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Influence of inner channel modifications on the morphodynamics of the outer Bahía Blanca Estuary, Argentina

Eduardo A. Gómez, Laura E. Grecco and Gerardo M.E. Perilló, Bahía Blanca

with 7 figures

Abstract: The geomorphology and historical evolution of an area located offshore Bahía Blanca Estuary in Argentina is analyzed. The area is conformed by subtidal sand banks and submarine channels with an almost parallel disposition. As sand banks have their sides dominated by opposite tidal currents, they evolve to zig-zag configuration and migrate eastward, in the direction of the navigation channel of Bahía Blanca Harbor Complex. More than 12 years ago major morphological modifications occurred at an internal channel mouth, which indirectly have arrested the evolution of the outer bank. At present, such beneficial influence would has almost finished, and a rapid sedimentation has started in the only access channel to the largest and deepest harbor of Argentina.

Resumen: Se analiza la geomorfología y la evolución histórica de un área ubicada costa afuera del Estuario de Bahía Blanca in Argentina. El sector está conformado por bancos de arena soubmareales y canales submarinos con una disposición casi paralela. Debido a que los bancos de arena tienen sus flancos dominados por sentidos opuestos de corrientes de marea, evolucionan hacia configuraciones en zig-zag y migran hacia el oeste donde se ubica el canal de navegación del Complejo Portuario de Bahía Blanca. Hace más de 12 años en la boca de un canal interior, ocurrieron modificaciones morfológicas mayores que indirectamente han disminuido la velocidad evolutiva del banco más exterior. Actualmente, tal benéfica influencia habría practicamente terminado, dando lugar al inicio de una rápida sedimentación en el único canal de acceso que existe al mayor y más profundo puerto de la Argentina.

Zusammenfassung: Wir analysieren die Geomorphologie und historische Entwicklung eines Gebietes vor der Küste des Estuario de Bahía Blanca in Argentinien. Dieses Gebiet besteht aus subtidalen Sandbänken und Unterwasserkanälen, die weitgehend parallel angeordnet sind. Weil die Sandbänke an ihren Flanken entgegengesetzte Gezeitenströmungen aufweisen, entwickeln sie sich in zick-zack Form und wandern ostwärts in Richtung des Schiffahrtskanals der zum Bahía Blanca Hafenkomplex führt. Vor mehr als 12 Jahren wurden größere morphologische Modifikationen an einer Mündung eines internen Kanals durchgeführt, die indirekt die Entwicklung einer äußeren Sandbank verhindert haben. Heute sind die positive Auswirkungen dieser Maßnahmen weitgehend abgeklungen. In der Folge hat eine rasche Sedimentation eingesetzt, die den Zufahrtskanal zum größten und tiefsten Hafen von Argentinien gefährdet.

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1. Introduction

Some 30 years ago, OFF (1963) described based on the study of detailed bathymetric charts rhythmic linear sand bodies around the world. His work involved the coasts of Asia, Africa, South America, Australia, and it also considered the ridges off Bahía Blanca, Argentina. Since then, specific studies were carried out in different regions such as in the North Sea (CASTON 1972, CASTON 1981), in the Moreton Bay of Australia (HARRIS et al. 1992, HARRIS & JONES 1988), in the Bristol Channel (STRIDE & BELDERSON 1990, 1991, HARRIS & COLLINS 1991), and in the Chesapeake Bay (LUDWICK 1973, 1974). URIEN & EWING (1974) described for the first time linear shoals on the Argentina shelf. PARKER et al. (1978) detected shoreface-connected linear shoals on the inner shelf south of the La Plata River Estuary, suggesting that these ridges are responses to intensive flow induced by the passage of "southeasters" storms. GÓMEZ (1988), GÓMEZ & PERILLO (1992, 1995), PERILLO & CUADRADO (1991) and CUADRADO & PERILLO (1997) studied submarine shoreface-connected and intertidal sand banks located at the mouth and external area of the Bahía Blanca Estuary. These sand banks are the result of modern reworking by tidal currents of the internal estuary sediments (GÓMEZ & PERILLO 1995), which were deposited as a delta complex developed during the Late Pleistocene/Early Holocene (PERILLO 1989).

The origin, stability and evolution of subtidal sand banks has been studied on inner continental shelves (HOUBOLT 1968, CASTON 1972, HUTHANCE 1972, SWIFT 1975) and in estuarine entrances (LUDWICK 1974, SWIFT & LUDWICK 1976). Particularly interesting are those shoals which present a zig-zag configuration that may occur due to the interdigitation of high- and low-tide-dominated channels or sinuses. Such processes were explained as a tidal wave phase lag as it passes over a submarine sill (SWIFT & LUDWICK 1976). Linear sand ridges seem to be initiated by helical vortices with axes parallel to the flow (WILSON 1972).

The Bahía Blanca Estuary is of great economic importance for Argentina, since one of the most important harbor complexes of the country is placed here. The major channels that form the Bahía Blanca Estuary are partly closed by highly modified tidal deltas (Fig. 1). In its outer area, there is a system of shoreface-connected sand banks that, combined with the tidal deltas, results in a complex bottom topography that is constantly evolving (GÓMEZ 1988, GÓMEZ & PERILLO 1992, 1995, PERILLO & CUADRADO 1991, CUADRADO & PERILLO 1997). The first outward 10 km of the access channel to the harbor complex in the outer area (Navigation Channel), exhibit natural depths greater than 13 m below the Datum Plane. Therefore, it was not necessary to dredge them until present. A sand bank called Largo Bank is placed here, which delimitates the Navigation Channel westwards for more than 13 km. In the present study, we focus mainly on the geomorphological evolution of the area and how it will eventually affect the Harbor Complex economy.

2. Methodology

In order to define the geomorphological characteristics of the study area, several bathymetric and side scan sonar surveys were made between 1983 and 1986. A partial bathymetric survey of a small sector of the area has been repeated in 1998. Bathymetric profiles were taken using a 208 kHz Raytheon echosounder and an EG&G SMS960 side scan sonar (105 kHz) which produced a vertical projection (similar to an aerial photograph) of bed forms and sediment characteristics of submarine channels.

Between 1983 and 1986, a microwave ranging device was used as navigation system (positions were known with an error less than 4 m), while in the survey carried out during 1998, Differential GPS was used (with an error in the order of 1 m). All bathymetric tracks were made crossing the area in the direction of maximum morphological variation with a distance between them of 1000, 500 or 200 m, depending on the bottom variability. Bathymetric data were corrected to the Datum Plane using tidal records. The Datum Plane for nautical charts in Argentina is defined as the level of the average spring low tides plus one standard deviation. Side scan sonar information was digitally recorded during surveys, reproduced and scale-corrected later in the office.

Bottom sediment samples were taken using a Shipek grab sampler and processed following usual laboratory procedures for grain-size analysis as described by Folk (1974). All maps were made using a Gauss-Krüger projection and all nautical charts, originally in Mercator projection, were also converted into this projection.

3. Results

3. 1 Sedimentology and geomorphology

The outer zone of Bermejo and Trinidad Islands (Fig. 1b) is covered by a series of nearly parallel shoals with a general NW-SE trend. Gómez (1988) named most of the features for the first time, and provided a general description of the area. From west to east, the Trinidad Channel, Bermejo Bank, Largo Channel, Largo Bank and, finally, the Navigation Channel to the harbor system are distinguished. Both banks and a great part of the southern area of the Navigation Channel are composed of fine to medium sand. Coarse shelly sand is found at the Trinidad Channel and north of the Navigation Channel. On the east side of the Trinidad Channel, the bed and the east side of the Largo Bank and at the Bermejo Channel mouth, there are fine stratified layers of muddy material related to ancient tidal flats outcrops (Gómez & Perillo 1995).

The Bermejo Channel, which runs between Trinidad and Bermejo islands, is very important in controlling the morphological evolution of some of the sectors of the area. Its mouth has recently undergone some major changes. Comparing

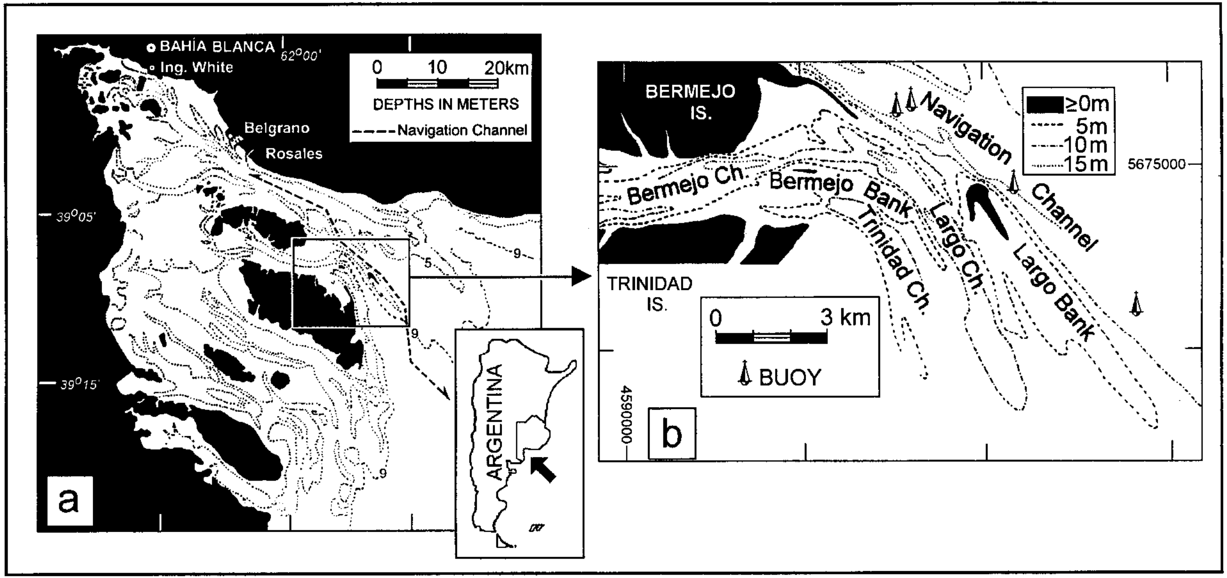

Fig. 1. a) Location of the study area. b) Major geomorphological units are shown in the Gauss-Krüger system of coordinates in meters. This system is used in all of the following charts.

data from historical charts prepared by the Hydrographic Service of Argentina in the study area (Fig. 2), it is possible to appreciate that the Bermejo Channel had once its mouth outlined by an ebb delta (depths less than 5 m) which clearly suggests an ebb dominance (Chart of 1916). Later, in 1944, the Bermejo Channel made its way southwards, outlining the Trinidad Island with depths greater than 10 m. This also suggests an ebb dominance. With minor bathymetric changes, such conditions remained at least until 1972.

In the next bathymetric survey made in 1983 (Fig. 3a), the Bermejo Channel mouth showed depths in the order of 10 m and an eastward trend, cutting the southward projection of the Bermejo Island. The former southward mouth was almost closed at its northern end, constituting the Trinidad Channel at present. The shape of the Trinidad Channel now suggests an opposite current dominance which is confirmed by the presence of flood oriented sand waves with heights in the order of 2 m (Fig. 4a) and up to 4.5 m in some cases.

The shape of the Largo Channel also indicated a flood dominance at least until 1972 (Fig. 2). The bottom of this channel is mainly composed of muddy

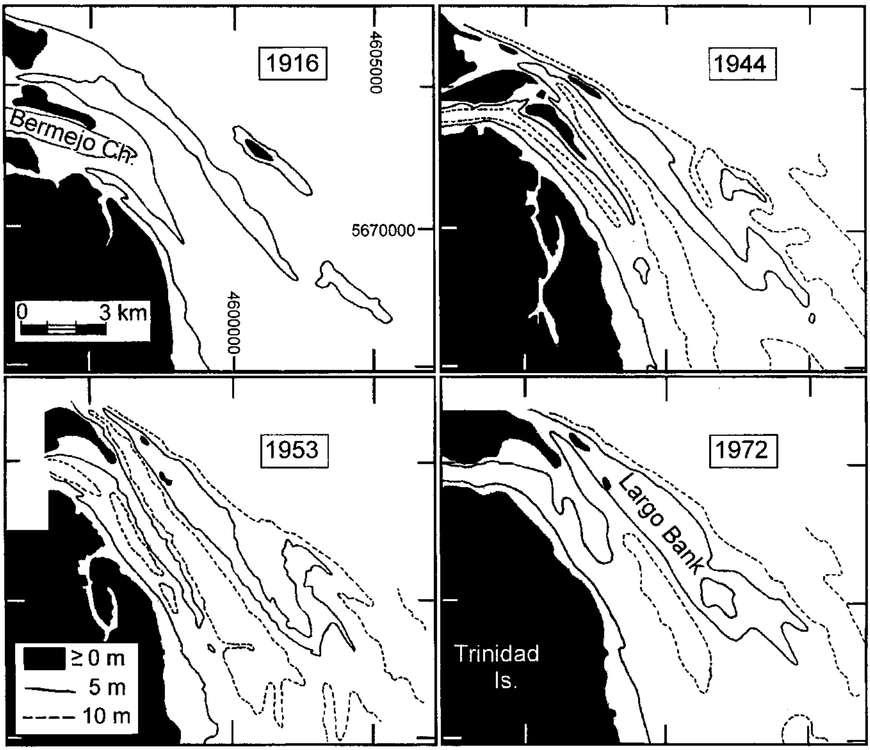

Fig. 2. Historical evolution of the study area from the beginning of the century. Data were extracted from historical charts made by the Hydrographic Service of Argentina.

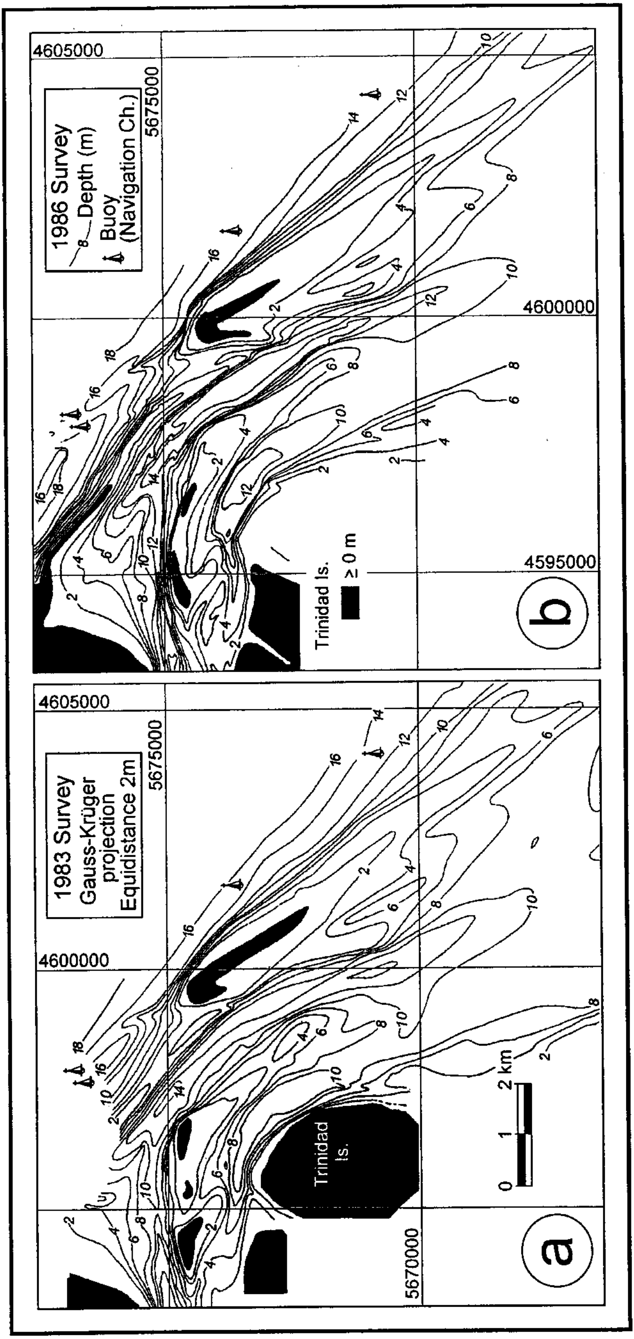

Fig. 3. Bathymetric charts of the study area. a) 1983 survey, b) 1986 survey.

materials related to ancient tidal flats now submerged (Gómez & Perillo 1995). For this reason, there are presently no sandwaves or megaripples exhibiting the direction of the net sediment transport. However, the shape of the Bermejo Bank's east side (similar to a meander point bar) indicates an ebb dominance (1983 and 1986 surveys, Fig. 3). Tidal currents between the Bermejo Channel and the Largo Channel should flow like in a river bend (meander), eroding the concave side and depositing sediments at the convex side (point bar). The relative position of such deposits at the east side of the Bermejo Bank in respect to the point of maximum bend inflection, clearly suggests a net ebb dominance. The differences in development that exhibit the scour marks located at both sides of a wreck placed in the middle of the Largo Channel (Fig. 4b), also confirms that the channel is presently dominated by ebb currents in its central and northern portion.

Using side scan sonar surveys made at the Navigation Channel, it was possible to identify several bed forms located mostly on the Largo Bank flank (Gómez & Perillo 1992). The northern and southern portions of the Navigation Channel are almost fully covered by megaripples, with heights of the order of 0.6 m, and sand waves up to 1.6 m height. All these bottom features exhibit their lee side

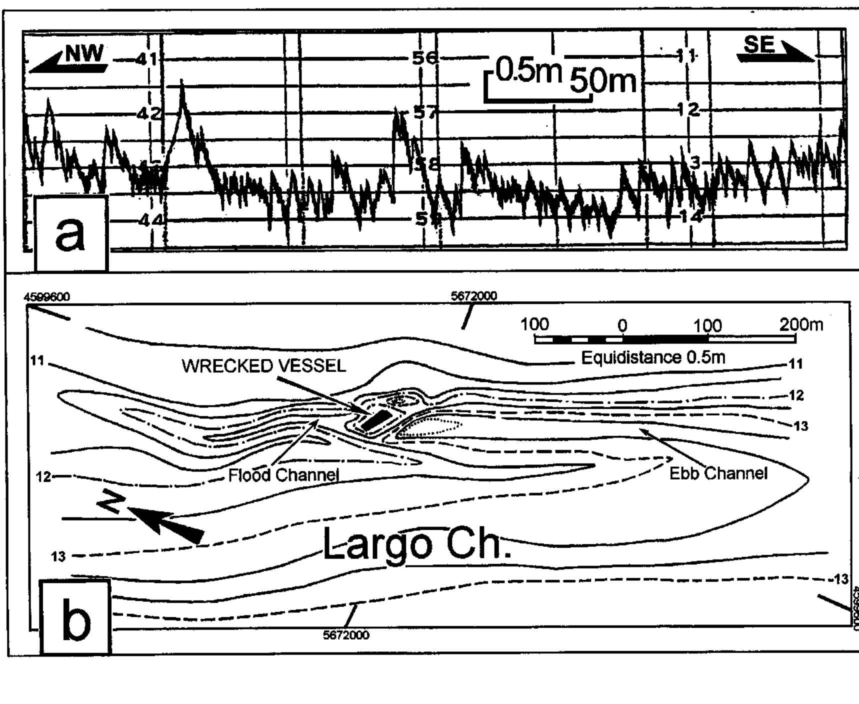

Fig. 4. a) Example of ecosounder records obtained along the Trinidad Channel. Note the NW orientation of the sand waves which indicate a dominant net sediment transport during flood. b) Detailed bathymetry of the Largo Channel from the wrecked vessel area. The differences in scour marks development indicate a net ebb dominance.

oriented to the southeast and indicate ebb dominance. This ebb dominance at the Navigation Channel is also confirmed by continuous current measurements carried out by NEDECO-ARCONSULT (1983) during 13.5 days.

3.2 Bathymetric comparison

In order to analyze the geomorphological evolution of the Bermejo Channel mouth, we compared the bathymetric data obtained during the surveys of 1983 and 1986 (Fig. 3). Differences in water depths were obtained using the overlapping portions of the two charts at all intersections of a common rectangular grid with 100 m of side length. Because of the error in the determination of the exact depth from the echosounder records, differences smaller than 20 cm, either erosional or depositional, were considered as equivalent to no change.

The bathymetric comparison shows that between 1983 and 1986 the entire area changed in a significant way (Fig. 5a). Great sediment accumulation occurred at the Trinidad Channel head (up to 1.4 m/year) and at the Bermejo Bank's east side (2.35 m/year). During the same time, the Trinidad Channel showed accretion in the order of 2.7 m/year at its south bank (Trinidad Island) and erosion up to 2 m/year at its north side (Bermejo Bank). The new west-east mouth of the Bermejo Channel exhibited erosion of up to 1.7 m/year in the area of the former southern end of the Bermejo Island. The portion of Largo Bank located just in front of the Bermejo Channel exhibited erosion on its west side (2.35 m/year) and sedimentation on its east side (1.7 m/year). A bank cross-section from this area (Fig. 5b) indicates that the Largo Bank inverted its asymmetry by moving its crest approximately 300 m eastward. The Largo Bank evolved to a zig-zag configuration by the interdigitation of ebb- and flood-dominated sinuses, with the ebb sinus deepening at 1.7 m/year through the northern bank crest (GÓMEZ & PERILLO 1992).

A partial bathymetric survey done in January 1998 at the Largo Bank's east side exhibited major morphological changes (Fig. 6). Within this surveyed area, the northern part of the bank has moved eastward for more than 500 m in 12 years increasing its steepness to the Access Channel, while minor changes have occurred in the south.

4. Discussion and conclusions

From the disposition and evolution of the major geomorphological features (the Bermejo, Largo and Trinidad Channels, and the Largo and Bermejo Banks) and the orientation of the bed forms located at the submarine channels, it is possible to deduce the net directions of sediment transport. The directions for the entire study area are shown qualitatively in Fig. 7.

According with the historical charts from the beginning of the century, we consider two nuclei of almost independent morphological evolution: the Bermejo

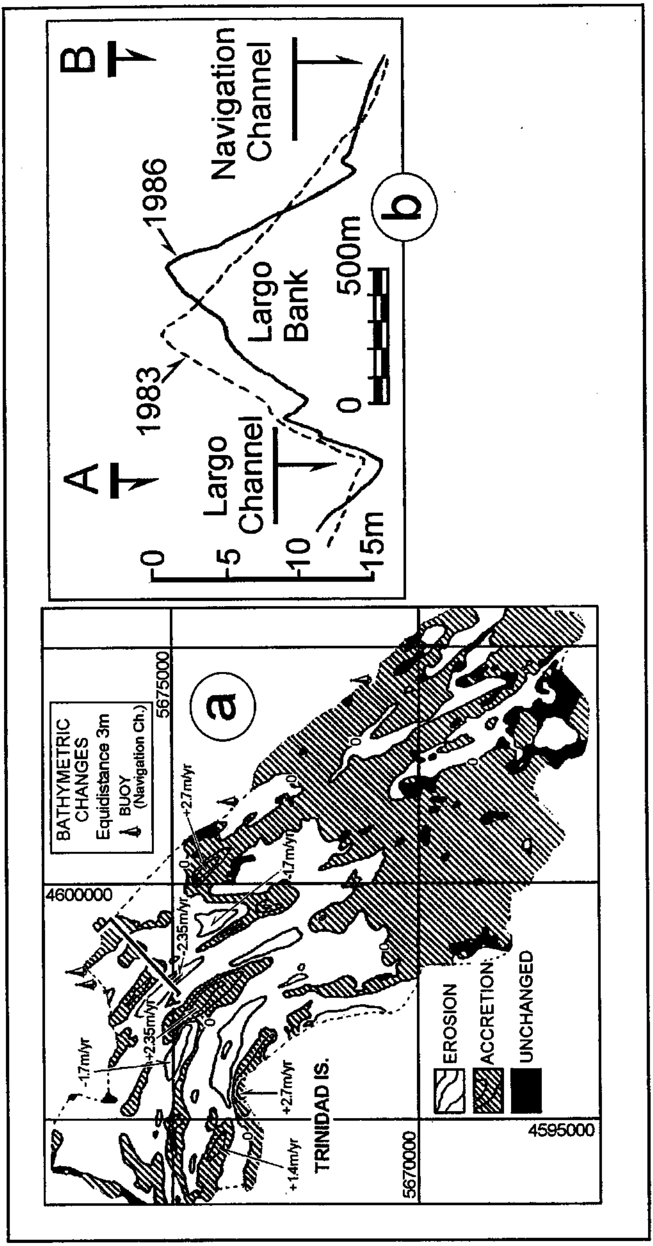

Fig. 5. a) Bathymetric changes between 1983 and 1986. b) Comparison of the bathymetric profile in the northern part of the Largo Bank. The location of the profile is given in (Fig. 5a).

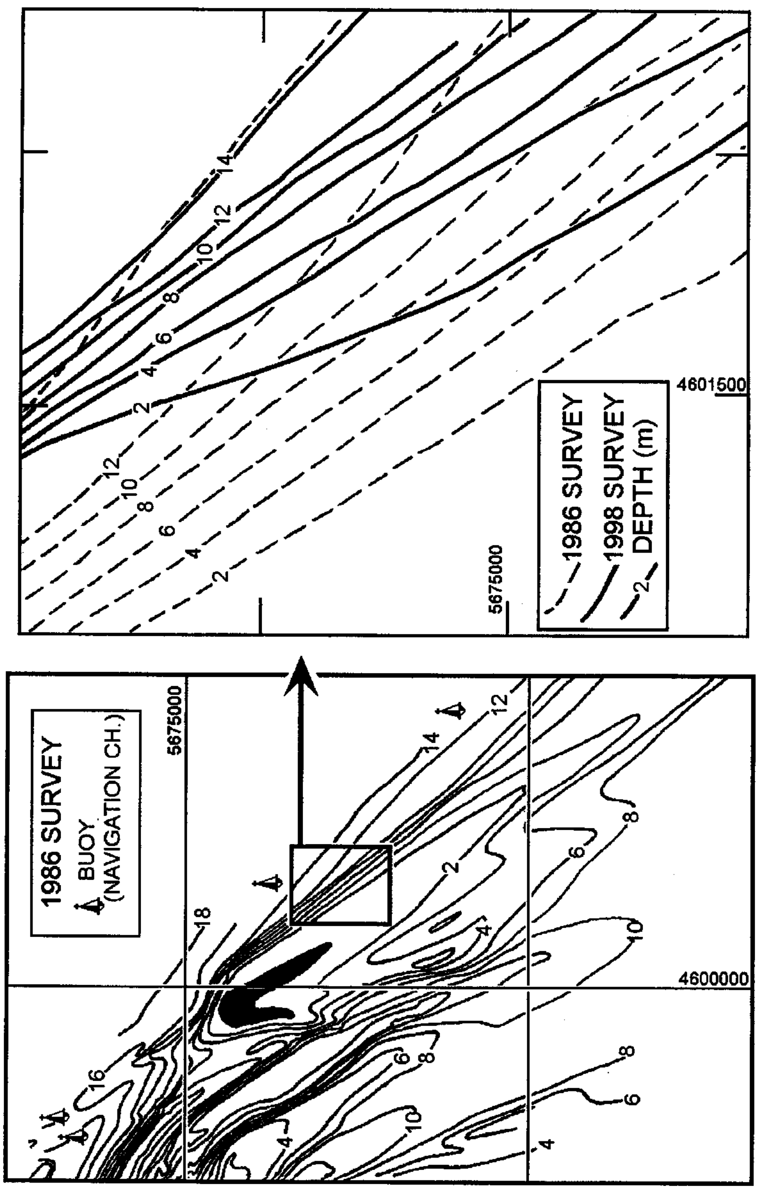

Fig. 6. Bathymetric comparison between 1986 and 1998 of an area on the east side of the Largo Bank.

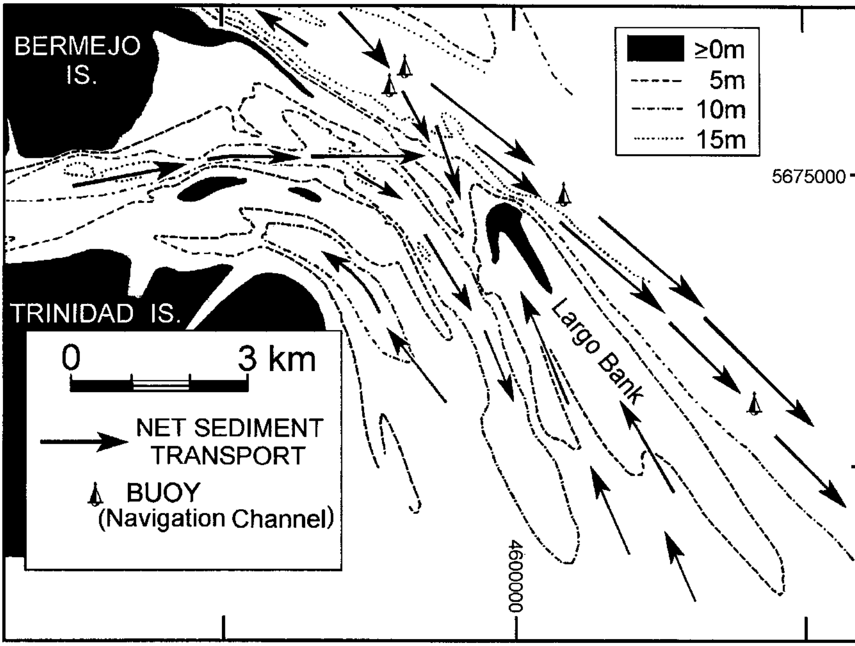

Fig. 7. Directions of net sediment transport deduced from the disposition and evolution of the major geomorphological features and bed form orientation.

Channel's mouth and the Largo Bank. Comparing the historical charts with the survey made in 1983, it is possible to appreciate that, while the Bermejo Channel has abruptly changed its mouth and formed the Trinidad Channel and the Bermejo Bank), the Largo Bank presents on its two sides net currents whose dominance is of opposite sign. The Largo Bank's west side is dominated by flood currents while its east side is dominated by ebb currents. At the same time, the currents at both bank sides are unbalanced which results in a significant eastward migration combined with a lateral growth of the bank. The evolution of the Largo Bank as observed in the bathymetric surveys made in 1983 and 1986 (Fig. 5a) indicates that the bank slowly acquired a zig-zag configuration as described by Caston (1972) for sand banks located in the North Sea. However in Caston's model, deformation precedes separation, while in the present case both processes seem to be simultaneous (Gómez & Perillo 1992).

The Navigation Channel's greatest depth is found besides the Largo Bank's core. In this case, the Largo Bank acts as a wall which leads to a great increment of the water velocity during ebb. At present, the eastward advance of the Largo Bank over the Navigation Channel, especially in its central portion, results in an obstacle to the ebb currents. Thus, these currents are divided and formed an ebb sinus immediately north of the shallower part of the bank crest. The deepening of this new crossing channel would cause a gradual decrease in the ebb currents in the Navigation Channel. As an immediate result, the sediment transported by these currents will be deposited in the Navigation Channel, as they loose competence.

However, at least during some periods of time, the opening of the Bermejo Channel has strongly affected the northern portion of Largo Bank. The action of the jet-like ebb current that exits this channel affected directly this sector of the bank (Fig. 5). The sediments carried to the Navigation Channel by the Bermejo Channel ebb currents would also be moved by the Navigation Channel ebb currents to the ebb sinus, counterbalancing the deepening of the Largo Bank northern ebb sinus. Such a process would stop the evolution of the bank core, as ebb currents in the Navigation Channel did not yet loose enough competence to retransport the sediments to the south which were carried over the bank crest by flood currents.

However, the impressive eastward grow of the Largo Bank's east side shown in the last partial survey done in the area (Fig. 6) suggests a greater rate of deepening of the bank ebb sinus because sand from the Largo Bank's northern portion was no longer available. Thus it is now expected that the central-southern part of the Largo Bank becomes soon independent. The deepening of the crossing ebb sinus will cause a gradual decrease in the speed of the ebb currents at the Navigation Channel. Because the ebb currents have a new way to flow north to the core of the Largo Bank, they loose in the future the strength to maintain the channel at navigable depths. The consequence of this process will be a rapid sedimentation in the only access channel to the largest and deepest harbor system of Argentina from which most of the cereal exports of the country take place. The Largo Bank will move over the Navigation Channel at increasing speed and make future expensive and futile dredging indispensable.

An study of the marine area located east Largo Bank is immediately needed in order to move the position of the Navigation Channel to a geomorphologically more stable place than the present one.

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Address of the authors:

Dr. Eduardo A. Gómez, Dr. Gerardo M.E. Perillo, Instituto Argentino de Oceanografía, Casilla de Correo 804, 8000 Bahía Blanca, Argentina.

Dr. Laura E. Grecco, Universidad Nacional del Sur, San Juan 670, 8000 Bahía Blanca, Argentina.