Onset and development of the Drake Passage and Scotia Sea gateways and its influence on global ocean circulation and climate (IODP proposal)

Inicio y desarrollo del Paso de Drake y de los portales oceánicos del Mar de Scotia y su influencia en el clima y la circulación oceánica global (Propuesta IODP)

F. J. Hernández-Molina[1], R.D. Larter[2], E. Thomas[3], L. F. Pérez[4], G. Eagles[5]; F. Bohoyo[6], E. Lodolo[7], X. Chuang Xuan[8], I.W.D. Dalziel[9], D.A.V. Stow[10], C. Escutia[11], J. Biddle[12], W. Sijp[13], D. Harwood[14] and D. A. Tassone[15]

1 Dept. Earth Sciences, Royal Holloway Univ. London, Egham, Surrey TW20 0EX, UK, javier.hernandez-molina@rhul.ac.uk
2 BAS, High Cross, Madingley Road, Cambridge CB3 0ET, UK, rdla@bas.ac.uk
3 Dept. Geology and Geophysics, Yale Univ., 210 Whitney Avenue, New Haven CT 06511, USA, ellen.thomas@yale.edu
4 Geophysical Dept. Geological Survey of Denmark and Greenland, Øster Volgade 10, DK-1350 Copenhagen, Denmark, lfp@geus.dk
5 AWI, Helmholtz Centre for Polar and Marine Research, Am Alten Hafen 26, Bremerhaven D-27568, Germany, geagles@awi.de
6 Instituto Geológico y Minero de España, Ríos Rosas, 23 28003, Madrid (Spain), f.bohoyo@igme.es
7 OGS, Trieste, Italy, elodolo@ogs.trieste.it
8 Ocean and Earth Science, Univ. Southampton. European Way Southampton, SO14 3ZH, UK, C.Xuan@soton.ac.uk
9 Univ. Texas at Austin, 10100 Burnet Road, Austin, Texas 78758, USA, ian@utig.ig.utexas.edu
10 IPE. Heriot-Watt Univ., Edinburgh EH14 4AS, Scotland, UK, Dorrik.Stow@pet.hw.ac.uk
11 IACT. CSIC-U. Granada. Campus de Fuentenueva s/n. 18002 Granada (Spain), cescutia@ugr.es
12 College of Earth, Ocean and the Environment, University of Delaware, 700 Pilottown Rd., Lewes, DE 19958, jfbiddle@udel.edu
13 Univ. New South Wales, Sydney NSW 2052, Australia, w.sijp@unsw.edu.au
14 Univ. Nebraska-Lincoln. Lincoln, NE 68588, USA, dharwood1@unl.edu
15 Univ. Buenos Aires, Buenos Aires, Argentina, atassone@gl.fcen.uba.ar

Abstract: The DRAKE-SCOTIA SEA GATEWAYS is a new multidisciplinary International Ocean Discovery Program (IODP) drilling proposal aimed at determining the time of opening and pattern of development of gateways in the Drake Passage and the adjacent Scotia Sea, and their influence on global ocean circulation, biotic evolution and climate. The Drake Passage with the adjacent Scotia Sea represent one of Earth's most important oceanic gateways, between the southern tip of South America and the Antarctic Peninsula, a crucial area for water mass exchange between the Pacific Ocean, the Atlantic Ocean and the Weddell Sea, the importance of which is evidence by in many multinational studies. Nevertheless, the region has not been yet drilled for scientific purposes. The objective of this work is to present the main scientific goals of this drilling proposal and its link with the IODP Science Plan for 2013-2023.

Key words: Gateways, plate tectonics, global implications, paleoceanography, environmental changes

Resumen: La propuesta *DRAKE-SCOTIA SEA GATEWAYS*, es una nueva propuesta multidiciplinar de perforación oceánica presentada al *International Ocean Discovery Program* (IODP) que pretende determinar la apertura y modelo de desarrollo de los portales oceánicos del Paso de Drake y de otros adyacentes en el Mar de Scotia, así como su influencia en la circulación oceánica global, evolución de la biota y el clima. El Paso del Drake y el Mar de Scotia representan uno de los portales oceánico mas importantes de la Tierra, ubicado entre Sudamérica y la Península Antárctica, un área de vital importancia para el intercambio de masas de agua entre el Océano Pacífico, Océano Atlántico, y el Mar de Weddell, como queda reflejado en numerosos estudios multinacionales. Sin embargo la región no ha sido perforada con objetivos científicos. El objetivo de este trabajo es presentar los principales objetivos científicos de esta propuesta de perforación oceánica y su relación con el plan estratégico del IODP para 2013-2023.

Palabras clave: *Portales oceánicos, Tectónica de placas, implicaciones globales, paleoceanografía, cambios ambientales*

INTRODUCTION

Ocean circulation is a major component of the Earth System. Mayor oceanic basins are connected by oceanic gateways. The opening, deepening and evolution of oceanic gateways that have been critical to the sedimentary evolution of basins, may have influenced global ocean circulation and climate, and have affected the exchange of water masses and associated sedimentary processes, as well as distribution of biota and evolution/extinction processes (Barker and Thomas 2006). The Drake Passage (DP) and the adjacent Scotia Sea (SS) represent one of Earth's most important oceanic gateways (Fig. 1), between the southern tip of South America and the Antarctic Peninsula, a crucial area for water mass exchange between the Pacific Ocean, the Atlantic Ocean, and the Weddell Sea. The DP - SS gateway controls ocean circulation and possibly climate in the southern hemisphere, with potential global effects. Its opening was a necessary condition for the

establishment of the Antarctic Circumpolar Current (ACC), and (tentatively) the thermal isolation of the Antarctic continent, although the climatic importance of the ACC is vigorously debated. Some deep gateways along the southern Scotia Sea constrain and control circulation of Antarctic Bottom Water (AABW) within the Scotia Sea (Fig. 2), and its subsequent circulation towards the west (South Pacific Ocean) and northeast (South Atlantic Ocean).

The opening and evolution of the DP - SS remain poorly understood, and the region has not yet been drilled for scientific objectives. The tectonic evolution is critical for understanding phenomena including: a) the processes and consequences of Gondwana break-up; current and past Southern Hemisphere plate-motion and mantle flow; ocean-basin tectonics; b) the behavior of the ACC and other water masses (i.e., AABW) directly involved in the Global Meridional Overturning Circulation, and their influence on global climate; and c) the development and stability of Antarctic ice-sheets, and oceanic productivity, biodiversity and biotic migrations in the Southern Hemisphere.

The timing of the ACC onset and development of the DP –SS is highly debated, and has been dated at any time between the middle Eocene and the middle Miocene (e.g.; Barker and Thomas 2006; Dalziel, 2014; Maldonado et al., 2014). There are significant discrepancies in data interpretations, especially regarding the age of development of small oceanic basins along the south Scotia Sea (Figs. 1, 2), due to the difficulty of identifying and assigning ages to the seafloor magnetic anomalies, as well as a lack of knowledge of the central Scotia Sea. Also, other questions like the relationship between onshore-offshore paleoenvironmental records, and paleoceanographic evolution and development of marine biota, including the rise in importance of the autotroph diatoms at the base of the oceanic food chain. Because of the lack of drilling in the Scotia Sea, researchers have had to assume (Maldonado *et al.*, 2006, 2014; Lindeque *et al.*, 2013), for instance, that sediment deposition occurred immediately after oceanic-crust formation, and has been continuous over time. Fundamental problems with global implications thus remain to be resolved. Some of these have been partially addressed in a previously submitted Integrated Ocean Drilling Program (IODP) proposal, entitled *The Antarctic Circumpolar Current - origin, evolution and influence on climate and biota* (P Barker *et al.*), submitted on August 17, 2003 (634-Pre), and March 29, 2005 (634-Full). A revised full proposal was submitted in April 2007, but it is not currently active at IODP. The DP and the SS were considered by the UNESCO-SCAR during the International Polar Year (IPY) in the Plates and Gates Project (2007-2008, K. Gohl and A. Haywood).

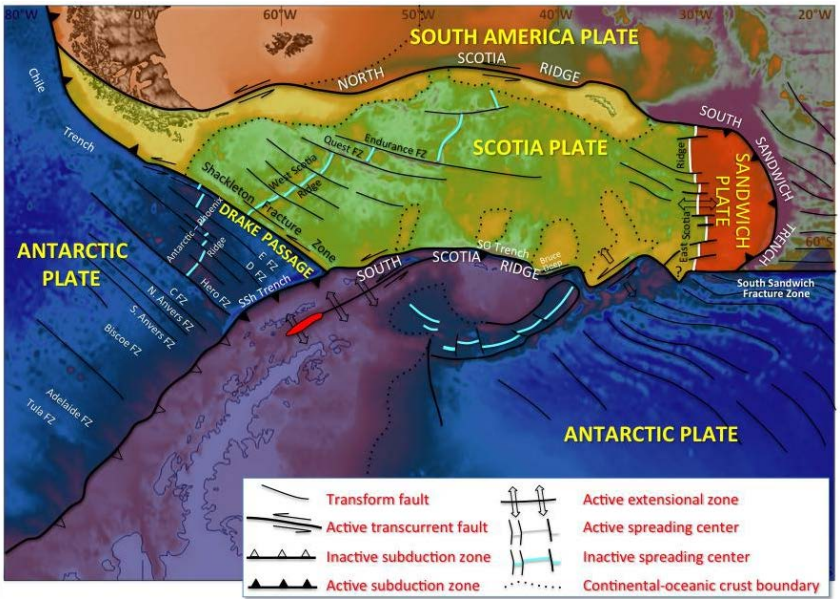

FIGURE 1. *General tectonic sketch, showing the Drake Passage (DP) and the Scotia Sea (SS). FZ: fracture zone.*

IODP PROPOSAL: DRAKE-SCOTIA SEA GATEWAY

The DRAKE-SCOTIA SEA GATEWAYS is a new multidisciplinary drilling proposal aiming to determine the time of opening and pattern of development of gateways in the DP - SS, and their influence on global ocean circulation, biotic evolution, and climate. This proposal was submitted to the IODP (2014), and after its evaluation by the Science Evaluation Panel (SEP), a new multi-phase drilling project (MDP) proposal is in preparation, to be re-submitted by 1st October 2016. Uncertainties about the early stages of development of the DP-SS would be resolved through drilling the oceanic basins in the central and southern Scotia Sea. The scientific goals of the DRAKE-SCOTIA SEA GATEWAYS pre-proposal are: 1) *Plate tectonic*

processes and their effects on Earth surface processes; 2) *Oceanic gateways and their influence on climatic, biotic and oceanographic changes*; 3) *Paleoceanography and global climatic significance of the onset of water mass formation*; 4) *Ice sheets, sea-level changes, bottom currents and sediment architecture*; and 5) *Deep life in a polar environment.* These goals address fundamental questions of the IODP Science Plan for 2013-2023 (IODP, 2011), and its outcomes are closely aligned with the goals of the Scientific Committee for Antarctic Research (SCAR) - PAIS (Past Antarctic Ice Sheet Dynamics) Science Program. Potential results will be integrated with those from other regional studies, including ODP Leg 113 (1987), ODP Leg 178 (1998) the currently active IODP proposal 732 on the Antarctic Peninsula Pacific margin, proposed drilling in IODP 902-Full and in the Falkland/Malvinas region (IODP Pre-862).

Drilling in the Scotia Sea offers a unique opportunity to tackle the broad scientific goals described above, as this area represents the final deep-water gateway for the ACC. The project will require six primary drill sites, to be drilled through the sedimentary cover, down into the top of the oceanic crust (Fig. 3). We will test the proposed hypotheses, and develop a spatial view of the stratigraphic and paleoceanographic evolution of the DP - SS, integrating the results from the proposed drill sites with a network of existing seismic reflection profiles. The seismic network has already been interpreted (Maldonado et al., 2006, 2014; Pérez et al., 2014a, b; 2015), although the inferred ages and conclusions need to be confirmed or refuted through proposed drilling.

Secondary objectives of the proposed drilling include: a) Acquisition of unique information on processes of deep sedimentation and of cyclicity control; b) contribution to the growing global array of sites with high-accumulation rate marine sediments; c) Identify teleconnection and feedback processes between marine and terrestrial systems, which is crucial for understanding climatic variability; d) Assist modeling efforts of physical oceanographers, paleoceanographers and numerical modelers who attempt to constrain possible ACC and AABW circulation paths in different configurations of the DP - SS; and e) verify existing Antarctic paleomagnetic records and those proposed in IODP proposal 732, and construct high resolution reference paleomagnetic directional and intensity changes at southern high latitudes, that are key to understanding the dynamics, causes, and consequences of geomagnetic field variation.

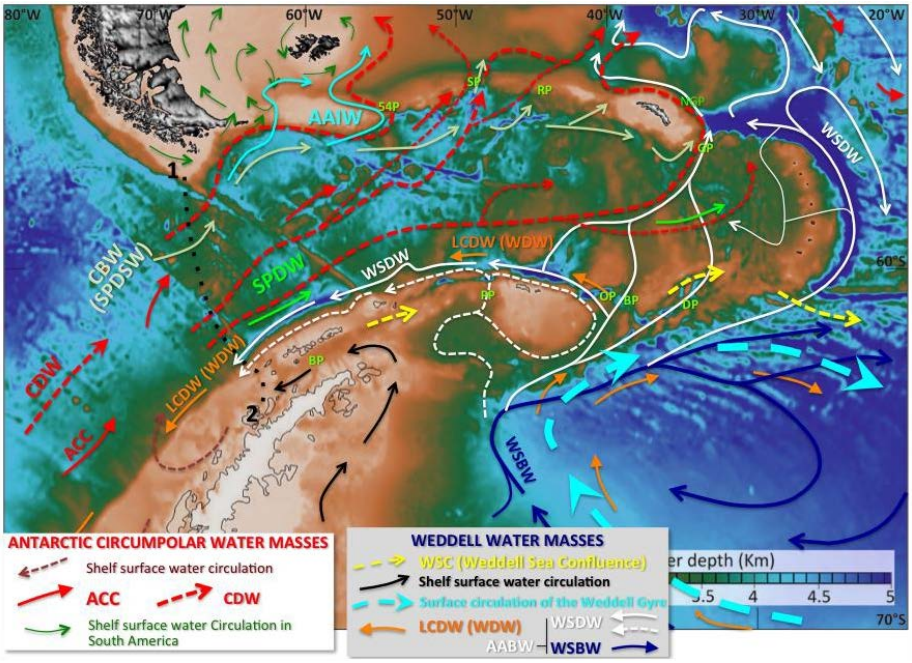

FIGURE 2. General sketch of the area spanning the Drake Passage and the Scotia Sea, showing the main water-mass circulation (*compilation by* Hernández-Molina *et al.*, 2006).

FINAL CONSIDERATIONS

The DRAKE-SCOTIA SEA GATEWAYS drilling proposal is timely and scientifically necessary. The proposed drilling will aid in understanding the evolution of the Antarctic during periods of major paleoenvironmental and paleoceanographic changes, and their global consequences. In view of the conceptual and global implications of linking solid Earth processes with (paleo)oceanographic, (paleo)environmental and biological processes, DRAKE-SCOTIA SEA GATEWAYS drilling is much needed. The drill-ship JOIDES Resolution (JR) is expected to operate in the Southern and South-Atlantic Oceans in 2019 and 2020, so the proposal is timely. The knowledge acquired from the DRAKE-SCOTIA SEA GATEWAYS drilling proposal will be invaluable for establishing the research framework and geological

understanding necessary for management by international organizations, such as the Scientific Committee on Antarctic Research (SCAR); Intergovernmental Panel on Climate Change (IPCC); International Geosphere-Biosphere Program (IGBP); and the Past Global Changes (PAGES) project.

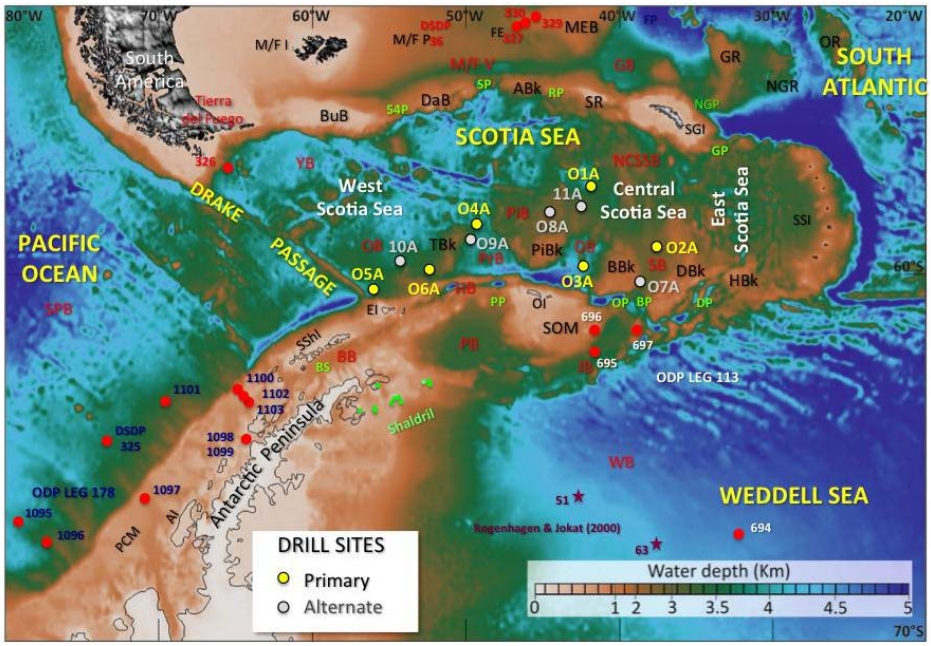

FIGURE 3. *General sketch of the Scotia Sea, showing the locations of the sedimentary basins and banks, and indicating the position of the discussed primary (yellow circles) and alternate (grey circles) sites of the DRAKE-SCOTIA SEA GATEWAYS drilling proposal presented herein. Also shown are previous IODP Legs and major cores. 54P, 54º-54º Passage ABk, Aurora Bank; AI, Adelaide Island; AP, Antarctic Peninsula; BB, Bransfield Basin; BBk, Bruce Bank; BS, Bransfield Strait;, BuB, Burdwood Bank; DaB, Davis Bank; DBk, Discovery Bank; DB, Dove Basin; DP, Discovery Passage; EI, Elephant Island; FE, Falkland Escarpment; GB, Georgia Basin; GP, South Georgia Passage; GR, South Georgia Rise; HB, Hesperides Basin; HBk, Herdman Bank; JB, Jane Basin; MEB, Malvinas Eastern Basin; M/F I Malvinas/Falkland Islands; M/F V Malvinas/Falkland Valley; NCSSB, North Central Scotia Sea Basin; NGP, North Georgia Passage; NGR, North Georgia Rise; OB, Ona Basin; OI, Orkney Islands; OP, Orkney Passage; OR, Orkney Ridge; PB, Powell Basin; PCM, Pacific Continental Margin; PiB, Pirie Basin; PP, Phillip Passage; PrB, Protector Basin; RP, Black Rocks Passage; SB, Scan Basin; SGI, South Georgia Island; SP, Shag Rock Passage; SShI, Shetland Islands; SOM, South Orkney Microcontinent; SPB, South Pacific Basin; SR, Shag (and Black) Rocks; SSI, South Sandwich Islands; TB, Terror Bank; WB, Weddell Basin; YB, Yaghan Basin.*

REFERENCIAS

Barker, P.F. and Thomas, E., 2004. Origin, signature and palaeoclimatic influence of the Antarctic Circumpolar Current. Earth-Science Reviews, 66(1-2), 143-162.

IODP, 2011. Science plan for the International Ocean Discovery Program (2013–2023), Illuminating Earth's Past, Present, and Future, IODP Management International, http://www.iodp.org.

Dalziel, I. W. D., 2014. Drake Passage and the Scotia arc: A tortuous space-time gateway for the Antarctic Circumpolar Current. Geology, 42 (4), 367-368.

Lindeque, A., Martos Martin, Y. M., Gohl, K., Maldonado, A., 2013. Deep-sea pre-glacial to glacial sedimentation in the Weddell Sea and southern Scotia Sea from a cross-basin seismic transect. Marine Geology, 336, 61-83.

Maldonado, A., Bohoyo, F., Galindo-Zaldívar, J., Hernández-Molina, F. J., Jabaloy, A., Lobo, F. J., Rodríguez-Fernández, J., Suriñach, E., Vázquez, J. T., 2006. Ocean basins near the Scotia - Antarctic plate boundary: influence of tectonics and paleoceanography on the Cenozoic deposits. Marine Geophysical Research, 27 (2), 83-107.

Maldonado, A., Bohoyo, F., Galindo-Zaldívar, J., Hernández-Molina, F.J., Lobo, F.J., Lodolo, E., Martos, Y.M., Pérez, L.F., Schreider, A.A., Somoza, L., 2014. A model of oceanic development by ridge jumping: opening of the Scotia Sea. *Global and Planetary Change*, 123: 152-173.

Pérez, L.F., Maldonado, A., Bohoyo, F., Hernández-Molina, F.J., Vázquez, J.T., Lobo. J., Martos, Y.M., 2014b. Depositional processes and growth patterns of isolated oceanic basins: the Protector and Pirie basins of the Southern Scotia Sea (Antarctica). *Marine Geology*, 357: 163-181.

Pérez, L.P., Lodolo, E., Hernández-Molina, F.J., Maldonado, A., Bohoyo, F., Galindo-Zaldívar, J., Lobo, F.J., 2014a. Tectonic development, sedimentation and paleoceanography of the Scan Basin (southern Scotia Sea, Antarctica). *Global and Planetary Change*, 123: 344-358.

Pérez L.F., Maldonado, A., Hernández-Molina, F.J., Lodolo, E., Bohoyo, F., Galindo-Zaldívar, J., 2015. Tectonic and oceanographic control of sedimentary patterns in a small oceanic basin: Dove Basin (Scotia Sea, Antarctica). *Basin Research* doi: 10.1111/bre.12148