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THE CENTRAL SCOTIA SEA FLOOR – IS IT AN PALEO-OCEANIC PLATE, AN YOUNG RIFTED PLATE OR AN PALEO-LAND SCOTIA?

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Abstract. Although the bathymetry and geophysics of the Scotia Sea basin is rather well studied in general and is discussed in many publications there are still remaining questions about tectonics of its Central Part. In the western part of the Sea tectonic nature is well demonstrated by West rifted ridge and in the eastern part by East back-arc rift. The floor of the central part does not show such well expressed tectonic features. The usual interpretation of that part of basin floor is described as introduced fragment of the Pacific paleo-Plate or as newly created oceanic plate resulted by supposed rifting. Recent bathymetry and other geophysics survey is complemented with geological sampling lead to hypothesis on the existence there of a large relict of continental bridge between South America and West Antarctica.
Key words: the Scotia Sea, rift, geophysical surveys, West Antarctica.

Реферат. Хотя рельеф дна и геофизические параметры ложа котловины моря Скоша в общем изучены довольно хорошо и рассматривались во многих публикациях, всё же до сих пор остаются вопросы о тектонике центральной части ложа этой котловины. Тектоническая природа западной части дна моря Скоша хорошо демонстрируется Западным рифтогенным хребтом, а в восточной части – Восточным задуговым рифтом. Центральная часть ложа котловины обычно интерпретируется как внедрённый фрагмент Тихоокеанской плиты или как заново созданная океаническая плита, результат предполагаемого рифтогенеза. Новейшие исследования рельефа дна и другие геофизические съёмки в сочетании со сбором геологических образцов приводят к предположению о существовании там большого реликта континентального моста между Южной Америкой и Западной Антарктидой – палео-Земли Скоша.
Ключевые слова: море Скоша, рифт, океаническая плита, геофизические съёмки, Западная Антарктида.

Реферат. Хоча рельєф дна і геофізичні параметри ложа котловини моря Скоша загалом вивчені досить добре і роглядалися в багатьох публікаціях, усе ж таки й досі залишаються питання щодо тектоніки центральної частини ложа цієї котловини. Тектонічна частина природи західної частини дна моря Скоша добре демонструється Західним рифтогенним хребтом, а у східній частині – Східним задуговим рифтом. Центральна частина ложа котловини зазвичай інтерпретується як упроваджений фрагмент Тихоокеанської плити або як заново створена океанічна плита, результат гаданого рифтогенезу. Найновіші дослідження рельєфу дна та інші геофізичні зйомки у сполученні зі збиранням геологічних зразків приводять до припущень про існування там великого релікту континентального моста поміж Південною Америкою і Західною Антарктидою – палео-Землі Скоша.
Ключові слова: море Скоша, рифт, океанічна плита, геофізичні зйомки, Західна Антарктида.

1. Introduction

Regional setting and history of previous investigations

The Scotia Sea is a large basin located between continental plates of South America and West Antarctica. In the Scotia Sea bordered by volcanic South Sandwich Arc while the western side is opened to Pacific Ocean. The Sea has received its geographical names in memory of works in 1901–1904 of the small research vessel «Scotia», operated by National Scottish Antarctic Expedition, headed by William Bruce. Two shallow water banks in southern area of basin of the Scotia Sea were named in memory of William Bruce and naturalist of his expedition James Pirie as Bruce and Pirie banks. One other bank in environs was named as Discovery bank in memory of RRS «Discovery», headed by Captain Robert Scott.

The tectonic frame around the Scotia Sea is well expressed on the maps of «Tectonic Map of the Scotia Arc» [BAS Misc. Sheets, scale 1;3 000 000, Cambridge,1985. Dalziel, Elliot, 1973, Barker, Dalziel, Storey, 1991].The main tectonic features of this frame-work are huge Gondwanal cratonic continental blocks - that are one of the extra-Andean Patagonia on the North side of the Sea and other one the set of Antarctic Peninsula with the South Orkney micro-continent on the South side. The mostly clear morphostructural framing of the Basin of the Scotia Sea are the Scotia Arc, surrounding the Sea along three sides – on the north, on the east and at the south. On the western side of the Sea the Gondwanal Andean oroclyn don't bend to the east, as it was supposed some time ago [Suess, 1883]. Now it is considered more probable that after continuation along the western side of the Terra del Fuego this oroclyn was cutten by series of faults with horizontal displacements to the south while opening of the Drake Passage in Cenozoic Time (Eocen-Oligocen) [Livermore, Eagles et al., 2004, Herve, Miller, Pimpirev, 2006].

The geology of the Scotia Arc is unlike to classical island arcs of the Fiery Circum-Pacific Ring. The North and South Ridges of the Scotia Arc are formed by systems of tectonic blocks – splinters of the neighbor Precambrian Gondwanaland cratons. Only the east part of the arc, connecting the North and South Ridges and closing the Scotia Sea from the Atlantic Ocean, is similar to majority of the island arcs of the Pacific Belt. That is the volcanic South Sandwich Arc. That Arc are very young. It consist of 11 islands and numerous banks – constructed by basalt and ryolite lavas with the age 0,7 to 4 Ma [Tectonic map of the Scotia Arc, 1985].

The Eastern continuation of the extra-Andean Patagonia are the Falkland Plateau with Maurice Ewing Bank, gradually submersing into the Northeast Georgia Rise in the area north of the South Georgia island [Ludwig, 1983, Ludwig, Rabinowitz, 1982, Ludwig et al. 1978, Kristoffersen, LaBrecque, 1991].

The narrow North Scotia Ridge, splinted from the huge pre-Cambrian craton of the extra-Andean Patagonia, is separated from it by as well narrow Falkland trough. The depth of the trough are lesser of the typical oceanic depths. The floor of the trough is underlined supposedly by thinned continental crust [Ewing J.I. et al., 1971, Lorenzo, Mutter,1988],

The geology at the blocks of the North Scotia Ridge – the Burdwood bank, Blake, Aurora and Shag Rocks, and the South Georgia Island everywhere are identical to the uppermost layers of the Falkland Plateau and the Maurice Ewing Bank. That is Mesozoic shallow water sedimentary rocks with age from upper Jurassic to lower Cretaceous, overlying Precambrian basement [Dalziel, Elliott, 1973, Barker, Dalziel, Storey, 1991].

The southern branch of the Scotia Arc – the South Scotia Ridge with South Orkney micro-continent and Antarctic Peninsula – is similar in its structure with the North Scotia Ridge. All these blocks are fragments of Gondwanals pre-Cambrian cratons, combined into continent of the West Antarctica. The mostly preserved the pre-Mesozoic structure are exposed in the huge micro-continental block of the South Orkney Islands and in the eastern back part of the Antarctic Peninsula. The basement there is submitted by Paleozoic-Mesozoic complexes also. The distinctive feature of the South Scotia Ridge and Antarctic Peninsula is the chain of propagating rifts. They can be considered as far extended to the West continuation of the rift system of the America-Antarctic branch of the South Atlantic mid-oceanic Ridge. The propagation of this rift is marked by intensive splitting of east part of the South Scotia Ridge, then emerged inside of the South Orkney Island micro-continent [Barker, Dalziel, Storey, 1991, King, Barker, 1988, Kavun, Vinnikovskaja, 1993], weakly active at the

Hesperide rift to the west from this micro-continent, and represented by active East and West Bransfield rifts [Gracia et al., 1996, Lawver et.al., 1996, Galindo-Zaldivar, Jabaloy, Maldonado, Galdeano, 1996]

The rear structures of the South Scotia Ridge are even more complicated by combination of the rifting with ancient regional spreading in northern part of the Weddell Sea [Livermore, Hunter, 1996], by dissipation of the Trans-Antarctic Rift in southern part of this sea, and by dyed local back-arc rift of the Jain Basin, accompanied with Jain paleo-arc and young Powell Basin [King E.C. et al., 1997]. However all this mosaic of structural systems does not mask continental residual basement of the blocks of the South Scotia Ridge.

The central part of the Scotia Sea floor was marked as rather stable Central Plate both in topography and gravity field and also in distribution of seismic activity, [Livermore, McAdoo, Marks, 1994]. Probably by virtue of marked stability it has attracted lesser attention of the researchers. The known here Pirie, Bruce and Discovery banks, were considered as fine splinters of the ancient continental bridge between South America and West Antarctica. The destruction of the former bridge in the area of the Drake Passage is interpreted as resulted by large scale horizontal displacements of continental plates reflected in linear magnetic anomalies [Barker P.F., et al., 1991; Tectonic map…, 1985; Barker, 1990, Barker, Thomas, 2004, Eagles, Livermore, Fairhead, Morris, 2005]. The Central Plate of the Scotia Sea was imaged as the mosaic collage of small continental fragments, represented by banks in the southern periphery, and by newly formed rifted oceanic basins in middle and northern areas[Eagles G. et al., 2005].

The scarcity of previous studies of the Central Plate of the Scotia Sea for understanding its tectonic and position in the process of the oceanic gateway's opening, stimulated our interest to its topography, structure, geophysics and geology. In the frame of the German-Russian program for studies the West Antarctic's geodynamics in the period of 1994–2005 there were maintained while five expeditions – in two cruises of r/v «Academik Boris Petrov» and in three cruises of the r/v «Polarstern».

2. The data obtained

Bathymetry and seismic profiling

In 1994–1998 in the expedition of the 21 cruise r/v «Akademik Boris Petrov» according to German Project of geokinematic monitoring in Western Antarctic Region there was created the basic network of geodetic stations in vatious points of this area.

In the expedition of the 29 cruise of that vessel the geokinematic monitoring was carried out. In parallel to that operations the multibeam echo sounding, seismic profiling along the 59°S, box survey and sampling of the rocks have been made in the area of the South Scotia Ridge and in the South part of the Central Plate of the Scotia Sea at the Pirie Bank and Discovery Bank [Galimov E.M. et al., 1999, Udintsev, Schenke, 2003]. In 2003–2005 while the r/v «Polarstern» expedition ANT-19/5 the detailed bathymetric survey and sampling at the Discovery Bank, and while ANT-22/4 the especially detailed great box-survey with 110% of covering by multibeam echo sounding was maintained at the northern part of the Central Plate [H.W.Schenke and W. Zenk, eds. Berichte zur Polar und Meeresforschung, 537, 2006].

Elaboration of the data obtained by the research vessels in combination with results of the Satellite altimetry [Sandwell, Smith, 1997] permit us to compile preliminary bathymetric charts of the Central plate of the Scotia Sea. These maps are more detailed as any previously available.

The topography of the Central Plate is now clearer in its macro-features and micro-features. The Pirie bank appeared as the pick of a small part of the top of an extensive rise, contoured in the upper part by isobaths 1500 m, and near the foot of slopes by isobaths 3000 m – the Pirie Rise. To the

North of it, in the area 58°40'S–57°30'S there are the plane terrace with the depths lesser 3200 m. This terrace we named the Pirie Plateau. To the North of 57°30'S the series of the hills and narrow ridges are positioned on the depth of the interval between 3200–3000 in the area up to 56°30'S. The largest and highest hill of that area rise up to depth lesser than 2500 m. This complex of irregular topography is like the marginal part of another large rise positioned to the north of 56°30'S. Uniting that rise with the above described marginal hills we propose to name it in whole as the Gettingen Rise. The morphology of that rise and its size inside isobaths 3300 m and uppermost tops with depths lesser than 2500–2000 m – resembles the morphology of the Pirie Rise.

The Pirie Rise together with Pirie Plateau and Gettingen Rise can be considered as united into the large morpho-structural province. We propose to name it as the Pirie-Gettingen Province. Its morpho-structure considered by us remarkable different from the structure of the rifted West Scotia Ridge Province, which lay to the west and can be limited along the line directed from the Elephant island, South Scotia Ridge, to N-E, to Shag Rocks of the North Scotia Ridge. The Pirie-Gettingen Province can be considered as the west marginal system of the Central Plate. The northern limit of the Province can be estimated by the deep trench, the name to which would be logic to give by the neighbor block of the North Scotia Ridge capped with Shag Rocks – as the Shag Trench. The southern limit of the Province corresponds to the deep South Orkney Trench.

In the limits of the structure of the Gettingen Rise are allocated sharp vertical dislocations having the form of the Graben with rather wide Trough. We offer the name for this structure as the Polarstern Graben. The width of the Pirie Graben' trough reaches 30 miles. The amplitude of the slopes of the trough reach 1000-2000 m and its steepness achieves 25°–30° . Especially step is the northern slope – its steepness on some places reaches almost 50°. The narrow profound troughs by the side of the trough's bottom surface leveled by sediments are positioned at the foot of the steep slopes on both sides of the Graben. Their depths reach 4000-4500 m, while the central depth of graben trough is only 3700–3800 m. The margins of a surface of the North Pirie Rise on the both boards of the trough are raised up to depths lesser than 2300–2200 м, reflecting, apparently, former dome uplift of wide arch, laterally collapsed in center with tensional failure and creation of the graben. Detailed bathymetry shows a small transverse ridge inside the northern part of the graben and 2000-2500 m depth on its crest.

To the east of the graben large circular depression is founded in the pattern of the 3500 m isobaths. The lens form deep is about 80-90 miles in diameter with a central depth at 56°45`S, 42°10`W of about 4400 m, a total of about 900 m of relief. The rim of the feature rises above surrounding seafloor by about 100–200 m, which would suggest a crater-like structure, as opposed to a simple basin. We propose to name this feature the Schott Basin in memory of outstanding German oceanographer. The diameter of this circular feature is comparable to diameter of crater Maniguan of Canada and crater of a Jucatan peninsula in the Gulf of Mexico. The ring structure of a Schott Basin seems too imposed on structures of east part trough of the Polarstern Graben and, by this, was formed after it.

The intensive dislocations of the floor shown on the recent mostly detailed bathymetry certainly are remarkable. However not of lesser, but especially important for the understanding of the genesis of the Pirie-Gettingen Province, its rises and plateau in the morphology of small forms, which are dominated at the surface. The detailed survey has allowed to establish regular character of morphology of the type of the hilly plains prevailing on overall surface of a Province. We can consider these hilly plains as genetically homogeneous surfaces. The statistical analysis of their morphology has allowed first of all to recognize dominant lineation of hilly crests making an orthogonal network with azimuths NE-NS-NE.

The statistical analysis shows also existence of several planar levels between the hilly plains. We have found out thus surfaces of hilly plains on depths 3400–3200 м, 3200–3000 м, 3000–2800 м. According the type of morphology we consider these planar surfaces as probable levels of subaerial erosion.

On a background of the large forms of topography such as extensive Rises of the Province the several detached flat-topped seamounts with character form of volcanic cones are grouped on fracture lines along steep scarps and cracks of surfaces.. The flat tops of these volcanic seamounts are the ancient terraces of marine erosion submerged now to depths about 2400 m (Hinz smt), 2350 m (Seeber smt), 2220 m (Wenzel smt), and 2025 m (Kertz smt) and 1800 m (Seibold smt). The planar surfaces of highest parts of the above described Pirie Bank – 740 m , Bruce Bank – 1089 m and Discovery Bank – 350 m, also are the result of marine erosion at the period when they were at the sea level under influence of sea waves activity. The disparity of the depth of these planar surfaces can be the evidence of the progressive and unequivocal submergence of the Pirie Province.

The Discovery and Bruce Banks according our survey are similarly to the Pirie Bank the highest parts of the large Rises of Sea floor. Their crests have the depth in the limits about1500–2500 m and their foots are contoured by isobaths 3200–3400 m. That Rises can be named as Bruce Rise and Discovery Rise. The southern halves of these rises are incorporated by wide terrace with depths lesser than 2800–3000 m. We propose to name this terrace as the Bruce-Discovery Plateau. This Plateau continues to the north till 58°S and to the north of it Bruce and Discovery Rises continues separated by trough with depths 3000–3300 m. The both this Rises approach 56°S and rather close to the foot of the South Georgia block of the North Scotia Ridge. It is logical to name the unity these features of the floor in their full extremity as the Bruce-Discovery Province. The east limit of this Province lay approximately on 35°W. The Bruce-Discovery Province can be considered as the eastern structural margin of the Central Plate. Several volcanic seamounts, some of them are flat topped, have been surveyed while expedition ANT-19/5 on the west linear margin of the Discovery Rise close to 36°W. The depths of their flat tops are 1100 m (Drigalsky smt) and 1200 (Lazarev smt). These volcanos are clearly positioned along large fractures directed to the South Georgia Island and supply the evidences of the submersion of the Discovery Rise block with vertical dislocation along these fractures.

Between the Pirie-Gettingen and Bruce-Discovery Provinces lay two rather large basins – above mentioned lens-like Schott Basin and to the south of it wide Dove Basin, named in the memory of outstanding German hydro-meteorologist of the 19th century. The sedimentary smoothed surface of its floor at the west and east periphery lays on depths about 3300–3800 м. In the axial part – approximately on 42°30' W it is depressed up to depths 4100–4200 м. The morphostructure of the middle part of the basins floor reflects small local dislocations. Approximately on an axis of the Dove basin at the longitude about 42°37'W lays the small narrow Guevara ridge of an asymmetric contours and asymmetric profile with depth above a crest 1670 m and abrupt eastern and gradual western slopes. The width of it in the basis of slopes is about 6 miles. It extents along lineation on azimuth 360° approximately 30 miles. To northeast from this ridge lay another ridge of asymmetric profile. Its crest focused on an azimuth 45° and extent only 15 miles. The depths at its crest are about 3413 m. The uplifted origin of this ridge is clearly shown on the seismic profile. The inclined fault planes of vertical dislocation are accompanied with compressonal folding of sedimentary layer to the east of this fault. Certain similarity of these two small ridges testifies their faulted origin which corresponds to compressive type dislocations of the brittle basement of the basin. The eastern-faulted slopes of the both ridges are straight-lined. These local structures have no similarity to typical structures of the oceanic rifts and it is unlikely to be considered as the evidences of the oceanic crust of the basin The seismic profile at the middle of the Scotia sea along 59°S demonstrates complex block structure of the brittle basement, and have no records of any rifts responsible for development of the Ona, Protector and Dove basins..

We suppose the both described large morphostructural Provinces together with Basins can be considered as characteristics for homogenous unit Province of the whole Central Plate of the Scotia Sea.

Geology

Samples dredged on the western escarp of the Pirie Bank by N.A.Kurentsova are represented by fragments of the rocks from ancient pre-Cambrian craton. There are gneisses, mica-slates of the upper pre-Cambrian (absolute age 579 Ma), granites of the lower Jurassic (183 Ma), rhyolites, liparites and basalts of the middle Jurassic (169–175 Ma) to aleurolites and sandstones of the Cretaceous (113 ma) Their systematic set and breaking off forms lead us to presume local origin more probable than ice rafting [Kurentsova, Udintsev, 2004].

Samples of stone breeds were reported for the Discovery Bank by Eagles (Livermore et al., 2005) and were obtained there by us with trawling. These rocks appeared be similar to samples from the outcrops of the slope of the Pirie Bank [Udintsev, Arntz et al., 2003].

The column of sediments obtained by corer at the Bruce Bank according to micro paleontological data demonstrates the evidences of high position of the Bank in the middle Eocene time. It contains relicts of Cretaceous fauna which confirms the continental nature of the Bruce Rise [Eagles, Livermore et al., 2005; Mao et al.,1995; Toker et al., 1991].

The geological section submitted on the Pirie Bank is close very much to the section demonstrated at hole drilled at DSDP sites 327, 329 and 330 of 36-th leg of d/v «Glomar Challenger» and by core sampling by r/v «Robert Conrad» on the Maurice Ewing Bank, as well as the holes 698, 699 and 700 of 114 leg of d/v «Joides Resolution» on the North-East Georgia Rise at the east extremity of the Falkland Plateau. Characterized by these holes and cores the geological section passes through a layer of sea deposits from recent to Miocene-Paleocene and Cretaceous-Jurassic deposits, overlaying the pre-Cambrian basement [Ludwig, 1983, Wise et al., 1982; Ciesielski et al.,1991]. The sets of rocks obtained on Bruce and Discovery Banks well supplement that similarity.

Gravity

Structure of the anomalous gravity field on the Central Plate of the Scotia Sea based on the satellite altimetry [Sandwell D.T., Smith, 1997] and onboard survey by «Polarstern», was topographically corrected by V.G.Udintsev into Bouger reduction. The similarity of the gravity field values are observed above the rises of the Pirie and Bruce-Discovery Provinces and above neighbor cratonic platforms at north and south of the Scotia Sea.

Magnetic anomalies and origin of the Protector, Dove and Polarstern Basins.

The structure of an anomalous magnetic field is shown on map «Tectonic of the Scotia Arc» [Tectonic map, 1985] and have been discussed for estimation of the age of the Central Plate [Barker, 1990, Barker, Dalziel, Storey, 1991, Eagles, Livermore, Fairhead, Morris, 2005]. A number of anomalies of W-E lineation locate in the Schott Basin and partly in the area south of it in the Dove Basin. These anomalies were identified according the age scale accepted by the authors as 5,5 c and 6, that corresponds to the ages of 10 Ma, 17 Ma and 20 Ma. The axial anomaly of the assumed rift should be laid probably along the axis of the Schott and Dove Basins. It was assumed by Barker and other authors that these linear magnetic anomalies correspond to the history of spreading along the local rift. It was accompanied with creation of the basins of the Central Plate and movements to the north the large continental fragment. That fragment of former continental bridge being displaced to the north and represent now by the South Georgia Island in the east end of the North Scotia Ridge. Similar supposition was made about the rift along the axes of Protector Basin [Eagles, Livermore, Fairthead, Morris, 2005, Eagles, Livermore, Morris, 2006]. However we not recognize in the topography of the floor and in the structure of the basement of these basins any evidences of typical structure of the rifts. We suppose the origin of the observed magnetic anomalies by diapirism of serpentinizied ultrabasic rocks at the large plume of the upper mantle into large fissures of extension in the deep part of the crustal basement. Identification of the Geological age of these anomalies seems to us rather equivocal.

The origin of these basins can be considered as corresponding to the extension and block dislocations of the brittle cratonic basement. Some parts of this basement experienced more deep submission relative to rises. Other reason to submission of the floor of these basins can be supposed as obliged to heating by upper mantle plums accompanied with out pouring the basalt flows and eclogitization of the crustal roots.The origin of the Schott Basin can be assumed also as related with impact of a large asteroid.

Geokinematics

Geodynamics of the structures inside of the Central Plate of Scotia Sea is revealed by results of geokinematic monitoring based on observations made at the net of basic geodetic stations installed on the Antarctic Peninsula, several Antarctic islands, South America, Gough Island, South Atlantic Ridge, and at South Africa [Dietrich R., 2000]. The comparison of the established vectors of horizontal displacement testifies to backlog of movement of the Antarctic Peninsula and Antarctic islands from delayed in this movement from continents of Southern America and Africa approximately on 5 mm/year. As the bodies of continents have very deep roots, their movements in time have to be the inertial steady, and the observed nowadays displacements could be extrapolated through the geological past. Probable result of extension of the crust between Patagonia and West Antarctica through the period of 20-30 ma would be expressed in the series of fractures like Falkland Trough, Shag, South Orkney Trenches and located inside the trough of the Polarstern Graben.

3. Interpretation

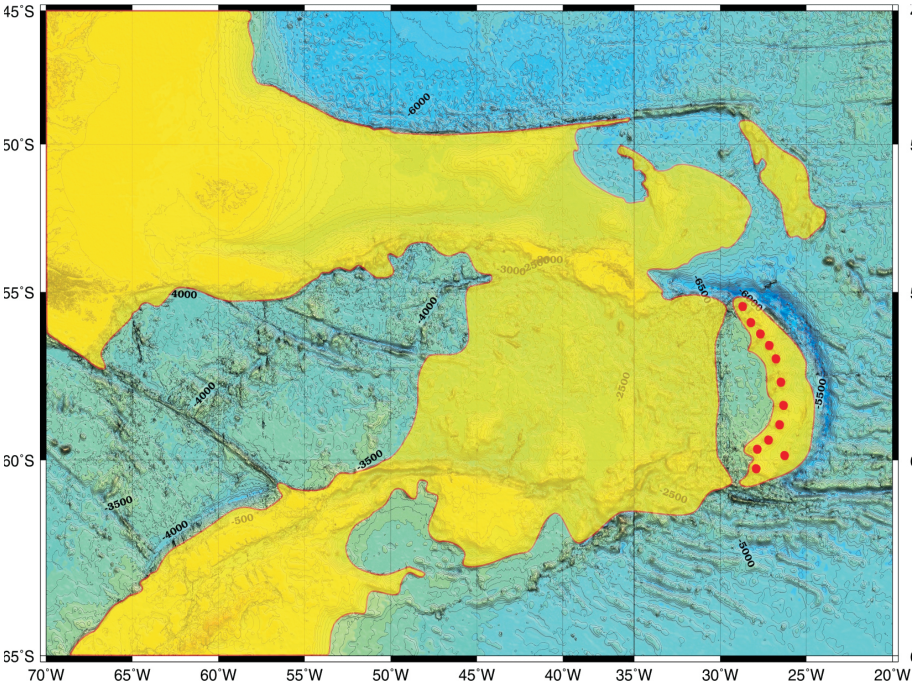

Figure. Morphostructure of the Central Part of Scotia Sea basin. The hypothetic relict of intercontinental bridge between South America and West Antarctica (paleo-Land Scotia) is marked.

Doing synthesis of data obtained we approach to hypothesis about Central Plate of the Scotia Sea as the huge fragment of extra-Andean Patagonia (see figure). This fragment was separated from both neighbor cratons in process of the long term regional extension, registered by geokinematic monitoring, and submerged to the level of depth similar to the Maurice Ewing Bank and the Northeast Georgia Rise. The reason for such hypothesis are data on morphology of the floor; on features of the brittleness of its basement, similar to easternmost part of the Falkland Plateau and South Orkney micro-continent; on identity of geology of the basement; using extrapolation of geological information from the southern parts of the rises of the Central Plate to its northern parts, based on similarity of the gravity field over the whole Central Plate and above neighbor extra-Andean cratons of Patagonia and West Antarctica. The existence of numerously observed planar surfaces are the unequivocal evidences of the submergence of that supposed cratonic fragment, which we would like name as the Scotia paleo-Land.

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