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Tectonics of the Scotia–Antarctica plate boundary constrained from seismic and seismological data

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ABSTRACT

The plate boundary between the Scotia and Antarctic plates runs along the broadly E–W trending South Scotia Ridge. It is a mainly transcurrent margin that juxtaposes thinned continental and transitional crust elements with restricted oceanic basins and deep troughs. Seismic profiles and regional-scale seismological constraints are used to define the peculiarities of the crustal structures in and around the southern Scotia Sea, and focal solutions from recent earthquakes help to understand the present-day geodynamic setting. The northern edge of the western South Scotia Ridge is marked by a sub-vertical, left-lateral master fault. Locally, a narrow wedge of accreted sediments is present at the base of the slope. This segment represents the boundary between the Scotia plate and the independent South Shetland continental block. Along the northern margin of the South Orkney microcontinent, the largest fragment of the South Scotia Ridge, an accretionary prism is present at the base of the slope, which was possibly created by the eastward drift of the South Orkney microcontinent and the consequent subduction of the transitional crust present to the north. East of the South Orkney microcontinent, the physiography and structure of the plate boundary are less constrained. Here the tectonic regime exhibits mainly strike–slip behavior with some grade of extensional component, and the plate boundary is segmented by a series of NNW–SSE trending release zones which favored the fragmentation and dispersion of the crustal blocks. Seismic data have also identified, along the northwestern edge of the South Scotia Ridge, an elevated region – the Ona Platform – which can be considered, along with the Terror Rise, as the conjugate margin of the Tierra del Fuego, before the Drake Passage opening. We propose here an evolutionary sketch for the plate boundary (from the Late Oligocene to the present) encompassing the segment from the Elephant Island platform to the Herdman Bank.

1. Introduction

The present-day, left-lateral transcurrent boundary between the Scotia and Antarctic plates runs along the South Scotia Ridge, a slightly arched, broadly E–W trending system which is composed by a series of structural highs, some of which emerged to form islands, small basins, and deep troughs. Morphologically, it represents the southern margin of the Scotia Arc, the vast oceanic region of the Southern Hemisphere that connects the southern tip of South America with the Antarctic Peninsula. The morphology and structural framework of the South Scotia Ridge derives from a relatively long (since latest Oligocene) and complex tectonic history. It initiated with the deformation, stretching, and early separation of the former continental bridge between the southern South America and the northern Antarctic Peninsula, the formation of oceanic crust in the nascent Scotia plate, and the subsequent dispersion of the continental blocks in the periphery of the Scotia Arc, and now located along the northern and southern margins of the Scotia Sea.

In the last 20 years, several geophysical and geological studies have been performed by various international scientific institutions in this remote region, and a significant amount of data – mostly multichannel seismic reflection profiles – are now available and useful to analyze regionally the South Scotia Ridge and southern Scotia Sea. At the same time, permanent seismological instruments installed in and around the Scotia and Sandwich plates, and some international experiments with a local deployment of seismic arrays allow to better define large scale crustal features up to mantle depths, and to characterize low- and medium-size earthquakes. Most of these studies, however, have considered only limited segments of the Scotia–Antarctica plate boundary, and lack a complete and comprehensive analysis along the entire margin.

In this paper, we present a crustal and structural map of the southern edge of the Scotia Sea along most of its length, through the analysis of all existing data, integrated with previously unpublished seismic profiles. After a brief overview of the main tectonic events that led to the formation of the Scotia Arc in general, and the western Scotia plate in particular, we will present a description of the main morphological and structural features characterizing the segment encompassing the

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Elephant Island continental platform to the west and the Herdman Bank to the east. Particular emphasis will be given in the analysis of the different crustal nature of the geological elements that compose the South Scotia Ridge. Then, we will propose a schematic evolutionary history of the South Scotia Ridge from Oligocene to the present time, which takes into account the main tectonic lineaments identified, and the crustal characteristics of the different blocks and basin that make-up the margin, supported with information derived from seismological analyses.

2. General tectonic framework of the Scotia Arc

The Scotia Arc is composed by locally emergent, shallow continental banks and elongated depressions, which enclose the Scotia Sea (Fig. 1, top panel). To the east the Arc is bounded by a volcanic chain – the South Sandwich Islands – while to the west it opens to the south-easternmost Pacific Ocean. The largest basin within the Scotia Arc – the western Scotia Sea – was created during Oligocene and Miocene times at the now-extinct west Scotia ridge spreading

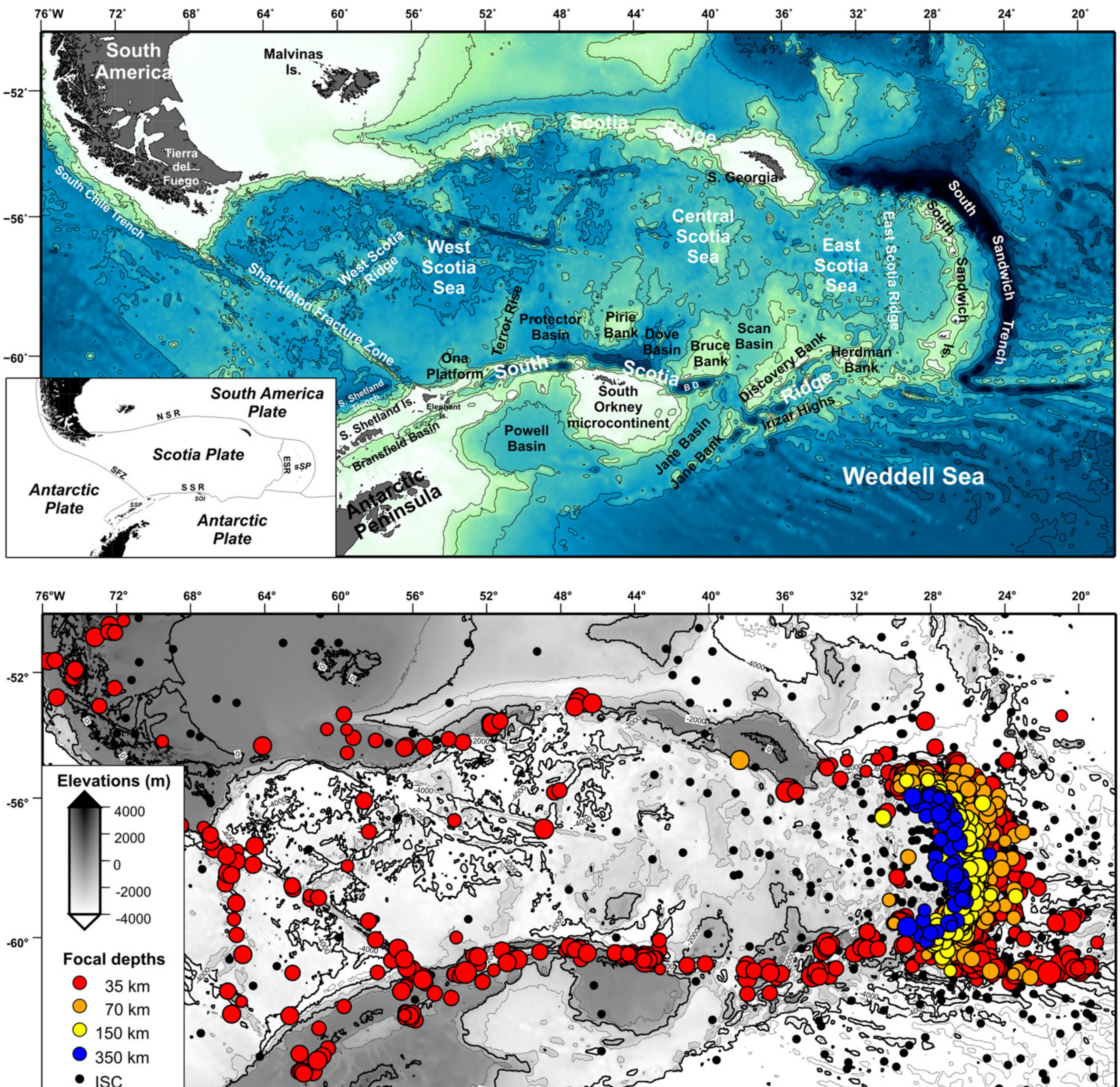


Fig. 1. (top panel) Physiographic map of the Scotia Arc, with the main geological provinces discussed in the text. Bathymetric contours from satellite-derived data (Smith and Sandwell, 1997). Box shows the present-day plate tectonic sketch for the Scotia Sea and surrounding regions. NSR, North Scotia Ridge; SSR, South Scotia Ridge; ESR, East Scotia Ridge; SFZ, Shackleton Fracture Zone; BD, Bruce Deep; SSP, South Shetland plate; sSP, South Sandwich plate. (bottom panel) Distribution of earthquakes in the Scotia Arc region. Epicenters and focal depths are obtained from EHB Bulletin (Engdahl et al., 1998). EHB shallow (red), intermediate (orange and yellow), and deep (blue), earthquakes are shown as circles. Smaller black circles represent earthquakes located by ISC (http://www.isc.ac.uk).

system (Eagles et al., 2005; Geletti et al., 2005; Lodolo et al., 2006). To the west lies the former Phoenix plate, now part of the Antarctic plate (Barker, 1982), limited to the east by the Shackleton Fracture Zone, a NW–SE trending oceanic fracture extending from the southernmost South America to the northern tip of the Antarctic Peninsula (Geletti et al., 2005; Kim et al., 1997; Livermore et al., 2004). The Drake Passage is the oceanic gateway between the Tierra del Fuego and the South Shetland Islands of Antarctica. The South Shetland block located to the west and east of the southern Shackleton Fracture Zone constitutes an independent element separated from the northern Antarctic Peninsula by the Early Pliocene, rift-related Bransfield Basin (Aldaya and Maldonado, 1996; Barker et al., 2003; Galindo-Zaldívar et al., 2004; Prieto et al., 1998). The evolution of this basin is interpreted to be associated with the roll-back of the subducting crust of the inactive Phoenix oceanic plate (Barker et al., 1991) at the South Shetland trench. The east Scotia Sea is an active back-arc basin behind the South Sandwich subduction zone that opens by sea-floor spreading at the East Scotia Ridge (Barker, 1972, 1995; Larter et al., 2003). The age and origin of the central part of the Scotia Sea are still enigmatic. Currently, the favored model in the literature for its formation is as a product of N–S directed sea-floor spreading that occurred in Miocene times (Hill and Barker, 1980), while Eagles (2010) proposes that it represents a Mesozoic fragment of oceanic crust trapped within the Scotia Arc.

The plate boundaries around the Scotia Arc are highlighted by the distribution of earthquake epicenters (Fig. 1, bottom panel). Most seismic activity takes place at the eastern part of the Arc, where the South Atlantic oceanic crust bends below the South Sandwich plate. All deep (>150 km) and most intermediate (70–150 km) events are concentrated here, while the other boundaries are mainly described by shallow events (0–70 km). Present-day relative motions, determined mainly from earthquake data (Forsyth, 1975; Giner-Robles et al., 2003; Pelayo and Wiens, 1989), and from global plate circuits (DeMets et al., 1990; DeMets et al., 1994; Thomas et al., 2003), show that in the Scotia Sea region the Antarctic plate is slowly moving (1.7 to 2.0 cm/year) easterly relative to the South America plate. These results are quite similar to recently-acquired GPS crustal data, combined with earthquake slip vector, transform azimuth, and spreading rates from the Scotia and South Sandwich plates (Smalley et al., 2007). The relative motion of these two major plates is presently partitioned along the left-lateral northern and southern boundaries of the Scotia plate (Pelayo and Wiens, 1989).

Several reconstructions for the Scotia plate have been proposed (Barker, 2001; Eagles et al., 2005; Maldonado et al., 2000, Lodolo et al., 2006, among the most recent), and it is suggested the reader refers to these works for a summary of the tectonic evolution of the region. This evolution has determined the formation and assemblage of several oceanic and continental/transitional crust elements. The south-western part of the Scotia plate is formed by some small basins (Protector, Dove and Scan basins) bounded by stretched and thinned continental/transitional crust blocks (Ona Platform, Terror Rise, Pirie Bank, Bruce Bank, Discovery Bank, Irizar Highs and Herdman Bank). The morphological barrier represented by the South Scotia Ridge extends from the Elephant Island platform to the Discovery Bank. Its western extremity is a complex region where the thickened oceanic crust of the Shackleton Fracture Zone is subducted along the northern boundary of the South Shetland continental block (Aldaya and Maldonado, 1996). Just to the east of the Shackleton Fracture Zone, the South Scotia Ridge comprises two narrow and broadly E–W elongated blocks that structurally pertain to the eastern sector of the South Shetland continental platform. East of the Discovery Bank, the southern edge of the Scotia Sea is structurally much less constrained because of the scarcity of geophysical and geological data. In the north-eastern part of the Antarctic Peninsula, lies the small oceanic Powell Basin, formed by the eastward drift of the South Orkney microcontinent (Barker et al., 1991; Coren et al., 1997; Eagles and Livermore, 2002; King and Barker, 1988; Rodríguez-Fernández et al., 1994, 1997), the largest continental fragment present along the South Scotia Ridge. The timing of Powell Basin opening is poorly constrained, mostly because the low amplitude of the magnetic anomalies. The proposed ages vary from 29 to 23 Ma (King and Barker, 1988), 30.5 Ma (Lawver et al., 1994), 27–18 Ma (Coren et al., 1997), and 32.1–23.3 Ma (Eagles and Livermore, 2002). The Jane Basin and Jane Bank are located at the south-eastern border of the South Orkney microcontinent. They constitute an arc–back-arc system related to the subduction of the oceanic crust of the Weddell Sea below the south-eastern margin of the South Orkney microcontinent (Barker et al., 1984). King and Barker (1988) proposed a 20–35 Ma time period for the opening of the Jane Basin, while Lawver et al. (1991) point to a range of 25–32 Ma. A more detailed study based on marine magnetic anomalies shows that spreading in the Jane Basin began around 17.6 Ma, and ended at about 14.4 Ma (Bohoyo et al., 2002). Gravimetric models (Bohoyo, 2007) suggest a quasi-normal oceanic crust flooring the Jane Basin and a transitional crust for the Jane Bank, possibly indicating a continental crust contaminated by basic rock intrusions.

3. Basins and highs located along the South Scotia Ridge

Here, we recall the main morphological and structural characteristics of the geologic elements that form the South Scotia Ridge, as revealed by published data. The two westernmost elevations (Ona Platform and Terror Rise) will be described later in a specific paragraph.

3.1. Protector Basin

Seismic data (Eagles et al., 2006; Galindo-Zaldívar et al., 2006) show that the central part of the Protector Basin is occupied by an oceanic crustal domain (~4000 m in water depth). The physiography shows a central N–S oriented ridge with flanks generally deepening toward the margins and whose basement cropping out in the northern area. In the Protector Basin, Hill and Barker (1980) identified linear magnetic anomalies indicating a period for spreading between 16 Ma and 13.1 Ma, although a period between 21 Ma and 17 Ma has been also proposed (Barker, 2001). More recently, Galindo-Zaldívar et al. (2006) suggest that the Protector Basin probably opened during the period comprised between 17.4 Ma and 13.8 Ma. Eagles et al. (2006), modeling the short magnetic anomaly profiles across the Protector Basin, and applying isostatic correction for its sedimentary fill, proposed a consistently older age for the opening (about 48.5–41 Ma).

3.2. Pirie Bank

Pirie Bank, located to the east of the Protector Basin, is a complex high that shallows at about 2000 m water depth. The central part of this bank hosts small basins bounded by normal faults, in a region of highly stretched continental crust (Galindo-Zaldívar et al., 2006). Modeled profiles for Pirie Bank have shown that the best fit is attained when an increase in densities with respect to the standard continental crust (2.67 g/cm^3), indicating the presence of transitional to oceanic crust in the thinned northern margin of the Pirie Bank. Moho depths are generally between 10 km and 13 km. Only in the central and southern part of this structural elevation, the Moho discontinuity reaches the deepest values of the region (14 km) in a sector of thinned continental crust (Galindo-Zaldívar et al., 2006).

3.3. Dove Basin

Dove Basin lies between the Pirie Bank and Bruce Bank and to the north opens to the abyssal part of the Scotia Sea. Only a single seismic profile is available up to now to analyze its structure (Eagles et al., 2006). A ridge elongated parallel to the axis of the basin, is found. The structural setting and seismic reflection character of the oceanic basement appear to be similar to those of Protector Basin. The seafloor in Dove Basin is slightly deeper than in Protector Basin and, once corrected for the presence of sediments, is consistent with an age range of 40–30 Ma (Eagles et al., 2006). Modeled magnetic anomalies show comparable ages ranging from ~41 Ma to 34.7 Ma (Eagles et al., 2006). According to Galindo-Zaldívar et al. (2006), the structural setting and seismic character of the oceanic basement of the Dove Basin appear to be similar to those of the Protector Basin, and hence the age of these two basins can be comparable.

3.4. South Orkney microcontinent

The South Orkney microcontinent represents the largest (~70,000 km^2) continental fragment of the southern part of the Scotia Arc. The emerged part of the platform forms the South Orkney Islands, mainly composed by metamorphic rocks interpreted to represent a subduction complex accreted along the active margin of Gondwana during the Early Mesozoic (Trouw et al., 1997). The N–NE margin of the South Orkney microcontinent presents structures and morphologies associated with convergence of the continental fragment with the Scotia plate oceanic crust, as proposed by Busetti et al. (2000), Lodolo et al. (1997), Lodolo et al. (2010), Kavoun and Vinnikovskaya (1994), Klepeis and Lawver (1996) and Maldonado et al. (1998). This convergence seems to terminate at the north-eastern corner of the South Orkney microcontinent. In general, the northern border of the South Orkney microcontinent is characterized by a WNW–ESE trending depression associated with a gravity minimum. A deep (up to 6000 m), WSW–ENE oriented trough (Bruce Deep) separates the north-easternmost South Orkney microcontinent from the Bruce Bank (Lodolo et al., 2010), suggesting the interpretation that it is possibly a shifted continuation of the South Orkney trough. The crustal nature of the South Orkney microcontinent was derived from gravity modeling along two seismic profiles, using geological constraints from seismic interpretation. The results give a crustal thickness of about 25 km for both the South Orkney microcontinent and Bruce Bank, and a thinning between them (Busetti et al., 2000).

3.5. Bruce Bank

Bruce Bank is located to the N–E of the South Orkney microcontinent, and separates the Dove Basin to the west from the Scan Basin to the east. It presents elevations of less than 2000 m in water depths. Seismic profiles (Eagles et al., 2006) have allowed deriving its broad morphological and structural settings. Its north-western margin is gently faulted and gradually slopes to the Dove Basin, whereas the south-western and southern margins present very steep slopes and are structurally complex. The surface of the bank is quite rough, with the presence of some structural highs of uncertain nature. To the east, the margin is quite steep and characterized by some diffraction possibly associated with volcanic manifestations.

3.6. Scan Basin

Scan Basin has been described for the first time by Hernández-Molina et al. (2007) on the basis of seismic profiles and bathymetric data. It is a small basin (average water depths of 3000 m) with a triangular shape and opens to the north connecting to the abyssal part of the central Scotia Sea. Data show that the southern sector of the basin is possibly floored by a crust of transitional type, greatly deformed due to the processes of crustal stretching that produced the separation between the Bruce Bank and the Discovery Bank. The northern part of the basin seems instead to be made up of oceanic crust. To date, there is no information about the age of this basin.

3.7. Discovery Bank

Discovery Bank is located to the east of the South Orkney microcontinent, and constitutes the largest fragment of the eastern part of the South Scotia Ridge. This bank is separated from the Bruce Bank by the Scan Basin. The few available data suggest that this high is of a continental nature, as demonstrated by the shallow bathymetry (about 500 m below sea level, comparable to water depths of most of the South Orkney microcontinent), the presence of large magnetic anomalies (probably due to massive basic igneous rocks intruded in the continental crust), the seismic tomography velocities (Vuan et al., 2005b), and seismic facies observed in multichannel seismic profiles (Galindo-Zaldívar et al., 2002; Vuan et al., 2005b). Discovery Bank is constituted by two distinct morphological highs, separated by a symmetric trough where the sedimentary cover has a negligible thickness. Gravimetric models produced along several multichannel seismic profiles (Bohoyo et al., 2007) seem to confirm that the basement is of a continental nature, with a very shallow mantle.

3.8. Irizar Highs

This province is located between 33°W and 38°W, and is constituted by a series of relatively narrow and steep elevations. These structural highs are collectively named as Irizar Highs (Lodolo et al., 2010). The geometry and the morphological continuity along strike of these highs are only inferred from satellite-derived data (Smith and Sandwell, 1997) because the paucity of underway geophysical profiles available. Only two multichannel seismic profiles have been up to now acquired across this remote region (Bohoyo et al., 2007). Data show that the structural highs composing the Irizar Highs are significantly different from each other in terms of width, length and slope morphology. They are elongated broadly SE–NW and appear to be structurally linked with the eastern part of the Jane Bank, where they constitute its morphological prolongation. The sequence of deep troughs and narrow depressions separating the structural highs are associated with normal and/or strike–slip faults. Dredging located along a flank of one of the western relieves of the Irizar Highs, recovered mainly fragments of metamorphic rocks, supporting the interpretation that these elevations have a crystalline nature (continental/transitional crust) (Lodolo et al., 2010; Tassone et al., 2009).

3.9. Herdman Bank

Herdman Bank is the easternmost shallow bank pertaining to the southern margin of the Scotia Sea. It is centered at 60°S, 32°W and is separated from the south-eastern margin of the Discovery Bank by a narrow trough, while to the east it connects in some ways to the southern termination of the East Scotia Ridge. Its crustal nature, structural setting, and tectonic history are almost unknown because of the absence of underway data. Most of the information comes from satellite-derived data (Smith and Sandwell, 1997) and a single seismic profile (Bohoyo, 2004) across the south-western part of the bank which shows the remarkable complexity of its morphology.

4. Structural architecture of the southern margin of the Scotia plate from seismic data

The general structural framework of the southern Scotia Sea, from the Elephant Island platform to the Discovery Bank, is here presented (Fig. 2). It has been derived from the analysis of a set of multichannel seismic profiles acquired in the last 20 years by several scientific institutions, and now available from the Antarctic *Seismic Data Library System* (http://snap.ogs.trieste.it). These profiles were recorded in different years, using acquisition and processing parameters that vary greatly from line to line. For this reason, we tried to standardize and homogenize as much as possible the appearance of the data images presented,

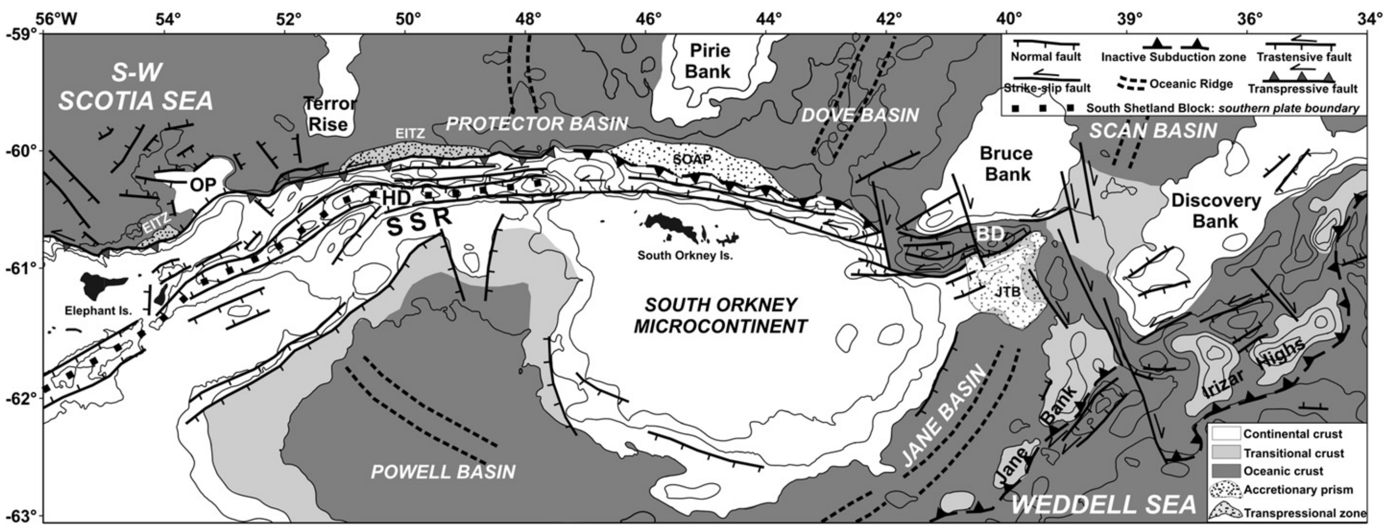


Fig. 2. General tectonic map of the Scotia–Antarctica plate boundary, from the Elephant Island to the Discovery Bank. SSR, South Scotia Ridge; OP, Ona Platform; SOAP, South Orkney accretionary prism; BD, Bruce Deep; HD, Hesperides Deep; JTB, Jane Thrust Belt; EITZ, Elephant Island transpressional zone.

through the application of appropriate post-stack filters and gain recovery to minimize the differences. Table 1 summarizes the principal acquisition parameters of the multichannel seismic reflection profiles presented in this paper.

Three main tectonic segments have been distinguished along the Scotia–Antarctica plate boundary, which are characterized by different structural styles, as described in the next paragraphs. The positions of the presented seismic lines are shown in Fig. 3.

4.1. Western segment (from the Elephant Island platform to the north-western corner of the South Orkney microcontinent)

The morpho-structure of this segment (about 200 km in length) is quite well known from multichannel seismic profiles published by Acosta and Uchupi (1996), Coren et al. (1997), Galindo-Zaldívar et al. (1996), Lodolo et al. (1997) and Lodolo et al. (2006). It is generally composed of two main elongated continental blocks separated by steep scarps and tectonic troughs. The deepest part of those depressions is the V-shaped Hesperides Deep (Acosta and Uchupi, 1996) which reaches over 5300 m in water depth. The main peculiarity of this margin is the abrupt and narrow transition between the continental crust of the northern flank of the South Scotia Ridge and the oceanic domain of the western Scotia Sea. This transition is generally characterized by very steep slopes, which would represent the trace of a sub-vertical, strike–slip master fault, and generally occurs in no more than 5–8 km, a distance which is at least one order of magnitude less than in classic passive continental margins. Along this segment, the predominant transpressional character caused the over thrusting of the continental blocks onto the western Scotia Sea oceanic crust (Galindo-Zaldívar et al., 1996; Lodolo et al., 1997).

Seismic line SA500-003 (Fig. 4) runs NE–SW and crosses the western margin of the Elephant Island continental platform and the oceanic crust of the south-westernmost Scotia Sea. This line shows, around SP 3900, the abrupt contact between the two types of crust, which is clearly marked by a sub-vertical fault dipping southward. The transpressional character of this master fault is testified by folded reflectors in the hanging wall. The top of the Scotia Sea oceanic crust lies at about 6.0 s TWT and is defined by a high-amplitude and continuous reflector which separates the sedimentary cover characterized by mostly sub parallel reflectors. The oceanic crust is affected by several normal faults which, in the northern part of the line (from SP 4700 to SP 3900) lower it up to 6.5–7.0 s TWT. The normal faults located from SP 5300 to SP 4200, show inclined planes toward S–W producing crustal block rotations. The sedimentary cover in the oceanic domain is tectonically undeformed and it thickens toward the continental slope up to about 2000 m (considering an average sound velocity of 2200 m/s). The Elephant Island continental platform is composed by two main structural highs separated by a narrow and deep trough. Also along seismic line SA500-002 (Fig. 5), running NNW–SSE, an abrupt contact between the Scotia Sea oceanic crust and South Scotia Ridge continental crust, corresponding to a sub-vertical master fault, is visible. A buried deformed zone, affected by compressional structures, is probably associated to reverse movements of the master fault. The oceanic basement is strongly deformed

Table 1
Acquisition parameters for the multichannel seismic reflection profiles presented in this paper.

Geophysical cruise	R/V *Almirante Camara* (1987) Brazil	R/V *Geolog Dmitriy Nalyvkin* (1990) Russia (former U.S.S.R.)	R/V *OGS-Explora* (1995) Italy	R/V *Hakurei-Maru* (1987) Japan	R/V *Hakurei-Maru* (1997) Japan
Seismic lines	SA500-002; SA500-003	A900003-02	IT-157; IT-157A; IT-158A; IT-162; IT-163	TH87-04B	TH97-10SMG
Energy source	8 air-guns (volume 8.8 L)	2 air-guns (volume 10.0 L)	36 air-guns (volume 80.4 L)	2 water-guns (volume 13.1 L)	GI-guns (volume 65.55 L)
Marine streamer	Length 1800 m 72 channels	Length 2400 m 48 channels	Length 3000 m 120 channels	Length 600 m 24 channels	Length 3000 m 240 channels

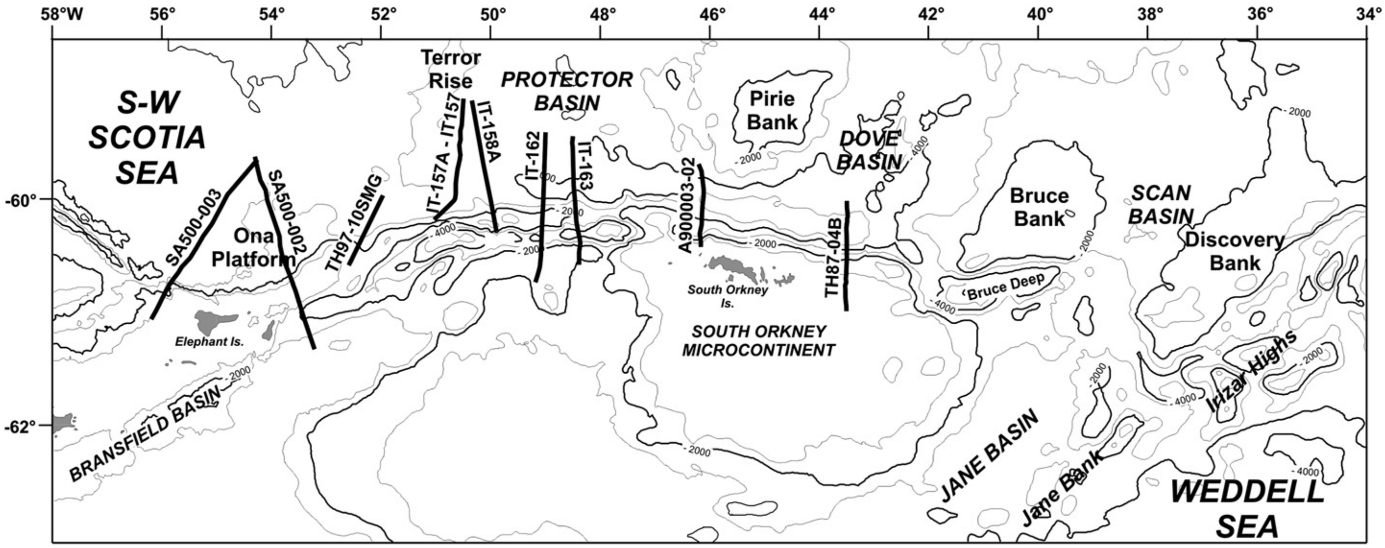


Fig. 3. Index map showing the positions of seismic profiles presented in Figs. 4 to 12. Line's name indicates the corresponding figures.

and characterized by several structural highs which may be interpreted as fracture zones. The sedimentary sequences progressively thicken toward the continental slope up to over 2500 m. In this zone, between SP 3200 and SP 4400, a landward dipping oceanic crust, located 6.0–7.0 s TWT in depth, is present. The continental crust shows a complex morpho-bathymetry because the presence of a large and flat structural high (northern block of the South Scotia Ridge), covered by a thin package of undeformed sediments and bounded by faults with a normal component of movements along the margins. The southern margin is down-faulted by at least two major faults, the southern of which represents the westernmost part of the Hesperides Deep, that here is wider than in the eastern sector, and with asymmetric flanks. Toward east, on seismic line TH97-10SMG (Fig. 6), the contact between the Scotia plate oceanic crust and the South Scotia Ridge continental crust is still abrupt and characterized by the presence of a pair of southward-dipping, sub-vertical master faults. These two structures border a deformed, semi-transparent body affected by compression. The top of the oceanic crust close to the base of the continental slope is located at about 6.0 s TWT and is affected by normal faults. The sedimentary cover is undeformed and is about 2000 m thick. The South Scotia Ridge northern block is covered by a quite thick and folded sedimentary succession in the northern part, while sub-horizontal reflectors are present in the southern part of the block. Seismic lines IT-157 and IT-157A (Fig. 7) are located just off the eastern margin of the Terror Rise. A 15-km-wide deformed zone, which affects a thickness of about 2500 m of sediments and possibly the upper oceanic crust, is present at the base of the slope and it is

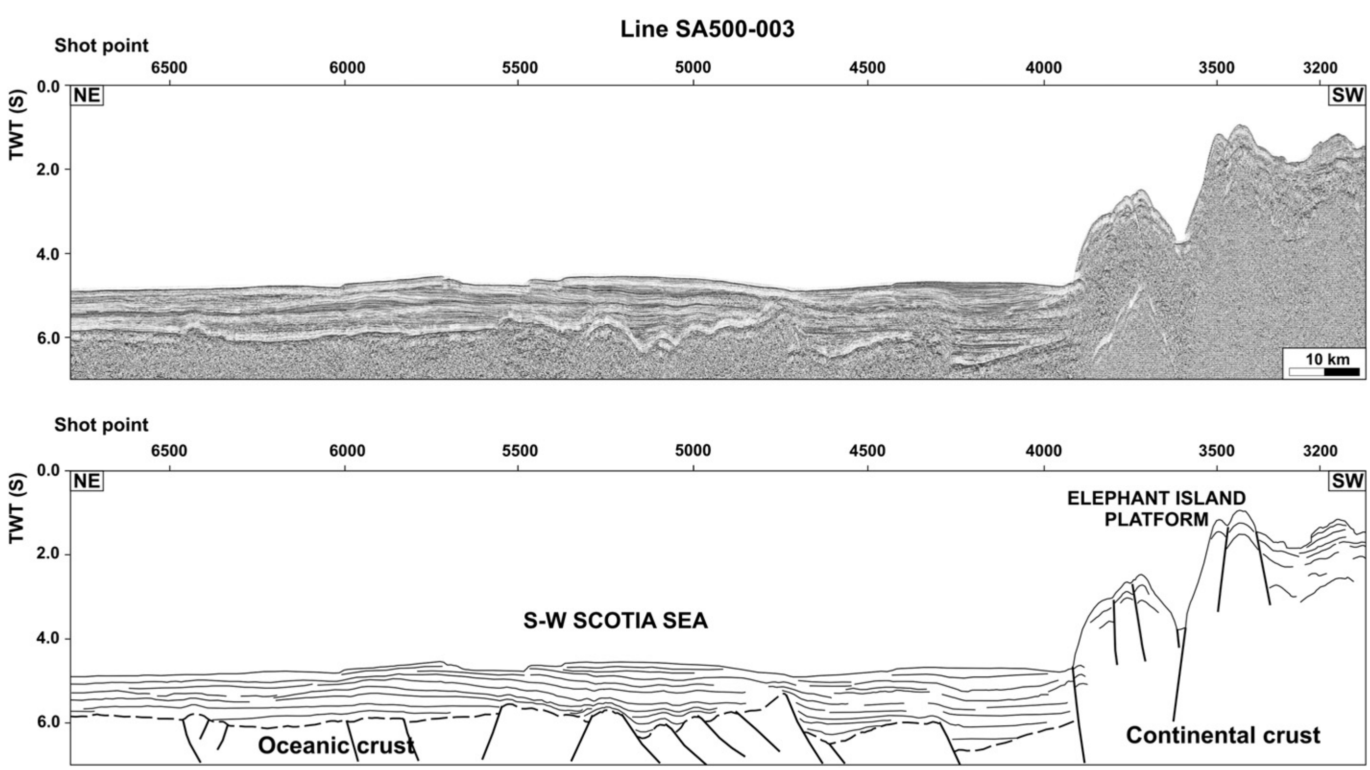


Fig. 4. Seismic profile SA500-003 (top), and simplified line-drawing (bottom). Location in Fig. 3.

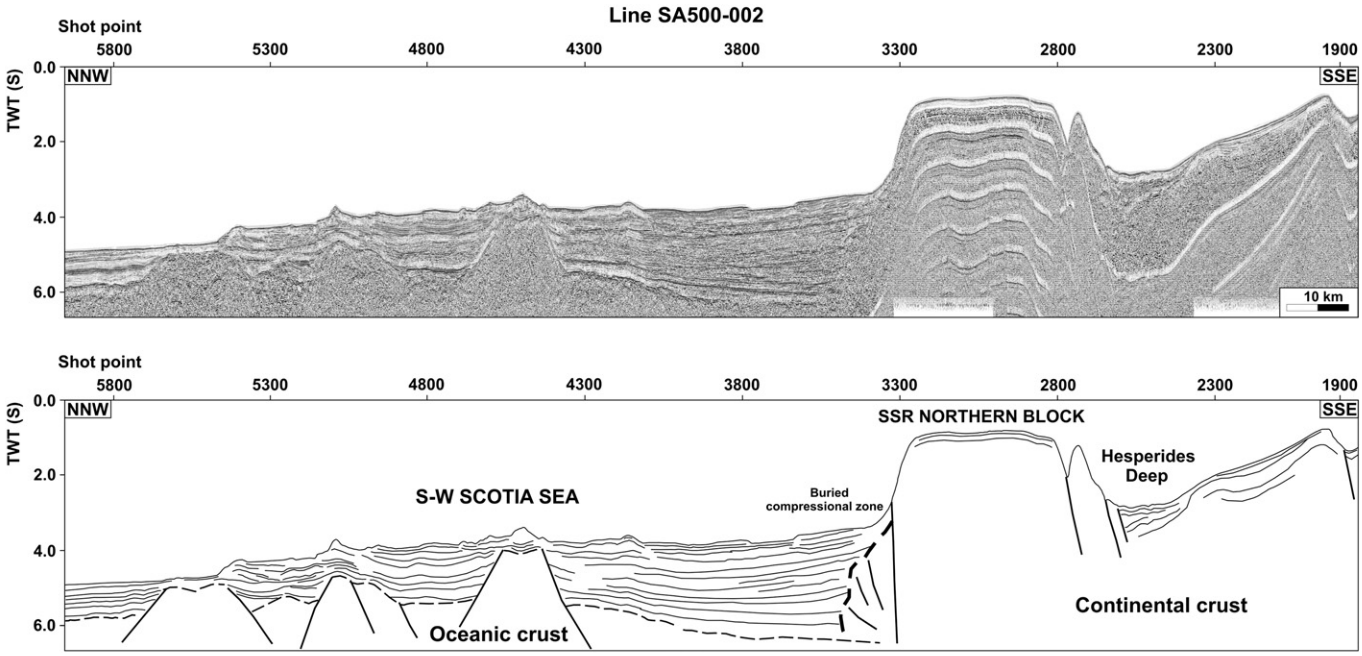


Fig. 5. Seismic profile SA500-002 (top), and simplified line-drawing (bottom). Location in Fig. 3.

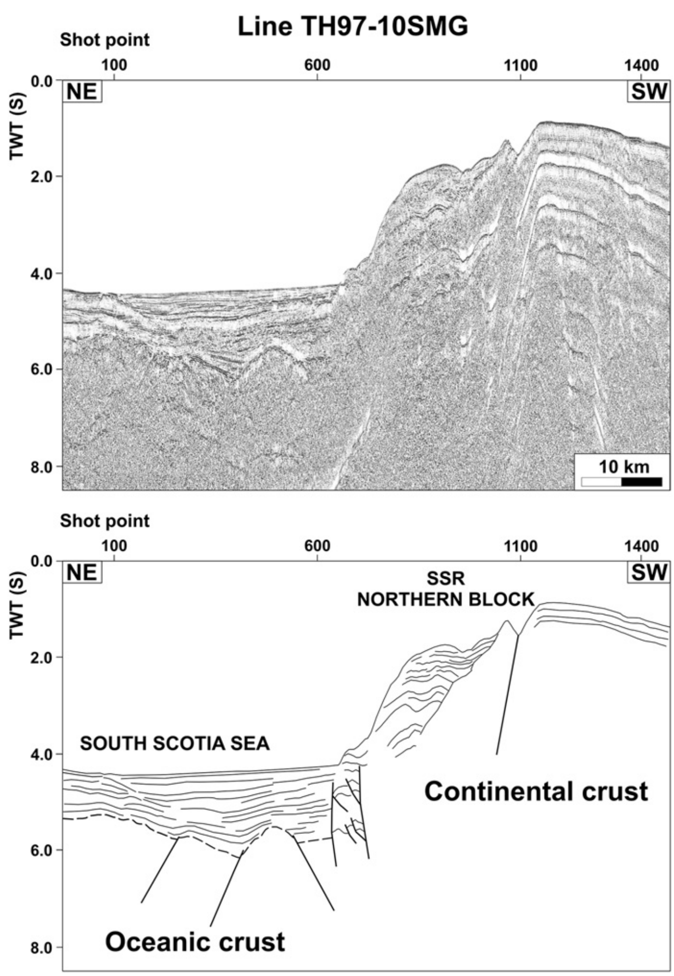


Fig. 6. Seismic profile TH97-10SMG (top), and simplified line-drawing (bottom). Location in Fig. 3.

probably associated with a transpressional activity of the master fault. In this zone are visible up-thrust, with modest offset, and related north-verging folds. The top of the Scotia Sea oceanic crust (Protector Basin) shows a progressive landward deepening from 5.0 to 6.0 s TWT along the line. The sedimentary cover is relatively thin in the northern part of the section and reaches a thickness of 1500 m close to the deformed zone. Seismic line IT-158A (Fig. 8) shows a structural architecture very similar to that described for lines IT-157 and IT-157A, with the presence of a main a sub-vertical fault with the development of a deformed body at the base of the slope, about 12 km-wide and 2.5 km thick. The top of the Scotia Sea oceanic crust (Protector Basin), well visible also under the prism, shows a progressive landward deepening from about 5.0 to 7.0 s TWT. In both seismic lines (IT-157/157A and IT-158), the trough located in front of the compressional deformation zone is filled by a gently deformed and tilted sedimentary sequence. The tectonic deformation generating the buried prism, associated to the master sub-vertical faults that mark the plate boundary, progressively decreases toward the South Orkney microcontinent. Along line IT-162 (Fig. 9) a modest deformation which developed a recognizable buried prism, is still present, while on line IT-163 (Fig. 10) it is lacking and it is replaced by a thick (about 2200 m) undeformed sedimentary succession. The two seismic profiles image the general morphology of this sector of the South Scotia Ridge, which is composed by two main structural highs, the northern of which presents a gently arcuate surface, separated by the narrow Hesperides Deep. In both seismic sections, the oceanic crust of the Scotia plate (Protector Basin) shows a progressive deepening toward the continental slope from 6.0 to over 7.5 s TWT.

In summary, the northern margin of the western South Scotia Ridge is characterized by the presence of a mostly sub-vertical, left-lateral master fault. Transpression is observed along two main segments: one located north of the Elephant Island platform, the other located from the eastern margin of the Ona Platform to the north-western corner of the South Orkney microcontinent. Along these two segments, deformed zones by up-thrusts and reverse faults are imaged by seismic data. The western compressional zone extends for about 50 km in a WSW–ENE direction, from the Elephant Island platform to the S–W margin of the Ona Platform, and affects both the Scotia Sea oceanic sediments and the upper crust up to 18 km seaward. The eastern zone

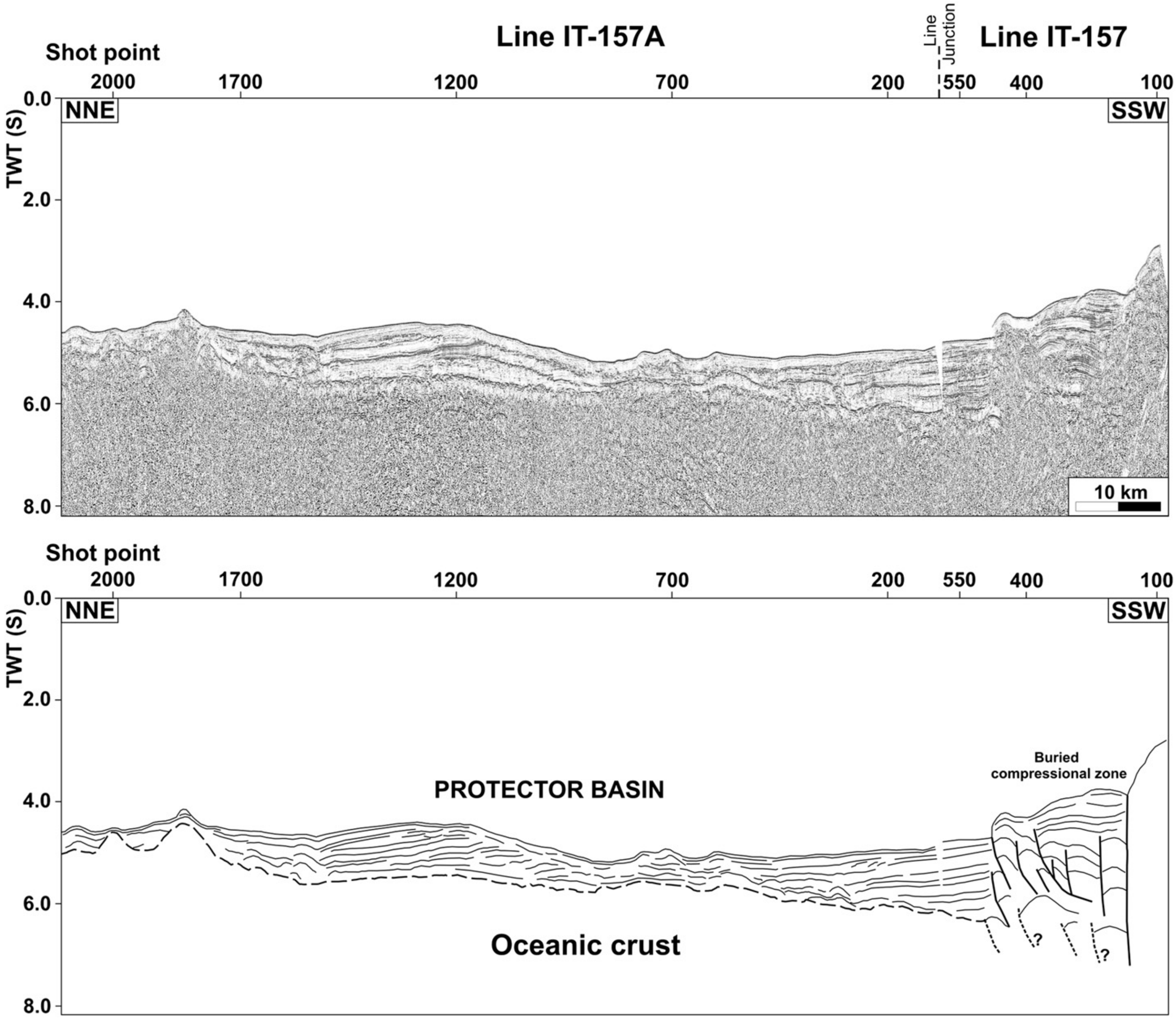


Fig. 7. Seismic profiles IT-157 and IT-157A (top), and simplified line-drawing (bottom). Location in Fig. 3.

shows a total length of about 100–120 km with a maximum width of about 15 km. Both contraction zones could be the consequence of the master fault transpressional activity which testifies an oblique convergence tectonic regime. Transtension is found in correspondence of the Ona Platform (see Figs. 2 and 13), where the plate boundary trends NE–SW. The principal sub-vertical fault visible from the presented seismic data in the segment spanning longitudes 56°W to 48°W represents the Scotia–South Shetland plate boundary. The southern limit of the South Shetland plate corresponds to the Hesperides Deep, which is interpreted as the eastward continuation of the rift-related Bransfield Basin (Galindo-Zaldívar et al., 2004).

4.2. Central segment (northern margin of the South Orkney microcontinent)

In this segment, the Scotia–Antarctica plate boundary is located along the northern margin of the South Orkney microcontinent. It presents a curved shape with a N105° trend. In its central-western part, an accretionary prism is present at the base of the slope, as documented by several geophysical studies (Busetti et al., 2000; Kavoun and Vinnikovskaya, 1994; Maldonado et al., 1998). Seismic line A900003-02 (Fig. 11), already described by Busetti et al. (2000) and Kavoun and Vinnikovskaya (1994), shows the presence of a steep scarp edging the South Orkney continental shelf with a thin sedimentary cover, following by a series of rotated blocks which mark the transition to the oceanic domain. The base of the slope ends at a sea floor depression, more than 5000 m deep, filled by about 2000 m of sediments. Between SP 1100 and SP 2000 an accretionary prism, about 40 km wide, is present. Evidence is mainly given by the smooth step morphology and abrupt change in the seismic facies occurring at the outer deformation front and continent-ward dipping reflectors (Busetti et al., 2000). The top of the oceanic crust is located at 7.0–7.5 s TWT in the vicinity of the accretionary prism. The presence of this relatively small in size accretionary prism present along the northern margin of the South Orkney microcontinent can be explained by the drift toward E–NE of this continental block during the opening of the Powell Basin, which initiated in the Early Oligocene. The migration has generated an over thrust of the lighter continental crust above the transitional crust separating the

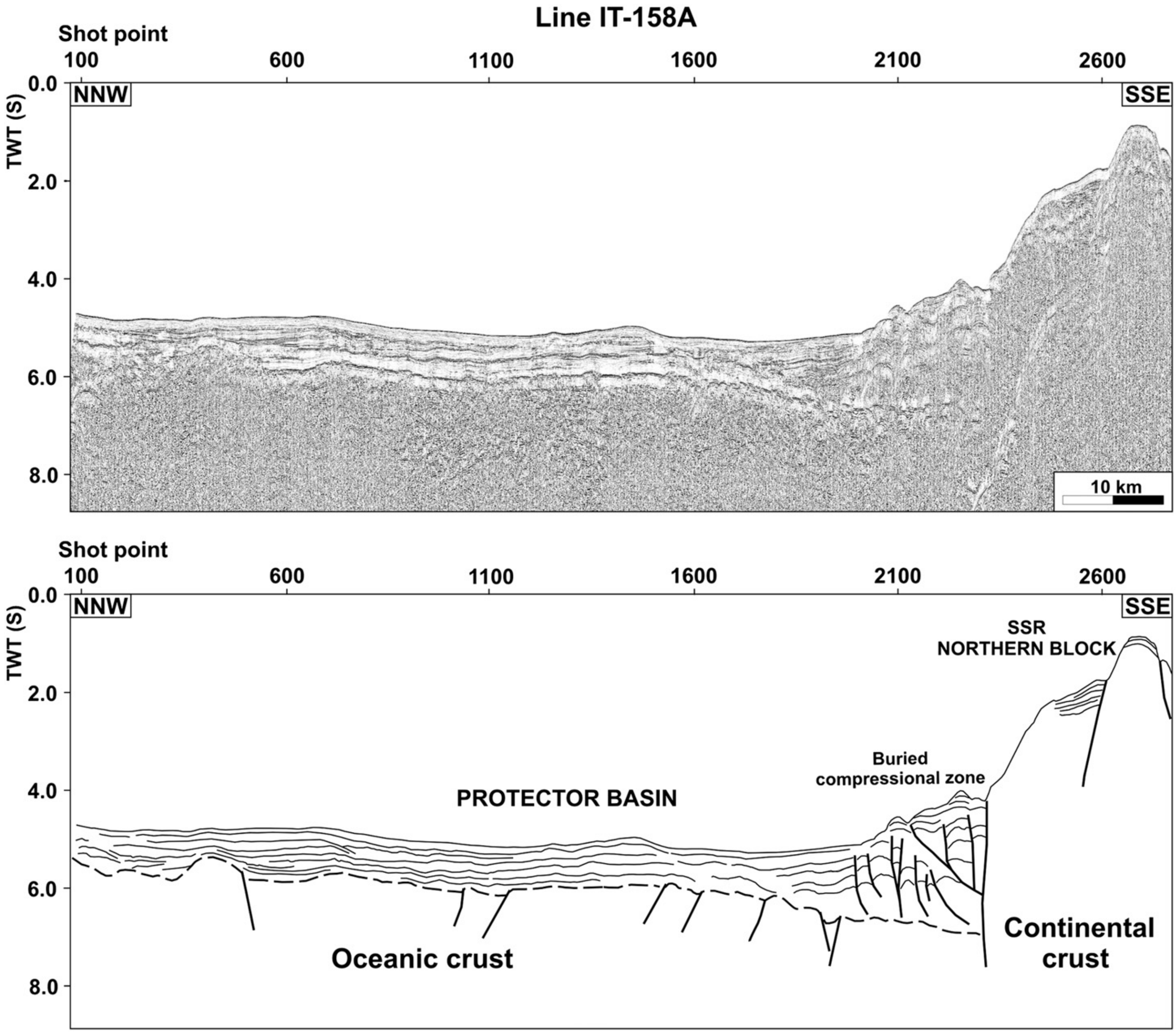


Fig. 8. Seismic profile IT-158A (top), and simplified line-drawing (bottom). Location in Fig. 3.

continental fragments present to the north. This phase encompassed a period of about 8–10 Ma, as indicated by the analyzed magnetic anomalies in the Powell Basin (e.g., Coren et al., 1997; Eagles and Livermore, 2002).

Moving toward east, the convergence becomes less evident, and produced mainly compressional structures in the oceanic sediment with folds and reverse faults, rather than forming an accretionary wedge. This is visible along seismic line TH87-04B (Fig. 12), which crosses the eastern part of the northern margin of the South Orkney microcontinent. The bulk of the continental block is undeformed in the uppermost sedimentary sequence, and characterized by sub-horizontal reflectors. Toward the slope, two major sub-vertical faults generate a steep and very narrow V-shaped trough which separates the main block from a symmetric structural high. This high trends parallel to the northern border of the South Orkney microcontinent and it is limited by a regional fault (fault escarpment of more than 4000 m) which shows a prevalent normal motion. At the base of the structural high, between SP 1300 and 1400 and at about 9.0 s TWT in depth, a reflector gently inclined toward south might represent the top of the Scotia Sea oceanic crust which merges beneath the South Orkney microcontinent. In the northern part of the seismic profile, deformed sedimentary successions are present. The evidence of compression is testified by the presence of folding linked to N-verging thrusts which in some cases would seem to deform the sea-floor (SP 1900).

4.3. Eastern segment (from the north-eastern corner of the South Orkney microcontinent to the Herdman Bank)

This part of the Scotia–Antarctica plate boundary has been already analyzed by Lodolo et al. (2010), and here we recall only its salient features. The convergence between the Scotia plate and the continental blocks pertaining to the South Scotia Ridge seems to terminate at the north-eastern corner of the South Orkney microcontinent. A deep trough (Bruce Deep), interpreted as a wide pull-apart basin, separates the South Orkney microcontinent from the Bruce Bank. Between the

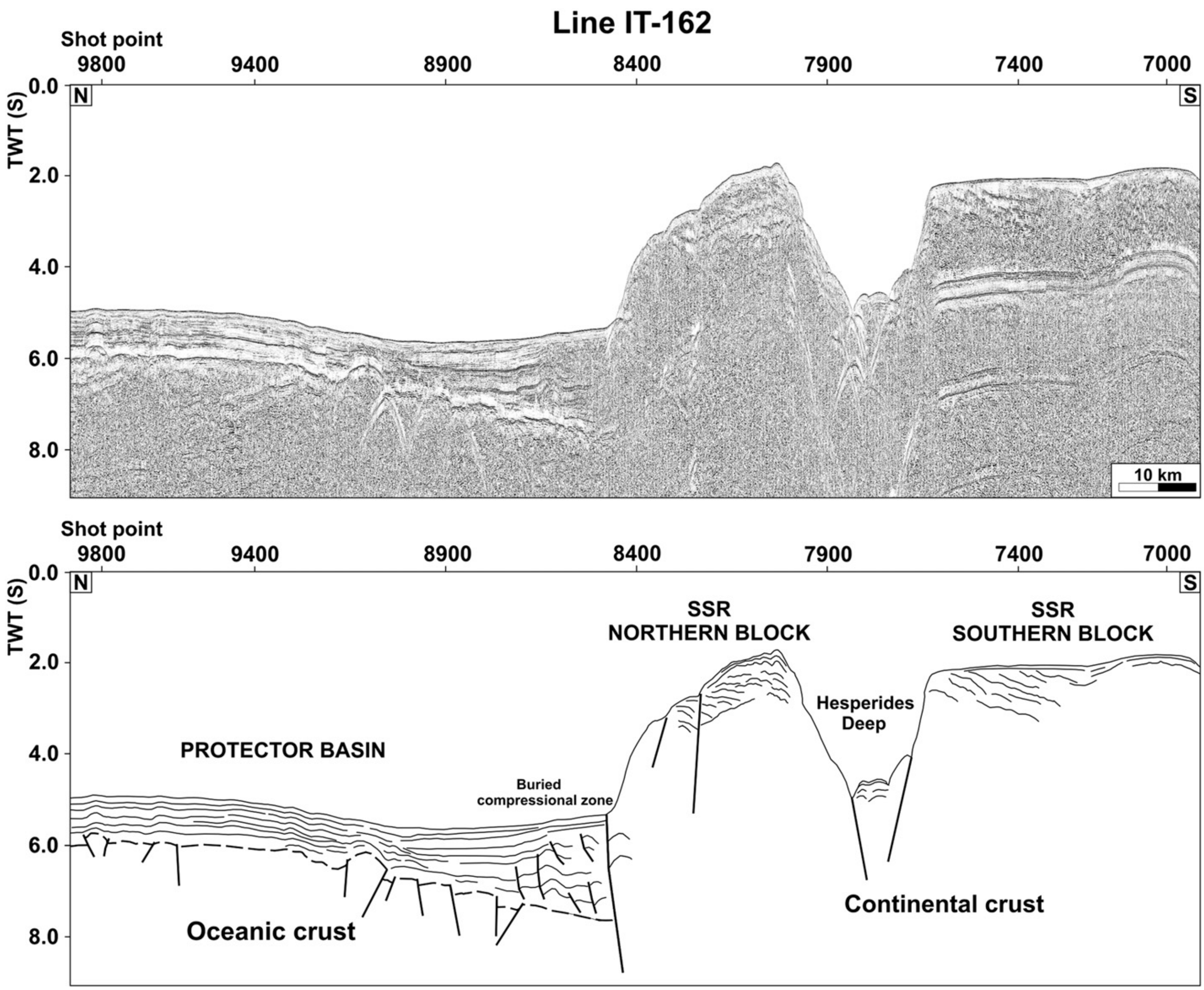


Fig. 9. Seismic profile IT-162 (top), and simplified line-drawing (bottom). Location in Fig. 3.

South Orkney microcontinent and the Bruce Bank, the tectonic regime of the plate boundary changes, exhibiting mainly strike–slip behavior with some grade of extensional component. In this segment, from W to the E, the Scotia–Antarctica plate boundary runs along the ENE–WSW oriented Bruce Deep, and along the southern margin of the Discovery Bank, where several small pull-apart basins are present. These segments are separated by a series of NNW–SSE trending release zones which correspond to mostly dextral strike–slip faults. South-east of the Bruce Deep, seismic profiles also show the presence of a wide area affected by compression, interpreted to represent an accretionary prism (Jane Thrust Belt) characterized by N-verging thrust and folds.

5. The conjugate margins of the western Scotia Sea

One of the major problems encountered when trying to restore the pre-drift geometry of the western Scotia Sea, is the identification of the conjugate margins located on its northern and southern edges. The Tierra del Fuego continental margin is supposed to be the conjugate margin of the westernmost South Scotia Ridge when spreading processes along the west Scotia Ridge begun. These processes definitively created the Drake Passage gateway. However, seismic profiles show profound differences in terms of geometry and morphology between the Tierra del Fuego margin and the segment of the South Scotia Ridge just to the east of the Elephant Island. Data acquired across the Tierra del Fuego continental margin show that it is a rather classic rifted passive margin (see Figs. 2 to 5 in Lodolo et al., 2006), where the transition between the continental and the oceanic crusts is gradual and generally occurs through a 30 to 40 km wide zone. The occurrence of sub-vertical faults, widely affecting the continental slope, reflects the dominance of an extensional tectonic regime.

Recently acquired geophysical data (*BIO Hesperides* campaign of January–February 2008, carried out in the frame of the *International Polar Year—IPY*) have shown that the most probable candidate for the conjugate margin of Tierra del Fuego is the Terror Rise (Galindo-Zaldívar et al., 2008), an elevated topographic rise located just to the north of the western part of the South Scotia Ridge, which shows many characteristics of a severely stretched continental block. Two profiles were recorded along the spreading corridors of the southern half of western Scotia ridge axis, crossing the oldest oceanic crust, the Terror Rise up to the oceanic Protector Basin. Both seismic lines show similar features and evidence the continental nature of the Terror Rise. It represents a NNE–SSW elongated ridge which top lies at about 2000 m water depth between abyssal plains more than 3000 m deep. Bouguer anomaly minima point to its thinned continental nature

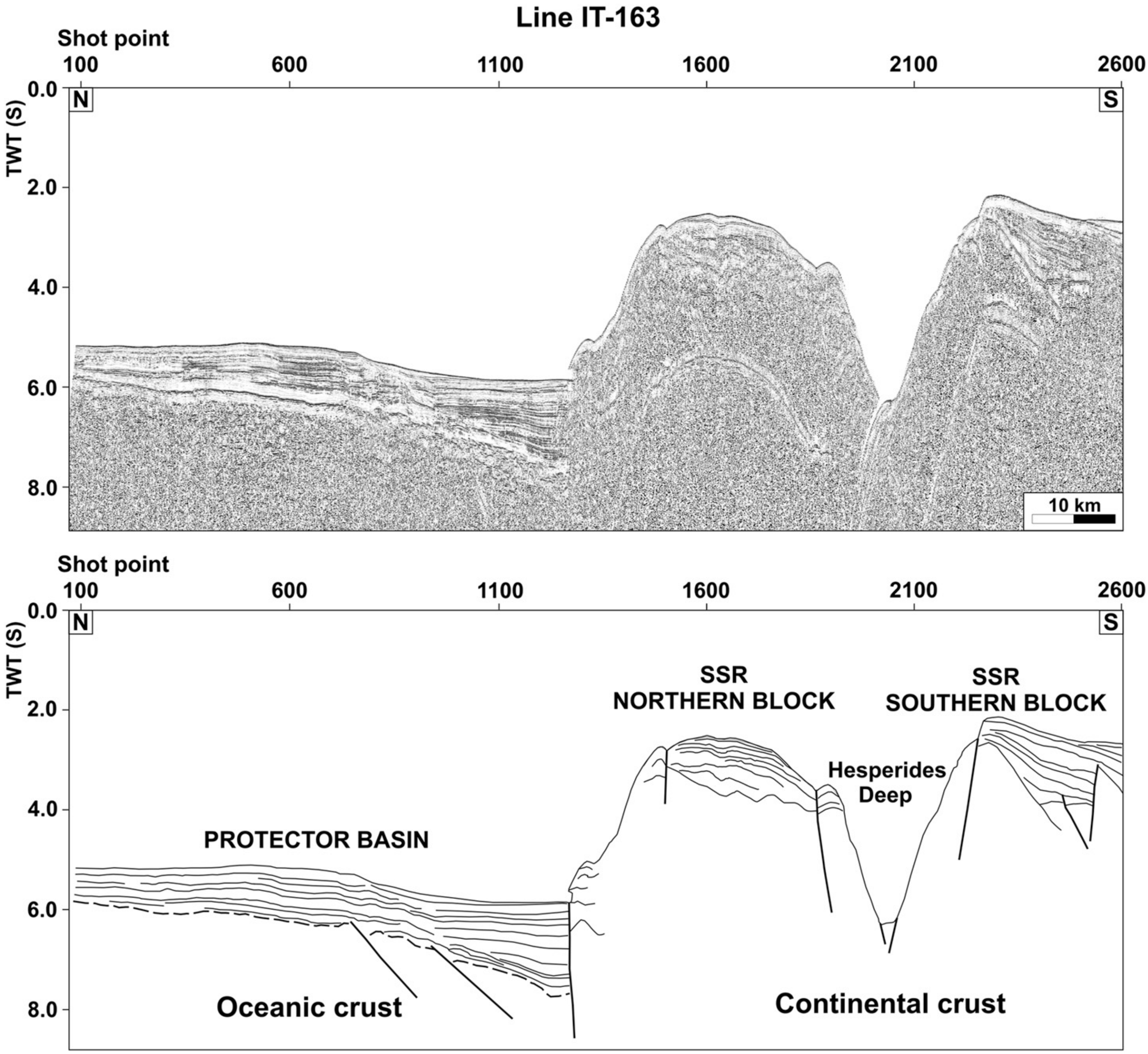


Fig. 10. Seismic profile IT-163 (top), and simplified line-drawing (bottom). Location in Fig. 3.

(Galindo-Zaldívar et al., 2008). Several half-grabens bounded by northwestwards dipping faults and with sedimentary wedges thickening toward S–E, of more than 1 km in thickness, suggest that the initial phase of rifting was followed by an oceanic spreading axis located northwestwards. These structures undoubtedly show that the Terror Rise is the remnant part of the stretched Antarctic passive margin during the Drake Passage opening. In its initial phase of evolution, the Protector Basin was not yet opened and this passive margin probably was adjacent to the western flank of the Pirie Bank, which is now located east to the Protector Basin, where overprinted deformations are found on its eastern margin (Galindo-Zaldívar et al., 2006). To the west of the Terror Rise, between longitudes 54° 30′W and 53°W, satellite-derived data show the presence of a morphological elevation – the Ona Platform – elongated roughly in a N–S direction, in a way similar to the Terror Rise (Fig. 13). The shallower parts of it lie at water depths of about 2000 m, with respect to the surrounding areas where the depths range from 3000 to 3600 m. Seismic profiles acquired across the northern margin of the South Shetland block and presented in this work, have shown that along this sector of the South Scotia Ridge, the morphology of the margin and its structural architecture differ significantly from the two segments located immediately to the west and to the east. There is no evidence of a sharp contact between the continental slope and the south-western Scotia Sea oceanic area, and a transitional/continental crust seems to be present in correspondence of the entire elevated region of the Ona Platform.

6. Seismicity and focal mechanisms along the South Scotia Ridge

Here we describe the recorded seismicity and available focal mechanisms that could help in interpreting seismic data along the south Scotia Sea margin from the Elephant Island to the Discovery Bank and in better constrain the location of the Scotia–Antarctica plate boundary.

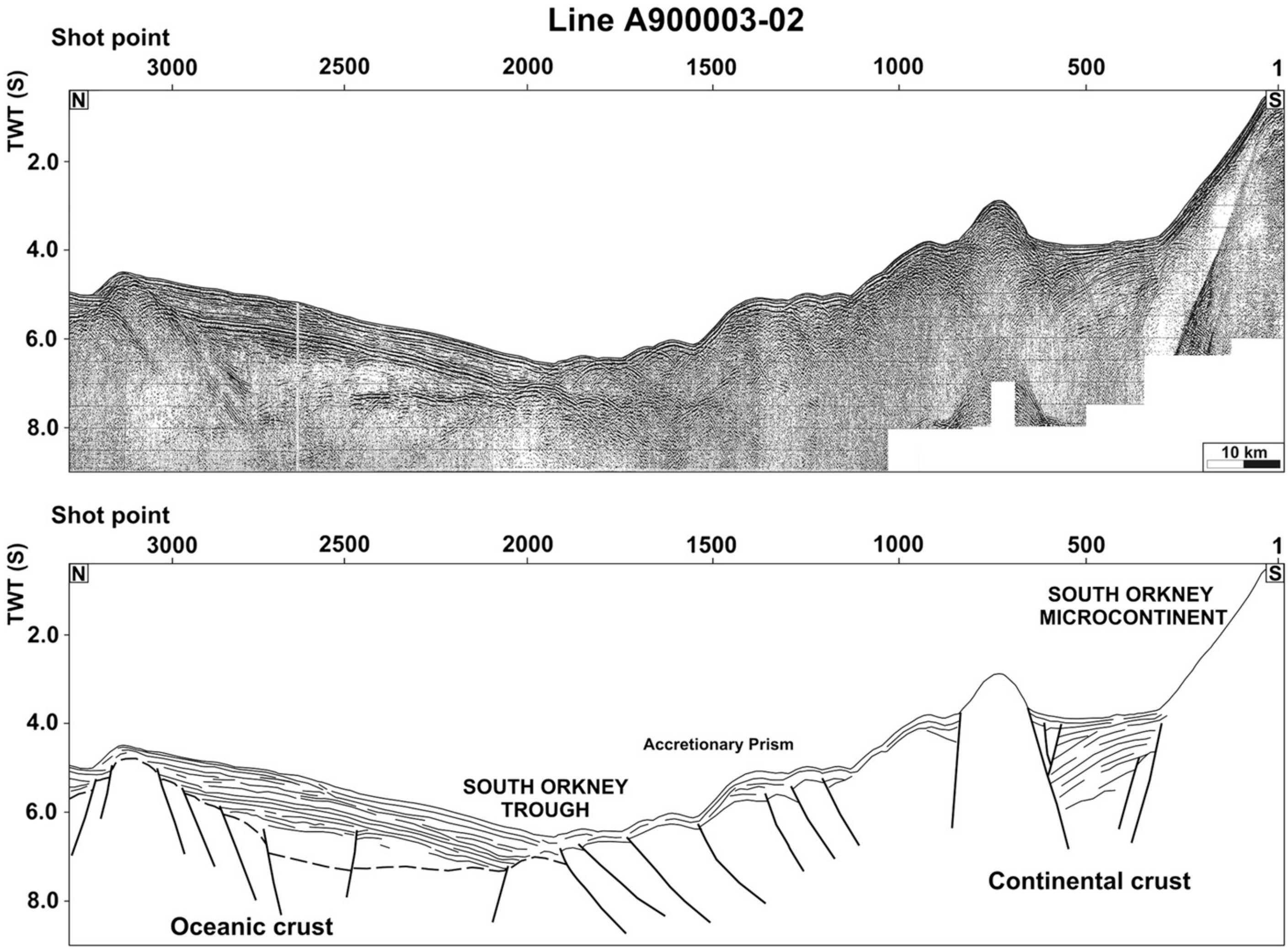


Fig. 11. Seismic profile A900003-02 (top), and simplified line-drawing (bottom). Location in Fig. 3.
Modified from Busetti et al. (2000).

EHB catalog (Engdahl, 2006; Engdahl et al., 1998) is used to get accurate earthquake locations since it uses a proper reference Earth model (AK135, Kennett et al., 1995); moreover, it limits the events of interest only to those that are teleseismically well-constrained. EHB location procedures have significantly improved by using iterative relocation with dynamic phase identification, use of teleseismic depth phases, and selection criteria for events having ten or more observations at teleseismic distances (see Engdahl, 2006). In the seismicity maps, because of the difficulties in accessing the Antarctic and sub-Antarctic regions, we expect some bias as a consequence of the paucity of seismic stations and the high permanent microseismic noise. Earthquake locations by seismic agencies and their seismicity patterns are generally acceptable only for a body wave magnitude threshold greater than 5.0 (Rouland et al., 1992) and from 1960 to today. Below this magnitude threshold, there are many earthquakes that are not detected, and this could hamper the tracing of the plate boundaries on a regional scale. Although uncertainties could be large, discrepancies observed by comparing bulletins from different agencies, having different seismic stations patterns, are limited horizontally to 10–20 km (see the International Seismological Centre (ISC) (2009) website at http://www.isc.ac.uk/search/custom/index.html). Similar uncertainties are consistent with the error ellipses given in Pelayo and Wiens (1989) for relocated historical earthquakes (from 1958 to 1962). Earthquake depth due to the lack of local seismic stations is still not well constrained in this remote region of the Southern Hemisphere. This makes difficult to identify weak zones in the lower crust from depth-dependent earthquake focal mechanism orientation (see Bokelmann and Beroza, 2000).

In Fig. 14 (top panel) the location of EHB earthquakes together with ISC bulletin events from 1960 to 2008 is shown. From W to E, the seismicity pattern of the area shows distinct behaviors following the different plate boundary segments that characterize the South Scotia Ridge. More details about local seismicity are available for the South Shetland Islands region and Bransfield Basin where some experiments with a local deployment of seismic arrays allowed in the past to better characterize low and medium size earthquakes. Robertson Maurice et al. (2003) located in the South Shetland Islands region many earthquakes (body wave magnitude 2–4) at depths indicating ongoing subduction. The maximum depth of seismicity is 65 km, but the majority of the events are shallower than 30 km and the estimated subduction rate is evaluated to be less than 1 cm/year. Many earthquakes in Bransfield Basin are associated with volcanism and rifting. Transtensional and extensional deformation (Fig. 14; middle panel) is suggested to be linked with disruption of the northern part of the South Shetland microplate and northern Bransfield Basin, and a creation of a new fault segment that transects the high angle intersection of the Shackleton Fracture Zone and the South Scotia Ridge transforms (e.g., Klepeis and Lawver, 1996). However, no meaningful medium-strong earthquakes are located along this supposed fault segment.

The plate boundary from 42°W to 50°W along the South Orkney microcontinent and up to the S–E margin of the Bruce Bank is well

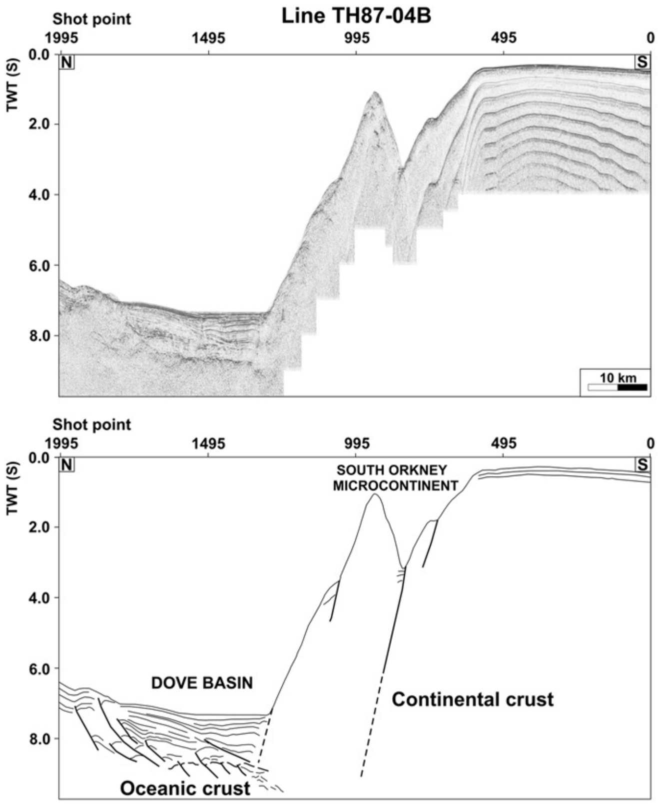


Fig. 12. Seismic profile TH87-04B (top), and simplified line-drawing (bottom). Location in Fig. 3.
Modified from Lodolo et al. (2010).

defined by the seismicity pattern that assumes a general W–E alignment. As already discussed, seismic data show the presence of an accretionary wedge along the northern margin of the South Orkney microcontinent, generated by a convergent component of motion. However, the Harvard CMT catalog (see Fig. 14; middle panel) contains only a focal mechanism showing reverse faulting (1991/05/24, Mw = 5.7). The size of this event is quite smaller than the Mw = 7.6 (2003/08/04) earthquake that occurred 75 km to the east of the South Orkney Islands, and characterized by a strike–slip faulting. Principally E-directed, co-seismic displacement associated with the Mw = 7.6 earthquake confirms accumulation of slip consistent with a left-lateral transform plate boundary (Smalley et al., 2007). The moment tensor source inversion of many aftershocks of the Mw = 7.6 event shows extension along a WNW–ESE fault plane (Plasencia, 2007) in agreement with moment tensor solutions from Harvard CMT Catalog. Moment tensor analysis along this margin is consistent with tectonic processes along a sinuous plate boundary zone that is slightly oblique to the vector of relative motion between the Scotia and Antarctic plates. Toward east from the Discovery Bank to Herdman Bank, earthquakes are located in a 150-km-wide area and on a regional scale are difficult to define unambiguously the plate boundary. Between the South Orkney microcontinent and Bruce Bank, strike–slip earthquake focal mechanism (Fig. 14 middle panel) points to a purely left-lateral regime on E–W oriented faults. East of the Bruce Bank up to Discovery Bank, the EHB catalog does not report earthquakes. Other catalogs (e.g., NEIC, ISC) that do not respect the selection criteria of EHB in terms of azimuthal coverage and number of useful phases, display some medium size earthquakes, probably not so strong to be well recorded at teleseismic distances and with an azimuth gap below 180°. Toward S–W and inside the Discovery Bank, left-lateral strike–slip earthquakes with an extensional component are dominant. The large seismic moment and the depth of the seismic events are consistent with a continental nature of the Discovery Bank. The mechanism of extension resembles diffuse rift zones or pull-apart basins and requires the presence of cold continental lithosphere (Pelayo and Wiens, 1989). The active faults are probably left-lateral lineaments trending ENE–WSW to E–W, consistent with one of the nodal planes of the focal mechanisms (Galindo-Zaldívar et al., 2002). At the base of the southern margin of the Discovery Bank, the seismicity and exposed fault scarps indicate present-day activity on faults that border one of the pull-apart basins present there (see Fig. 3 of Galindo-Zaldívar et al., 2002).

In general, earthquake focal mechanisms (Forsyth, 1975; Giner-Robles et al., 2003; Guidarelli and Panza, 2006; Klepeis and Lawver, 1996; Pelayo and Wiens, 1989; Plasencia, 2007; Robertson Maurice et al., 2003; Thomas et al., 2003) show that the analyzed segment of the Scotia–Antarctica plate boundary is characterized by different structural styles. The western segment of the South Scotia Ridge from Elephant Island to Bruce Bank can be interpreted as a left-lateral transform plate boundary with a significant extensional component documented by a lot of normal fault mechanisms; the eastern segment of the plate boundary from Bruce Bank to Herdman Bank is the result of a complex deformational history associated to the presence of mostly short segments (some of them occupied by restricted pull-apart basins), offset by prevalent dextral strike–slip lineaments.

6.1. Crustal models for the South Scotia Ridge from wave tomography

The crustal nature of the geological elements distributed along the southern margin of the Scotia Sea is still poorly constrained, and the information from regional surface wave tomography represents a very powerful tool to define the relevant physical properties of the crust and upper mantle. During the last 15 years there has been a major instrumentation deployment in the islands and continental regions surrounding the Scotia plate (see Vuan et al., 2000) and some seismic experiments involving earthquake detection in southern Patagonia, Antarctica and South Sandwich Islands were performed (e.g., Robertson Maurice et al., 2003; Larter et al., 1998). Thus, in the last years the collection of earthquake data is increased allowing for tomographic studies on a regional scale. However, because of the average path length (~1700 km) and coverage used in the regional tomography, the spatial resolution is still limited to about 200–300 km (see Vuan et al., 2000). In Fig. 14 (bottom panel) the 35 s Rayleigh wave map from Vuan et al. (2000) highlights the main South Scotia Ridge features. 35–40 s Rayleigh wave group velocity anomalies are related to the crustal thickness and lower crust-upper mantle S-wave velocities. Along the South Scotia Ridge, two clear low group velocity anomalies centered on the Bransfield Basin and on the Discovery Bank (−8%) are seen; while a −2% anomaly is found along South Orkney microcontinent.

The resolution of tomographic maps cannot give reason of the lack of a low velocity anomaly beneath the South Orkney microcontinent, which has a considerable extension. Moreover, other global or regional surface wave studies (e.g., Vdovin et al., 1999) are in agreement with a smooth low velocity anomaly. To explain the observed higher group velocities beneath the South Orkney microcontinent in comparison with the Antarctic Peninsula crust, we suggest three possible hypothesis: (1) a denser and less buoyant oceanic crust, sliding at a low angle from the Scotia Sea under the northern margin of the South Orkney microcontinent, that could have modified the properties of the continental crust at depth; (2) fast velocities beneath the South Orkney microcontinent can be related to the subduction from the south (the northward-directed Weddell Sea subduction); (3) a simply thinned crust of the South Orkney microcontinent. Continental fragments dispersed along the South Scotia Ridge and rifting phenomena that occurred along the plate boundary are responsible of the observed low velocity anomalies at 35 s (Vuan et al., 2005a, 2005b). The crustal models based on surface wave tomography at periods from 15 s to 50 s helped in defining the S-wave velocities along the South Scotia Ridge. This knowledge together with the earthquake parameters and

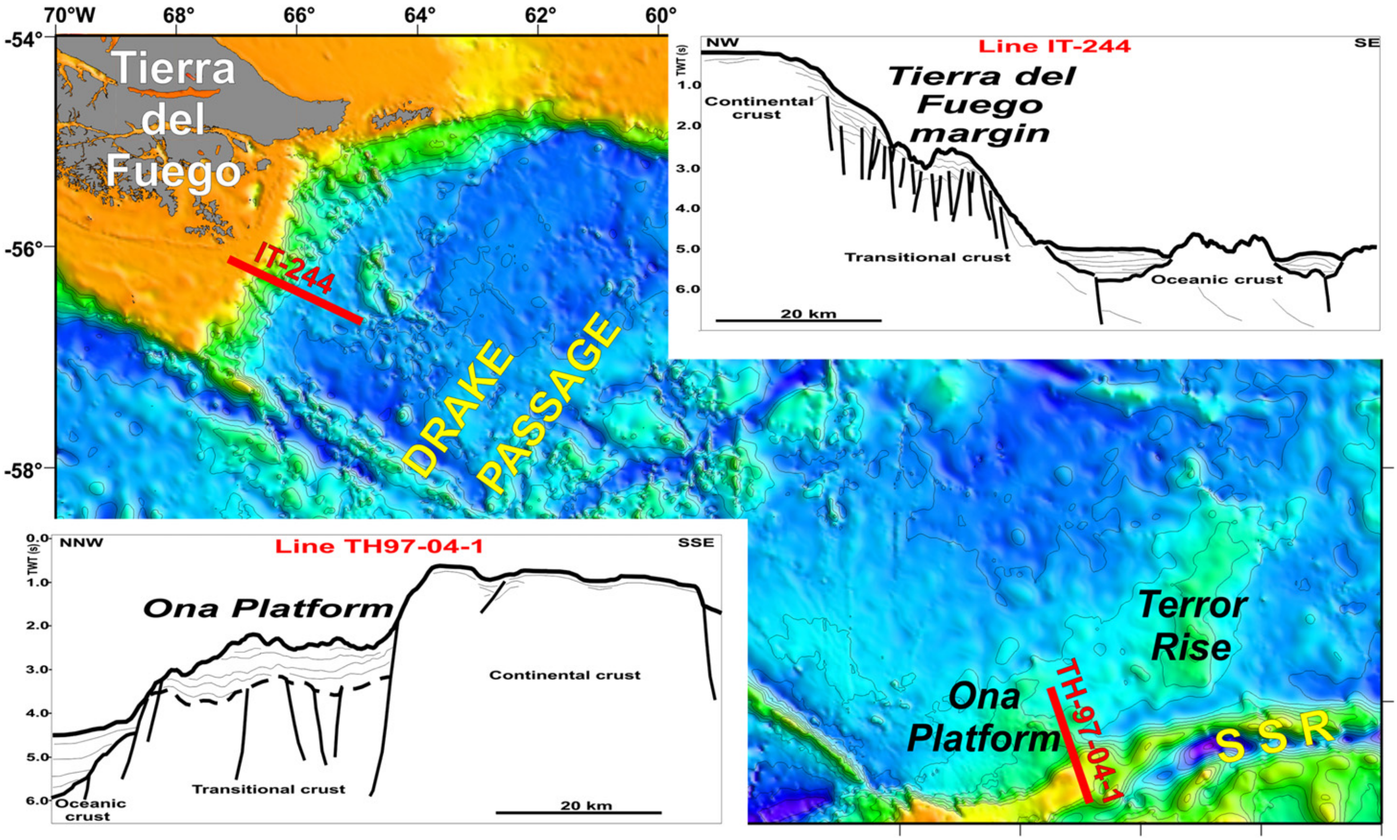


Fig. 13. Satellite-derived bathymetric map (Smith and Sandwell, 1997) of the Drake Passage between Tierra del Fuego and the northern tip of the Antarctic Peninsula. Red segments refer to two representative seismic profiles (here presented as simplified line-drawings) crossing the conjugate margins of Tierra del Fuego (line IT-244, taken from Lodolo et al., 2006) and the Ona Platform (line TH97-04-1). SSR, South Scotia Ridge.

local seismic reflection data can lead to define the structural character of the main features especially in the eastern sector of the South Scotia Ridge (Vuan et al., 2005b).

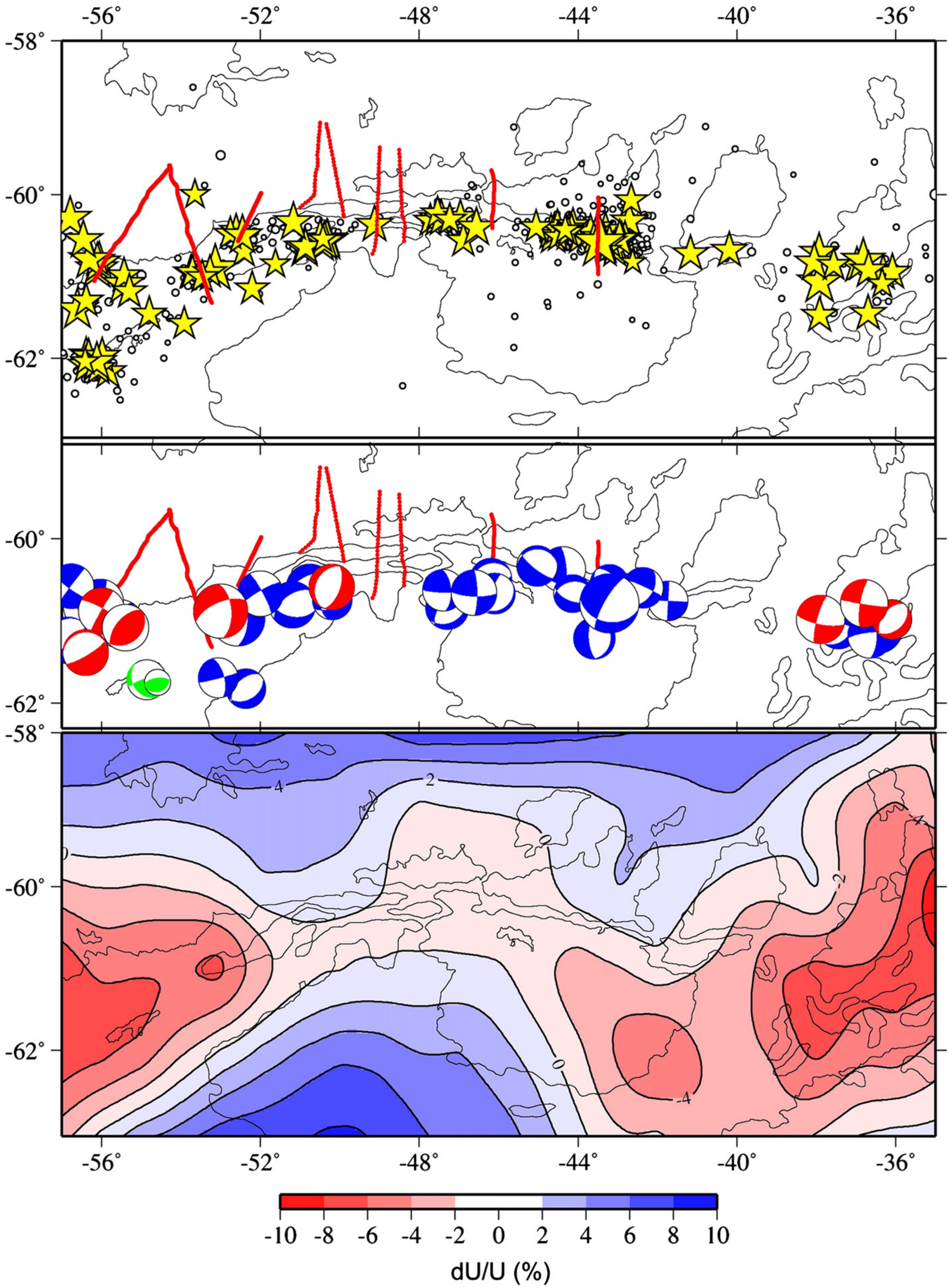
7. Tectonic development of the Scotia–Antarctica plate boundary

The recognition of the tectonic phases which led to the development of the Scotia–Antarctica plate boundary is a complex task, both because of the different timing of the opening of the various basins present along the south Scotia Sea margin, and the difficulties in defining the crustal nature of the various crustal blocks that compose it. Furthermore, they have been severely deformed by vigorous and often overlapping tectonic mechanisms, and this often precludes the recognition of their original structure, size, and shape. Despite these significant uncertainties, a simplified sketch of a possible tectonic development of the Scotia–Antarctica plate boundary comprised between the Elephant Island and Herdman Bank, is here attempted (Fig. 15). This reconstruction, presented in different temporal phases, includes all the morpho-structural elements identified from the analysis of seismic profiles, combined with available information from literature.

(1) Late Oligocene-Early Miocene (about 25 Ma). At the Late Oligocene-Early Miocene boundary, the central and eastern parts of the future south Scotia Sea margin were characterized by a NW-directed convergence of the Weddell Sea beneath a series of assembled bathymetric highs, some of them composed of continental crust. Much of the northern flank of the Weddell Sea ridge was subsequently lost by subduction beneath the growing Scotia Sea. To the west, the South Orkney microcontinent initiated its separation from the north-eastern Antarctic Peninsula due to the opening of the Powell Basin. This created an accretionary prism along the northern margin of the South Orkney microcontinent. The small basins located to the north of the present-day South Scotia Ridge probably were not yet opened at this time.

(2) Middle Miocene (about 12 Ma). In this period, two different geodynamic settings can be identified along the South Scotia Ridge. Along the northern margin of the South Orkney microcontinent continued the convergence and partial subduction of the Scotia Sea oceanic crust, which produced an accretionary prism, whereas along the segment encompassing the Elephant Island and the north-western margin of the South Orkney microcontinent, the plate boundary was marked by a sub-vertical, left-lateral master fault which juxtaposed the Scotia Sea oceanic crust with the South Scotia Ridge continental crust. Transpression along this segment was dominant, and caused both the partial overlap of the South Scotia Ridge continental crust above the Scotia plate oceanic crust, and

Fig. 14. (top panel) Seismicity along the South Scotia Ridge from EHB (yellow stars) and ISC (circles) catalogs; (middle panel) focal mechanisms from Harvard CMT (blue), Guidarelli and Panza (2006) (green) and Pelayo and Wiens (1989) (red); (bottom panel) 40 s group velocity tomography at the Scotia–Antarctic plate boundary from Vuan et al. (2000). Group velocity U is presented as a percentage deviation from the average velocity. Blues indicate faster than group velocities average, and reds slower than group velocities average. Contour of 2000 m water depth is shown in the background.


-56°
-52°
-48°
-44°
-40°
-36°
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-10 -8 -6 -4 -2 0 2 4 6 8 10
dU/U (%)

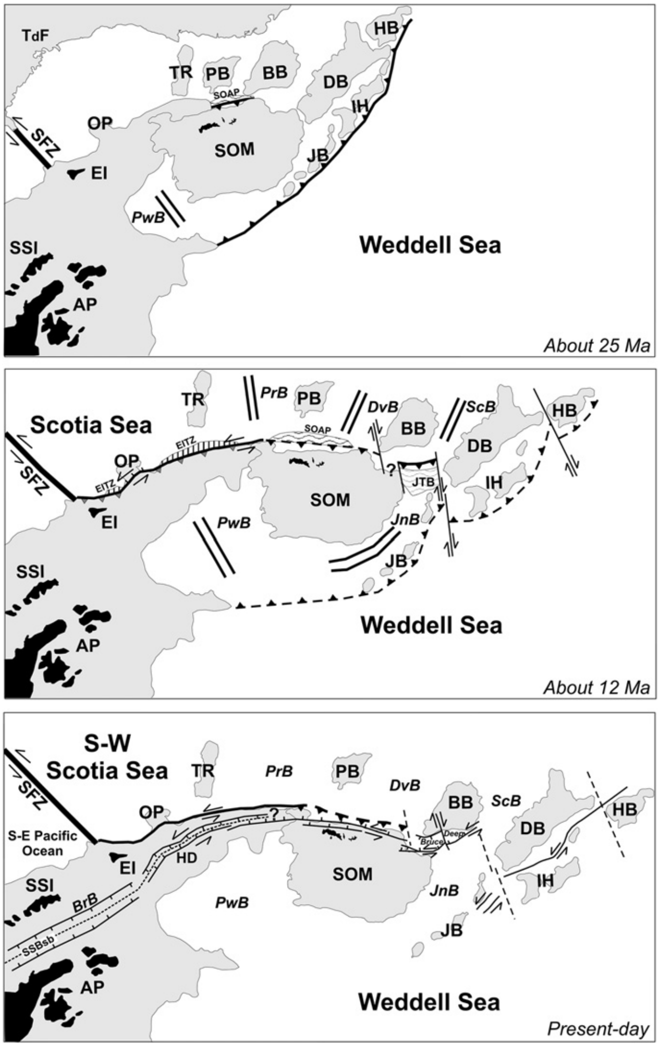

Fig. 15. Simplified sketches of a possible tectonic evolution of the Scotia–Antarctica plate boundary between the northern Antarctic Peninsula and Herdman Bank. TdF, Tierra del Fuego; OP, Ona Platform; TR, Terror Rise; SOM, South Orkney microcontinent; PB, Pirie Bank; BB, Bruce Bank; JB, Jane Bank; DB, Discovery Bank; IH, Irizar Highs; HB, Herdman Bank; JTB, Jane Thrust Belt; PrB, Protector Basin; DvB, Dove Basin; ScB, Scan Basin; PwB, Powell Basin; JnB, Jane Basin; SOAP, South Orkney accretionary prism; EITZ, Elephant Island transpressional zone; EI, Elephant Island; AP, Antarctic Peninsula; SSI, South Shetland Islands; SFZ, Shackleton Fracture Zone; BrB, Bransfield Basin; HD, Hesperides Deep; SSBsb, South Shetland block southern boundary.

development of contraction zones characterized by N-verging thrust and folds. The orientation of the margin with respect to the general Scotia–Antarctica plate kinematic vector, probably has determined its different structural architectures seen along the margin. A system of dextral strike–slip faults, oriented N–NW, was active in the region to the east of the South Orkney microcontinent, separating zones with different direction of movement. These faults have dismembered both the Scotia Sea subduction zone, and the previous NW-oriented Weddell Sea subduction zone, and also facilitated the process of fragmentation and dispersion of the crustal blocks. The convergent/subduction zone characterizing the northern margin of the South Orkney microcontinent probably shifted toward east in the Bruce Bank area, possibly because the opening of the Dove Basin which caused the S–E migration of the Bruce Bank. Compressional structures, folds and N-verging thrust sheets, have been detected along this convergent zone (the Jane Thrust Belt). During upper Pliocene, the Bransfield Basin initiated to open, and this rift-related structure progressively migrated toward E–NE in the Hesperides Deep (Galindo-Zaldívar et al., 2004). These processes lead to the formation of the independent South Shetland block, which represents a tectonic element fragmented from the Antarctic Peninsula continental crust.

(3) Quaternary to Present. During this period, the plate boundary has acquired a distinctive transcurrent, left-lateral character. It is actually constituted by a kilometric-scale fault system with a variable orientation, from E–NE in the western sector, to E–W in the central sector, to W–NW in the eastern sector to the west of the Bruce Bank. The master fault observed in the western part of the South Scotia Ridge seems to be presently quiescent, or with moderate tectonic activity, as testified by the absence of earthquakes in recent times. The earthquake epicenters are mostly located along the Bransfield Basin–Hesperides Deep axis. The subduction along the northern margin of the South Orkney microcontinent seems to have ceased, and it was superimposed by a mainly transtensional system oriented W–NW, and characterized by a strong earthquake activity in the recent past. Transtensional stresses, still active in recent times, generated narrow pull-apart basins in the fore-arc sectors of the Weddell Sea convergent zone to the east of the South Orkney microcontinent.

8. Conclusions

The South Scotia Ridge is a complex system of structural highs, small basins and narrow depressions that marks the morphological limit of the south Scotia Sea. This puzzle of blocks of different crustal nature was generated since Late Oligocene by the gradual stretching, separation and final dispersion of the original continental bridge between the southern South America and the northern Antarctic Peninsula. Seismic profiles have shown that the margins of the Tierra del Fuego and the Ona Platform and Terror Rise, two bathymetric elevations now located just to the N–W of the South Scotia Ridge, were once adjacent, and possibly represent the conjugate margins of the western Scotia Sea before the opening of the Drake Passage. The South Scotia Ridge is the locus of the present-day, left-lateral Scotia–Antarctica plate boundary. Analysis of seismic profiles, earthquake data and morpho-structural considerations, in combination with available gravity data modeling, has allowed reconstructing the structural setting of this plate boundary. From the Elephant Island to the northwesternmost margin of the South Orkney microcontinent, runs the plate boundary between the Scotia plate and the independent South Shetland continental block, tectonically limited to the south by the rift-related Bransfield Basin and its eastern prolongation within the Hesperides Deep. This boundary is defined by a sub-vertical master fault which abruptly juxtaposes the Scotia Sea oceanic crust against the continental crust. The movement along the fault has a mostly transpressional character, testified by the presence of a buried compressional zones, apart for the segment located in correspondence of the Ona Platform where extension is dominant. To the east, along the northern margin of the South Orkney microcontinent, an accretionary wedge has been identified, testifying the occurrence of a subduction zone presently inactive. Earthquake fault–plane solutions show a dominant extensional regime with some grade of strike–slip motion along this segment of the plate boundary. The segment to the east of the microcontinent is represented by an E–NE oriented pull-apart basin (Bruce Deep), separating the Bruce Bank from the eastern promontory of the South Orkney microcontinent. To the south of the Bruce Deep, a wide deformation zone with reverse faults and thrusts has been identified from seismic data. This eastern part of the plate boundary is the less constrained because the paucity of data and its inherent morphologic complexity. It may be composed by a series of pull-apart basins, separated by an array of NNW–SSE trending, strike–slip faults, disposed in *en-echelon* geometry. From the Bruce Bank to the east, focal mechanisms maintain a prevalent left-lateral strike–slip motion combined with an extensional component. In this sector, earthquakes are located in a 150 km wide area and on a local scale are difficult to follow unambiguously the plate boundary.

We have proposed an evolutionary sketch for the Scotia-Antarctica plate boundary, starting from the Late Oligocene-Early Miocene. During the Early Miocene, the Weddell Sea oceanic crust subducted northward below a series of bathymetric highs constituting the former South Scotia Ridge, and the process of fragmentation and dispersion of the crustal blocks by prevalent transcurrent motion between the two principal South America and Antarctic plates, had taken place. The northern margin of the South Orkney microcontinent was characterized by convergence and subduction of the crust separating the continental fragments, with the formation of an accretionary wedge. This was possibly generated by the eastward migration of the South Orkney microcontinent as a consequence of the Powell Basin opening initiated in the Early Oligocene. Along the segment encompassing the Elephant Island/north-western margin of the South Orkney microcontinent the plate boundary was marked by a sub-vertical, transcurrent master fault which juxtaposed the Scotia Sea oceanic crust with the South Scotia Ridge continental crust. The development of a dextral, N–NW trending *en-echelon* fault system dismembered both the Scotia Sea subduction zone, and the NW-oriented Weddell Sea subduction zone, and also facilitated the process of fragmentation and dispersion of the crustal blocks. During the upper Pliocene, Bransfield Basin initiated to open, and this rift-related structure progressively migrated toward E–NE forming the Hesperides Deep, and leading to the formation of the independent South Shetland microplate. Finally, the left-lateral transtensional tectonism generated narrow pull-apart basins in the forearc sectors of the convergent zones.

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