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The Scotia Sea gateway: No outlet for Pacific mantle

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ABSTRACT

The Scotia Sea in the South Atlantic holds a prominent position in geodynamics, because it has been proposed as a potential outlet of asthenosphere from under the shrinking Pacific into the mantle beneath the opening Atlantic. Shear wave splitting and geochemical studies have previously tested this hypothesis. Here, we take a different approach by calculating present-day dynamic topography of the region in search for a systematic trend in dynamic topography decreasing from west to east in response to a flow-related pressure gradient in the sublithospheric mantle. To this end, we reconstruct the kinematic history of the Scotia Sea, which is characterized by complex back-arc spreading processes active on a range of time scales. Our plate reconstructions allow us to derive an oceanic age-grid and to calculate the associated residual (dynamically maintained) topography of the Scotia Sea by comparing present-day isostatically corrected topography with that predicted from our reconstruction. The results provide no indication for a systematic trend in dynamic topography and we conclude that the material needed to supply the growing subatlantic mantle must be derived from elsewhere.

1. Introduction

According to Alvarez (1982) the isolation of Antarctica by opening of the Drake Passage in the Scotia Sea (Fig. 1) had profound consequences for the global mantle circulation system by establishing subsurface mantle flow from under the Pacific into the Atlantic Ocean domain. As he conceived continental roots and subducting slabs as effective barriers to lateral mantle flow from under the Pacific into the Atlantic hemisphere, he proposed the newly formed seaway as an outlet for flow within the asthenosphere and a potential mechanism to establish mass balance between the shrinking Pacific and the growing Atlantic mantle reservoirs.

The notion of an asthenosphere has a long history in the geophysics, dating from 19th century investigations of isostatic support of mountain belts (see Watts, 2001 for a review). Early on in the 20th century, geodynamicists conjectured it provides a zone of weakness over which plates glide easily (Chase, 1979). Modern geophysical evidence for an asthenosphere comes in the form of geoid and postglacial rebound studies (Hager and Richards, 1989; Mitrovica, 1996), supported by investigations into global azimuthal seismic anisotropy (Debayle et al., 2005), and seismic (Grand and Helmberger, 1984) and mineralogical (Stixrude and Lithgow-Bertelloni, 2005) work on the properties of the low seismic velocity zone found at a depth of between 100 and 400 km beneath oceanic and tectonically active regions. 3-D spherical mantle convection models are consistent with the view of a weak upper mantle. The models show that a low-viscosity asthenosphere has a profound effect on convection by promoting a long-wavelength convective planform with only a few large elongated mantle convection cells (Bunge et al., 1996), comparable to the long wavelength pattern that characterizes global mantle flow. The dominant influence of the asthenosphere on the convective planform has also been inferred from analytic fluid dynamic considerations (Busse et al., 2006), and it has been proposed that the existence of an asthenosphere is essential in stabilizing the unusual plate tectonic style of convection that prevails on Earth (Richards et al., 2001).

Complementary to the mobility of the asthenosphere are mechanically stable keels, termed tectosphere, which may exist beneath old portions of the continental lithosphere (Jordan, 1978). Such keels are presumed to pierce through the entire asthenosphere, promoting coupling between continents and the deeper mantle, and restricting the asthenosphere to the subsurface beneath oceanic realms (Conrad and Lithgow-Bertelloni, 2006).

Here we revisit the hypothesis of Pacific-to-Atlantic asthenosphere flux around the tip of South America. The Scotia Sea provides an ideal location, as noted by Alvarez (1982), to explore the pattern of upper mantle flow, as no continental roots or an active subduction zone provide a barrier to asthenospheric flow. By reconstructing the

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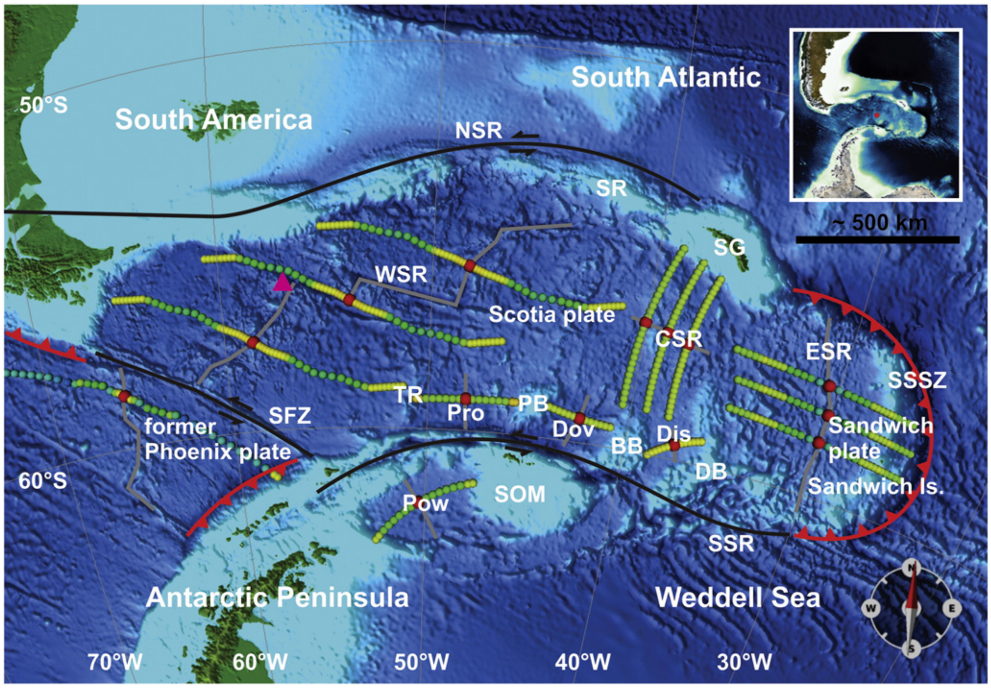

Fig. 1. View of Scotia Sea consisting of the Scotia and Sandwich plates, located in between the Antarctic Peninsula and South America (see also insert map, where the red dot indicates the center of the top view map). The region is framed by transform boundaries in the north (North Scotia Ridge (NSR)), south (South Scotia Ridge (SSR)), west (Shackelton Fracture Zone (SFZ)), and the South Sandwich subduction zone (SSSZ) in the east. Other features are Shag Rocks (SR), South Georgia (SG), and the South Orkney Microcontinent (SOM). Flowlines displaying motion paths of different continental fragments are shown in green. Active spreading (East Scotia Ridge (ESR)) exists in the East Scotia Sea. Extinct spreading ridges are found in the West Scotia Sea (West Scotia Ridge (WSR)), Central Scotia Sea (Central Scotia Ridge (CSR) which remains controversial; see Subsection 2.2) and in the Protector (Pro), Dove (Dov), and Discovery Basins (Dis), respectively, which are bounded by presumably — as some discussion on their origin persists — South American continental fragments (Terror Rise (TR), Pirie Bank (PB), Discovery Bank (DB)). Extinct ridges are also found on the boundary between the Antarctic plate and former Phoenix plate as well as in the Powell Basin (Pow). Location of the dredge sample with Pacific mantle type signature (Pearce et al., 2001) [see discussion] is marked by a triangle.

plate kinematic history of the Scotia Sea we present a geodynamic approach that allows us to detect a dynamically maintained component of topography associated with viscous stresses created by upper mantle flow via Drake Passage through the Scotia Sea, rather than by thermal subsidence related to cooling within the oceanic lithosphere (Braun, 2010).

Our paper is organized as follows: we begin with a general estimate on the pressure gradient required to generate sufficient Pacific mantle flow through the Scotia Sea to achieve mass balance in the Atlantic. Thereafter, we describe the applied dynamic topography deconvolution method, which is followed by a results section and a discussion.

2. Methodology

2.1. Asthenosphere flow estimates

We begin this section with a simple scaling argument, under the assumption that the mass balance required to accommodate Atlantic opening is purely achieved through Pacific mantle flow through the Scotia Sea. We estimate the volume growth rate (Q) of the South Atlantic to be ~ 50 km^3/yr, for which we assumed a length of 10.000 km and a full-spreading rate of 2.5 cm/yr of the South Atlantic mid-ocean ridge system, respectively, as well as a 200 km thick asthenosphere directly under the ridge.

Based on this rate, the pressure difference (Δp) between the western and eastern ends of the Scotia Sea required to compensate the Atlantic growth by Pacific-to-Atlantic mantle flow can be estimated from a simple Poiseuille flow, viewing the Scotia Sea as a channel with thickness h = 200 km (i.e. asthenosphere thickness), width Δy = 1000 km, and length Δx = 3000 km. The pressure difference is given by:

$$\Delta p = \frac{Q * 12\mu * \Delta x}{\Delta y * h^3} \quad (1)$$

Assuming an asthenospheric viscosity (μ) of 10^{19} Pa*s, we arrive at Δp ~ 600 bar, so that the expected dynamic topography in the West Scotia Sea is about 1800 m, large enough to be detectable, although we note that major uncertainties exist regarding the thickness and viscosity of the asthenosphere.

2.2. Dynamic topography deconvolution method

The dynamic component of the actual bathymetry can be unraveled by calculating the difference between the expected bathymetry based on standard cooling models and the isostatically corrected, observed ocean depth (Kido and Seno, 1994). A precise age-grid is therefore crucial, which can be derived from plate reconstruction models which are typically based on magnetic anomaly interpretations. To this end we developed a reconstruction model of the Scotia Sea by using 4DPlates (Clark et al., 2012), a new software package developed by Simula Research Laboratory and Statoil. Deriving an age-grid for the Scotia Sea directly from magnetic lineations is difficult. Indeed various magnetic lineations have been discovered on the ocean floor of the Scotia Sea, but most of them can be correlated to multiple sections of the magnetic reversal

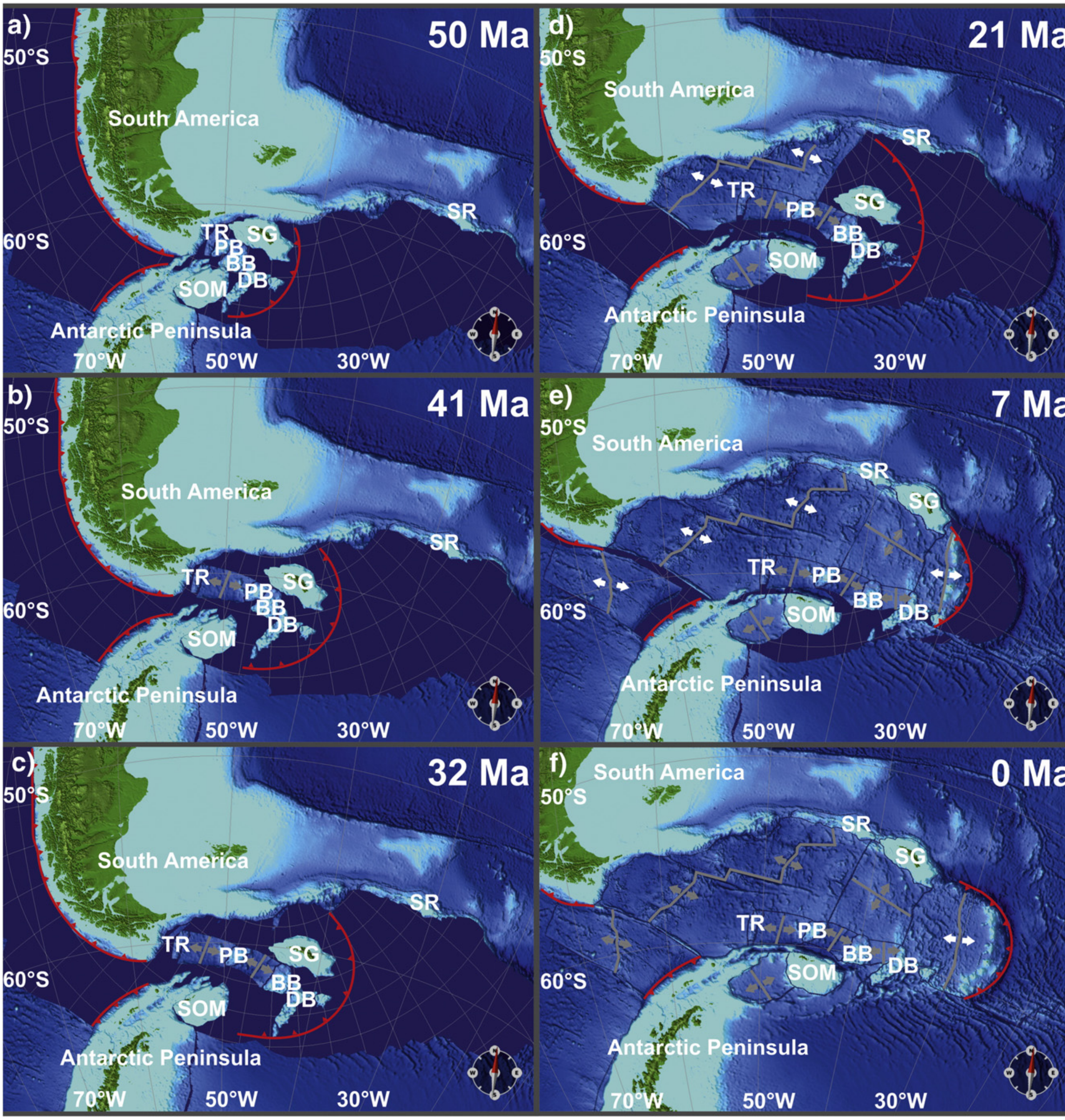

Fig. 2. Tectonic reconstructions corresponding to 50 (a), 41 (b), 32 (c), 21 (d), 7 (e) and 0 Ma (f); labels as in Fig. 1; present-day bathymetry is shown (i.e. no age-masking). White/grey arrows indicate active/inactive spreading. 50 Ma ago, South America and Antarctica are connected by a coherent bridge of continental fragments. At 41 Ma, separation between South America and Antarctica and subduction behind Discovery Bank and South Georgia has started, as suggested by Barker (2001). Protector Basin has opened. 32 Ma ago, active spreading occurs along the West Scotia Ridge but has ceased in Dove Basin. At 21 Ma, further subduction behind Discovery Bank leads to opening of Discovery Basin. Moreover, subduction behind South Georgia is about to cause back-arc spreading in the Central Scotia Sea. Powell Basin is already fully open, placing the South Orkney Microcontinent to its present position relative to Antarctica. Seafloor spreading lasts along the West Scotia Ridge. 7 Ma ago spreading occurs along the West and East Scotia Ridges and ceases along the Central Scotia Ridge.

scale (Eagles et al., 2006). For this paper, we did not re-interpret magnetic data. Instead we developed a reconstruction model in the moving Atlantic-Indian hotspot reference frame (O'Neill et al., 2005) by testing various age suggestions for each basin within the Scotia Sea directly for plate tectonic consistency (i.e. a “best-fit” reconstruction by avoiding plate overlap).

Our model is shown in Fig. 2. It displays that the kinematic history of the Scotia Sea is characterized by back-arc spreading processes causing the initial opening of Protector and then Dove basin. We note that both basins may also have opened purely as a result of divergence between South America and Antarctica (Livermore et al., 2005). The early opening phase was followed by further eastward

Table 1
Ages, rotation poles, and rotation angles as implemented in the reconstruction model (Fig. 2). All other rotations are based on the global rotation file[a] provided by the EarthByte group.

Plate pairs	Age	Rotation pole (long)	Rotation pole (lat)	Rotation angle (degree)
Sandwich Plate East–Sandwich Plate West (East Scotia Ridge)	0.0	0.0	0.0	0.0
	1.7	80.0	−16.57	−1.50
	6.0	80.0	−16.57	−4.11
	10.0	80.0	−16.57	−5.76
	11.5	80.0	−16.57	−6.30
	15.0	80.0	−16.57	−8.04
South Georgia–Bruce Bank (Central Scotia Ridge)	0.0	0.0	0.0	0.0
	7.0	0.0	0.0	0.0
	21.0	−57.38	−21.44	24.56
Drake Passage North–Drake Passage South (West Scotia Ridge)[b]	0.0	0.0	0.0	0.0
	6.25	0.0	0.0	0.0
	10.95	6.21	−27.89	−0.97
	16.73	37.71	−23.37	−2.16
	20.13	27.89	−23.64	−3.60
	23.07	31.76	−27.49	−5.00
	26.55	17.21	−32.12	−6.64
	34.0	20.96	−36.46	−8.20
Former Phoenix Plate–Antarctica[c]	0.0	0.0	0.0	0.0
	3.3	0.0	0.0	0.0
	5.23	68.07	91.96	−1.83
	6.57	69.21	97.32	−3.07
	8.07	68.98	90.41	−5.85
	9.31	69.77	92.17	−7.94
	10.95	69.98	94.12	−11.23
	12.40	70.23	96.68	−13.38
	14.61	70.02	94.97	−18.94
	23.41	70.02	94.97	−38.94
Pirie Bank–Terror Rise (Protector Basin)	0.0	0.0	0.0	0.0
	41.0	0.0	0.0	0.0
	48.5	80.82	135.66	−6.84
Bruce Bank–Pirie Bank (Dove Basin)	0.0	0.0	0.0	0.0
	34.7	0.0	0.0	0.0
	41.0	−50.04	−39.80	−10.0
Discovery Bank–Bruce Bank (Discovery Basin)	0.0	0.0	0.0	0.0
	14.4	0.0	0.0	0.0
	21.0	−62.56	−34.38	25.84
South Orkney Microcontinent–Antarctic Peninsula (Powell Basin)	0.0	0.0	0.0	0.0
	21.8	0.0	0.0	0.0
	29.7	−65.13	−45.38	−43.79

Literature sources for the kinematic reconstruction

Basin name	Reference for spreading onset (Ma)	Reference for spreading cessation (Ma)
West Scotia Ridge	Livermore et al. (2005)	Eagles et al. (2005)
Central Scotia Ridge	Barker (2001)	Barker (2001)
East Scotia Ridge	Larter et al. (2003)	still active
Protector Basin	Eagles et al. (2006)	Eagles et al. (2006)
Dove Basin	Eagles et al. (2006)	Eagles et al. (2006)
Discovery Basin	Lodolo et al. (2010)	Lodolo et al. (2010)
Powell Basin	Eagles and Livermore (2002)	Eagles and Livermore (2002)
Phoenix Plate	Manually extrapolated	Eagles (2003)

[a] http://www.earthbyte.org/Resources/earthbyte_gplates.html.
[b] Rotations are based on Eagles et al. (2005).
[c] Rotations are based on Eagles (2003).

subduction retreat and spreading along the West, Central, and East Scotia Ridges (Table 1).

The age of the Central Scotia Sea is controversial. We treated it as a Miocene back-arc basin, based on for example Barker (2001) (Fig. 2). Yet, heat flow measurements, lack of a visible fossil ridge, fracture zones, and triple-junction traces, as well as the flexural strength of the lithosphere, for example, have led Eagles (2010) and De Wit (1977) to propose that the Central Scotia Sea might be a Mesozoic plate fragment. We could not develop a kinematically consistent reconstruction model that avoids large plate overlap based on this idea, but we acknowledge Eagles' (2010) reconstruction model. However, because he did not provide rotation poles along with his paper and showed only very large time steps, we could not reappraise his model.

Another controversial topic is the opening sequence of Dove (41–34.7 Ma) (Eagles et al., 2006) and Protector Basin. The latter has been suggested to be of Miocene (17.4–13.8 Ma) (Galindo-Zaldivar et al., 2006), Oligocene (34–30 Ma) or Eocene age (~48–41 Ma) (Eagles et al, 2006), respectively. A Miocene aged Protector Basin in our model results in plate overlap of the southern continental fragments with the South Orkney Microcontinent. Also, the Oligocene age assumption would cause plate overlap in our reconstruction model, which we avoided by adopting the Eocene age suggestion. Different age suggestions exist also for the other basins, e.g.,

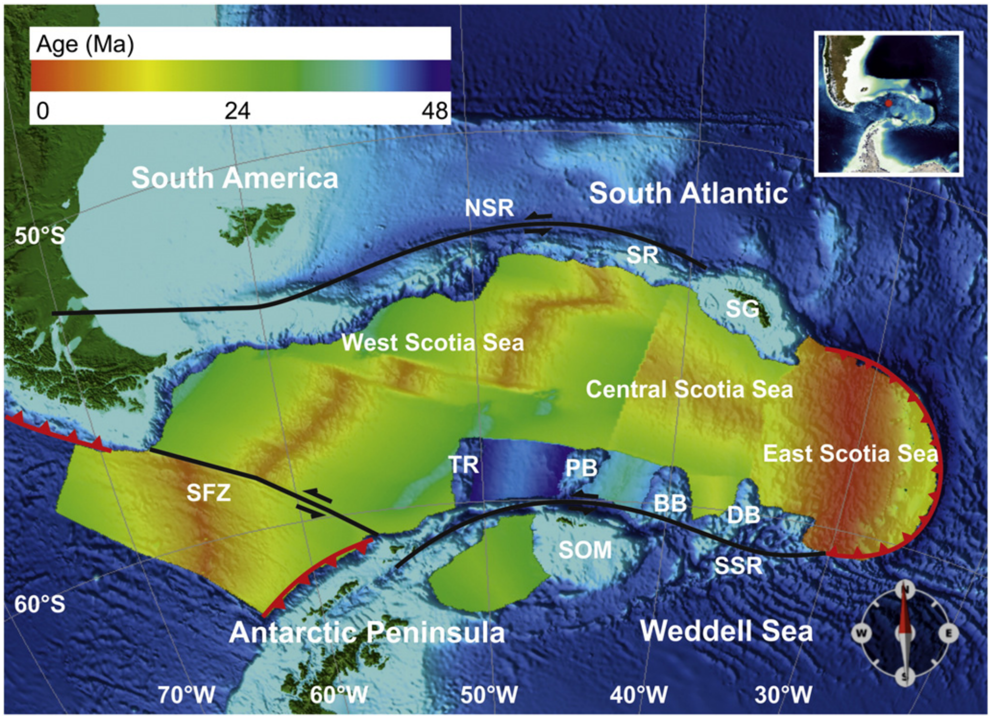

Fig. 3. Synthetic age-grid based on the reconstruction model as shown in Fig. 2.

the onset of spreading along the West and East Scotia ridges remains under discussion, but the variations are not as large as for the Central Scotia Sea or Protector Basin.

4DPlates uses flowlines to derive an age-grid from our reconstruction model. They are based on the rotation file (see Table 1) and represent the motion of the continental fragments and microcontinents for each time step, respectively. By exporting the flowlines from the program, we created a synthetic age-grid (Fig. 3) containing pairs of longitude and latitude as well as the associated age for each location within the Scotia Sea.

It is well known that a half-space cooling model predicts deeper basement depths for old ocean floor than so called plate models.

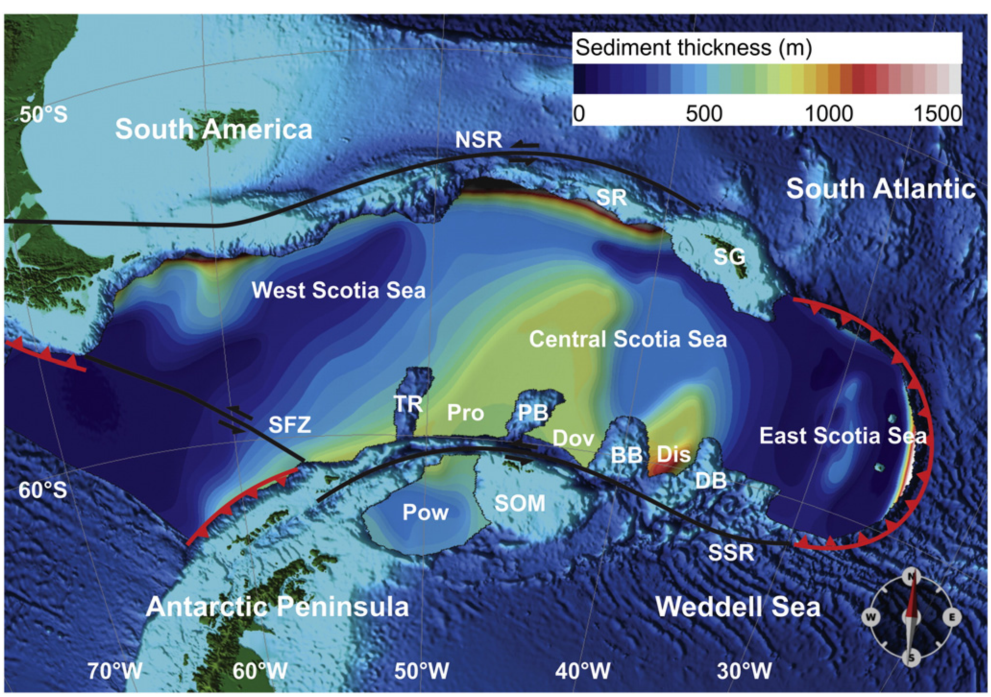

Fig. 4. Sediment distribution in the Scotia Sea based on the 5 arc-minute by 5 arc-minute global grid that is available from the National Geophysical Data Center (NGDC). The sediment thickness is generally rather low (<1000 m). Note that this also applies to the Central Scotia Sea but uncertainties exist (see discussion).

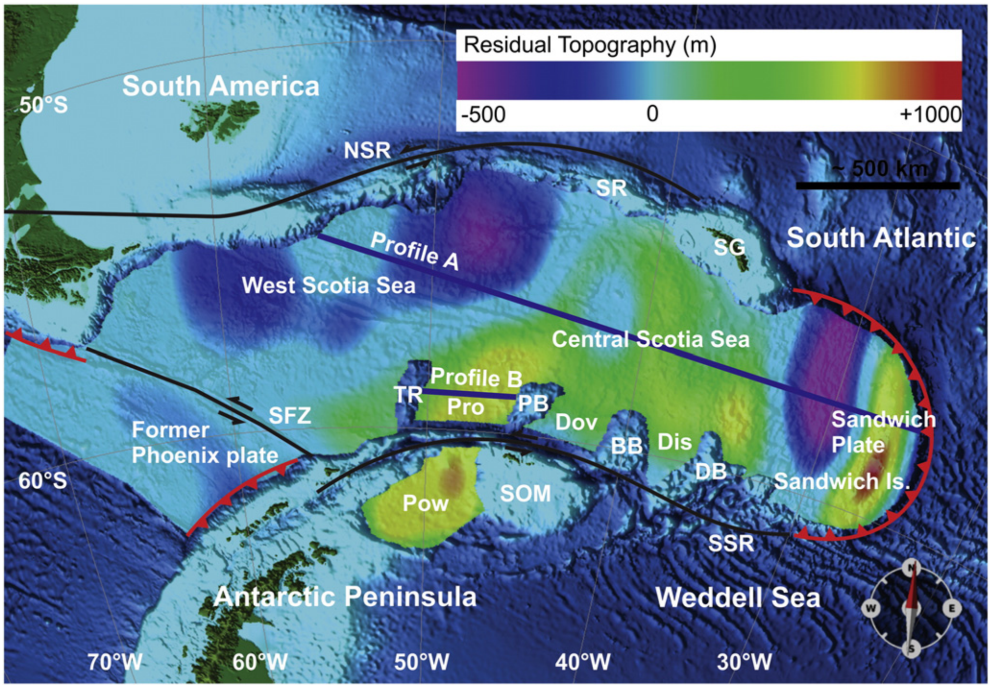

Fig. 5. Present-day bathymetry with superimposed residual (dynamic) topography based on a half-space cooling model (Turcotte and Oxburgh, 1967). Note the regional low dynamic topography in the north-west and the high in the east. Note also the strong local dynamic topography signal associated with the subduction of the Scotia arc. The blue lines labeled Profile A and B indicate the location of the profiles illustrated in Figs. 6 and 7, respectively.

For the sake of comparison, we therefore converted our synthetic age-grid (Fig. 3) into expected basement depth based on three standard lithospheric cooling models. The half-space cooling model (Turcotte and Oxburgh, 1967) is uniformly based on the function: $\text{depth} = 2600 + 345 \times \sqrt{(\text{age})}$. The GDH1 (Stein and Stein, 1992) and PSM (Parsons and Sclater, 1977) plate models deviate from the continuous "square-root of age" assumption in that these models assume exponential functions for ages greater than 20 Ma and 70 Ma, respectively.

The observed bathymetry (Amante and Eakins, 2009) was isostatically corrected for sediments following Sykes (1996) and using the dataset provided by the National Geophysical Data Center (Fig. 4). The difference between the age corrected depth and the isostatically adjusted observed bathymetry was identified as dynamically maintained topography, assuming it is related to mantle flow. Potential sources of error that we will return to in the discussion section are (1) inaccuracies in sediment amounts, (2) uncertainties in crustal thickness as well as (3) in the assumed basin ages (as already pointed out). Since dynamic topography is a long-wavelength feature we low-pass filtered (cut-off wavelength: 500 km) our results.

3. Results

Fig. 5 shows the estimated dynamic topography based on the half-space cooling model (Turcotte and Oxburgh, 1967). The difference in the calculated dynamic topography is negligible between the different cooling models, as we assume a rather young history of the Scotia Sea in our reconstruction model. Thus, we report values based on the half-space cooling model only and refer to Fig. 6a for the inferred dynamic topography along a profile across the Scotia Sea (Profile A in Fig. 5) based on the different cooling models.

We see from Fig. 5 that the calculated present-day dynamic topography of the Scotia Sea is generally low. The western part, including the former Phoenix plate, shows no significant dynamic topography, while the eastern part shows a signal of 90 ± 330 m. A negative signal is observed on the northern flank of the West Scotia Ridge (-100 ± 130 m), while the southern flank shows a positive signal (80 ± 180 m). The East Scotia Ridge shows negligible dynamic topography on the western side (10 ± 270 m) and dynamic topography of 150 ± 350 m on the eastern side (Sandwich plate). The ridge and nearby areas show a negative signal of up to 470 m, while the Central Scotia Sea signal (290 ± 90 m) is on the order of those calculated for the southern basins (i.e. Protector, Dove, and Discovery Basin), which on average show some 330 m of positive dynamic topography. The Powell Basin shows a positive signal of 520 ± 120 m.

4. Discussion

Our results are of great interest as they show no indication for a systematic eastward decrease in dynamic topography (Fig. 5) that one would expect in the presence of substantial asthenosphere flux from the Pacific into the Atlantic around the southern tip of South America (Alvarez, 1982).

This finding agrees well with teleseismic shear-wave splitting studies (Helffrich et al., 2002), which map upper mantle flow directions in the southern Atlantic. The seismically inferred flow directions parallel the absolute plate motion of South America but provide no indication for direct asthenosphere flow through the Drake Passage. Similarly, while there is evidence from geochemical studies for a mantle domain boundary between the Drake Passage and the East Scotia Sea and hence for some Pacific-to-Atlantic upper-mantle transport through the Drake Passage, the inferred amount is minor and probably related to regional tectonic constraints, rather than global mass-balance requirements (Pearce et al., 2001) (Fig. 1).

In Fig. 6b we tested the consequences of assuming a Mesozoic plate fragment (assuming an age of 80 Ma) in terms of dynamic topography. Note that approximately 2 km of dynamic topography

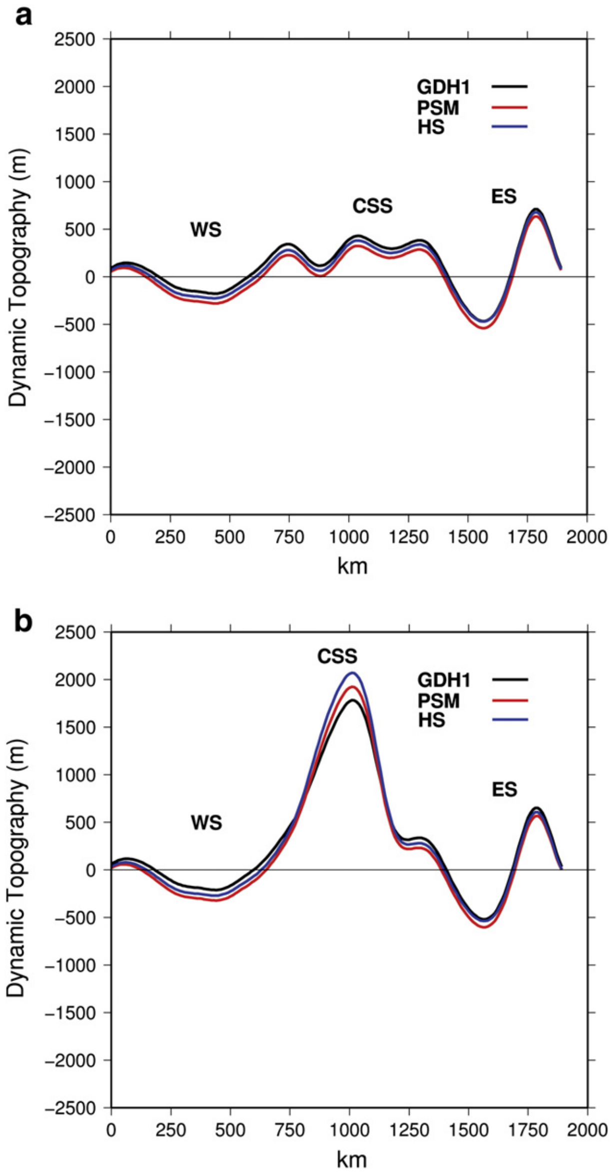

Fig. 6. Dynamic topography based on three different lithospheric cooling models along profile A (see Fig. 5 for location). Labels are: West Scotia Sea (WS), Central Scotia Sea (CSS), East Scotia Sea (ES), and half-space model (HS). a) Dynamic topography based on the reconstruction model as shown in Fig. 2. b) Dynamic topography based on an 80 Ma old plate fragment in the Central Scotia Sea (CSS). Note that such an old fragment implies ~2 km of dynamic topography. The neighboring regions, i.e. the West Scotia Sea (WS) and East Scotia Sea (ES), show considerably lower dynamic topography.

would be implied in this case, no matter what lithospheric cooling model is used, in order to compensate for the fact that a Mesozoic plate fragment would yield much deeper ocean floor in the Central Scotia Sea than what is actually observed. Such large dynamic topography is difficult to understand on geodynamic grounds, as the Scotia Sea is generally characterized by low dynamic topography < 1 km (see results and Fig. 6a and b). Of course, uncertainties exist regarding the sediment amount and crustal thickness of the Central Scotia Sea, as noted before. With respect to the sediments, we had access to two global sediment grids, i.e. a 1 degree by 1 degree grid (Laske and Masters, 1997) and the eventually used 5 arc-minute by 5 arc-minute grid from the National Geophysical Data Center (Fig. 4). Both grids are mostly based on the same data for the southern oceans provided by Hayes and LaBrecque (1991), so unsurprisingly we found no major deviations between these two grids for the Central Scotia Sea (Table 2). Both indicate that the sediment coverage in the Central Scotia Sea is similar to the surrounding environment and rather low. Nevertheless, in parts of the Central Scotia Sea, the sediment thickness seems to be higher, since Eagles (2010) suggests sediment thicknesses between 800 m and 1500 m based on seismic profile data. In this case, the dynamic topography signal of the Central Scotia Sea would obviously be smaller and potentially make the assumption of an old Mesozoic plate fragment more reasonable. As to the crustal thickness we also cannot entirely rule out thickened crust. Unpublished work presented at the 11th International Symposium on Antarctic Earth Science held in Edinburgh in July, 2011 points in this direction, but overall in the Scotia Sea it is likely to be small because of the presumably young history of the region.

Table 2
Comparison of the sediment amounts in the Central Scotia Sea based on the 1 degree by 1 degree sediment grid provided by Laske and Masters (1997) and the 5 arc-minute by 5 arc-minute sediment grid available from the NGDC database.

	Laske and Masters (1997)	NGDC
Minimum (m)	325	189
Maximum (m)	1063	844
Average (m)	566	471
Standard deviation (m)	162	171

We also calculated the dynamic topography of the Protector Basin, based on the various age suggestions that were mentioned in Section 2.2. In Fig. 7a, b, c we illustrate the expected magnitude of dynamic topography along profile B in Fig. 5. A Miocene aged Protector Basin yields negative dynamic topography of ~ 140 to 240 m (Fig. 7a), depending on which cooling model is considered. This result would be difficult to understand, as the surrounding area shows positive dynamic topography. The suggested Oligocene and Eocene ages instead imply a positive dynamic topography signal (Fig. 7b and c) on the same order of magnitude as the surrounding area. The Oligocene age (Fig. 7b), however, results in plate overlap in our reconstruction so that we implemented the Eocene age (Fig. 7c) in our model as was pointed out above.

The low dynamic topography in the West Scotia Sea may be related to the prominent dynamic topography low of the Argentine Basin (Fig. 8), while small scale positive dynamic topography signals in the Central Scotia Sea and in the smaller basins in the south have been attributed to mid-ocean ridge subduction (Guillaume et al., 2009). Magnetic anomalies within the northern Weddell Sea (Fig. 1) south of the Scotia Sea, for example, become progressively younger northwards, suggesting ridge-crest subduction (Barker et al., 1984). These collisions are proposed to be youngest to the east and oldest to the west, with an extent probably as far west as the Antarctic Peninsula at 50 degree west (Barker, 2001).

The apparent lack of upper mantle flux from the Pacific into the Atlantic around the southern portion of South America raises questions about the origin of the material needed to supply the growing South Atlantic mantle reservoir. According to Alvarez (1982), the main gateway from the East Pacific into the Atlantic in addition to the Drake Passage is located in the Caribbean Sea. Shear wave splitting studies by Russo et al. (1996) support the notion of Pacific mantle outflow through this region. Likewise, Heintz et al. (2005) deduced along-strike variation at the western margin of South America with lowered upper mantle seismic velocities corresponding to the intersection of the Carnegie and Chile ridges with the continent. They argued for a slab window in this region and a weakness in the subducted plate which might accommodate asthenospheric mantle transfer from the Pacific to the Atlantic region. A similar slab window was proposed by Hole et al. (1994) for the Antarctic Peninsula region.

A far more likely source to supply the growing South Atlantic mantle reservoir, however, is located in the deep mantle beneath Africa. Courtillot et al. (2003) identified a number of primary hotspots in this region and several strong mantle plumes have been imaged in the Sub-Atlantic mantle in recent seismic tomography models that account for finite frequency effects (Montelli et al., 2004). The so-called African superplume, which up-lifts much of the southeastern Atlantic Ocean and parts of the African continent by as much as ~1 km (Lithgow-Bertelloni and Silver, 1998) in the so-called African superswell (Nyblade and Robinson, 1994), is particularly well known. Geodynamic studies favor a substantial hotspot contribution to the mantle energy budget (Bunge et al., 2001). Also, a significant role of plumes in general mantle circulation would adequately explain the nature of the prominent seismic low velocity anomaly harbored in the deep mantle beneath Africa (Schuberth et al., 2009a, 2009b). The elevated topography of the African superswell contrasts with significant negative dynamic topography of up to ~1 km inferred for the conjugate South American margin in the Argentine Basin (Fig. 8) (e.g., Winterbourne et al., 2009). The remarkable dynamic topography gradient across the South Atlantic is consistent with westward flow emanating from the African superplume, as suggested by Behn et al. (2004) and Husson et al. (2012), rather than eastward flow through the Drake Passage. Equally important is the fact that the magnitude of the basal shear tractions associated with westward fluxing subatlantic asthenosphere may be sufficient to balance the budget of driving and resisting forces acting on the South American plate (Iaffaldano and Bunge, 2009). Thus a variety of evidence suggests that mass balance between the Pacific and Atlantic mantle domains is achieved through deep mantle processes rather than shallow upper mantle flux in the asthenosphere.

We close by noting that our regional dynamic topography results confirm earlier results by Husson (2006), which show a slab related negative dynamic topography signal in the East Scotia Sea, while the South Sandwich island arc accounts for the positive signal in the easternmost Scotia Sea. The larger amplitude inferred by Husson (2006) relative to our results is probably due to three reasons: firstly, our dynamic topography results are band-pass filtered, as noted before; secondly we adopt an earlier spreading onset (15 Ma) based on identified magnetic lineations (Larter et al., 2003) compared to Barker (2001); thirdly, we have used a higher resolution sediment thickness grid.

In summary, our dynamic topography results for the Scotia Sea provide no indication for large-scale asthenosphere flux from the Pacific into the Atlantic through the Drake Passage, consistent with previous findings from seismology and geochemistry, and we suggest that mass balance between the Pacific and Atlantic mantle domains must be achieved through deep mantle related plume processes rather than upper mantle flux.

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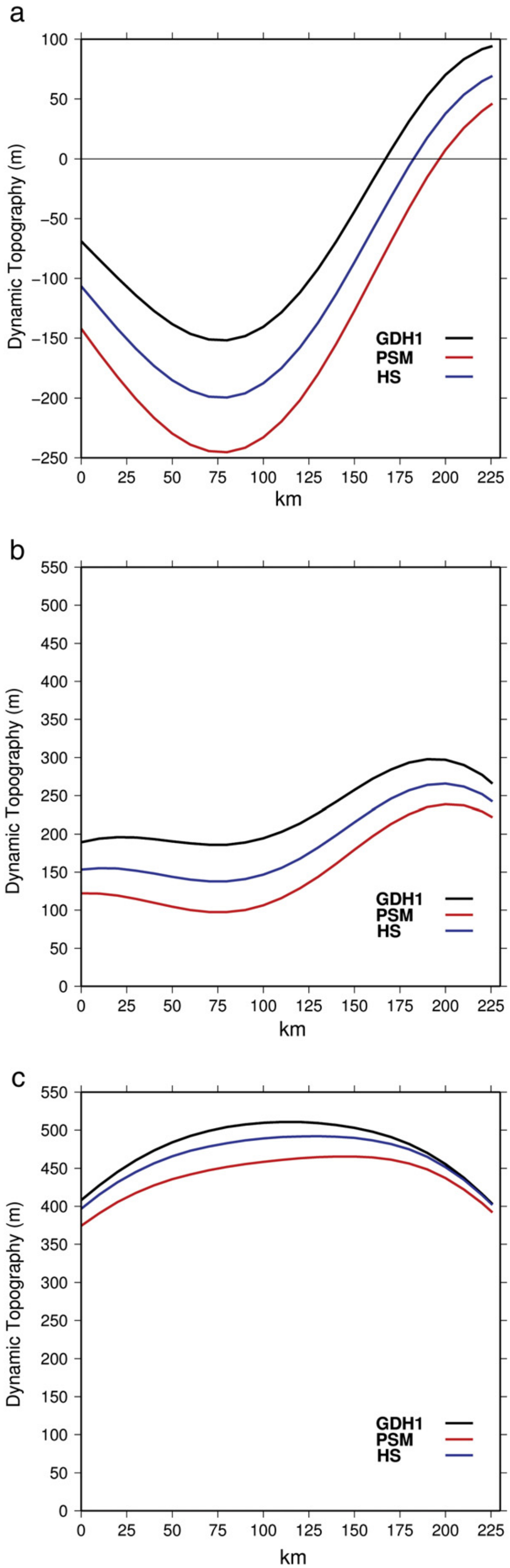

Fig. 7. Dynamic topography based on different lithospheric cooling models along profile B located in the Protector Basin (see Fig. 5). Labels as in Fig. 6 a) Assuming a rather young age of this basin, as was proposed by Galindo-Zaldivar et al. (2006), results in negative dynamic topography in parts of this basin. Assuming an b) Oligocene or c) Eocene age (the age adopted in our plate reconstruction model), as proposed by Eagles et al. (2006), results in positive dynamic topography on the order of a few hundred meters.

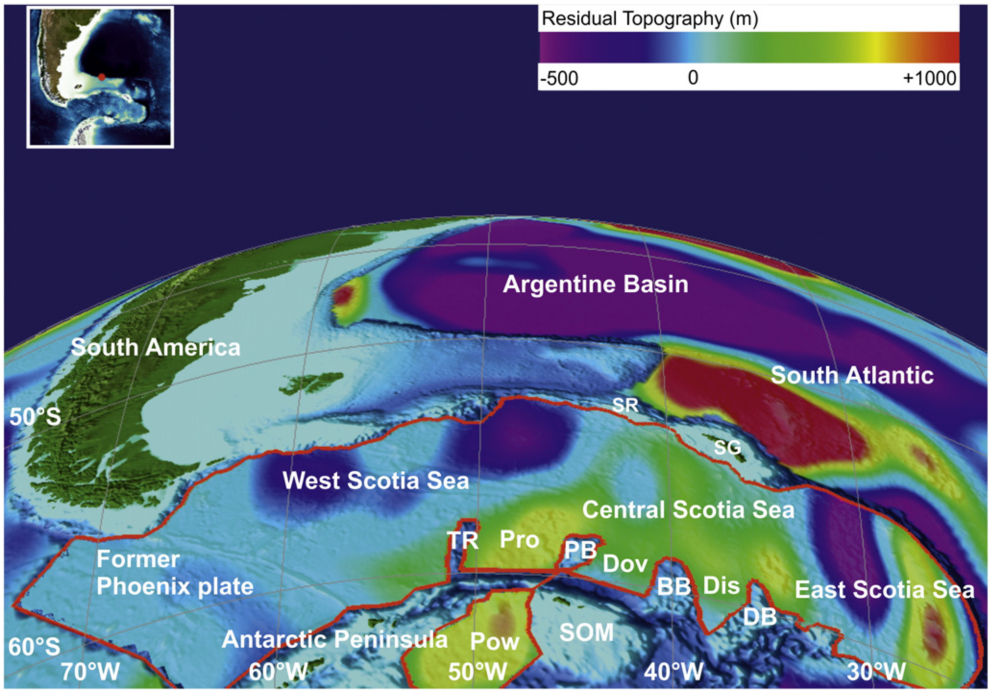

Fig. 8. Northeast view from Antarctica. Note the large residual (dynamic) topography low (>500 m Winterbourne et al., 2009) in the Argentine Basin (based on a half-space cooling model (Turcotte and Oxburgh, 1967)).

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