

The Scan Basin evolution: oceanographic consequences of the deep connection between the Weddell and Scotia Seas (Antarctica)

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Abstract. Scan Basin is a small oceanic basin located in the southern central Scotia Sea, north of the Bruce Passage (BP) which represents the main gateway between the Weddell Sea and the Scotia Sea. A seismic stratigraphy analysis has been carried out by multichannel seismic reflection profiles, to determine the Miocene to present evolution of that basin. Five seismic units are identified. The last four units represent the *post-drift* deposits, characterizing three major evolutionary stages: a) Pre- BP opening stage (Sc-4 unit); b) BP opening stage (Sc3 and Sc2 units) and c) Post- BP opening stage (Sc1 unit). The second stage is formed once the BP is deep enough to allow the exit of the Weddell Sea Deep Water (WSDW) to the Scotia Sea, and since then large contourite drifts were developed migrating northwards. The last stage has been developed during the present-day sinistral transcurrent compressive regime.

Introduction

Several independent small basins bounded by extended continental blocks are recognised in southern Scotia Sea and northern Weddell Sea, near the Scotia-Antarctic plate boundary (Fig. 1). All those basins have been developed in relation with sea-floor spreading in the Scotia Sea and subduction of the Weddell Sea and Southern Atlantic below several fragments of an eastward and southward migrating trench (Maldonado et al., 2006). The main aim of this work is to elucidate the Miocene to present evolution of Scan Basin, located between Bruce Bank (BB) to the W and Discovery Bank (DB) to the E, and northeast of Bruce Passage (BP), which represents the main connection between Weddell and Scotia seas through Jane Basin (JB) (Fig. 1B). Southwards, a complex tectonic structure comprising highs and troughs constitutes the plate boundary, and separates the basin, through the BP, from the NE prolongation of both the South Orkney Microcontinent (SOM) and JB. Northwards, the Scan Basin is connected to the abyssal plain of Central Scotia Sea. Tectonic deformation of that plate boundary is concentrated along the South Scotia Ridge (SSR), formed by a complex array of continental blocks that show evidence of tectonic activity related to the present-day sinistral transcurrent motion (Bohoyo et al., 2007).

The present study is based on new geophysical data collected during the SCAN2004 cruise onboard R/V Hesperides (Fig. 1A). We have focused on interpretation of multichannel seismic reflection (MCS) profiles, which are two sections, orthogonal to the Scan Basin margins and one section parallel to the eastern margin.

Oceanographic framework

Among the deep-water masses in the Weddell and Scotia Seas region, two distinct components can be distinguished (Naveira-Garabato et al., 2002) (Fig. 1C):

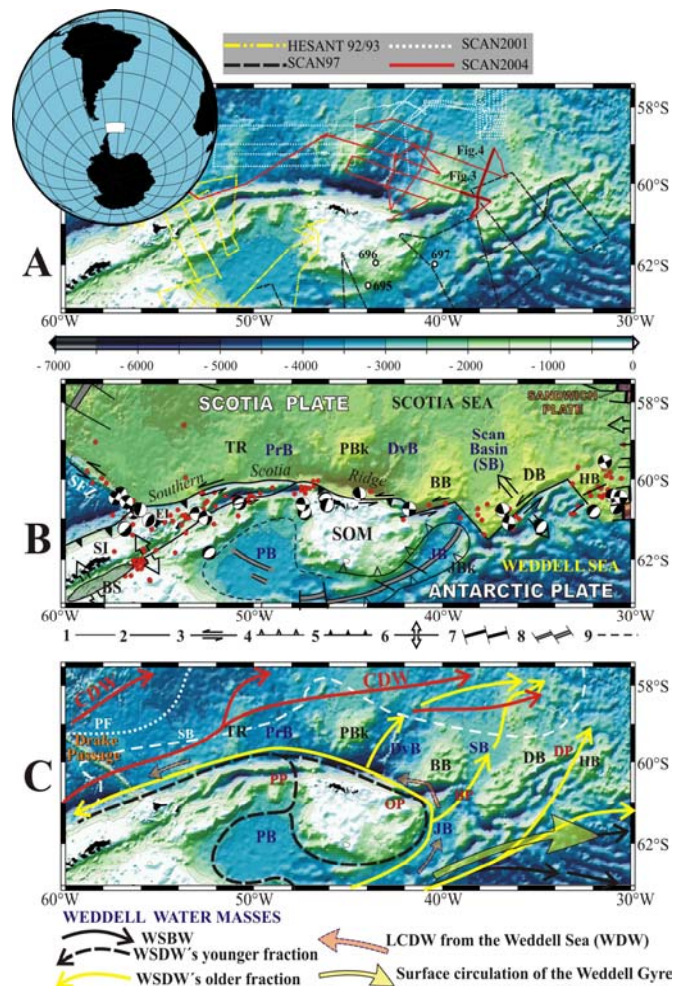


Figure 1. Location of the Scan Basin. A) Bathymetric map, showing the position of seismic profiles collected in the area. B) Geological setting. 1: transform fault; 2: active transcurrent fault; 3: inactive subduction zone; 4: active subduction zone; 5: active extensional zone; 6: active transtensional zone; 7: active spreading centre; 8: inactive; spreading centre; 9: continental-oceanic crust boundary. BB: Bruce Bank; DB: Discovery Bank; DvB: Dove Basin; HB: Herdman Bank; JB: Jane Basin; JBk: Jane Bank; PB: Powell Basin; PBk: Pirie Bank; PrB: Protector Basin; SB: Scan Basin; SOM: South Orkney Microcontinent; TR: Terror Rise; C) Regional deep-water masses circulation. BP = Bruce Passage; DP = Discovery Passage; OP = Orkney Passage; PP = Philip Passage

1) One is the Circumpolar Deep Water (CDW) flowing mostly to the E with the ACC. It is internally sub-divided into Upper (UCDW) and Lower (LCDW). The LCDW is the densest fraction, derived mainly from North Atlantic Deep Water (NADW) intruding into the ACC in the Atlantic sector.

2) The deepest water mass is the Antarctic Bottom Water (AABW), which is composed by the Weddell Sea Bottom Water (WSBW) and the Weddell Sea Deep Water (WSDW). The Warm Deep Water flowing above the WSDW (WDW) is a branch of the LCDW in the Weddell Sea. WSBW is the deepest water mass and is bathymetrically constrained to circulate within the Weddell Gyre. The WSDW is not a uniform water mass, and can be sub-divided into younger and older fractions. The WSDW's older fraction flows below 1600 m, and is divided into two different main cores. One core is channelled through JB and overflows into the Scotia Sea beyond the SOM mainly through Orkney Passage (OP), BP and Discovery Passage (DP) (Fig 2). Another important core moves (as does the WSBW), around the South Sandwich Trench towards the north. The WSDW spills over the SSR and spreads westward reaching Drake Passage and filling the bottom of the South Shetland Trench.

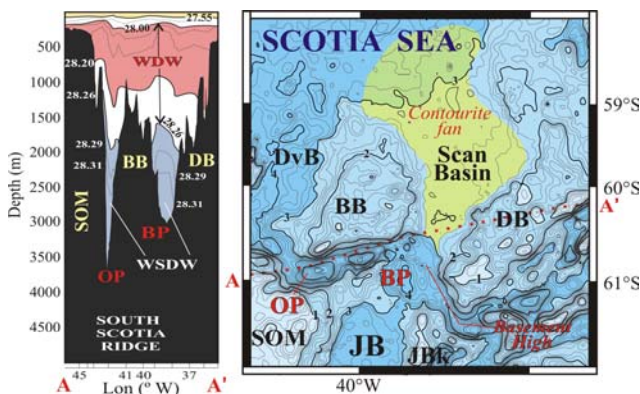


Figure 2. Location of the Scan Basin. Main morphologies and vertical distribution of water masses with density contours are showed (Legend in Fig.1).

This modern oceanographic regime was set up, once (a) a deep water pathway was established in Drake Passage when the Scotia Sea started to develop, (b) gaps opened between the continental and arc fragments to the east in the Scotia Sea to allow a complete, full-ocean-depth ACC to develop, and (c) gaps opened in the SSR to allow WSDW (and WDW) to escape from the Weddell Gyre into the Scotia Sea, and then to flow westwards. For Maldonado et al., (2003) initial incursions of the WSDW into the Scotia Sea were possible from the Middle Miocene.

Morpho-structure and seismic stratigraphy analysis

Scan Basin is a small oceanic basin with a NE trend, showing a triangular shape wider to the north and ranging from 40 to 150 km and around 250 km in length (Fig. 1B & 2). The morphology and orientation of the basin suggests that an oceanic spreading or continental crustal stretching producing the separation of BB and DB took place in an

ENE-WSW direction. A WNW-ESE oriented basement high is located in the eastern part of BP, at the southernmost sector of the Scan Basin and northernmost of JB. This basement structure is approximately 1000 m high, 30 km wide and 45 km long (Fig. 2 & 3). The sedimentary record is deformed over the basement high, reaching a total of ~1500 ms (tw) in thickness but thinning out northwards where is reduced to ~1200 ms (tw). A seismic stratigraphy analysis permitted the recognition of five seismic units (SU), Sc5 to Sc1, characterising four evolutionary stages of the Basin (Fig. 3 & 4). The basement was not identified in the southern sector, where internal reflections could be attributed to a thinned continental crust. Nevertheless, the oceanic basement is clearly identified at variable depths of 5-6 s in the northern sector.

In the southern sector a thick deposit (Sc5 unit) characterised the pre- and syn-drift stage (Fig. 3). This unit is identified, over the eastern flank of BB where it is ~800 ms thick and shows high-amplitude internal reflections tilted toward the E and with high lateral continuity. The internal configuration changes eastward to massive, chaotic seismic facies. Four major SUs constitute the post-drift sedimentary record (Sc4 to Sc1 units). These SUs abut westward against BB in the southern sector, sealing pre- and syn-drift deposits. Nevertheless, in the northern sector they can be correlated with the DvB over BB. Eastwards, these deposits occur over DB where they are deformed and tilted toward the W. Sc4 to Sc1 units characterise the following three evolutionary stages (Fig. 3 & 4):

a) Pre- BP opening stage (Sc-4 unit)

This unit shows a patchy distribution over both previous Sc5 unit in the south and over the oceanic basement northwards. It is ~400 ms thick on average, but it may reach up to 1 s over the eastern flank of DB or pinch out laterally. Internal reflections display high amplitude and lateral continuity, showing a southward progradational trend.

b) BP opening stage (Sc3 and Sc2 units)

The onset of this stage is recorded by a widespread, high-amplitude discontinuity (reflection c), that can be traced at basin scale. Sc3 and Sc2 units display similar seismic facies, but are separated by reflection b, characterising a large confined drift. Although sheet-like morphologies are common in both SUs, locally show mounded geometries. SUs Sc3 and Sc2 prograde northward in the southernmost sector, and internal reflections display high to very high amplitudes and low lateral continuity. Sc3 and Sc2 depocenters occur close to DB constituting an asymmetrical basin, where Reflectors c & b determined paleo-valleys positioned at the base and parallel to the DB (at eastern part of Scan Basin). Sc3 unit shows two internal subunits (b & a) downlapping over Reflection- c, with an overall thickness of ~400 ms in the southern sector but thinning out considerably towards the north. The upper boundary (Reflection- b) is an erosive unconformity with low to moderate amplitude. The younger Sc2 unit is up to 600 ms thick in the southern sector, thinning out northward, where it is ~400 ms thick on average. Sc2 unit shows downlap terminations over the Reflection- b, and displays mounded

and sheet-like external shapes, and superimposed sedimentary waves are recognized locally

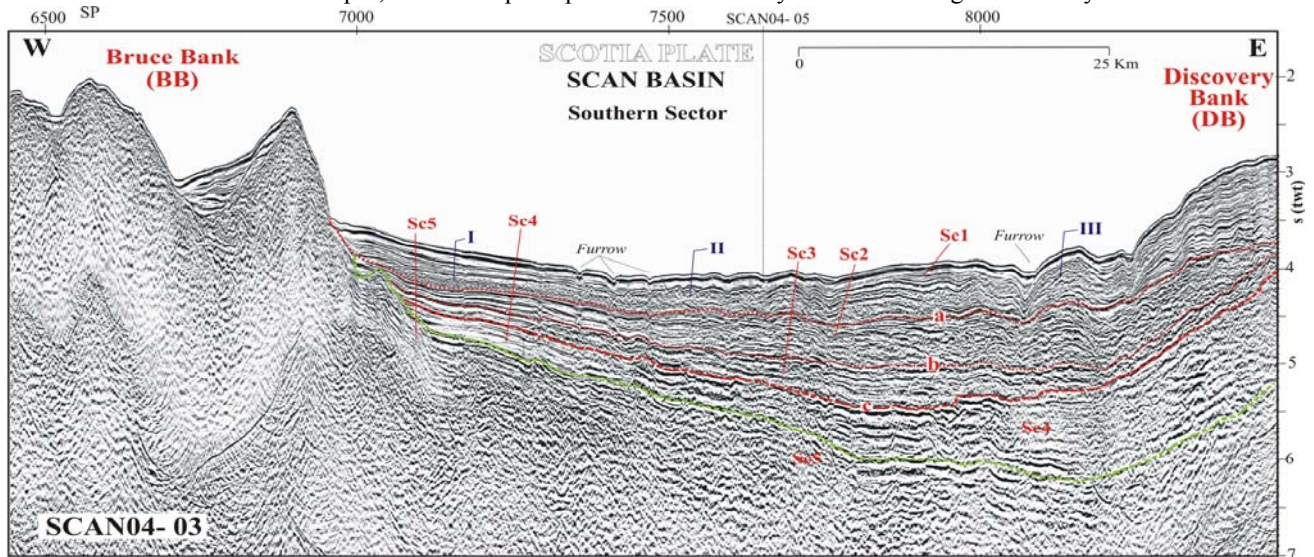


Figure 3. Seismic profile Scan04-05 collected across the Scan Basin. Seismic units (Sc5 to Sc1) are illustrated. Location in Fig. 1A

c) Post- BP opening stage (Sc1 unit)

The most recent SU is composed of several subunits. The lower discontinuity (Reflection-a) shows high amplitude and high lateral continuation, constituting a significant change in the sedimentary evolution of the basin. This boundary is considered an erosive surface which controls a paleo-valley situated at the base and parallel to the BB (at western part of Scan Basin). Four lobate subunits (IV, III, II & I in Fig. 3 & 4) with chaotic to massive seismic facies compose this unit. The distribution of the subunits shows a progressive northward displacement from oldest to youngest. Above them, a thick homogeneous new subunit with a wide distribution and reflective acoustic responses is determined. Over the basement, high in the southernmost sector, this deposit is quite thin (~100 ms twt), reaching ~400 ms (twt) in the southern sector but 600 ms (twt) in the northernmost sector. This deposit is characterized by thin well stratified sub-parallel reflectors with very good lateral continuity and progradation northwards downlapping the basal discontinuity. Small amplitude sediment waves are identified locally. Sc1 unit is interpreted as a huge contourite fan. Three internal subunits (c, b & a) can be identified within it, as well as many furrows especially in the southern sector of the basin.

Discussion and conclusion: the Scan basin evolution and its oceanographic consequences

The NNE margin of the SOM, with WNW-ESE orientation, is characterised by a convergent component that produces the subduction of the Scotia Plate below the Antarctic Plate, as proposed by Buseti et al. (2000). Between the SOM and BB, an E-W oriented depression with seismic activity and strike-slip earthquake focal mechanism points to a purely sinistral regime on E-W oriented faults (Bohoyo et al., 2007).

The four aforementioned stages within the Scan Basin should be placed in the context of basin evolution and the

connection between the Weddell Sea and Scotia Sea through the BP. The basement age of the Scan Basin is difficult to determine, but, taking in consideration the regional tectonic (Galindo-Zaldívar et al., 2006; Bohoyo et al., 2007), the opening age of Scan Basin should be coeval to the opening age of Protector and Dove Basins, which took place between 14 to 12 Ma (Middle Miocene), later than JB, which was completely open by 14.4 Ma (Bohoyo et al., 2002). Sc-4 was probably deposited once the Scan and JB were already opened but without any deep connection between them. This unit should be probably Middle Miocene in age. In any case, by the Early Miocene, a deep water pathway had certainly been established through Drake Passage, allowing vigorous ACC circulation. Paleobathymetric analysis shows that at 20 Ma the deep basins of the southern hemisphere were well connected (Lawver and Gahagan, 2003). The progradation of the deposits southwards was induced by the effect of the circulation of one southern core of the CDW within the Scan Basin.

Reflection- c represents the beginning of the BP opening stage, instaurated once this passage was opened (or deep enough) for the deep water circulation. The existence of different units (Sc3, Sc2 and Sc1) suggests that the connection took place in different steps which produce the stacking of large drifts migrating northwards as a consequence of the WSDW exit to the Scotia Sea, but being restricted first to the interior of the Scan Basin (Sc3 unit). Sykes et al., (1998) suggested that by 15 Ma, due to waning proto-AABW production, bottom current activity due to AABW was mainly restricted to water depths greater than ~5500 m, and therefore the branch of dense WSDW flowing to the Pacific Margin may have been relatively weak during the Middle-Late Miocene, which could explain why the Sc3 unit thins out northwards. Paleo-valleys related to Reflections- c & b, allow to infer that during the deposition of Sc3 and Sc2 units, the main core of the WSDW was

located on the east part of the Scan Basin (right downstream), at the base of the DB.

The Post- BP opening stage represents the last major evolutionary stage of Scan Basin, starting with Reflection-a. The deposition of the four lobular chaotic subunits (VI, III, II & I) deposition should represent an important event related to the present compressive regime in the Scan Basin. This compressive regime probably produced: (a) the deformation and tilting of the units generated in the previous stages, (b) the basement high located eastern part of the BP, which may represent a pop-up structure due to a local compressive regime as Bohoyo et al. (2007) propose in its tectonic model; (c) the lateral migration of the main core position of the WSDW which has been located since then to the present on the west part of the basin (left downstream) at the base of the BB. This lateral change in the position of the main core should be related to the basement high formation in the BP which forces the water mass to produce its major core in the western part of it. This present-day sinistral transcurrent regime, with local

compressive, was set up in general terms, once (a) all basins located in the southern Scotia Sea were completely opened (10-12 Ma, Galindo-Zaldivar et al., 2006); (b) the beginning of the oceanic spreading in the East Scotia Ridge (C5C?-16.4 Ma, Larter et al., 2003) took place, and (c) cessation of spreading in the West Scotia Ridge (C4- 6 Ma, Maldonado et al., 2000).

A huge contourite fan migrating northwards was coeval with the compressive regime. Internal facies and common erosive features suggest an intensification of the WSDW energy in comparison with previous units. Therefore these deposits could be related to the later, waxing of AABW during the latest Miocene-early Pliocene which permitted the reconnection of the deep basins, activating a strong thermohaline circulation (Sykes et al., 1998).

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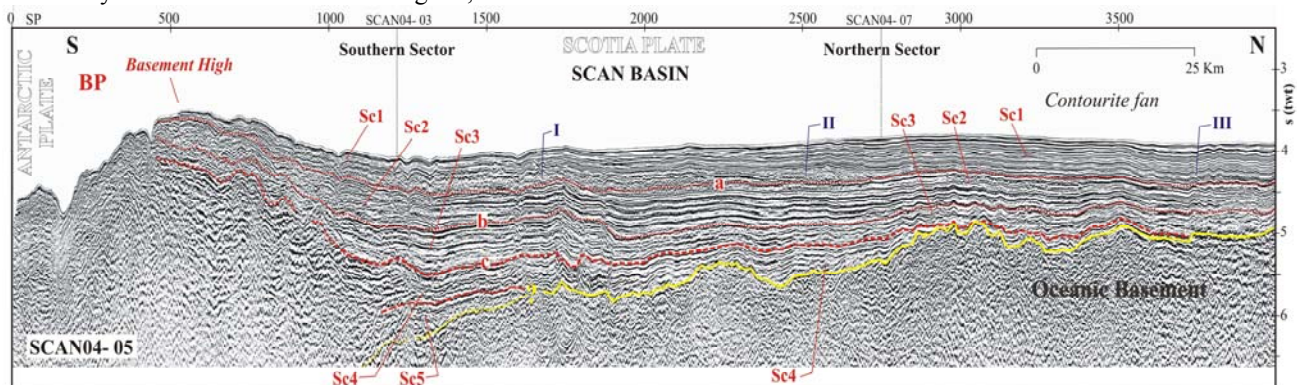


Figure 4. Seismic profile Scan04-05 collected along the Scan Basin. Seismic units (Sc5 to Sc1) and basement are illustrated. Location in Fig. 1A

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