Early opening of Drake Passage: regional seismic stratigraphy and paleoceanographic implications

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Summary The tectonics and distribution of seismic units of the central and southern Scotia Sea are described based on multichannel seismic profiles and magnetic anomalies. Recently acquired profiles suggest that spreading in the Drake Passage was active prior to 30.9 Ma, although the tectonics of the area suggests that rifting of the margins and shallow gateways existed well before that time. After breakup, the Scotia Sea developed from several spreading centers that produced ocean basins. Five main seismic units are identified in the Cenozoic sedimentary section. The three youngest units exhibit similar seismic facies and are correlated at regional scale. These deposits contain a variety of contourite drifts resulting from the interplay between the northeastward flow of the Weddell Sea Deep Water, the Antarctic Circumpolar Current and the complex bathymetry. The three units were deposited after the Middle Miocene connection between the Scotia Sea and the Weddell Sea was established.

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Introduction

The opening of Drake Passage facilitated the development of the final gateway for a continuous deep-water circulation around Antarctica (Barker, 2001; Lawver and Gahagan, 2003; Livermore et al., 2004). The gateway between South America and Antarctica allowed the initiation of the Antarctic Circumpolar Current (ACC), which is proposed to have profound effects on the evolution of the Antarctic climate and the north-south ocean circulation patterns. In addition, the ACC provides the only linkage between the three main world ocean basins and it controls the transport of heat, salt and nutrients around the globe (Naveira Garabato et al., 2003).

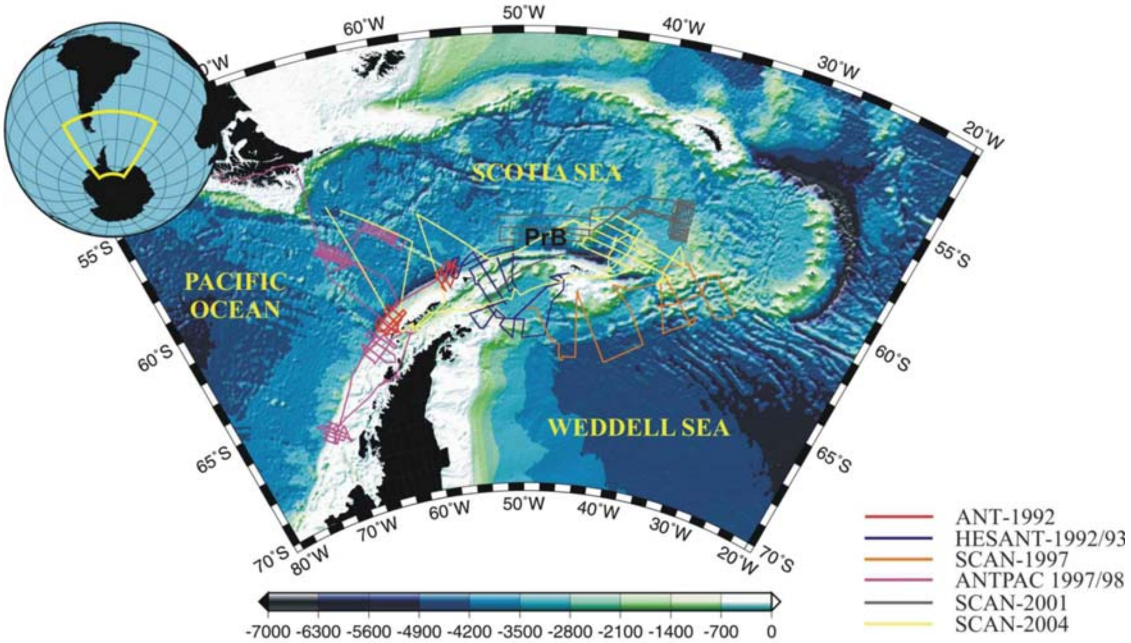

Figure 1. Simplified bathymetric map from the GEOSAT of the Scotia Sea (Sandwell and Smith, 1997), showing the location of cruises obtained in the area. PrB: Protector Basin.

Multichannel seismic reflection profiles and magnetic anomalies of the region that we collected over the last decade allow us to establish the main tectonic events and the geodynamics of the area (Fig. 1). We also propose a preliminary correlation of deposits of the basins and show how their evolution was influenced by tectonics, which controlled the opening and closing of gateways, and by global paleoceanographic events. The units are tentatively dated on the basis of interpreted magnetic spreading anomalies, the total thickness of the deposits, information from Ocean Drilling Program boreholes data, and sedimentation rates from sediment cores (Maldonado et al., 2003, 2006).

Basin age and seismic stratigraphy

Spreading of the Drake Passage was active prior 30.9 Ma (Chron C12n), although the tectonics of the area suggests that rifting of the margins and shallow seaways between the Antarctic Peninsula and South America existed was underway prior to that time (Figs. 1, 2). The development of the Protector Basin is well constrained by the seafloor magnetic anomalies (14.0-14.4 to 17.6 Ma), whereas the magnetic anomalies of the central Scotia Sea indicate an age of spreading between 20.7 and 14.2 Ma (Maldonado et al., 2003, 2006; Galindo-Zaldívar et al., 2006).

Five main seismic units are identified regionally (Maldonado et al., 2006) (Figs. 3, 4). The units are bounded by high-amplitude continuous reflectors, named a to d from top to bottom. The two older units are of different age and seismic facies in each basin and they generally correspond to post breakup deposits of the early drift phase and are not considered further here. The three youngest units (3 to 1) exhibit, in contrast, similar seismic facies between the basins and can be correlated at a regional scale (Figs. 3, 4). The deposits show a variety of contourite drifts that resulted from the interplay between the northeastward flows of the Weddell Sea Deep Water (WSDW), the Antarctic Circumpolar Current (ACC) and the complex bathymetry. A major paleoceanographic event was recorded by Reflector c (~12.1-12.6 Ma) which represents the connection between the Scotia Sea and the Weddell Sea (Maldonado et al., 2006). Unit 3 (~Middle to Late Miocene) shows the initial incursions of the WSDW into the Scotia Sea, which influenced a northward progradational pattern, in contrast to the underlying deposits. The tentative age calculated for Reflector b is coincident with the end of spreading in the West Scotia Ridge (~6.4 Ma). The deposits of Unit 2 (~Late Miocene to Early Pliocene) contain abundant high-energy, sheeted deposits in the northern Weddell Sea, which may reflect a higher production of WSDW as result of the advance of the West Antarctic ice-sheet onto the continental shelf. Reflector a represents the last major regional paleoceanographic change. The timing of this event (~3.5-3.8 Ma) coincides with the end of spreading at the Phoenix-Antarctic ridge, but it may be also correlated with global events such as the initiation of the permanent Northern Hemisphere ice-sheet and a major sea level fall. Unit 1 (~Late Pliocene to Recent) is characterized by high-energy contourite deposits, which suggest intensified deep water production. Units 1 and 2 show, in addition, a cyclic pattern, more abundant wavy deposits and the development of internal unconformities, all of which attest to alternative periods of increased bottom current energy.

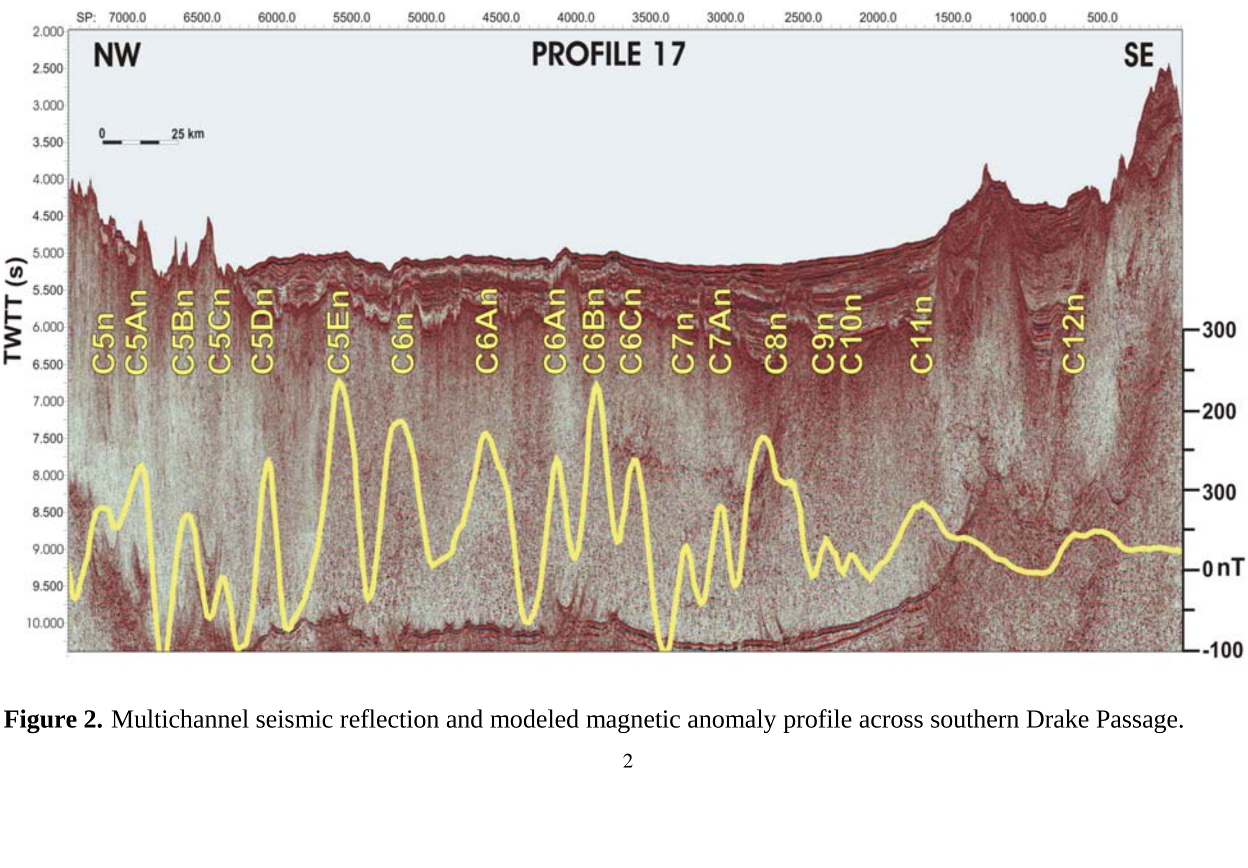

Figure 2. Multichannel seismic reflection and modeled magnetic anomaly profile across southern Drake Passage.

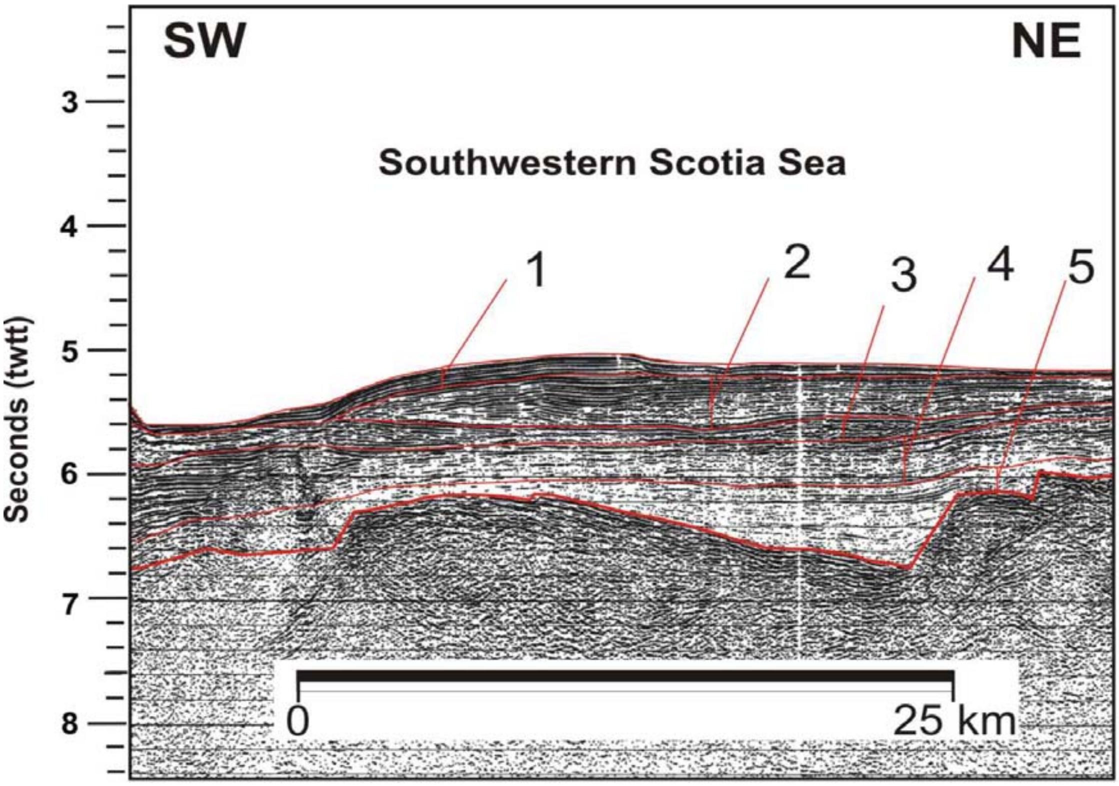

Figure 3. Interpreted section of multichannel seismic reflection profile M02 illustrating seismic units in the southwestern Scotia Sea abyssal plain.

Discussion and conclusions

The Earth's climate experienced a major change near the Eocene-Oligocene boundary, but whether it can be explained strictly as a result of the opening of southern latitude oceanic gateways, or attributed to changes in atmospheric CO_2 concentrations, or is in fact the result of multiple causes, is a subject of debate (Lawver and Gahagan, 2003; DeConto and Pollard, 2003; Livermore et al., 2004). The new magnetic anomalies indicate, however, the development of oceanic crust in Drake Passage and that an oceanic gateway existed between South America and the Antarctic Peninsula prior to 30.9 Ma. Taking into consideration the timing for breakup and the tectonics of the area, a gateway may have developed in Drake Passage close to the Eocene/Oligocene boundary. The ridges and basins that were active during the early stages in the evolution of the Scotia Sea controlled the development of the Antarctic Circumpolar Current and the deep water flows (Barker, 2001; Maldonado et al., 2003). The major regional unconformity represented by Reflector c seems coeval with a major Miocene glaciation (Mi4), a lowering of sea level (Ser3) and with the initiation of the permanent East Antarctic ice-sheet. This reflector suggests a major event in the dynamics of bottom water circulation, which would represent the connection between the Scotia Sea and the Weddell Sea across the South Scotia Ridge.

The Oligocene glaciers of Antarctica were isolated and a West Antarctic ice-sheet that advanced onto the continental shelf did not develop until the Late Miocene (Anderson and Shipp, 2001), which seems to be recorded by Reflector b and may also be coincident with the end of spreading at the West Scotia Ridge. It has been proposed that a major factor for the present global ocean circulation and the Late Pliocene formation of the West Antarctic and Northern Hemisphere ice-sheets was the closure of the Isthmus of Panama, at about 3.7-3.0 Ma ago (Lawver and Gahagan, 2003). The coincidence between the ages calculated for Reflector a and the timing of closure of the Panamanian seaway is remarkable. Spreading ended almost coetaneous at the Phoenix Ridge, however, which may also had a more significant influence on the paleoceanography of the area by modifying the deep water flows through significant changes in the sea bottom topography of Drake Passage.

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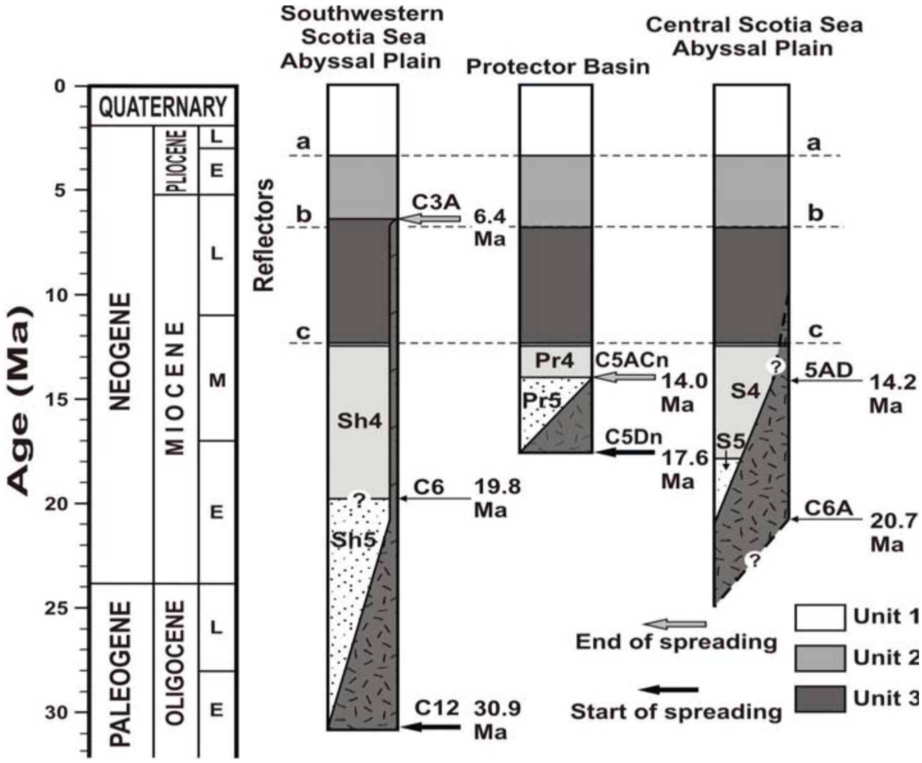

Figure 4. Correlation of seismic units identified in the southern and central Scotia Sea

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