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Sediment Transport Circulation Pattern through Mesotidal Channels System

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1. Introduction

There are three modes of sediment in motion, which are recognized as rolling and/or sliding; jumped and suspension particles motion. These particles motion include two essential sediment transport modes, which are bedload and suspended load. The first corresponds to the part of the total load which is moving very close to the bed. On this opportunity, the sediment is transported by rolling and/or sliding along the floor or jumping immediately above the bed. The suspended load comprises the particles that are carried away at suspension in the moving fluid. Bedload transport occurs in low velocity flow and/or large grain sizes, while suspended load take place at high velocity flow and/or small grain sizes.

The sediment transport theory to point out that sediment capacity flow and sediment availability in channels regulates the motion of sediments. The sediment transport capacity is the maximum load that can be transported by flow and the sediment availability is the material supply that the flow can put in motion.

In general, the sediment load that moves in a rolling or saltating mode is smaller compared with the suspended load transported in a natural flow. However, the bedload sediment is important for its contribution to the morphological change of the channel. Moreover, it is the most important factor in determining the stability of natural channel, the bed topography, and, therefore, the cause of the hydraulic resistance and some properties of the flow. Accordingly, on this chapter we focus on the bed sediment transport pointing to the pathway migration rather than the sediment transport rate itself.

The sediments transport as bedload in estuarine environment controls the bottom morphology. Therefore, estimating the transport of non-cohesive sediments, mobilized by the channel floor, has relevance to the understanding of many pressing environmental problems including eutrophication, contaminant transport, sediment bed erosion, siltation and waste disposal, which impacts on seabed stability and at times on ecosystem distribution. Also, sediments that are moving on the bed generate different bedforms such as shoal, dunes, point bar, etc., which can be hazards to navigation and to affect the flow conditions and the flanks channel stability.

There are different approaches to analyze and estimate the rates and pathways of sediment transport as bedload. Among them there are recording and analysis through indirect observations of the morphological and sedimentological features, the bedform geometry and their asymmetry, and the internal sedimentary structures, carried out with acoustic instrument (side-scan sonar, echo-sounder, multibeam, seismic, etc.), and/or the use of empirical formulas to estimating the quantity and net direction of sediment displaced as a function of the near-bed flow velocity. However, in tidal environment, the alternating ebb and flood currents as well as the effect of turbulence, become more difficult to estimate the bedload transport using empirical formulas from laboratory studies. Therefore, we consider that a best estimate of the bedload transport rates and directions should be in combination used empirical formulas with the techniques of indirect observations.

Numerous authors (Bagnold, 1956, 1963; Yalin, 1963; Engelund & Hansen,1967; Ackers & White, 1973; Madsen & Grant, 1976; Gadd et al., 1978; Langhorne, 1981) have given to know a number formulas for estimating the quantity of sediment transported as bedload as a function of the current velocity. The earliest formulas proposed to estimate bedload transport were mainly based on the concept that the sediment transport rate can be related to the bottom shear stress (Meyer-Peter & Müller, 1948; Einstein, 1950) and these formulas were valid for steady, uni-directional flows. In coastal and marine environments, the process of sediment transport becomes more complex due to the presence of oscillatory flows, and the interaction between steady and oscillatory flows (Bijker, 1967; Watanabe, 1982; Van Rijn, 1993). So, cited by Zheng-Gang Ji (2008) the bedload sediment transport formulas have the general semiempirical relation of

$$\frac{q_B}{\rho_s d_s \sqrt{g d_s}} = \Phi(\tau_0, \tau_{*cr})$$

where Φ is a function of the Shields parameter (τ_0) and its critical value (τ_{*cr}), q_B bedload transport rate (mass-per-unit time-per unit-width normal to the flow direction), d_s the sediment particle diameter, ρ_s the sediment density. Therefore, to predict of sediment transport rates, an important parameter is the shear stress (τ), which is the tangential force per unit area that a moving fluid exerts on the sediment bed. When the bottom shear stress (τ_0) exceeds the critical shear stress (τ_{*cr}), the sediment particles that are resting on the bed only start moving. The shear stress is related to the flow velocity above the bed (u) through $\tau = \rho u^2$, thus the flow velocity must exceed a critical value before particles start to move.

Many attempts have been made to determine the bedload transport sediment through the use of theoretical formulas, empirically deduced. However, to despite of many formulas existing, not yet was reached an agreement to accept of these equations as the more satisfactory for the determination of bedload transport. Therefore, the choice of an appropriate equation for tidal environments is still an open question.

2. Bedload sediment transport at tidal channels

2.1 Methods of analysis

Under all those considerations and taking account there are few studies about the movement of bed sediment at interconnected tidal channels system, the chapter purpose is to depict the sediment transport behavior as bedload in this type of sub-environment and determine the tidal flow as controlling factor of such transport pathways. Understand the

processes and mechanisms controlling the rate and directions of sandy grain-size transport are very important because the maintenance of estuaries is closely linked with their transport paths. Specially, if the estuary is integrated by an interconnecting tidal channels system. Similarly, the construction of structures, oil pipelines, and sewages outfalls is dependent on the nature and stability of the bottom sediments. Therefore, the accurate knowledge of transport paths as bedload sediment is essential if the environmental managers be able to asses the ultimate destination of material.

Because the exchange of floor sediments between the interconnected channels is not well know, being subject of present investigations, and as our intend is to advance in this type of research, in this chapter we show how may be the pathways of bedload sediment transport at interconnected tidal channels system. Surprisingly, few field evidences supports studies on inferred the bedload transport rates and directions at an interconnecting tidal channels system. The majority studies dealing with specific aspects on intertidal dynamics as tidal asymmetries and morphodynamics of tidal channels but based in laboratory experiments and theoretical models (Friedrichs, 1995; Schuttelaars & de Swart, 2000; Lanzoni & Seminara, 2002; Bolla Pittaluga & Seminara, 2003; Tambroni et al., 2005). Under these considerations and based on studies carried out many years ago at Bahía Blanca estuary about sediment dynamics in interconnecting tidal channels, we evaluated the pathways and sediment transport rates as bedload at these sub-environments. A detailed set of in-situ field measurements include continuous monitoring of bottom currents during at least one tidal cycle (13 h) at different deployment sites; analysis and interpretation the morphological features as bedforms orientation (i.e. dunes, sand ribbons, point bar, shoals, etc) and analysis of sub-bottom strata characteristics that conform these features. All those data were collected during different campaigns, using high seismic-reflection profiles, side scan sonar records, bathymetric and current-meters data. In this context, we focusses our analysis mainly on the description of bedforms geometry, erosion-deposition process and, asymmetry and analysis of bottom currents in a tidal channels system of the Bahía Blanca estuary (Argentina).

2.2 General characteristics of channel systems

The regional coastal configuration of Bahía Blanca (Fig. 1) corresponds to a plain estuary formed by transgressive-regressive sedimentary processes during the latest postglacial events (Aliotta & Farinati, 1990). This mesomareal estuary is located to south of Buenos Aires Province (Argentina) and is characterizes because the freshwater input is very small compared to the tidal prism. There is extensive mudflats with one large sinuous main channel, where in some sectors the water depth is maintained by dredging (15 m) to ensure the passage of ships to ports and it is called Principal channel. The south side of the Principal channel is formed by an extensive intertidal area with an interconnected tidal channels system of sizes different, very sinuous or meandering and with general orientation NW-SE (Fig. 1). Because of the little contribution of runoff from terrestrial sources, the maintenance of channels depends on inflow and outflow tidal. The tidal regime of this estuary is a semidiurnal periodicity with mean range of around 2 m at the mouth and more than 4 m at its head, with tidal ranges 2.5 m for neap tides and of 3.42 m for spring tides. The tide wave propagates following a hypersynchronic mode, generating currents higher than 1.05 m s^{-1} (Perillo & Piccolo, 1991). This channel has tidal currents reversible with mean velocities, measurement recently by us with ADCP, of 1 m s^{-1} and 1.4 m s^{-1} for flood and ebb

conditions, respectively. Maximum speeds of currents, along cross section to Principal channel, are occurring near the south coast.
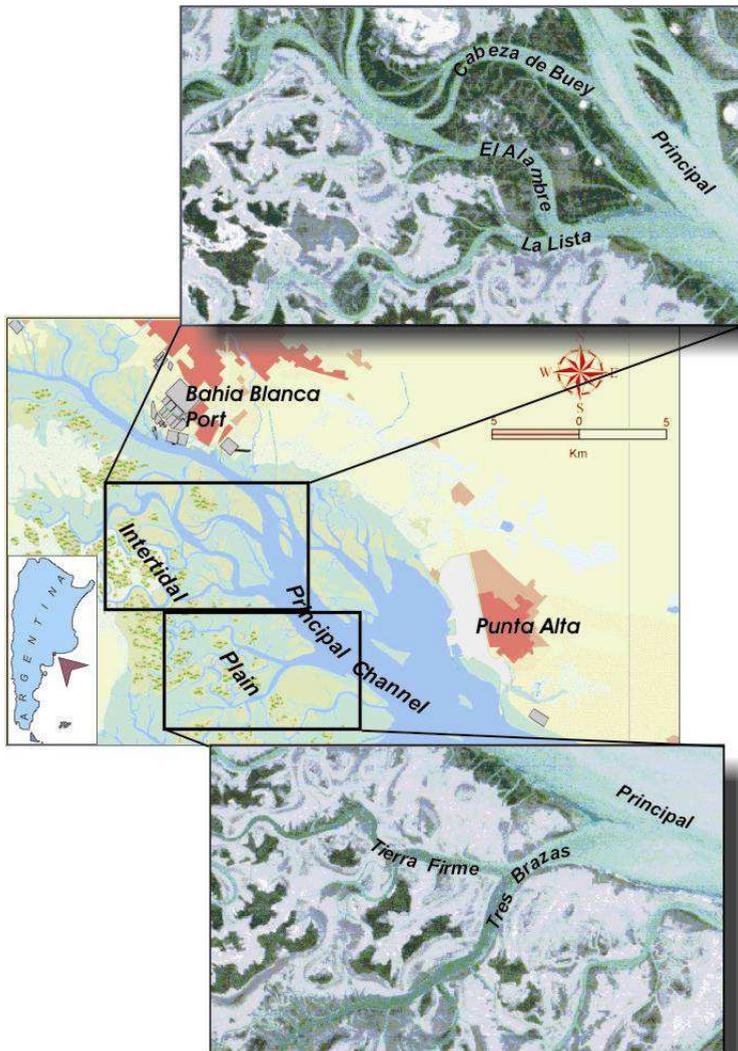

Fig. 1. Bahía Blanca Estuary. Intertidal plain with interconnected tidal channels system.

According to the different dimensions, tidal channels have been classified as large channels, creeks and gullies (Fig. 2). Generally, the smaller channels (gullies and creeks) flow into the large tidal channels and these latest flows into the Principal Channel. The width and depth ranges the former may from few tens of centimeters up to 1m, while the large channels could have reach more than 10m depth and width of 1km in their mouth (Ginsberg & Perillo, 2004). In plan view, the courses of large channels have shown a low to medium

sinuosity pattern while the smaller channels are predominantly strongly sinuous or meandering and their curvatures increases inward. The mouth of the large channels is highly dynamic area, with considerable movement of sediments and associated morphological changes, leading sometimes to an infilling as shoal.

In general, the topographic profile is different in relation to channel size (width depth ration varies) and the bottoms of the larger tidal channels are mostly sandy, enriched in shells and mud pebbles (Fig. 2). The bottom sediment of smaller channels and gullies of the intertidal zone are mainly muddy with a low percentage of sand fractions. The sub-bottom sedimentary material that characterizes sedimentologically the wide tidal plain of Bahía Blanca, was described by Aliotta et al. (2004) from a vertical stratigraphic profile made on the erosive flank of a large channel (Tierra Firme channel) (Fig. 3). It is composed at the bottom with gray-dark to brownish fine-sand and contains about 25% of mud. Upward of profile the percentage of silt + clay fraction increases more than 75%. A deposit - classified as clay silty sand - with horizontal parallel bedding made up of thin laminae of fine-to-very-fine sand (2 mm) and mud (4 mm) outcrops in the intertidal zone, which is characterized by escarpment levels. The sand/mud interlayered is eroded during the lateral displacement of channels. Studies in restricted sites indicate values of lateral displacement of up to 25 m yr^{-1} (Ginsberg & Perillo, 2004). Erosion can result in the formation of small terraces and cut bank rotational slumping of large blocks, where consolidated sediments after collapse can be accumulated on the bed along the bank (Fig. 4). Later all these sediments are transported as bedload. Depending on the strength of the currents, these deposits are carried away as bedload, normally following the channel currents dominance. Sometimes, large amounts of sediment are deposited as
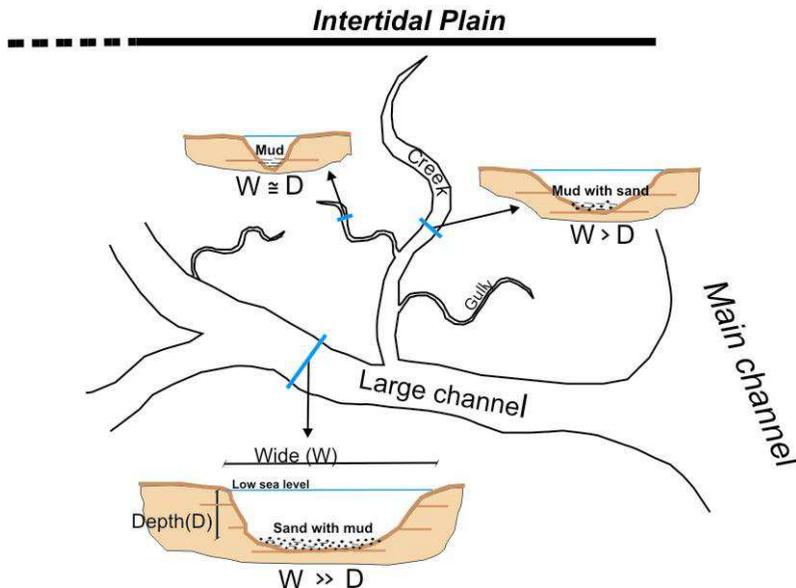

Fig. 2. Tidal courses classification. Classification of different channels based on their sizes range and bottom sediments
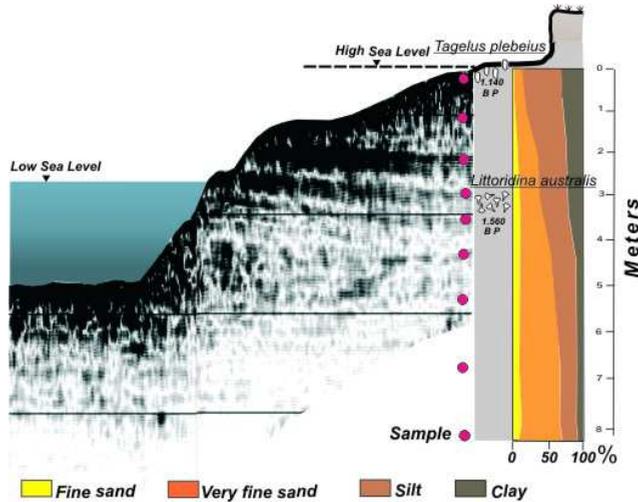
Fig. 3. Seismic-stratigraphic and sedimentological profile along erosive flank of a large channel.

shoals in mouth of tidal channels. The shoals lie partly below mean sea level, but most of the larger shoals have become intertidal. Usually, the floors of tidal channel consist of relatively coarse and fine sand, with mud balls. The shoals are sandy, sometimes with layers of sandy silt on top.
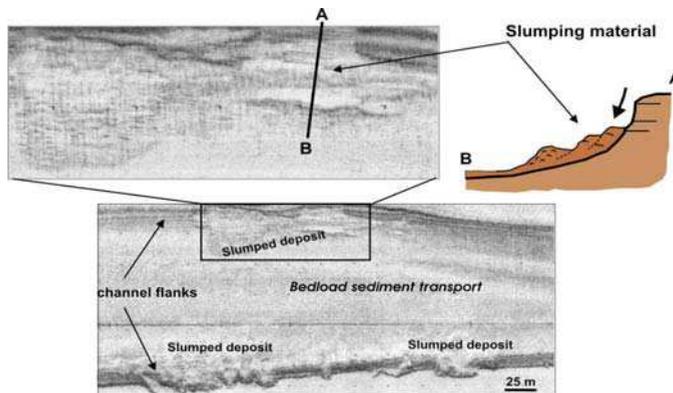

Fig. 4. Sediment slumped along channel flank. Side Scan Sonar record is showing this process.

3. Estimation of the bedload sediment transport and relationship with the morphodynamic

To improve our understanding of the processes and sediment transport as bedload in an interconnecting tidal channels system, on this chapter we focus in two systems at Bahía Blanca estuary (Fig. 1). One of them is composed of Cabeza de Buey, El Alambre, La Lista

and Principal channels and the other system by Tierra Firme, Tres Brazas and Principal channels. At the first system, the Cabeza de Buey channel is connected to La Lista channel through El Alambre channel. The first two flow into the Principal channel. The second system corresponds to the Tierra Firme-Tres Brazas channels, where the first is a distributary of the second channel. The latter is flowing into the Principal channel.

Arguably, the most important factor controlling the sediment transport as bedload is the number and pattern of distributaries channels. The pattern in the transport of sediment through the distributaries channel generally follows the flow of water. However, variability in the sediment load carried by each branch, depend of the sediment availability at each channel. Recalling that sediment transport mainly depends on flow velocity, it is possible to relate the residual sediment transport to the peak values of velocity during the ebb and flood phases. In addition, is known that the magnitude and direction of the residual transport along a tidal cycle is mainly affected by tidal asymmetries which are favored by unequal duration and/or unequal magnitude of ebb and flood (Dronkers, 1986). In particular, flow asymmetry characterized by shorter flood duration and higher velocity flood current (i.e., flood dominance) induces a landward sediment transport (Lanzoni & Seminara, 2002). Conversely, shorter periods fall flow and maximum velocity ebb current (ebb dominance) cause a net outward sediment transport. To determine the flood/ebb dominance in the net transport through several sectors of channels has been made an approach depending on both the duration of each tidal phase and also its peak velocity. Tidal currents observations carried out in some tidal channels of Bahía Blanca estuary by Montesarchio & Lizasoain (1981); NEDECO-ARCONSULT (1983); Ginsberg & Perillo (1999, 2004); Vecchi (2009); Ginsberg & Aliotta, (2009) indicate that the behaviour of tidal currents during the flood phase is different from the ebb phase (Fig. 5). These measurements suggest the ebb peak is higher than the flood peak, but the duration of the ebb phase is shorter. For instance, evaluation of maximum velocity indicates that in general average maximum flood velocities have about 0.80 m s^{-1} and average maximum ebb velocities is about 1.20 m s^{-1}. Examination of currents duration indicates that flood time dominance is about 7 h while ebb period is 5 h. In particular, detailed analysis of the near-bed velocity in the Tres Brazas channel and its tributary (Tierra Firme channel) indicates the ebb dominance, with maximum flood velocities of about 0.60 m s^{-1} and maximum ebb velocities around 0.85 m s^{-1}. At El Alambre channel the maximum velocity is ebb-direction, which reaches 0.65 m s^{-1}, while flood is about 0.50 m s^{-1}, and at La Lista channel the observations indicate a dominance of the ebb current with average velocity of 0.50 m s^{-1} while flood current have maximum average values of 0.40 m s^{-1}. All these measurements indicate that the system is at present ebb-dominated because have a tidal asymmetry with a peak current velocities 30 % faster during ebb period and with relatively more longer duration of the flood currents. Therefore, under those considerations, all these measurements indicate that the strongest current is in ebb direction, suggesting a net sediment transport towards outer zone of channels.

Based on the velocity measurements above the bed, some of aforementioned specialists have predicted the net bedload sediment transport rate in some channels. Among them, Vecchi et al. (2008) and Vecchi (2009) calculation of the sediment transport found in the inner sector of La Lista and El Alambre channels values of the 0.07745 g cm^{-1} s^{-1} and 0.08773 g cm^{-1} s^{-1}, respectively, both in the ebb direction. At La Lista mouth, their estimates indicate that the sediment transport decreases to reach 0.02188 g cm^{-1} s^{-1}, also in ebb direction. Ginsberg & Perillo (1999), estimate the sediment transport at Tres Brazas and Tierra Firme channels, based on the theory where the bedload sediment transport is proportional to the stream

power (Bagnold, 1966). The results of these studies showed the following values: 489 erg cm^2 s^{-1} for inner sector of Tres Brazas channel and 379 erg cm^2 s^{-1} for the other channel. All the studies discussed above demonstrate that in terms of bedload transport, the large channels are ebb-dominated and in consequence there is export of sediment from landward. These results showing that the velocity asymmetry at present-day channels, which is consistent with the residual sediment transport, controls the bed sediment movement towards Principal channel or outward area.

In order to have an over view complete of the sandy sediment mobility within different sectors of channels and knowing that bedform characteristics as well as the configurations of channel system are also determining in pathways sediment transport is given a complete review of different morphological features that several authors have found in each channel of both systems. The results indicate that bottom morphology consists of a wide variety of bedforms at scales ranging for centimeters to tens meters (Ginsberg & Perillo, 2004; Lizasoain, 2007; Ginsberg et al., 2009 a,b; Ginsberg & Aliotta, 2009). The location and distribution of bedform types reflects the patterns circulation of sediment transport. Accordingly, we considered that flood/ebb tidal dominance together with the channels morphology will give rise to illustrate sediment circulation as bedload at tidal interconnected channels. For instance, we can mention some junction zones of channels, which exert an important effect on the hydrodynamics, and therefore on sediment transport as bedload, increasing or decreasing the ability of the tidal flow to induce a scour holes or deposits, in these zones. Hence, the changing bottom features will affect the hydrodynamics and will cause significant changes in the transport pattern. In consequence, local changes as a meandering sector, point bars, shoals mouth and the junction channels zone could be responsible for the changes in transport within the channel system. As a result, we will use these features development in tidal channels as an important tool for evaluation of the bottom sediment transport.

The main characteristics in channels of Bahía Blanca are asymmetric dunes, whose distribution, pattern and morphology provide information on bottom currents on the assumption that they are in equilibrium under the current hydrodynamic conditions (Boothroyd, 1985; Ikehara & Kinoshita, 1994). In addition, sediment transport as bedload could be inferred from its asymmetry (Allen, 1968 a,b; Bokuniewicz et al., 1977; Swift & Freeland, 1978; Harris, 1988). Taking these concepts into account, the examination of the asymmetry of these dunes carried out by several authors in the systems considered here, have provided information on sediment transport as bedload as well as on sedimentary circulation pattern. From the different nomenclatures to available for the description of these features (Allen, 1968a; Boothroyd & Hubbard, 1975; Ashley, 1990; Berné et al., 1993) was chosen the classification scheme of Ashley (1990) which considered height (H) and wavelength (L) as the most important parameters. Two main bedforms scales were identified in the system considered namely medium dunes (5 m<L<10 m; 0.4 m < H<0.75 m) and large dunes (10m<L<100m; 0.75 m < H<5m).

Medium dune is the most common bedform in various sites of different tidal channels of Bahía Blanca estuary (Aliotta et al., 2004; Lizasoain, 2007; Ginsberg et al., 2009b). In particular, the channel system of Tres Brazas-El Alambre (Ginsberg et al., 2009a) have been found these bedforms (L=8–10 m; H=0.4– 0.6 m) on a relatively thin sand belt, in the inner sector of Tres Brazas channel. Also, they found large dunes (L=12 m and H=0.8 m) in the mouth of Tres Brazas channel with their crestlines very sinuous and barchanoid structure with low lateral continuity. Their profile is asymmetric with the ebb current. Large dunes
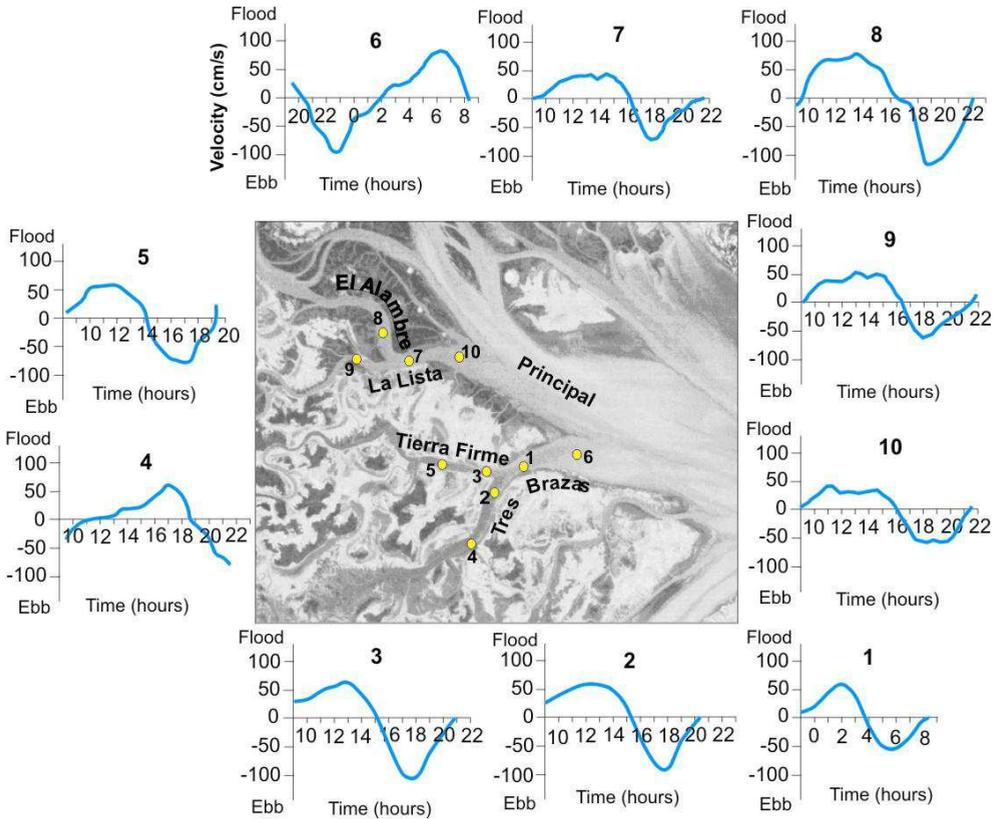
Fig. 5. Current measurements at tidal channels of Bahía Blanca estuary. The tidal asymmetry showing the difference of phases between flood and ebb.

are, in general, formed at a 5–6 m depth towards the inner part of Tres Brazas channel, and at higher depths they disappear, thus forming a sand bottom plane. These authors indicate that under different tidal conditions, the dunes always have displayed an asymmetric profile with the lee side towards the Principal channel. On the other hand, according to Ginsberg et al. (2009a) the morphological and seismic studies in the system Tres Brazas-Tierra Firme are also indicative of ebb dominance in both channels, although only in the inner part of Tres Brazas channel there is a significant availability of sandy sediment mobilized as bedload transport. This circulation pattern is evidenced by the formation of the dunes above mentioned. The sandy sediments coming from the inner zone of Tres Brazas channel are mobilized along their southern flank. The major part of the Tres Brazas channel sediments are transported along this channel towards the Principal channel and the other partly settles on mouth to form sand shoal. In contrast, the above mentioned authors have observed that the Tierra Firme channel have a low contribution of sandy sediment and no will result an important input of them.

Geomorphologically, tidal dominance on sediment transport as bedload produces also bed forms as sedimentary corps that can using to predict the pathways of sediment transport. So, based on point bar formation on meander bends, Aliotta et al. (2004) and Vecchi (2009)

provide useful information to determine the net flood/ebb dominance in the bed-material transport direction through the channels. They have been described different point bars configurations and we assume that the difference on nature is in response to sediment availability that each channel has. Hence, Aliotta et al. (2004) note that the point bar formation at the inner side of Tierra Firme channel bends is characterized as bank-attached bar with lateral sedimentation. They observed through analyzing 3.5 kHz seismic data at Tierra Firme channel (Fig. 6), that the sedimentation on the point bar takes place laterally in the form of inclined beds. The downlap reflection terminations indicate progradation and migration of sedimentary body or point bar, which shows an oblique progradational pattern (Fig. 6, I) formed by sandy silt material supply. This type of seismic facies suggests (Mitchum et al., 1977) a relatively high hydrodynamic regime. These beds are curved and of short lateral extent. The layers curved show the sediment transport direction. The maximum ebb current velocity transports sediment as bedload outside of channel, and some of these materials tend to be deposited on point bar (Fig. 6, II).
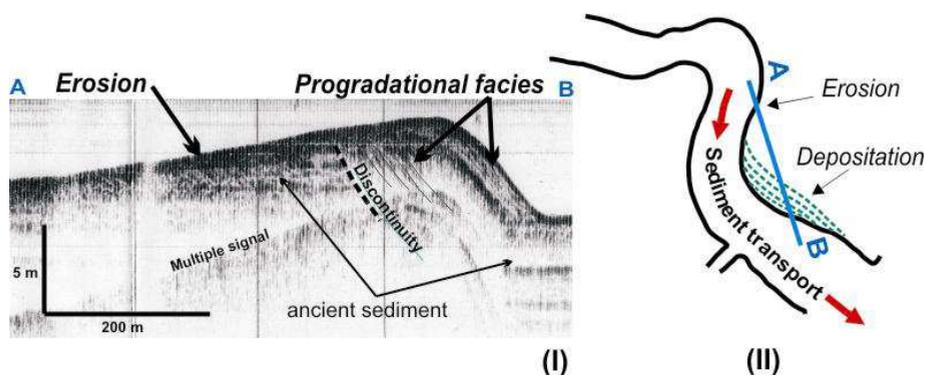

Fig. 6. Point bar in a tidal channel. (I) Seismic record showing the stratigraphic evidences of a point bar evolution. (1II) Scheme showing the dominant sediment transport direction.

Vecchi (2009), also observed the formation of a point bar in El Alambre channel (Fig. 7), but she recognized that the high amount sediment mobilized from inside the channel have a strong influence on natural development of this point bar. Is so those sediment mobilized by ebb dominance are accumulated on downstream portion of the point bar and cause a growth of this bar with development an ebb barb. Therefore, a short elongate tidal bar (spit bar) is formed as a bank attached to point bar (Fig. 7) with separation of the flow into mutually evasive flood-and ebb-dominated channels. Medium dunes with lee face oriented to ebb tide migrate on the surface of this bar.

As a resume, point bars are formed by aggradations during the channel migration by the ebb-domination, typifying meander bends in rivers (Fagherazzi et al., 2004). The current direction dominance obtained through this feature, indicates a current running parallel to the strike direction of the layers of longitudinal cross-bedding. The lateral sedimentation on the point bar demonstrates that bar sediment grow in the ebb-direction. The transformation of point bar at El Alambre channel as spit bar is the result of the increased sediment availability as bedload in this channel, relating to hydrodynamic regimes.

Other important area that modifies the sediment movement as bedload within the interconnected tidal channels system is the larger channels junction or bifurcation sector.

Several important changes in bed morphology are produced in the confluence/bifurcation at fluvial or tidal tributaries, being the most significant a deep scour hole formation as result from remobilization of sediment at the bottom. In this particular case, the spatial patterns of flow structure and bedload transport will depend on the morphological characteristics of the area. Various authors (Kjierfve et al., 1979; Ginsberg & Perillo, 1999; Aliotta et al., 2004; Ginsberg et al., 2009 a; Vecchi, 2009) have studied the dynamic conditions at the junction/bifurcation area of channels and they came to the conclusion that sediment movement in this zone follows a very complicated pattern. The flow bifurcation or junction creates steeper surfaces at the mouth of each confluent channel and a gentle sloping on the opposite downstream side. Although, erosion and deposition is take place at each face during the tidal cycle, there is always certain dominance of one of these processes based on the asymmetry of the tidal currents. As pointed out by Kjierfve et al. (1979) and Ginsberg & Perillo (1999) the nature of the tidal circulation associated to this zone and estimates of the sediment transport pathways are related to flood-dominance acting on the steep sides of tributaries mouth and the ebb-dominance acting over the gentler outer side. The latter authors observed that holes migrate toward the inner sector of channels, in an opposite pattern to fluvial holes. Analyzing the bedload circulation, they have found an important
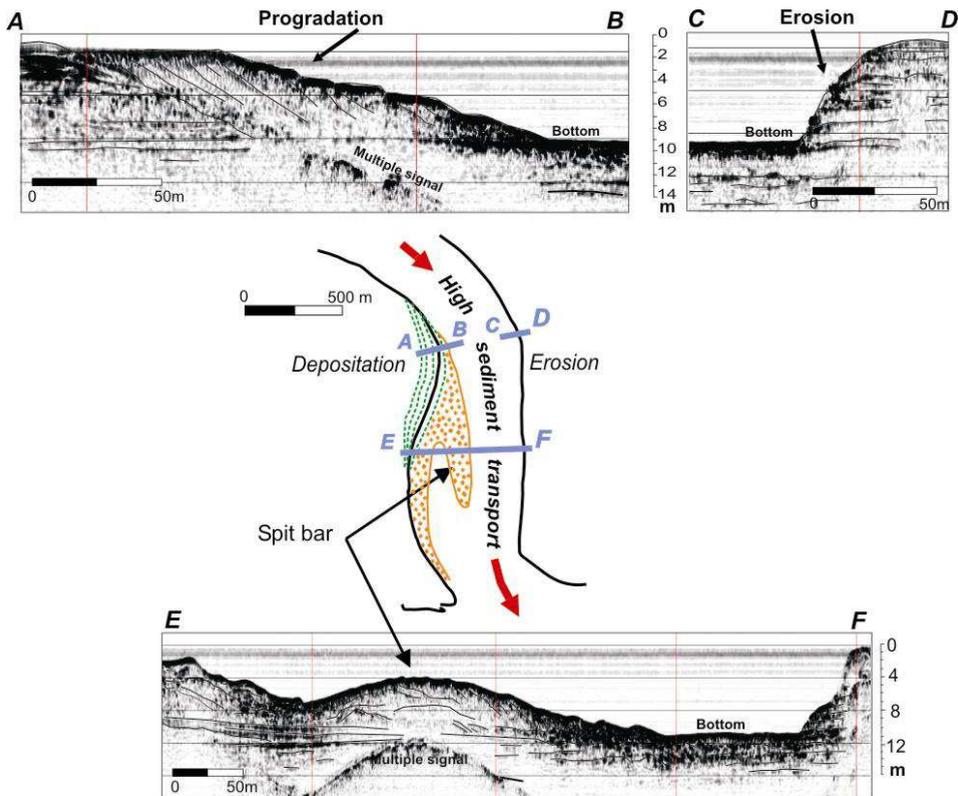

Fig. 7. Point bar in a tidal channel with high sediment transport rate. Seismic records that show erosion-deposition and sediment transport.

asymmetry in the transport direction toward the ebb current. On the basis of the currents measurements and near-bottom sediment flux, they have been recognized that flood-current eroding act the material within the hole and on the tributary channels, while most of the sediment is later transported in the ebb direction. Then, some material is deposited on the gentler outer flank of hole while another large fraction is actually exported towards the outer system.

Ginsberg et al. (2009 a), through seismic study in Tres Brazas-Tierra Firme channels, also described and interpreted the depositional and erosive sequences that characterize the hole developed at junction zone of both channels. This investigation has documented in the sub-bottom the existence of seismic sequences which found at confluence or bifurcation zone where the hole has the steeper slopes (Fig. 8A). One of these sequences corresponds to old sedimentary strata with parallel–subparallel bedding and high lateral continuity and the other consisting of cross-bedding and a complex sigmoid-oblique seismic progradational pattern. These facies occur in the inner area on the mouth of each tributary and takes place by erosive processes. The first facies, located in the lower part, is interpreted as flood flat deposits and the other, located in the upper, as a lateral migration of ancient stream beds, probably close to datum level. The materials showing alternating fine sand and silt layering. All these sediments are overlying by marine transgressive materials, corresponding to sand with containing different proportions of fragments of shells and pebbles. Contrary to this zone, in opposite direction, on the slope gentler flank is observed a progradational sequences mainly related to depositional processes. This sequence is characterized by oblique clinoforms which evidence a progressive lateral development of slightly sloping depositional surfaces (Fig. 8, B) with their downlap termination on an erosive discontinuity that forms in the ancient fluviodeltaic and marine transgressive materials. According to Ginsberg et al. (2009 a) this prograding clinoform pattern is similar to that produced by the accretion and migration of banks in tidal environments (Marsset et al., 1999; Tessier et al., 1999). These authors point out that the above-mentioned discontinuity is covered by 4-5 m of fine sandy sediment, and continuing laterally in the sub-bottom of the less steep slope of the hole.

Ginsberg et al. (2009 b) considered that turbulence flows are generated, whether when two flows combine during ebb tide or through flow division during flood tide, causing scour at the mouth of each tributaries, and extending into central deeper part and steeper flanks of the hole, resulting an increased in its depth and width. They also discuss the principal sediment transport pathway as bedload at the two channels and on junction zone. Bottom sediment circulation at channels confluence zone shows that sediment moving within distinct corridors, but ever there is an ebb-dominated sediment transport in both channels and the confluence zone. They concluded that largest material transport pathways occur essentially surrounding the scour hole (Fig. 8, C) and no bed sediment transport within of the confluence. They have also been revealed that sediment circulation is modifies on the face of low angle slope since the material is moves in a counter-clockwise direction (looking inward), causing introduce of sediments from upstream and thus an accretion effect. As mentioned above, this observation it is supported by the seismic configuration which evidences a sandy sedimentation process with prograding clinoforms on this face. The presence of downlap terminations on the ancient materials indicates that the deposition of these sediments occurs under flood current conditions (Fig. 8). These authors also point out that the distribution of sediment as bedload around this confluence or bifurcation depends on the availability of sediment that each tributary has and their capacity to mobilize them.
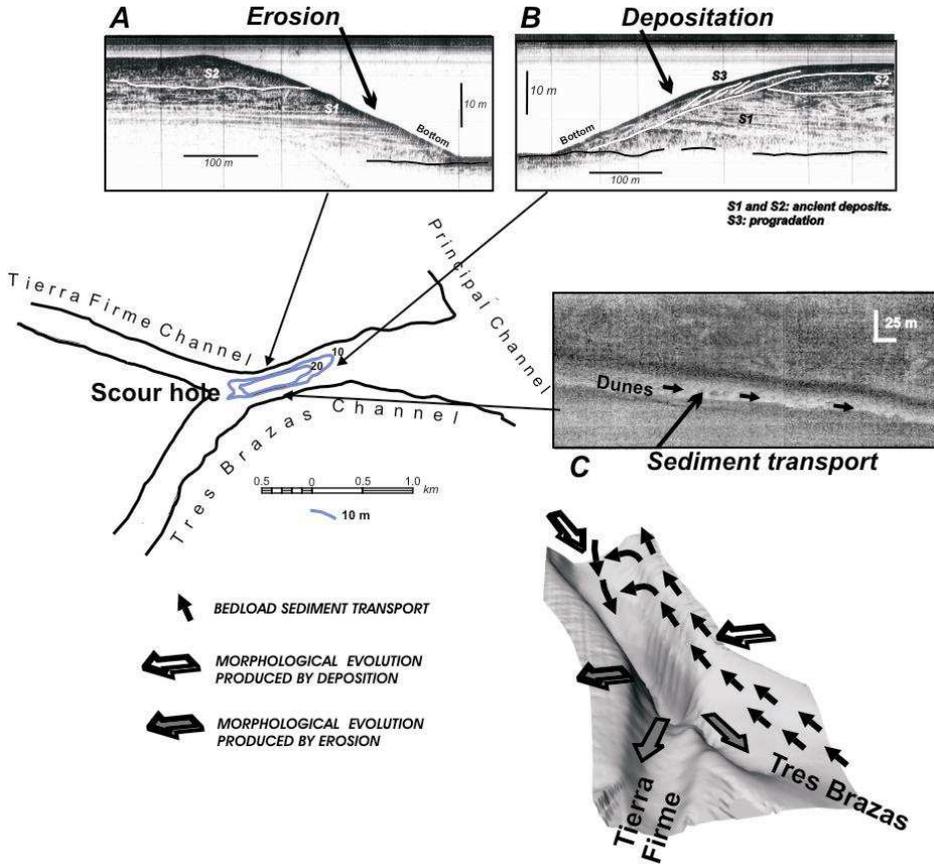
Fig. 8. Bedload sediment transport at confluence zone of Tres Brazas-Tierra Firme channels. A and B: seismic records, C: side scan sonar record.

Vecchi (2009), studied the confluence of La Lista-El Alambre channels, and found an analogous sediment transport pattern as described by Ginsberg and colleagues. She has been estimated the movement path of sediment as bedload at surrounding the confluence zone of these channels through analysis and interpretation of bedforms and seismostratigraphic sequences (Fig. 9). However, she have been observed an important sediment accretion along the steeper slope area of the hole, suggesting that a high sediment supply derived from the inner sectors of La Lista and El Alambre channels (Fig. 9, A), by ebb- dominance, is responsible for redistribution of sediment in these places. Her investigation has documented the existence of high-continuity parallel and sub-parallel reflectors that characterize the sub-bottom sedimentary sequences, with onlapping fill configuration at the flanks of the hole. Erosive sequences are obvious towards the lower parts of the sedimentary pile, indicating that contemporary scour processes continue to rework the bottom sediments of hole and the deeper sector of El Alambre mouth. The bedforms reveal the change in the current direction, which is aligned closely to the change in the topography and explain the ebb dominance. Therefore, the principal sediment

transport pathway is to bypass through the thalweg towards outside channel, although amount sediment considerable is also transported and deposited over the flanks and around the periphery of the hole (Fig. 9, B). The results highlight the significant control of higher ebb velocity from the El Alambre channel over the bed morphology of the hole, since it is curved abruptly for aligned with the ebb dominance.
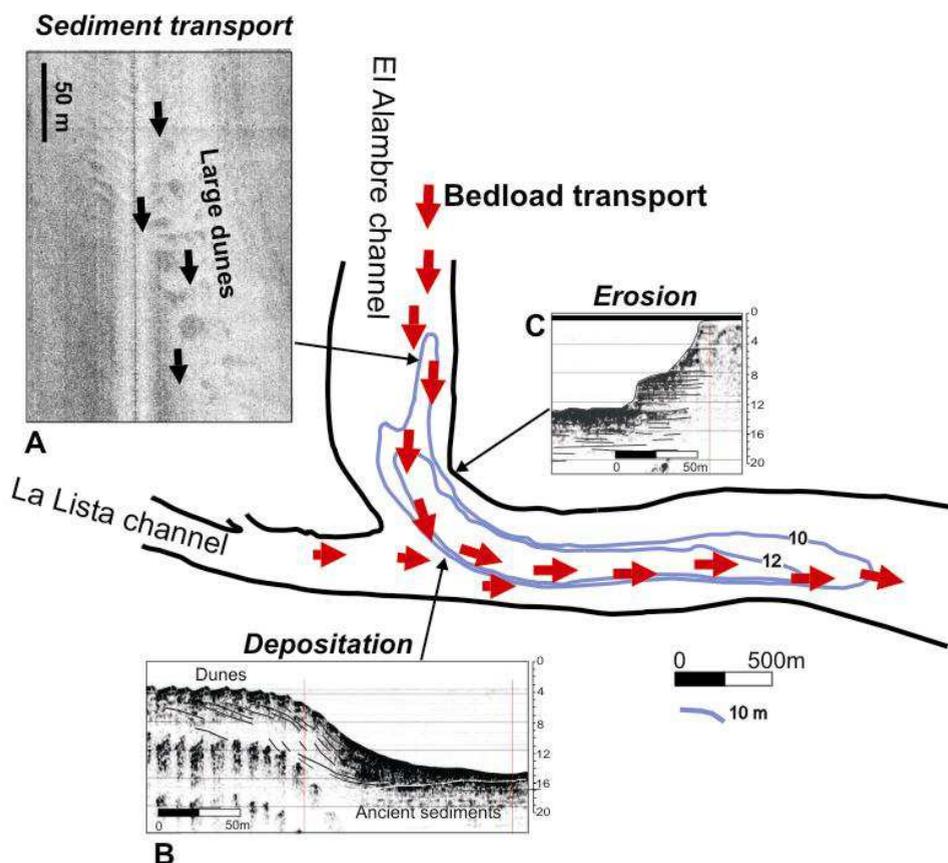

Fig. 9. Bedload sediment transport at confluence zone of El Alambre-La Lista channels. A: side scan sonar record with dunes, B and C: seismic records of the hole slopes.

On the other hand, scour hole less deep than the confluence scour may be occur by the interaction of fluid flow with a natural obstacle that protrudes above the surrounding seabed as can be a rock. Caston (1979) indicated that these scour marks adjacent to these outcrops have been used to elucidate present bottom-flow regimes in the absence of other data. This process is characterized by the removal of bottom material from around the exposed features induced a sediment transport due to currents (Whitehouse, 1998; Vijaya Kumar et al., 2003; Myrhaug & Rue, 2005; Dey & Barbhuiya, 2006; Callagway et al. ,2009). According to Ram Babu et al. (2002), the erosion is produced when drag and lift forces of the flow are higher than the gravitational, frictional and cohesive forces that support the join sediment particles. Natural structures, such as rock basement exposed, constitute

topographic highs, where significant scour occur around these highs suggesting that flows are diverted by the highs and erosion removes sediment preferentially close to the elevations. Like so, Ginsberg & Aliotta (2009) have been observed a high topographic in the Cabeza de Buey channel associated with a topographic control of the underlying basement at the bed of this channel (Fig. 10). The hydrodynamics at Cabeza de Buey channel (Fig. 1) is characterized by no or very low bed-material transport within this channel. The suspended sediment concentrations are generally high; the particles are fine, cohesive, and prone to flocculate. Therefore, the net bedload transport becomes less important and promotes suspended load transport. In consequence, as no bedforms were present along the channel, scour hole linked to this topographic irregularity will be taken into account to provide information about dominant bottom flow. In this sense, through characterization of seismic
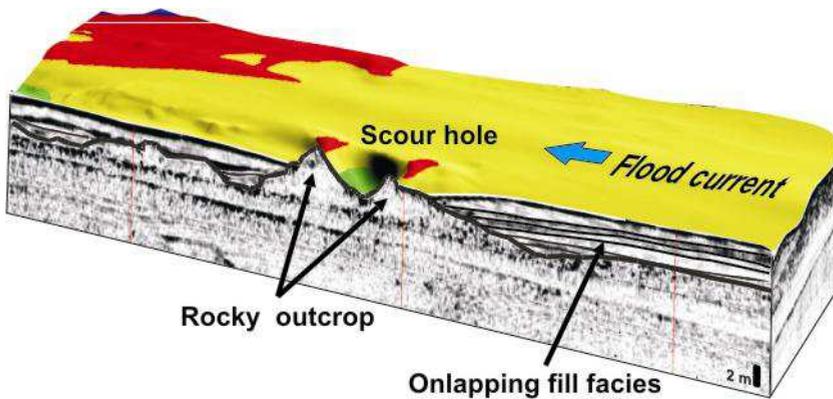

Fig. 10. 3D view of a rocky outcrop in Cabeza de Buey channel. The sub-bottom is a seismic record and the seabed was determined with multibeem survey.

facies and tidal currents data around this obstacle, these authors, have inferred the bottom sediment transport pathways. The deepest part of the scour occurs immediately upstream of the exposed bedrock, inward the channel. During ebb period within the hollow, the strongest currents form eddies which occurring at the deeper side. In contrast, the sediment deposition occurs on the flank of the exposed bedrock located towards the outflow channel, being characterized by the sedimentary sequences with onlapping fill configurations (Fig. 10). This provides an insight of the sediment transport around the exposed rock resulting in sediment removal by ebb dominance towards inner side of the channel and deposition of sediment occurring towards outer side of channel by flood dominance. Therefore, the hollow orientation around the exposed rock suggests that the ebb current affects removing sediment, while the flood current mobilizes a small amount material of bottom towards inside the channel. Ginsberg & Aliotta (2009), based on the analysis of flow, sedimentary structures and sedimentation–erosion patterns around of this high topographic suggest that, although there are less mobilized bedload material, the sediments would be transported inward by flood dominance.

Another bedform which can use to predict the pathways of sediment transport and are produced by bedload movement is the shoals-mouth. These sedimentary corps at the channels may be considered as terminus features of sand transport in the system as consequence of the ebb current dominance. A result of the sediment convergence towards

single channel is the development at mouth of the channels an elongate shoal, indicating that a greater percentage of total sediment load is mobilized throughout this course by the ebb tidal, contributing to its formation.

In general, sand shoal present in large channel mouths are aligned parallel to the general direction of the strong tidal currents. They have an elongated shape and are submerged during high tide and exposed partially at low tide. In plan view, they are curvilinear and have asymmetrical cross-sections. Large and medium 3D dunes are present all over the shoals. Particularly, at tidal channel system of Bahía Blanca the shoal-mouth (Fig. 11) have this type of dunes with heights lower than 1m and wavelengths between 6 and 18 m. The morphological evolution of this elongated
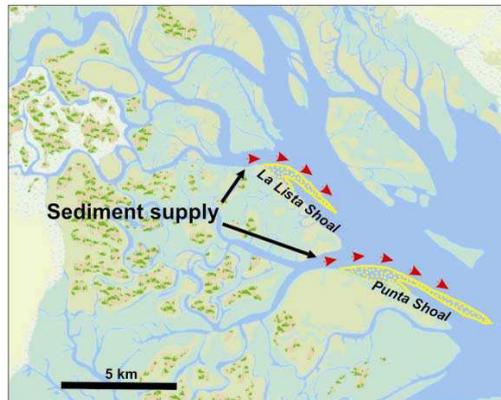
Fig. 11. Sand shoal mouth at large tidal channels. They are result of higher sediment supply.

sedimentary body is related to a residual sediment transport model with trajectories opposite to its two flanks. This process leads to a gradual increase in the height and longitudinal growth of the shoal. In the case of an interconnected tidal channels system, the convergence of sediment towards an only one channel exerts an important effect on the hydrodynamics since plays a significant role in forming sand deposits at the channel mouth due to an increasing in availability of sediment.

4. Conclusion

The sediment movement pattern as bedload in an interconnected channels system is a consequence of tidal currents combined with the system configuration, which result a net sediment transport through single channel. From this study seems more plausible that an ebb increase velocity combined with a short duration, will result in ebb dominance causing sediment loss from each channel. However, sediments are internally redistributed to be later mobilizing as bedload through only one channel. In Figure 12 can see that at Bahía Blanca estuary, the La Lista channel who makes up Cabeza de Buey-El Alambre-La Lista- Principal system, and Tres Brazas channel, which constitutes Tierra Firme-Tres Brazas-Principal channel system, are the channels where the sediment converges, before to be disperse into Principal channel. Additionally, not only the net transport as bedload will be controlled by ebb dominant at channel but it also will depend on whether the sediment availability at each channel is significantly high. Specially, in absence of data, field observations as bedform,

point bar and other topographic and seismic-stratigraphic characteristics development in tidal channels are useful diagnostic features to providing an interpretation and predicting sediment mobilization throughout the interconnected tidal channel system.
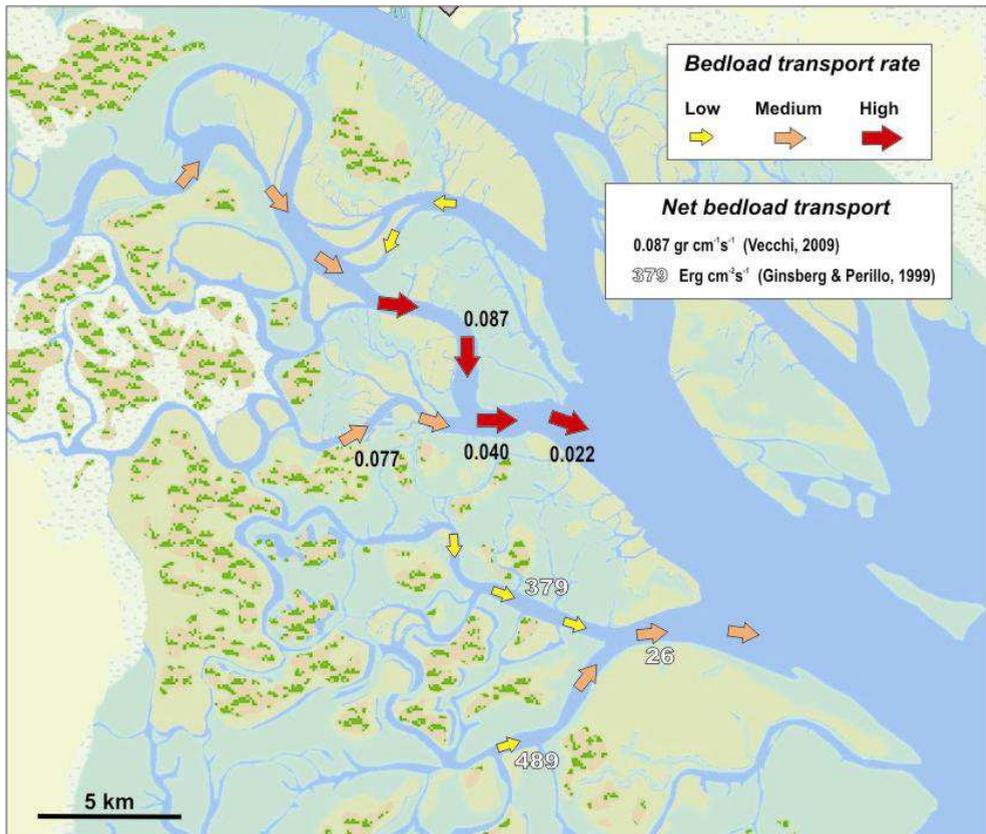

Fig. 12. Circulation pattern of sediment transport as bedload obtained of morphological, seismic and currents integration data. The arrows indicate the estimation of sediment transport rate according to availability sediment. The numbers indicate the flow capability for sediment transport.

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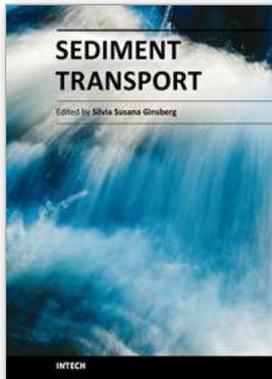
Sediment Transport

Edited by Dr. Silvia Susana Ginsberg

Sediment transport is a book that covers a wide variety of subject matters. It combines the personal and professional experience of the authors on solid particles transport and related problems, whose expertise is focused in aqueous systems and in laboratory flumes. This includes a series of chapters on hydrodynamics and their relationship with sediment transport and morphological development. The different contributions deal with issues such as the sediment transport modeling; sediment dynamics in stream confluence or river diversion, in meandering channels, at interconnected tidal channels system; changes in sediment transport under fine materials, cohesive materials and ice cover; environmental remediation of contaminated fine sediments. This is an invaluable interdisciplinary textbook and an important contribution to the sediment transport field. I strongly recommend this textbook to those in charge of conducting research on engineering issues or wishing to deal with equally important scientific problems.

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