Journal of Volcanology and Geothermal Research 265 (2013) 60–77

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Volcanic evolution of the South Sandwich volcanic arc, South Atlantic, from multibeam bathymetry

Philip T. Leat [a,b,*], Simon J. Day [c], Alex J. Tate [a], Tara J. Martin [a,d], Matthew J. Owen [e], David R. Tappin [f]

[a] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK
[b] Department of Geology, University of Leicester, University Road, Leicester LE1 7RH, UK
[c] Aon Benfield UCL Hazard Research Centre, Department of Earth Sciences, University College London, 136 Gower Street, London WC1E 6BT, UK
[d] CSIRO National Marine Facility, Castray Esplanade, Hobart, Tasmania, Australia
[e] Department of Geography, University College London, 136 Gower Street, London WC1E 6BT, UK
[f] British Geological Survey, Keyworth, Nottingham NG12 5GG, UK

A R T I C L E I N F O

Article history:
Received 1 May 2013
Accepted 24 August 2013
Available online 4 September 2013

Keywords:
Volcanic arc
Subduction zone
Caldera
Seamount
Submarine volcanism

A B S T R A C T

New multibeam bathymetry data are presented for the South Sandwich intra-oceanic arc which occupies the small Sandwich plate in the South Atlantic, and is widely considered to be a simple end-member in the range of intra-oceanic arc types. The images show for the first time the distribution of submarine volcanic, tectonic and erosional–depositional features along the whole length of the 540 km long volcanic arc, allowing systematic investigation of along-arc variations. The data confirm that the volcanic arc has a simple structure composed of large volcanoes which form a well-defined volcanic front, but with three parallel cross-cutting seamount chains extending 38–60 km from near the volcanic front into the rear-arc. There is no evidence for intra-arc rifting or extinct volcanic lines. Topographic evidence for faulting is generally absent, except near the northern and southern plate boundaries. Most of the volcanic arc appears to be built on ocean crust formed at the associated back-arc spreading centre, as previously proposed from magnetic data, but the southern part of the arc appears to be underlain by older arc or continental crust whose west-facing rifted margin facing the back-arc basin is defined by the new bathymetry. The new survey shows nine main volcanic edifices along the volcanic front and ca. 20 main seamounts. The main volcanoes form largely glaciated islands with summits 3.0–3.5 km above base levels which are 2500–3000 m deep in the north and shallower at 2000–2500 m deep in the south. Some of the component seamounts are interpreted to have been active since the last glacial maximum, and so are approximately contemporaneous with the volcanic front volcanism. Seven calderas, all either submarine or ice-filled, have been identified: Adventure volcano, a newly discovered submarine volcanic front caldera volcano is described for the first time. All but one of the calderas are situated on summits of large volcanoes in the southern part of the arc, and most are associated with current or historic volcanic or hydrothermal activity. Shallow shelves around the islands are generally 1–10 km wide. Submerged banks up to 1100 m deep are interpreted as subsided erosional surfaces. Seamounts and emergent volcanoes experienced a range of mass wasting processes including by landsliding and smaller mass flows.

1. Introduction

The South Sandwich volcanic arc, situated in the South Atlantic (Fig. 1), is a tectonically simple, active, intra-oceanic arc, and is ideally suited to studies of volcanic arc crustal structure, geochemical investigation of mantle processes above a subduction zone, and sedimentation in an early stage of arc evolution. The active arc is built largely on oceanic crust of the small Sandwich plate which formed about 10 Ma at the back-arc East Scotia ridge spreading centre (Larter et al., 2003). The arc is forming in response to steeply inclined subduction of the South American plate beneath the Sandwich plate at the rate of 67–79 km/Ma (Thomas et al., 2003). It is relatively free of complicating factors such as intra-arc rifting, the presence of remnant arcs, or collision with seamount chains, oceanic plateaux or ridges. All the sediment arriving at the trench on the South American plate is subducted, and there is no accretionary prism (Vanneste and Larter, 2002).

For all these reasons, therefore, the South Sandwich volcanic arc is commonly viewed as representative of the "simple" or "primitive" end-member in the spectrum of intra-oceanic island arc systems (Baker, 1968; Wilson, 1989; Pearce et al., 1995). However, until the programme of seabed mapping and associated investigations discussed here was carried out, there had been no systematic study of the submarine morphology and structure of the arc. Therefore, it was not known if

* Corresponding author. Tel.: +44 1223 221432; fax: +44 1223 221646.
E-mail addresses: ptle@bas.ac.uk (P.T. Leat), simonday_ucl@yahoo.co.uk (S.J. Day), T.Martin@csiro.au (T.J. Martin), m.owen@ucl.ac.uk (M.J. Owen), drta@bgs.ac.uk (D.R. Tappin).

0377-0273/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jvolgeores.2013.08.013

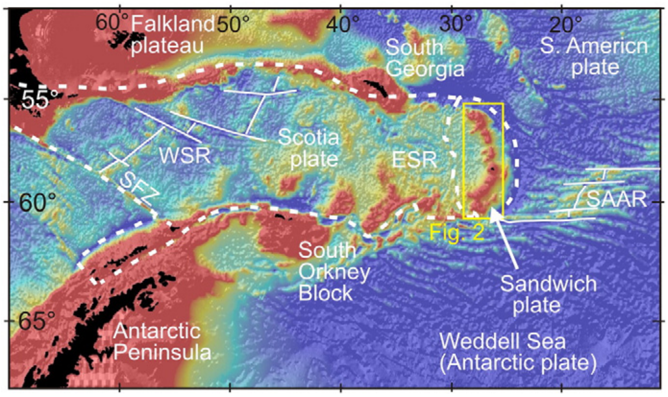

Fig. 1. Sketch map of the Scotia Sea showing the tectonic position of the Sandwich plate. Data are gravity-derived bathymetry. Tectonic boundaries of the Scotia and Sandwich plates are shown by white dashed lines. The extinct West Scotia Ridge (WSR) and active South America–Antarctica Ridge (SAAR) are shown by solid white lines. The Scotia and Sandwich plates are spreading apart at the East Scotia Ridge (ESR). SFZ, Shackleton Fracture Zone.

the subaerial volcanoes previously sampled and studied were representative of the whole of the arc or if the arc itself did not entirely conform to its own supposed "end-member" characteristics. It was not known if there were systematic along-arc variations in volcano morphology and structure, such as the development of submarine volcanic vents or submarine calderas, or submarine seamount volcanism in the fore- or rear-arc regions along cross-arc structures as seen in some other arcs. It was also not known whether submerged remnants of older arcs or displaced blocks of continental crust existed, especially along the northern and southern ends of the arc where it curves into transform fault zones known to contain such blocks. In this paper, we address these questions using the first comprehensive seabed mapping of the entire length of the South Sandwich arc. This paper presents hull-mounted multibeam echo sounder data which nearly completes bathymetric coverage of the volcanic arc.

The South Sandwich subduction zone may also be significant with respect to natural hazards and to the ecosystems of the Southern Ocean. The subduction zone is seismogenic but its potential for producing giant earthquakes is unknown. Should such earthquakes occur, the resulting tsunamis have the potential to be hazardous to South American and African coastlines (Dragani et al., 2009; Okal and Hartnady, 2009), especially in view of the present lack of tsunami sensors close to the arc. Tsunami risk from volcano slope failure in the island arc is present, but as yet unquantified. The volcanic arc is important biologically, as it hosts abundant marine life and sea bird colonies, and has a surprisingly rich benthic fauna (Kaiser et al., 2008). Distal ash falls, subglacial water discharges and sediment plumes, and sea level hydrothermal discharges from the South Sandwich arc are all potential sources of micronutrient element supplies to the surface layer of the Southern Ocean. Newly found seamounts are likely to be biodiversity hotspots, especially where hydrothermally active. New discoveries of submarine hydrothermal vents with associated communities in the back-arc and arc are among the most remote in the World's oceans (Rogers et al., 2012).

All the volcanoes forming the curved volcanic front are recently volcanically active or currently hydrothermally active, or both (Gass et al., 1963; Holdgate, 1963; Baker, 1990; Lachlan-Cope et al., 2001; Leat et al., 2003; Patrick et al., 2005; Patrick and Smellie, 2013). Even within the short period (less than 100 years) of historical records, eruptions from the South Sandwich arc have been varied, ranging from submarine explosive eruptions (Protector Shoal, 1962) through strombolian eruptions with associated lava flows (Montagu Island, 2001–2007 and Bristol Island, 1956), to possible lava lake activity (Saunders Island, 1995–1998).

The sub-Antarctic islands of the South Sandwich arc are small, the largest being Montagu which is 12 km across (Fig. 2). They are mainly ice-covered, and almost entirely devoid of vegetation. The extent of ice cover on the islands increases with latitude and height, and the large southern Islands, Montagu, Bristol, and Cook and Thule islands of the Southern Thule group, are heavily glaciated. Rates of erosion of the islands by a combination of glacial and coastal processes are probably high compared to other intra-oceanic arcs, and the resultant high sediment supply is thought to have led to the development of relatively prominent and large sediment wave fields on the submarine flanks of the islands (Leat et al., 2010a). We briefly comment upon further occurrences of sediment waves in newly-surveyed areas described in this paper, but their development and mechanisms of formation will be discussed in detail elsewhere.

There are seven large volcanoes along the curved volcanic front that emerge above sea level to form islands. These islands represent a small fraction of the volume of their respective volcanoes, which are very largely submarine. In a previous paper, Leat et al. (2010a) used multibeam data to document the submarine volcanic and sedimentological features of most of the northern part of the volcanic arc. Multibeam data have also been obtained for the submerged Douglas Strait Caldera on Southern Thule (Allen and Smellie, 2008), and Kemp seamount and the adjacent Kemp caldera (Supplementary Material S1). The East Scotia Ridge back-arc spreading centre and a section of the fore-arc have been mapped using the lower resolution towed Hawaii MR1 sonar (Livermore et al., 1997; Vanneste and Larter, 2002; Livermore, 2003). Previous sounding data are shown on the UK Admiralty Chart (Hydrographic Office, 2003), which was an invaluable route-finder during the survey work.

In this paper, we present multibeam data for the previously unsurveyed remainder of the volcanic arc, including the submarine parts of volcanoes that emerge as Saunders, Montagu and Bristol islands and the Southern Thule island group, a newly discovered volcanic front volcano named Adventure in the southern part of the arc, and the seamount cluster around Nelson Seamount. In addition we present data for parts of the area around Protector Shoal not previously surveyed. We compare these data with those from the northern part of the arc (Leat et al., 2010a), to allow us to examine trends along the length of the arc.

2. Methodology

The bathymetric data were acquired during two cruises (Supplementary Material S1). The northern part of the arc was investigated during 7-day cruise JR168 (NERC Cruise leg JR20070418) on British research ship RRS *James Clark Ross* in April–May 2007. These data were reported in Leat et al. (2010a). The new data that form the main basis for this paper were acquired from the same ship during 21 days in January–February 2010 on cruise JR206 (NERC Cruise leg JR20100118). The 2010 survey extended the area covered in 2007 in the northern part of Protector Seamounts, around Leskov Island, and the area from Saunders Island to the south of the arc (Fig. 2). Both cruises employed the same equipment and data acquisition methods. Bathymetric data were acquired using a hull-mounted Simrad EM 120 multibeam echo sounder. The system had a 12 kHz operating frequency and a 191 beam array with real-time beam steering and active pitch and roll compensation (Tate and Leat, 2007; Leat et al., 2010b). Data were acquired using Simrad's Merlin software and were cleaned manually using MB System v5.0.9 software. Cleaned data were gridded at 100 m horizontal resolution. Vertical measurement accuracy is in the order of 50 cm or 0.2% of depth RMS (whichever is greater). A number of new submarine volcanoes and other bathymetric features have been identified and informally named: the reasons for the choice of these names are discussed in Supplementary Material S2. Slope analysis used the 100 m resolution gridded data (Supplementary Material S3).