Seasonal Behaviour of Mar Chiquita Tidal Inlet in Relation to Adjacent Beaches, Argentina*

Federico Ignacio Isla

CONICET
Centro de Geología de Costas y del Cuaternario
UNMDP, c. c. 722
7600 Mar Del Plata, Argentina

ABSTRACT


Mar Chiquita microtidal inlet is subject to seasonal periods of summer sand availability and winter scarcity. In the long-term trend the coast is erosive although these environments were deposited in the last 5,000 years due to a sea-level fluctuation of 2 m. In the past, the inlet used to migrate northwards and episodically to obstruct.

There are sediment interchanges between the inlet and adjacent beaches. During the summer, sand is stored as a flood-tidal delta covered by flood-oriented megagropes. The ebb channel is narrow, shallow and oriented to the southeast. It's bottom is floored by dunes composed of fine sand and oriented seawards. During the autumn and caused by an increase in precipitation, sand is transferred offshore to form an asymmetrical tidal inlet. The channel bottom becomes floored by lag beach-rock gravels lying over cohesive muds related to the former and extended coastal lagoon. During winter, this ebb-tidal delta bypasses sand to the northern beach. The ebb channel is then oriented to the northeast increasing the discharge along the longshore troughs of the northern beach. Sand is therefore transported northwards along this beach and diminishing wave-induced losses downdrift of the hydraulic jetty. Averaging Spring (October), drift reversed and sand is transported southwards shoaling the inlet, progressively oriented to the southeast again.

Although Mar Chiquita is a typical coastal lagoon, its degree of sediment infill prevents tidal effects within the entire basin. Tidal amplitude diminishes in a short distance along the channel. The inlet flow area is in a first approach in relation to the potential tidal prism, but its main changes are in relation to precipitations within the basin. The minimum flow area can vary 10 times in relation to rainfall within the catchment basin.

ADDITIONAL INDEX WORDS: Coastal evolution, inlet development, sediment transport, beach, tidal current.

INTRODUCTION

Tidal inlets and beaches are very dynamic coastal environments in response to tides, waves and currents. Tidal inlets have more dynamics and therefore can alter beach budgets. Tidal deltas can be dominated by the action of flood or ebb currents (HUBBARD et al., 1979).

Mar Chiquita tidal channel is the first inlet south of 180 km long barrier coastline from the Rio de la Plata estuary, Argentina. It is draining 1,000,000 hm² from the Tandilia Range across the Pampa Alluvial Plain (Figure 1). It communicates the small microtidal Mar Chiquita coastal lagoon to the Atlantic Ocean by the mean of a long channel that cuts across marshes and a dune barrier. The lagoon is therefore a choked coastal lagoon (KIERVE and MAGILL, 1989). The coast is known to be under erosion withstanding that the sediments being eroded were deposited during the last 5,000 years (SCHNACK et al., 1982). At the same time, the inlet had a rapid migration rate to the north and a natural obstruction trend. Although a jetty today diminishes this drift amount, the inlet's dynamic is today out of control as much sand bypasses that jetty.

Since 1979 a doctoral thesis proposed to monitor the morphological and sedimentological changes that occurred at the inlet and adjacent beaches (ISLA, 1986). This paper resumes that study focused on the tidal, longshore-drift, runoff and storm effects.

SETTING

Mar Chiquita Coastal Lagoon inlet is located 35 km north of Mar del Plata city (Figure 1). It constitutes the boundary between an erosive cliffy coast to the south, and a sandy barrier to the north (supposedly to represent a accreting coast). The region is known to be affected by a sea-level fluctuation of 2 m for the last 6,000 years ago (SCHNACK et al., 1982). Pleistocene sandy silts (with a high content of volcanic ash and indurated caliche levels) dominate to the south. Holocene sandy muds related to former coastal lagoons are deposited to the north. These environments and related marshes are separated from the sea by a duned barrier of a maximum width of 3.5 km. Sand ribbons characterize that portion of the continental shelf between Mar del Plata and Mar Chiquita (ISLA and SCHNACK, 1986).

Tides are semidiurnal with amplitudes varying between 0.6 to 1 m at the open coast; within the lagoon tidal range diminishes to less than 0.10 m. Although the tides may become assymetrically distorted along shallow-water lagoons
Figure 1. Location map.

Figure 2. Morphological variations of Mar Chiquita inlet during the 1885–1912 period (Servicio de Hidrografia Naval, laguna Mar Chiquita chart).
HISTORICAL TRENDS

To recognize the natural trend in the inlet evolution of Mar Chiquita coastal lagoon, historical maps, nautical charts and ancient aerial photographs were consulted. Naturally, the inlet migrated to the north until it became obstructed repeatedly.

The first description mentioned 300 steps between the goon: from a salt content higher than the sea during the summer (due to its marine origin and evaporation), it becomes fresh water during the rainy autumn (Fasano et al., 1982). The lagoon has a mean depth of 0.60 m, but soundings of 2 m can be measured along the discharge channel.

**HISTORICAL TRENDS**

To recognize the natural trend in the inlet evolution of Mar Chiquita coastal lagoon, historical maps, nautical charts and ancient aerial photographs were consulted. Naturally, the inlet migrated to the north until it became obstructed repeatedly.

The first description mentioned 300 steps between the goon: from a salt content higher than the sea during the summer (due to its marine origin and evaporation), it becomes fresh water during the rainy autumn (Fasano et al., 1982). The lagoon has a mean depth of 0.60 m, but soundings of 2 m can be measured along the discharge channel.
coastal lagoon and the ocean beach (CARDIEL, 1748). An English chart drawn by Kitchin in 1772 described the inlet as “misfit for boats”. A compilation made between 1885 and 1912 (Figure 2) denoted the trend of the inlet to migrate to the north until it became blocked (STORNI, 1915). From historical photographs an inlet migration rate of 200 m/yr was averaged (ISLA, 1986). Many times, man had to open the inlet. The farmers used to wait for strong winds from the north that piled up water to the southern shore of the lagoon. At that moment, they practiced a channel that rapidly became broader and deeper.

Since the first aerial photograph of the area (1957), the
MORPHOLOGICAL CHANGES

During the summer of 1979-1980, the minimum flow area decreased (40 m³) compared to the maps of the spring, and a flood tidal delta formed. The ebb channel was narrow, shallow and oriented to the southeast.

The village of Mar Chiquita suffered a critical erosion of the order of 7 m/yr (ISLA, 1980). The inlet had changed its morphology, in a general migrating trend, until it has been partially fixed by a jetty construction in 1971 (Figure 3). Erosion continued at the same rate at the southern beaches of the village.

METHODS

Topographic surveys were performed approximately every month at the inlet area. Surficial sediment samples were collected from the sandbanks and from the bottom of the ebb channels.

At both beaches adjacent to the inlet, 9 beach profiles were surveyed every 100 m. Altitudes were measured every 5 m along the profile. Either at the inlet and at the beaches, it was tested if the submerged cohesive abrasion platform (sandy mud) is covered by sand, gravels, or exhumated.

Waves (height and period) and longshore currents (direction and velocity) were measured at the beaches. At the inlet, the maximum ebb current was measured by dye tracers (rodamine B), usually less than 1.3 m/sec.

Successive topographic maps were combined into erosion-deposition isopach maps, as proposed by Fox and Davis (1978). Seasonal budgets (erosive or accumulative) were calculated in order to be interpreted as function of wave energy, storm episodes, maximum tidal currents or water discharge at the inlet (ISLA, 1986).

During the autumn, heavy rainfalls induced the complete erosion of that flood delta and the inlet channel became deeper and wider, orientating to the E; minimum flow area be-

Figure 5. Daily volumetric variations of different profiles of the beaches of Mar Chiquita and CELPA. Direction and amount (order of magnitude) of sand drift are estimated in relation to longshore and ebb currents parallel to the shoreline and causing erosion and deposition.
came of 320 m² (Figure 4). An abrasion platform (Holocene sandy muds) was exhumed covered by oblate beachrock gravels imbricated on the bottom of the ebb channel. Recovering processes took place immediately after these floods that affected the extended pampian plain. A subtidal bank began to move shorewards in a similar way that a bar attaches to the beach as a tidal berm. This transport ended with the reconstruction of the spit on the southern margin of the inlet. An assymetric ebb-tidal delta had been formed. It has recently been concluded that the volume of ebb tidal deltas responds primarily to tidal prisms (Hicks and Hume, 1996). Variations in the water volume interchanged by the inlet therefore caused variations in the sizes of the ebb tidal deltas.

Along the winter, waves also induced the longshore spit growth, migrating the inlet channel to the north and bypassing sand to the northern margin.

In October (spring), the dominance of the northwards drift reversed to the south. This reversal provoked the reconstruction of the flood delta and a reorientation of the outlet to the SE. These processes used to continue until the end of the summer; minimum flow area became again of the order of 30 m² (Figure 4).
It became clear that during autumn-winter, the daily volumetric difference between beach profiles indicated a longshore transport towards the north. This trend reversed during spring, when the flood-tidal delta began to be restored (Figure 5). In CELPA beach, the northwards migration of the ebb-tidal delta continued due to the discharge effects of the inlet oriented to the north and parallel to the beach (Figure 4).

**TIDAL EFFECTS**

Inlet flow-area dimensions were related to tidal prism in the sense proposed by O'BRIEN (1969) and JARRETT (1976). This empirical relationship was recently modified applying a stability shear stress coefficient (FRIEDRICH, 1996). However, at Mar Chiquita lagoon effective tidal prism does not fit with potential tidal prism (in the sense of MEHTA and HOU, 1978). The relationship established empirically by O'BRIEN and tested by Jarrett does not fit sharply for Argentine inlets (Figure 6).

Using simultaneous records from different places of the lagoon, it is clear that the tidal excursion exponentially attenuates towards the headlands (Figure 7).

Much of these effects are man made in the sense that the bridge of CELPA reduced the flow area to the third of the original natural channel. This bridge not only prevents the natural drainage of the lagoon (becoming worse during floods...
as 1980), but also originates changes in turbidity, salinity and temperature; affecting significantly the estuarine fauna.

**PRECIPITATION EFFECTS**

Mar Chiquita lagoon is draining a basin of $1 \times 10^6$ km$^2$. The headlands at the Tandilia Range are quartzitic plateaus that sharply grade to the typical pampian plains. At the foot of these hills, the landscape is dominated by relict and very low relief longitudinal dunes oriented in the WSW–ENE direction. To the east, and close to the coastal lagoon, the morphology is defined by relict deflation ponds related to (half-moon-shaped) silty dunes (SCHNACK *et al.*, 1982). This ancient pediplain of Upper Pleistocene or Lower Holocene age came to receive 1000 mm rainfall during the mid-Holocene. The eolian bedforms did not make runoff easy as the half-moon-shaped dunes are normal to the regional gradient.

Today, rainy periods produce a rise of water table. Runoff and the water-table rise affect significantly Mar Chiquita lagoon producing floods, as in 1980. These effects affected significantly the inlet causing important morphological changes with a lag of approximately 30 days (Figure 8).

**BEACH DRIFT EFFECTS**

At Punta Médanos (100 km north), beach drift was calculated in 400,000 m$^3$/year, average of 4 years (CAVIGLIA *et al.*, 1992). At Mar Chiquita beach, today protected by a jetty, drift effects are not much evident (Figure 5a).

Mar Chiquita microtidal inlet area is therefore sensible to wave effects. Waves coming from the east diverge at the inlet while those from the southeast converge, and therefore produce erosion during storms (Figure 9). At the inlet area, the longshore growing of the spit increases during the winter and
spring months (July–November; Figure 5). During the end of the spring and summer, the drift is toward the south and produces an inlet orientation to the SE.

At CELPA beach, there is more influence of the inlet. In that sense, the accumulations of sand comprising an ebb-tidal delta (May of 1980) clearly migrated northwards in response to longshore currents and also by the alongshore orientation of the ebb channel (Figure 5b).

**STORM EFFECTS**

Sand ribbons and sand ridges cover the continental shelf dominated by storms of the southeastern Buenos Aires Province. Coastal landforms as dune and berm scarps also reflect these episodic effects (Figure 10). South of Mar Chiquita inlet, the scarcity of sand is reflected by a sand-ribbon field and coastal erosive features.

During the period of surveys, several storms affected the coast of Mar Chiquita inlet. These episodic effects produced critic erosion at the beaches (Figure 11); at the inlet spit and at the beaches they were recognized by washover processes.

**SEASONAL BEHAVIOR**

During winter, episodic southeasterly storms move across a narrow shelf converging wave orthogonals towards Mar Chiquita (Figure 9). The inlet migrates to the north with danger to become obstruct. During spring, winds from northeast dominate inducing waves to travel across a wider continental shelf, and across a sand-ridge field (ISLA and SCHNACK, 1986). As this situation persists during the summer, the inlet orientates to the south while sand is recovered. To the end of the summer, the inlet orientates to the southeast. There is also danger for the inlet to shoal, mainly by landward migration of a littoral bar.

Although 1980 was not a normal year, the seasonality was very evident in relation to the minimum flow area variations (Figure 12). It varied from 30 to 320 m². At the same time, the construction of a flood tidal-delta during the summer diminish the minimum flow area. Channel erosion during the fall exhumated an ancient abrasion platform. These effects on the bottom of the inlet are the response of bedforms to maintain maximum currents via shear stress modifications (BRUUN, 1969). When maximum currents are strong enough, the flood delta eroded completely, and a carpet of oblate gravels covered an abrasion platform composed by former lagoonal deposits related to the Holocene sea-level fluctuation (SCHNACK et al., 1982).

The bottom of the discharge channel is covered by dunes oriented seawards during the summer. The floods of the autumn exhumated a cohesive bottom covered by lag gravels. During the spring it became covered by dunes again. This seasonal behaviour is indicating sensitive changes in the drag effects during the year in relation to mean ebb currents.

**STABILITY CRITERIA**

BRUUN and GERRITSEN (1960) established a stability criterion based on the ability of the inlet to maintain open (tidal prism) and the littoral drift amount (Mm) to close it. Based
Today Mar Chiquita coastal lagoon is mostly infilled and in a very mature stage of its geomorphological evolution. As the susceptibility of an inlet to closure is not only matter of a previous morphology, but it depends significantly on the flushing ability of the tidal prism to control the flow area.

Against the tidal prism, the processes proposed to act are the deep-water wave energy during the tidal period (ratio C of O'BRIEN, 1976) or the littoral drift (P/M ratio of BRUUN and GERRITSEN, 1959; BRUUN, 1978; ISLA, 1995). Both are conditioned to the sand availability outside the inlet area.

For the case of Mar Chiquita, it is clear that inlet closure could occur during summer, when there is plenty of sand just outside the inlet. During the 1980 spring (September–November), the growing of the sand spit towards the north diminished the flow area. If during those days coastal-lagoon discharge diminished, the ebb channel would have lost its flushing ability and the inlet might have closed (Figure 4).

**FORECAST AND POSSIBLE IMPROVEMENTS**

Today Mar Chiquita coastal lagoon is mostly infilled and in a very mature stage of its geomorphological evolution. As on this criterium, MCBRIDE (1987) recognized for the Florida coast tidal inlets wave-dominated (< 50), transitional and tide-dominated (> 150).

A distinction should be made between closure and susceptibility to closure (MEHTA and HOU, 1974; O'BRIEN, 1980). Both are subject to a previous morphology outside the throat. An obstruction commonly occurs by a storm effect. It was stated that it depends on the intensity and duration of a storm and the tidal range (MEHTA and HOU, 1974). A specific closure criterion has been proposed, where the inlet's width (Wc), onshore component of wave power (Ip), flood duration (Tf), bay range (ab) and the ebb prism (Pe) were related.

\[ CC = \frac{Wc \cdot Ip \cdot Tf}{Pe \cdot ab} \]  

(O'BRIEN, 1980)

The susceptibility of an inlet to closure is not only matter of a previous morphology, but it depends significantly on the flushing ability of the tidal prism to control the flow area. Against the tidal prism, the processes proposed to act are the deep-water wave energy during the tidal period (ratio C of O'BRIEN, 1976) or the littoral drift (P/M ratio of BRUUN and GERRITSEN, 1959; BRUUN, 1978; ISLA, 1995). Both are conditioned to the sand availability outside the inlet area.
Conclusions achieved here are:

1. Drift amount and fluvial runoff are the principal variables involved in the morphological changes that take place at Mar Chiquita inlet.
2. There is a seasonal developing of tidal deltas (flood and ebb) due to the combined action of wave climate and fluvial runoff.

**DISCUSSION**

Slingerland (1983) stressed the statistical relationship between tidal-inlet forms and processes (wave climate and tidal level). Using aerial photographs, Fitzgerald et al. (1978) stated that inlet migration is more important at shallow inlets where the main channel does not scour into the more resistant marine or lagoonal muds underlying the barrier islands.

The inefficiency of the tidal inlet led some people to consider another artificial opening but this may cause other environmental problems. Van de Kreeke (1985) stated a method to predict the hydraulic stability of a lagoon with two inlets.

For the case of Mar Chiquita coastal lagoon, another inlet at the north can improve the ability for flushing much of the mud accumulated, but close to the village there would be an increase in the filling rate that can deteriorate the tourist area (Table 1).

**Table 1.**

<table>
<thead>
<tr>
<th>Present Environmental Problems</th>
<th>Two Inlets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal erosion</td>
<td>Better</td>
</tr>
<tr>
<td>Coastal-lagoon erosion</td>
<td>Better</td>
</tr>
<tr>
<td>Sediment infill</td>
<td>Better</td>
</tr>
<tr>
<td>Turbidity increase</td>
<td>Worse</td>
</tr>
<tr>
<td>Biothermal growth</td>
<td>Better</td>
</tr>
<tr>
<td>Restriction in saline excursion</td>
<td>Better</td>
</tr>
<tr>
<td>Important saline fluctuations</td>
<td>Better</td>
</tr>
<tr>
<td>Floods (water table increase)</td>
<td>Equal</td>
</tr>
<tr>
<td>Inlet sand embankments</td>
<td>Worse</td>
</tr>
<tr>
<td>Increase in organisms sediment-related</td>
<td>Equal</td>
</tr>
<tr>
<td>Resuspension induced by organisms</td>
<td>Better</td>
</tr>
</tbody>
</table>

Two Inlets Problems

| Coastal erosion to the north                           | Better     |
| Instability of the new inlet                           |            |
| Dune instability                                       |            |
| Coastal-lagoon bottom erosion                          |            |
| Marsh and tidal-flat erosion                           |            |

Figure 12. Seasonality of $A_c$ (during the period Dec 1979–March 1981) is related also to variations in longshore drift (daily rates, + to the north, − to the south) evaluated as growth or erosion of the spit (m$^3$/day).
Inlet morphology (channel width, depth, bedforms and minimum flow area) and bottom composition have significant changes along the year.

Minimum flow area can vary from 30 to 320 m² along the year in response to precipitations within the basin, with a lag of one month.

The sand stored naturally within the inlet during the summer (flood-tidal delta) helps to mitigate coastal erosion deficits at the adjacent beaches.

On these adjacent beaches, it is difficult to recognized between the drift effects caused by ocean waves refracted and the sand transport produced by ebb currents parallel to the shoreline.

ACKNOWLEDGEMENTS

Much of the hydraulic data of Mar Chiquita Lagoon were collected by N.W. Lanfredi and E.S. Gaido. The Ph.D. work was supervised by E.J. Schnack and L.A. Spalletti. Draftings were carried out by M.J. Bo, M.V. Bernasconi and M.O. Ferenga. P. Bruun made useful comments to the original manuscript. This study was financed by the Buenos Aires Research Council (CIC).

LITERATURE CITED


