Journal of Volcanology and Geothermal Research 308 (2015) 39–60

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

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

Dynamics and pre-eruptive conditions of catastrophic, ignimbrite-producing eruptions from the Yenkahe Caldera, Vanuatu

Chris W. Firth [a,*], Shane J. Cronin [b], Simon P. Turner [a], Heather K. Handley [a], Clement Gaildry [a], Ian Smith [b]

[a] Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW 2109, Australia
[b] School of Environment, University of Auckland, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 13 May 2015
Accepted 7 October 2015
Available online 22 October 2015

Keywords:
Mafic ignimbrite
Caldera
Magma mixing
Crystal mush
Yasur
Vanuatu

ABSTRACT

A combined stratigraphic and geochemical examination of ~43 kyr of volcanic activity is presented for the Yenkahe Caldera, a mafic–intermediate volcanic system on the island of Tanna, in the Vanuatu Arc. Through this period two catastrophic ignimbrite-producing eruptions have occurred: the Siwi eruption and the older, Old Tanna Ignimbrite eruption. The latter was previously linked with a different edifice to the north-east, however re-examination has shown it was derived from the Yenkahe Caldera. Radiocarbon dating of this ignimbrite gives an age of ~43 kyr B.P. Both eruptions produced voluminous ignimbrite sheets, however differences in deposit sequences show that the eruptions followed distinct courses. Deposits from the more recent Siwi eruption display greater evidence for phreatomagmatic phases during eruption onset. Both ignimbrites are distributed asymmetrically about the caldera, indicating partial collapse in each case. The early stages of the Siwi eruption produced directed pyroclastic surges and spatter fountains. Between these two major eruptions, volcanic activity was maintained through the formation of small, discrete volcanic cones, such as Yasur, which is active today. Whole rock major and trace element data show that intra-caldera activity between cataclysmic eruptions produced magmas of uniform basaltic-trachy-andesitic composition (SiO_2 ~ 56 wt.%). Minerals within these lavas appear to be in equilibrium with their host. The Siwi eruption produced the most evolved, trachy-andesitic magma (SiO_2 > 58 wt.%), while the Old Tanna eruption is associated with less evolved, basaltic-andesite magma (SiO_2 ~ 53 wt.%). Juvenile clasts from both ignimbrites display diverse mineral chemistry and mineral disequilibrium textures. From these variations in geochemistry and petrology we suggest that a crystal mush or resident magma remained following low-magnitude, intra-caldera activity. MELTS modelling suggest that this was stored at shallow depths, equivalent to pressures <1 kbar. Injection and mingling/mixing with primitive magma rejuvenated this mush component to trigger the ignimbrite eruptions.

1. Introduction

Catastrophic, ignimbrite-producing, caldera-forming eruptions are amongst the most violent and damaging forms of volcanic unrest. In small island nations they have the potential for causing severe social disturbance and have even been known to completely destroy civilisations. Well-known examples of such cataclysmic eruptions include the 1620 B.C. eruption of Santorini (e.g. McCoy and Heikern, 2000; Bruins et al., 2008) and the 1815 A.D. Tambora eruption (Oppenheimer, 2003). Regional and global effects of such eruptions are also propagated through knock-on phenomena such as tsunamis (Waythomas and Neal, 1998; Carey et al., 2000) and climatic perturbations (McCormick et al., 1995; Self et al., 2004). Given the long repose times between such large-magnitude eruptions (10^3–10^5 kyr) they can be overlooked in hazard assessments. Detailed examination of the geology and accurate dating of these deposits is necessary to understand their significance within the wider magmatic system.

Evidence for caldera-forming eruptions has been identified at a number of volcanoes in the Vanuatu Arc (e.g. Robin et al., 1993; Monzier et al., 1994; Robin et al., 1995; Allen, 2004; Gao et al., 2006; Witter and Self, 2007). Of these, the Yenkahe Caldera, on the island of Tanna, displays the strongest evidence for violent formation during a paroxysmal eruption, with voluminous ignimbrite deposits preserved around its margin (Nairn et al., 1988; Robin et al., 1994; Allen, 2004). Deposits of two ignimbrites have been identified on Tanna: the Siwi Ignimbrite, which is known to have originated from the Yenkahe Caldera, and the Old Tanna Ignimbrite, which is proposed to have been erupted from a vent off the east coast of Tanna (Robin et al., 1994). Here the stratigraphy of these deposits is re-examined and revised following observations from additional locations. Radiometric ages for formation of the Yenkahe Caldera are also provided for the first time. This is combined with mineralogical, petrological and geochemical examination of pre-, syn- and post-ignimbrite volcanic rocks to understand the processes leading to cataclysmic, caldera-forming eruptions and their

* Corresponding author. Tel.: +61 2 9850 4405.
E-mail address: christopher.firth@students.mq.edu.au (C.W. Firth).

http://dx.doi.org/10.1016/j.jvolgeores.2015.10.012
0377-0273/

context within the wider history of the volcano. This is crucial for a full hazard assessment of the volcanic system.

1.1. Geological setting

Tanna is a large, volcanic island at the southern end of the Vanuatu island arc, in the south-west Pacific Ocean (Fig. 1). The island has been volcanically active for the last 2.5 Myr, with three main phases of volcanism: the oldest, Pliocene–Pleistocene Green Hills Formation in the north; the mid-late Pleistocene Tukasmera Volcanics in the south-west and the late Pleistocene–Holocene Yenkahe Group in the south-east. The latter includes deposits from both the Siwi Ignimbrite and subsequent activity at Yasur, which continues today (Carney and McFarlane, 1979).

The Siwi Ignimbrite is genetically linked with the Yenkahe Caldera in the island's south-east (Nairn et al., 1988). This caldera is ~24 km^2 in area and is surrounded by the Siwi Ring Fault (Allen, 2004). The caldera is oval-shaped, elongated in an east–west orientation and opens to the sea in the east (Fig. 1). Marginal scarps are well defined in the north-east of the caldera, but infilling by post-caldera volcanics, uplift and erosion have masked the caldera margin in other areas. Allen (2004) described the Siwi Ignimbrite as a pumice-rich pyroclastic flow deposit with lenses of variably-welded, lithic-rich spatter agglomerate. Textural and lithofacies characteristics allow the eruption to be divided into a number of phases of varying explosivity, including initial base surges, catastrophic collapse of the chamber roof associated with lava fountaining and final collapse of a Plinian eruption column, producing the voluminous upper ignimbrite unit. This unit is underlain by a volcanic breccia and a plagioclase-phyric lava (Fig. 2) and overlain by post-ignimbrite tephra (Allen, 2004). Deposits of an older ignimbrite unit, known as the Old Tanna Ignimbrite (OTI), were identified along the eastern coast of the island by Robin et al. (1994) (Fig. 1). They consist of ash flow deposits and bedded tuffs, overlain by scoria-flows deposits containing an range of juvenile and accidental clasts. This ignimbrite was ascribed to a caldera-forming eruption located off the north-east coast of the island, at a, now-obliterated, feature known as the Eastern Tanna Volcano (Robin et al., 1994).

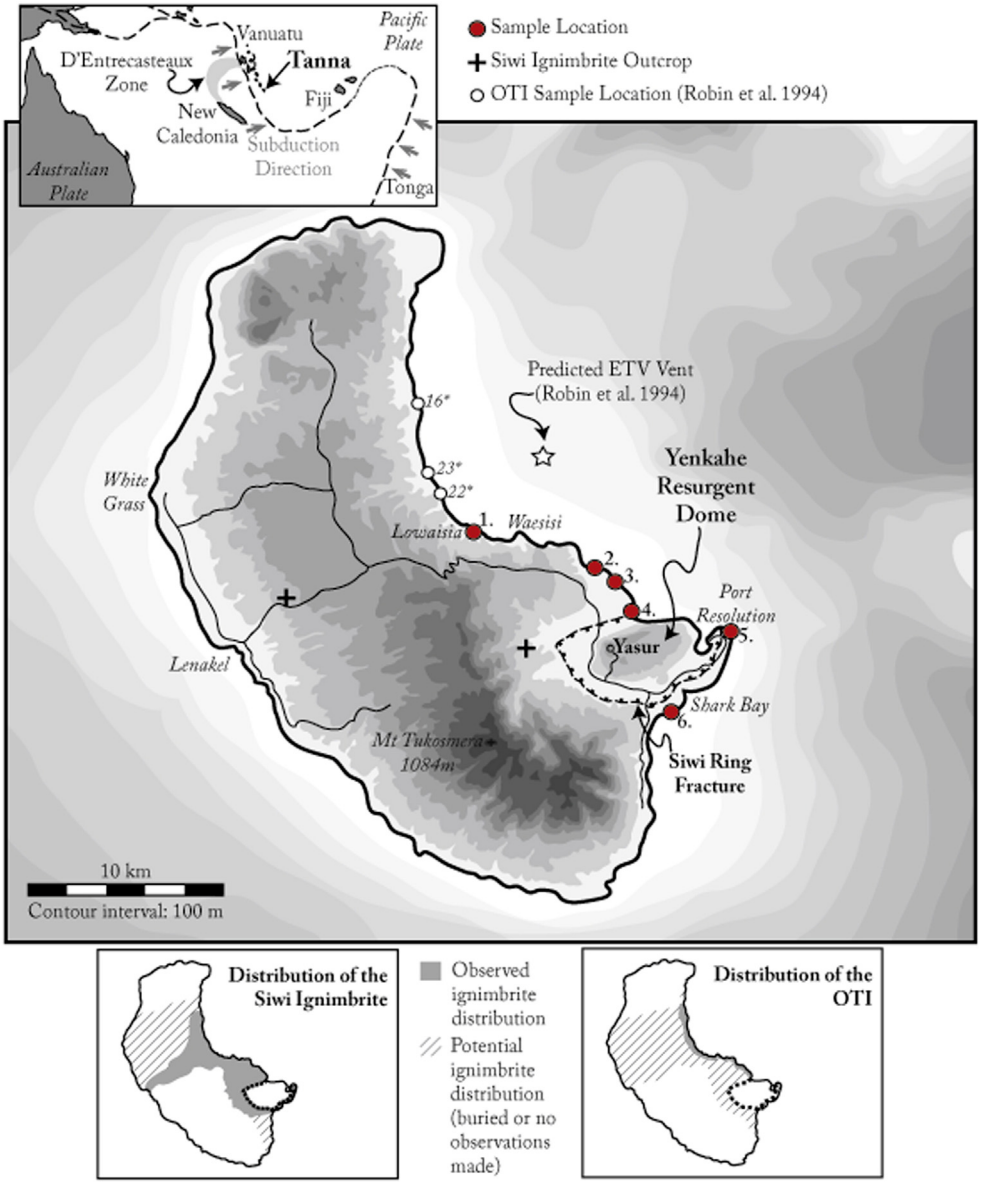

Fig. 1. Map of Tanna, showing the location of the Yenkahe Caldera relative to stratigraphic sections discussed here. Stratigraphic sections examined by Robin et al. (1994) are also shown for comparison. The location and tectonic regime of Tanna are shown in the upper inset, while the lower insets show the observed and inferred outcrop distribution of both the Siwi Ignimbrite and OTI.