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Tectonics and palaeoceanographic evolution recorded by contourite features in southern Drake Passage (Antarctica)

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A B S T R A C T

The sedimentary record in the vicinity of the triple junction at the southern Drake Passage is analyzed in order to decode the palaeoceanographic evolution and the influence of tectonic events. The break-up of the last connection between South America and Antarctica led to the circulation of important oceanographic bottom flows, including the Antarctic Circumpolar Current (ACC) and the Weddell Sea Deep Water (WSDW). The Shackleton Fracture Zone (SFZ), a ridge crossing the central Drake Passage, has been proposed as a major barrier that constrained the free circulation of bottom flows in the area, but whose timing and importance is poorly established. Also, the South Scotia Ridge (SSR), a prominent relief composing the southern part of the Scotia Arc, has controlled oceanographic exchanges between the Weddell and Scotia seas, as bottom flows from the Weddell Sea to the Scotia Sea have been conducted across narrow gateways along the SSR. On the basis of a network of multichannel seismic profiles, we interpret the uplift dynamics of the SFZ in the southern Drake Passage and its influence on the evolution of the bottom-current circulation and by extension on contourite processes.

Six main seismic units, identified and correlated between the Scotia and the Former Phoenix plates, depict a south-west-directed tilting of the deposits above a mid-Miocene reflector (Reflector c) on the Phoenix Plate. The regional correlation of the main reflections and contourite features indicates that the deepest fraction of the ACC, the Lower Circumpolar Deep Water (LCDW as the lower part of the Circumpolar Deep Water, CDW), flowed freely from the latest Eocene to the middle Miocene, and that these palaeo-flows have been active until the present in the abyssal plain of the central–western Scotia Sea. SFZ uplift was initiated, at the latest, during the middle Miocene (about 12 Ma), when the SFZ began to be an effective barrier to bottom flows in the southern Drake Passage. The ridge forced the ACC and the Polar Front to shift northward contributing to the thermal isolation of Antarctica and more polar conditions. The northward displacement of the LCDW and the opening of passages along the SSR favored the insertion of WSDW flows along the southern part of the Drake Passage, westward into the Pacific Ocean and northward into the abyssal plain of the southwestern Scotia Sea. Based on the morphology and evolution of the main erosional features, we also calculate a ratio between two volumetric flow rates related to the two major branches of the WSDW in the southwestern Scotia Sea area. The highest ratio is found for the age of Reflector b and is probably related with the strongest incursions of the WSDW in the area, as well as with SFZ uplift. This work demonstrates the common occurrence of large depositional and erosional features in deep marine environments related to bottom-current activity and their important implications on decoding palaeoceanographic, climatic and tectonic events.

1. Introduction

The Drake Passage is a deep gateway the entire length of which is crossed by the Shackleton Fracture Zone (SFZ), a significant structural relief with elevations of hundreds to thousands of meters above the surrounding ocean floor (Maldonado et al., 2000; Livermore et al., 2004). The age of the initial tectonic opening of the Drake Passage is not well constrained, but likely has significant implications for global oceanic circulation and climate evolution in Antarctica as it created the final gateway to allow the establishment of a full circum-Antarctic circulation and the thermal isolation of the Antarctic continent (cf., Kennett, 1977; Lawver et al., 1992; Barker, 2001; Barker and Thomas, 2004; Livermore et al., 2004; Maldonado et al., 2006) coeval with global reduction in the atmospheric CO_2 (Deconto and Pollard, 2003). However, the importance of the opening of the Drake Passage as trigger of the Antarctic thermal isolation is a subject of controversy as some authors suggest that the heat anomalies caused by the

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opening and the initial circumpolar current were weak to lead to the abrupt Cenozoic cooling (Huber and Sloan, 2001; Zhong-Shi et al., 2010).

The southwestern Scotia Sea is a key region for constraining the time of opening because it contains the oceanic crust that developed during the initial phases of oceanic spreading (Aldaya and Maldonado, 1996; Lodolo et al., 2006, 2010). The oldest oceanic magnetic anomalies interpreted in the region suggest an early Oligocene opening age (ca. 32 Ma, Lodolo and Tassone, 2010), and arguments based on plate tectonic reconstructions propose an opening during the middle Eocene (ca. 45 Ma, Livermore et al., 2007), the Oligocene (Lawver and Gahagan, 2003; Geletti et al., 2005; Lodolo et al., 2010), or the Miocene (Barker, 2001). In addition to its influence during the initial evolutionary stages, the SFZ has been suggested as a significant barrier to the circumpolar deep flow since the late Miocene (8 Ma, Livermore et al., 2004). In addition, the deformed continental blocks of the South Scotia Ridge (SSR) have also influenced the bottom-current distribution in the area. Therefore, the complex tectonic evolution of this region has influenced bottom-current circulation, which in turn has controlled the growth patterns of contourite drifts (Fig. 1).

We analyze the triple junction region in the southwestern Scotia Sea, where the extinct Phoenix, Antarctic, and Scotia plates meet (Aldaya and Maldonado, 1996). The study area is located where the SFZ intersects the SSR and where the Weddell Sea Deep Water (WSDW) enters the Pacific Ocean from the Scotia Sea. Above the WSDW is flowing east the Circumpolar Deep Water (CDW), specially its lower fraction, the Lower Circumpolar Deep Water (LCDW) (the deeper fraction of the Antarctic Circumpolar Current (ACC)) (Carter et al., 2008) (Fig. 1). In this context, we focus on two main objectives:

(1) To characterize the type, distribution, and development of deposits that resulted from the interaction between the sea-bottom reliefs, caused by active tectonics, such as SFZ uplift and the SSR development, and the circulation of the main

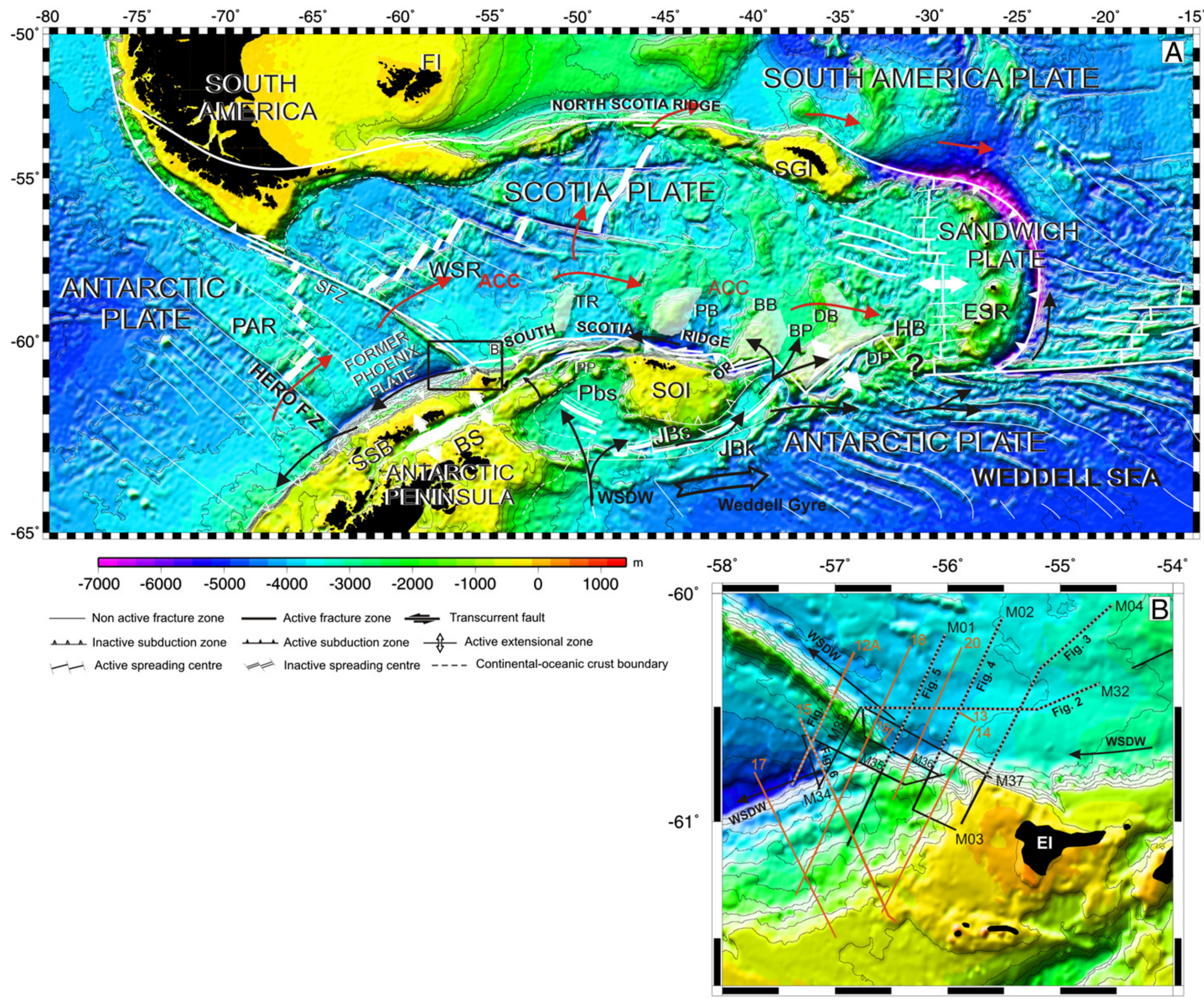

Fig. 1. A) Geological setting and satellite bathymetry map (data from Smith and Sandwell, 1997) of the Scotia Sea (Modified from Bohoyo et al., 2007). Study area is located in the black square. *Legend of physiographic features*: APR, Antarctic–Phoenix Ridge; BB, Bruce Bank; BS, Bransfield Strait; BP, Bruce Passage; DB, Discovery Bank; DP; Discovery Passage; ESR, East Scotia Ridge; HB, Herdman Bank; JBs, Jane Basin; JBk, Jane Bank; OP, Orkney Passage; PB, Pirie Bank; Pbs, Powell Basin; PP, Philips Passage; SFZ, Shackleton Fracture Zone; SGI; South Georgia Islands; SOI, South Orkney Islands; SSB, South Shetland Block; TR, Terror Rise; WSR, West Scotia Ridge. *Legend of main water masses*: ACC, Antarctic Circumpolar Current; WDSW, Weddell Sea Deep Water. B) Detailed map of the triple junction area. Profiles from ANT92 (orange lines) and HESANT92/93 (black lines) cruises are located in the map. Gray dashed lines represent the profiles shown in this study. EI, Elephant Island.