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Kinematics and segmentation of the South Shetland Islands-Bransfield basin system, northern Antarctic Peninsula

Frederick W. Taylor
Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, J. J. Pickle Research Campus, Building 196, 10100 Burnet Road (R2200), Austin, Texas 78758, USA

Michael G. Bevis
School of Earth Sciences, Ohio State University, 125 South Oval Mall, Columbus, Ohio 43210, USA

Ian W. D. Dalziel
Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, J. J. Pickle Research Campus, Building 196, 10100 Burnet Road (R2200), Austin, Texas 78758, USA

Robert Smalley Jr.
Center for Earthquake Research and Information, University of Memphis, 3890 Central Avenue, Suite 1, Memphis, Tennessee 38152, USA (smalley@ceri.memphis.edu)

Cliff Frohlich
Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, J. J. Pickle Research Campus, Building 196, 10100 Burnet Road (R2200), Austin, Texas 78758, USA

Eric Kendrick
School of Earth Sciences, Ohio State University, 125 South Oval Mall, Columbus, Ohio 43210, USA

James Foster
Hawaii Institute for Geophysics and Planetology, University of Hawai'i, 1680 East-West Road, POST Suite #602, Honolulu, Hawaii 96822, USA

David Phillips
UNAVCO Inc., 6350 Nautilus Drive, Boulder, Colorado 80301, USA

Krishnavikas Gudipati
Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, J. J. Pickle Research Campus, Building 196, 10100 Burnet Road (R2200), Austin, Texas 78758, USA

[1] New GPS measurements demonstrate tectonic segmentation of the South Shetland Islands platform, regarded as a microplate separating the Antarctic Peninsula from the oceanic portion of the Antarctic plate. King George, Greenwich, and Livingston islands on the central and largest segment are separating from the Antarctic Peninsula at 7–9 mm/a, moving NNW, roughly perpendicular to the continental margin. Smith and Low islands on the small southwestern segment are moving in the same direction, but at 2.2–3.0 mm/a. The Elephant Island subgroup in the northeast moves at ~7 mm/a relative to the Peninsula, like the central group, but toward the WNW. This implies that it is presently coupled to the Scotia plate on the northern side of the South Scotia Ridge transform boundary; thus the uplift of these northeasternmost islands may be caused by Scotia-Antarctic plate convergence rather than by subduction of thickened oceanic crust.

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1. Introduction

[2] In this paper we report new GPS measurements that constrain microplate motions in the South Shetlands-Bransfield basin-Antarctic Peninsula region and compare these measurements with previous results [*Niemeier and Salbach*, 1998; *Bouin and Vigny*, 2000; *Dietrich et al.*, 2001, 2004]. The region has attracted interest because of its unusual and enigmatic plate configuration along the only active portion of the margin of the Antarctic continent, and because it affords opportunities to investigate the early stages of back-arc rifting as well as the tectonic relationships between the Antarctic and Scotia plates along the southern limb of the Scotia arc (Figure 1). This investigation is part of the Scotia Arc GPS Project (SCARP), which was initiated in 1996 to determine the partitioning of South American-Antarctic plate motion between the North and South Scotia ridges bounding the Scotia arc [*Smalley et al.*, 2003].

[3] Between the Hero and Shackleton fracture zones (Figure 1), the platform of the inactive South Shetland Islands Cenozoic volcanic arc is bounded on the Pacific side by an oceanic trench over 5000 m deep and separated from the Antarctic Peninsula by the Bransfield basin, which reaches a depth over 1500 m. The Bransfield basin has a volcanically active axis [*Lawver et al.*, 1996], and both our and previous GPS results indicate that the basin is presently extending in a direction roughly perpendicular to this axis [*Dietrich et al.*, 2001, 2004].

[4] The Phoenix plate spreading ridge segments were sequentially subducted beneath West Antarctica from west to east during the Late Cretaceous and Cenozoic, effectively welding oceanic lithosphere to the Antarctic continent as part of a single Antarctic plate. Following the cessation of seafloor spreading ~4 Ma on the last segment of the Antarctic-Phoenix ridge east of the Hero fracture zone, the remainder of Phoenix plate was amalgamated to the Antarctic plate at the ridge, but leaving a short segment of subducting slab between the Hero and Shackleton fracture zones [*Larter and Barker*, 1991]. Subsequently back-arc rifting began behind the inactive South Shetland Islands arc and initiated the Bransfield basin within the continental lithosphere of the Antarctic Peninsula [*Barker and Dalziel*, 1983; *Larter and Barker*, 1991]. The precise nature of the active tectonism along the northwestern margin of the Antarctic Peninsula remains uncertain [*Pelayo and Wiens*, 1989; *Lawver et al.*, 1996; *Barker et al.*, 2003]. Apart from the geodetic evidence of extension and axial active volcanism, normal faulting and crustal thinning provide strong evidence of rifting within the Bransfield basin [*Barker and Austin*, 1998; *Robertson Maurice et al.*, 2003; *Christeson et al.*, 2003]. However, there are no well-organized magnetic anomalies characteristic of mature back-arc basins [*Barker and Austin*, 1998; *Lawver et al.*, 1996]. The presence of earthquakes with focal depths of 40–80 km beneath South Shetland Islands platform [*Robertson Maurice et al.*, 2003] may manifest continued subduction: so slow that the slab may be too warm to accumulate elastic strain once it has sunk deeper than 80 km.

2. Methods

[5] Between 1993 and 1997 we and various colleagues installed nine GPS sites (Figure 2 and Table 1): seven of these sites are on six of the South Shetland Islands, two are on the Antarctic Peninsula. All monuments were emplaced in solid bedrock using a drill and epoxy. We collected GPS data using Ashtech Z-12 receivers and choke-ring antennas with the radomes attached. For campaign GPS sites, we used fixed height Tech 2000 antenna

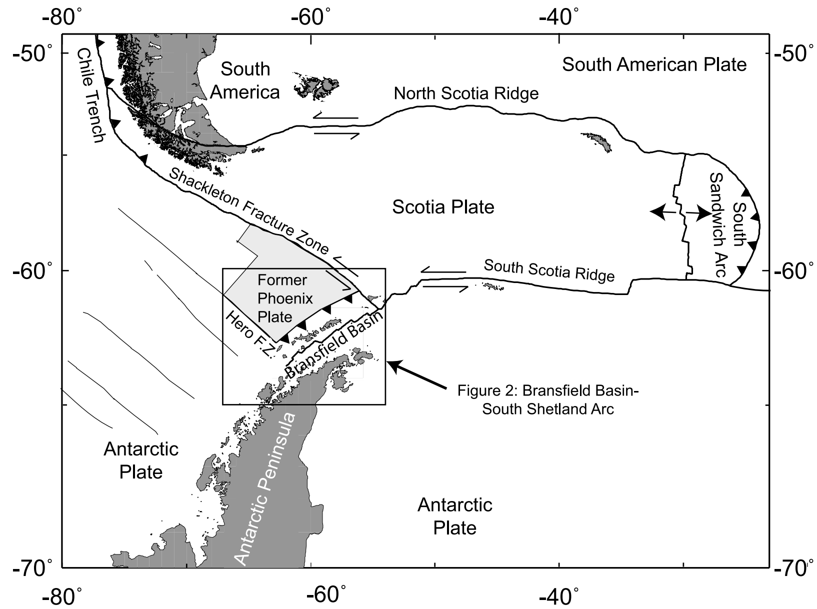

Figure 1. Regional plate tectonic setting of the Bransfield Strait-South Shetland Islands continental margin, northern Antarctic Peninsula. The South Shetland Islands are separated from the Antarctic Peninsula by the volcanically active Bransfield basin (zigzag line) and lie immediately south of the South Shetland trench. Box indicates region shown in Figure 2.

masts that are more stable than tripods in high winds.

[6] We occupied each site during the months of November and December in 1997, 1998 and 2002, with no cases of antenna masts moving perceptibly during deployment. Our goal was to acquire at least two 24-h GMT data sets at each site during each occupation [see *Bevis et al.*, 1997]. However, bad weather and time limitations in 2002 forced us to withdraw our equipment prematurely from Elephant Island (ELPH). In addition to these campaign stations, we processed data from eight continuous GPS (CGPS) stations including FREI on King George Island, OHIG and OHI2 on the tip of the Antarctic Peninsula, and PALM at Anvers Island farther south along the Peninsula.

[7] The GPS data were analyzed using GAMIT/GLOBK software [*King and Bock*, 2002] and the approach described by *Kendrick et al.* [2001]. All velocities (Table 1) are reported in an Antarctica-fixed reference frame. The stability of this frame is characterized a posteriori by the RMS horizontal velocity of the CGPS stations used to realize the frame, which is 0.8 mm/a.

[8] The two campaign sites we measured on the Antarctic Peninsula, SPPT at Spring Point and MRAN at Base O'Higgins, appear to be part of the Antarctic plate, as their relative motions (1.3 ± 0.3 and 0.6 ± 0.7 mm/a) fall within the range (0–1.5 mm/a) of the Antarctic CGPS reference stations (Table 1). However, in our solutions and those of *Bouin and Vigny* [2000] the CGPS stations OHIG and OHI2 at O'Higgins Base are moving 2–3 mm/a relative to the Peninsula. In contrast, *Dietrich et al.* [2004] reported no more than 1–2 mm/a motion among sites on the Antarctic Peninsula that include OHIG and OHI2, while *Niemeier and Salbach* [1998] reported that a third GPS site at Base O'Higgins, OHG1, was stable relative to three other Peninsula sites between 1995 and 1998. We choose to accept our result for the campaign station MRAN, which is clearly set into stable bedrock, and so conclude that O'Higgins Base is part of stable Antarctica.

3. Results

[9] The six GPS sites on the central and southwestern segments of the South Shetland Islands platform, including the CGPS site FREI, unambiguously indicate extension across the Bransfield basin (Figure 2). Azimuths for these South Shetland GPS sites with respect to the Antarctic Plate

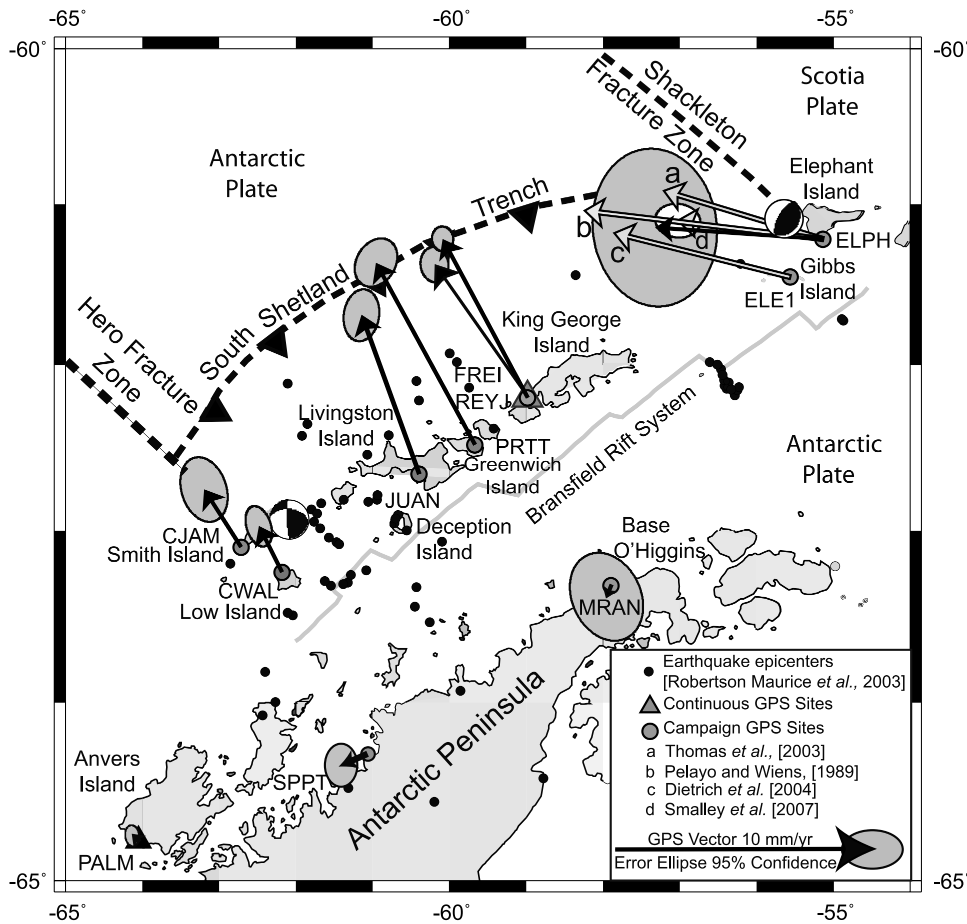

Figure 2. GPS velocities with respect to the Antarctic continent for sites discussed in text (circles, campaign; triangles, continuous). Sites on the Antarctic Peninsula show that it moves with the entire Antarctic continent. GPS velocities for the South Shetland Islands indicate that at least two forearc blocks accommodate extension of the Bransfield basin at rates of ~7 mm/a (central) and 2.3–3.0 mm/a (southwest) while the Elephant Island subgroup in the northeast presently moves with the Scotia plate. Vectors for continuous GPS sites have no apparent error ellipses because the large number of measurements produces formal error ellipses too small to distinguish. At ELPH the vector for our site is black and has the larger error ellipse. For comparison we plot in gray the vectors for Scotia-Antarctic plate relative motion at ELPH from other sources [*Pelayo and Wiens*, 1989; *Thomas et al.*, 2003; *Smalley et al.*, 2007], and we also plot the published vector for site ELE1 on Gibbs Island [*Dietrich et al.*, 2004]. The smaller error ellipse is for the predicted motion from *Smalley et al*. [2007]. The vector associated with this ellipse is nearly hidden behind the GPS vector for ELPH. Black circles are better located shallow seismicity determined from locally recorded data [*Robertson Maurice et al.*, 2003]. The two focal mechanisms shown, one between Smith and Low islands for the earthquake of 30 March 1984 and one near Elephant Island for the earthquake of 18 January 1981, are as reported by Columbia's Global CMT group (formerly, Harvard CMT) and plotted at the location determined by *Engdahl et al.* [1998]. The 1984 focal mechanism is consistent with ongoing lateral motion between Smith and Livingston islands (see text).

range from −20° to −35°, but the smallest uncertainty is for CGPS site FREI where measurements began in 1996. There the azimuth is −35° ± 0.4°. All these azimuths are nearly perpendicular to the axial trend of the Bransfield basin.

[10] The velocities determined for these sites, however, fall into two distinct groups. GPS sites on Livingston (JUAN), Greenwich (PRTT), and King George (REYJ and FREI) islands on the main central part of the platform have velocities of 7.3 ± 0.4, 9.0 ± 0.4, 7.8 ± 0.2, and 7.0 ± 0.1 mm/a, respectively. The velocities for these sites are too tightly grouped for their differences to be significant over the 5-year to 8-year periods of data collection. We note that *Dietrich et al.* [2004] reported a velocity of 7 mm/a and a similar azimuth for extension across the Bransfield basin based on

Table 1. GPS Sites and Velocities[a]

Station Name	Location	Latitude	Longitude	Time Span (years)	Vhor (mm/a)	SD (±mm)	Azm (degrees)	SD (±degrees)	Station Type
				South Shetland Islands					
ELPH	Elephant Island	−61.22004	−55.13656	5.014	7.3	1.1	−86.3	10.7	campaign
FREI	King George Island	−62.19410	−58.98050	7.306	7.0	0.1	−35.0	0.9	continuous
REYJ*	King George Island	−62.20111	−58.97921	9.047	7.8	0.2	−27.8	1.4	campaign
PRTT	Greenwich Island	−62.48429	−59.66613	4.997	9.0	0.4	−28.6	2.7	campaign
JUAN	Livingston Island	−62.66229	−60.3961	4.964	7.3	0.4	−19.8	2.7	campaign
CJAM	Smith Island	−63.09652	−62.7162	4.926	3.0	0.6	−32.0	7.6	campaign
CWAL	Low Island	−63.24532	−62.1833	4.929	2.2	0.4	−26.4	5.6	campaign
				Antarctic Peninsula					
MRAN*	O'Higgins Base	−63.32102	−57.89439	8.819	0.6	0.7	−156.6	74.2	campaign
OHIG**	O'Higgins Base	−63.32108	−57.90133	6.946	2.7	0.1	133.8	2.8	continuous
OHI2**	O'Higgins Base	−63.32072	−57.90034	3.214	3.0	0.4	119.2	7.7	continuous
SPPT	Spring Point	−64.29443	−61.05156	4.942	1.3	0.3	−111.3	16.4	campaign
PALM**	Palmer Station	−64.77509	−64.05112	7.691	0.3	0.1	−39.4	4.4	continuous
				Stable Antarctic Plate Continuous GPS Sites Used as a Reference Frame					
CAS1**	Casey Station	−66.28336	110.51971	10.899	0.7	0.2	−58.0	15.4	continuous
DAV1**	Davis Station	−68.57732	77.97261	10.899	0.3	0.2	111.0	28.0	continuous
KERG**	Kerguelen Island	−49.35147	70.25552	10.532	1.5	0.2	30.9	8.5	continuous
MAW1**	Mawson Station	−67.60477	62.87072	7.406	0.9	0.2	165.5	11.5	continuous
MCM4**	McMurdo Base	−77.83835	166.66933	8.520	0.1	0.2	136.2	77.0	continuous
PALM**	Palmer Station	−64.77509	−64.05112	7.691	0.3	0.1	−39.4	11.0	continuous
SYOG**	E. Ongle Island	−69.00696	39.58374	5.012	0.6	0.5	−19.5	46.0	continuous
VESL**	Sanae IV Base	−71.6738	−2.84178	6.792	1.0	0.1	−82.4	6.6	continuous

[a] Single asterisks indicate stations established by the Military Geodetic Institute of Chile, and double asterisks indicate IGS stations. The authors installed all the other sites including the continuous site FREI. Vhor, horizontal velocity; Azm, azimuth.

two independent GPS sites near our GPS sites on Greenwich and King George islands. *Niemeier and Salbach* [1998] reported similar results. The general agreement between these measurements, obtained over different time periods, suggests that the motion is largely continuous, rather than episodic. Over a distance of ~90 km from GPS sites REYJ and FREI on King George Island until site JUAN on Livingston Island, there is no measurable difference in velocity of this block of the South Shetlands forearc. Thus, we conclude that the sites on Livingston, Greenwich, and King George islands lie on a single lithospheric microplate moving uniformly at 7–9 mm/a with respect to the Antarctic Peninsula.

[11] In contrast, the velocities at GPS sites CJAM and CWAL on Smith and Low islands in the southwest are only 3.0 ± 0.6 and 2.2 ± 0.4 mm/a, respectively. Errors for the azimuths are relatively larger because of the slower velocities, but are consistent with one another and with azimuths for the other four South Shetland sites. This demonstrates that the southwestern part of the Bransfield basin opens significantly more slowly than the main central part. The available results, however, do not indicate that extension decreases uniformly or gradually to the southwest along the South Shetlands forearc; rather, extension rates decrease abruptly somewhere in the 112 km gap between GPS site JUAN on Livingston Island and sites CWAL and CJAM on Low and Smith islands. Such forearc segmentation had been suspected on the basis of segmentation and southwestward propagation of rifting in the Bransfield basin [*Barker and Austin*, 1998; *Barker et al.*, 2003].

[12] The GPS site ELPH on Elephant Island in the northeast has a velocity of 7.3 ± 1.1 mm/a and azimuth of −86.3° ± 10.7°. The uncertainties are larger than normal, perhaps because of the short third epoch measurement, but the azimuth is significantly more westerly than the azimuths for the GPS sites on the central and southwestern blocks of the South Shetland Islands platform, suggesting that Elephant Island is moving differently from them. *Dietrich et al.* [2004] reported, but did not discuss or interpret, a velocity for their site in the Elephant Island subgroup, ELE1, which is actually on Gibbs Island and about 40 km southwest of our site ELPH on southern Elephant Island. The ve-

locity for ELE1 is also considerably more westerly than the velocities for their two South Shetland Island sites The Elephant Island subgroup has been regarded as part of the South Shetlands microplate because the Bransfield basin extends to the south and east. Indeed, the location determined by *Engdahl et al.* [1998] for the dip-slip earthquake of 18 January 1981 with M_W 6.1 is less than 25 km from the ELPH site (Figure 2). *Klepeis and Lawver* [1996] suggested that the junction between the Shackleton fracture zone and the South Scotia Ridge passes northeast of the group. Our GPS velocity at ELPH, however, is consistent with it being coupled to the Scotia plate (Figure 2) on the basis of the Scotia-Antarctica relative motion calculated using the Antarctic-Scotia Euler poles from *Pelayo and Wiens* [1989], *Thomas et al.* [2003], and from *Smalley et al.* [2007].

4. Discussion and Conclusions

[13] Our new data strongly support the interpretation of the Antarctic Peninsula as a single unit attached to the Antarctic Plate. In particular, on Anvers Island the CGPS station PALM, a well-sited GPS station installed in massive igneous rock, does not move significantly with respect to SPPT and MRAN, or other GPS stations on the Antarctic Peninsula. Hence we are able to analyze the data from our sites on the South Shetland Islands with respect to a reference frame attached to the entire continent, including the peninsula.

[14] The new results reveal that the South Shetland Islands platform, the only tectonically active part of the Antarctic continental margin, is more complex than previously appreciated. Our principal new result is that the central and southwestern parts of the South Shetland Islands platform occupy two distinct microplates that move differently with respect to the Antarctic Peninsula. King George, Greenwich, and Livingston islands on the central part of the platform move at about 7–9 mm/a in a direction approximately perpendicular to Bransfield basin and the South Shetland trench; this contrasts with Smith and Low islands on the smaller southwestern part that move at about 2–3 mm/a in nearly the same direction. Our study cannot constrain precisely how and where the 4–6 mm/a of motion is taken up between Livingston Island and Smith and Low islands. However, we note that *Robertson Maurice et al.* [2003] located numerous shallow earthquakes with epicenters lying along a northwest-southeast trending bathymetric depression within this gap, and that on 30 March 1984 a teleseismically reported earthquake with a significant amount of strike-slip motion occurred there as well (Figure 2). It is thus plausible that relative motion is concentrated along a transverse accommodation structure extending from near the trench axis to the Bransfield basin rift system.

[15] An open question concerns how the opening of the Bransfield basin terminates south of Smith and Low islands. The southwestern end of the hanging slab of the former Phoenix plate should be near where the Hero fracture zone intersects the arc, but the precise location is ambiguous given available bathymetric data and shoaling caused by the topography associated with the Hero fracture zone. Farther southwest, the spreading ridge between the Phoenix and Antarctic plates entered the trench and might have allowed the two plates to decouple and open a slab window [*Barker*, 1982]. If sinking of the slab of Antarctic (formerly Phoenix) plate beneath the South Shetlands forearc facilitated opening of the Bransfield basin as suggested by *Barker and Austin* [1998], then we would expect that the extension would terminate near where the trench terminates. For the hanging slab to continue sinking, a tear fault must exist, probably along the Hero fracture zone. However, the termination may not be abrupt if the edge of the Antarctic plate southwest of the Hero fracture zone is dragged down with the sinking slab because of resistance to tearing. On the northwestern side of the basin the bathymetric expression of the South Shetlands trench extends a little beyond its intersection of the Hero fracture zone offshore of Smith Island. On the southeastern side there are no teleseismically reported normal faulting earthquakes significantly south of Low Island. Thus we have no direct information concerning how the final 2–3 mm/a of extension is distributed in the region between Smith and Low islands and Anvers Island.

[16] The result of our observations on Elephant Island, together with an earlier result of *Dietrich et al.* [2004] from Gibbs Island some 40 km to the southwest, indicate that the Elephant Island subgroup is located on a separate block of the South Shetland Islands platform, a block that is presently coupled to the Scotia plate and moving westward with respect to the Antarctic Peninsula and entire Antarctic plate. If the Shackleton fracture zone is developing a new break to the east of these islands as suggested by *Klepeis and Lawver* [1996], it has yet to detach this block from the Scotia plate.

[17] Uplift of subduction complex rocks to form the islands has previously been attributed to subduction of thickened oceanic crust, most likely associated with the Shackleton fracture zone [*Dalziel*, 1984; *Trouw et al.*, 1998]. The new data indicate that it may be the result of Scotia-Antarctic plate convergence.

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References

Barker, D. H. N., and J. A. Austin (1998), Rift propagation, detachment faulting, and associated magmatism in Bransfield Strait, Antarctic Peninsula, *J. Geophys. Res.*, *103*, 24,017–24,043.

Barker, D. H. N., G. Christeson, J. A. Austin, and I. W. D. Dalziel (2003), Back-arc basin evolution and cordilleran orogenesis: Insights from new ocean bottom seismograph refraction profiling in Bransfield Strait, Antarctica, *Geology*, *31*, 107–110.

Barker, P. F. (1982), The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: Ridge crest-trench interactions, *J. Geol. Soc. London*, *139*, 787–801.

Barker, P. F., and I. W. D. Dalziel (1983), Progress in geodynamics in the Scotia Arc region, in *Geodynamics of the Eastern Pacific Region, Caribbean and Scotia Arcs. Geodyn. Ser.*, vol. 9, edited by R. Cabre, pp. 137–170, AGU, Washington, D. C.

Bevis, M., Y. Bock, P. Fang, R. Reilinger, T. Herring, J. Stowell, and R. Smalley (1997), Blending old and new approaches to regional geodesy, *Eos Trans. AGU*, *78*, 64–66.

Bouin, M.-N., and C. Vigny (2000), New constraints on Antarctic plate motion and deformation from GPS data, *J. Geophys. Res.*, *105*(B12), 28,279–28,293.

Christeson, G. L., D. H. N. Barker, J. A. Austin, and I. W. D. Dalziel (2003), Deep crustal of Bransfield Strait: initiation of a back-arc basin by rift activation and propagation, *J. Geophys. Res.*, *108*(B10), 2492, doi:10.1029/2003JB002468.

Dalziel, I. W. D. (1984), Tectonic evolution of a fore-arc terrane, southern Scotia Ridge, Antarctica, *Spec. Pap. Geol. Soc. Am., 200*, 32 pp.

Dietrich, R. (2001), ITRF coordinates and plate velocities from repeated GPS campaigns in Antarctica—An analysis based on different individual solutions, *J. Geod.*, *74*, 756–766.

Dietrich, R., A. Rulke, J. Ihde, K. Lindner, H. Miller, W. Niemeier, H.-W. Schenke, and G. Seeber (2004), Plate kinematics and deformation status of the Antarctic Peninsula based on GPS, *Global Planet. Change*, *42*, 313–321.

Engdahl, E. R., R. van der Hilst, and R. Buland (1998), Global teleseismic earthquake relocation with improved travel times and procedures for depth determination, *Bull. Seismol. Soc. Am.*, *88*, 722–743.

Kendrick, E., M. Bevis, R. Smalley Jr., and B. Brooks (2001), An integrated crustal velocity field for the central Andes, *Geochem. Geophys. Geosyst.*, *2*(11), doi:10.1029/2001GC000191.

King, R., and Y. Bock (2002), Documentation for the GAMIT GPS analysis software, Eelease 10.0, Mass. Inst. of Technol., Cambridge.

Klepeis, K. A., and L. A. Lawver (1996), Tectonics of the Antarctic-Scotia plate boundary near Elephant and Clarence Islands, West Antarctica, *J. Geophys. Res.*, *101*, 20,211–20,231.

Larter, R. D., and P. F. Barker (1991), Effects of ridge crest-trench interaction on Antarctic-Phoenix spreading: Forces on a young subducting plate, *J. Geophys. Res.*, *96*, 19,583–19,607.

Lawver, L. A., B. J. Sloan, D. H. N. Barker, M. Ghidella, R. P. von Herzen, R. A. Keller, G. P. Klinkhammer, and C. S. Chin (1996), Distributed, active extensions in Bransfield Basin, Antarctic Peninsula: Evidence from multibeam bathymetry, *GSA Today*, *6*, 1–6.

Niemeier, W., and H. Salbach (1998), Modeling of time-dependent deformation processes in the Western Antarctic region from GPS epoch campaigns between 1995 und 1998, *Eos Trans. AGU*, *79*, Fall Meet. Suppl., F187.

Pelayo, A. M., and D. A. Wiens (1989), Seismotectonics and relative plate motions in the Scotia Sea region, *J. Geophys. Res.*, *94*, 7293–7320.

Robertson Maurice, S. D., D. A. Wiens, P. J. Shore, E. Vera, and L. M. Dorman (2003), Seismicity and tectonics of the South Shetland Islands and Bransfield Strait from a regional broadband seismograph deployment, *J. Geophys. Res.*, *108*(B10), 2461, doi:10.1029/2003JB002416.

Smalley, R., Jr., E. Kendrick, M. G. Bevis, I. W. D. Dalziel, F. Taylor, E. Lauría, R. Barriga, G. Casassa, E. Olivero, and E. Piana (2003), Geodetic determination of relative plate motion and crustal deformation across the Scotia-South America plate boundary in eastern Tierra del Fuego, *Geochem. Geophys. Geosyst.*, *4*(9), 1070, doi:10.1029/2002GC000446.

Smalley, R., Jr., I. W. D. Dalziel, M. G. Bevis, E. Kendrick, D. S. Stamps, E. C. King, F. W. Taylor, E. Lauría, A. Zakrajsek, and H. Parra (2007), Scotia arc kinematics from GPS geodesy, *Geophys. Res. Lett.*, *34*, L21308, doi:10.1029/2007GL031699.

Thomas, C., R. Livermore, and F. Pollitz (2003), Motion of the Scotia Sea plates, *Geophys. J. Int.*, *155*, 789–804.

Trouw, R. A. J., L. S. A. L.Simoes, and C. S. Valladares (1998), Metamorphic evolution of a subduction complex, South Shetland Islands, Antarctica, *J. Metamorph. Geol.*, *16*, 475–490.