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Tidal Sandbanks in Mar Chiquita Coastal Lagoon, Argentina[1]

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ABSTRACT

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Tides and tidal currents were measured continuously over the tidal inlet and coastal lagoon of Mar Chiquita, southeastern Argentina. The oceanic tides present semidiurnal characteristics, predominantly the M_2 component. Pronounced asymmetries observed inside the lagoon respond to contributions from superior harmonics. The friction terms of this dispersive medium play an important role in the translation of tidal waves. Considering the combined effects of wave agitation and net transport by tidal currents, it is inferred that a mechanism may exist between the outer bank and the tidal inlet to which it supplies sand. During the 12 day field study it was observed that strong storms can construct a major bank in a matter of hours.

ADDITIONAL INDEX WORDS: *Coastal lagoon, tidal inlet, tidal currents, sediment dynamics, tidal sandbanks, bank formation, power spectra, depth closure.*

INTRODUCTION

The role played by tides and tidal currents in tidal inlets has been the subject of numerous studies around the world (BARWIS, 1976). In Argentina, this line of inquiry is the first experiment conducted in the Argentine lagoon, Mar Chiquita, in the Province of Buenos Aires (Figure 1). Argentine scientists have studied the lagoon from a geological standpoint (SCHNACK *et al.*, 1980, 1982), but scarce attention was paid to hydraulic conditions. The inlet area is characterized by a small smoothly contoured seaward shoal. DEAN (1976) suggested that those well-shaped shoals are found in high wave energy areas. During the field experiment, high waves generated by a twenty-hour-long northeasterly storm, transported 500 m^3 of very coarse sand from the outer shoal to the bayward margin of the channel. Two small channels around the new bank were formed at the same time. High velocities during ebb time and half depth amplitude sand waves were observed there.

Considering the cross sectional area of the channel and the sediment transport around the groin the stability of the inlet was estimated following procedures outlined by BRUUN (1960, 1974) and O'BRIEN (1969). The results indicated poor stability of the inlet.

Our data on lagoon dynamics comprises a continuous time series of tidal current measurements, in addition to a shorter series of tidal observations. We summarise here the tidal actions, the behavior of tidal currents and a first approximation of the possible mechanism of sediment transport.

HISTORY

The oldest information available, held by the Drainage Commission of the Buenos Aires Province (January 1885), is reflected in the nautical chart of 1915, from which variations in location of the mouth are evident since 1908 (Figure 2). Analysis shows that the inlet maintained its general character throughout that time period.

After an intial stage, based on responses to effects of waves and related sedimentary processes,

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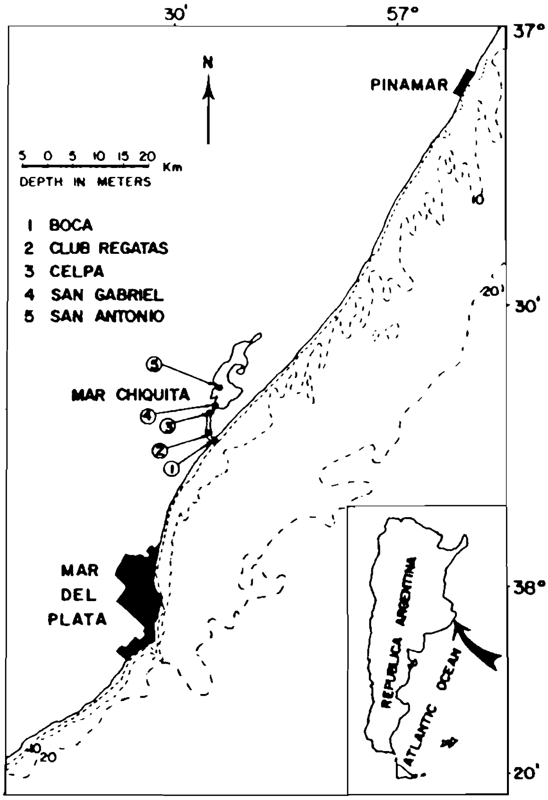

Figure 1. Index map.

the mouth migrated approximately 100 m/yr. In 1904, an artificial channel was dug across the terrain. Because it was very narrow, the migration continued northeasterly. The cartographic map of 1915 shows that a new artificial channel, constructed in 1912, was successful because three years after its construction, the entrance channel occupied a more stable position to the southwest than it did in 1885.

In 1967, the Geodetic Directorate of the Buenos Aires Province prepared a new map. This map allowed the calculation of further migration of the mouth 300 m to the northwest over in a period of 50 years. In the 1970's, a rubble mound groin was constructed to control the displacement of the mouth. The structure arrested the supply of sand to the mouth and it was stabilized in its 1967 location.

To prevent the erosion that soon started at the landward end of the groin, an additional stone groin was constructed, reducing the width of the entrance to about 200 m. Although this effort was to protect the main groin, its efficiency declined as stones sank into the sand.

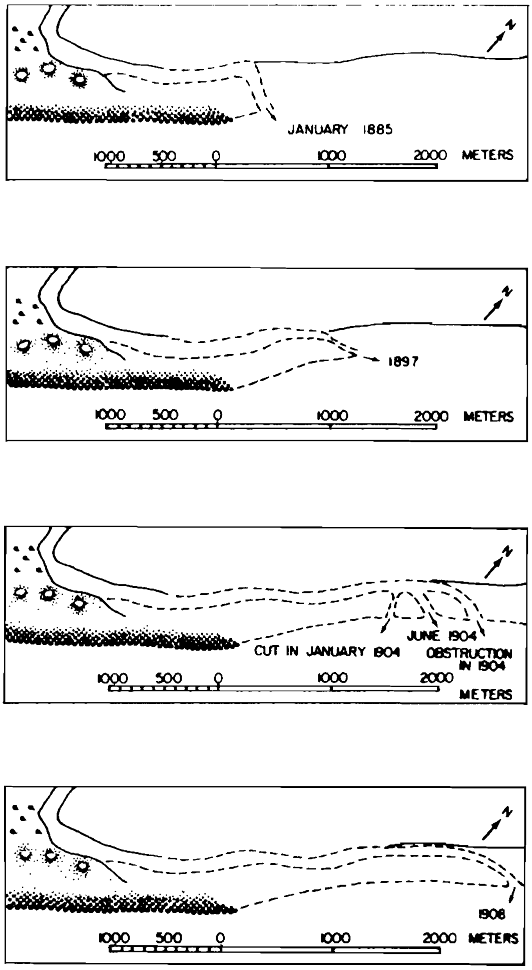

Figure 2. Tidal inlet migration between 1885 and 1908.

FIELD SITE METHODS

The lagoon is about 46 km^2 in size; it is irregular in shape, but the bottom topography very smooth with a maximum water depth of 1.50 m. The lagoon is connected to the sea by an elongated inlet channel, approximately 6 km and up 200 m wide. Current measurements were carried out in January 1985 in the entrance of the mouth and inside the lagoon. Observations from aerial photographs indicated that the coastline outside the inlet, was very straight prior to construction of the groin. The presence of the groin induced considerable erosion on the lee (northeastern) side. The beach profiles average about 0.01 in slope (tan β).

During field experiments the beach was accreting following a relatively calm period. The beach front was steep on the upstream side of the groin beach cusps, lengths about 20 m (NIELSEN, 1985).

The wave climate was inferred from direct wave measurements at two neighboring settlements (Mar del Plata and Pinamar). The significant wave heights for Mar del Plata were on the order of 0.5 to 1.50 m about 90% of the time. The least significant height was not under 0.30 m and the maximum significant height was about 5.60 m. Peak periods were between 6 and 15 seconds. The Pinamar wave climate is similar. Morphological evidences indicate a prevailing northeastward littoral drift.

TIDES OF MAR CHIQUITA LAGOON

Tides in the Buenos Aires Province are semidiurnal. The mean spring amplitude prevailing in Mar del Plata (25 km from Mar Chiquita), is 0.91 m.

The position of the mareographic stations, where portable Balauff and Aanderaa mareographs were installed as shown in Figure 1. Table 1 lists some characteristics of the tide inside the lagoon.

Figure 3 presents tidal curves of the area for one day. The Aanderaa water level gauge was positioned on the CELPA (Air Force Base) bridge, with a sampling rate of 15 minutes provided 929 data points. During the analysis, a series of 643 values was used (one value every 30 minutes) to calculate a spectral analysis applying the Fast Fourier Transforms (FFT). This analysis shows a signal power that is excessively concentrated in the continuous and very low frequency region. In order to make the harmonic part evident, the signal was filtered through a differences filter; spectral peaks in the bands corresponding to diurnal, semidiurnal, terdiurnal, quarterdiurnal, sixth diurnal, and eighth diurnal waves were easily recognized. They are indicated as M_1, M_2, M_3, M_4, M_6, and M_8. The spectrum was analysed up to 1 cph in 231 discrete parts and with a frequency step of $\Delta f = 0.0043$ cph. For each frequency, the spectral estimate was calculated, giving

Table 1. *Tidal characteristics in the interior of Mar Chiquita lagoon.*

Station	Amplitude (m)	Δt HW h m	Δt LW h m
Boca (mouth)	1.38		-
Club Regatas	.96	30	1 12
CELPA	77	1 06	1 24
San Gabriel	.30	2 18	2 12
San Antonio	.05		

Δt HW
Δt LW > Time lag between high water or low water

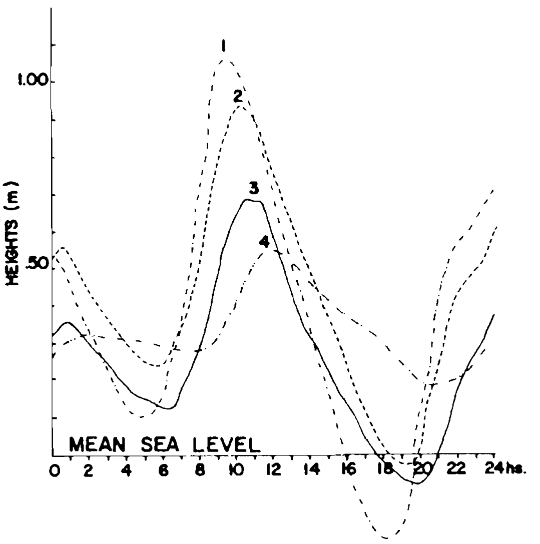

Figure 3. Tidal curves for the 11 January, 1985.

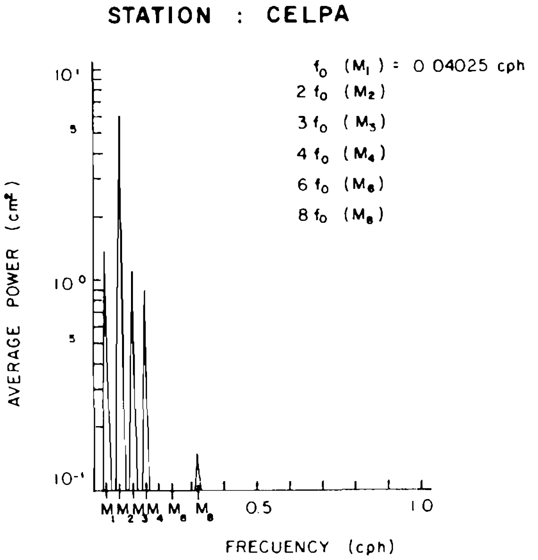

Figure 4. Power spectra of the time series.

a maximum for the semidiurnal band of 6.00 cm^2 For frequencies greater than 0.5 cph, spectral estimates have negligible values. The sum of power of bands is 20.03 cm^2 and represents 92% of the total, showing that the greatest part of harmonic energy is concentrated in these bands.

Figure 4 shows the mean power contributed by each of the 231 harmonics in which the filtered signal was dissembled (JENKINS and WATTS 1968). Since the Aanderaa gauge has a 1 cm resolution, the spectrum shows the contributions of power starting with 0.1 cm^2. By means of the amplitude response of the used filter, the different bands were recolored. Table 2 shows the recolored and integrated values of the power. Table 3 presents the calculated amplitudes, assigning to each band the corresponding harmonics of M_2. The relative importance of shallow water components is manifested in this phenomenon.

According to preliminary results, the tidal wave travels with a velocity that causes a time lag between Club de Regatas and San Gabriel on the order of 1 hour 48 min., an excessively large time interval. The propagation velocity C of an external gravity wave in shallow water is $C = u \pm (g\,d)^{1/2}$, where u = velocity of the mean flow and d = depth.

Analysis of a 5 day current measurement program at the Club de Regatas station gave a value for u= 14.4 cm/s (u= permanent current) with a direction of 314° (NW). This value is obviously of a minor order of magnitude compared to the term $(g\,d)^{1/2}$ = 2.21 m/s with d being approximately 0.5 m for the studied area.

Table 2. *Recolored and integrated values of the power*

Band	M_1	M_2	M_3	M_4	M_6	M_8
Mean power (cm^2)	3.01	12.73	2.24	1.51	0.24	0.30

Table 3. *Amplitude of the filtered data and amplitude of the recolored spectrum.*

Bands	M_1	M_2	M_3	M_4	M_6	M_8
Amplitude (cm) Filtered data	2.45	5.05	2.12	1.74	0.69	0.77
Amplitude (cm) Recolored	19.5	20.0	5.6	3.2	0.9	0.7

Table 4. *Characteristics of the current stations*

Station	Instrument	Velocity (cm/s) Max.	Velocity (cm/s) Min.	Remarks
Boca (mouth)	Mecabolier	140	0	
Club Regatas	Mecabolier	50	0	
CELPA	Mecabolier	–	–	Failed
San Gabriel	Mecabolier	40	0	

This equation presented above assumes that the amplitude of the wave is negligible compared with the depth. In this case it is an invalid assumption because it was observed that the amplitudes assigned to the different bands, which result from spectral analysis, are of the same order as the estimated depth. This implies a nonlinearity in the dynamic equations for the posed problem. This results in dispersal and dissipation of the effects, jointly with the refraction and reflexion in the propagation of the wave, because it is logical to assume a significant retardation of the disturbance.

TIDAL CURRENTS

Table 4 shows the position and characteristics of the current stations. The temporal series of the velocity are more and less in phase. Aside from the inmediately apparent semidiurnal periodicity, the most conspicuous feature of the current record is the symmetry of the flood (+) versus ebb (−) setting currents about the zero line during the first 15 hours, after which an asymmetry can be observed.

The skewed form of the tidal current cycle is typical for finite amplitude waves in shallow water. This asymmetry manifests itself as a swift acceleration just before the high tide. These asymmetries in the waves generally reflect the contributions of the highest harmonic of the primary oscillation (semidiurnal tide). The presence of the highest frequency oscillations on the order of 2 to 3 hours is also conspicuous as superimposed velocity fluctuations which are most obvious.

In our experiment, the station at the inlet mouth represents the velocity of net current without contributions by waves because the current meter removes wave effects. We found a shoreward decrease in the current velocity; this trend suggests a lateral retardation of tidal flows corresponding to the shoreward decrease in water depth. This may explain the flows at low tide. The asymmetry may be accounted for by topographic effects.

SEDIMENT TRANSPORT

The tidal inlet is characterized by its constantly changing location but is limited laterally by extensive beaches and seaward by a bank. During summer, a series of low sand bars aligned with the entrance; they seem active at high tide but are exposed at low tide. During high tide waves and currents move the sediments, forming new bars and destroying the old ones.

Wave measurements in Mar del Plata, Pinamar, and at sites near Mar Chiquita, indicated waves on the order of 5 m during autumn and winter. Consequently the presence of similar waves are envisioned in the mouth and across the extensive sand bar that forms the outer bank. These conditions leave the dunes exposed to erosion that endangers some of the dwellings in the area. During spring and summer, the bank supplies the mouth and beach with sand. This phenomenon was observed during a strong northeasterly wind (which blew for approximately twenty hours) and formed a bank volume of the order of 500 m^3 in the entrance. Except for the interruption created by the mouth, the coastline is very straight. During January 1985, typical beach profiles were observed for the season (summer in the southern hemisphere) with steep fronts, and waves breaking near the coast but not over the bar. The profile was steeper on the southern side of the groin where the supply of sand is larger. The construction of the groin maintained the position of the mouth but the position of the main channel showed seasonal variation.

The lower boundary of the active beach profile can be estimated from the yearly maximum significant height (H_s). HALLERMEIER (1981) calls it the depth of closure: Depth of closure $\cong 2\,(H_s)_{max}$. This shows that the depth of closure of Mar Chiquita is on the order of 10 m and that the volume lost in 15 years (after the construction of the groin) is 600,000 m^3. This represents a yearly deficit in the amount of littoral drift past the groin of 4×10^4 m^3/year.

CONCLUSIONS

During calm wind conditions, tides are observed as far inland as San Gabriel with a lag time of 2.5 and 2.2 hours from the mouth, for high and low tides respectively. The reduction in amplitude at San Gabriel is 78% with respect to the mouth. The semidiurnal component is the most important. The dissipation and dispersion of energy and other associated phenomena create considerable delays. Tidal currents inside the lagoon are weak. Erosional capability has been observed in the entrance channel where the highest registered velocity was 140 cm/s. The close relationship between the mouth and the outer bank is evident. Due to the action of storms, the bank supplies sand to the mouth. The wave action is perceived in the first few meters of the channel; together with currents they transport sediments toward the interior of the lagoon, depositing them some hundred meters upstream. The fixed bank in the center of the mouth does not prevent sediments from entering because they enter in a turbulent manner (possibly mostly in suspension). During the ebb tide, sediments move along the bottom as bed load and the bank obstructs the back flow. Velocities are almost zero at that time and sediment accumulation takes place.

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☐ ZUSAMMENFASSUNG ☐

Die Ebbe und Flut des Ozeans darstellen halbtägliche Merkmale, worin das M_2-Teil beherrscht. Drinnen der Lagune wurden besondere Asymmetrien beachtet, die auf höhere Harmoniken reagieren. Die Reibungszahlen dieses Verstreuungsmittels sind sehr wichtig, um Ebbe- und Flutwellen zu übersetzen. Wenn die Wirkungen der Wellenagitation und Reintransport der Ebbe- und Flutströme in Betracht gezogen werden, wird es daraus geschlossen, dass ein Mechanismus zwischen der Aussenbank und der Bucht, die sie Sand liefert, existiert. Während der 12-Tage Forschungsperiode wurde es bewiesen, dass im Lauf ein paar Stunde können schwere Stürme eine grosse Sandbank bauen.--*Stephen A. Murdock, CERF, Charlottesville, Virginia, USA*

☐ RÉSUMÉ ☐

Après avoir mesuré en continu la marée et les courants de marée dans le goulet et le lagon de Mar Chiquita, constante que les marées présentent des caractéristiques semi-diurnes où la composante M_2 prédomine. L'observation d'asymétries prononcées à l'intérieur du lagon correspond aux contributions d'harmoniques supérieures. Les termes de friction jouent un rôle important dans le déplacement de l'onde de marée. Si on considère les effets combinés de l'agitation des vagues et du transport net par les courants de marée, il est supposé que peut exister un "mécanisme" entre le banc externe et le goulet auquel il fournit le sable. Pendent 12 jours d'étude de terrain, on a observé que par forte tempête, quelques heures suffisent à la construction de bancs majeurs.--*Catherine Bressolier, EPHE, Montrouge, France*