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Physical volcanology of the Gubisa Formation, Kone Volcanic Complex, Ethiopia

Michael L. Rampey [a,*], Clive Oppenheimer [a], David M. Pyle [b], Gezahegn Yirgu [c]

[a] Department of Geography, University of Cambridge, Cambridge CB2 3EN, UK
[b] Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK
[c] Department of Earth Sciences, Addis Ababa University, Addis Ababa, Ethiopia

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ABSTRACT

Despite their significance for understanding the potential environmental factors involved in hominin evolution in Ethiopia, very few modern volcanologic studies have been carried out on the Quaternary calderas and associated silicic tephra deposits of the Ethiopian Rift. We present here the second of a set of papers reporting the findings of fieldwork and laboratory analyses of one of the largest of these structures, Kone Caldera, located within the Kone Volcanic Complex in the northern Main Ethiopian Rift. The most recent major episode of explosive eruptive activity at Kone Caldera was apparently associated with formation of part of the overall 8-km-diameter collapse area, and deposited a widely-dispersed alkali rhyolite tephra that reaches a thickness of up to 60 m in vent-proximal deposits. We report here the physical characteristics of this unit in order to constrain eruptive conditions. The pumice fall deposit suggests that an abrupt decrease in magma discharge rate occurred part way through the eruption.

1. Introduction

Plio-Quaternary volcanism in the Main Ethiopian Rift (MER) is of great significance in understanding the petrogenesis of magmas in continental rifts and in reconstructing the palaeoenvironments occupied by hominins. The larger explosive eruptions from silicic centers in the MER generated widespread tephra layers (Pyle, 1999) that represent vital chronometers for human evolutionary studies in the region (e.g., Haile-Selassie et al., 2007). This record of volcanism in the MER has played an important role in human evolution and migration (e.g., Basell, 2008; Bailey et al., 2011). There are, however, very few modern studies of the large eruptions in the region (Pyle, 1999). Our primary aim, therefore, has been to reconstruct the eruptive history of one of the largest volcanic centers in the northern MER, the Quaternary Kone Volcanic Complex (KVC; Rampey et al., 2010), intending that the characterization of these explosive eruptions will increase understanding of deposits that may support future human evolutionary studies in the area. We focused on the KVC due to its role in the development of the northern part of the MER (e.g., Kurtz et al., 2007), and its accessibility and size: it comprises two calderas of ~8 and ~11 km diameter (Kone Caldera and Birenti Caldera, respectively), suggesting large magnitude eruptions capable of yielding important regional tephras (Rampey et al., 2010). Additionally, historic eruptions are documented for the KVC and thus the location merits evaluation in terms of its present hazards.

In the first of our contributions on the KVC, formerly known as the Gariboldi Pass cauldrons (Mohr, 1962) or the Gariboldi Volcanic Complex (Cole, 1968a,b; 1969), we reported the first detailed tephrastratigraphy for the center based on field mapping, laboratory analysis and interpretation of remotely sensed imagery (Rampey et al., 2010). Of the two calderas located within the KVC, Kone Caldera is by far the younger and better preserved and therefore was the more extensively studied. The following observations about Kone Caldera summarize the main findings of Rampey et al. (2010): Kone Caldera consists of a main collapse area, actually comprised of several adjacent zones of subsidence, and a peripheral collapse area referred to by name as the Korke embayment (Fig. 1). The Korke embayment is the most recently formed area of subsidence at Kone Caldera. The Kone Caldera compound collapse structure formed by subsidence of the northeastern flank and summit of a trachyte and alkali rhyolite lava edifice. The stratigraphy of the pyroclastic deposits located on the rim and flanks of Kone Caldera suggests that the explosive eruptive history that resulted in the various episodes of subsidence can be divided into four main phases (Fig. 2 and Rampey et al., 2010). Initial explosive activity resulted in the deposition of alkali trachyte pumice fall and then ash fall material. This was followed by brief pyroclastic

* Corresponding author. Present address: Chemin des Oeuches 18, 2533 Evilard, Switzerland. Tel.: +41 77 425 4505.
E-mail address: mrampey3@gmail.com (M.L. Rampey).

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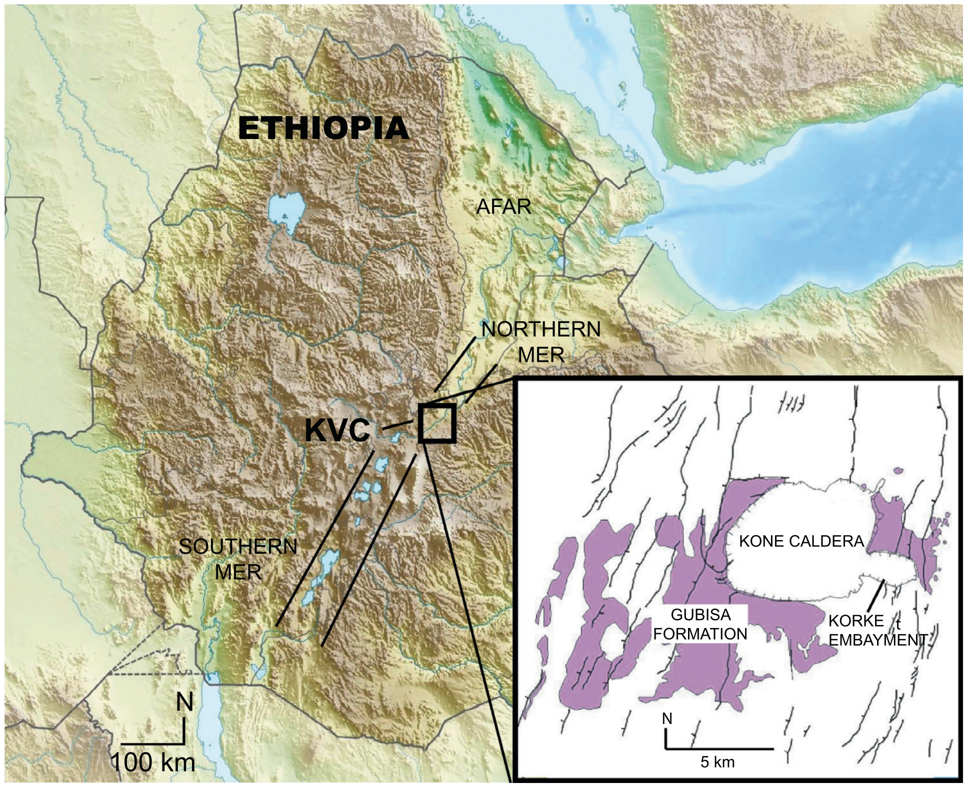

Fig. 1. The location of the Kone Volcanic Complex (KVC) within the northern segment of the Main Ethiopian Rift. Inset: the present-day distribution of the Gubisa Formation materials with respect to the Kone Caldera collapse structures of the KVC.

surge activity and then by the emplacement of two widespread, densely-welded ignimbrites (up to 10 m thick at caldera-rim deposits), presumably resulting from collapse of the eruption column, separated by a voluminous trachytic pumice fall. The deposition of the second ignimbrite concluded the first explosive phase and was followed by extrusion of mafic lavas.

The second explosive eruptive phase opened with the most intense period of Plinian activity of the entire Kone Caldera eruptions sequence, resulting in the deposition of a widespread, fines-poor, alkali-rhyolite pumice fall unit, which is very thick at caldera escarpment exposures (up to 40 m). The eventual collapse of this eruptive column led to the deposition of a widespread, thin (1–3 m), partially welded ignimbrite. Minor basalt lava flows were also erupted at this time. The third phase consisted of a relatively brief episode of Plinian or sub-Plinian activity that formed a thin (1–2 m), alkali rhyolite pumice fall unit overlain by a fine ash fall deposit, presumably formed by the settling of ash-cloud fines following the Plinian outburst. The ash was subsequently reworked during an hiatus in eruptive activity. The fourth and final phase of explosive eruptive activity deposited the very thick (up to 60 m at the caldera rim), alkali rhyolite ash and pumice unit that is the subject of this paper.

We focus here on the most recent major episode of explosive volcanism, which we informally term the "Gubisa Formation" from the local name for the area in which the deposits are thickest. We reconstruct the key aspects of the plume dynamics of the eruption through modeling of the tephra characteristics. We additionally include compositional data in order to further facilitate the stated purpose of supporting future studies in the area.

2. Methods

This study is based primarily on field observations. Thickness data were measured directly at the outcrops, using a hand-held tape-measure. Many outcrops were eroded and therefore the recorded thicknesses must be regarded as minima. The clast size data were obtained by averaging the lengths of three orthogonal axes of the 3–5 largest pumice and lithic clasts at each site. Grain size data were obtained by sieving approximately 10 kg of material at each analysis location using −8 to −1 phi mesh sieves in the field and 0–4 phi mesh sieves in the laboratory. All geochemical data were obtained using an ARL 8420+ X-ray Fluorescence spectrometer (XRF) at the Open University, Milton Keynes, UK and have been recalculated to 100% on an H_2O-free basis. Densities of bulk juvenile material were calculated using the measured densities of individual pumice clasts and known-volume container quantities of matrix material (fines <1 mm in diameter). Ash grain size is defined as follows: a fine-grained layer or deposit is one in which >50 wt% of the material is finer than 0.125 mm, while a coarse-grained layer or deposit is one in which >50 wt% of the ash material ranges in diameter from 0.25 to 2 mm. Sample petrography was determined using petrographic microscopes at the University of Cambridge, UK; thin sections were derived from blanks cut by the first author.

3. Gubisa Formation characteristics

3.1. Deposit morphology

The Gubisa Formation is a thick, white pumice-and-ash deposit that covers the southern, southwestern, western and northeastern Kone Caldera rim and flanks (Fig. 3a). This material was erupted from a vent presumably located within the present-day caldera. Deposits are up to 60 m thick at the southwestern caldera rim and thin rapidly to <10 m thick at ~2.5 km from the rim.

Deposits at the caldera rim are often eroded into rounded hills, though some flat-topped deposits dip gently away from the caldera center. External flank deposits crop out occasionally in fault graben