Bathymetry and geological setting of the Drake Passage (Antarctica)

Batimetría y contexto geológico del Paso de Drake (Antártida)

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Abstract: The Drake Passage is an oceanic gateway of about 850 km width located between South America and the Antarctic Peninsula that connects the southeastern Pacific and the southwestern Atlantic oceans and is an important gateway for mantle flow, oceanographic water masses, and migrations of biota. This gateway developed within the framework of geological evolution of the Scotia Arc. As a consequence of this and subsequent submarine processes, this region shows a varied physiography. The new detailed map in the Drake Passage region is mainly founded on a compilation of precise multibeam bathymetric data obtained on cruises between 1992 and 2014, and covers the area between parallels 52ºS and 63ºS and meridians 70ºW and 50ºW. The new map that we present is based in a DTM with 200 m cell resolution of the seafloor in Drake Passage that permits identification of the main seafloor features and the map includes additional useful geological information. This work constitutes an international cooperative effort and is part of IBCSO project (International Bathymetric Chart of the Southern Ocean), under the SCAR umbrella.

Key words: bathymetry, seafloor, Drake-Passage, Scotia-Arc, Antarctica.

Resumen: *El Paso de Drake es un pasillo oceánico de 850 km de anchura, localizado entre Sudamérica y la Península Antártica, que conecta los océanos Pacífico suroriental y el Atlántico suroccidental. Es un importante paso para el flujo mantélico, las masas de agua oceanográficas y las migraciones de la biota. Su desarrollo se enmarca dentro de la evolución geodinámica del Arco de Scotia. Debido a esto y a los procesos submarinos posteriores, esta región presenta una fisiografía del fondo muy variada. El nuevo mapa de detalle de la región del Paso de Drake esta principalmente fundamentado en la compilación de batimetría multihaz de alta resolución obtenida en campañas desde 1992 a 2014 y que cubre un área entre los paralelos 52ºS y 63ºS y los meridianos 70ºO y 50ºO. El nuevo mapa, del relieve del fondo del mar en el Paso de Drake, que presentamos con este trabajo está basado en un MDT con una resolución de 200m de paso de malla, que permite la identificación de las principales estructuras morfológicas, e incluye sobreimpuesta otra información geológica de utilidad. Este trabajo constituido en el marco de una cooperación internacional es parte del proyecto IBCSO (International Bathymetric Chart of the Southern Ocean), bajo los auspicios del SCAR.*

Palabras clave: *batimetría, fondo marino, Paso de Drake, Arco de Scotia, Antártida.*

INTRODUCTION

The opening of the main southern oceanic gateways, Drake Passage and Tasmanian gateway separating South America and Australia from Antarctica respectively, permitted the modern pattern of global ocean circulation to be established. This allowed extensive exchange of water between the main ocean basins and led to the development of the Antarctic Circumpolar Current, which contributed to the thermal isolation of Antarctica, and was partially responsible for global cooling at the Eocene-Oligocene boundary and played an important role in late Miocene cooling.

The Drake Passage is an oceanic gateway of about 850 km width located between South America and the Antarctic Peninsula that connects the southeastern Pacific and the southwestern Atlantic oceans and influences exchanges of mantle flow, oceanographic water masses, and migrations of biota. This gateway developed within the framework of geological evolution of the Scotia Arc.

We present a new detailed map, with a 200 m cell resolution of the seafloor in Drake Passage that permits identification of the main seafloor features. This initiative is part of IBCSO (International Bathymetric Chart of the Southern Ocean) (Arndt et al., 2012), under the SCAR (Scientific Committee on Antarctic Research) umbrella, which recognizes the importance of regional data compilations and mapping programs in areas of particular scientific interest around Antarctica, such as the Ross Sea, Drake Passage and the southern margin of the Weddell Sea.

GEOLOGICAL SETTING

The Scotia Arc includes the Scotia and Sandwich plates, which is bounded to the north by the North Scotia Ridge, to the south by the South Scotia Ridge, to the west by the Shackleton Fracture Zone, and to the east by the South Sandwich Trench. The Scotia Sea contains several active and extinct spreading ridges that led to the opening of the Drake Passage. Several continental banks and oceanic basins are located in Scotia Sea, notably its southern part (Fig.1; Barker 2001).

The Shackleton Fracture Zone (SFZ) occupies a central position in the Drake Passage and is an intra-oceanic ridge which rises several hundreds to thousands of meters above the surrounding seafloor. The SFZ separates the Scotia Plate of the Scotia Sea to the east and the former Phoenix and Antarctic plates to the west, part of the Pacific Ocean. The SFZ is an active transpressional and left-lateral transcurrent fault that accommodates, in conjunction with the North Scotia Ridge and South Scotia Ridge, the relative motion between the Scotia Plate and the South-American and Antarctic plates and connects the Chile Trench with the South Shetland Trough. The SFZ is underthrusted below Elephant Island. The SFZ intersects two extinct spreading centers – the West Scotia Ridge and the Phoenix–Antarctic Ridge – between which the SFZ acted as an oceanic ridge-to-ridge transform fault when both spreading centers were active (Bohoyo et al., 2016). The geodynamic evolution of the region, seismic activity and tectonic data suggest a complex evolution of the Drake Passage such that the SFZ began as an oceanic transform fault with strike-slip motion along most of its length and then formed a transpressive transcurrent fault zone as at present day. Uplift of the SFZ in the last 8 Ma has formed a barrier for bottom oceanic currents (Fig. 1; Livermore et al., 2004). The Phoenix-Antarctic spreading axis was extinct by chron C2A (2.6-3.6 Ma), when the Phoenix Plate became part of the Antarctic Plate, and following a long period of late Mesozoic and Cenozoic subduction of the Phoenix Plate below the Pacific Margin of the Antarctic Peninsula. Subduction continued at the South Shetland Trough due to rollback processes at the hinge of subduction and active spreading in the Bransfield Strait (Larter y Barker, 1991; Maldonado et al., 1994).

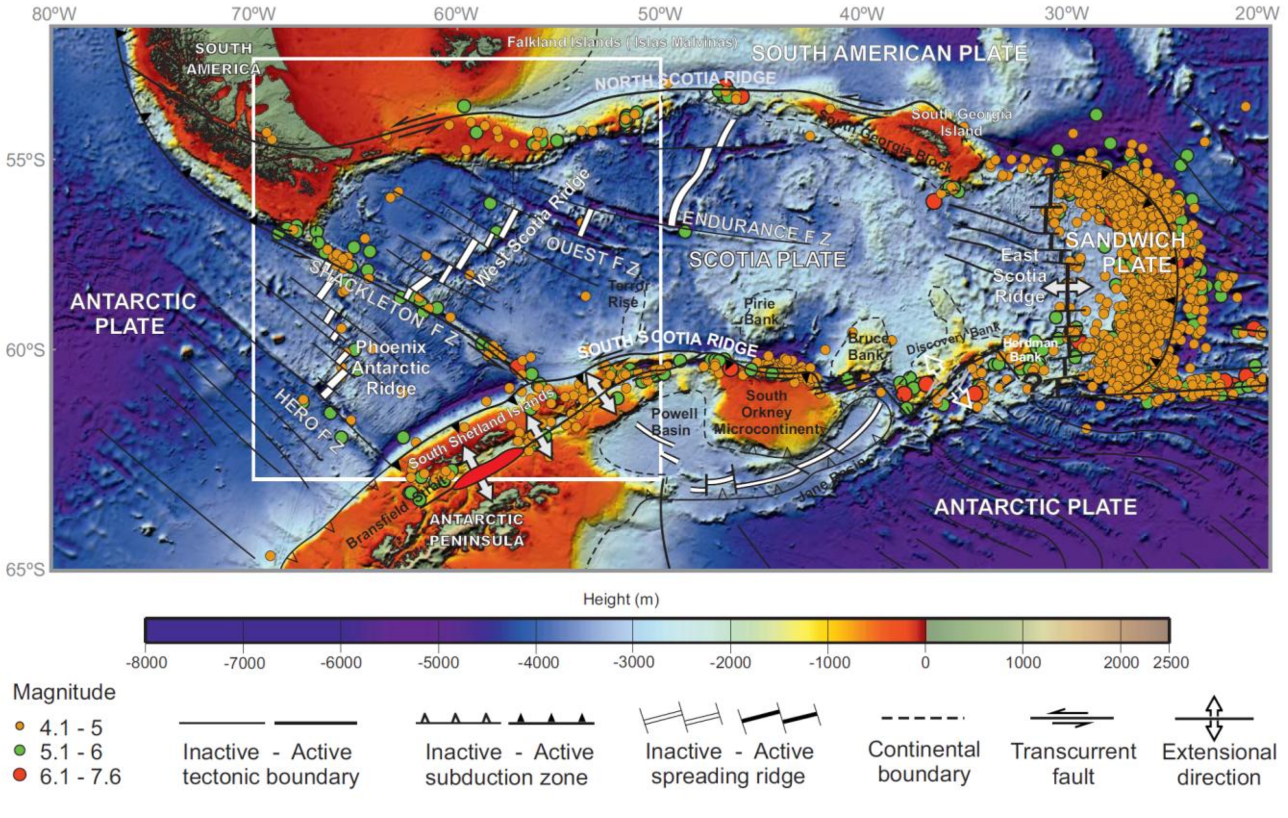

FIGURE 1. Geological map of the Scotia Arc. Bathymetry from GEBCO14 including IBCSO v1.0. White square identify the study region (Modified from Bohoyo et al., 2016)

The West Scotia Ridge formed most of the oceanic crust of the Scotia Sea from early Oligocene to its extinction after chron C3A (6.4 Ma) during a period of regional Scotia Sea compression after 17 Ma due to the migration of the pole of rotation (Maldonado et al., 2000). The West Scotia Ridge spreading segments are separated by former transform faults where the easternmost Endurance and Quest Fracture Zones are recognizable. Recent studies of the Drake Passage geodynamics suggest opening of oceanic basins that developed in the southwestern Scotia Arc during Eocene time (Fig.1; Eagles y Jokat, 2014; Maldonado et al., 2014).

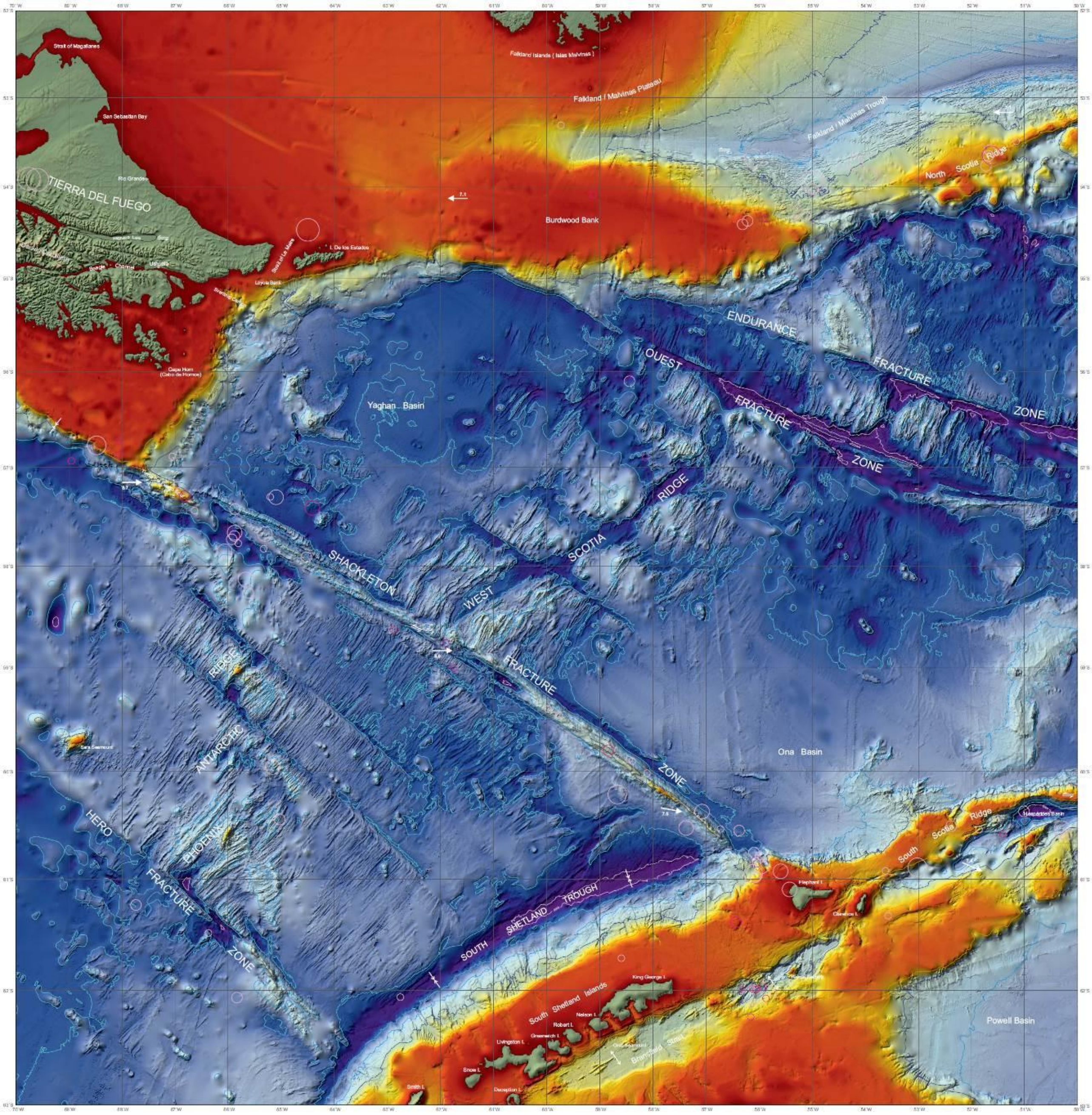

FIGURE 2. Bathymetry and geological setting of the Drake Passage. Color scale in Fig. 1. (Modified from Bohoyo et al., 2016)

METHODOLOGY AND DATA

The map is mainly based on a compilation of precise multibeam bathymetric data obtained on cruises between 1992 and 2014 in the Drake Passage region, and covers the area between parallels 52ºS and 63ºS and meridians 70ºW and 50ºW (Fig. 2). This first version of the compilation constitutes an international cooperative effort coordinated by the Geological Survey of Spain (IGME), the British Antarctic Survey (BAS), the Alfred Wegener Institute (AWI) and the Korean Polar Research Institute (KOPRI), together with USA data available from the Lamont-Doherty Earth Observatory (LDEO). The GEBCO14 dataset, including IBCSO v1.0 (Arndt et al., 2012), was used in order to fill gaps in the coverage (Fig. 3). This dataset use satellite altimetry in areas where data is sparse. Merging and gridding the dataset has been conducted using GMT, Fledermaus, ArcGIS and Global Mapper.

The map's main cartographic characteristics are: a scale of 1: 1 500 000, Mercator projection in WGS84 ellipsoid, a DTM with a 200 m cell resolution displayed as a color image using a color table ranging from -6000 to 2500 m. Additionally, other useful geological information shown includes: seafloor magnetic lineations, historical seismicity (depth and magnitude) from the USGS Catalog, relative plate motion according TLP2003 (Thomas et al., 2003) model and main tectonic structures, together a brief geological setting description including the main scientific and cartographic references (Fig. 2).

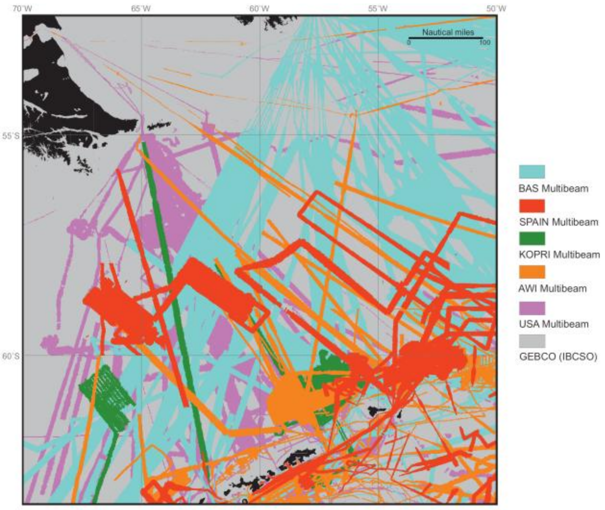

FIGURE 3. Map of bathymetry coverage compiled from a variety of different data sources. (Modified from Bohoyo et al., 2016)

CONCLUSIONS

Seafloor digital elevation models are very important in geosciences, physical sciences and life sciences. The seafloor topography in the Drake Passage region is an important boundary condition for high-resolution ocean circulation models and also provides constraints on geodynamic models for the initiation and development of Drake Passage opening.

This new detailed geological and bathymetrical map in the Drake Passage region, mainly founded on a compilation of precise multibeam bathymetric data obtained on cruises between 1992 and 2014, that covers the area between parallels 52ºS and 63ºS and meridians 70ºW and 50ºW, represent an important resource to the Antarctic scientific community.

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REFERENCES

Arndt, J. E., Schenke, H. W., Jakobsson, M., Nitsche, F. O., Buys, G., Goleby, B., Rebesco, M., Bohoyo, F., Hong, J., Black, J., Greku, R., Udintsev, G., Barrios, F., Reynoso-Peralta, W., Taisei, M. y Wigley, R. (2013): The International Bathymetric Chart of the Southern Ocean (IBCSO) Version 1.0 A new bathymetric compilation covering circum-Antarctic waters. *Geophysical Research Letters*, 40: 3111–3117

Barker, P.F. (2001): Scotia Sea regional tectonic evolution: implications for mantle flow and palaeocirculation. *Earth-Science Reviews*, 55: 1-39.

Bohoyo, F., Larter, R.D., Galindo-Zaldívar, J., Leat, P.T., Maldonado, A., Tate, A.J., Gowland, E.J.M., Arndt, J.E., Dorschel, B., Kim, Y.D., Hong J.K., Flexas M.M., López-Martínez, J., Maestro, A., Bermudez, O., Nitsche, F. O. (2016 in edition): *Bathymetry and Geological Setting of the Drake Passage (1:1.500.000)*. BAS GEOMAP 2 series,Sheet 7, British Antarctic Survey, Cambridge, UK.

Eagles, G. y Jokat, W. (2014): Tectonic reconstructions for paleobathymetry in Drake Passage. *Tectonophysics*, 611: 28-50.

Larter, R.D. y Barker, P.F. (1991): Effects of ridge crest-trench interaction on Antarctic–Phoenix spreading: forces on a young subducting plate. *Journal of Geophysical Research*, 96 (B12): 19586-19607.

Livermore, R., Eagles, G., Morris, P. y Maldonado, A. (2004): Shackleton Fracture Zone: no barrier to early circumpolar ocean circulation. *Geology*, 32 (9): 797-800.

Maldonado, A., Balanyá, J.C., Barnolas, A., Galindo-Zaldivar, J., Hernández, J., Jabaloy, A., Livermore, R., Martínez-Martínez, J.M., Rodríguez-Fernández, J., De Galdeano, C.S., Somoza, L., Suriñach, E. y Viseras, C. (2000): Tectonics of an extinct ridge-transform intersection, Drake Passage (Antarctica). *Marine Geophysical Researches*, 21 (1-2): 43-67.

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. y Somoza, L. (2014): A model of oceanic development by ridge jumping: Opening of the Scotia Sea. *Global and Planetary Change*, (123/B): 152-173.

Maldonado, A., Larter, R. D. y Aldaya, F. (1994): Forearc tectonic evolution of the South Sheltand margin, Antarctic Peninsula. *Tectonics*, 13 (6): 1345-1370.

Thomas, C., Livermore, R. y Pollitz, F. (2003): Motion of the Scotia Sea plates. *Geophysical Journal International*, 155: 789–804.