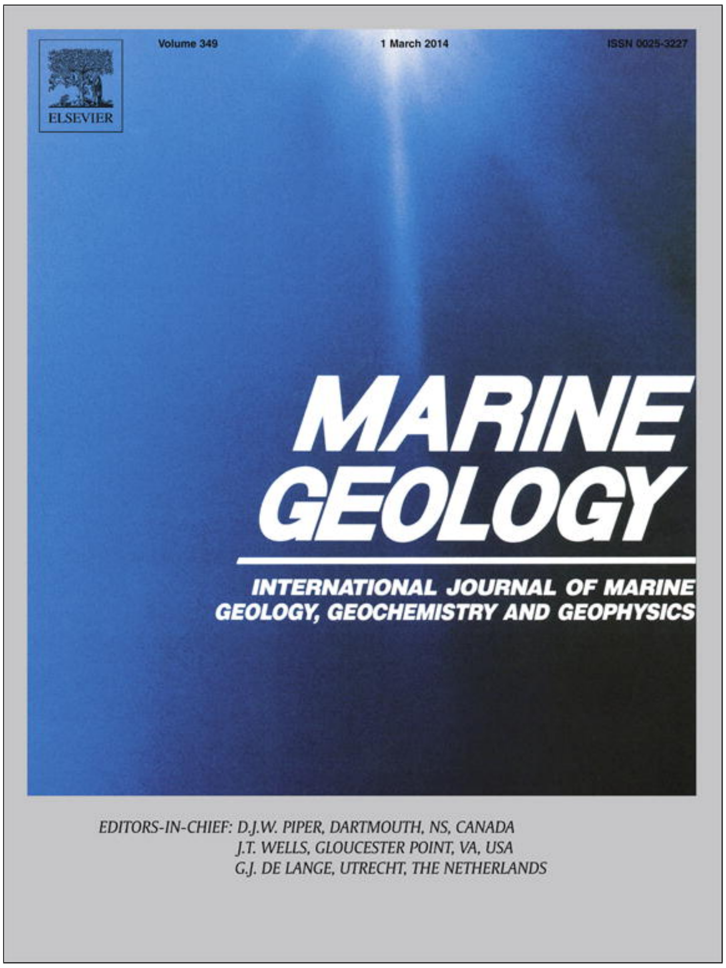
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Hydrodynamic and geomorphological controls on surface sedimentation at the Subtropical Shelf Front / Brazil–Malvinas Confluence transition off Uruguay (Southwestern Atlantic Continental Margin)

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ABSTRACT

The hydrology of the Southwestern Atlantic margin is dominated by the confluence of water masses with contrasting thermohaline properties, generating a frontal zone that extends from the Brazil-Malvinas Confluence zone (BMC) in the open ocean to the Subtropical Shelf Front (STSF) on the continental shelf. However, the hydrodynamics of the transition between these hydrographic features is still not fully understood. High-resolution morphological (multibeam) and hydrological (CTD) data were integrated with sedimentological data (textural and productivity proxies) in order to develop a sound framework to understand surface sedimentation of the slope extension of the STSF (subsurface, outer shelf and upper slope) and of the BMC (intermediate level, middle slope) on the Uruguayan continental margin (34° to 36°S). Since the detailed morphology of the study area is presented for the first time, related geological processes are briefly discussed. On the outer shelf and upper slope, and north of the STSF, the current direction of erosive mound scarps indicates the dominance of the southward-flowing Brazil Current (BC). This suggests a northernmost boundary for the distribution of the STSF. A strong flux of the BC favored by a steeper slope as well as by the occurrence of canyons incised on the upper slope is evidenced by the occurrence of coarser sediments and low values of productivity proxies, but also by the presence of deep sea coral reefs. Southwards, the effect of a less energetic Malvinas Current (MC) and the highly productive STSF is indicated by the deposition of fine sediments with high organic matter content, as well as by the absence of deep sea coral reefs. This depositional scenario is enhanced by a smooth slope and the occurrence of canyons incised deeper in the middle slope. Off-shelf sediment transport along the STSF is inferred by the similar texture registered between the outer shelf and shallow upper slope, the occurrence of biogenic shelly reworked sands and gravel, and by the observed decrease in grain size with depth. Glacial iceberg transport northwards and/or gravity processes are suggested by the occurrence of igneous/metamorphic gravel in lag deposits on the upper slope. On the middle slope, the northernmost influence of the erosive Antarctic Intermediate Water is evidenced by the vanishing of morphologic contouritic structures. This is also imprinted in a pronounced northward fining in grain size. This contribution increase our understanding of this highly dynamic and complex area, providing the first detailed analysis of the regional sediment patterns and oceanographic and morphological controls on surface sedimentation.

1. Introduction

Due to the close relationship between hydrology and sedimentation, the knowledge of modern depositional environments is a key piece of information in order to understand both current and past regional oceanic circulation regimes. In the Atlantic Ocean, the Southwestern Atlantic Margin (SAM) is recognized as one of the most productive and energetic regions in the world. This is mainly due to the convergence of the southward-flowing Brazil Current (BC) with the northward-flowing Malvinas Current (MC), resulting in the Brazil–Malvinas Confluence (BMC) (Schmid and Garzoli, 2009). Depending on the wind regime, the BMC occurs near 39°S in winter and near 36°S in summer, with a mean position near 38°S (Fig. 1A) (Schmid and Garzoli, 2009). This

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large-scale oceanographic process is closely related with the shelf circulation, as suggested by numerical simulations (Matano et al., 2010). Over the shelf, the extension of the BMC, known as the Subtropical Shelf Front (STSF), separates subantarctic and subtropical waters (Piola et al., 2000). This narrow and sharp front extends between 32°S at 50 m of water column depth and 36°S over the shelf break (Fig. 1A) and its distribution appears stable throughout the year (Piola et al., 2000).

Notwithstanding the importance of this complex regional hydrological system, the dynamic processes that govern the oceanic-shelf circulation are still poorly known (Matano et al., 2010). In this sense, studies on oceanographic and sediment dynamics have been focused exclusively in the BMC in the open ocean (e.g. Frenz et al., 2003; Schmid and Garzoli, 2009; Preu et al., 2013) or in the STSF over the continental shelf (e.g. Piola et al., 2000; Campos et al., 2008; Nagai et al., 2013). Consequently, there is a gap of information regarding the dynamics associated with the transition region between these oceanographic features on the Southwestern Atlantic Margin. Climatology derived from 10-year satellite imagery (Fig. 1B) evidences the continuity between both oceanographic fronts and shows the conspicuous thermal front that characterized the transition area. Within the Southwestern Atlantic Margin, the Uruguayan continental margin (34°–36°S) is located at the transition zone between STSF and BMC (Fig. 1B), and includes the northern limit of the BMC. Moreover, it is influenced by the Rio de la Plata (RdlP), which discharges freshwater from the second largest hydrographic basin in South America (average value of 22,000 m^3/s; Framiñan and Brown, 1996).

In general, regional sediment dynamics studies often lack integration of in situ hydrological and morphological sampling, precluding the detailed analysis of environmental controls on sedimentation. In this sense, this work integrates high-resolution morphological (multibeam) and hydrological (CTD) data with sedimentological data (textural and productivity proxies) in order to achieve a sound framework to better understand surface sedimentation along the outer shelf and upper and middle slope off Uruguay, and thus improve our understanding on regional circulation patterns.

2. Regional setting

2.1. Hydrography

The Southwestern Atlantic Margin is characterized by its complex hydrography. At the BMC, the southward-flowing BC separates from the continental margin and collides with the northward-flowing MC. Here water masses are displaced off-shore and flux as part of the Anticyclonic Atlantic Subtropical Gyre (Schmid and Garzoli, 2009).

The BC is a baroclinic boundary current that concentrates its main flux up to 500 m, carrying Tropical Waters (TW;Emilson, 1961; Piola and Matano, 2001; Palma et al., 2008) at the surface and South Atlantic Central Waters (SACW; Emilson, 1961; Thomsen, 1962) below the surface (Table 1). The MC is a strong barotropic boundary current that advects Sub-Antarctic Waters (SAW; Thomsen, 1962) at the surface and Atlantic Intermediate Water (AAIW; Tomczak and Godfrey, 1994) below (Table 1). The AAIW flows not only northwards, but also polewards below the BC, as a result of the recirculation of this water mass in the Subtropical Gyre (Boebel et al., 1999; Nuñes-Riboni et al., 2005). Deeper, the southward flow of the North Atlantic Deep Water (NADW; Sverdrup et al., 1942) constitutes the principal source of ocean ventilation below the thermocline (Silveira et al., 2000; Piola and Matano, 2001).

Hydrographic simulations suggest that water masses transported by the BC and MC entrained the continental shelf along the shelf break of the Brazil Basin and Patagonia, respectively (Matano et al., 2010). Subtropical Shelf Waters (STSW) and Subantarctic Shelf Waters (SASW) are displaced southward and northward, respectively, along the continental shelf, and are diluted by the continental runoff of the Rio de la Plata and the Patos Lagoon. This water masses conflux at the STSF, where they are presumably detached off shore (Piola et al., 2000). Consequently, the STSF is considered a critical component of the oceanographic process connecting the Southwestern Atlantic shelf to the deep ocean (Piola et al., 2000; Matano et al., 2010).

2.2. Morphosedimentary context

The Southwestern Atlantic Margin comprises three physiographic domains: an extensive continental shelf that widens towards the Argentinean margin (c.a. 200 km; Urien and Ewing, 1974), a steep slope and an extensive continental rise (Ewing et al., 1963; Urien and Ewing, 1974; Violante et al., 2010).

The continental shelf is dominated by a relict sand coverture which has been deposited in littoral, barrier and estuary environments and reworked during the several Cenozoic transgressive–regressive events (Urien et al., 1980a,b). Sediment distribution is closely associated to the regional circulation. Sediments of Pampean–Patagonian origin distribute along the Argentinean margin up to the Rio de la Plata mouth and are transported northward by the Malvinas Current (Etchichury

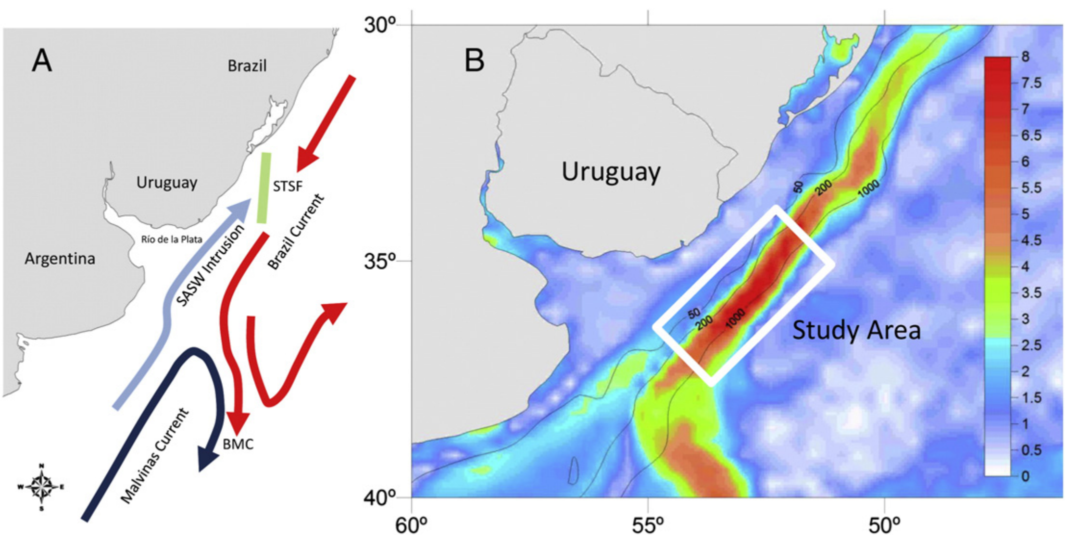

Fig. 1. Scheme of the regional circulation of the Southwestern Atlantic continental shelf and slope, re-drawn from Matano et al. (2010) (A); Map showing winter sea surface temperature gradient derived from ten year (2002–2011) winter climatology composite MODIS-Aqua satellite image (Moderate Resolution Spectroradiometer; http://oceancolor.gsfc.nasa.gov) (B). Note the frontal zone that extends from the Malvinas–Brazil Confluence zone (open ocean) to the Subtropical Shelf Front (continental shelf) and the location of the study area in the transition zone. Scale in °C/108 km. SASW: subantarctic shelf water.

Table 1
Temperature and salinity values characteristic of Southwestern Atlantic water masses published elsewhere and used for identification of water masses. TW: Tropical Water (Emilson, 1961; Piola and Matano, 2001; Palma et al., 2008); SACW: South Atlantic Central Water (Emilson, 1961; Thomsen, 1962); SAW: Subantartic Water (Thomsen, 1962); AAIW: Antarctic Intermediate Water (Tomczak and Godfrey, 1994); NADW: North Atlantic Deep Water (Sverdrup et al., 1942).

Water mass	T (°C)	S
TW	>20	>36
SACW	6 < T < 20	34.6 < S < 36
SAW	4 < T < 15	33.7 < S < 34.1
AAIW	3 < T < 6	34.2 < S < 34.6
NADW	3 < T < 4	34 < S < 35

and Remiro, 1963; Mahiques et al., 2008). Sandy sediments from the Uruguayan basement distribute off the Rio de la Plata while the Rio de la Plata fine sediments distribute along an inner shelf paleovalley ("Rio de la Plata mud belt"; Urien et al., 1980a,b) influencing sedimentation up to the Brazilian continental shelf (Mahiques et al., 2008). Over the Rio de la Plata paleovalley, along the 50 m isobath, the STSF appears as a barrier for coarse sediment distribution (Campos et al., 2008; Nagai et al., 2013).

On the continental slope, a well-developed Contourite Depositional System (CDS) exhibits both erosive (terraces and channels) and depositional (drifts) features associated with the action of different Antarctic water masses and their interfaces (Hernández-Molina et al., 2009; Preu et al., 2013). Thus, these are well developed along the Argentinean margin and gradually disappear towards the north, where across-slope (turbiditic) processes dominate (Hernández-Molina et al., 2009; Violante et al., 2010). Submarine Canyon Systems (SCSs) were first reported by Lonardi and Ewing (1971), between 35° and 38°S, of which the northernmost (the Rio de la Plata canyon system) reaches the study area.

3. Materials and methods

3.1. Study area

In austral summer 2010, a high resolution, large scale sampling was performed onboard *B/O Miguel Oliver* during a joint research cruise by the Dirección Nacional de Recursos Acuáticos (DINARA, Uruguay) and Secretaría General del Mar (SGM) and Instituto Español de Oceanografía (IEO) (Spain). The surveyed area is located along the Uruguayan outer shelf and upper and middle slope between latitudes 34°38′ S and 36°30′ S and longitudes 52°00′ W and 53°30′ W (ca. 5000 km^2, Figs. 1 and 2). Bathymetrical and hydrographic parameters were gathered from 200 to 2000 m deep, whereas sediment sampling covered the 175–1000 m fringe (Fig. 2). Based on present evidences of morphological and surface sediment distribution, and for practical descriptive purposes, the study area was divided a posteriori into: three latitudinal sectors, namely the northern (sector 1), central (sector 2) and southern (sector 3) regions (Fig. 2). Also, three depth-related regions were defined: the outer shelf (down to ca. 180 m), upper slope (from 180 to 500 m) and middle slope (from 500 to 1000 m).

3.2. Water column

Seawater column temperature and salinity were measured using an SBE 25 SEALOGGER CTD. Water masses were classified by means of temperature–salinity (TS) diagrams based on criteria for water masses identification published elsewhere (see Table 1). Vertical and horizontal bottom distribution contours of temperature and salinity were constructed using spatial interpolation methods.

3.3. Geomorphology

A Simrad EM-302 (transducers 30 kHz) multibeam system was used to map the margin. The EM 302 echosounder system emits a fanned arc

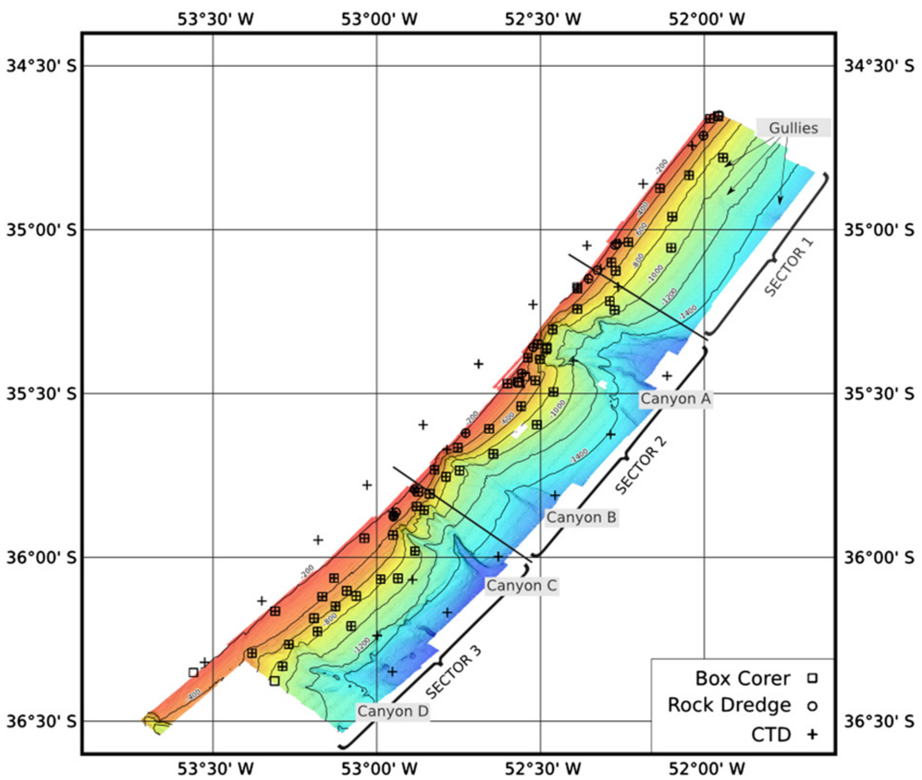

Fig. 2. Multibeam coverage of the study area (see Fig. 1 for regional location) showing canyons and gullies, the delimited latitudinal sectors (sectors 1, 2 and 3) and sedimentological and hydrological sampling stations.

composed of up to 432 individual beams, each with a width as narrow as one vertical degree by one horizontal degree, with a possible swath angle of 150°. Swath data were processed through the removal of anomalous pings and gridded at cell sizes of 30 m using MB-System software. Bathymetrical profiles from the non-sampled shelf break zone (ca. 175–200 m) were obtained from the National Geophysical Data Center, NOAA, available at http://www.ngdc.noaa.gov/mgg/geodas/trackline.html.

3.4. Grain size and textural parameters

Sixty bottom surface sediment samples (Fig. 2) were collected using a giant box-corer ULSNER (0.25 m^2) sampling all water depth ranges. In undisturbed box-cores, short-cores of 12 cm long and 10 cm in diameter were obtained for sedimentological analyses. Samples were described and photographed onboard. Short-cores were sliced into subsamples of 1 cm. For this study, only the first subsample (1st cm) was analyzed. Immediately after sampling, samples were frozen and stored for subsequent laboratory analyses. Grain size analyses were performed using low angle light scattering (LALLS; coupled with a Malvern Mastersizer 2000 analyzer) after acidifying the samples to eliminate the $CaCO_3$. Percentages of 17 intervals (0.5 subclasses) were determined between 9 and −1.5 Φ. Sediment parameters were calculated according to Shepard (1954)—sand/silt/clay triangular classification—and to Folk and Ward (1957)—mean, sorting, skewness and mode. Although biogenic opal was not removed before grain-size measurements, its potential influence on the sediment grain size data may be neglected. This is due to the very low (<1.3%) biogenic opal content registered in surface sediments from the Southwestern Atlantic Ocean (Romero and Hensen, 2002; Frenz et al., 2003).

3.5. Rock dredge sampling

Rock dredge sampling was performed near previously mapped seamounts or other prominent features (Fig. 2). The rock dredge was coupled with a 10 mm mesh size net. Samples were described and photographed on board.

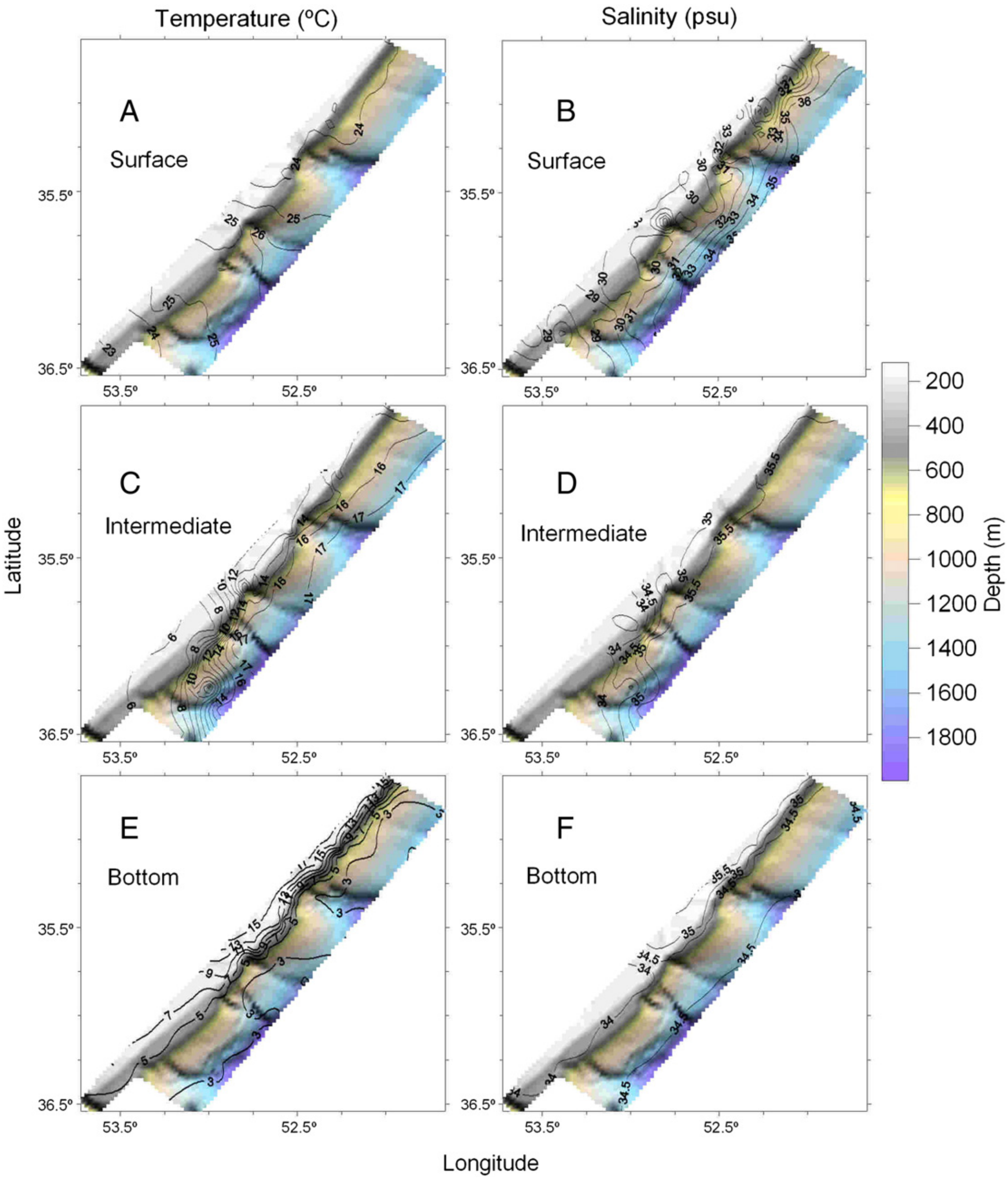

Fig. 3. Surface (50 m isobath; A, B), intermediate (200 m isobath; C, D) and bottom (E, F) horizontal distributions of temperature and salinity superimposed on the multibeam coverage.

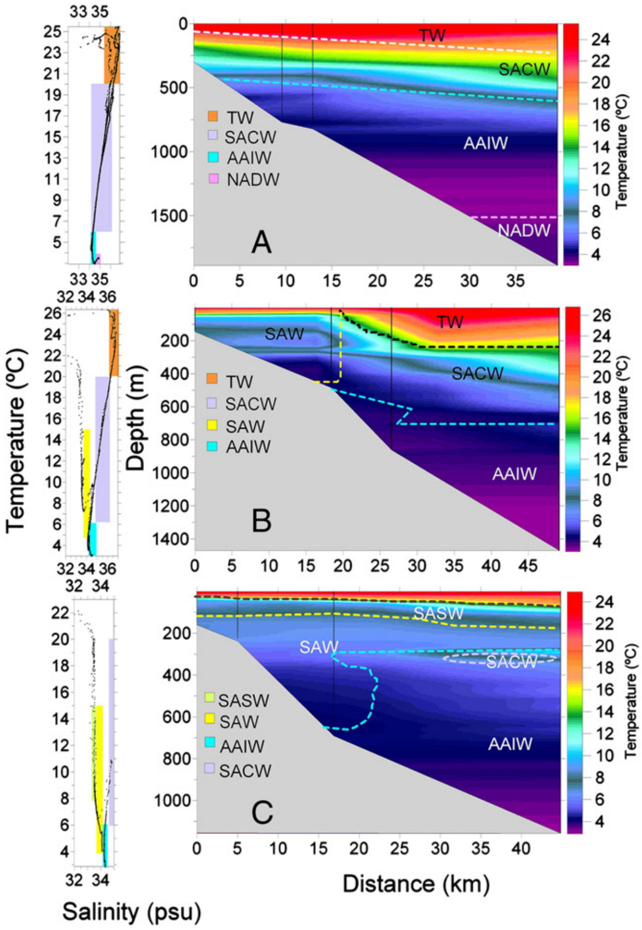

Fig. 4. Vertical distribution of temperature, TS scatter plot and the schematic setting of water masses of transects distributed in the northern (sector 1, A); center (sector 2, B) and southern (sector 3, C) region of the study area; color scale in °C.

3.6. Productivity proxies

Productivity proxies were analyzed from box corer sediment samples (see Section 3.4). Calcium carbonate content ($CaCO_3$) was determined by means of the weight difference prior to and after the acidification of 2 g of the sample with a 10% solution of hydrochloric acid (HCl). Organic carbon (C_{org}) and total nitrogen (N_t) were determined using a Costech Elemental Analyzer. Each of the aforementioned analyses was performed at the Oceanographic Institute of the University of São Paulo, Brazil.

Surface distribution maps of relevant variables were generated based on spatial interpolation methods (natural neighbor) using a Geographic Information System (GIS).

4. Results

4.1. Water column

The horizontal distribution of temperature (T) and salinity (S) is shown for the surface, intermediate and bottom waters (Fig. 3A, B and C). The scatter plot and schematic setting of water masses present in the study area are shown in vertical sections representative of the north (sector 1), central (sector 2) and southern (sector 3) regions (Fig. 4, A, B and C).

The surface distribution is characterized by the predominance of warm and diluted waters along the outer continental shelf extending along the slope mainly southward (sector 3) (Figs. 3A, B, 4C) where it merges with the Subantartic Shelf Water (SASW) (Fig. 4C). A well-defined shelf break front, relatively parallel to the isobaths, is the result of the convergence of diluted shelf water with high-salinity oceanic water (Fig. 3A,B).

At the upper continental slope, TW and SACW dominate northwards (sectors 1 and 2), SAW dominates southwards (sector 3) while the convergence of these water masses is observed along the central region (sector 2) (Fig. 4A,B,C). The strong front resulting from this convergence is particularly well delineated at intermediate depths in the horizontal TS distribution, mainly in sectors 2 and 3 (Fig. 3C,D).

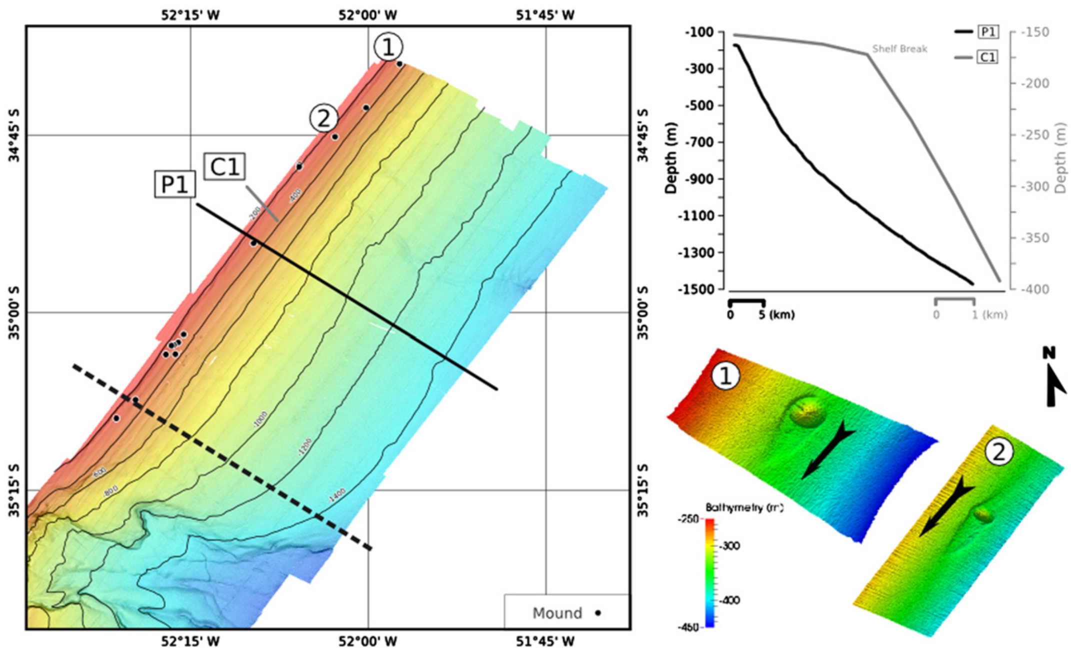

Fig. 5. Multibeam image of the northern (sector 1) region showing location of mounds (left). Vertical profiles of the continental slope (P1, multibeam) and shelf break (C1, NOAA) and mound erosive scarps showing the inferred direction of the dominant current (right).

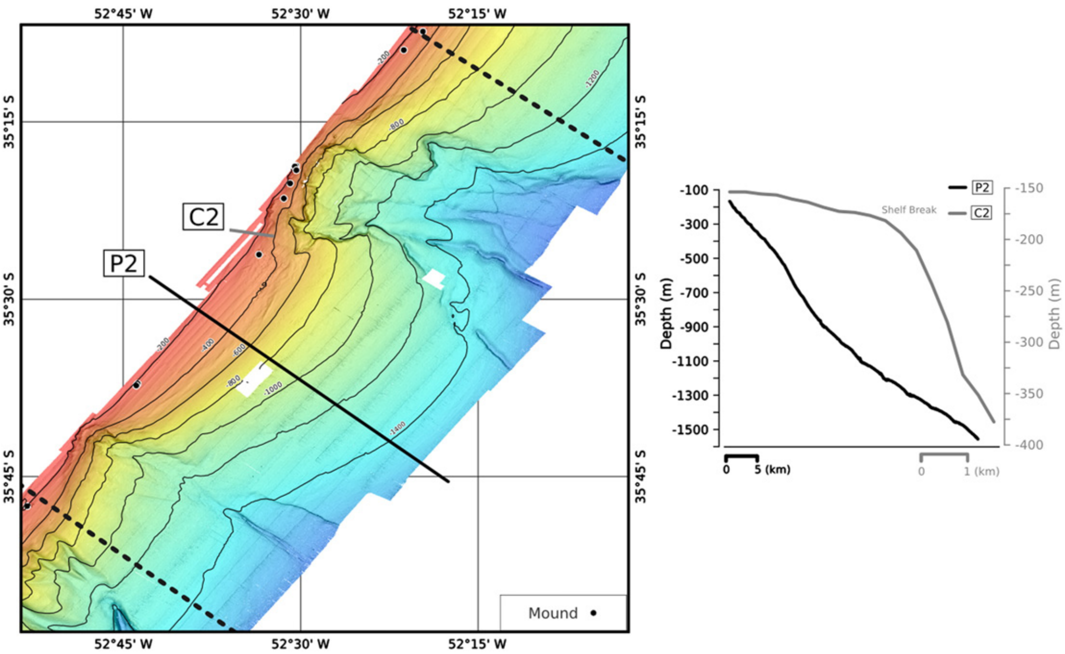

Fig. 6. Multibeam image of the center (sector 2) region showing location of mounds (left). Vertical profiles of the continental slope (P2, multibeam) and shelf break (C2, NOAA) and mound erosive scarps showing the inferred direction of the dominant current (right).

Along the middle slope, the low temperatures and relatively high salinities of waters correspond to the AAIW along the entire study area, and to the NADW in sector 1 (>2000 m) (Fig. 4A,B,C). The contrasting hydrographic characteristics between SACW and AAIW and the steep topographic slope defined a sharp temperature and haline gradient that marked a well-defined bottom shelf breakfront (Fig. 3E,F).

4.2. Geomorphology

The morphology of the whole study area and of sectors 1, 2 and 3, is shown in Figs. 2, 5, 6 and 7, respectively. Fig. 8 presents bathymetrical profiles representative of each sector. The shelf break occurs at ca. 180 m (Figs. 5, 6, 7).

There is a clear latitudinal change in slope morphology characterized by an increasing concavity northwards (Fig. 8). This results in a northward deepening of the continental slope including a more inclined angle in the upper slope (2.5° in sector 3 -P3- to 4.5° in sector 1 -P1-) and a more homogeneous angle in the middle slope (2.6° in sector 1 -P1- to 3° in sector 3 -P3-).

Gullies with their heads located at the 500 m isobath characterized sector 1. In sector 2, two canyons (canyons A and B) appear incised into the upper slope. Canyon A, with a width of 25 km, has its head

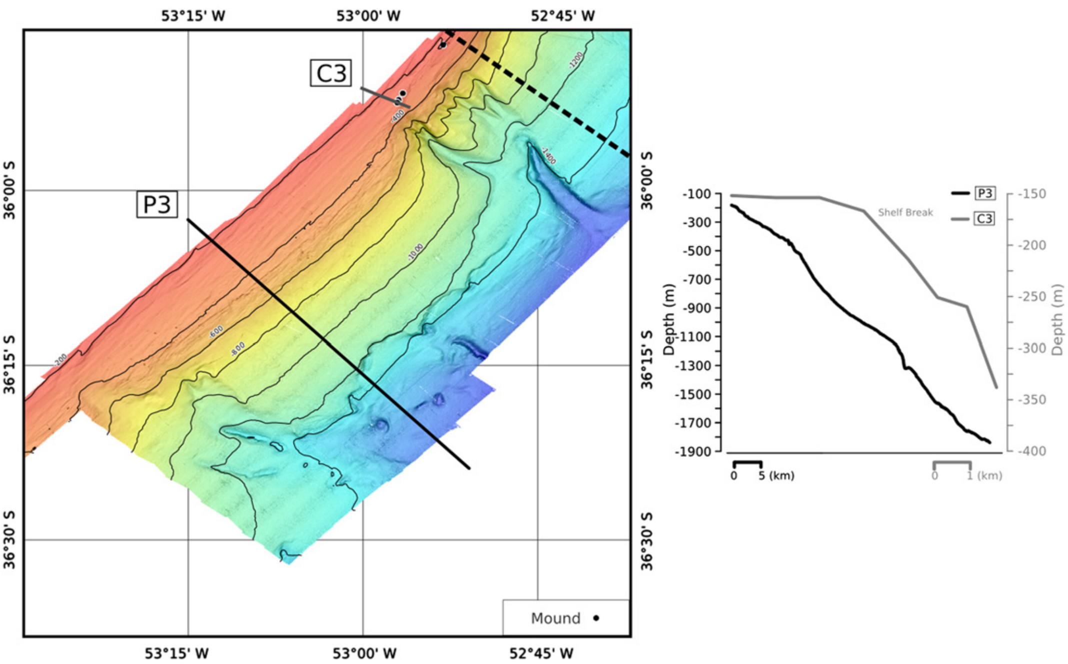

Fig. 7. Multibeam image of the southern (sector 3) region (left) and vertical profiles of the continental slope (P3, multibeam) and shelf break (C3, NOAA) (right).

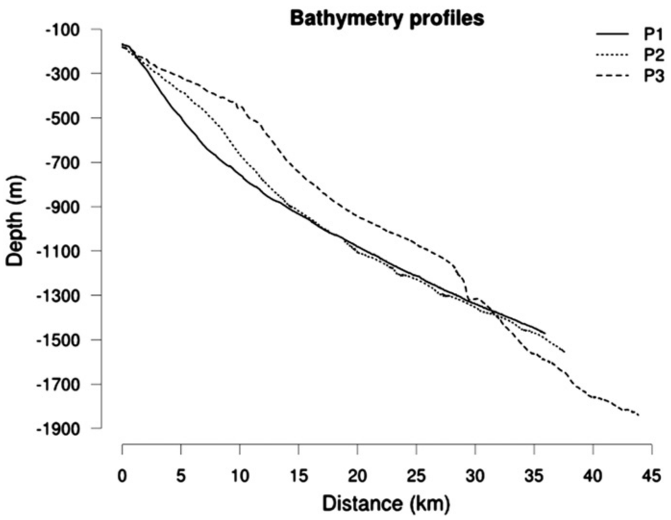

Fig. 8. Representative vertical bathymetric profiles of the northern (P3), center (P2) and southern (P1) regions of the study area (see Fig. 5 for location), showing the latitudinal change in the slope configuration.

incised at ca. 190 m and exhibits an amphitheater-like morphology with several tributary basins. Its southern slope is steeper and has an irregular morphology between the 250 and 550 m isobaths. Its main axis is W–E oriented. Canyon B, with a width of 10 km, has its head incised at ca. 200 m and presents a main NW–SE axis and a "V-shaped" morphology along its main course. Secondary channels occur mainly along its southern slope (Fig. 6).

In sector 3, channels are incised in the middle slope. Canyon C, with a width of 14 km, is incised at a 400 m depth. Its complex head is composed of three independent channels that join together at 1300 m and constitute a "U-shaped" morphology. Southward-facing mid-slope depressions constitute the beginning of canyon D (Fig. 7).

Mounds with associated coral reefs, represented as both isolated pinnacles or aggregations (Carranza et al., 2012), are concentrated between the 250–400 m isobaths mainly along sectors 1 and 2 in both fluvial and inter-fluvial regions (Figs. 5, 6). Their heights and diameters vary, respectively, from 24 m to 20 m and from 1200 m to 450 m (Carranza et al., 2012). In particular, mounds with isolated cusps

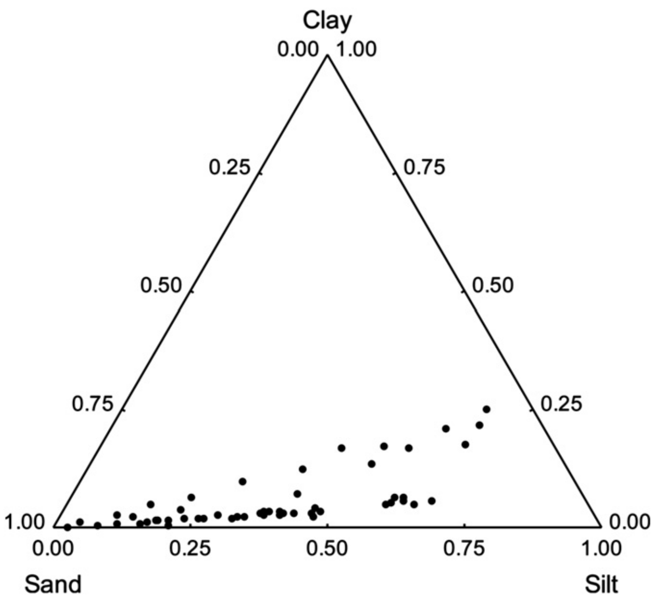

Fig. 9. Shepard sand–silt–clay relationships (in wt.%) of surface sediments from the study area.

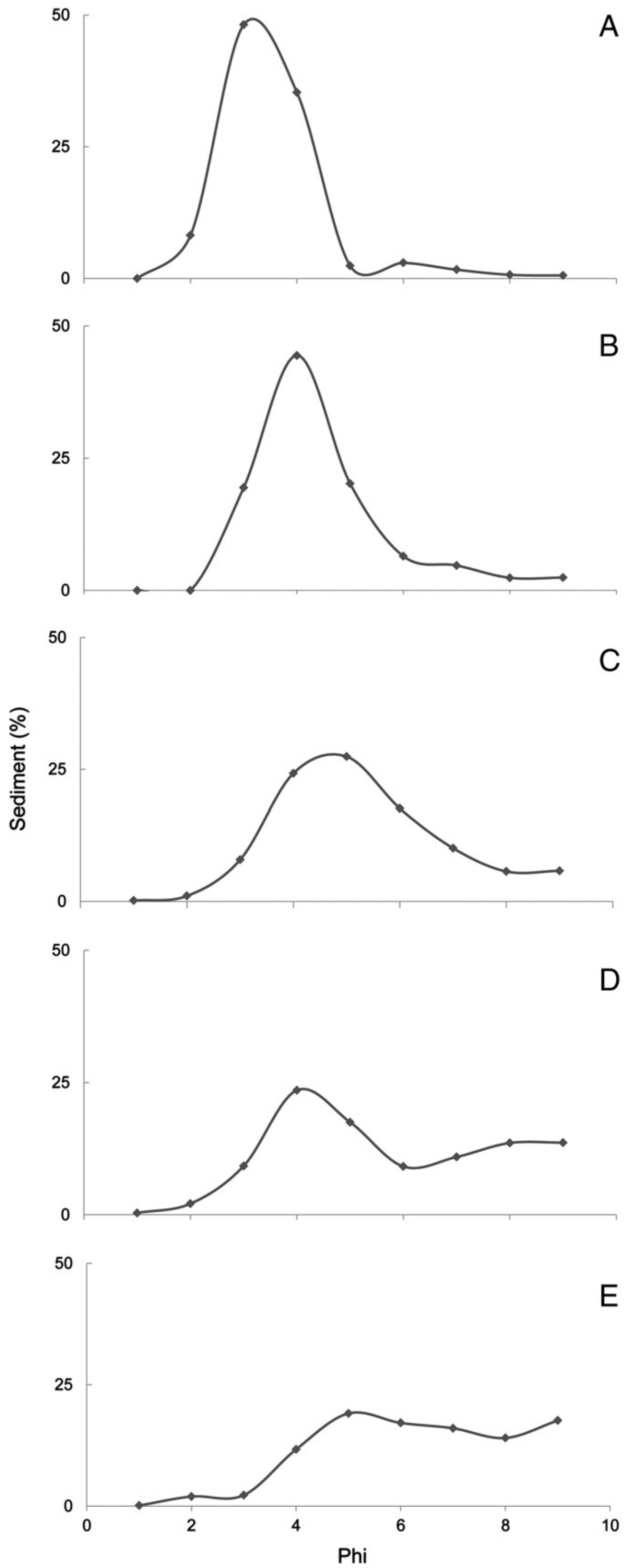

Fig. 10. Frequency distribution of the sedimentary facies of surface sediments described in the text; A: sand, B: silty sand, C: sandy silt, sub-facies A, D: sandy silt, sub-facies B, E: clayey silt.

morphologies have facilitated the erosion of the seafloor creating an elongated, depressed topography around the mounds exhibiting NE–SW-oriented scarps (Figs. 5, 6).

4.3. Sediment analyses and facies

Sands and silty sands, with relatively low clay percentages (ca. 4%) dominate the study area and grade to sandy silt and clay/silt sediments with a maximum of 25% clay (Fig. 9). The highest sand percentages are represented by fine and very fine sands. Poorly sorted, fine skewed sediments dominate the area.

In general, $CaCO_3$ values range between 3.6% and 32%. However, high $CaCO_3$ concentrations (48% and 56%) are observed along the northernmost region of the outer shelf and shallow upper slope. Thus, according to the classification of Larsonneur et al. (1982), lithoclastic sediments (<30%) dominate the study area with a subordinate bioclastic facies. C_{org} and N_t values range between 0.24% and 7% and 0.06% and 0.84%, respectively. Shepard grain size frequency (Fig. 10) and distribution (Fig. 11), together with textural parameters (Figs. 12 and 13) and productivity proxies (Fig. 14) allow the identification of sedimentary facies.

The sands and silty sands exhibit poor sorting and very positive skewness. Sands, characterized by fine sand modes, dominate the outer shelf, shallow (down to 250 m) upper slope, and the areas near the canyon heads and flanks (lag deposits). This facies has medium (up to 44%) and coarse (up to 7%) sand content. High carbonate-content sediments with ferruginous and reworked textures are observed along the outer shelf and shallow (down to 250 m) upper slope of sector 1. Well and moderately sorted sediment is observed on the outer shelf and in head of canyon A. Silty sands are distributed along the lower (250 to 500 m) upper slope of sectors 1 and 2 and along the middle slope of sectors 2 and 3. This facies exhibits very fine sand modes. High medium sand content (between 8 and 20%) is present in middle slope areas.

Sandy silt facies exhibit positive skewness and is characterized by two sub-facies. Sub-facies A, distributed along the upper slope in sector 3, is characterized by a very fine sand mode and by the presence of high silt content. The three productivity proxies studied ($CaCO_3$, C_{org}, N_t) have their maxima in this sub-facies. Sub-facies B occurs along the middle slope in sector 1. It shows the poorest sorting of all sediments within the study area and is characterized by two modes: a dominant, very fine sand fraction and a secondary clay mode.

Clayey silts are found in samples obtained along a fringe located at ca. 500 m (sector 1) and inside canyons (sector 2). Quasi-symmetric curves with a mode in fine fractions (fine and very fine silts and clays) characterize this facies.

As a rule, different bathymetric patterns are observed between sectors 1–2 and sector 3. While in sectors 1 and 2, mean grain size and values of productivity proxies decrease with depth in sector 3, mean grain size decreases rapidly between the outer shelf and upper slope and then increases down-slope. The productivity proxies analyzed here exhibit the inverse pattern. Regarding latitudinal variations, in the upper slope, grain size decreases from north (sectors 1–2) to south (sectors 2–3) while productivity increases accordingly. Meanwhile, in the middle slope, grain size decreases northwards from sectors 2–3 to sectors 1–2. Preliminary comparison of textural data with backscatter data confirms the distribution of these facies. These data will be presented elsewhere.

4.4. Rock dredge samples

Igneous/metamorphic rock cobbles and boulders were collected along the upper slope near mounds and canyon heads (Fig. 15). Igneous and metamorphic rock fragments consist of rounded to sub-rounded clasts with diameters varying from 1 to 15 cm.

5. Discussion

5.1. Along slope configuration and canyon genesis

Even though this study lacks geophysical data, the registered latitudinal change in slope configuration resembles the bathymetric profiles recognized by Soto et al. (in press) at the northern and southern limits of the Uruguayan margin. According to these authors, this morphological change is related to a structural control associated to the Rio de la Plata transfer system (RPTS) and/or to a decreasing contouritic

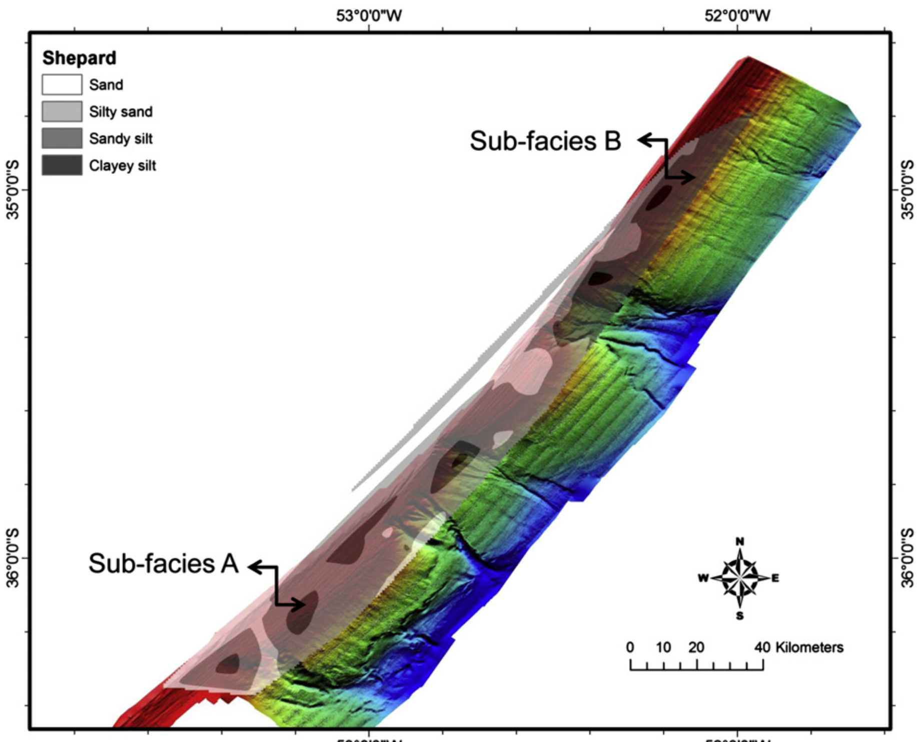

Fig. 11. Distribution of Shepard sedimentary facies in surface sediments along the study area.

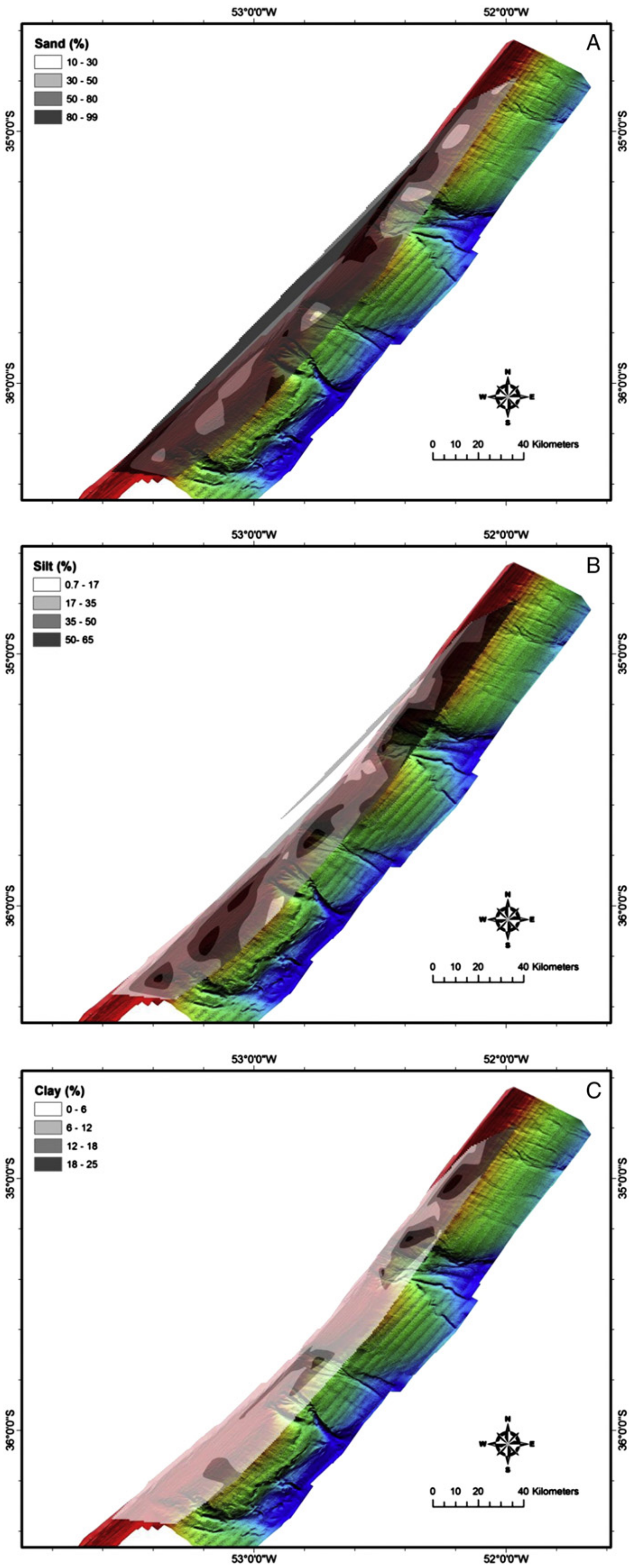

Fig. 12. Distribution of sand (A), silt (B) and clay (C) in surface sediments of the study area.

influence related to the position of the BMC. Thus, the southern region of the study area likely includes the northernmost prolongation of the Argentinean Contourite Depositional System. According to Preu et al. (2013) on the Argentinean margin, T1, a locally confined terrace that distributes between 500 and 600 m, sharply narrows northward while T2, a regional continuous feature between 1100 and 1400 m, extends towards the north. Our data precludes identification of terraces, although the abovementioned latitudinal distribution indicates the probable occurrence of T2 in the southernmost profiles. This is corroborated for the middle slope of the study area where, based on geophysical and core data, contouritic deposits were identified (Krastel et al., 2011).

The origin of canyons on passive continental margins has been traditionally explained by two contrasting hypotheses (Nittrouer et al., 2007; Krastel et al., 2011): 1) direct river erosion of conduit valleys across an emergent continental shelf during low standing sea-level conditions; or 2) local slope failures not necessarily associated with river discharge. In the present contribution, canyons were found incised on the upper (canyons A and B, north) and middle (canyons C and D, south) continental slope, but the spatial extent of our mapping is not enough to visualize whether canyons extend towards the shelf break. Moreover, to date, there are no geophysical data available to evaluate the existence of outer shelf channels connecting this slope canyon system with the continent. However, an ETOPO1 image presented by Urien et al. (2012) indicates the presence of channels in the outer shelf continuing these slope canyons, which could indicate an ancient off-shelf discharge. Despite the low resolution of this technique, it suggests that the northernmost canyons may be related to gravity flows occurring during low sea level conditions (hypothesis 1). Failures and subsequent landslides (hypothesis 2), with or without gravity flows, are likely mechanisms underlying the genesis of the two smaller “U-shaped” canyons registered in the south, as well as the gullies observed along the upper continental slope (Farre et al., 1983; Nittrouer et al., 2007).

5.2. Imprint and sedimentary processes associated to the slope extension of the STSF

Oceanographic data showed that surface waters at the study area were under the influence of the Rio de la Plata diluted waters. De Mello et al. (in press) related the low salinity surface waters observed in the study area during the sampling period with increased freshwater runoff associated to an El Niño event.

According to Piola et al. (2000) and Matano et al. (2010) the shelf circulation presents distinct scenarios at the southern and northern regions of the STSF. In the north, the STSW dominates in the inner shelf while the middle and outer shelf is under the influence of oceanic subtropical water masses. Meanwhile, in the southern portion, continental shelf waters (SASW) are always more diluted than open waters, and thus mixing of water masses occurs only along the outer shelf and upper slope. In this context, the STSF is distributed in a north–south direction extending towards 36°S at the outer shelf. The subsurface hydrographical regime observed along the outer shelf and upper continental slope agrees with this distribution of STSF water masses. Thus, this corroborates that the study area is under the influence of the outer shelf and upper slope extension of the STSF.

In this sense, the northward transition from a subantarctic (and STSF) (sectors 2–3) to a subtropical (sectors 1–2) water mass domain is accompanied by (1) the presence of erosive mound scarps indicating a dominant southward flux; (2) a coarsening in grain size, from sand to biogenic sand facies between 175 and 250 m and from sandy silt (sub-facies A) to silty sand facies between 250 and 500 m; (3) a decrease in the values of productivity proxies; (4) the occurrence of mounds associated with coral reefs; (5) a steeper slope and (6) the occurrence of canyons indented in shallower depths of the slope (ca. 200 m, sector 2 versus ca. 500, sector 3).

Considering the patterns listed above, Piola et al. (2000) stated that north of the STSF the BC flows southward while south of the STSF the MC flows northward. In this sense, the direction of the erosive mound scarps corroborates the dominance of the southward-flowing BC in the northern portion of the study area. Consequently, this suggests

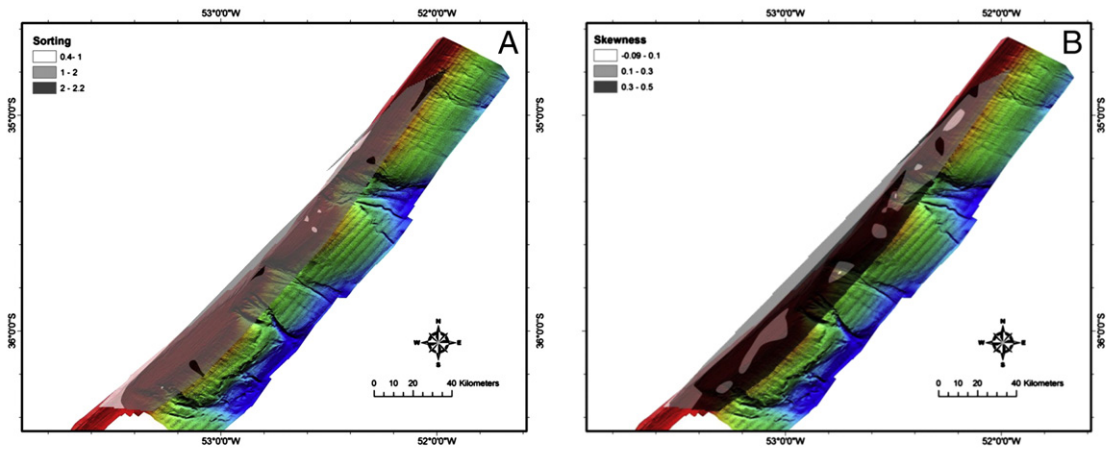

Fig. 13. Distribution of sorting (A) and skewness (B) in surface sediments of the study area.

that the MC dominates southward, presumably providing evidence of the mean northernmost distribution of the STSF. It is known that depending on the wind regime, the regional circulation system is displaced southwards during austral summer and northward during the austral winter. The present hydrographic data were obtained during the summer season, and consequently it represents the southernmost location of the STSF. Therefore, the hydrographical and sedimentary data indicates a relatively stable position of the STSF over the slope (ca. 36°). This is in agreement with Piola et al. (2000) who suggested that the STSF is stable throughout the year. Moreover, the surface sediment integrates mean values over a longer period of time (decadal to centurial timescales). Therefore the dynamics of the STSF is expected to be imprinted on the sediment distribution.

Concerning the northward coarsening in grain size, it indicates that a highly energetic environment is associated with the BC, while a less energetic environment characterizes the MC and STSF environments. This is in agreement with numerical simulations based on the shelf and oceanic circulation of the boundary currents in their respective basins (Matano et al., 2010). These authors suggested that a strong flux characterized the southward flowing BC north of the STSF. Notwithstanding, according to McCave (1982) the remobilization of sediments is favored by the generally turbulent bottom-currents, which are locally enhanced along a steep slope. Accordingly, lower flow velocities are related to smoother slopes. Moreover, the trapping of advected sediments inside canyons may decrease sediment availability for sedimentation. Thus, the observed depositional environments likely reflect the flow intensities along the STSF favored by the morphologic configuration. Deep sea coral reefs need high energetic environments in order to allow transport of food particles avoiding clogging (Roberts et al., 2006; Muñoz et al., 2012). Thus, the distribution of mounds associated with coral reefs, mainly in the north, supports the surface sediment distribution being thus a secondary indicator of the hydrodynamics along the STSF.

The northward decrease in the values of the productivity proxies is in line with the characteristics of the respective dominant water masses (oligotrophic subtropical and nutrient-rich subantartic waters, Piola et al., 2000), and with the high productivity and entrapment of particles that characterized hydrological fronts (Acha et al., 2004). However, the occurrence of the surface shelf break front formed between TW and shelf-diluted water masses indicates fertilization of oceanic waters along the whole study area (de Mello et al., in press). Therefore, the erosive flow of the BC may enable organic matter sedimentation, explaining the relatively low values of productivity proxies in the north. Hence, the lateral variation in organic matter content reflects the productivity distribution along the STSF, further controlled by the bottom hydrodynamics.

5.2.1. Off-shelf sediment transport

The similar texture registered between the outer shelf and shallow region of the upper slope (i.e., from 175 to 250 m; bioclastic sands in the north and fine sands in the south) and the seaward decrease in grain size appointt off-shelf sand export as a probable transport mechanism. This is further indicated by the texture itself since bioclastic reworked and ferruginous sediment reflects the presence of a relict coastal deposit. During the LGM, sea level was located between 130 and 150 m on the Southwestern Atlantic Margin (Cavallotto et al., 2005). To date, in the region, reworked shelly sediments and calcareous debris, indicative of LGM shoreline environments, have been registered down to 150 m (Urien et al., 1980a). Thus, this suggests a seaward transport from a proximal continental shelf relict coastal deposit during glacial and/or postglacial times. On the Uruguayan continental margin, off-shelf sediment transport has already been suggested by Urien et al. (1980a,b) and by Bender (2012). According to Piola et al. (2000), little or no mixing of subantartic and subtropical shelf waters occurs along the STSF suggesting that water masses must be detached offshore along the STSF (Piola et al., 2000). Hence, this across shelf circulation may control the sediment transport towards the continental slope. Moreover, the distribution of coarser (biogenic) sediments north of the STSF suggests a more efficient off-shelf transport associated to the BC flux north of the STSF thus, reinforcing the strong flow of this current.

5.2.2. Gravel transport processes

The presence of igneous and metamorphic clasts along the upper continental slope is intriguing, considering the passive character of this Atlantic margin and the relatively large extension (ca. 120 km) of the continental shelf (Urien et al., 1980a). Two possible transport mechanisms can be considered: fluvial transport and iceberg displacement. The first one implies direct river discharge along a glacial, emerged continental shelf and subsequent mass wasting transport towards the slope. Thus, the outer shelf channels indicated by Urien et al. (2012) may have acted as sediment conduits for at least the smallest pebbles. However, the size (up to 15 cm) of some pebbles and the fact that some have acute edges point to iceberg transport as a more probable explanation. Moreover, rock fragments of unknown origin have been also registered southward on the Argentinean continental slope (Violante et al., 2010). The distribution of icebergs during glacial times (Carta H1, Fernandez, 1964) supports the hypothesis of northward iceberg transport to the study area. Moreover, the fact that the rock fragments are not exclusively distributed in canyon heads (lag deposits) but along inter-fluvial environments (in mound erosion scarps) supports the latter hypothesis. The melting of icebergs and concomitant release of drop stones may have been enhanced by the influence of warm

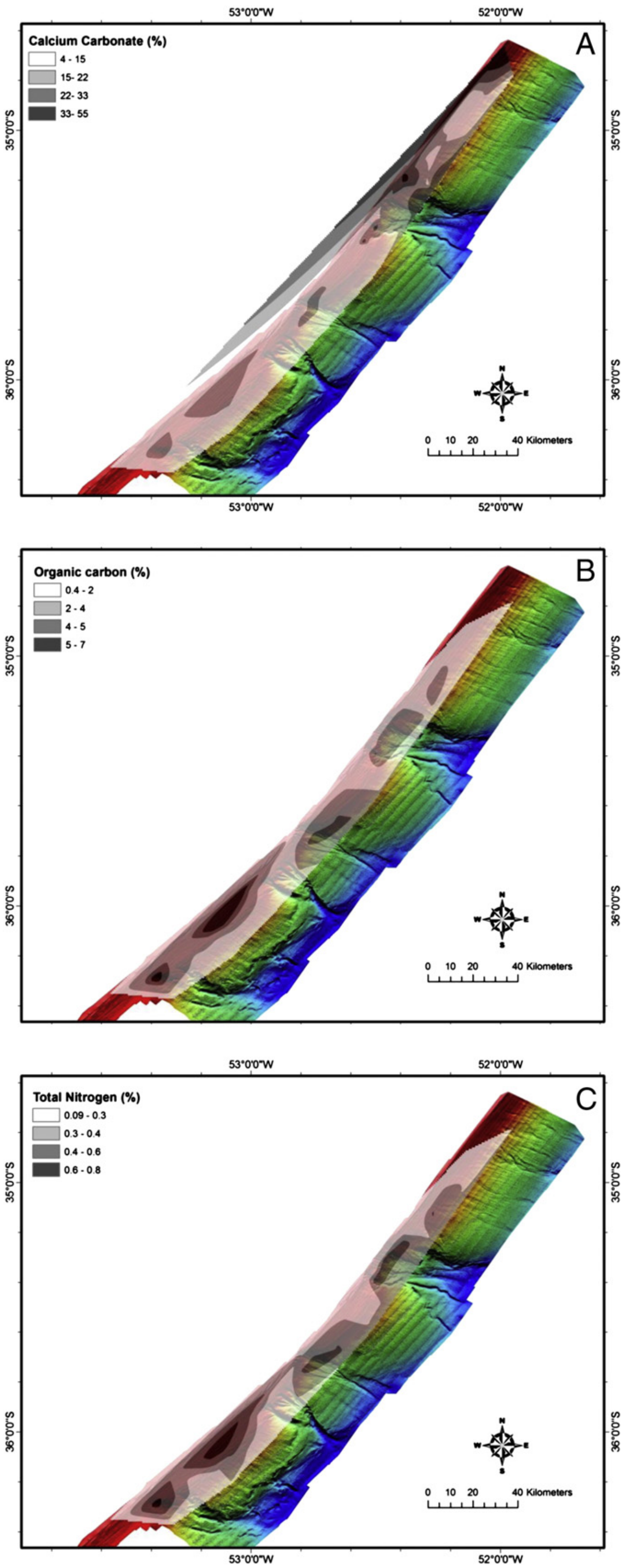

Fig. 14. Distribution of calcium carbonate (A), organic carbon (B) and total nitrogen (C) in surface sediments of the study area.

southward flowing subtropical waters. If this is correct, rock fragment distribution may be used as an indicator of the STSF position during glacial times.

5.3. Imprint of AAIW at intermediate level of the BMC

The middle slope is dominated by AAIW. According to Boebel et al. (1999), the BMC is marked by the inflow of aged, subtropical AAIW from the north and fresh AAIW from southern, shallower layers. Thereby, the dynamics of the BMC are complex at intermediate levels. On the Argentinean continental slope, the northward flow of the AAIW promotes, by means of a strong bottom current, the development of contourite deposits (including T2, Hernández-Molina et al., 2009; Preu et al., 2013) and sandy surface sediments (Frenz et al., 2003; Bozzano et al., 2012). Although the mean position of the BMC is located at ca. 38°S, recent studies (Schmid and Garzoli, 2009) indicate that its northernmost distribution reaches 36°S which coincides with the location of the study area.

The northward sharp fining in grain size (from silty sand facies with relatively high medium sand content (sectors 2–3) to sandy silt facies (or sub-facies B, sector 1)) is accompanied by a deepening of the continental slope associated with the disappearance of contouritic structures as corroborated by Krastel et al. (2011). Thus, in the southern region of the study area, both the morphology and the surface erosive environment could indicate the northernmost influence of the strong AAIW displaced northwards by the MC. According to Preu et al. (2013), measurements of high turbidity suggest the presence of intermediate nepheloid layers fed by processes occurring along the erosive margin within the AAIW. Thus, the sharp textural northward fining may be promoted by the deepening of the continental slope that allows plenty lateral space to spread, enhancing a drop of current speed and the release of fine particles in the north.

The fine fringe (clayey silt) facies located along the upper–middle slope transition (ca. 500 m) in the northern region and inside canyons in the transitional region coincides with the interface between the southward flowing SACW (upper slope) and the aforementioned northward flowing AAIW (middle slope). According to Mahiques et al. (2011), on the southeastern Brazilian margin, higher sedimentation rates occur between contrasting current cores. Thus, the same mechanism may explain the depositional environment of our study area.

6. Conclusions

The integration of high resolution hydrological, morphological and sedimentological data allowed the identification of key sedimentary processes, the evaluation of the environmental control on surface sedimentation and the characterization of the sediment imprint of the hydrological setting influencing the Uruguayan continental outer shelf and upper and middle slope. These are summarized in Fig. 16. The study area is influenced by the Rio de la Plata discharge at the surface, by the slope extension of the STSF at subsurficial depths and by the AAIW at intermediate levels. A latitudinal change on the slope and canyon configuration characterizes the morphology. The former includes the northward prolongation of the Argentinean Contourite Depositional System while the latter is presumably associated with low stands of sea level. Surface sedimentation along the outer shelf and upper and middle slope exhibits latitudinal gradients that can be explained by the dynamics related to the oceanographic regime and morphology. On the outer shelf and upper slope, as well as north of the STSF, the distribution and direction of erosive mound scarps indicating the dominance of the BC suggest that this region is close to the northernmost mean position of the STSF. An erosive bottom character reflects the strong flux of the southward flowing BC enhanced by a steeper slope and by the occurrence of canyons incised shallow in the upper slope. Southward, a high productive and depositional environment evidenced a less energetic MC flux and settling processes associated with the STSF favored by a smooth slope and by canyons incised deeper on the upper slope. Off shelf sediment export associated to the detachment of water masses along the STSF is suggested by the textural distribution. The occurrence of igneous and metamorphic clasts indicates iceberg

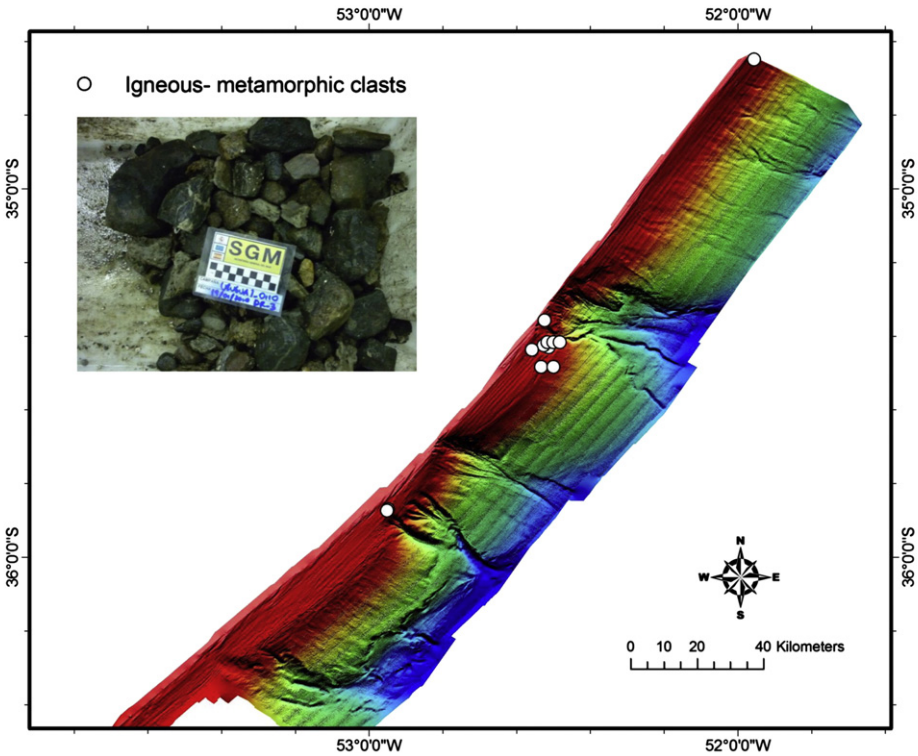

Fig. 15. Distribution and photograph of representative igneous–metamorphic clasts sampled along the study area.

transport related to the glacial STSF distribution and/or gravity transport processes. In the middle slope, the disappearance of contouritic structures and the sharp decrease in grain size reflect the northernmost influence of the strong northward flowing flux of the AAIW. The information reported in this paper is particularly important to better understand the regional hydrodynamics based on the geomorphological and sedimentological imprint as a consequence of the transition between the shelf STSF and the oceanic BMC. Future work related with local hydrodynamics would increase our understanding of the signatures and hydrodynamic control in this complex system.

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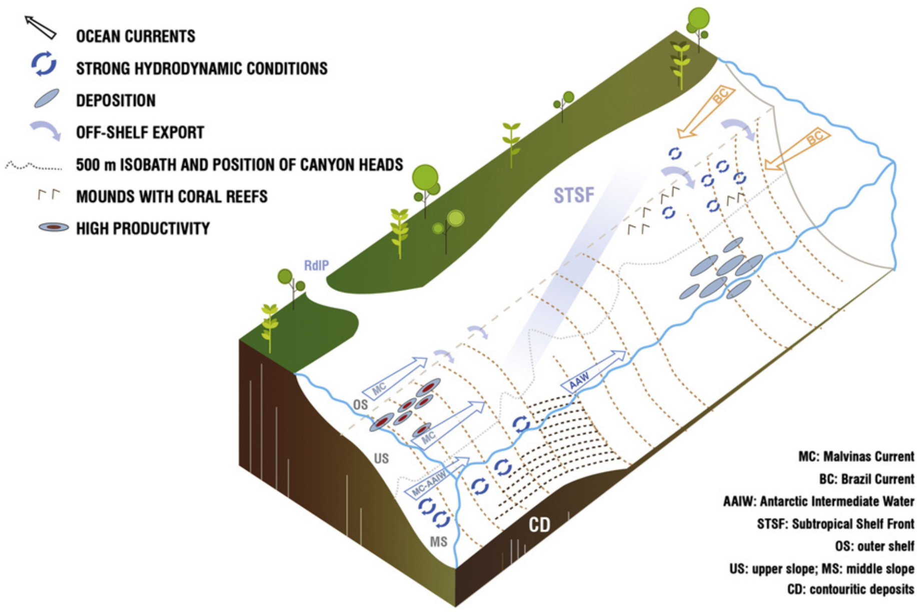

Fig. 16. Schematic diagram showing the sediment dynamics and sedimentary processes associated to the regional hydrology and morphology. The relative intensity of the sedimentary processes is indicated by the size of the respective markers.

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References

Acha, E.M., Mianzanb, H.W., Guerreroa, R.A., Faveroa, M., Bavab, J., 2004. Marine fronts at the continental shelves of austral South America Physical and ecological processes. Journal of Marine Systems 44, 83–105.

Bender, V.B., 2012. From shelf dynamics to shelf export: evidences from sedimetologic and paleoceanographyc slope record. Doctorate theses presented to Uuroprox University of Bremen, Germany.

Boebel, O., Schmid, C., Zenk, W., 1999. Kinematic elements of Antarctic Intermediate Water in the western South Atlantic. Deep Sea Research Part II: Topical Studies in Oceanography 46, 355–392.

Bozzano, G., Violante, R.A., Cerredo, M.E., 2012. Middle slope contourite deposits and associated sedimentary facies off NE Argentina. Geo-Marine Letters 31, 495–507.

Campos, E.J.D., Mulkerherjee, S., Piola, A.R., de Carvalho, F.M.S., 2008. A note on a mineralogical analysis of the sediments associated with the Plata River and Patos Lagoon outflows. Continental Shelf Research 28, 1687–1691.

Carranza, A., Muñoz-Recio, A., Kitahara, M., Scarabino, F., Ortega, L., López, G., Franco-Fraguas, P., de Mello, C., Acosta, J., Fontan, A., 2012. Deep-water coral reefs from the Uruguayan outer shelf and slope. Marine Biodiversity 42, 411–414.

Cavallotto, J.L., Violante, R., Colombo, F., 2005. Evolución y cambios ambientales de la llanura costera de la cabecera del río de la Plata. Revista de la Asociación Geológica Argentina 60, 353–367.

de Mello, C., Burone, L., Ortega, L., Franco-Fraguas, P., Lahuerta, N., Mahiques, M., Marin, Y., in press. Benthic foraminiferal distributions on the Uruguayan continental margin (South-western Atlantic) and controlling environmental factors. Journal of Marine Biology.

Emilson, I., 1961. The shelf and coastal waters off southern Brazil. Boletim do Instituto Oceanográfico da Universidade de São Paulo 11, 101–112.

Etchichury, M.C., Remiro, J., 1963. La corriente de Malvinas y los sedimentos pampeano-patagónicos. Rev Museo Argentino Bernardino Rivadavia. Cs. Geológicas. I.

Ewing, M., Ludwig, W.J., Ewing, J.I., 1963. Geophysical investigations in the submerged Argentine coastal plain. Geological Society of America Bulletin 74, 275–295.

Farre, J.A., McGregor, B.A., Ryan, W.B.F., Robb, J.M., 1983. Breaching the shelf break; passage from youthful to mature phase in submarine canyon evolution. In: Moore, D.J.S.a.G.T. (Ed.), The Shelf Break. Critical Interface on Continental Margins. Special Publication, 33. Society of Economic Paleontologists and Mineralogists, Tulsa, OK, pp. 25–39.

Fernandez, S.A., 1964. 5a edicion 1992. Ultima correccion 1995. ed. Servicio de Hidrografia Naval de la Secretaria de la Marina, Buenos Aires, p. Carta H1. Acceso al Rio de la Plata.

Folk, R.L., Ward, W.C., 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology 27, 3–26.

Framiñan, M.B., Brown, O.B., 1996. Study of the Río de la Plata turbidity front Part I: spatial and temporal distribution. Continental Shelf Research 16, 1259–1282.

Frenz, M., Höppner, R., Stuut, J.B.W., Wagner, T., Henrich, R., 2003. Surface sediment bulk geochemistry and grain-size composition related to the oceanic circulation along the south American continental margin in the southwest Atlantic. In: Wefer, G., Mulitza, S., Ratmeyer, V. (Eds.), The South Atlantic in the Late Quaternary: Reconstruction of Material Budgets and Current Systems. Springer-Verlag, Berlin Heidelberg New York Tokyo, pp. 347–373.

Hernández-Molina, F.J., Paterlini, M., Violante, R., Marshall, P., de Isasi, M., Somoza, L., Rebesco, M., 2009. Contourite depositional system on the Argentine Slope: an exceptional record of the influence of Antarctic water masses. Geology 37, 507–510.

Krastel, S., Wefer, G., Hanebuth, T.J.J., Antobreh, A.A., Freudenthal, T., Preu, B., Schwenk, T., Strasser, M., Violante, R., Winkelmann, D., 2011. Sediment dynamics and geohazards off Uruguay and the de la Plata River region (northern Argentina and Uruguay) M78/3 shipboard scientific party. Geo-Marine Letters 31, 271–283.

Larsonneur, C., Bouysse, P., Aufret, J.P., 1982. The surficial sediments of the English Channel and its western approaches. Sedimentology 29, 851–864.

Lonardi, A.G., Ewing, M., 1971. Sediment transport and distribution in the Argentine Basin. 4. Bathymetry of the continental margin. Argentine Basin and other related provinces. Canyons and sources of sediments. Physics and Chemistry of the Earth. Pergamon Press, Oxford, pp. 79–121.

Mahiques, M.M., Gaeta Tassinari, C.C., Marcolini, S., Violante, R.A., Lopes Figueira, R.C., Almeida da Silveira, I.C., Burone, L., Sousa, S.H.M., 2008. Nd and Pb isotopes signatures on the southeastern southamerica upper margin: implication for sediment transport and source rocks. Marine Geology 250, 51–63.

Mahiques, M.M., Sousa, S.H., Burone, L., Nagai, R., Almeida da Silveira, I.C., Lopes Figueira, R.C., Soutelino, R.G., Ponsoni, L., Klein, D.A., 2011. Radiocarbon geochronology of the sediments of the São Paulo Bight (southern Brazilian upper margin). Analis da Academia Brasileira de Ciencias 83, 817–834.

Matano, R.P., Palma, E.D., Piola, A.R., 2010. The influence of the Brazil and Malvinas Currents on the Southwestern Atlantic Shelf circulation. Ocean Science 6, 983–995.

McCave, I.N., 1982. Erosion and deposition by currents on submarines slopes. Bulletin de l'Institut de Géologie du Bassin d'Aquitaine 31, 47–55.

Muñoz, A., Cristobo, J., Rios, P., Druet, M., Polonio, V., Uchupi, E., Acosta, J., Group, A., 2012. Sediment drifts and cold-water coral reefs in the Patagonian upper and middle continental slope. Marine and Petroleum Geology 36, 70–82.

Nagai, R.H., Ferreira, P.A.L., Mulkherjee, S., Martins, V.M., Figueira, R.C.L., Sousa, S.H.M., Mahiques, M.M., 2013. Hydrodynamic controls on the distribution of surface sediments from the southeast South American continental shelf between 23°S and 38°S. Continental Shelf Research. http://dx.doi.org/10.1016/j.csr.2013.09.016.

Nittrouer, C.A., Austin, J.A., Field, M.E., Kravitz, J.H., Syvitski, J.P.M., Wiberg, P.L., 2007. Continental Margin Sedimentation: From Sediment Transport to Sequence Stratigraphy. Blackwell Publishing Ltd International Association of Sedimentologists.

Nuñes-Riboni, I., Boebel, O., Ollitrault, M., You, Y., Richardson, P.L., Davis, R., 2005. Lagrangian circulation of Antarctic Intermediate Water in the subtropical South Atlantic. Deep Sea Research Part II: Topical Studies in Oceanography 52, 545–564.

Palma, E.D., Matano, R.P., Piola, A.R., 2008. A numerical study of the Southwestern Atlantic Shelf circulation: stratified ocean response to local and offshore forcing. Journal of Geophysical Research 113, 1–22.

Piola, A.R., Matano, R.P., 2001. The South Atlantic Western Boundary Currents Brazil/Falkland (Malvinas) Currents. In: Steele, J.M., Thorpe, S.A., Turekian, K.K. (Eds.), Encyclopedia of Ocean Sciences. Academic Press, London, UK, pp. 340–349.

Piola, A.R., Campos, E.J.D., Moller, J.R.O.O., Charo, M., Martinez, C., 2000. Subtropical shelf front off Eastern South America. Journal of Geophysical Research 105, 6565–6578.

Preu, B., Hernandez-Molina, F.J., Violante, R., Piola, A., Paterlini, C.M., Schwenk, T., Voigt, I., Krastel, S., Spiess, V., 2013. Morphosedimentary and hydrographic features of the northern Argentine margin: the interplay between erosive, depositional and gravitational processes and its conceptual implications. Deep-Sea Research Part I: Oceanographic Research Papers 157–174.

Roberts, J.M., Wheeler, A.J., Freiwald, A., 2006. Reefs of the deep: the biology and geology of cold-water coral ecosystems. Science 312, 543–547.

Romero, O., Hensen, C., 2002. Oceanographic control of biogenic opal and diatoms in surface sediments of the Southwestern Atlantic. Marine Geology 186, 263–280.

Schmid, C., Garzoli, S.L., 2009. New observations of the spreading and variability of the Antarctic intermediate water in the Atlantic. Journal of Marine Research 67, 815–843.

Shepard, F.P., 1954. Nomenclature based on sand–silt–clay ratios. Journal of Sedimentary Petrology 24, 151–158.

Silveira, I.C.A., Schmidt, A.C.K., Campos, E.J.D., Godoy, S.S., Ikeda, Y., 2000. A Corrente do Brasil ao largo da Costa Leste Brasileira. Revista Brasilera de Oceanografía 48, 171–183.

Soto, M., Morales, E., Hernández-Molina, F.J., Veroslavsky, G., Tomasini, J., de Santa Ana, H., 2013. Procesos sedimentarios en el talud continental de Uruguay: una síntesis actualizada. (in press) DIRAC-Facultad de Ciencias.

Sverdrup, H.U., Johnson, M., Fleming, R., 1942. The Oceans. Their Physics, Chemistry and General Biology. Prentice Hall, New York.

Thomsen, H., 1962. Masas de agua características del Océano Atlántico (parte Sudoeste). Buenos Aires: Servicio de Hidrografía Naval, Secretaría Marina, Publication, H632 1–27.

Tomczak, M., Godfrey, J.S., 1994. Regional Oceanography: An introduction. Pergamon Press.

Urien, C.M., Ewing, M., 1974. Recent sediments and environment of southern Brazil, Uruguay, Buenos Aires, and Rio Negro continental shelf. In: Burk, C.A., Drake, C.L. (Eds.), The Geology of Continental Margins. Springer, New York, N.Y., pp. 157–177.

Urien, C.M., Martins, L.R., Martins, I.R., 1980a. Evolução geológica do Quaternário do litoral atlântico uruguaio, plataforma continental e regiões vizinhas. Notas Técnicas, 3. CECO/URFGS 7–43.

Urien, C.M., Martins, L.R., Martins, I.R., 1980b. Modelos deposicionais na plataforma continental do Rio Grande do Sul (Brasil), Uruguai e Buenos Aires. Notas Técnicas, CECO/URFGS 3, 13–25.

Urien, C.M., Paterlini, M., Berbeglia, Y., Jimenez, M., 2012. La Cuenca del Plata: un tema para pensar, II Workshop Antropicosta Iberoamerica, Montevideo, Uruguay. 40.

Violante, R.A., Paterlini, C.C., Costa, I.P., Hernández-Molina, F.J., Segovia, L.M., Cavallotto, J.L., Marcolini, S., Bozzano, G., Laprida, C., García Chapori, N., Bickert, T., Spieß, V., 2010. Sismoestratigrafia y evolucion geomorfológica del talud continental adyacente al litoral del este bonaerense, Argentina. Latin American Journal of Sedimentology and Basin Analysis 17, 33–62.