The development of the Deception Island volcano caldera under control of the Bransfield basin sinistral strike-slip tectonic regime (NW Antarctica)

Fernando C. Lopes[(1,2)]*, Albert Caselli[(3)], Adriane Machado[(1)] and Teresa Barata[(1)]
(1) CGUC, Universidade de Coimbra, Portugal;
(2) DCT, Universidade de Coimbra, Portugal;
(3)GESVA, Dpto.Cs. Geológicas, Universidad de Buenos Aires, Argentina

**E-mail: fcarlos@dct.uc.pt*

Abstract. The distribution and orientation of fracture systems that affect Deception Island, and the elongated geometry of its volcanic caldera, a horseshoe-shaped slightly warped in sigmoid, with the major axis oriented NW-SE, are typical of a Riedel model induced by a regional left-lateral simple shear zone. It is suggested that this caldera was formed by a volcano-tectonic process above a magma chamber stretched under the control of the regional transtensional regime. The folds that affect the glacier in the eastern flank of the island, which are visible along the Costa Recta shore-line, may have been induced or favoured by this deformation.

Keywords: NW Antarctic, Deception island volcano caldera, left-lateral simple shear, Riedel deformation model

1 Introduction

The regional shear zone corridors control magma movements, deform volcanoes and may destabilise their flanks. It can also contribute to the formation of volcanic calderas.

Holohan et al. (2008) demonstrated, through analogue experiments, that volcanic calderas, in regional strike-slip tectonic context result from the interaction between structures associated with regional deformation and volcano-tectonic subsidence, generated by local magmatic/volcanic processes, such as, the ascent and eruption of magma and the consequent emptying out of the magma chamber over long periods of time after several eruptive cycles, creating unit imbalance. According to these authors, in strike-slip tectonic contexts, the volcanic calderas are formed above the magma chambers which have become elongated and elliptical. This geometry, which is visible in the final geometry of the caldera, may have been a result of magma chamber elongation, through simple shearing in a pre-collapse phase and is stretched and slightly sigmoidal roughly parallel to the regional distension (orientation of the major axis of the deformation ellipsis). The regional pre-collapse faulting, generally resulting from Riedel deformation, with tangential orientations to the core of the magma chamber and the faults associated with the edges of the magma chamber would have been reactivated in order to accommodate subsidence in the caldera bottom. Reverse ring faults, formed at the end of the shortening axis, would spread towards the lengthening axis. Initally, the collapse take place, on a small scale, on the flanks that are in compression (along the shortening axis). However, a large collapse occur on the flanks that are in extension (along the extended axis) (Mathieu et al., 2011). The goal of this work is to relate the elongated geometry of Deception Island volcanic caldera with the elongation of the magma chamber through simple shear conditioned by the regional transtensional regime, by analogy with the one proposed by Holohan et al. (2008) and Mathieu et al. (2011).

2 Geological setting

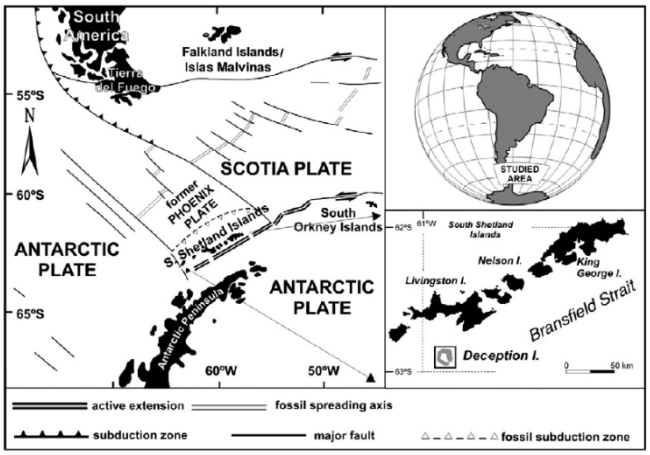

Figure 1. Tectonic and Geographical Location of Deception Island (after Torrecilas et al., 2011).

Deception Island is a small, volcanically-active island (diameter < 15 km), of the quaternary age (< 780 thousand years old), located in the marginal basin of Bransfield Strait (Bransfield Trench; 62º 57' S; 60º 37' W), which separates the South Shetland Islands from the Antarctic Peninsula (e.g. Smellie, 2002) (Figure 1). The opening of the Bransfield trench, with a NE-SW orientation and a length of 500 km, results from the conjunction of two processes: 1) a transtensional basin related with the left-lateral motion between the Antarctic plate and the Scotia plate (e.g. González-Casado et al., 2000); 2) a back-arc process resulting from the very slow oblique subduction or

the roll-back of the ancient Phoenix Plate under the Antarctic plate (e.g. Lawver et al., 1995, 1996). The orientation of the macrostructures which define the current morphology of this basin corresponds to that of a sinistral shear zone, created by a stress field, whose maximum horizontal compressive stress (σ1) was oriented N30ºE (Maestro et al., 2007).

The origin of the Deception caldera remains controversial. For some authors, the large interior bay (Port Foster) is a result of the passive collapse of the caldera along orthogonal faults (e.g. Marti and Baraldo, 1990). However, others believe the evolution and collapse of the volcanic edifice was influenced by the great regional faults (e.g. Smellie, 2002).

3 Observations

Deception Island has got an elongated horseshoe shape, which measures 15 km in diameter, inside which there is a totally inundated volcanic caldera (Port Foster). The island developed in the complex regional tectonic context of Bransfield Strait, resulting from a combination between a back-arc basin and a transtensional regime, which was the consequence of a left-lateral strike-slip motion along the Shakelton fault and the south Scotia ridge. It is possible to highlight some features which suggest that the formation of Deception volcanic caldera was strongly influenced by the regional tectonic context:

a) The orientation of the macrostructures which define the morphology of Bransfield Strait suggest that this basin is a large regional left-lateral simple shear zone corridor, whose movements are controlled by a stress field with σ1 oriented N30ºE;

b) Deception island has an elliptical caldera, which is revealed by seismic tomography, with semi-axes measuring 4.5 km and 2.7 km in length (Ben-Zvi et al., 2009). The semi-major axis is oriented N25-30W, roughly parallel to the direction of the regional extension and is slightly sigmoidal in plan view (Lopes et al, 2012);

c) The orientation of the faults and fractures observed on in the field (e.g. Maestro et al., 2007) and the orientation of structural lineaments interpreted from morpho-structural analysis of DTMs (e.g. Lopes et al, 2012) are similar to the orientations of fractures which characterize a Riedel's deformation model. On the basis of the geometrical and kinematic relationship between the location and orientation
on the faults and fractures it is possible to distinguish two Riedel stages. These stages can be relate to an inferred counterclockwise rotation of Deception Island (Maestro et al., 2007);

d) The glacier which covers the ENE flank of the island displays, along the Costa Recta cliff, a range of folds, whose vergence seems turned in the direction of the caldera's semi-minor axis (Caselli personal communication).

e) The spatial distribution of the historic volcanic eruptions, within Port Foster caldera, shows that its age decreases from SE to NW, which could be compatible with the counterclockwise rotation of the island.

4 Discussion and Comments

4.1 The hypothesis

In our opinion, the collapse of Deception caldera results from a volcano-tectonic process above the magma chamber previously stretched under the control of the regional left-lateral transtensional regime, which can be explained through the analogue models proposed by Holohan et al. (2008) and Mathieu et al. (2011) for volcanic calderas formation in strike-slip faults scenarios.

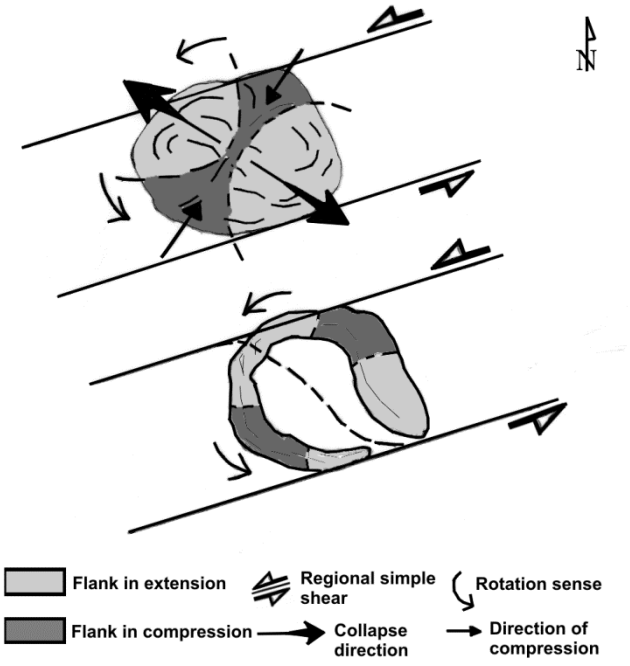

Figure 2. A schema of the hypothtical Deception island caldera formation process.

As the magma chamber undergoes a counterclockwise rotation in the regional left-lateral shear zone, it acquires a elliptical shape, with stretching roughly parallel to the direction of the regional distension and shortening according to the direction of the regional maximum compressive stress (σ1) (Figure 2). Perpendicularly to the distension and maximum compression axes, distensive and compressive structures, respectively, develop. As the rotation continues, it changes the orientation of a Riedel's first stage deformation structures and leads to the development of a Riedel's second stage. Due to the combination of continuous regional stretching and volcano-tectonic fractionation, the caldera subsides, above

the sigmoidally elongated magma chamber. The collapse may have occurred, initially, on a small scale, along the compressed flanks (along the shortening axis). However, the main and large collapse events affect the flanks that are in extension (along the lengthening axis).

4.2 Final remarks

The subsidence of Deception Island caldera may have been strongly controlled by the regional pre-collapse tectonics under control of the Bransfield basin sinistral strike-slip tectonic regime. It is intended, in the near future, to develop more studies to corroborate the hypothesis suggested here. Among them we can highlight field work for structural analysis and to collect sample, a detailed morpho-tectonic analysis using DTMs and remote sensing data, chemical and isotopic analysis, the K-Ar and U-Pb dating of total rock and minerals and the development of analogue models in the CGUC (Center for Geophysics of the University of Coimbra) technophysics laboratory. All the information obtained from studies mentioned above will be collated into a Geographic Information System (GIS) for simulation and analysis of various scenarios for the tectonic evolution of Deception Island.

References

Ben-Zvi, T., Wilcock, W. S. D., Barclay, A. H., Zandomeneghi, D., Ibáñez, J. M., and Almendros, J. 2009. The P-wave velocity structure of Deception Island, Antarctica, from two-dimensional seismic tomography. Journal of Volcanology and Geothermal Research, 180: 67-80.

González-Casado, J.M., Giner, J. and Lopez-Martinez, J. 2000. Bransfield Basin, Antarctic Peninsula: not a normal backarc basin. Geology, 28: 1043–1046.

Holohan, E.P., Wyk de Vries, B. e Troll, V.R. 2008. Analogue models of caldera collapse in strike-slip tectonic regime. Bull. Volcanology, 70: 773-796.

Lawver, L.A., Keller, R.A., Fisk, M.R. e Strelin, J.A. 1995. Bransfield Basin, Antarctic Peninsula: active extension behind a dead ar. In Backarc basins: tectonic and magmatism. (Taylor, B. editor). Plenum Press: 315–342. Amsterdam.

Lopes, F. C., Caselli, A., Machado, A. and Barata, M. T. 2012. A importância do contexto tectónico em desligamento esquerdo na morfo-estrutura da caldeira vulcânica da Ilha de Deception, In Henriques, M. H., Andrade, A. I., Lopes, F. C., Pena dos Reis, R., Quinta-Ferreira, M. and Barata, M. T. (Coords.) (2012). I Congresso Internacional Geociências na CPLP: 240 Anos de Geociências na CPLP, Coimbra, 12-19 Maio, Centro de Geociências e Centro de Geofísica da Universidade de Coimbra (editors) (Abstracts), p. 198, Coimbra, Portugal. ISBN 978-972-95640-8-6 /978-989-97823-0-3.

Maestro, A., Somoza, L., Rey, J., Martínez-Frias, J. and Lopez-Martínez, J. 2007. Active tectonics, fault patterns, and stress fiel od Deception Island: a response to obliqúe convergence between the Pacific and Anterctic plates. Journal of South American Earth Sciences, 23: 256-268.

Marti, J., e Baraldo, A., 1990. Pre-caldera pyroclastic deposits of Deception Island (South Shetland Islands). Antarctic Science, 2: 345-352.

Mathieu, L., Van Wyk de Vries, B., Pilato, M. and Troll, V. R. 2011. The interaction between volcanoes and strike-slip, transtensional and transpressional fault zones: Analogue models and natural examples. Journal of Structural Geology, 33: 898-906.

Smellie, J.L. 2002. Geology. In Geology and Geomorphology of Deception Island.(Smellie, J. L., Lopez-Martinez, J., et al. editors). Sheets 6-A and 6-B, 1:25000. *BAS* GEOMAP series. Cambridge: British Antarctic Survey: 11–30.

Torrecillas, C., Berrocoso, M., Pérez-López, R. e Torrecillas, M. D. 2012. Determination of volumetric variations and coastal changes due to historical volcanic eruptions using historical maps and remote-sensing at Deception Island (West-Antarctica). Geomorfology, 136: 6-14.