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Geodetic implications on block formation and geodynamic domains in the South Shetland Islands, Antarctic Peninsula

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ABSTRACT

The South Shetland Islands archipelago is dynamically complex due to its tectonic surroundings. Most islands are part of a formerly active volcanic arc, although Deception, Penguin and Bridgeman Islands, as well as several submarine volcanoes, are characterized by active back-arc volcanism. Geodetic benchmarks were deployed and the movement of the lithosphere to which they were fixed measured to provide geodynamic insight for the South Shetland Islands, Bransfield Basin and Antarctic Peninsula area based on surface deformation. These benchmarks' data add spatial and temporal coverage to previous results. The results reveal two different geodynamic patterns, each confined to a distinct part of the South Shetland Islands archipelago. The inferred absolute horizontal velocity vectors for the benchmarks in the northeastern part of the archipelago are consistent with the opening of the Bransfield Basin, while benchmark vectors in the southwestern part of the archipelago are similar to those of the benchmarks on the Antarctic Peninsula. In between, Snow, Deception and Livingston Islands represent a transition zone. In this area, the horizontal velocity vectors relative to the Antarctic plate shift northeastwards from N to NW. Furthermore, the South Shetland Islands benchmarks, except for that at Gibbs (Elephant) Islands, indicate subsidence, which might be a consequence of the slab roll-back at the South Shetland Trench. In contrast, the uplift revealed by the Antarctic Peninsula benchmarks suggests glacial isostatic adjustment after the Larson B ice-shelf breakup.

1. Geological background and tectonic setting

The region defined by the South Shetland Islands archipelago, the Bransfield Basin and the Antarctic Peninsula is characterized by highly complex and unique geotectonic surroundings. Today, two major tectonic plates are converging in the area, the South American and the Antarctic Plates. Furthermore, several minor tectonic plates are interacting, namely the Scotia, Phoenix and South Shetland Plates (Galindo-Zaldívar et al., 2004; Maestro et al., 2007) (Fig. 1).

The Antarctic Peninsula magmatic arc developed as part of the Andean–Antarctic continental margin from late Triassic to recent times. Subduction of the long-lived Phoenix Microplate ocean floor beneath the South Shetland Islands archipelago and its development as a separate magmatic arc began during the Cretaceous, though arc volcanism may have ceased at about 20 Ma (Fretzdorff et al., 2004; Smellie et al., 1984). Thus, the part of the volcanic arc located in the South Shetland Islands belongs to a much younger phase in geodynamic history. The spreading center in the western Drake Passage became virtually inactive about 3.3 Ma ago (Barker, 1976, 1982; Barker et al., 1991; Jin et al., 2009; Larter and Barker, 1991; Livermore et al., 2000; Robertson-Maurice et al., 2003) and the South Shetland Trench was partly filled with sediments. To the north, the South Shetland Trench ends at the left-lateral Shackleton Fracture Zone near Elephant Island, and to the south at the Hero Fracture Zone (Galindo-Zaldívar et al., 2004; Maestro et al., 2007).

Today, this last part of the formerly much larger subduction zone is the only area around the entire Antarctic continent where subduction still takes place, though at very low velocities (Barker, 1982). Assuming that subduction is still continuing, the rate should resemble that of the opening of Bransfield Basin, which is estimated at approximately 10 mm/year (Dietrich et al., 2000). Indeed, a convergence rate of close to 10 mm/year has been determined at the South Shetland Trench (Dietrich et al., 2001, 2004; González-Ferrán, 1991; Jiang et al., 2009; Taylor et al., 2008) and attributed to the NNW–SSE Bransfield Basin extension and to the Phoenix Microplate shortening or subduction. Based on the displacement of the South Shetland Islands to the NW, the amount of stretching and the width of new oceanic crust formed during rifting and spreading in the Bransfield basin area, Henriet et al. (1992)

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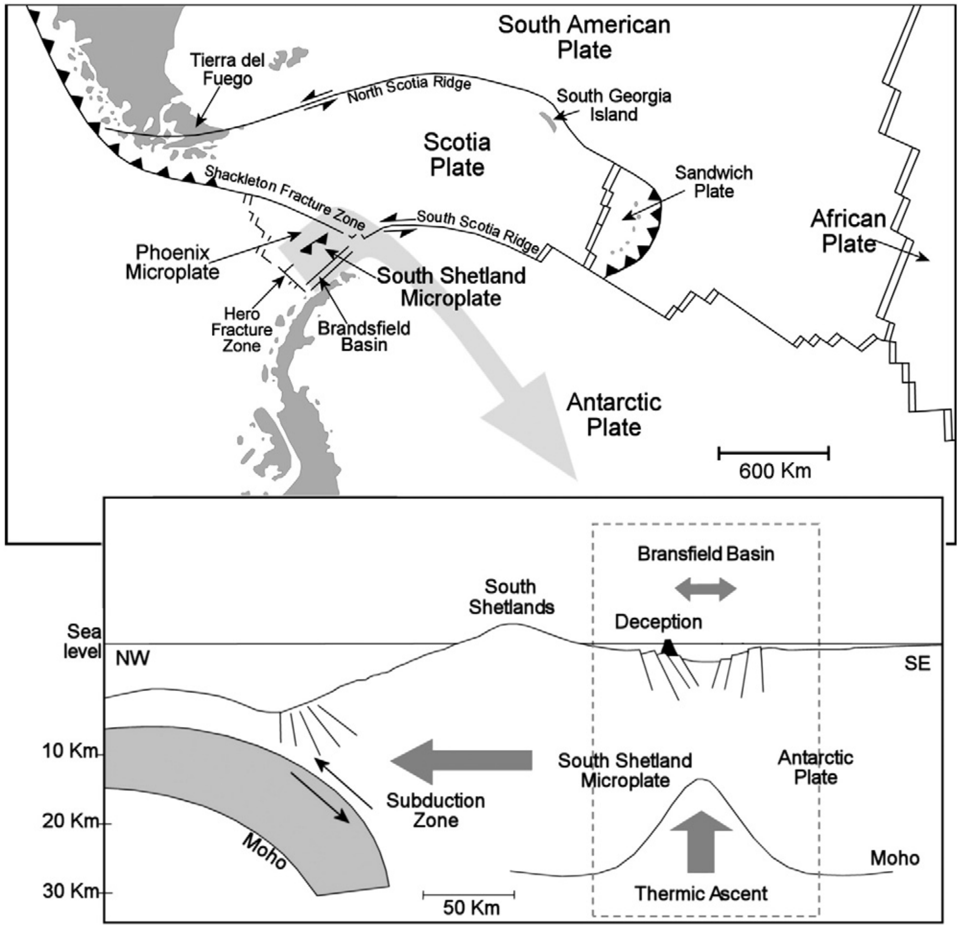

Fig. 1. Plate tectonic situation in the northern Antarctic Peninsula region. The South Shetland Microplate is situated between the Bransfield Basin and the South Shetland Trench. Wedge formed by the Shackleton Fracture Zone meeting the South Scotia Ridge and related left-lateral simple-shear couple between the Scotia and the Antarctic Plates. The Bransfield Basin back-arc opening separates the South Shetland volcanic arc from the Antarctic Peninsula.

estimate for the South Shetland Trench convergence rates of 2.5 to 7.5 mm/year during the last 2 Ma. Recent seismic data also suggest convergence along the South Shetland subduction zone, with earthquake locations indicating an association of seismicity with slow subduction of young lithosphere, rifting, active volcanism and transcurrent plate boundaries (Robertson et al., 2002).

Due to the regional northeastwards movement of the Antarctic Plate, the South Shetland Trench has an additional left-lateral component that extends to the also left-lateral South Scotia Ridge, the Antarctic–Scotia boundary (Maestro et al., 2007). This setting might compete with the slab roll-back at the South Shetland Trench as the main mechanism behind the Bransfield Basin extensional regime (Galindo-Zaldívar et al., 2004; Maestro et al., 2007; Solari et al., 2008). These mechanisms cause the nearly orthogonal fault system, trending NNW–SSE and NNE–SSW, which has been recognized in the Bransfield Basin region (Maestro et al., 2007). Nevertheless, in addition to plate subduction and slab roll-back, the propagation of the South Scotia Ridge southwestwards beyond the Shackleton Fracture Zone is also thought to contribute to the transtensional regime in the Bransfield Basin region (Fretzdorff et al., 2004; González-Casado et al., 2000). Thus, the Bransfield Basin is possibly not a back-arc basin sensu strictu, as its opening might be related to left-lateral simple-shear couple between the Scotia and the Antarctic Plates (González-Casado et al., 2000).

The tectonic setting of the region is reflected in the modern volcanism along the western side of the northern Antarctic Peninsula. Starting shortly after about 4 Ma ago, the slow subduction rate led to crustal extension and rifting processes which opened the Bransfield Basin between the Antarctic Peninsula and the South Shetland Islands. Similar extensional processes on the eastern side of the Antarctic Peninsula are responsible for the volcanism along the Larsen Rift (González-Ferrán, 1983, 1995; Kraus et al., 2013). The back-arc volcanism within the Bransfield Basin is characterized by emergent volcanoes like Deception, Penguin and Bridgeman Islands, plus several submarine volcanoes at different evolutionary stages that are aligned along the NNE–SSW main direction of the basin (Canals et al., 1997).

Deception Island, the largest and most active volcano in the area, is situated ~40 km south of Livingston Island close to the nascent spreading axis of the immature Bransfield Basin back-arc. The upper crustal structure of the area comprises continental crust north of Deception Island and more basic crust to the south (Muñoz-Martín et al., 2005). The tectonic setting of the volcano has been described as extensional, with maximum horizontal shortening in NE–SW and NW–SE directions (Pérez-López et al., 2007) and local compressional stress states (Maestro et al., 2007). Geometrical relationships between the location and orientation of joints and faults indicate two evolutionary phases, implying a counter-clockwise rotation of Deception Island which might be related to regional left-lateral strike-slip movements. In recent years the geodetically inferred NNE–SSW compression rate was higher than the NNW–SSE extension rate at Deception Island (Berrocoso et al., 2012; Prates, 2012; Prates et al., 2013). Recent paleostress regimes were determined for Deception Island (Maestro et al., 2007) and Byers Peninsula on Livingston Island (Alfaro et al., 2010), showing similar patterns following a NNW–SSE to NNE–SSW extension related to the Bransfield Basin opening and left-lateral transtension at the Antarctic–Phoenix boundary, as well as NE–SW and NW–SE compressional states related to the Antarctic–Scotia convergence and the Phoenix Microplate