Journal of Volcanology and Geothermal Research 221–222 (2012) 71–82

Contents lists available at SciVerse ScienceDirect

Journal of Volcanology and Geothermal Research

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

Variations in welding characteristics within the Plinian air-fall deposit of the Middle Pumice eruption, Santorini, Greece

Julie Ann Boyce *, Ralf Gertisser

School of Physical and Geographical Sciences, Keele University, Keele, Staffordshire, ST5 5BG, United Kingdom

ARTICLE INFO

Article history:
Received 17 November 2010
Accepted 10 January 2012
Available online 20 January 2012

Keywords:
Santorini
Aegean arc
Middle Pumice
Plinian eruption
Welding
Welded fall deposit

ABSTRACT

The welded Plinian air-fall deposit of the Middle Pumice A (MP-A) eruption, Santorini, Greece (144.6 ka), was analysed in order to document welding characteristics and determine the factors that control welding due to the sintering of hot ash- to block-sized pyroclasts. There are vertical and lateral variations in welding intensity, with welding increasing upwards within deposit sections and decreasing laterally away from the source. Four welding grades are distinguished: a = densely-welded, b = slightly-welded, c = tack-welded, and d = non-welded. Lateral welding zones are defined by the highest welding grade observed: zone A = densely-welded (<0.25 km from the source); zone B = slightly-welded (0.25–1.26 km); zone C = tack-welded (1.26–3.7 km), and zone D = non-welded (>3.7 km). Pumice density increases (and porosity decreases) with welding, with the most densely-welded part having a density of 2290 kg m^{-3} and a porosity of 5%. Distal, non-welded pumices have a density of 370 kg m^{-3} and porosities of >75%. Clast oblateness varies from 0.79 in the densely-welded proximal deposit sections to 0.54 in the distal, non-welded deposits in southern Thera. Strain, determined using the Rf/ϕ method, indicates that the deposit is moderately flattened but relatively undeformed. The MP-A deposit is dacitic to andesitic in composition, becoming more mafic with stratigraphic height, where the degree of welding is highest. Welding is controlled by geochemical variations, compactional load and local variations in accumulation rate and clast sizes.

1. Introduction

Welded calc-alkaline, andesitic to rhyolitic Plinian air-fall deposits are relatively uncommon in the geological record when compared to non-welded deposits. Examples are found in the Thera and Therasia Tuffs, Santorini (Sparks and Wright, 1979), the Pinnacle Ridge Tuff, Ruapehu, New Zealand (Hackett and Houghton, 1985) and the Askja 1875 eruption (Carey et al., 2008a, b). The vast majority of welded pyroclastic deposits are related to pumice-rich pyroclastic flows (ignimbrites) (Smith, 1960; Turbeville, 1992; Freundt and Schmincke, 1993; Kokelaar and Königer, 2000; Keating, 2004; Pioli and Rosi, 2004; Grunder and Russell, 2005; Sheridan and Wang, 2005).

Welding of pyroclastic deposits occurs when hot pumice fragments and glass shards are sintered together under a compactional load (Ross and Smith, 1961; Ragan and Sheridan, 1972). Compaction is a result of loading, controlled by viscosity, temperature and total thickness of the deposit (Sparks and Wright, 1979; Russell and Quane, 2005). Primary porosity is reduced and density increases (Sheridan and Ragan, 1976; Russell and Quane, 2005). Welding compaction occurs when high temperatures and pressures cause the slow viscous deformation of glass fragments (Friedman et al., 1963; Sheridan and Wang, 2005), leading to the formation of a eutaxitic texture (Sheridan and Ragan, 1976; Russell and Quane, 2005). Welding occurs when the glass transition temperature (the boundary between a liquid and solid response to stress) is exceeded (Smith, 1960; Ross and Smith, 1961; Ragan and Sheridan, 1972). The extent of welding is controlled by the time particles remain or are exposed to these temperatures (Sheridan and Wang, 2005), with those at the top and base of the deposit subjected for less time than those towards the centre (Quane and Russell, 2005).

The Plinian Middle Pumice A (MP-A) deposit of Santorini, Greece constitutes a classic example of a welded pumice-fall deposit. Interpreted as a welded ignimbrite in the early literature (Pichler, 1963; Pichler and Kussmaul, 1972), it was first recognised as a welded air-fall deposit in the pioneering work of Sparks and Wright (1979), who referred to the Middle Pumice deposit as the Thera tuff. The deposit is almost continuously exposed in the caldera wall of Thera, up to 8.5 km from source, and has been dated at 144.6 ka (Keller et al., 2000; Schwarz, 2000). Present day thickness and grain-size decrease away from the vent, and the highest degrees of welding occur where the deposit is presently thickest. With increasing welding intensity, strain ratio and pumice density increases and porosity decreases. Strain studies have shown that the welded section is compactionally deformed (Sparks and Wright, (1979)). The MP-A deposit is dacitic at the base, changing to andesitic at the top, suggestive of a magma chamber with a felsic roof zone and a more mafic lower portion (Sparks and Wright, 1979; Druitt, 1983; Druitt et al., 1999).

* Corresponding author at: Present address: School of Geosciences, Building 28, Monash University, Victoria 3800, Australia. Tel.: +61 3 9905 5768; fax: +61 3 9905 4903.
E-mail address: Julie.Boyce@monash.edu (J.A. Boyce).

0377-0273/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.jvolgeores.2012.01.004

The MP-A deposit provides a unique opportunity to document a well-preserved welded air-fall deposit that includes both proximal and medial eruption products. Very few welded air-fall deposits have been fully characterised, and descriptional terminology applying to the welding of ignimbrites is not suitable for that of air-fall. This paper builds on the early work of the MP-A deposit by Sparks and Wright (1979), determining deposit characteristics such as welding intensity (welding grades), density, porosity and flattening ratios across the caldera. Lateral and vertical variations in welding characteristics are established. Pumice textures, whole-rock geochemistry and deposit distribution are utilised to establish the factors that control welding in the MP-A deposit.

2. Geological background

Santorini is situated in the Aegean volcanic arc, 140 km north of Crete, associated with the northward subduction of the African plate beneath the South Aegean micro-plate. The Santorini volcanic complex is composed of the islands Nea and Palaea Kameni in a flooded caldera, surrounded by the islands of Thera, Therasia and Aspronisi (Druitt et al., 1999; Vespa et al., 2006) (Fig. 1). Two NE–SW trending faults, the Kameni and Columbos lines (Druitt et al., 1999) influence volcanic activity.

The products of the twelve Plinian and numerous interplinian eruptions of the Thera Pyroclastic Formation (Druitt et al., 1999;

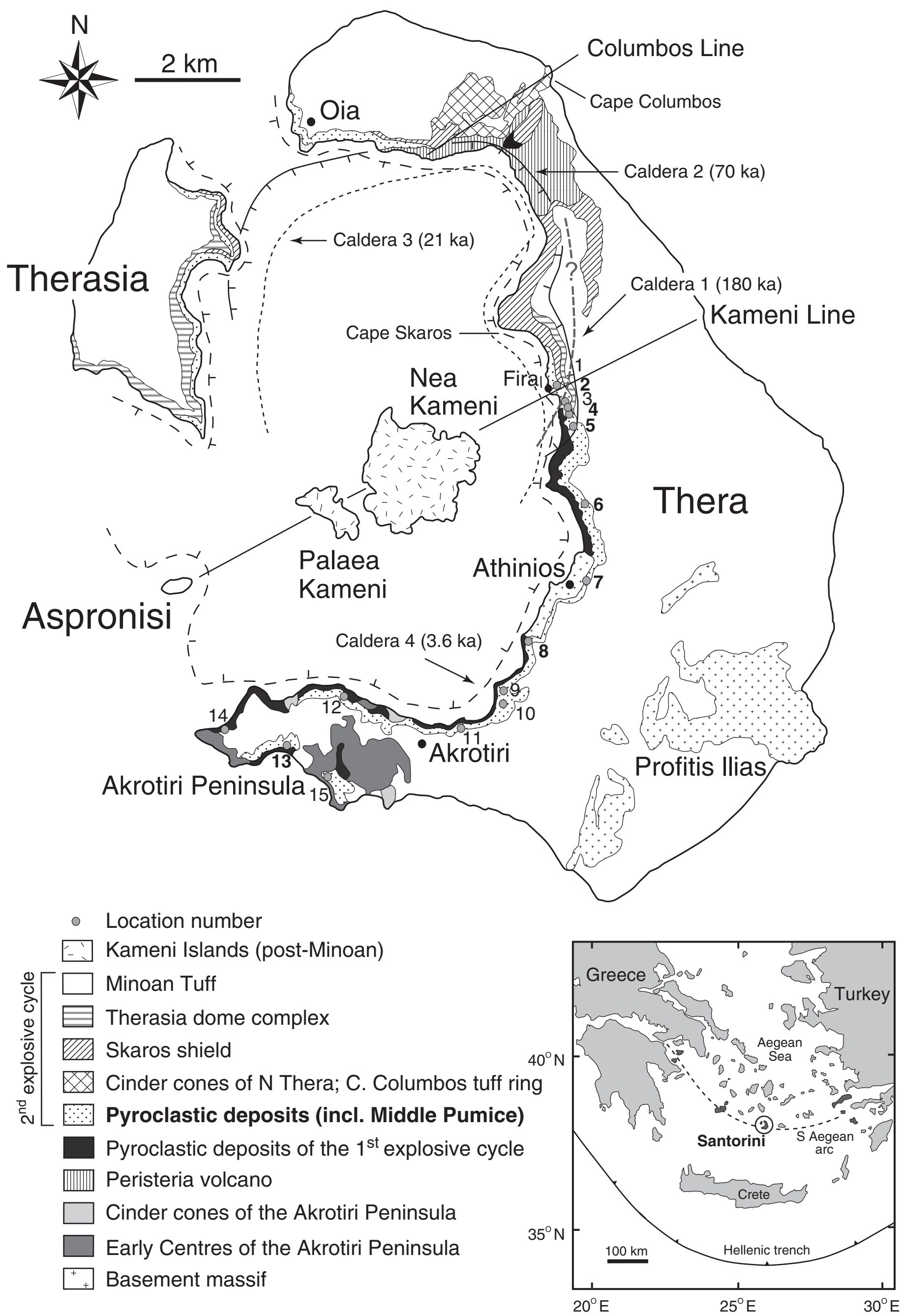

Fig. 1. Simplified geological map of Santorini, highlighting the distribution of the products of the second explosive cycle of the Thera Pyroclastic Formation (including those of the Middle Pumice A (MP-A) eruption) and the inferred outlines and ages of the four calderas formed throughout the history of the volcano (after Druitt et al., 1999). A general map of the Aegean area and the southern Aegean volcanic arc (dashed line) with its active volcanic centres (dark grey) is shown in the inset (after Keller, 1982). Superimposed on the map are sites and sample locations (L) from this study (samples analysed in bold): L1 = North of Fira Steps, L2 = Fira Steps, L3 = South of Fira Steps, L4 = Fira Quarry 2, L5 = Fira Quarry 1, L6 = Cape Alonaki, L7 = Athinios, L8 = Cape Plaka, L9 = Cape Therma, L10 = Mavromatis Quarry, L11 = Caldera beach, L12 = Cape Loumaravi, L13 = Mesa Pigadia beach, L14 = Cape Akrotiri, L15 = Kambia beach.