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Holocene Sea Levels in Anegada Bay, Argentine Republic

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ABSTRACT

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This paper analyzes littoral deposits of the Holocene transgression in Anegada Bay, Argentine Republic (39°50'S to 40°00'S and 62°15'W). At least five transgressive episodes were identified as Transgresive Stages (TS 0 to V) being marked by barrier island and lagoon development. Their Probable Geological Age (PGA = the minimum ^{14}C age) and Approximate Ages (AA = with ^{14}C ages obtained from mollusk-shells in life position), are: TS-0 = 6560 ± 130; TS-I = 6190; TS-II = 5570; TS-III = 5200; TS-IV = 4350 and TS-V = 3600 BP. The TS-I represents the maximum Holocene Transgression and the TS-0 corresponds to a previous event. Both could be related to maximum solar activity peaks (thermoeustatic transgression). The younger TS (TS-II to V) show minor transgressive episodes which could be related to exceptionally high tides (coincident with the Progressive Cycle of the Lunar Perigee) and to high wave-energy episodes (exceptional storms). The storm episodes could be coupled to episodic events of great magnitude such as the ENSO (past ENSO-like = El Niño Southern Oscillations events). These kind of events might have caused massive sediment pulses and changes in the direction of the littoral drift.

ADDITIONAL INDEX WORDS: *Barrier islands, radiocarbon dating, ENSO, eustasy, Lunar Perigee.*

INTRODUCTION

A summary of results obtained and published in previous papers by the author and colleagues is presented together with new field data and ^{14}C dates. The main objective of this work is to provide data that will help to determine the eustatic behavior of this area and its relation with surrounding areas, in order to acquire prior knowledge of the future eustatic behaviour.

This work is part of the activities developed in the frame of the "Paleoclimate and Geochronology of the late Pleistocene and Holocene in mid-latitudes in the Argentine Republic" Research and Development Program, Project N°039 19608/85, of the Consejo Nacional de Investigaciones Cientificas y Técnicas (CONICET), in an area that extends from 33°S to 44°S. The study area is located at 62°30'W and from 39°55'S to 40°13'S (Figure 1). Aerial photographs obtained by the Instituto de Fotointerpretación Argentino (IFTA), topographic maps of the Instituto Geográfico Militar (IGM) on a scale of 1:50,000, and field observations were used to make the map shown in Figure 2.

The presence of quarries opened to obtain gravel and sand used in the construction and improvement of neighboring roads, and the canals made by Corporación Frutihortícola del Río Colorado (CORFO) provided data for analysis of the profiles. Different sedimentary facies were identified in the profiles. Samples were taken to determine the calcareous microfauna (foraminífers and ostracods) and for ^{14}C dates. Dates were made in the ^{14}C Laboratory of the Instituto de Geocronología y Geología (INGEIS).

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PREVIOUS STUDIES

Many authors made reference to changes in the sea level that took place during the Quaternary in the coastal area that goes from the Bahía Blanca estuary to San Blas island (Figure 1) (D'ORBIGNY, 1842; DARWIN, 1842; BRAVARD, 1857; AMEGHINO, 1880; DOERING, 1882; ROTH, 1898; WITTE, 1916; GROEBER, 1952; AUER, 1959, 1970; CORTELEZZI *et al.*, 1965; CORTELEZZI and DILLON, 1974; CAPPANINNI and LORES, 1966).

GONZALEZ *et al.*, (1886, 1988a and b), and WEILER, (1988a, 1993, 1996) remarked on the presence of littoral deposits corresponding to relatively high marine levels which occurred during the late Pleistocene (Sangamon? and Mid-Wisconsian) in the Río Colorado delta and in Anegada Bay.

The Holocene littoral deposits of these areas were analyzed by CODIGNOTTO and WEILER (1980), GONZALEZ and WEILER (1983), WEILER (1983, 1988b, 1993 and 1996). In this way WEILER (1983), made a geomorphological analysis of the Holocene barrier islands located in the Río Colorado delta and north of Anegada bay.

The littoral deposits of the Holocene in Bahía Blanca estuary, the Río Colorado delta, and north of Anegada Bay, originated after the maximum Holocene Transgression (*ca.* 6000 BP), during high energy periods identified as Trans-

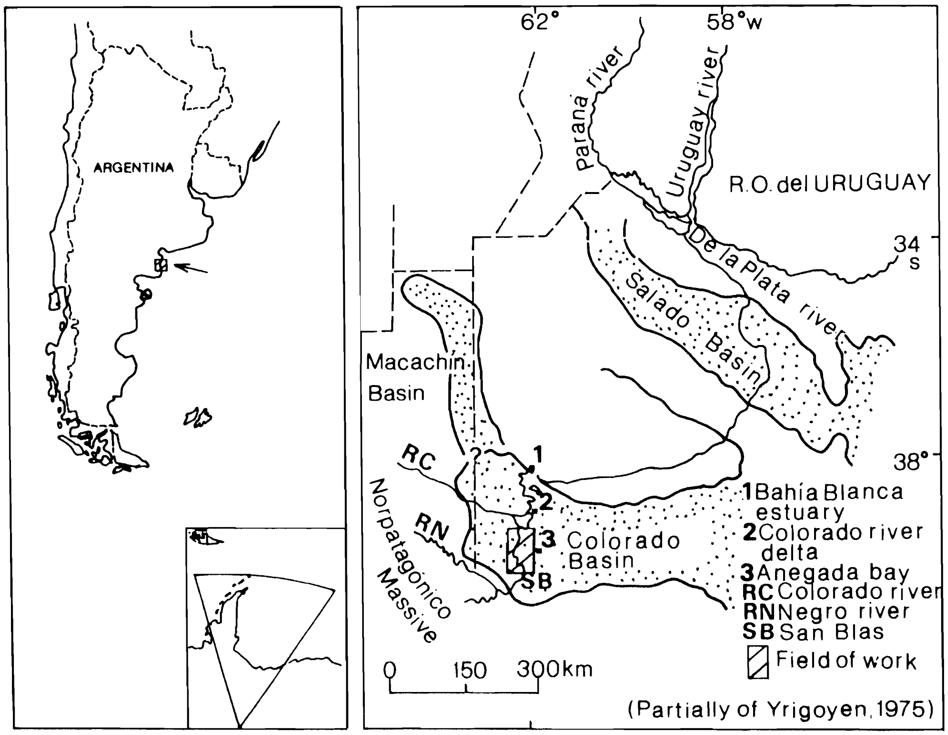

Figure 1. General location.

gressive Stages (GONZALEZ and WEILER 1983). These episodes, according to the same authors, have a periodicity of about 500 years, seem to be coupled also to exceptional high tide events which occur when the moon is closest to the earth (the Culmination of the Perigee Progression), every 556 years.

WEILER and GONZALEZ (1990) made a statistical analysis based on 96 ^{14}C dates from a littoral strip between 33°S and 41°S. Most of them came from to the Bahía Blanca estuary, the Río Colorado delta, and the northern sector of Anegada Bay. That analysis gave evidence of three Holocene transgressive peaks that occurred at: 5550 ± 335 BP, 4225 ± 335 BP, and 3600 ± 100 BP. Besides this, WEILER (1988a,b, 1993) indicated that in the north sector of Anegada Bay, barrier islands were formed during four Transgressive Stages (TS-0; I; II; III). TS-I corresponds to the maximum Holocene transgression, TS-0 to an event previous to it, and TS-II; III to two posterior ones. WEILER (1996) also observed beach ridges littoral alignments in the mid-sector of Anegada Bay (Los Pocitos bathing resort), formed during high energy wave periods with the following ages: 4500 ± 90 BP (2 m a.s.l) and 3750 ± 150 BP (1 m a.s.l).

RESULTS

Morphology

The 35 km long and 6 km wide sector of shoreline, gradually rises from the present shoreline up to 10 m a.s.l. It is located in the central area of the morphostructural region named Cuenca del Colorado by YRIGOYEN (1975) (Figure 1). GONZALEZ *et al.* (1986) determined from the analysis of the altimetrical positions of the littoral deposits, that this area remained tectonically stable during the late Pleistocene and Holocene.

Barrier islands corresponding to the Late Pleistocene (Mid-Wisconsian) are observed between the 10 m a.s.l. and 5 m a.s.l. Their ages range from 30,000 BP to 36,000 BP (WEILER, 1988a, 1993), their length from 3 km to 3.5 km, and their width from 200 m to 300 m (Figure 2). They are correspond to beach ridges 4 m to 5 m height with respect to the adjacent surface and are composed of gravel and coarse sand horizons, with abundant mollusk-shells.

The Holocene barrier islands, which developed over a wave abrasion platform eroded over shore and lagoon deposits corresponding to the Mid-Wisconsian, are located from 5 m a.s.l. down to the present coastal line. These barrier islands and their respective lagoons are arranged in three systems decreasing in age towards the sea.

The oldest barrier islands (System 1, Figure 2) are located between 4 and 4.5 m a.s.l.. They have an average length ranging from 2 km to 2.5 km and an approximate width of 150 m to 200 m in their central part, and from 300 m to 400 m in the extremes. They are arranged in simple beach ridges sets without truncation surfaces. Though these barriers do not possess clear morphologic evidence from which to determine the drift paleocurrent direction, their increasing width toward the southern extremes would indicate that the current was oriented towards the south.

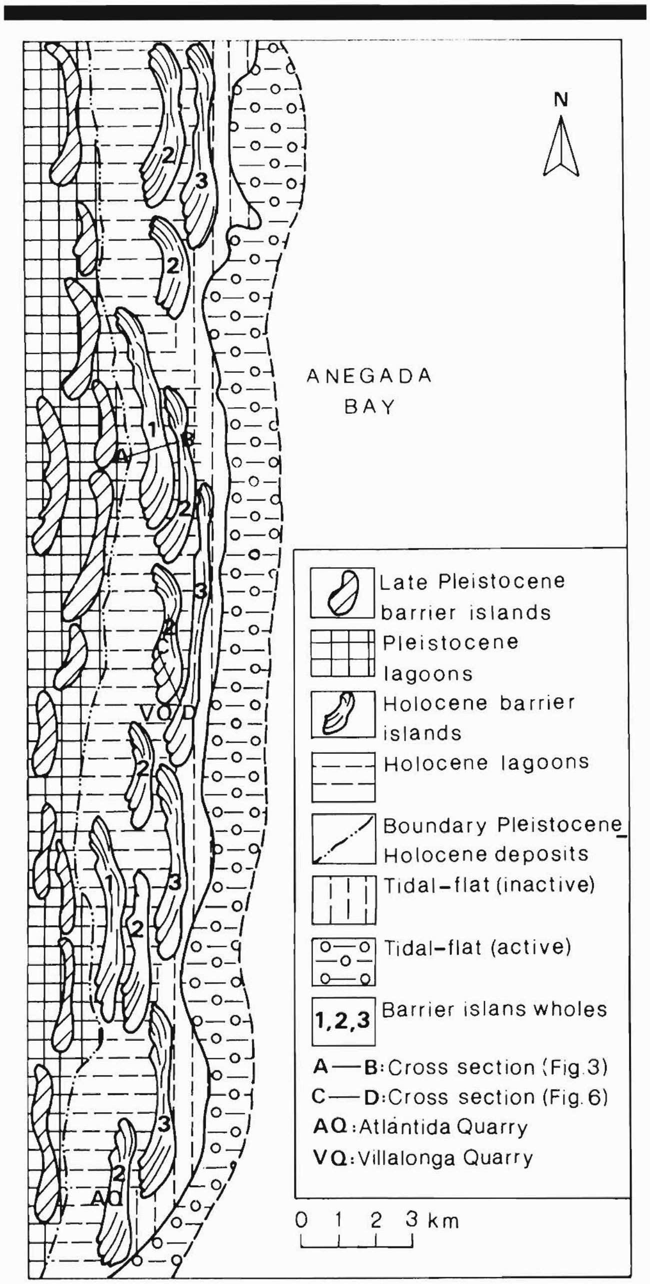

Figure 2. Detail of the geoforms in the Anegada bay.

The intermediate age barrier islands (System 2, Figure 2), located from about 2,50 m to about 3 m a.s.l. Their average length is 3 km to 4 km. They are wider toward the south reaching from 500 m to 600 m, while to the northern extreme they only reach 200 m to 600 m, looking in occasions like barrier spits (Figure 2). This clearly indicates a north-south direction of the drift current when they were formed, while at present the current has a south-north direction. The beach ridges that characterize these barriers show internal truncations in different sectors that would indicate changes in the dynamics of the environment after they were formed. This dynamic change would indicate a slight rise in the sea level, during which the preexistent ridges were in part eroded, with a change in the littoral drift, which allowed the transport of the material to the south.

The youngest system of barrier islands (System 3) is located from 2 m to 1.5 m a.s.l. and is composed by forms 5 km to 6 km long, and a with increasing from 100 m to 200 m in the center, to 300 m to 400 m in the curved extremes. They are more elongated that those of to System 2, and the beach ridges are often truncated into sectors, with new beach ridges added. This feature would indicate as in the former case, a southward drift tendency of these landforms. The lagoons are morphologically represented by narrow and slightly depressed zones ("swales"), located landward of the beach ridges which conform to the barrier islands. According to Hoyt (1967), the limited development of these lagoons would indicate that the barrier islands were formed during transgressive events.

A tidal flat with a gentle seaward slope extends to the east of the barrier islands, from 1.50 m a.s.l. down to the level of the daily maximum tide level. Two different zones are observed from west to east, the highest one only floods during spring tides, while the lower one that is crossed by numerous tidal channels, floods with the daily tides. Each zone has a different vegetative association. Over the inactive tidal flat deposits, composed by silty-clay sand with an incipient edaphic development, there is a halophyte vegetal community. It is mainly composed of species of the genera *Salicornia, Atriples, Scirpus, Heliottropium, Sesevium, Limonium,* and *Cressa* sp.

The active tidal flat is characterized by a silt-clay deposit marked by crab community proliferates and small barren islands with a vegetal (rush) only community primarily of *Juncus actus*. These environments represent the present lagoon but is very different from those of the Holocene which developed in a low-energy coastal environment.

Stratigraphy

Beach Ridge Deposits

(1) Location: These deposits are parallel at subparallel to the present shoreline above 4 m a.s.l., conforming with the beach ridges of the barrier islands (Figure 2).

(2) Description: (a) Lithology: The upper part of these deposits is in general 5 m to 6 m thick (Figures 3, 5, and 6). Their base is composed of medium gravel (3 cm to 4 cm), ranging to the top layers with layers of finer gravel (2 cm), and parallel-bedded fine to coarse sand. These materials have a planar cross-bedded structure, with slopes of approximately 15° to 20° seaward, in a typical foreshore facies (*sensu* Spalletti, 1980). The gravel beds are dominated by volcanic rock pebbles mainly ryolites, andesites, and basalts), from the "*Rodados Patagónicos*" (a local name given by Fidalgo and Riggi, 1970 for the sandy gravels capping the Patagonian Plateau from the coast to the Andes), and "tosca" pebbles (local name for carbonate crusts, caliche, or calcrete). The *Rodados Patagónicos* were transported to the sea by Patagonian rivers and carried along the coast by the littoral drift currents. In this coastal sector there is a significant

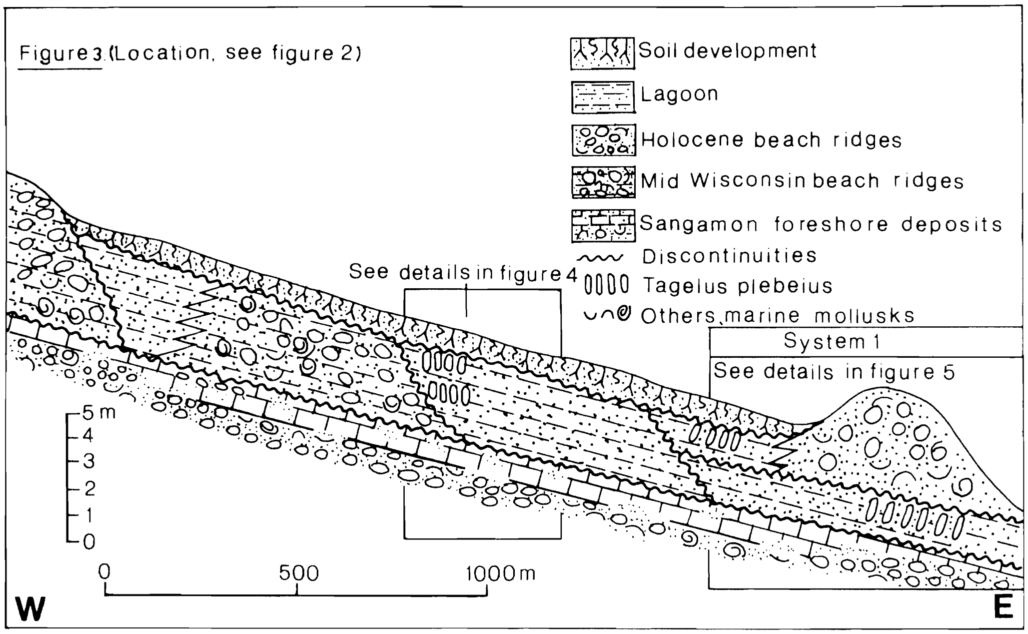

Figure 3. Cross section over Late Pleistocene-Holocene deposits (A–B in Figure 2).

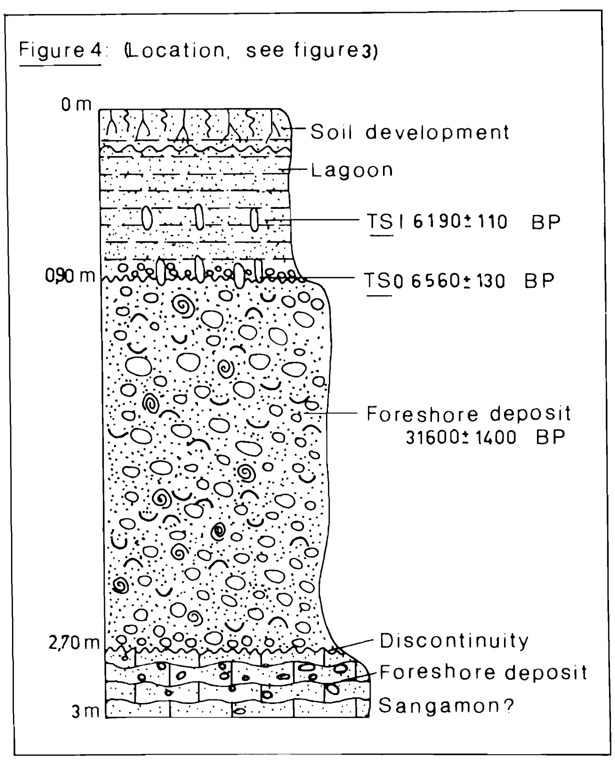

Figure 4. Detail of figure. Late Pleistocene beach ridge and Holocene lagoon deposits.

contribution of sediments from the Río Negro as a consequence of the present south-north littoral drift. In the case of a reversal of the littoral drift, the sediment contribution would come from the Río Colorado.

(b) Biological elements: Marine mollusk-shells from different habitats and mixed by waves are frequently found in these beach ridges. The following species were identified among the bivalves: *Pitar rostrata* (Koch), *Glycymeris longior* (Sowerby), *Amiantis purpurata* (Lamark), *Crassostrea rizophoras* (Guilding), *Chlamys tehuelchus* (d'Orbigny), *Erodona mactroides* (Daudin), *Carditamera plata* (Ihering), *Tivela isabelleana* (d'Orbigny) and, among gastropods, *Olivancillaria urceus* (Roding), *Buccinanops globulosum* (Keiner), B. *deformis* (King); *Tegula patagonica* (d'Orbigny), *Crepidula aculeata* (Gmelin); Natica isabelleana (d'Orbigny), Anachis isabellei (d'Orbigny), *Calliostoma carcellesi* (Clench-Aguayo), and others in fragments, (FARINATI, personal communication). The Zidona angulata Swaison and the Adelomedon Dall, both are big gastropods, abundant in the sandy beds.

(c) Stratgraphic relations: The deposits corresponding to the beach ridges of systems 1, 2, and 3 of the barrier islands (Figure 2, A–B transect) rest with a in discordance on the oldest lagoon deposits (Figures 3, 5 and 6).

Lagoonal Deposits

(1) Location: These deposits are located landward of the barrier islands and parallel to them (Figure 2).

(2) Description: (a) Lithology: In most cases the lagoon deposits do not exceed 1.50 m to 2 m in elevation (Figures 3, 4, 5, and 6). They are composed of very fine silty sand mixed with some small, sparse gravels. The gravels are gray-green-

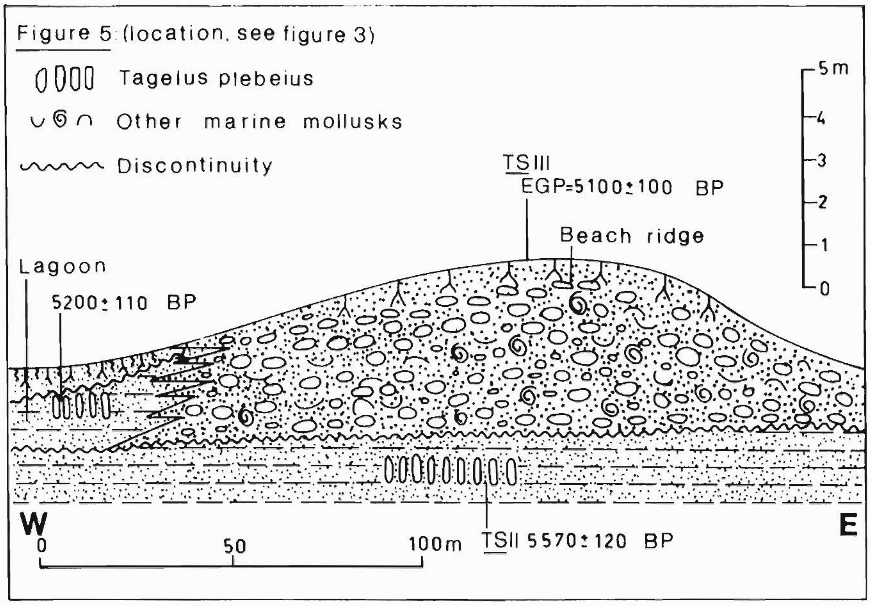

Figure 5. Detail of figure. Holocene beach-ridge and lagoon deposits.

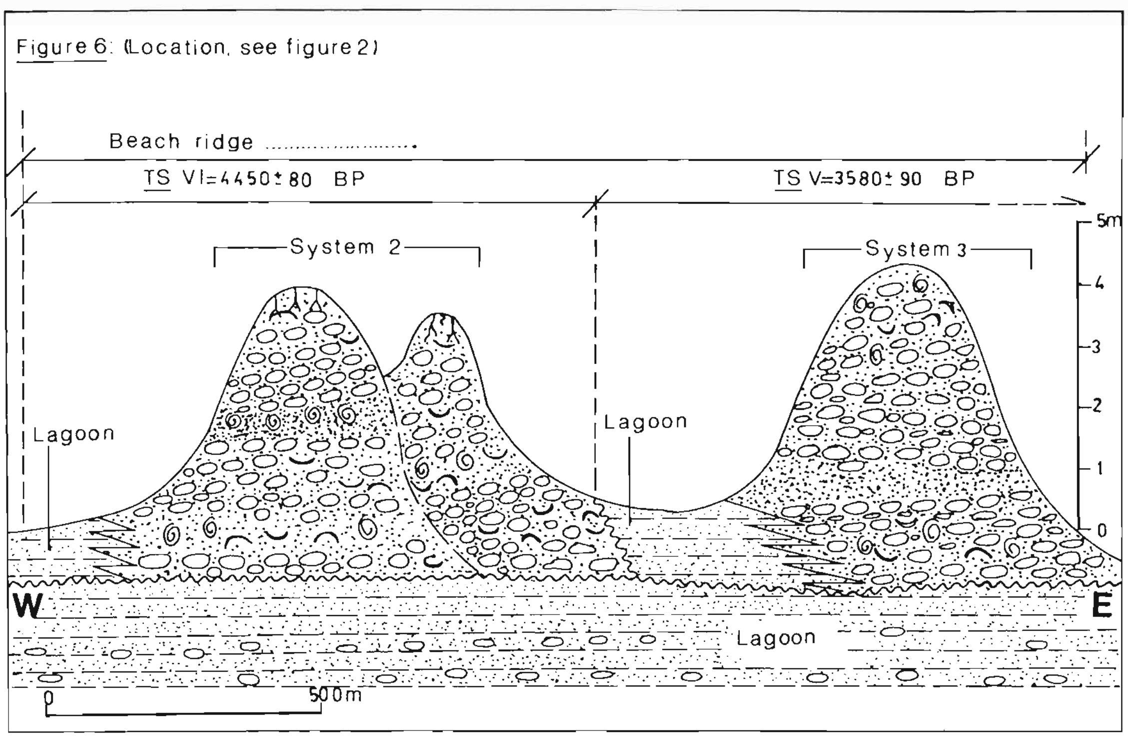

Figure 6. Cross-section over Holocene beach-ridge and lagoon deposits (C–D in Figure 2).

ish in their bases and red-brownish at their tops. They present hydromorphisms (red and yellow spots and dark concretions and small biogenic cylindrical root bore-holes and worms), which show a weak edaphic development, similar to the present one.

(b) Biological elements: these deposits have abundant shells at one or two levels. The Tagelus plebeius (Lightfoot), which are articulated and in life position (Figures 3, 4, and 5), and some *Littordina* sp valves. Also are the following microfossil species: *Bolivina striatula* Cushman; *Elphidium* gunteri Cole; *E. discoidale* d'Orbigny; *Fissutina* sp; *Rotalia becarii parkinsoniana* d'Orbigny; *Buccela frigida* (Cushman); *B. Peruviana campsi* Boltovskoy (Foraminífers); *Callistocythere* sp; *Cytheropteron* sp; *Cypredeis* sp (Ostrácodes) (GARCIA, personal communication).

(c) Stratgraphic relations: The oldest lagoonal deposits were found discordantly over Mid-Wisconsian interestadial transgressive deposits (see Figures 3 and 4). Generally, they are topped by an erosional discordance corresponding to the barrier island deposits (see Figures 3, 5 and 6).

Geochronology

All the radiocarbonic dates used in this work are presented uncalibrated or "corrected", in years before present referred to 1950. They were obtained in the INGEIS laboratory (CONICET-Argentina), with the methodology described by ALBERO *et al.*, (1980). Analytic data and ^{14}C ages corresponding to each deposit are shown in Tables 1 and 2.

The ^{14}C samples for the analysis were originated in:

(a) High energy coarse sediment deposits. In this case mollusk-shells are re-worked and redeposited. Thus, their ages were considered as not representative of the time in which the sampled deposit was formed. The *Probable Geologic Age* (PGA) criteria was applied according to GONZALEZ and WEILER (1983). The PGA is considered to be the minimal age obtained of a single high energy deposit. According to this critereon, a deposit can be younger but not older than the PGA and the PGA thus represents a Maximum Age.

(b) Low energy deposits (lagoons): Mollusks shells in life position were selected to obtain dates in this kind of deposits. Their respective ^{14}C ages were considered positively representative of the time of origin of the deposit (AA = *Approximate ages*). The existence in this area of at least six episodes during which there was a rise in sea level, was proved from the ^{14}C ages obtained. These rises caused the migration of the barrier islands toward the mainland. This can be seen in the basal relations of the deposits as the beach ridges of these barriers are in discordance with the lagoon facies. These episodes were named Transgressive Stages (TS) 0, I, II, III, IV, V, and V, according to GONZALEZ and WEILER (1983).

They have the following ^{14}C ages:

TS-0: 6560 ± 130 BP (AA) 4.50 m a.s.l.

TS-0: 6190 ± 130 BP (AA) 5.00 m a.s.l.

TS-0: 5570 ± 120 BP (AA) 3.00 m a.s.l.

TS-0: 5200 ± 100 BP (AA) 3.50 m a.s.l.

TS-0: 4470 ± 80 BP (PGA) 2.50 m a.s.l.

TS-0: 3580 ± 90 BP (PGA) 1.50 m a.s.l.

These transgressive Stages coincide in age and height above sea level with those described by GONZALEZ and WEILER (1983) for the Río Colorado delta, and the Bahía Blanca estuary (GONZALEZ, 1989), except that in this case another stage(TS-0) was found. On this latter stage deposits rest on the ones corresponding to the maximum transgression of the Holocene.

Lagoon deposits whose corresponding barrier islands were eroded, are represented by the TS-0, I, and II stages. The TS-III corresponds to a lagoonal deposit together with its beach ridge deposit. The TS-IV and V are represented only by the barrier deposits. It was also observed that those TS present a periodicity of around 500 ± 100 years.

DISCUSSION

The littoral deposits examined were formed during the fluctuations of sea level following the melting of the last great Glaciation of the late Pleistocene, known as the Postglacial Transgression. From a geomorphological, stratigraphical, and geochronological point of view, these deposits can be clearly distinguished from those of the late Pleistocene (Mid-Wisconsian).

The Holocene Transgression does not seem to mark a simple sea-level rise cycle and a continuous fall to the present level. The sedimentary record and the ^{14}C dates pose some problems that require different interpretations. The deposits corresponding to the TS 0 and I are considered to be related to the global warming episode (maximum solar activity peaks) which characterized the Mid-Holocene (SISCOE 1978). The TS II, III, IV, and V are probably related to other events which led to progressive of the marine sea levels of less magnitude.

According to GONZALEZ and WEILER (1983), and GONZALEZ (1989), two main factors determined the origin of the Holocene beach ridges in the Bahía Blanca estuary and in the Río Colorado delta. The first and most important one responds to the solar activity peaks identified by SISCOE (1978), which coincided with the major transgression of the Holocene (termoeustatic transgression) represented by TS-I (PGA = *ca.* 6000 BP). The second factor seems to be related to the Progression of the Lunar Perigee Cycle, which could have caused unusual tidal episodes when the moon was closest to the earth, along with the general regressive trend. According to the same authors, these episodes are represented by each TS younger than TS-I, and their ^{14}C ages are be related to a probable periodicity of about 500 years (GONZALEZ and WEILER 1983).

Therefore, the ST-0 and I in this area are probably related to the maximum solar activity peaks referred to by SISCOE (1978). The remaining (TS II to V) are coincident with the Progression Cycle of the Lunar Perigee, probably enhanced by important storm events when high wave-energy would have caused the barrier islands migration toward the continent.

It is important to consider that a rise in the sea level alone is not a sufficient condition for the beach barrier system to migrate landward, as the major sediment transport only occurs only during extreme events (LEATHERMAN, 1980). An

Table 1. *Analytical dates of the ^{14}C ages presented in this paper.*

Sample N	Activity ^{14}C %	$\delta^{13}C$ Sample	Activity Standard NBS cpm %	Activity Back Ground cpm	$\delta^{13}C$ Standard	Age Years Before Present
AC-0052	36.00 ± 0.27	0.98 ± 0.03	53.9 ± 0.6	10.08 ± 0.10	−10.84 ± 0.04	4,850 ± 90
AC-0053	31.04 ± 0.20	0.99 ± 0.03	30.4 ± 0.4	12.05 ± 0.09	−10.84 ± 0.04	9,460 ± 120
AC-0054	32.60 ± 0.27	1.65 ± 0.03	47.2 ± 0.6	9.98 ± 0.07	10.84 ± 0.04	5,900 ± 100
AC-0055	31.45 ± 0.27	0.59 ± 0.06	42.5 ± 0.5	10.91 ± 0.10	19.00 ± 0.3	6,760 ± 100
AC-0239	34.67 ± 0.46	1.50 ± 0.50	57.06 ± 0.27	10.83 ± 0.08	19.00 ± 0.1	5,140 ± 110
AC-0240	34.67 ± 0.45	1.50 ± 0.50	57.06 ± 0.27	10.56 ± 0.10	19.00 ± 0.1	5,305 ± 165
AC-0240 bis	34.25 ± 0.28	1.60 ± 0.20	57.53 ± 0.12	10.91 ± 0.10	−19.00 ± 0.1	5,590 ± 110
AC-0244	26.60 ± 0.23	1.90 ± 0.20	57.06 ± 0.27	10.56 ± 0.11	19.00 ± 0.1	8,590 ± 135
AC-0245	26.30 ± 0.23	1.10 ± 0.20	57.06 ± 0.27	10.56 ± 0.11	−19.00 ± 0.1	8,720 ± 110
AC-0246	35.10 ± 0.26	1.20 ± 0.30	56.76 ± 0.12	10.54 ± 0.10	19.00 ± 0.1	5,100 ± 100
AC-0252	28.78 ± 0.40	1.60 ± 0.20	57.06 ± 0.27	10.56 ± 0.11	19.00 ± 0.1	7,560 ± 190
AC-0252 bis	25.20 ± 0.23	1.40 ± 0.20	57.18 ± 0.13	10.80 ± 0.10	−19.00 ± 0.1	9,420 ± 150
AC-0253	28.31 ± 0.24	1.30 ± 0.30	56.85 ± 0.12	10.38 ± 0.09	19.00 ± 0.2	7,850 ± 130
AC-0362	35.95 ± 0.27	1.10 ± 0.20	56.85 ± 0.12	10.38 ± 0.09	19.00 ± 0.2	4,820 ± 100
AC-0363	35.23 ± 0.25	1.10 ± 0.20	56.85 ± 0.12	10.38 ± 0.09	−19.00 ± 0.2	5,050 ± 100
AC-0464	37.64 ± 0.19	1.60 ± 0.10	57.47 ± 0.24	10.09 ± 0.10	−18.60 ± 0.1	4,380 ± 80
AC-1013 bis	32.67 ± 0.26	0.80 ± 0.30	57.06 ± 0.27	10.56 ± 0.27	−19.00 ± 0.2	5,980 ± 90
AC-1014	33.69 ± 0.34	1.90 ± 0.30	56.85 ± 0.12	10.38 ± 0.09	19.00 ± 0.2	5,570 ± 120
AC-1017	35.68 ± 0.27	1.40 ± 0.20	57.53 ± 0.23	10.91 ± 0.10	19.00 ± 0.1	5,200 ± 100
AC-1020	26.70 ± 0.22	1.89 ± 0.20	57.05 ± 0.26	10.55 ± 0.10	−19.00 ± 0.2	8,570 ± 120
AC-1021	31.46 ± 0.25	1.03 ± 0.30	57.52 ± 0.23	10.90 ± 0.11	−19.00 ± 0.2	6,560 ± 130
AC-1021 bis	32.57 ± 0.30	2.30 ± 0.10	57.37 ± 0.22	10.57 ± 0.08	−19.00 ± 0.2	6,190 ± 110
AC-1065	32.67 ± 0.25	1.50 ± 0.30	57.06 ± 0.27	10.56 ± 0.09	−19.00 ± 0.2	5,960 ± 120
AC-1129	33.35 ± 0.28	1.31 ± 0.20	58.84 ± 0.11	10.80 ± 0.09	−19.00 ± 0.2	5,630 ± 170
AC-1202	34.59 ± 0.33	1.87 ± 0.30	56.83 ± 0.12	10.37 ± 0.09	−19.00 ± 0.2	4,450 ± 80
AC-1205	37.15 ± 0.26	1.00 ± 0.10	57.30 ± 0.15	9.95 ± 0.07	18.40 ± 0.2	4,350 ± 90
AC-1216	36.90 ± 0.32	2.90 ± 0.30	57.30 ± 0.17	9.35 ± 0.06	−18.30 ± 0.2	8,660 ± 110
AC-1217	26.61 ± 0.23	1.89 ± 0.30	57.05 ± 0.26	10.54 ± 0.10	−19.00 ± 0.1	3,560 ± 90
AC-1221	39.95 ± 0.27	2.40 ± 0.20	56.56 ± 0.23	9.56 ± 0.09	−20.00 ± 0.2	3,780 ± 100
AC-1224	40.05 ± 0.23	2.40 ± 0.20	61.47 ± 0.81	13.34 ± 0.15	−20.56 ± 0.3	3,870 ± 60

example of one such extreme events was the case when the storms are still more effective when coincident with spring high tides, as it happened in 1962 from Cape Hatteras to Cape Cod, USA, as well as in northern Europe, in the North Sea (WOOD, 1976, 1985). This author has listed all the simultaneous occurrences of catastrophic coastal storms and perigean tidals that occurred from 1635 to 1976, on the east coast of the United States.

These major wave-energy episodes in Anegada Bay, which took place during a period starting 6000 BP and continuing at least until 3600 BP, could have been associated with unusual storm events marked by persistent northeast winds. The persistence of the northeast winds, may have even caused a change in the direction of the littoral drift current. Easteriles are intensified during warming episodes, causing abundant rain over the Pampean region and even over Patagonian regions. Important landforms and high energy deposits probably originated with an increase of wave-energy here.

SANDWEISS (1986) explained the origin of the beach ridges along the Pacific coast, as being a consequence of the episodic events of great magnitude (*e.g.* past ENSO = El Niño Southern oscillation events). He assumed that episodes similar to the present ENSO, characterized by rainfall anomalies and changes in the wind direction, would have caused massive pulses of sediment accumulation which formed the littoral deposits. Later, FOURNIER *et al.* (1990) and MACHARE *et al.* (1990), related the formation of the littoral beach ridges in Colan (Northwest of Peru), from 3500 to 900 BP, to major El Niño events. ORTLIEB *et al.* (1989) observed that according with the ^{14}C ages, 100 to 1000 years passed from the formation of one of the beach ridges until the formation of the next. Paleoclimatic data of the last 7000 years showed signals similar to those of the Southern Oscillation (a larger amount of rain, a larger contribution of sediments, and reversals in the direction of the littoral drift) in the Brazilian coast (MARTIN *et al.* 1993).

Both, the southward outlet of the tidal inlets of the barrier islands in systems 1 and 3, and the increasing width in the same direction of the barrier islands of System 2, show the occurrence of a reversal in the littoral drift current with respect to the present one, at least during the Transgressive Stages III, IV, and V. The probable persistence of strong northeast winds could have been related to the same climatic phenomena that caused effects similar to those of EL Niño Southern Oscillation (changes in the atmospheric circulation and an increase in air temperature and humidity).

A periodicity of about 400 to 500 in the oscillations of the Holocene sea level has been observed by others specialists (FAIRBRIDGE, 1976; FAIRBRIDGE and HILLARIE-MARCEL, 1977; VAN DE PLASSCHE, 1982; MORNER, 1976; COLQUHOUN *et al.*, 1981; FOURNIER, *et al.*, 1990). A higher frequency was observed between 4700–4300 BP and 3800–3500 BP (COLQUHOUN *et al.*, 1981 and COLQUHOUN, written communication).

Table 2. *Geoforms and ages of each transgressive stage.*

Sample N°	Age BP	Sample Location in Each Profile and Corresponding Geoform	Transgressive Stages and Probable Geological and Approximate Age (PGA and AA bp)
AC-1021	6,560 ± 130	Lagoon figures 3 y 4	TS-0 = 6,530 ± 130 (AA)
AC-1021bis	6,190 ± 130	Lagoon figures 3 y 4	TS-I = 6,190 ± 130 (AA)
AC-1014	5,570 ± 120	Lagoon figures 3 y 5	TS-II = 5,570 ± 120 (AA)
AC-1017	5,200 ± 100	Lagoon figure 5	TS-III 5,200 ± 110 (AA) 5,100 ± 100 (PGA)
AC-0240	5,300 ± 165	Beach ridge System 1 figure 2	
AC-0240bis	5,590 ± 110		
AC-0246	5,100 ± 100		
AC-0054	5,900 ± 110		
AC-1129	6,130 ± 120		
AC-0055	6,760 ± 100		
AC-0239	5,140 ± 100		
AC-1013bis	5,980 ± 90		
AC-1202	5,630 ± 170		
AC-1065	5,900 ± 120		
AC-0252	7,560 ± 190		
AC-1065bis	5,960 ± 120		
AC-0362	4,820 ± 90	Beach ridge System 2 figure 2	TS-IV = 4,450 ± 80 (PGA)
AC-0052	4,850 ± 90		
AC-1205	4,450 ± 80		
AC-0253	7,850 ± 130		
AC-0363	5,050 ± 100		
AC-1217	8,660 ± 110		
AC-0053	9,460 ± 120		
AC-1204	11,300 ± 180		
AC-0464	4,380 ± 90	Beach ridge System 3 figure 2	TS-V = 3,580 ± 70 (PGA)
AC-1221	3,870 ± 60		
AC-1216	4,350 ± 90		
AC-1224	3,580 ± 90		
AC-0245	8,720 ± 140		
AC-0252	9,420 ± 150		
AC-0244	8,570 ± 135		

RICHARDSON (1983), also determined a 500 years periodicity in the formation of the littoral beach ridges in the Peruvian coast (Chira), from anthropogenic radiocarbon dates.

Furthermore, Table 1 shows one age of 11,300 ± 180 BP, two ages close to 9500 BP (9460 ± 120 and 9420 ± 150), four ages of approximately 8700 BP (8720 ± 140; 8590 ± 150; 8660 ± 110 and 8570 ± 120) and two ages of about 7800 BP (7850 ± 130 and 7560 ± 190) (beach ridges) whose PGA is essentially earlier. WEILER and GONZALEZ (1990) also believed that samples between *ca.* 11,300 BP and *ca.* 9,500 BP, belonged to deposits formed during high wave-energy pulses, before the maximum of the Post-glacial transgression, when the sea level was somewhat below, or close, to the present one. These authors, related those pulses to the 23,000 years planetary cycle of precession of the equinoxes, described by MILANKOVITCH (1941).

It is considered that only one or two ages for each of the datings is not enough to make a definite interpretation. It is believed that those ages are associated to previous ones as barrier islands in this area could have migrated landward as the sea level rose (KRAFT *et al.*, 1973, FISHER and SIMPSON 1979, and COLQUHOUN and GUILCHER, 1981). Thus, some of the materials in the barrier islands beach ridges (clastics and bioclastics) may have migrated and have been redeposited together with younger materials. Therefore, some of the beach ridges show also ages from *ca.* 8700 and 7600 BP. It is important to mention that the valves used to obtain these ages were not seriously eroded as if they had not been transported for a long distance. KOKOT *et al.* (1993), suggested the probable existence of barrier paleislands submerged in front of the southern coast of Anegada Bay.

CONCLUSIONS

(1) It was observed that fluctuations in the sea level occurred in the area during the Holocene, from 6590 to 3660 BP, leaving the barrier islands as evidence.

(2) The barrier islands of this area, migrated landward during the rise in the sea level. This happened at least since 11,000 BP up to the time when they reached the transgressive maximum at about 6000 BP (TS = 5 m a.s.l.)

(3) During the development of the transgressive-regressive cycles of the Holocene, there were at least six episodes characterized by an exceptionally energetic weaving, during which the barrier islands migrated inwards continent. These six episodes were named Transgressive Stages (TS) 0 to V and their respective ages are as follows:

TS-0: 6530 ± 130 BP (prior to the maximum Transgression of the Holocene)

TS-I: 6190 ± 130 BP (posterior to the maximum Transgression of the Holocene)

TS-II: 5570 ± 120 BP (posterior to the maximum Transgression of the Holocene)

TS-III: 5100 ± 100 BP (posterior to the maximum Transgression of the Holocene)

TS-IV: 4450 ± 80 BP (posterior to the maximum Transgression of the Holocene)

TS-V: 3580 ± 90 BP (posterior to the maximum Transgression of the Holocene)

They present a periodicity close to 500 years.

(4) The ages of the I to V Transgressive Stages coincide with those seen in the Bahía Blanca estuary and in the Río Colorado delta (areas close and to the north of this location).

(5) The 0 and I Transgressive Stages could be related to the maximum solar radiation cycle (SISCOE 1978). The II, III, IV, and V Transgressive Stages might be associated to exceptional tidals coincident with Progression Cycle of The Lunar Perigee together with unusual storms. These storms might have been generated as a consequence of climatic changes related to episodic events, of the type of El Niño Southern Oscilation.

(6) The occurrence of an reversal in the direction of the littoral drift current was determined, during the ST III, IV, and V through the observation of morphology of the barrier islands in the area.

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LITERATURE CITED

ALBERO, M.C.; ANGIOLINI, F.; BALBUENA, J.L.; CODIGNOTTO, J.O.; LINARES, E., and WEILER, N.E., 1980. Primeras edades carbono-14 de afloramientos de conchillas de la República Argentina. *Asoc. Geol. Arg., Rev.* 35(3), 363–374.

AMEGHINO, F., 1880. La antigüedad del hombre el el Plata. Florentino Ameghino. *Obras Completas* y *Correspondencia Científica*, Tomo 3, 1–81. Edición Oficial del gobierno de la provincia de Buenos Aires. La Plata.

AUER, V., 1959. The Pleistocene of Fuego-Patagonia. Part. III. Shoreline Displacement. *Ann. Acd. Sci. Fennicae*, III, A. 60, 1–237.

AUER, V., 1970. *The Pleistocene of Fuego-Patagonia*. Part. V. Ann. Acad. Sci. Fennicae. A 100, 1–193

BRAVARD, A., 1857. Observaciones geológicas sobre diferentes terrenos en la hoya del Plata. *Biblioteca Diario La Prensa*. Buenos Aires.

CAPPANNINNI, D. and LORES, R., 1966. Los suelos del valle inferior del río Colorado. INTA. *Colección Suelos* N° 12, 1–127.

CODIGNOTTO, J. and WEILER N.E., 1980. Evolución morfodinámica del sector costanero comprendido entre Punta Laberinto e Isla Olga, provincia de Buenos Aires. *Simposio sobre problemas geológicos del litoral atlántico bonaerense.* CIC, Mar del Plata, Jul. 1980. Resúmenes, pp. 35–43.

COLQUHOUM, D. and GUILCHER, A., 1981. Influence of sea level change on barrier island evolution. *Oceanis*, 7(4), 327–487.

COLQUHOUN D.J.; BROOKS, M.J.; MICHIE, J.; ABBOT, W.B.; STAPOR, F.W.; NEWMAN, W., and PARDI, R.R., 1981. Location of Archaeological Sites with respect to Sea Level in the Southeastern United Stated. *Striae*, 14, 144–150.

CORTELEZZI and DILLON, 1974. Estudio de las variaciones morfológicas en las playas de la zona de San Blas, Partido de Patagones, Provincia de Buenos Aires. *LEMIT.* An. 2, 75–84 (La Plata).

CORTELEZZI, C.R.; DE SALVO, and DE FRANSCESCO, F., 1965. Estudio de las gravas tehuelches de la región comprendida entre el río Negro y el río Colorado desde la costa atlántica hasta la cordillera. *II Jorn. Geol. Arg.*, 3, 123–141.

DARWIN, CH., 1842. *Geological notes during a survey of the south and west of South America in the years 1832–35.*

DOERING, A., 1882. *Informe oficial de la comisión científica agregada al Estado Mayor General de la Expedición al Río Negro* (Patagonia) *realizada en los meses de Abril, Mayo* y *Junio de* 1879, *bajo las órdenes del General Julio A. Roca*. Geología, Entrega 3, 3a. Parte, Págs. 297–530. Buenos Aires.

D'ORBIGNY, A., 1842. *Voyage dans L'Amerique Meridionale.* Vol. 3, Part. 3. París et Strasbourg.

FAIRBRIDGE, R.W., 1976. Shellfish-eating preceramic indians in coastal Brazil. *Science*, 191, 353–359.

FAIRBRIDGE, R.W., 1990. Some Guidelines for Coastal Dating. *Note to the INQUA Holocene & Shoreline Commision Members*; Feb. 15, 1990. 4p. Unpublished.

FAIRBRIDGE, R.W. and HILLARIE-MARCEL, C., 1977. An 8000 yr. paleoclimatic record of the 'Double-Halle' 45 YR. Solar Cycle. *Nature*, 268, 413–416.

FIDALGO, F. and RIGGI, 1970. Consideraciones geomorfológicas y sedimentológicas sobre los Rodados Patagónicos. Asoc. Geol. Arg., Rev., 25(4), 430–443.

FISHER Y SIMPSON, 1979. Washover and tidal sedimentation factors indevelopment of a transgressive barrier shorelaine. *In:* S.P. LEATHERMAN, (ed.), *Barrier Islands*. New York: Academic pp. 127–149.

FOURNIER, M.; MACHARE, J., and ORTLIEB, L., 1990. Fechamiento de cordones litorales Holocenos en Colán, noroeste peruano, y cronologías de eventos mayores del fenómeno "El Niño". *2a. Reunión del Proyecto 281 del PICG: Climas Cuaternarios de América del Sur*, Medellín, May, 1990. Actas 10p.; Univ. EAFIT. *Resúmenes* y *Contrib. Científicas, Publ. Especial N° 2*, Medellín.

GONZALEZ, M.A., 1989. Holocene levels in the Bahía Blanca estuary, Argentine Republic. *Journal of Coastal Research*, 5(1), 65–77.

GONZALEZ, M.A. and WEILER, N.E., 1983. Ciclicidad de niveles marinos holocénicos en Bahía Blanca y en el delta del río Colorado (Provincia de Buenos Aires), en base a edades carbono-14. In: *Oscilaciones del nivel del mar durante el Hemiciclo Deglacial en Argentina* (Mar del Plata), *IGCP Proyect N° 61*. Actas, 69–90.

GONZALEZ, M.A.; WEILER, N.E., and GUIDA, N.G., 1986. Late Pleistocene transgressive deposits from 33° S.L. to 40° S.L., Argentine Republic. *Journal of Coastal Research*, Special Issue N° 1, pp. 39–48.

GONZALEZ, M.A.; WEILER, N.E., and GUIDA N.G., 1988a. Late Pleistocene and Holocene Coastal Behaviour From 33° S.L. to 40° S.L. (Argentine Republic). *Journal of Coastal Research*, 4(1), 59–68.

GONZALEZ, M.A.; GUIDA, N.G., and WEILER, N.E., 1988b. Transgressive Deposits of the Mid Wisconsin Interstadial From 33° S.L. to 40° S.L. (Argentine Republic). Reability of its Carbono-14 Ages. *Journal of Coastal Research*, 4(4), 667–676.

GROEBER, P., 1952. Resumen preliminar de las observaciones realizadas en el viaje a la región de Bahía Blanca en Enero de 1947. *Notas del Museo de La Plata*, T. XIV, N° 57: 239–266.

HOYT, J. H., 1967. Barrier island formation. *Geological Society America Bulletin*, 78(9), 1125–1136.

KOKOT, R.R.; MARCOMINI, S., and CODIGNOTTO, J.O., 1993. Islas de barrera sumergidas y geoformas asociadas frente a bahía Anegada. provincia de Buenos Aires. *3as. Jornadas Nacionales de Ciencias del Mar.* Resúmenes. p. 184.

KRAFT, J.C.; BIGGS, R.B., and HALSEY, S.D., 1973. Morphology and vertical sedimentary sequence models transgressive barrier systems. *In:* D.R. COATES, (ed.), *Coastal Geomorphology.* Binghamton, New York: State University of New York.

LEATHERMAN, S.P., 1980. *Barrier Island Handbook.* National Park Service, pp. 1–101.

MACHARE, J.; ORTLIEB, L.; WOODMAN, R, and GUEVARA, J., 1990. Posibles registros de lluvias relacionadas a "El Niño", en el desierto de Sechura, noroeste del Perú. *2a. Reunión del Provecto 281 del PICG: Climas Cuaternarios de América del Sur,* (Medellín, May, 1990). Actas, 4p.; Univ. EAFIT. *Resúmenes y Contrib. Científicas. Publ. Especial* N°2, Medellín.

MARTIN, L.; FOURNIER, M.; MOURGUIART, P.; SIFEDDINE, A., and TURCO, B., 1993. Southern Oscillation Signal in South American Paleoclimatic data of the last 7,000 years. *Quaternary Research,* 39, 339–346.

MILANKOVITCH, 1941. Canon of insolation and the Ice Age Problem (Koniglich serbische Akademie, Belgrado). English translation by the Israel Program for Scientific Translation, Jerusalem, 1969.

MÖRNER, N.A., 1976. Eustasy and Geoid. *Journal of Geology,* 84(2), 123–151.

ORTLIEB, L; MACHARE 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, 80, 107–121.

PLASSCHE, O. VAN DE, 1982. Sea-level change and water level movements in the Netherlands during the Holocene. *Academisch Proefschrift,* Vrije Universiteit Amsterdam, pp. 1–148.

RICHARDSON, J.B., 1983. The Chira beach ridges, sea level change, and the origins of the maritime economies on the Peruvian coast. *Ann. Carnegie Mus.,* 52, 265–276.

ROTH, S., 1898. Apuntes sobre la geologia y la paleontología de los territorios del río Negro y Neuquén (diciembre de 1895 a junio de 1886). Museo de La Plata reconocimiento de la Región Andina de la República Argentina. *Rev. Mus.* IX: 156- I–VII. Lám. La Plata.

SANDWEISS, D.E., 1986. The Beach ridge at Santa, Perú: El Niño, Uplift, and prehistory. *Geoarchaeology,* 1, 17–28.

SISCOE, G.L., 1978. Solar-Terrestrial influences on weather and climate. *Nature,* 276, 348–352.

SPALLETTI, L.A., 1980. Paleoambientes sedimentarios en secuencias silicoclásticas. *Asoc. Geol. Arg.* Serie "B" Didáctica y Complementaria, N° 8: 1–175.

WEILER, N.E., 1983. Rasgos evolutivos del sector costanero comprendido entre Bahía Verde e Isla Gaviota, provincia de Buenos Aires. *Asoc. Geol. Arg., Rev.,* 38(3-4), 392–404.

WEILER, N.E., 1988a. Depósitos litorales del Pleistoceno tardío y Holoceno en bahía Anegada, provincia de Buenos Aires. En: *2a Reunión Arg. de Sedimentol.* Buenos Aires, Aug. 1988. Actas, 245–249.

WEILER, N.E., 1988b. Evidencias paleoeustáticas del Holoceno en Bahía Anegada, provincia de Buenos Aires. *Simposio Internacional sobre el Holoceno en América del Sur.* CADINQUA. Entre Ríos, Nov. 1988. Resúmenes. p. 9.

WEILER, N.E., 1993. Niveles marinos del Pleistoceno tardío y Holoceno en Bahía Anegada, Provincia de Buenos Aires: Geocronología y correlaciones. *Asoc. Geol. Arg., Rev.,* 48(3-4), 207–216.

WEILER, N.E., 1996. Depósitos lirorales del Pleistoceno tardío y Holoceno en área del Balneario Los Pocitos, provincia de Buenos Aires. *VI Reunión Arg. de Sedimentol.,* (Bahía Blanca, 16 to 26 May. 1996). Actas, 129–134.

WEILER, N.E. and GONZALEZ, M.A., 1990. Evolución eustática del Holoceno en latitudes medias de la República Argentina. *2a. Reunión del Proyecto 281 del PICG: Climas Cuaternarios de América del Sur,* (Medellín, May, 1990). Actas, 17p.; Univ. EAFIT. *Resúmenes* y *Contrib. Científicas, Publ. Especial* N° 2, Medellín.

WITTE, L., 1916. Estudios geológicos de la región de San Blas. *Rev. del Museo de La Plata* Tomo XXIV (2a. Serie Tomo XII, 1a. Parte). 1–99. La Plata.

WOOD, F.J., 1976. *The Strategic Role of Perigean Spring Tides.* U.S. Department of Commerce, NOAA, U.S. Government Printing Office.

WOOD, F.J., 1985. *Tidal Dynamics-Coastal Flooding.* Dordrecht: Reidel (Kluwer), pp. 1–720.

YRIGOYEN, M., 1975. Geología del subsuelo y plataforma continental. En: *VI Congr. Geol. Arg., Relatorio,* 139–168 (Buenos Aires).

□ RESUMEN □

Se analizaron depósitos litorales de la transgresión del Holoceno en la bahía Anegada (39°50′ a 40°00′ Sur y 62°15 oeste, República Argentina) Se determinaron por lo menos cinco episodios transgresivos que fueron denominados Estadios Transgresivos (ET O a V); durante los mismos se originaron crestas de playa (islas de barrera) y albuferas. Las respectivas edades de esos ET ^{14}C, con Edad Geológica Probable (EGP = la menor edad ^{14}C) y Edades Aproximadas (EA = son las ^{14}C obtenidas a partir de valvas de moluscos en posición de vida), son: TS-0 = 6560 ± 130; TS-I = 6190; TS-II = 5570; TS-III = 5200; TS-IV = 4350 y TS-V = 3600 BP. El ET-I representa el máximo alcance de la transgresión del Holoceno y el ET-0 corresponde a un evento transgresivo anterior. Ambos estarían vinculados con picos de máxima actividad solar (transgresión termoeustática). Los ET más jóvenes (ET- II a V) indican episodios transgresivos menores asociados posiblemente a mareas excepcionalmente altas (coincidentes con el Ciclo de Progresión del Perigeo Lunar) y a fuerte oleaje (tormentas excepcionales). Los episodios de tormenta podrían estar condicionados por eventos episódicos de gran magnitud del tipo ENSO (eventos pasados del ENSO = El Niño Oscilación Sur) los que habrian causado masivos pulsos de sedimentos y cambios en la dirección de deriva litoral.