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Stratigraphy of the Pleistocene, phonolitic Cão Grande Formation on Santo Antão, Cape Verde

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ABSTRACT

The Cão Grande Formation (CGF) on the western plateau of Santo Antão Island is part of the younger volcanic sequence that originated from both, basanitic and nephelinitic magmatic suites, respectively called COVA and COROA suites. Based on our detailed revised stratigraphy of the CGF, including two yet unknown tephra units, we can show that both suites produced multiple, highly differentiated eruptions over a contemporaneous period. Correlations of CGF tephras with marine ash layers provide distal dispersal data for Cão Grande I (CG I) and also identify two highly explosive, phonolitic eruptions that pre-date the CGF tephra deposits known on land. Within the CGF, the lowermost, 220 ± 7 ka old unit Canudo Tephra (CT; COVA suite) comprises phonolitic fall deposits and ignimbrites; it is partly eroded and overlain by debris flow deposits marking a hiatus in highly differentiated eruptions. The phonolitic CG I Tephra (COROA suite) consists of an initial major Plinian fall deposit and associated ignimbrite and terminal surge deposits. This is immediately overlain by the phonolitic to phono-tephritic Cão Grande II (CG II; COVA suite), a complex succession of numerous fallout layers and density-current deposits. CG I and CG II have radiometric ages of 106 ± 3 ka and 107 ± 15 ka, respectively, that are identical within their error limits. The youngest CGF unit, the Furninha Tephra (FT; COROA suite), consists of three foidic–phonolitic fall deposits interbedded with proximal scoria deposits from a different vent.

The phonolitic eruptions switched to and fro between both magmatic suites, in each case with a stronger first followed by a weaker second eruption. Each eruption evolved from stable to unstable eruption columns. During their terminal phases, both magma systems also leaked evolved dome-forming lavas next to the tephras. Distal ashes increase the CG I tephra volume to ~10 km^3, about twice the previously published estimate. The tephra volume of CG II is ~3 km^3; CT and FT are too poorly exposed for volume estimation. The characteristics of the CGF tephra units outline hazard conditions that may be expected from future evolved explosive eruptions on the western plateau of Santo Antão.

1. Introduction

The Cape Verde Archipelago differs from other hotspot ocean island groups in the sense that it is quasi-stationary with respect to its melting source (Burke and Wilson, 1972; McNutt, 1988). As a consequence, the archipelago represents a site of long-lived volcanism and although there is some age progression from the eastern to both the northwestern and southwestern islands, the evolutionary stages including periods of intense volcanic activity as well as periods of reduced volcanic activity dominated by erosion strongly overlap in time between different islands (Holm et al., 2008; Ramalho et al., 2010a,2010b). The dominantly mafic shield-building phase on the island of Santo Antão comprised two magmatic series, an older basanite–phonolite series (7.5–0.3 Ma) and a younger nephelinite–phonolite series (0.7–0.1 Ma), which partly coexisted (Holm et al., 2006). Phonolitic products remained rare in both series during the shield-building phase but towards the end of this phase, and in transition to the erosional stage, highly explosive eruptions emplaced the voluminous phonolitic Cão Grande Formation tephras. We have logged this tephra succession in detail in order to constrain variations in eruption style and to establish the temporal order of geochemical changes and their causative petrogenetic processes. Correlations with the marine record of ash layers from the surrounding ocean floor improve the quantification of tephra dispersal. This study therefore provides the basis to explore the changes in magmatic and volcanic processes that occur during the terminal period of shield building on a highly alkalic ocean island such as Santo Antão, contributing to our knowledge on the establishment of differentiating magma chambers

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and ensuing large explosive eruptions. However, here we focus on the stratigraphic and chronological details while the detailed petrogenetic processes will be discussed elsewhere.

2. Geological setting

The Cape Verde Archipelago, 500 km off the Senegalese coast (14°40′–17°30′ N and 21°30′–25°′30 W) in the North Atlantic, consists of ten major islands, several minor islets, and a number of peripheral seamounts (Fig. 1A). It is situated on the Cape Verde Rise (CVR), the largest bathymetric swell on Earth, which is thought to have formed in response to mantle plume activity (McNutt, 1988; Phipps Morgan et al., 1995; Grevemeyer, 1999; Montelli et al., 2004) or by the spreading of melt residue from the hotspot (Ramalho et al., 2010b). The westward-opening, crescent-shaped archipelago can geomorphologically be divided into two island chains, a "northern chain" comprising Santo Antão, São Vicente, Santa Luzia, and São Nicolau, and an "eastern-to-southern chain" including Sal, Boa Vista, Maio, Santiago, Fogo, and Brava (see Fig. 1A). Volcanic activity started around the Oligocene/Miocene (Torres et al., 2002) and volcanoes rest on uplifted oceanic crust made up of Jurassic pillow lavas with mid-ocean ridge basalt (MORB) affinity, uplifted relics of which occur on Maio and Santiago (Stillman et al., 1982; Gerlach et al., 1988). However, age determinations suggest that most of the islands were formed during the last 16 Ma with a slight age progression from east to west. (Mitchell et al., 1983; Plesner et al., 2002; Torres et al., 2002; Holm et al., 2008; Ramalho et al., 2010a, 2010b).

Santo Antão is the second largest island of the Cape Verde Archipelago with an area of 779 km^2 (Fig. 1A). The island was initially built by three volcanic centers, the central Ribeira das Patas volcano, the younger Cova de Paul volcano in the east, and the youngest Tope de Coroa stratovolcano on the western plateau (Tarff and Day, 2013), which forms the highest peak in the island (1979 m a.s.l.) and rests on a scarp from a flank collapse at the west coast of Santo Antão (Fig. 1B). The deeply cut topography of Santo Antão corresponds to an early post-erosional stage (Ramalho et al., 2010b). Subsequently, monogenetic scoria cones, phreatomagmatic tuff cones and lava domes were emplaced. The oldest volcanics have been dated at >7.6 Ma, and the most recent dated eruption took place at 0.09 Ma (Plesner et al., 2002). Bebiano (1932) and Holm et al. (2006) showed that the rock compositions on Santo Antão range from nephelinitic and basanitic to phonolitic. Holm et al. (2006) distinguished the nephelinite–phonolite COROA suite and the basanite–phonolite COVA suite; however these geochemical suites occur across the structural stratigraphic units distinguished by Tarff and Day (2013).

Plesner et al. (2002) identified the Cão Grande Formation (CGF) on the western plateau of Santo Antão and Holm et al. (2006) distinguished two phonolitic to tephri-phonolitic tephra units which they termed Cão Grande I (CG I) and Cão Grande II (CG II). Type localities and all major outcrops of the CGF are situated on the plateau east of the Tope de Coroa. The CG I pumice fallout forms a significant widespread marker bed within the youngest volcanics on Santo Antão. Plesner et al. (2002) estimated an age between 220 ka and 170 ka for the CG I fallout deposit from its stratigraphic position with respect to $^{40}Ar/^{39}Ar$ dated rock units of Santo Antão. Holm et al. (2006) showed that CG I is geochemically related to the nephelinite–phonolite COROA series, whereas CG II is related to the basanite–phonolite COVA series. A detailed stratigraphic and petrologic study of the CG I pumice fallout deposit was carried out by Mortensen et al. (2009), estimating a sub-Plinian to Plinian eruption from a vent close to the Tope de Coroa, but its exact location has not yet been established. We have revisited the Cão Grande Formation and expanded the earlier stratigraphy by identifying four phonolitic tephra units as described below.

3. Methods

Our on-land tephrostratigraphic profile is based on 17 logged outcrops on the western plateau of Santo Antão (Fig. 1b). Lithological and geochemical comparisons are used to correlate sub-units between outcrops. A total of 70 stratigraphically logged tephra samples were taken.

In addition to land-based fieldwork, fifteen sediment cores of up to 9 m length were taken around the northern chain of the Cape Verde Archipelago during the *R/V METEOR* cruise M80/3 (Hansteen et al., 2014) (Fig. 1A) and were used to correlate marine ash beds with on-land tephras to better constrain distribution characteristics of eruptions from Santo Antão. The cores were taken at distances of 60 to 400 km from Santo Antão and at 3350 to 4320 m water depth in areas outside landslide and turbidite depositional fans as judged from bathymetric data. Visual logging of the sediment cores identified 111 ash layers, from which glass shards were separated for geochemical microanalyses.

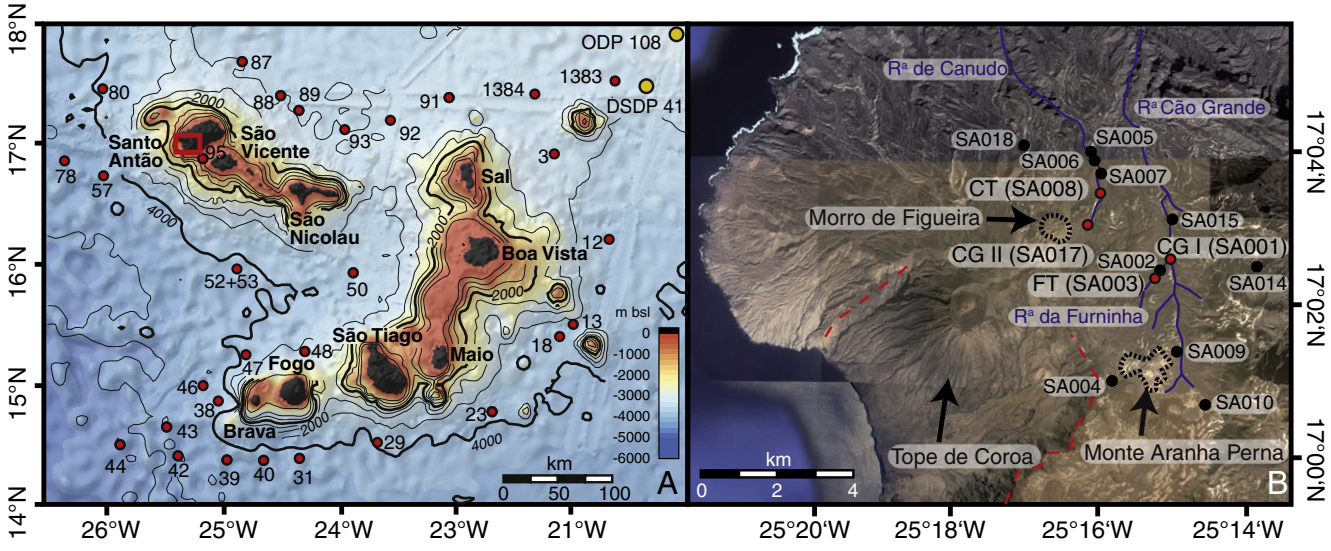

Fig. 1. A) Overview map of the Cape Verde Archipelago with bathymetric data from Sandwell et al. (2014). M80/3 gravity core stations (red dots) and schematic profiles of cores used in this study are shown. The red rectangle marks the main study area on Santo Antão. ODP and DSDP core stations (yellow dots) are shown for comparison. B) Satellite map of the western plateau on Santo Antão (map source Google Earth). Red dots mark type localities and black dots mark additional outcrops logged for this study. Phonolitic domes are marked by black dotted lines. Blue lines are riverbeds mentioned in this study. Red dotted line traces slope failure scarp partly covered by Tope de Coroa volcano.