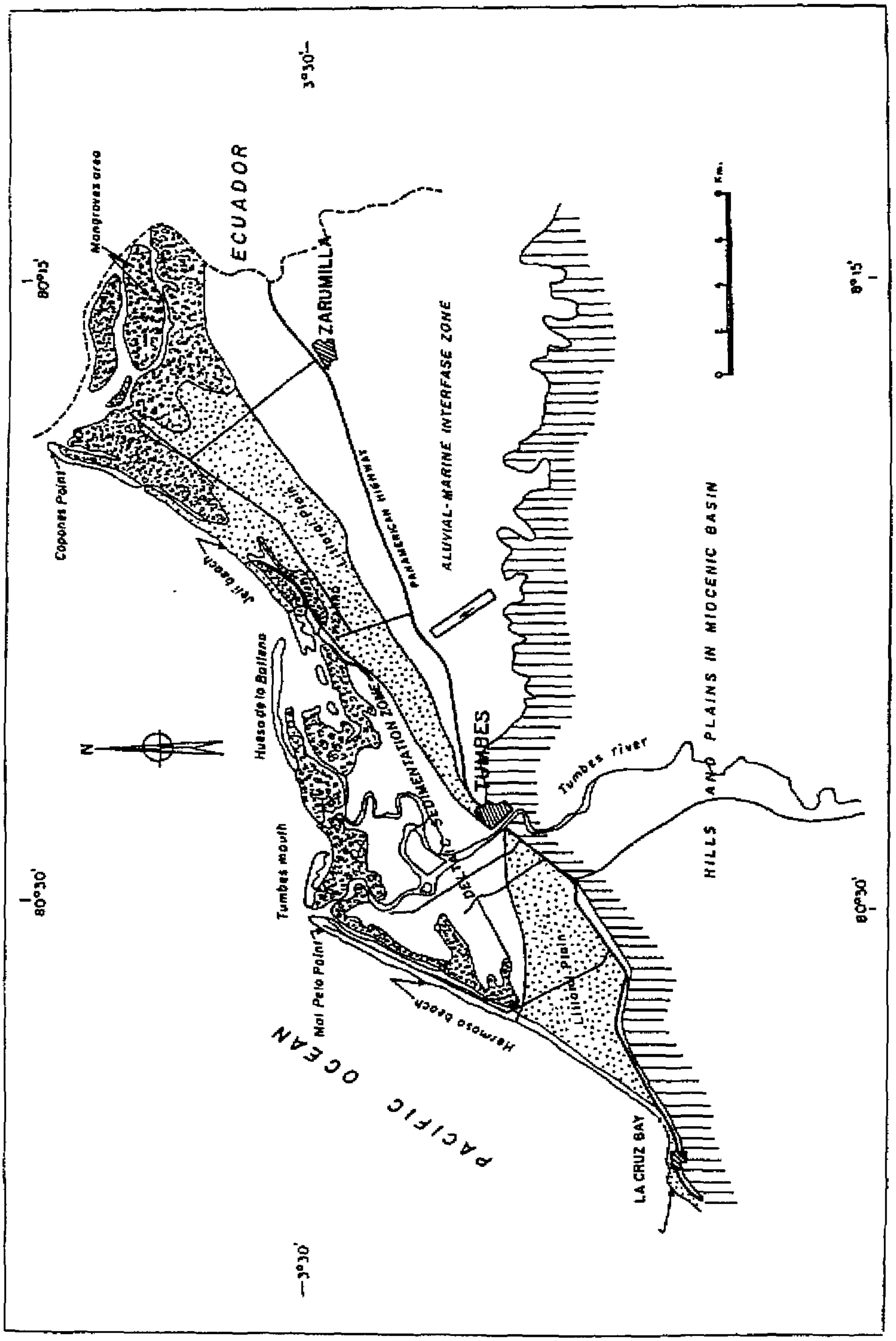

Fig. 2 - Geomorphological map from coastal region of Tumbes (modified from J. Dávila).

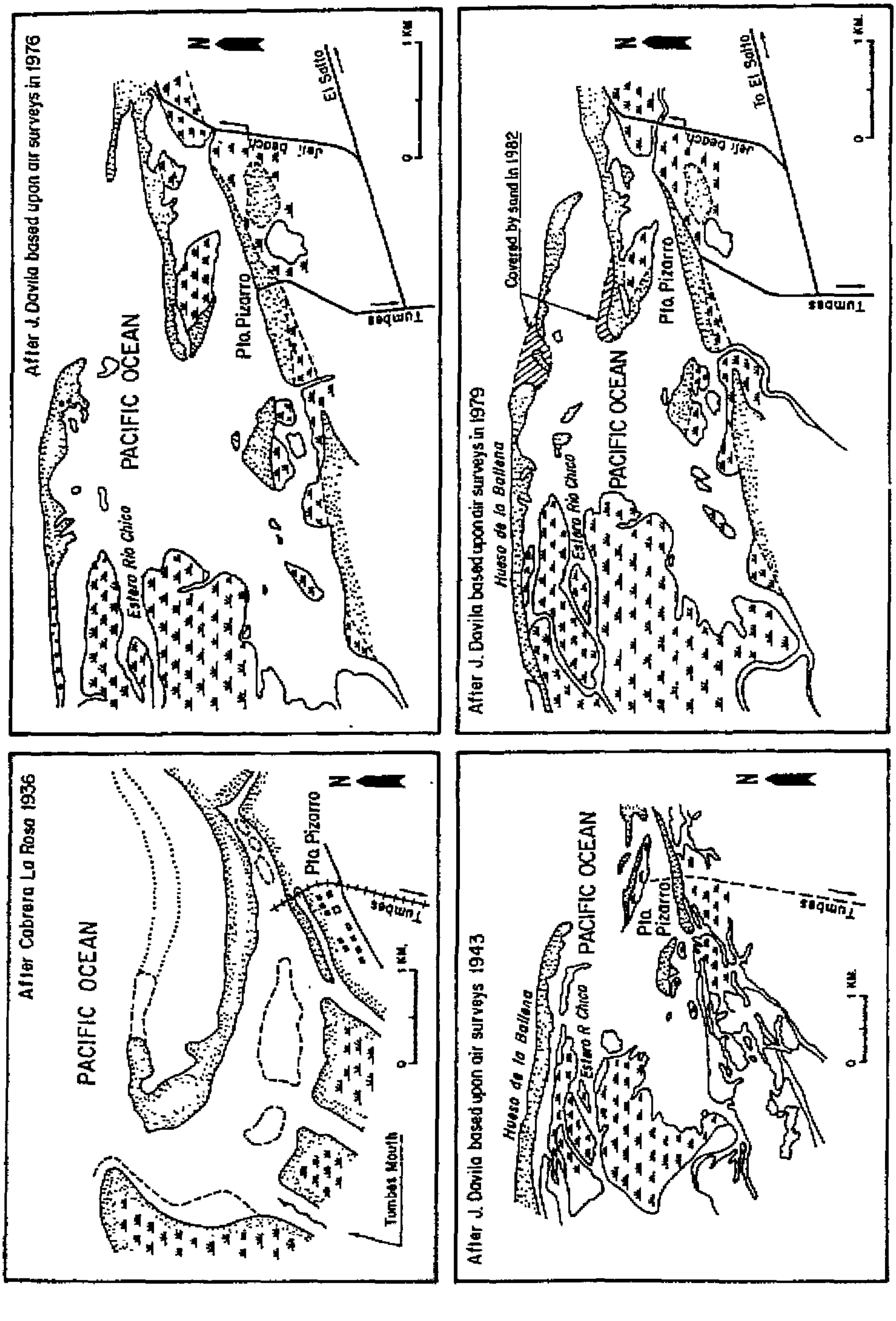

Fig. 3 - Geomorphological evolution of Puerto Pizarro area.

- Incorporation of new territories.

The comparison of Puerto Pizarro maps from Cabrera La Rosa (1939) and Dávila (1983) based upon air surveys (1943, 1976, 1979) and field work (1982) shows that Tumbes river mouth was in Puerto Pizarro lagoon and later moved to Mal Pelo Point. The old mouth in Puerto Pizarro is now the Estero Rio Chico. In 1936, Puerto Pizarro lagoon was deep enough to admit small ships, but at present it is shallower and only small boats can sail there.

The aerial photographic of the Tumbes delta from 1976 and 1979 show the evolution of the accretion and a minor erosion at Mal Pelo Point.

4.2. Erosion in Piura river

The great increase of Piura river discharge in 1983, produced strong erosion on the river margins and excavation in the river bed. These phenomena associated to gravity mass movements provoked many damages and destroyed houses and civil engineering works.

The lithostratigraphic units that crop out in Piura area are the Tertiary Zapallal Formation and Quaternary marine, fluvial and aeolian deposits. Zapallal Formation is made up of gray and green shales and siltstone; in the upper part, there are fine grained sandstones cemented with salts; the upper beds are almost impermeable, while the lower interbedded sandstones are permeable and constitutes aquifers. This formation changes laterally into deltaic and shallow-marine deposits.

The Quaternary marine beds have great areal distribution and uniformity. Aeolian deposits are formed of very fine sands that cover superficially wide areas in the plains. Fluvial deposits are not so thick because the Piura river has changed its course, as shown by several abandoned channels; the deposits are made up predominantly of fine and very fine sands (Fig. 4, 5).

The Zapallal formation crops out in the right margin of Piura river. It is covered by detritic sediments, in the surroundings of Piura city. These detritals are 4 - 5 m thick between Bolognesi and Sanchez Cerro bridges; the matrix is fine sand near the top, and quite muddy toward the bottom of the unit. Underlying this, a bank of clear gray fine sands, probably fluvial bed deposits, is resting over greenish gray shales and siltstones. These sediments are 2 - 3 m thick in the left margin.

Some cross profiles of the Piura river bed were measured monthly, from December 1982 to August 1983 at Bolognesi bridge. These measurements showed an excavation of the river bed related with the increasing river flow. In December 1982, the river eroded its bed to form two channels of two and one meter depth; in February 1983, the channels were 3 and 4.5 m deep, respectively; in March they reached 4 and 4.5 m in depth; in April and May there was a single 5 m deep channel all across the river bed. This excavation probably saved Piura city from a catastrophic flood. In June 1983, Piura river refilled its scoured bed with the diminution of the river discharge, and in August 1983, the river bed reached its normal level. The fluvial bed deposits are light gray fine sands with small brick fragments coming from the eroded margins. On basis of drilling and geoelectric profiles data, we assume that the fluvial bed deposits are 4 - 4.5 m thick along the river bed upstream Bolognesi bridge. If we estimate a 10 Km length of the excavation along the Piura river bed, the volume of removed sediments would be enough to form a beach ridge of 15 Km long.

The fluvial bed deposits of very loose fine sands were eroded from the Piura river margine during the large flows. The river bed became wider and shallower. The present deepening of the river bed is directly related to the presence of the bridges crossing the Piura river that limited the lateral erosion.

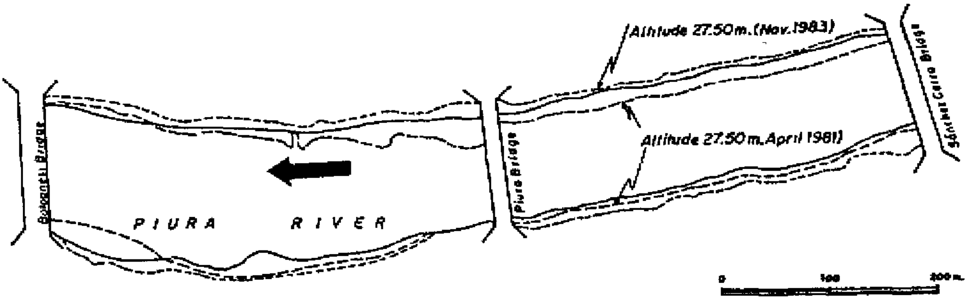

Fig. 4 - Erosion of margins of Piura river.

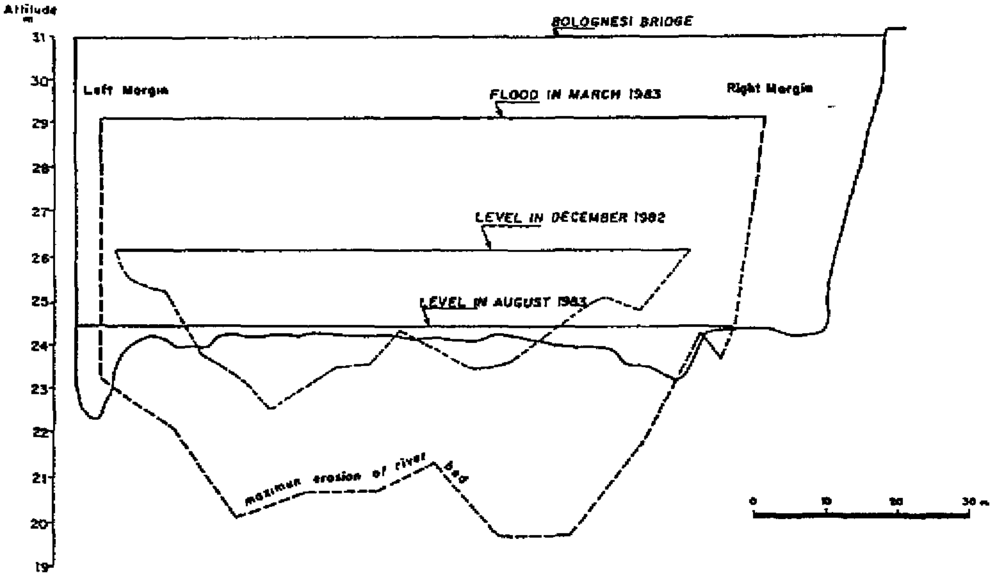

Fig. 5 - Cross sections in Piura river.

Comparisons were made between two topographic maps of the river margins prepared before and after the flood of 1983. The level curve of 27.50 m from April 1981 map compared with November 1983 map shows that the right margin suffered a lateral erosion of 10 - 15 m in average.

The maximun discharge of the century was measured in 1983 (2,947.3 m^3/s in March 1983) and produced a major river bed erosion, but in the future, minor increase in river discharge could remove all the present river bed filling. This is the reason why any project designed to protect the river margins should take into account this problem and should be focused on the limitation of future river bed excavation (Teves, 1983).

4.3. Sediment Transport of Jequetepeque river

Jequetepeque river is one of the few rivers on the Peruvian coast that carries water to the sea all the year round. The river is 155 Km long; its source is located at more than 4000 m above sea level. The hydrographic basin is about 4,230 Km^2 wide with almost 1,500 Km^2 above 2,000 m (where the yearly rainfall varies from 900 to 1,300 mm). The volume of anual water transport at Ventanillas station is irregular and varied from 88.6 to 2,074.9 millions of cubic meters in a period of 16 hydrological years (1968 - 1984).

The coastal area in the Jequetepeque river basin shows abundant Quaternary fluvial and aeolian deposits (Teves, 1982). Twenty lithostratigraphic units were recognized: 15 sedimentary formations and 5 volcanoclastic units. Igneous rocks constitute the coastal batolith and minor plutons. Volcanoclastic units are more prone to weathering and erosion.

Strong rainfall in 1983 removed great volumes of fluvial sediments not considered in previous studies before the construction of Callito Ciego Dam. If the dam would have been built before such exceptional quantities of sediment were transported, it would have retained a great part of the sediments thus diminishing the reservoir capacity by 20%.

A research study on the sedimentological impact of the strong runoff resulted in an evaluation of the sediment transport in Jequetepeque river basin during 1983. This study considered16 hydrological years (1968 - 1984) with a transport of suspended material at Ventanillas station of 45'474,515.90 m^3. The maximun annual transport was registered in 1982-1983 hydrological year with 22'057,141 m^3, and the minimum in 1977-1978 with 19,305.7 m^3.

The calculated volume of transported coarse sediments (grain size superior to 20 mm) was 7'317,500 m^3 and of finer sediments (20-2 mm) was 1'945,000 m^3. The total volume of transported fluvial sediments, including suspended materials, was of 31'319,641 m^3 in 1982-1983 hydrological year (Teves, 1986).

Hydrological year	Annual water mass (millions of m^3)	Annual mass of suspended sediments (m^3)
1968 - 1969	640.2	1'477, 541
1969 - 1970	627.0	301, 367
1970 - 1971	1,192.0	3'876, 407
1971 - 1972	996.7	1'499, 798
1972 - 1973	1,193.5	3'083, 254
1973 - 1974	901.0	692, 947
1974 - 1975	1,081.6	2'687, 914
1975 - 1976	844.0	366, 301
1976 - 1977	854.9	1'314, 663
1977 - 1978	264.0	19, 304
1978 - 1979	601.8	680, 802
1979 - 1980	88.6	58, 307
1980 - 1981	819.4	1'781, 603
1981 - 1982	425.0	142, 473
1982 - 1983	2,074.9	22'057, 141
1983 - 1984	1,561.3	5'428, 690

Table 1 - Suspended sediments transport at Ventanillas station (Jequetepeque river).

5. COMPARISON WITH PREVIOUS EL NIÑO EVENTS

The erosion and sedimentation processes of the northern coastal rivers were exceptional during the 1982-1983 El Niño phenomenon, which would have a recurrency of 300 years. In base of compiled information Vreeland (1985) recognized three events of this type: 500 B.C., 1,100 A.D. and 1982-83 and established a "mythological El Niño" every 850 years.

A comparison of volumes of transported sediments by the Jequetepeque river during the last 20 years suggests a relation between the intensity of the El Niño events and the amount of fluvial transported sediments. The transport of suspended sediments by the Jequetepeque river was 22'057,141 m^3 in 1982-1983, 3'083,254 m^3 in 1972-1973 and 1'314,663 m^3 in 1976.

Detailed studies in Piura and Jequetepeque rivers in 1982-1983 would allow to establish a relationship between these catastrophic events and the origin of the Holocene beach ridges developed north of Chira, Piura and Santa river mouths and in Colan. The dating of the 8 beach ridges preserved in Colan ranged from 3,200 to 800 years B.P. Radiocarbon dating of shells and charcoal fragments have given a relative chronology with lapses that vary from one to four centuries between the formation of each littoral ridge (Ortlieb *et al.*, 1989).

The calculated volumes of eroded and transported sediments in Piura and Jequetepeque rivers are comparable with those of the beach ridges and it is suggested that a direct relationship between the two features may be deduced: exceptional El Niño events produce abnormally high river discharges erosion and transport to the coastal areas where coastal and nearshore processes build longshore bars and beach ridges after periods of strong wave action and erosion.

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