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SEDIMENTARY PROCESSES IN THE HEAD OF THE CABO POLONIO MEGA SLIDE CANYON (SOUTHWESTERN ATLANTIC MARGIN OFF URUGUAY)

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ABSTRACT

The Southwestern Atlantic margin is characterized by several canyon systems incised on a huge contourite depositional system associated with the interaction of strong Antarctic water masses with the seafloor. So far, however, only one mega slide canyon (Cabo Polonio) has been described in the Uruguayan continental slope. In this work, sedimentary processes dominating the head of this mega slide canyon are described and interpreted based on the analysis of the composition (texture and fossils) and distribution of widespread gravel along its head and thalweg. This information is integrated with acoustic (multibeam and seismic) and hydrological data. Results suggest that the evolution of the head of the canyon presents retrogressive erosion related to debris and turbidity flows. This erosion is ongoing and/or has been active during the recent past and contourite deposits are involved in headwall erosion. The pathway of gravel along the canyon and the thalweg was reconstructed. The strong flow of the South Atlantic Central Water, and its interaction with the Antarctic Intermediate Water, dominates the modern hydrology, promoting highly energetic conditions enhancing headwall erosion. This work contributes to a better understanding of the sedimentary processes connected to an mega slide canyon in the upper slope off Uruguay and located in the northernmost distribution of the South Atlantic Contourite Depositional System.

INTRODUCTION

Submarine canyons represent one of the most erosive features on earth and are major players in the transport of sediments towards the deep sea. In particular, mega slide canyons cover broad areas and pose a potential hazard for seabed infrastructure (Masson *et al.*, 2006). In this context, much concern relies on the active or inactive stages of these canyons and their relationship to along-slope processes.

In general, the knowledge of sediment gravity flows related to submarine canyons arose from deep-sea fans and thalweg deposits. However, the configuration of canyon heads and their deposits record important information regarding the sedimentary processes involved in canyon dynamics, including knowledge of back-stepping erosion (Mulder *et al*., 2012). On the other hand, in deep open waters, coarse sediments (i.e., cobbles to boulders) are scarce and associated with highly energetic environments including canyon settings (Shanmugam *et al.,* 1994; Stow and Mayall 2000; Rebesco *et al.,* 2014). Even though few deposits have been analyzed, these coarse sediments can provide important information regarding the sedimentary processes involved in their distribution (Shanmugam *et al*., 1994; Bozzano *et al*., 2011).

The Southwestern Atlantic margin is characterized by several canyon systems incised on contourite deposits mainly along the Argentinean and Uruguayan margins (Ewing *et al*., 1964; Lonardi and Ewing 1971; Hernandez-Molina *et al*., 2009, 2015; Violante *et al*., 2010; Preu *et al*., 2013) and Brazilian margins (Kowsmann and Costa, 1979; Viana, *et al*., 1998, 2002, 2007; Gonthier et al., 2003). Along the former, a huge Contourite Depositional System (CDS) (Hernandez-Molina *et al*., 2009, 2015) is associated with the interaction of strong Antarctic water masses with the seafloor (Hernandez-Molina *et al*., 2009, 2015; Preu *et al*., 2013). In this setting, canyons are mainly slope-derived features and different evolutionary stages have been recognized (Lastras *et al*., 2011; Krastel *et al*., 2011) and their interaction with along-slope processes described (Lastras *et al*., 2011; Violante *et al*., 2010; Preu *et al*., 2013; Voigt *et al*., 2013). However, to date, only one mega slide canyon (Cabo Polonio mega slide canyon) has been described in the Uruguayan continental slope (Franco-Fraguas *et al*., 2014; Hernandez-Molina *et al*., 2015).

This feature spans more than 4000 km^2, exemplifying large-scale features associated with downslope processes, and does not present a conspicuous connection to continental shelf channels (Hernandez-Molina *et al*., 2015). Its location coincides with the northernmost distribution of the Southwestern Atlantic CDS and hence contrasting sedimentary regimes dominate to the south and north of its location (Franco-Fraguas *et al*., 2014; Hernandez-Molina *et al*., 2015). Its head presents an amphitheater-like morphology and presents a wide sand lag-deposit in its southern flank (Franco-Fraguas *et al*., 2014) where contouritic deposits dominate (Hernandez-Molina *et al*., 2015). Hence, it arises as an important morphological feature to better understand the processes related to mega slides as well as the interplay between deep sea gravitational and contouritic sedimentary processes.

In this work, we describe the environmental setting of the head and thalweg of the Cabo Polonio mega slide canyon and interpret the processes involved in this distribution. It is based on the composition and distribution of the surface sediments (gravel and fine sediments) assisted by bathymetrical (multibeam) and geophysical (acoustic) data. The evidences presented suggests that the head of the mega slide canyon exhibits active retrogressive headwall erosion and that upper-slope contouritic sediments are implicated in this erosion.

PHYSICAL SETTING

The Southwestern Atlantic Margin (SAM) is a typical example of a passive margin, presenting one of the widest shelves in the world. It was formed during the opening of the South Atlantic in the early Cretaceous (Hinz *et al*., 1999; Franke *et al*., 2007). Post rifting Tertiary tectonic activity was generally considered insignificant in the study area (Hinz *et al*., 1999; Schnabel *et al*., 2008). However, recent historically documented intraplate seismicity aligned along the Martín García fracture zone or “Salado Transfer Zone” (i.e., an inherited extensional tectonic lineament striking NW-SE, Fig. 1) suggests present-day tectonic activity in the area, which is likely in a state of active subsidence (Benavídez Sosa 1998).

In the SAM, large-scale oceanographic processes are closely associated with shelf circulation (Matano *et al*., 2010). In the deep ocean and at the Brazil-Malvinas confluence, the southward-flowing Brazil Current (BC), displacing subtropical water masses, encounters the northward-flowing Malvinas Current (MC), that displaces Antarctic water masses. These water masses are moved offshore as part of the South Atlantic Subtropical Gyre (Schmid and Garzoli 2009). On the continental shelf and along the Subtropical Shelf Front (the shelf extension of

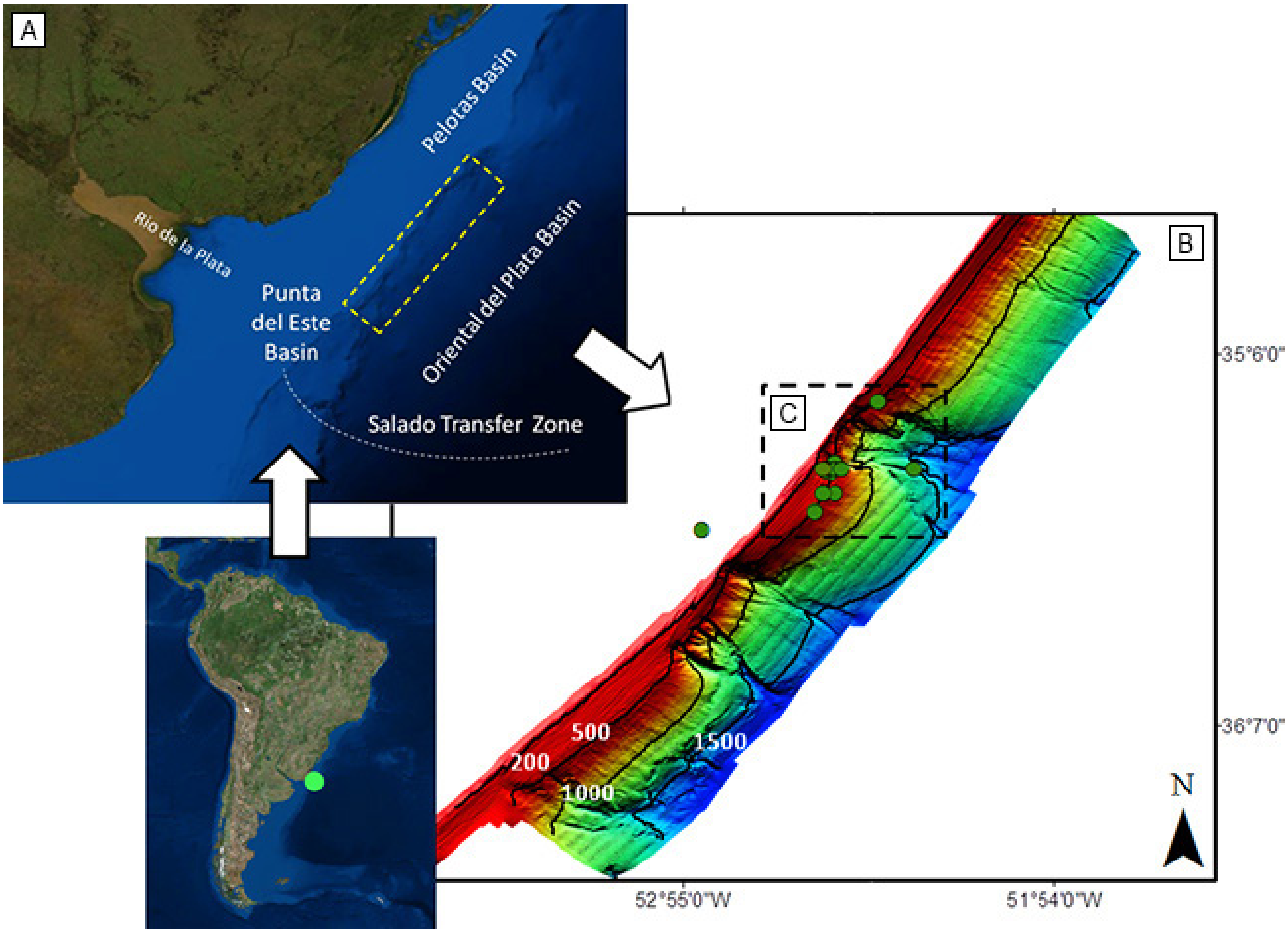

Figure 1. (a) Regional geological context showing the dominant ocean basins and the Salado transfer zone discussed in the text. Modified from Soto *et al.* (2011). (b) Detailed morphology of the Uruguayan margin after Franco-Fraguas *et al.* (2014). (c) Study area showing sampling sites associated to the mega slide canyon.

the Brazil-Malvinas confluence), the southward-flowing Subtropical Shelf Waters mixes with the northward-flowing Subantarctic Shelf Waters (Piola *et al.*, 2008). These water masses are diluted by the continental runoff from the Rio de la Plata and the Patos Lagoon.

On the continental slope, a Contourite Depositional System extends along the Argentinean and Uruguayan margin related to the constant flow of strong Antarctic currents and the interfaces within water masses since the middle to late Miocene (Hernández-Molina *et al.*, 2009; Violante *et al.*, 2010; Hernández-Molina *et al.*, 2015). Submarine canyon systems are also distinctive features of the region and were first reported by Lonardi and Ewing (1971) between 35° and 38°S. Submarine landslides and transport by sediment gravity flows were recently reported from the deep Uruguayan and Argentine margins (Henkel *et al.*, 2011; Krastel *et al.*, 2011; Preu *et al.*, 2013; Ai *et al.*, 2014; Hernández-Molina *et al.*, 2015). The northernmost submarine canyon system, the Rio de la Plata canyon system, recently mapped with bathymetric high-resolution methods, reaches the study area (Franco-Fraguas *et al.*, 2014; Hernández-Molina *et al.*, 2015). This canyon system cuts sequences deposited from Miocene-Pliocene to the present (Hernández-Molina *et al.*, 2015; Soto *et al.*, 2015).

STUDY AREA

The study area is located in the upper slope of the Uruguayan margin (Fig. 1). The detailed characterization of the hydrography, morphology and surface sedimentation of the study area is presented in Franco-Fraguas *et al.* (2014) and extended in

Franco-Fraguas *et al*. (2016). The description and interpretation of the contourite system can be found in Hernández-Molina *et al*. (2015). The shelf break occurs at ca. 180 m. A clear latitudinal change characterizes the slope configuration and its limit coincides with the Cabo Polonio mega slide canyon; the southernmost region presents a smoother slope (i.e., 2.5°, Franco-Fraguas *et al*., 2014) associated with the development of the northernmost distribution of the Argentinean Contouritic Depositional System (Hernández-Molina *et al*., 2015). Northwards, a steeper slope (i.e., 4.5°, Franco-Fraguas *et al*., 2014) marks a prograded slope (Hernández-Molina *et al*., 2015), where down-slope processes dominate. Nowadays, these processes have presumably suffered a southward shift with respect to glacial sedimentation restricting sedimentation related to contourite features to the south (Franco-Fraguas *et al*., 2016). Aggregated and isolated mound morphologies with associated deep-sea coral reefs dominate the upper slope of the northern region (Carranza *et al*., 2012; Franco-Fraguas *et al*., 2014). According to Hernández-Molina *et al*. (2015) in the Uruguayan margin widespread mass transport deposits dominate the lower slope and transition with the continental rise and especially in the northernmost region of the Rio de la Plata Transfer System and Pelotas sector, indicating a greater degree of margin instability in those regions.

The submarine canyon analyzed here (Fig. 1) was originally referred as Canyon A by Franco-Fraguas *et al*. (2014), and later named Cabo Polonio mega slide canyon by Hernández-Molina *et al*. (2015). It has a mean width of 15 km, its head is incised at ca. 190 m in the continental shelf and exhibits an amphitheater-like morphology with several tributary basins. Its main axis is oriented W–E. Its southern slope is steeper and a hanging secondary channel occurs below the 1300 m isobath. The northern slope is oriented parallel to the main channel while the southernmost one presents NW-SE direction (Franco-Fraguas *et al*., 2014).

MATERIALS AND METHODS

The characterization of the southern head of the Cabo Polonio mega slide canyon was attained with acoustic data obtained during the B/O Miguel Oliver cruise in austral summer, 2010. Hydrological data previously published assisted in the environmental interpretation. During that survey, a high resolution, large-scale sampling, was performed during a joint research cruise by the Dirección Nacional de Recursos Acuáticos (DINARA, Uruguay), the Secretaría General del Mar (SGM, Spain) and the Instituto Español de Oceanografía (IEO, Spain).

Acoustic data were acquired using two hull-mounted systems, namely a Kongsberg-Simrad EM 302 multi-beam swath-bathymetry system and a Topographic Parametric Sonar (TOPAS) PS 18 sub-bottom profiler. Swath data were processed through the removal of anomalous pings and gridded at cell sizes of 50 m using Kongsberg-Simrad NEPTUNE software. Soft sediment data were obtained with a Mega box-corer (see Franco-Fraguas *et al*., 2014). Rock fragments were obtained by means of two different sampling equipments: a) incidental retrieval of rock fragments entangled in traps used in the red crab *Chaceon notialis* fishery during 2009 and 2012 collected by onboard observers from the national fisheries authority (DINARA) and b) hard-duty rock dredge targeting specific geomorphologic items (i.e., previously identified mounds with deep-sea corals) on board of the B/O Miguel Oliver (Carranza *et al*., 2012; Franco-Fraguas *et al*., 2014). Distribution maps of sediments were generated using a Geographic Information System (GIS).

All sedimentary fragments were grouped and classified according to apparent visual similarities. Subsequently, rocks that present textural evidence relevant for this work were analyzed. Sedimentary rock fragments were described focusing on texture, reaction to hydrochloric acid for the presence of carbonate cement, and degree of consolidation. Observation of biological material aided in the interpretation of the above-mentioned issues. In particular, the identity, chronology, ecology (i.e., known habitat of observed species) and taphonomic information stored as preserved biogenic material and/or imprints of hard parts (e.g., for mollusks) were analyzed and related to hypotheses on provenance and features of the environmental settings. Additionally, the distribution of igneous and metamorphic rock samples recovered in the study area assisted in the interpretation. Petrologic analysis of these fragments will be presented herein.

RESULTS

A detailed view of the southern head of the

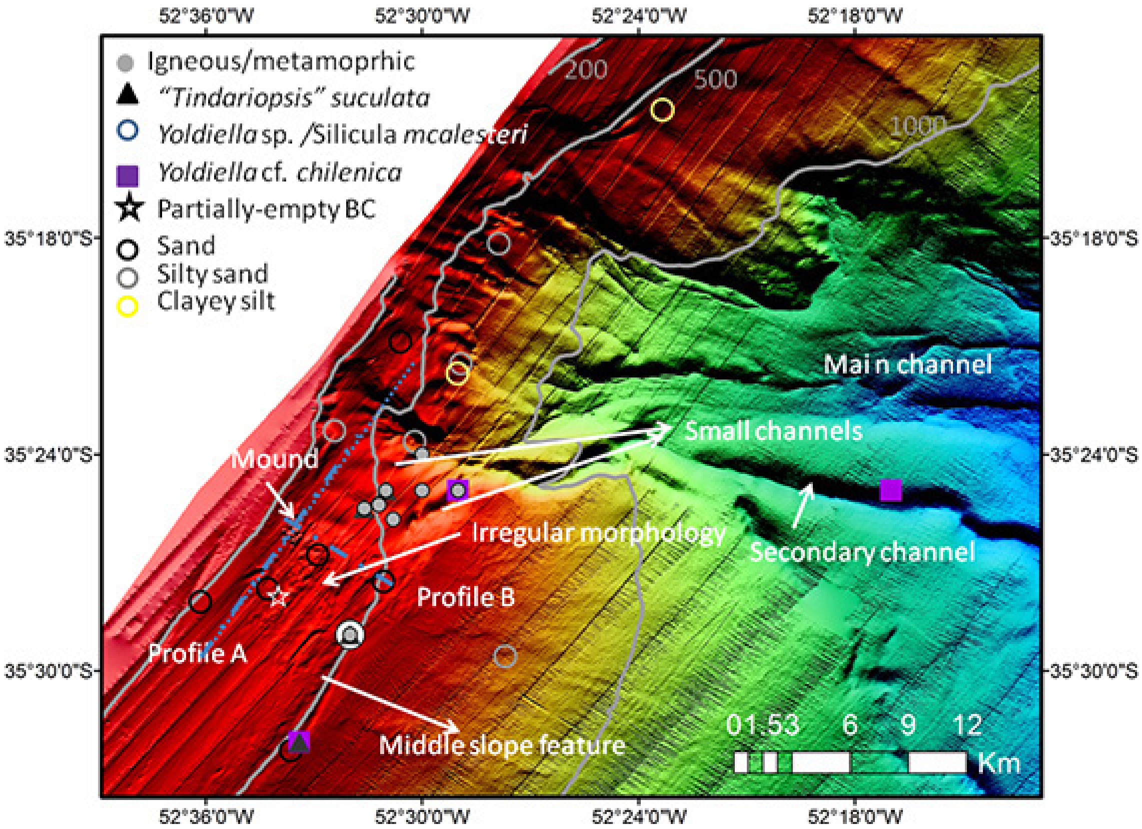

Figure 2. Morphological configuration of the mega slide canyon showing main morphological features, the distribution and composition of fine and coarse sediments (showing igneous/metamorphic and biogenic-related composition of sedimentary rock fragments), and the location of acoustic profiles. Note that the extension of the bathymetrical profile A (thin dashed line, Fig. 3 inside the picture) is longer than the seismic profile (coarse dashed line, Fig. 3).

mega slide canyon allowed identifying a complex configuration and sediment cover. Multibeam coverage revealed a hummocky morphology between the 250 and 550 m isobaths and an aggregated mound (mean diameter of 300 m; Carranza *et al.*, 2012) distributed at its shallower limit (Fig. 2). Two relatively small channels extend towards the canyon secondary channel. Downslope and along the ~ 500 isobaths an erosive feature occurs parallel to the isobaths and extends continuously from the south (Fig. 2).

Two seismic profiles that intercept within the aggregated mound location show the subsurface sedimentation. Despite the low quality of the original records, three main sedimentary units were observed. The SW-NE acoustic profile (profile A, parallel to the slope isobaths, Fig. 3a) shows a succession of facies towards the edge of the canyon head. It revealed an area with low penetration of acoustic reflectors (i.e., acoustic basement, AB) that cuts units presenting relatively parallel reflectors; U1 to the west, and U2 and U3 to the east, extending toward the canyon edge. The acoustic basement coincides with the location of the hummocky morphology registered with multibeam data.

Unit U1 lies over the acoustic basement in a channel-like feature and its internal reflectors vary from channel-fill to parallel morphologies. Its upper termination is concordant with the present sea bottom. On the other hand, unit U2 lies in concordance with AB and presents parallel, inclined reflectors. Its upper termination is partially toplapped with the sea bottom, as well as erosionally truncated by unit U3, thus indicating an interruption of deposition. Finally, unit U3 downlaps onto the acoustic basement and its internal reflectors are parallel and inclined.

According to the NW-SE profile (profile B, perpendicular to the slope isobaths, Fig. 3b) and based on multibeam data, the above described seismic facies seem to extend seaward along the canyon head. It

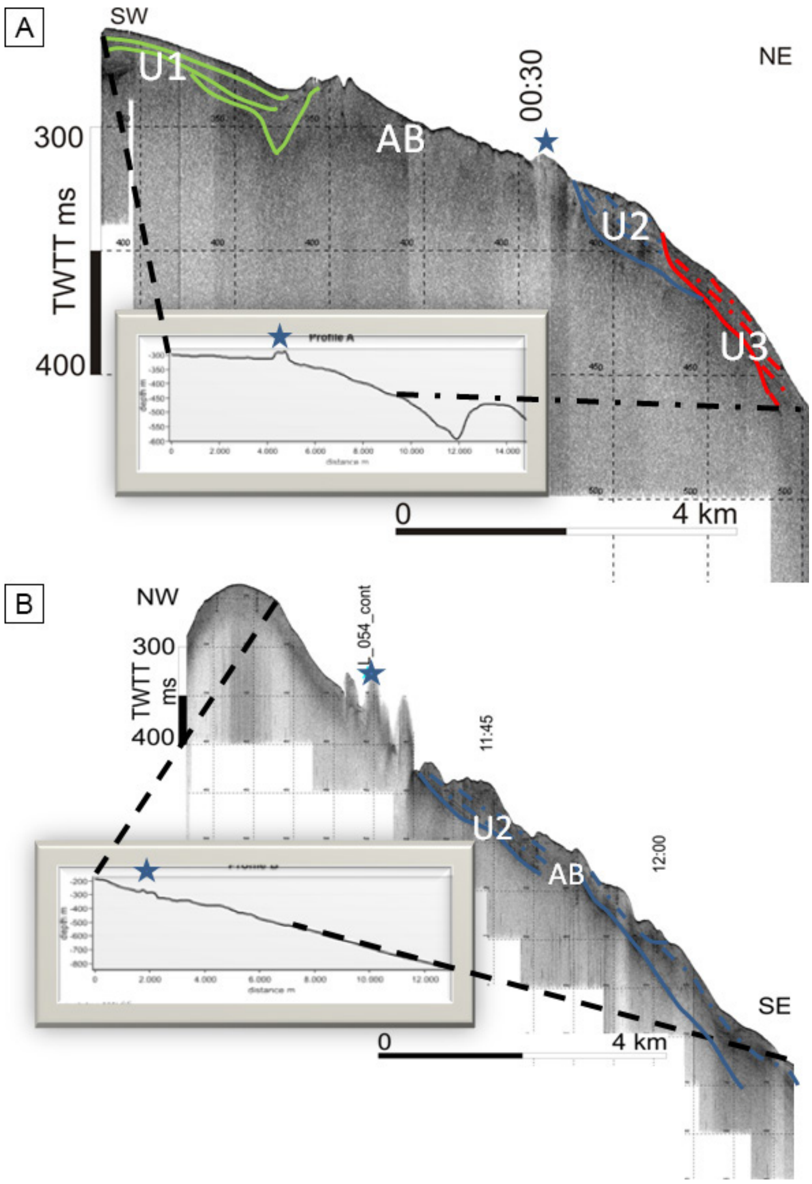

Figure 3. (a) Vertical SW-NE profile (profile A in Fig. 2) and (b) NW-SE profile (profile B in Fig. 2) showing seismical and bathymetrical (inside) profiles with interpreted units. Intersection (star) between seismic profiles coincides with the agglomerated mound and in (b) it shows acoustic plumes.

revealed that inclined and parallel reflectors are present in the down slope prolongation of U2 and are intercepted by acoustic plumes and/or side echoes next to the aggregated mound location. The downslope distribution of U2, further suggests that in some places AB cuts U2. An irregular morphology is evident in surface AB and U2 (profile A and B) in accordance with the hummocky morphology registered with multibeam data. The SW-NE profile presents a mean slope of 1.7° towards the edge of the canyon, although a steep inclination occurs off the aggregated mound coinciding with AB. A mean slope of 2.3° characterizes the NW-SE profile (Fig. 3a,b).

Silty sands dominate westward from the canyon head coinciding with the location of U1, while well-sorted to moderately sorted sands characterizes surface sediments in the hummocky morphology and AB (Fig. 2). In the latter region, two additional box-corers were sampled (Fig. 2); the first was retrieved empty and the second recovered little material composed of both fine (gray and stiff) and coarse sandy sediment.

Rock fragments (12 sampling stations, 107 pieces) were recovered mainly canyon-wards from AB (i.e., NE, nearby the two small channels) as well as downslope in the middle slope erosive feature (Fig. 2). In addition, inside the canyon, rock fragments were retrieved in the secondary channel, whereas fine-grained (clayey silts) sediments were recovered in shallower regions (Fig. 2). In all canyon stations, igneous-metamorphic and sedimentary rock fragments were retrieved. Exceptions included the canyon thalweg, where only sedimentary rock fragments were collected. The number of rocks recovered per station varied from one to twenty-one fragments (mean of 8 rocks per station). From a total of 107 fragments, 27 fragments (24.5%) were igneous or metamorphic and 80 fragments (75%) were sedimentary.

Analyzed fragments presented different degree of consolidation, texture and biological imprints and mainly consist of 1) carbonate cemented, partly-consolidated (i.e., stiff) mudstones, some with well-preserved shells of the bivalves *Yoldiella* cf. *chilenica* (Dall, 1908) (Bivalvia: Yoldiidae) and fragments of *Austrochlamys walosseki* Jonkers, 2003, (Bivalvia; Pectinidae) (14 fragments, Fig. 4a); 2) moderately-consolidated mudstones, some coated by a dark film, bioeroded and with shells and/or molds of *Yoldiella* cf. *chilenica* (9 fragments, Fig. 4b); 3) moderately-consolidated sandstones containing molds of the nuculanoidean bivalves *Yoldiella* sp. and *Silicula mcalesteri* Allen and Sanders, 1973 and of "*Tindariopsis*" *sulculata* (Couthouy, 1852) (2 fragments); and 4) well-consolidated sandstones with molds of "*Tindariopsis*" *sulculata* (3 fragments, Fig. 4c). In general, all fragments present angular shapes (Fig. 4).

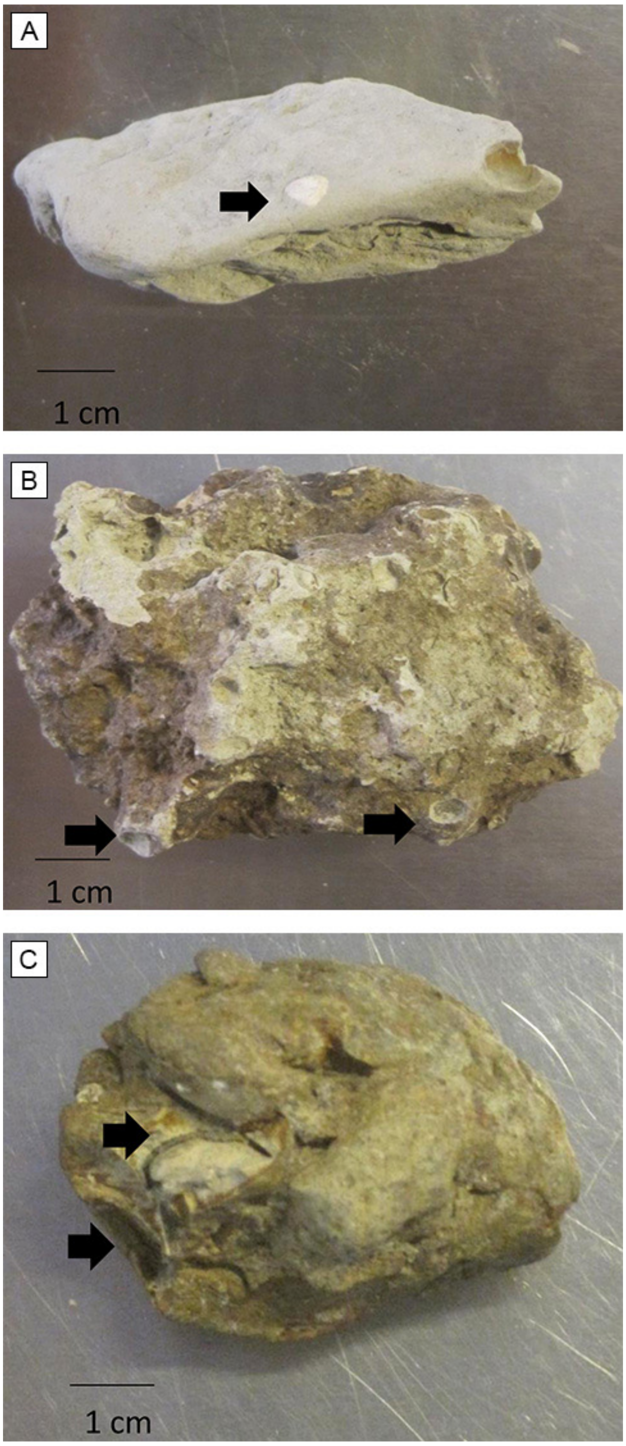

Figure 4. Examples of rock fragments investigated in this study. (a) Partially-consolidated fragment with shells of *Yoldiella* cf. *chilenica* (arrow). (b) Moderately-consolidated fragment with molds of *Yoldiella* cf. *chilenica* (arrow) and evidencing the dark film coverture. (c) Well-consolidated fragment with molds of "*Tindariopsis*" *sulculata* (arrow).

DISCUSSION

Depositional conditions

Facies distribution. The current edge of the canyon head is presumably located in AB as indicated by the change in slope (i.e., steeper slope) towards the canyon. The irregular configuration of AB presumably represents mass transport deposits. However, its high amplitude signal suggests that it may represent ancient (Miocene?) sediments located near the surface (Muñoz *et al*., 2012) or surface hard bottom related to hydrodynamic processes (Roberts *et al*., 2006). Seismic reflectors of units U1, U2 and U3, on the other hand, points to depositional facies.

In the SW, silty sands likely represent the lithology of U1. In the canyon edge, the lack of penetration of one box corer supports the presence of patchy, relatively hard exposed sediments presumably of AB. Moreover, the content of the relatively empty box corer suggests that in some places a stiff facies is located near outcrops. Hence, besides AB this stiff sediment could also have inhibited box corer penetration and consequently, could reflect early diagenetic processes (Mulder *et al*., 2012) presumably associated to U2. A thin sandy facies accommodates between these exposed consolidated deposits.

In the Uruguayan upper slope, igneous and metamorphic fragments have been recently registered nearby carbonate mounds and canyon heads and have been related to iceberg rafting and/or gravity processes during glacial times (Franco-Fraguas *et al*., 2014). In the study area, igneous and metamorphic rock fragments are similarly distributed with sedimentary rock fragments. This suggests that the sedimentary fragments could have been transported by the same glacial mechanisms. However, the characteristics of the sedimentary rock fragments here analyzed suggest they are related to erosion from nearby outcrops and hence, represent local sedimentary processes.

Composition and distribution of sedimentary fragments. The general appearance of partly consolidated fragments including the low degree of lithification suggests autochthonous sediments eroded from nearby outcrops of relatively recent age. Indeed, the occurrence of *Yoldiella* cf. *chilenica* shells within these fragments suggests a late Pleistocene age for these outcrops. This species of *Yoldiella* differs from any other recorded as currently living in the area (Allen *et al*., 1995), but is similar to cold water (Magellanic) species such as *Y. chilenica* (e.g., Cardenas *et al*., 2008), which may have been distributed northwards of its present range during Pleistocene glacial times. This is further supported by the presence of associated *Austrochlamys walosseki*, an extinct and cold water species from the Argentine shelf and the Campbell plateau with a tentative age ranging from late Pliocene to ?Holocene (Jonkers 2003; Beu and Taviani 2014). The distribution and texture of these fragments (i.e., resembling the stiff gray fine sediment collected within the hummocky morphology) suggest its relation with exposed U2 and indicated that this unit is also exposed in the scarp environment.

The composition of moderately consolidated rocks, i.e., grain size and *Yoldiella* cf. *chilenica* molds, resembles that of partly consolidated fragments recovered in similar locations. However, moderately-consolidated fragments present an external appearance (i.e., dark crust, bio-erosion) that indicates long exposure to seawater environmental conditions. This suggests that they correspond to the same geological unit but that have suffered contrasting diagenetic processes. An autochthonous origin is supported by the angular shape of these fragments. According to Noe *et al*. (2006), in the deep-water carbonate mounds of the NE Atlantic, Pleistocene sediments that have been influenced by early diagenetic processes within subsurface marine sediments have been exposed to the action of vigorous currents and subsequently increase their cementation, becoming hard grounds. This mechanism includes the pumping of carbonate ions from saturated seawater towards the exposed sediments enhancing carbonate cementation. After consolidation, these sediments are exposed to bio-erosion, incrustation by local fauna and are coated by a Fe-Mn film (Noe *et al*., 2006). As the consolidated fragments described in this study show these attributes, we interpret them as products of the longer exposure of patches of late Pleistocene stiff unit (U2) to strong bottom current activity. These patches of the more consolidated U2 unit are thereafter called U2'.

Currently, *Yoldiella* sp. and *Silicula mcalesteri* are distributed in slope environments of the study area (Allen and Sanders 1973; Allen *et al*., 1995; Scarabino, pers. obs.) whereas "*Tindariopsis*" *sulculata* is associated with the continental outer shelf (Scarabino *et al*., 2016). The association of these species to different environments, therefore, suggests that sandstones containing these imprints may correspond to different geological units. Well-consolidated rocks containing "*Tindariopsis*" *sulculata* resemble ancient (Miocene?) sediments especially due to the occurrence of molds rather than shells. However, the fact that this is a recent species and that it also appears in moderately-consolidated rocks also suggests that these fragments may correspond to a more recent unit. It does, however, indicate also a cold water environment as this species has a Magellanic distribution that extends off Rio de la Plata, associated with Subantarctic waters (Scarabino *et al*., 2016). In this case, its main sandy composition could have facilitated carbonate pumping (Noe *et al*., 2006) explaining the high degree of consolidation of fragments. These characteristics hence indicate, on one hand, transport due to gravitational processes from the outer shelf and, on the other hand, its association with AB. If this is correct, strong surface cementation could explain the high amplitude signal of unit AB.

In sum, we interpreted that unconsolidated silty sands (U1) dominate in the SW, whereas fine, stiff, partly-consolidated Pleistocene sediments (U2) dominate in the NW. Finally, the edge of the canyon and the scarp environmen are dominanted by both Pleistocene sediments from fine moderately-consolidated (U2') and sandy consolidated (AB) facies (Fig. 5). The edge of the canyon is further covered by a sheet of unconsolidated sands and igneous, metamorphic and sedimentary rock fragments eroded from U2, U2' and presumably from AB, and dominate the surface of U2 and U3, as well as inside the canyon and below the scarp environment (Fig. 5). These conditions indicate that the head of the Cabo Polonio mega slide canyon is characterized by a highly energetic environment where Pleistocene Antarctic-originated sediments are exposed, consolidated, eroded and displaced along the head environment and towards the canyon thalweg.

Sedimentary processes in the southern head of the mega slide canyon and canyon thalweg

In the Southwestern Atlantic margin, canyon complexes connected directly to main rivers during glacial stages are find in the southeastern Brazilian margin (e.g., the Paraiba River connected to Almirante Camara canyon according to Kowsmann and Costa, 1979). Unlike its northern counterpart, canyons located in the Uruguayan and Argentine margin, including the Cabo Polonio mega slide canyon, do not have any obvious connection to modern or ancient continental drainage channels and hence, represent slope-originated canyons (Krastel *et al*., 2011; Hernández-Molina *et al*., 2015). In this context, the amphitheater-like morphology of the mega slide canyon suggests upslope erosion for the canyon dynamics. This model assumes that the first failure occurred in the most downslope position, and seems to erode upward due to repeated collapses at the canyon head. This forces the canyon to cut-in retrogressively headward and to eventually indent the shelf break (Twichell and Roberts 1982; Farre *et al*., 1983). Debris flow deposits are characterized by a reverse grading and floating mudstones and, excluding the case of hydroplaning, are capable of seafloor erosion (Shanmugam, 2000). Turbidity currents, on the other hand, can erode pre-existing sediments and carve channels (Shanmugam, 2000; Piper and Normark, 2009). Thereafter, described conditions appoint to headward erosion dominated by the action of debris flows and turbidity currents suggesting the action of retrogressive erosion in the mega slide canyon. The similar properties of rock samples recovered in the head of the canyon and in the canyon thalweg evidenced the path of sediment gravity flows linking regions within the canyon. In marine environments dominated by fine sediments, traps used in the red crab *Chaceon notialis* fishery could eventually displace up to a few centimeters of surface sediment (Yamandu Marin, personal communication). This indicates that thalweg clasts could eventually be overlaid by a thin hemipelagic drape lost while retrieving the traps. Thereafter, this evidenced that sediment gravity flows are ongoing and/or have been active during the recent past (Krastel *et al*., 2011; Mulder *et al*., 2012).

Regionally, ongoing retrogressive erosion of canyon headwall dominates a small canyon (Krastel *et al*., 2011) located southward from the Cabo Polonio mega slide canyon. In opposition, the Mar del Plata canyon, located southward from this small canyon, does not show clear indications of relatively recent failures close to the head region (Krastel *et al*., 2011). Hence, these authors argue that, even though it presents an amphitheater-like configuration, this canyon represents a mature structure without significant headward erosion. A possible explanation is the location of the head region on the broad and flat contouritic Ewing terrace, which might have stopped, or significantly slowed down, the further headward erosion of the canyon (Krastel *et al*., 2011). The mega slide canyon, on the contrary, is incised in the continental shelf and along a smooth slope erosional contouritic surface located immediately landward from the northernmost prolongation of the Ewing terrace (Hernández-Molina *et al*., 2015). This could hence provide sediment instability promoting headwall erosion. According to these authors, these along-slope sediments were deposited during glacial times, mainly by the influence of Antarctic Intermediate Waters, when the Brazil-Malvinas confluence was located in its northernmost position. In fact, the widespread occurrence of rock fragments containing fauna of cold environments evidenced that eroded deposits were deposited by Antarctic water masses flowing northward in the Malvinas current. Eroded deposits thus represent contouritic sediments of the South Atlantic, providing evidence of the erosion of contourite deposits involved in

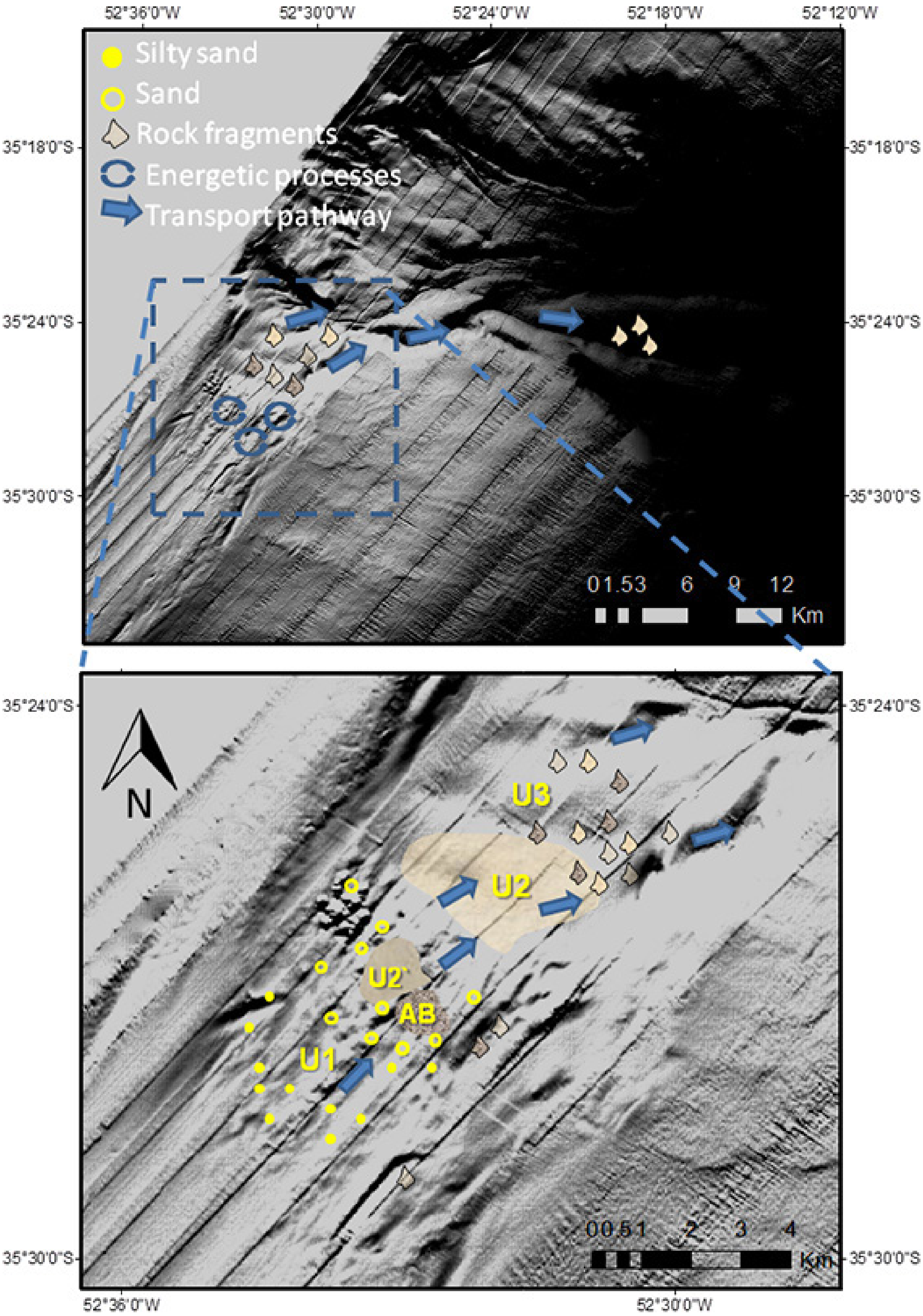

Figure 5. Schematic diagram showing the distribution of acoustic facies and sediment facies, together with the interpreted sedimentary processes. SW of the canyon edge unconsolidated silty sands represent the lithology of unit U1. Coinciding with the irregular morphology of the canyon edge, a thin unconsolidated sandy facies accommodates within exposed Pleistocene consolidated (unit AB) and moderately consolidated (U2´) deposits. Canyonward, Pleistocene partly-consolidated sediments (unit U2) and U3 sediments are covered by igneous/metamorphic and sedimentary rock fragments eroded from U2, U2'and AB. The color of sedimentary rock fragments is related to the corresponding facies (i.e., AB, U2 and/or U2'). Highly energetic processes (i.e., exposition, consolidation and erosion of sediments) in the canyon head and the pathway of sedimentary gravel along the mega slide canyon are shown.

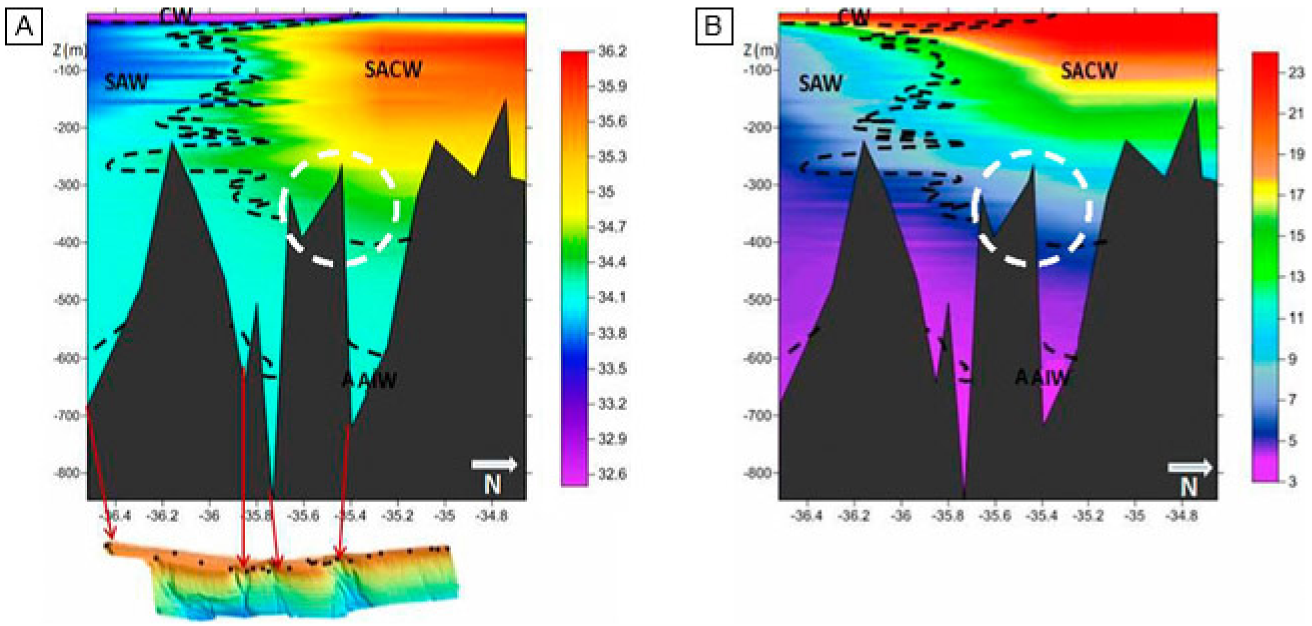

Figure 6. Water masses distribution related to the location of the Cabo Polonio mega slide canyon (circle) after (A) salinity and (B) temperature *in situ* data. Color scale bar represent salinity units (A) and Celsius degrees (B). Modified from De Melo *et al.* (2014). Note that the study area (circle) is influenced by the southward flowing Brazil current displacing South Atlantic Central Water (SACW) and by its interface with Antarctic Intermediate Water (AAIW). CW: Coastal Waters; SAW: Subantarctic Water.

canyon evolution.

Nowadays, the study area is dominated by the strong flow of southward-flowing Brazil current while detaching from the continental shelf in the Brazil-Malvinas confluence zone, and by its interface with the Antarctic Intermediate Water (de Mello *et al.*, 2014; see Fig. 6). Northward of the mega slide canyon, the strong flow of the Brazil current has been related to the transport of coarse shelly shelf sediments towards the upper slope (Franco-Fraguas *et al.*, 2014). This current could be also involved in the transport of shelf sands towards the canyon head taking advantage of its configuration and further enhancing the described energetic processes (i.e., exposure, cementation and erosion). According to Hernández-Molina *et al.* (2015), in the study area, Antarctic Intermediate Water is represented by a narrow band of northward flowing water dominating the 500 isobaths while the recirculated Antarctic Intermediate Water, flowing southward, dominates below. This interface between water masses as well as intermittent currents (i.e., eddies, Rebesco *et al.*, 2014) associated with the Brazil-Malvinas Confluence zone (Boebel *et al.*, 1999) could enhance the canyon head erosional setting. Hence, these modern conditions and the interplay with the canyon head configuration (Viana *et al.*, 2007) promote high energetic conditions at the canyon head, that together with preconditioning and triggering factors likely control sedimentary processes.

Preconditioning factors could include, besides contourite deposits (Laberg *et al.*, 2003), gas hydrates and fluid flows. Gas hydrates are widespread along the Uruguayan margin beyond the 500 m water depth (Tomasini *et al.*, 2011) and seeping fluid and/or gas discharge have been proposed to occur regionally mainly associated with mound structures (Carranza *et al.*, 2012). However, this remains speculative and more evidence is needed in order to evaluate these mechanisms. Triggering factors could include the dynamic stress imposed by seismic activity as proposed by Henkel *et al.* (2011) and Ai *et al.* (2014) in deep waters (>1500 m) of the Uruguayan slope. Indeed, Henkel *et al.* (2011) related slide deposits of recent age (<30 years) to the 1988 earthquake felt in the Río de la Plata basin, which had its epicenter only ~70 km southeast from the study area.

CONCLUSIONS

In this work, the composition and distribution of sediment gravel assisted by bathymetric, seismic and hydrographic data were used to characterize and interpret sedimentary processes in the head of the Cabo Polonio mega slide canyon. The canyon edge is dominated by patchy outcrops of Pleistocene mass deposits transported from the continental shelf and contouritic sediments transported from the south by Antarctic water masses during glacial times. Widespread gravel dominates the canyon head and thalweg. We interpreted that ongoing retrogressive erosion dominated the head of the mega slide canyon. Processes involved includes debris flows and turbidity currents, presumably triggered by seismic activity, and assisted by modern highly energetic conditions related to the Brazil current and its interaction with Antarctic Intermediate Water. Contouritic deposits are implicated in canyon erosion; we demonstrated that these deposits are exposed, further consolidated and eroded leaving loosed sedimentary and igneous/metamorphic gravel around the canyon head and transported towards the canyon thalweg.

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