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Nearsurface Suspended Sediments at Monte Hermoso Beach, Argentina: I. Descriptive Characteristics[1]

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ABSTRACT

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The Southwestern Buenos Aires Province coast is characterized by the presence of a zone of high nearsurface suspended sediments (ZOS) with total concentrations ranging from 35 to more than 160 mg/l. The ZOS is variable in width, degree of contact with the shore and sediment concentration. The ZOS may originate from the outflow of fine suspended sediments from the adjacent Bahía Blanca Estuary and is deflected towards the northern coast by Coriolis force. Otherwise, only the sand sized material found in the samples is autochthonous and suspended by the local wave dynamics. The width of ZOS is related to wind direction being larger (> 500 m) with continental (north and northwest) winds.

ADDITIONAL INDEX WORDS: *Suspended sediments, zone of sediments, coastal processes, Monte Hermoso coast (Argentina).*

INTRODUCTION

Only within the last 15 years suspended sediment processes in the nearshore and surf zone have received increased attention. Most authors studied the sediment transport in suspension form, but mainly focused on the sand sized material (KOMAR, 1978; BRENNINKMEYER, 1974, 1975; FAIRCHILD, 1973, 1977; KANA, 1976). Although, outflow of estuarine fine suspended sediment into the continental shelf have been considered by several studies (NITTROUER, *et al.*, 1986; CASTAING and ALLEN, 1981) we have not found in the literature any mention of the behavior of these sediments in the nearshore and surf zone.

This zone named here as "zone of sediments" (ZOS) is a "brown" strip of water owing its coloration to the fine suspended sediments that contrast with the typical green color of the continental shelf water found offshore. The ZOS is variable in width, degree of contact with the shore and sediment concentration. The coast between Pehuen-Có and Monte Hermoso (Argentina) (Figure 1) is characterized by a large nearsurface suspended sediment concentration zone. This region is practically the only place along the Argentine coast where the phenomenon is continuously seen. PERILLO (1975) has reported a similar situation in the northern beaches of the Buenos Aires Province, but there, the ZOS is correlated to intense northeast winds driving heavily laden Rio de la Plata water against those N-S beaches.

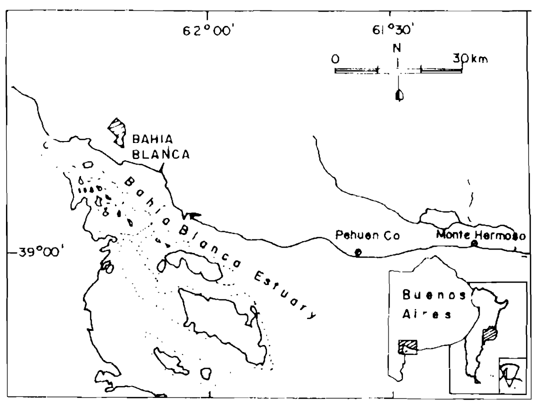

Figure 1. Location of the study area near the Bahía Blanca Estuary.

The coastal area considered here is located in

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the southwest of the Buenos Aires Province and has an E-W general trend. Both localities, Pehuen Có and Monte Hermoso, are resort areas, but only Monte Hermoso has a pier adequate for a detailed study of the ZOS. However, unpublished data let us assume that the results described hereafter are characteristics of the complete coastal stretch.

Most of the sediment transported within the Bahía Blanca Estuary, adjacent to Monte Hermoso and Pehuen-Có (Figure 1), is in suspension. The net gravitational and tidal circulations are directed toward the mouth of the estuary (PERILLO *et al.*, 1987; PICCOLO and PERILLO, 1989). PERILLO (1989) considers that the estuary is clearly undergoing an erosional process due mostly to the lack of sediment input from the rivers and the inner shelf. Hence all the sediments carried by tidal currents within the estuary are provided by the erosion of its marginal coasts. After several tidal cycles, the suspended sediments are exported from the estuary into the inner shelf.

The purpose of the present study is therefore to investigate the general characteristics and possible origin of the ZOS in Monte Hermoso beach. Its dynamic and degree of variability are correlated with tides and wind conditions.

METHOD AND EXPERIMENT DESIGN

The suspended sediment data discussed in this paper were gathered during five surveys which comprised different meteorological and oceanographic conditions. The average conditions registered on each survey are shown in Table 1.

Observations were made from the fishing pier at Monte Hermoso beach which extends about 300 m offshore. Its length provided the opportunity for sampling surface water at several places within the surf and breaker zones and offshore of the breakers. As tide level rises and falls, the strip of water covered by the pier also changed. Therefore, the number of stations on each sampling varied from 4 to 8. However, separation between stations was always 40 m. The distribution of the stations on the pier and the extreme boundaries of the swash and breaker zones found during the five sampling surveys are presented in Figure 2.

Surface water samples were obtained using a weighted plastic bucket at preselected stations along the fishing pier. Based on the results of previous field experiments (CUADRADO and PERILLO, 1989) samples were taken from the wave crest while it passed through the sampling point. To avoid major disturbances from the pier structure, all procedures were carried out on the side from which waves were approaching.

The water in the bucket was stirred vigorously and funneled to 1 l clean, screw-capped plastic bottles. Every three hours, water samples were stored in 5 l plastic bottles. Sampling was done every hour on the hour for more than 10 hs. We could not complete a tidal period due to the lack of adequate lighting that prevented the determination of the wave parameters and the width of the ZOS. Sampling procedures typically required less than 1 minute; considering a maximum of 8 stations, all were sampled in about 10 minutes, and in 15 minutes in poor weather conditions.

Beach profiles and bottom samples were obtained on each survey. The profiles were measured using a theodolite from the foredune to about 1 m below still water level, and with a weighted rope from there to the end of the pier, taking care to avoid the pier columns. Reference points on the pier were leveled and related to the beach datum level. Bottom sediment samples at each station were collected with a Snapper drag operated manually from the pier. Surface beach samples were taken with each survey.

Table 1. *Average wave and wind conditions during the surveys.*

Survey	Date	Wave T(s)	Wave H(cm)	Wind V(km/h)	Wind D	Width of ZOS
C1	10- 5-83	3.1	40	12.5	N	> 500 m
C2	7- 6-84	7.4	110	21.3	SW	> 500 m
C3	8-23-84	5.9	60	32.1	SW	> 500 m
C4	10-11-84	8.0	35	7.6	NNW	> 500 m
C5	12-17-84	5.4	45	26.1	SSE	undetermined

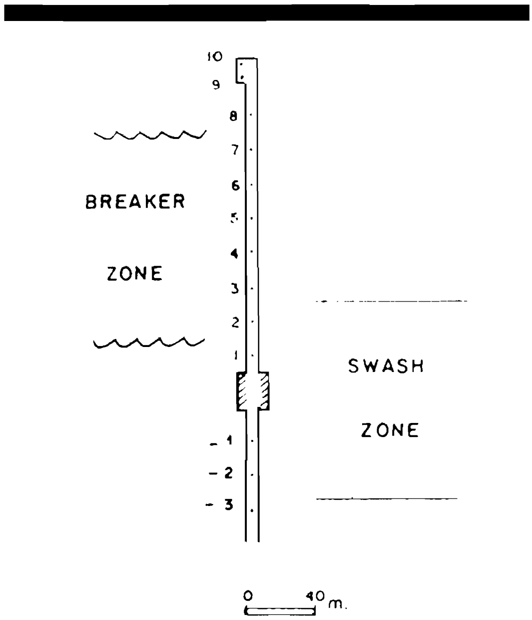

Figure 2. Sampling stations along the Monte Hermoso fishing pier. The breaker and swash zones were determined for each survey. The offshore limit of the breaker zone and the nearshore limit of the swash zone were reached during C2. The nearshore limit of the breaker zone was observed during C4 and the offshore limit of the swash zone was observed during C1.

During the field study, visual wave data (period, height, breaking angle and breaker type) were estimated during water sampling following the Programa de Observaciones Costeras (POC) procedures (PERILLO and PICCOLO, 1987) simultaneously to the water sampling. The width of the ZOS was also visually determined being estimated rather accurately up to 500 m (200 m offshore from the end of the pier). Meteorological parameters were obtained from the Instituto Argentino de Oceanografía (IADO) meteorological station located less than 200 m from the pier.

In the laboratory, over 300 samples were wet sieved through an ASTM 230 sieve to retain the sand sized material contained in a known volume of water. Sand concentration was reduced to 1 l volume. Concentration of finer material was determined by vacuum filtering. A volume equal to 250 ml of the sieved water was filtered through preweighted 47 mm diameter Sartorius filters with a 0.6 μm pore size. Each filter was oven dried at 40°C for a minimum of 12 hs before cooling in a desiccator and reweighted to determine dry weight.

Grain size distribution of suspended sediment was estimated from the 5 l samples employing the Bottom Extration Tube Method (BETM) as described by the INTERAGENCY COMMITTEE (1953). Bottom and beach samples were analyzed following standard sieving determinations with ½ ϕ sieve separation as presented in FOLK (1974). Suspended sediment samples containing sand grains and selected bottom and beach samples were observed under microscope to determine their mineralogical content. X-ray diffraction was carried out in fine sediments samples to define their mineralogical composition.

RESULTS

A typical beach profile made near the pier and corresponding to C4 is presented in Figure 3. Total length of the profile is 280 m and the basic geoforms observed are one berm, a swash bar, two break point bars and their associated troughs. Coarser sediments (coarse to medium sand, 0.94 ϕ) are found on the swash and break point bars, while in the troughs and offshore the sand is fine (2.09 ϕ). The backshore is characterized by medium sand (1.61 ϕ) principally in the berm. The fine fraction is less than 1% in all of the bottom samples.

Since 1983 the POC has had observers at both Monte Hermoso and Pehuen-Có beaches. The visual observations, taken twice a day, made by this program include wave, tide, littoral currents, meteorological and beach geomorphological parameters and the width of the ZOS. Based on more than 2 years of POC observations typical incident waves on Monte Hermoso beach are less than 1 m in height with periods ranging from 2 to 9 s. During storms, average wave height is about 1.6 m with periods between 3 to 5 s.

The Monte Hermoso coast orientation is almost east-west, with about half of the waves arriving from the southeast sector and the rest from the southwest and south. The latter are locally generated waves with short periods (about 3 s). In most conditions, breakers are of the spilling type and rarely some plunging waves are seen. Longshore current directions determined by following a small float show that they are closely related to the breaker angle.

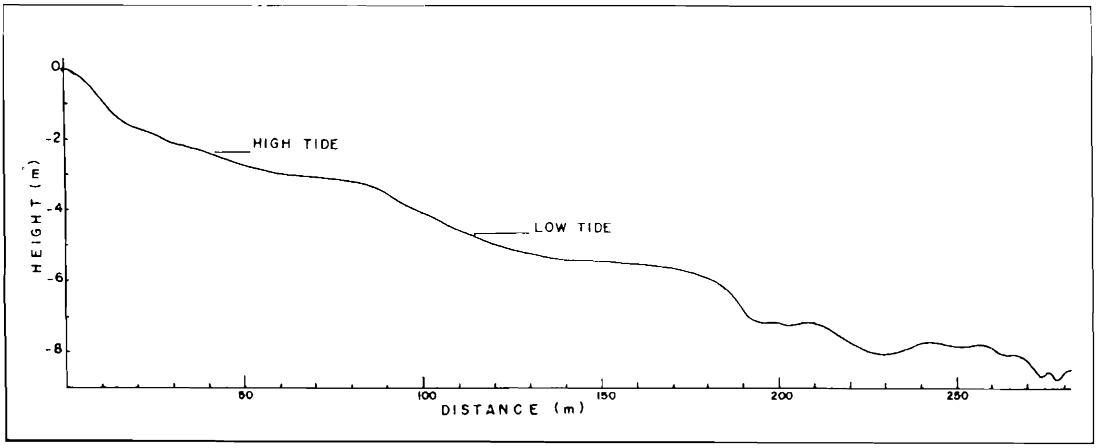

Figure 3. A typical beach profile corresponding to C4.

Prevailing winds for the area are from the northwest and north directions due to the influence of the South Atlantic Semipermanent High (PICCOLO, 1987). Offshore directed winds produce waves at the beach that are less than 15 cm in height during about 30% of the year. Southern winds are less frequent but more intense.

The sea breeze is a major factor in wave generation during the late spring, summer and early autumn months (VARELA, 1982). The typical counter-clockwise wind rotation has an average duration of 8 hs. However, we also observed some cases in which the rotation was clockwise. The phenomenon is very strong during the afternoon hours generating very-short waves with heights on the order of 30–45 cm.

As indicated, the width of the ZOS is highly variable. It may range from less than 100 m to 500 m or, as in many occasions, its boundary is too far offshore to be determinated accurately. The percent frequency of the width of the ZOS related to wind direction is presented in Figure 4. The data is based on 623 determinations taken at Monte Hermoso in 25 months. Weather conditions (*i.e.*, cloudy skies, fog, storms, *etc.*) and inadequate sun elevation prevented accurate visual determinations in more than 300 cases. Through the period considered, in only 31 occasions the ZOS was definitely not detected. Figure 4 further shows that more than 57% of the time the wind approached from the northwest quadrant (west to north). The widest ZOS

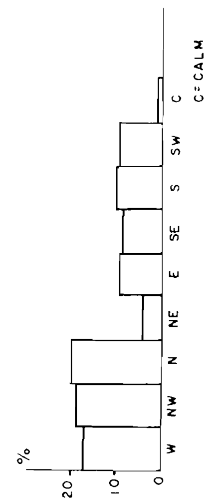

Figure 4. Percentage of wind direction for the several widths of the zone of sediments.

conditions were normally associated to these directions.

Surface water samples were taken from the Monte Hermoso fishing pier on five occasions from October 1983 to December 1984 (Table 1). During each data collection the width of the ZOS was continuously monitored. For instance, the ZOS was all the time greater than 500 m in C2, C3 and C4, while during C5 its onshore boundary was beyond the end of the pier. The largest variations in width, encountered during C1, were clearly related to the changes in wind direction (Figure 5). From the beginning of the data collection up to the 14 hs sampling, the width was greater than 500 m. But as the wind rotated from north to south-southeast due to the sea breeze the offshore boundary came closer to the shore, up to a minimum of 80 m. At 15:30 hs the sea breeze effect disappeared and the land breeze together with the Northern synoptic wind dominated the area again, pushing the boundary offshore (> 500 m). In this case, the wind rotation coincided with one of those rare situations in which the rotation is clockwise. Other than the wind rotation in C1, wave and wind conditions during each survey were fairly constant. Average values for wind and waves are given in Table 1.

Suspended Sediment Characteristics

The nearsurface suspended sediment samples at Monte Hermoso were initially separated in sand and fine (silt plus clay) fractions. They are analyzed separately due to their different origin and dynamical behavior. Fine sediments (< 4 ϕ) appear as the largest constituent of the material in suspension, but sand particles comprise more than 50% per weight in many samples.

Figure 6 shows two typical time averaged concentrations of nearsurface fine sediments along the fishing pier. The origin (0 m) is at the breaker zone, positive numbers are landward (surf zone) and negative numbers seaward. The highest concentrations are normally at or near the breaker zone with a marked reduction offshore. Only during C3 (Figure 6b) an increase at the inner end of the surf zone is observed. The concentrations of fine sediments in this survey were almost twice as much as in the other field experiments.

The evolution of fine sediment concentrations during a sea breeze event (C1) is presented in Figure 5. The data taken during C1 shows an homogeneous concentration between 70 and 90 mg/l with north wind from 8 to 13 hs. From 14 to 15 hs the wind rotated to the SSE together with a drop of 10 to 20 mg/l in the concentration in all the stations. At 15:30 hs the wind

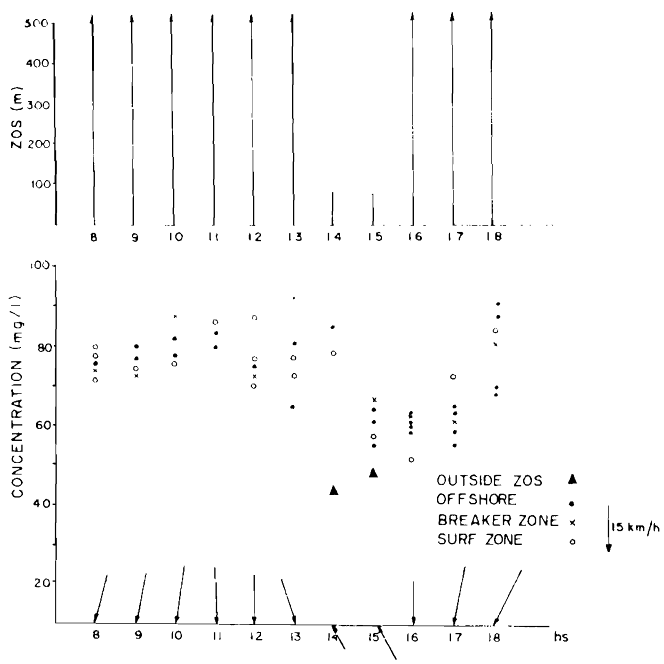

Figure 5. Variation of fine suspended sediment concentrations during C1 as a function of the variation in wind direction. The arrows are wind vectors.

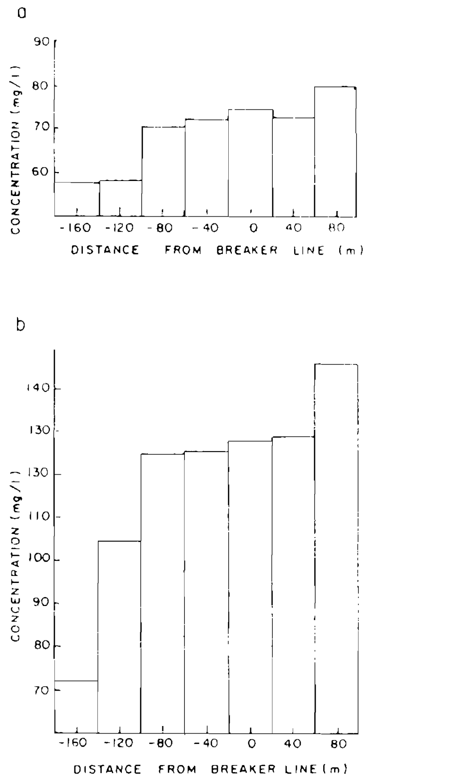

Figure 6. Distribution of time-average fine suspended sediment concentrations along the fishing pier. (a) in C1. (b) in C3. Positive values indicate distances landward of the breaker zone, negative ones are seaward distances.

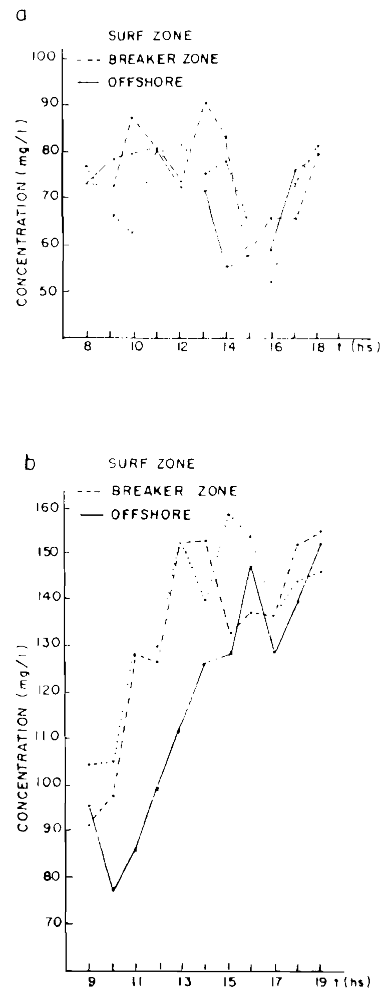

Figure 7. Variation of the fine suspended sediment concentrations corresponding to the three zones: surf, breaker and offshore. (a) in C1. (b) in C3.

returned to its previous Northern direction and the suspended sediment concentration gradually recovered their original values.

The ZOS was wider than 500 m at the beginning of the survey, with the wind blowing from the continent (north) and reached its narrowest level (80 m) when rotated to the south-southeast. At 14 and 15 hs, it was possible to obtain water samples outside the ZOS. The concentration of fine suspended sediment in the samples is about half the value of samples taken within the ZOS (Figure 5). As the wind turned north, in less than 30 minutes the ZOS returned to the original width. Figure 7a shows in a simplified form (averaging all samples corresponding to each of the three zones) the general drop in concentration of fine sediment at 14 hs and its return to the original level at 17 hs. A different behavior is observed during the sampling period of C3 (Figure 7b) where the average fine sediment concentration in the three zones increases gradually, almost doubling the starting values at 19 hs.

The envelope of cumulative curves for the fine sediments on each sample taken from the three sectors and for all dates are presented in Figure 8. The largest percentage of coarser sediments were obtained at the breaker zone; meanwhile for particles finer than 10 ϕ the largest dispersion is found in the offshore zone. For all the sectors and surveys, the highest percentage of grains were normally concentrated between 7.5 and 9 ϕ. The analysis of bottom sediments

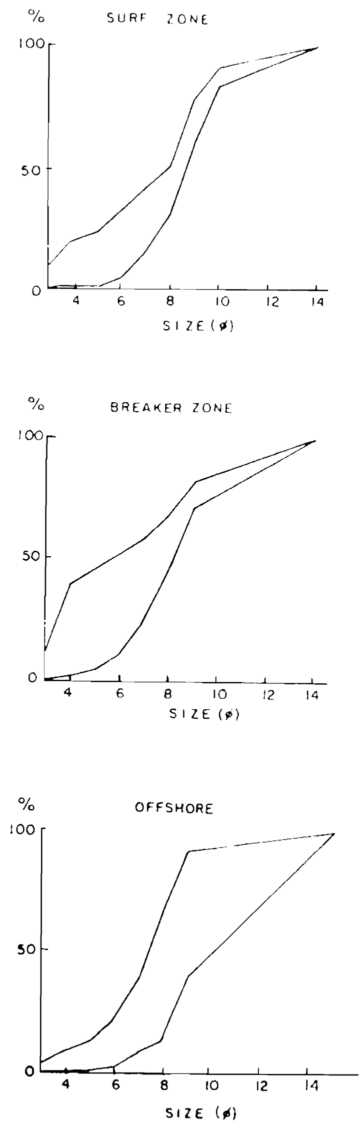

Figure 8. Envelopes of cumulative curves for fine sediments at the (a) surf, (b) breaker, and (c) offshore zones.

shows that the fine fraction is a very small component of the sediment (less than 2%), and cannot be regarded as a source for the fine sediments in suspension.

The mineralogical analysis of the suspended sand fraction shows a composition similar to that observed on the bottom material at Bahía Blanca Estuary (GELOS and SPAGNUOLO, 1985) and in most of the beaches of the Buenos Aires Province (TERUGGI, *et al.*, 1959; TERUGGI, 1964). On the other hand, X-ray analysis of the fine fraction indicates that its composition is identical to the fine bottom sediments sampled in the Bahía Blanca Estuary by MARCOS (1985).

DISCUSSION

The distribution of nearsurface suspended sediments along the Monte Hermoso pier can be divided in three sectors based on concentration, grain size and dynamical conditions: offshore, breaker and surf zones. The offshore zone normally has the lowest concentrations of both sand and fine sediments. The latter are mostly very fine silt and clay.

Sediment concentration increases toward the shore, being larger at the breaker zone. The increment on the percentage of sand is largely associated to the turbulence generated by the wave as it breaks. MILLER and ZIEGLER (1958) have stressed that the breaker zone presents the coarsest material in a beach. Bottom and suspended sediment samples taken at Monte Hermoso generally follow this typical distribution.

The increase in sediment concentration during the sampling period at C3 (Figure 7) cannot be related to changes in forcing because the wind and wave conditions were quite stable throughout the data collection. However, an analysis of the tidal record reveals that high tide was coincident with the highest concentrations (between 13 and 15 hs). This fact may indicate that tidal currents are likely to contribute to the input of fine sediments into the ZOS. Another possible explanation is that a constant southwest wind caused the gradual increase in the percentage of fine suspended sediment by advecting sediment from an external source. The width of the ZOS appears to be related to the wind direction. Figure 4 clearly indicates the influence of continental winds (from the northwest quadrant) increasing the width of the ZOS normal to the shore. A change in wind direction, such as a sea-breeze phenomenon, produces modifications in the width of the "brown" strip of sediments. As the width of the ZOS was reduced with local wind blowing from the SSE during C1, an increase in the concentration of fine sediments in the surf and breaker zones was expected. However, the converse was true. A possible explanation for this effect is found when considering that all samples were taken from the water surface as a wave crest passed by. The SSE wind produced a flux of sediment-free surface water towards the coast in a fashion similar to that presented by COOK and GORSLINE (1972). The input of this "clear" water produced a dilution in the surface concentration.

When the sea breeze ceased, the continental wind blew, driving the "clear" surface waters offshore. Thus the ZOS returned to its original width. Furthermore, a typical small-scale coastal upwelling process was observed since the concentration increased again, even with still smaller waves (H < 30 cm). In this sense, VARELA (1982) commented on the high correlation between the appearance of jellyfish in Monte Hermoso with the persistence of north winds for several days. Therefore, the seaward transport of the surface water produces that the jellyfishes and the mid-column suspended sediments are dragged up during the upwelling process.

It is necessary to note that this type of circulation process can be considered as an adequate explanation of the variation in the width of the ZOS and the concentration of suspended sediments, because the wave activity is very small. As indicated, when the northern winds blow, waves are only observed at the contact zone between water and beach. However, waves are being generated some 500 to 1000 m from the coast and they move in the offshore direction. Therefore during these situations the vertical mixing of the water column due to the waves is lacking or is greatly reduced and only a wind induced circulation is presented in the nearshore.

Several factors indicate that the origin of the ZOS found along the shore of the southwestern Buenos Aires Province can be related to the outflow of suspended sediment from the Bahía Blanca Estuary. First of all is the identical mineralogical composition between the material found in the estuary and that determined in this study. On the other hand, the general residual circulation of the middle and outer reaches of the Bahía Blanca Estuary is clearly directed toward the mouth of the estuary (PERILLO, 1989). The residual currents obtained from 11 currentmeter stations occupied by NEDECO-ARCONSULT (1983) in the outer estuary and the inner continental shelf were analyzed (Figure 9). Those located in the estuary show a predominant direction towards the mouth. However, those stations located close to Pehuen-Có and Monte Hermoso clearly show a residual transport directed toward the coast. The tidal currents at the station located in the inner shelf are rotational, that is, affected by Coriolis, contrary to the reversing type observed into the channels.

CONCLUSIONS

The southwest coast of the Buenos Aires Province is characterized by the presence of high concentrations of nearsurface suspended sediments. The observed concentrations of fine suspended sediment ranged from 35 to more than 160 mg/l. These values are mostly related to their position within the ZOS, with lower values in the offshore zone. Suspended sand particles are important only in the nearshore zone (breaker and surf zone).

Based on mineralogical comparisons and the circulation conditions of the inner shelf, the origin of the ZOS can be related to the Bahía Blanca Estuary outflow. Meanwhile the suspended sand sized particles observed are autochthonous of Monte Hermoso beach.

The width of the ZOS is clearly related to wind direction, increasing to more than 500 m with continental outflow and being reduced with wind coming from the sea.

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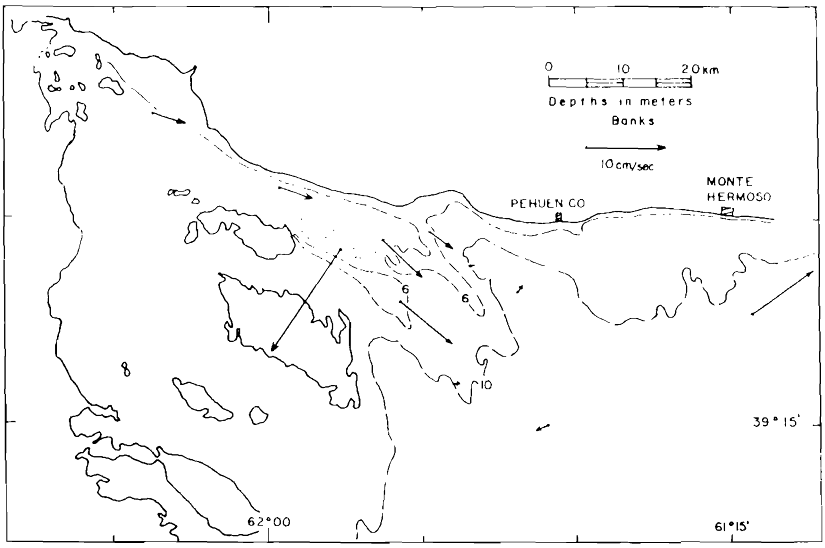

Figure 9. Residual currents for 11 currentmeter stations located in and out of the Bahía Blanca Estuary. The residual current at the stations near Pehuen-Có and Monte Hermoso is directed toward the coast.

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□ RESUMEN □

El sudeste de la Provincia de Buenos Aires se caracteriza por la presencia de una zona con elevado sedimento en suspensión (ZOS) con concentraciones desde 35 hasta más de 160 mg/l. La zona de sedimentos varía en ancho, la forma de contacto con la costa y en la concentración de sedimentos. El origen de esta zona podría deberse a la descarga de los sedimentos finos en suspensión provenientes del Estuario de Bahía Blanca que se encuentra adyacente a las costas estudiadas. La fuerza de Coriolis desviaría su rumbo hacia la costa. Por otro lado, sólo la arena encontrada en las muestras es autóctona y suspendida por la dinámica local de las olas. El ancho de la zona de sedimentos se ha relacionado con la dirección del viento, siendo mayor a 500 m con vientos continentales (norte y noroeste).

□ RÉSUMÉ □

Les eaux de la côte Sud-est de la province de Buenos Aires sont caractérissées par la présence d'une zone à forte concentration de sédiment en suspension (ZOS) (35 mg/l à 160 mg/l). Cette zone est soumise a changements de position par rapport a la côte, étant variable sa largeur et sa concentration des sédiments. L'origine de cette région sédimentaire se devrait a la décharge de sédiments fins en suspension, en provenance de l'éstuarie de Bahía Blanca, l'effect Coriolis changeant sa direction vers la côte. D'ailleurs seulement le sable trouvé dans les échantillons est autochtone et mise en suspension par l'action des vagues. La largeur de la zone des sédiments est rattachée à la direction du vent, attaignant plus de 500 m par des vents d'origine continentale (nord - nord ouest).

□ ZUSAMMENFASSUNG □

Charakteristisch für die Küste im Südwesten der Provinz Buenos Aires ist eine Zone oberflächennah suspendierter Sedimente mit Konzentrationen zwischen 35 und 160 mg/l. Diese Zone ist variabel in ihrer Breite, im Ausmaß des Kontaktes mit dem Ufer und in der Sedimentkonzentration. Die suspendierten Sedimente müssen aus der Schwebstoffracht des nahen Bahía Blanca Ästuars stammen und durch Corioliseffekte nordwärts verdriftet worden sein. Andernfalls wären nur Kornfraktionen der örtlich vorhandenen Sedimente durch die lokalen Wellenbewegungen in Suspension übergegangen. Die jeweilige Breite der Sedimentzone ergibt sich aus den Windrichtungen und ist breiter als 500 m bei ablandigen Winden aus Nord und Nordwest.—*Reinhard Dieckmann, WSA Bremerhaven, FRG.*