Geological Structure of the South Orkney Microcontinent

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Abstract - The South Orkney Microcontinent (SOM) is the biggest (250 x 350 km) continental element of the South Scotia Ridge between Antarctic and Scotia Plate. The northern margin of the SOM is the Antarctic-Scotia Plate boundary with a sinistral strike-slip movement accomplished by an oblique plate convergence in the western part, and a divergence component eastward toward the Bruce Bank. Seismic and gravity data show two main domains with different structural trends related to the complexity of the geodynamic activity in the surroundings: a) in the southern part of the SOM the north-south trend of Airy, Bouguer and Eötvös Basins formed during the Oligocene extensional phase of the Scotia Ridge fragmentation and formation of the Powell and Jane Basins to the south-east and south-west margins of the SOM respectively, b) in the northern part of the SOM, an east-west trend following the transform plate boundary, affected the structure of the basement high and the Newton Basin.

INTRODUCTION

The South Orkney Islands are constituted by the same rock assemblage of some locations in the islands of the South Scotia Ridge (Smith and Elephant islands) collectively named the Scotia metamorphic complex (Tanner et al., 1982; Dalziel, 1984). Highly deformed and variably metamorphosed, (greenschist to amphibolite facies, greywacke-shale sequences with conglomerate) Upper Paleozoic - Lower Mesozoic metasedimentary and metavolcanic rocks are unconformably overlain by Upper Jurassic or Lower Cretaceous and Tertiary strata (Caminos, 1962; & Massabie, 1980; Dalziel, 1984; BAS, 1985; Barker et al., 1991; Grunow et al., 1992). They are interpreted to represent a subduction complex that was accreted to the South American and Antarctic Peninsula segments of Gondwanaland during the Early Mesozoic and prior to the break-up. The entire prism reflects a complex history of accretion. In the South Orkney Islands the metamorphic ages which may constrain the time of accretion are approximately 200-180 Ma (Trouw et al., 1998).

During the Cenozoic the continuous active margin along South America and the Antarctic Peninsula, as a consequence of the Gondwana break up, split away forming the South Scotia Ridge and several spreading episodes produced the microplate of the Scotia Sea (Barker et al., 1991). The South Orkney Microcontinent (SOM) is the biggest (250 x 350 km) lithospheric fragment of the South Scotia Ridge between Antarctica and the Scotia Plate (Fig. 1), representing a remnant of the original link connecting South America with the Antarctic Peninsula. (Dalziel & Elliot, 1973; de Wit, 1977; Dalziel, 1984).

The new plate tectonic arrangement includes an active sinistral transform fault at the Antarctic-Scotia Plate boundary, located at the northern margin of the South Scotia Ridge (Forsyth 1975, BAS 1985), (Fig. 1).

In the last decade geophysical studies westward of the SOM

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recognised a complex geodynamic setting of this boundary. Besides the strike slip kinematics also a convergent component producing the subduction of the Scotia Plate below the Antarctic Plate has been proposed by Kavoun & Vinnikovskaia, (1994), Lodolo et al., (1998), Maldonado et al. (1998). From seismological studies Pelayo & Wiens, (1989) suggested a transtension tectonic for the plate boundary and Acosta & Uchupi, (1996) recognised extensional structure at the Antarctic Plate edge. The eastern part of the plate boundary separates the SOM from the Pirie and Bruce Banks with a morphological expression characterised by a 6000 meter deep basin.

The south-east and south-west South Orkney Microcontinent passive margins are connected to the proto-oceanic Powell and the oceanic Jane basins respectively, formed after the rifting between the microcontinent and the Antarctic Peninsula in the ?Eocene/Early Oligocene (Coren et al., 1997) and in the Oligocene respectively (Lawver et al., 1991).

The tectonic activity of the area affected also the SOM. King and Barker, (1988) from geophysical data suggested the presence of two major structural trends: an east-west trend comprising a magnetic arc, fore-arc basin and accretionary complex created when the SOM was at the Pacific margin, and a younger, approximately north-south trend comprising the Airy, Bouguer and Eötvös Basins, related to the rifting of eastern and western margins.

**DATA USED**

About 5000 km of multichannel seismic reflection profiles were collected in the past decade by the Osservatorio Geofisico Sperimentale (Italy), the Marine Arctic Geological Expedition (Russia), the British Antarctic Survey (United Kingdom) and the Japanese National Oil Company (Japan) (Fig. 2). The seismic interpretations were tied to the ODP wells 695, 696 and 697 (Barker & Kenneth, et al., 1988) (Fig. 2). The well stratigraphy on the continental shelf can be simplified by dividing the stratigraphic column into three units, that can also be recognised in the seismic data interpretation: 1) a ?Late Eocene/Early Oligocene condensed terrigenous sedimentary succession; 2) Upper Middle Miocene/?Lower Pliocene mainly biosiliceous deposits; 3) Upper Pliocene/Quaternary diatom bearing silty and clayey muds (Fig. 3).

Gravity data from ERS-1 and Geosat Geodetic Altimetry (Andersen & Knudsen, 1998) were used to compile a free air anomaly map (Fig. 4), for correlation of the geological structure inferred from seismic interpretations. The crustal structure of the South Orkney Microcontinent has been investigated through modelling of gravity data collected during a geophysical survey by the Osservatorio Geofisico Sperimentale along seismic profiles. The modelling is constrained by seismic interpretation.

**RESULTS**

From a comparison of seismic data interpretations and the gravity anomaly map, two main structural domains with their own trend have been identified. The east-west trend in the northern domain is expressed by the structural high of a mainly undeformed acoustic basement, by the island chain, and by the epicontinental Newton Basin (Fig. 5). In the southern area an approximately north–south trend is followed by the Airy, Bouguer and Eötvös Basins (Fig. 5), and by mainly undeformed or low deformed structural highs or blocks, bordering the eastern and western margin of the SOM. Orientation of the basins range from north-north west/south-south-east of Airy Basin, on the
Fig. 3 - The stratigraphy of the ODP Leg 113 wells (modified after Barker, Kenneth, et al. 1988). Three main units can be identified: I) a condensed terrigenous sediment dating from probably Late Eocene to Early Oligocene deposited before separation of the South Orkney Microcontinent from the Antarctica Peninsula; II) a middle unit constituted by an expanded Upper Middle Miocene and ?Lower Pliocene, dominated by biosiliceous sediment, about the 90% of diatoms, deposits after separation from the Antarctic Peninsula; III) condensed unit, ranging from Upper Pliocene to Quaternary, constituted by diatom bearing silty and clayey muds, related to the development during the Latest Miocene, of a major and probably permanent West Antarctica Ice-Sheet, the main supplier of fine terrigenous sediments to the West Antarctic continental margin (Barker, Kenneth, et al. 1988). Hz-1 and Hz-2 indicate the boundary between Miocene - Pliocene and ?Eocene/Oligocene - Miocene respectively that have been used as seismic marker (See Fig. 6a and 6b).

According to the ODP well stratigraphy (Barker & Kenneth, et al., 1988) the basins are filled by Late Eocene/Oligocene terrigenous sediments (Fig. 3). In the depocentre, below or in the Late Eocene/Oligocene deposits there is, occasionally, a seismo-stratigraphic sequence characterised by high amplitude and continuous reflectors, faulted and deformed by rifting activity. The terrigenous sequence is present in the basins of the southern part of the SOM, and is sealed by a strong reflector (Hz-2) merging with the surface of the structural highs. The marine Miocene deposits seal the basins onlapping on the highs like the older sequence (Fig. 6). In most cases the top of this unit (Hz-1) merges with the top of Eocene/Oligocene (Hz-2) in correspondence with the structural highs. Occasionally this unit is present also on the basement highs. The mainly terrigenous Plio-Quaternary sequence drapes over the whole SOM (Fig. 6).

The northern margin of the SOM is a transform plate boundary with a complex morphological expression. The continental shelf close to the border is a flat surface at about 300 meters deep, draped with stratified sediment. At the shelf edge a steep wall with a thin sedimentary cover and a complex series of blocks settings marks the transition to the oceanic domain (Fig. 7). Also the block morphology is characterised by steep flanks and small tectonically controlled basins between the blocks. The base of the slope ends at a sea floor depression, more than 5000 meters in depth.

![Fig. 4](image1.png)

**Fig. 4** - Free air gravity anomaly map from ERS-1 and Geosat Geodetic Altimetry (Andersen & Knudsen, 1998). Strong negative and positive gravity anomalies are located in correspondence with the South Orkney Trough (up to -200 mGal), and in the South Orkney Islands (up to 200 mGal) respectively. The main structural elements like basins and basement highs have a good correlation in the anomalies (see Fig. 5).

![Fig. 5](image2.png)

**Fig. 5** - Structural map of the South Orkney Microcontinent, obtained from interpretation of seismic data. Two main domains with different structural trends are recognizable: a) the east-west trend following the transform plate boundary, affected by the structure of the basement high and the Newton Basin; b) the north-south trend of Airy, Bouguer and Eötvös Basins formed during the Oligocene extentional phase of the Scotia Ridge fragmentation and formation of the Powell and Jane Basins to the south-east and south-west margins of the SOM, respectively.
depth, constituted by a basin with about 2 km of sediment. In the western part of the northern border of the SOM an accretionary prism is probably present at the base of the slope (Kavoun & Vinnikovskaya, 1994; Maldonado et al., 1998). Evidence of the accretionary prism is given by the smooth step morphology, no evidence of stratified layers (as they are deformed in the melange complex), an abrupt change in the seismic characteristics occurring at the outer deformation front and continentward dipping reflectors (Fig. 7). Moving towards the east the convergence evidence become less clear, producing mainly compressional structures in the oceanic sediment with folds and reverse faults, rather than forming an accretionary wedge. The convergent structures end at the north–east corner of the SOM. A big trough up to 6000 meters deep separates the SOM from the Bruce Bank (Fig. 8), suggesting that it is possibly a shifted continuation of the South Orkney Trough, from which it is separated by a shoulder of about 3000 meters in depth. The Bruce Bank in the north and a 2000 meter deep bank in the south delimit the eastern part of the trough. Steep morphology characterises the slope of the SOM and the banks, including, besides the transform feature, also some extensional faults, which together with the stratified sedimentary wedge on the Bruce Bank and no evidence of downward reflectors, suggest a transtensional tectonic regime in the area (Fig. 8).

Gravity data (Fig. 4) show a steep gradient delimiting the SOM in the northern part, plus articulated features all along the plate boundary, with strong negative anomalies, up to -180 mGal in the South Orkney Trough. Positive anomalies with values of about or less than 40 mGal characterise the basins, while the structural highs have higher values of positive anomalies.

To investigate the crustal structure of the SOM gravity modelling was calculated along the gravimetric and seismic profiles IT91AW93 and IT91AW94 using geological constrains from seismic interpretations for the upper part of the model and the estimated densities of rocks according to depth (Fig. 9). Modelling results provide a crustal thickness of around 25 km for the SOM and the Bruce Bank, and thinning in between both, arguing for an extensional component in the transcurrent regime, and also towards the proto-oceanic Powell Basin.

**DISCUSSION**

Due to the complexity of the structural setting of the area and the different tectonic regime (transform, convergence and divergence) in the surroundings, the
Fig. 7 - Seismic profiles across the northern plate boundary margin of the South Orkney microcontinent. The transform fault is located at the steep margin of the SOM. At the base of the slope an accretionary prism is probably present (Kavoun and Vinnikovskaia, 1994; Maldonado et al., 1998). Evidence of the accretionary prism are the smooth step morphology, no stratified layers (as they are deformed in the melange complex), an abrupt change in seismic characteristics occurring at the outer deformation front and continent deeping reflectors (modified after Kavoun and Vinnikovskaia, 1994).

Fig. 8 - Seismic profiles across the Antarctic - Scotia Plate between the SOM and the Bruce Bank. Faults geometries suggest the location of the main strike slip motion on the very steep flank of the SOM couple with some extensional faults on the Bruce Bank margin side.
small microcontinent has a complicated geological history.

The Eocene-Oligocene age of the terrigenous sediment filling of the basins in the SOM is coeval with the opening of the Powell (Coren et al., 1997) and Jane Basin (Lawver et al., 1991) suggesting that the tectonic phase of basin formation is related to the rifting of the Powell and Jane Basins. Drifting of the Powell Basin occurred in the Miocene (Coren et al., 1997), causing the isolation of the SOM from the Antarctic Peninsula and hence the end of terrigenous supplies and the starting of the deposition of marine sediment. During this period no sedimentation occurred on the structural highs separating the basins.

From Pliocene to Recent all the area was affected by the sedimentation of a draping of diatom-bearing silty and clayey mud deposit influenced by the glacial/interglacial conditions. This unit produced sea floor topography conformable to the basin structure (Fig. 6).

The Antarctic and Scotia Plate boundary at the northern margin of the SOM is probably a large area of deformation between the sinistral strike slip fault at the shelf edge of the microcontinent and the deepest part of the South Orkney Trough, about 30-40 km north, where the compressive structures are present (Fig. 5 & 7). This geometry has been modelled, considering the distribution of crustal deformation, by Braun & Beaumont (1995), and their results indicate that the strain partitioning with a thrust zone that accommodates convergent motion in the ocean area and the vertical strike-slip zones that accommodate the transcurrent motion at the border of the steep escarpment correspond to an obliquely convergent plate boundary dominated by a transcurrent condition.

Going eastward the convergent component seems to decrease until the vertical component of deformation at the plate boundary appears to change in the area between the SOM and the Bruce Bank. Block faulting and steep escarpment also on the eastern flank of the SOM suggest a transtensional regime of the margin (Fig. 8). The key point of change seems to be the north eastern corner of the SOM where an abrupt variation in the direction of the South Orkney Trough is present (Fig. 4).

CONCLUSIONS

The main tectonic activity in the north-south elongated Airy, Bouguer and Òtítovs basins started locally in the pre Eocene/Oligocene time, related to the rifting of the South Scotia Ridge fragmentation, and consequently the Powell Basin development. The separation was completed before the beginning of the Miocene, testified by a change from terrigenous, hence continental, supply, to marine sedimentation. During the Miocene the basins were filled by deposits, and from Pliocene to Recent draping of sediment all over the SOM indicate the end of the main extensional phase.

The northern plate boundary is an obliquely convergent plate boundary dominated by a transcurrent condition exhibiting strain partitioning of convergent motion accommodated by a thrust zone in the ocean area and vertical strike-slip zones at the border of the steep escarpment of the SOM. Between the SOM and the Bruce Bank, the plate boundary changes, exhibiting a transcurrent and extensional regime.

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REFERENCES


