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Large scale pantelleritic ash flow eruptions during the Late Miocene in central Kenya and evidence for significant environmental impact

L. Claessens [a,d,*], A. Veldkamp [b], J.M. Schoorl [a], J.R. Wijbrans [c], W. van Gorp [a], R. Macdonald [e,f]

[a] Soil Geography and Landscape group, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[b] Faculty ITC, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands
[c] Department of Earth Science, Vrije Universiteit, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
[d] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Box 39063, 00623 Nairobi, Kenya
[e] Environmental Science Division, Lancaster University, Lancaster LA1 4YQ, UK
[f] IGMiP Faculty of Geology, University of Warsaw, 02-089 Warszawa, Poland

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ABSTRACT

In the area south-east of Mount Kenya, four previously unrecorded peralkaline rhyolitic (pantelleritic) ash flow tuffs have been located. These predominantly greyish welded and non-welded tuffs form up to 12 m thick units, which are sometimes characterized by a basal vitrophyre. The four flow units yielded $^{40}Ar/^{39}Ar$ ages ranging from 6.36 to 8.13 Ma, indicating a period of ~1.8 Ma of pantelleritic volcanic activity during the Late Miocene in central Kenya. Tentative compositional and age correlations with other known tuff deposits suggest that the pantelleritic tuffs originally covered 40,000 km^2 in central Kenya, extending much further than earlier recorded Pliocene tuffs. This newly identified magmatic phase occurred between the phonolitic flood eruptions (16–8 Ma) and the Pliocene tuff eruptions (6–4 Ma). The occurrence of multiple ash flow tuff deposits up to 150 km away from the inferred eruptive center(s) in the central sector of the Kenya Rift, indicates multi-cyclic peralkaline supereruptions during the Late Miocene. By analogy with more recent pantelleritic eruptions, the tuffs are thought to have been sulfur-rich; during eruption, they formed stratospheric aerosols, with significant environmental impact. The timing of the eruptions coincides with the shift towards more savannah-dominated environments in East Africa.

1. Introduction

The onset of uplift, rifting and associated volcanism in East Africa was recently constrained by the (re)discovery of a 17 Ma old whale fossil in the Turkana region in northern Kenya 740 km inland from the present-day coastline of the Indian Ocean at an elevation of 620 m (Wichura et al., 2015). Since its formation during the Miocene, the Kenya Rift Valley has been estimated to have erupted >150,000 km^3 of volcanic rocks (Smith, 1994). The majority of these eruptives belong to the Plateau phonolites phase that erupted between 16 and 8 Ma ago (Macdonald, 2003). In the central sector of the Kenya Rift this phase was followed by a more explosive phase depositing thick (100–300 m) sequences of welded and non-welded ash flows and air-fall tuffs, labeled 'Pliocene tuffs'(Smith, 1994; Fig. 1-A). A first broad correlation suggests that an area of 29,000 km^2 was covered by these deposits and that the ash flows were sourced in the Nakuru-Naivasha-Suswa area (McCall, 1967; Baker et al., 1988; Leat, 1991; Smith, 1994). The so-called 'Pliocene tuffs' cover a roughly circular area centered by Lake Naivasha and with a radius of approximately 90 km (Fig. 1). Various different tuff deposits are recognized with only a handful of reliable age determinations that range from 6.4 to 4.2 Ma (Jones and Lippard, 1979). The oldest dated tuffs are the Mau tuffs which consist of at least four ash flow units of peralkaline trachytic composition. The youngest two flows have K—Ar ages of 6.0–5.8 Ma (Jones and Lippard, 1979) indicating late Miocene emplacement. Despite these clear late Miocene ages, Smith (1994) assembled all mainly trachytic (alkalis-silica classification; Le Bas et al., 1992) tuff deposits and defined them as 'Pliocene tuffs', heavily relying on the correlation of all eastern tuffs, specifically the Kinangop tuff (5.7–3.4 Ma) in the Kinangop plateau (Baker et al., 1988). Other accurate $^{40}Ar/^{39}Ar$ age estimates of tuffs and related deposits were obtained at hominid sites such as the Tugen Hills (Kingston et al., 2002) and near Lake Turkana, where Late Miocene and Pliocene tuffs have been dated (Brown and McDougall, 2011). All these tuffs are considered to have originated in the central sector of the Kenyan Rift from several potential eruptive centers (Smith, 1994). During geological mapping of the area south and south-east of Mount Kenya, different tuff deposits were described (Bear, 1952; Fairburn, 1963, 1966). The tuffs are partly buried by predominantly phonolitic lava flows and volcanic debris avalanche deposits (agglomerates) of Mount Kenya, indicating an older origin. The main volcanic activity of Mount Kenya has recently been dated accurately and occurred between 5.27 and 2.8 Ma

* Corresponding author at: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), P.O. Box 39063, 00623 Nairobi, Kenya.
E-mail address: l.claessens@cgiar.org (L. Claessens).

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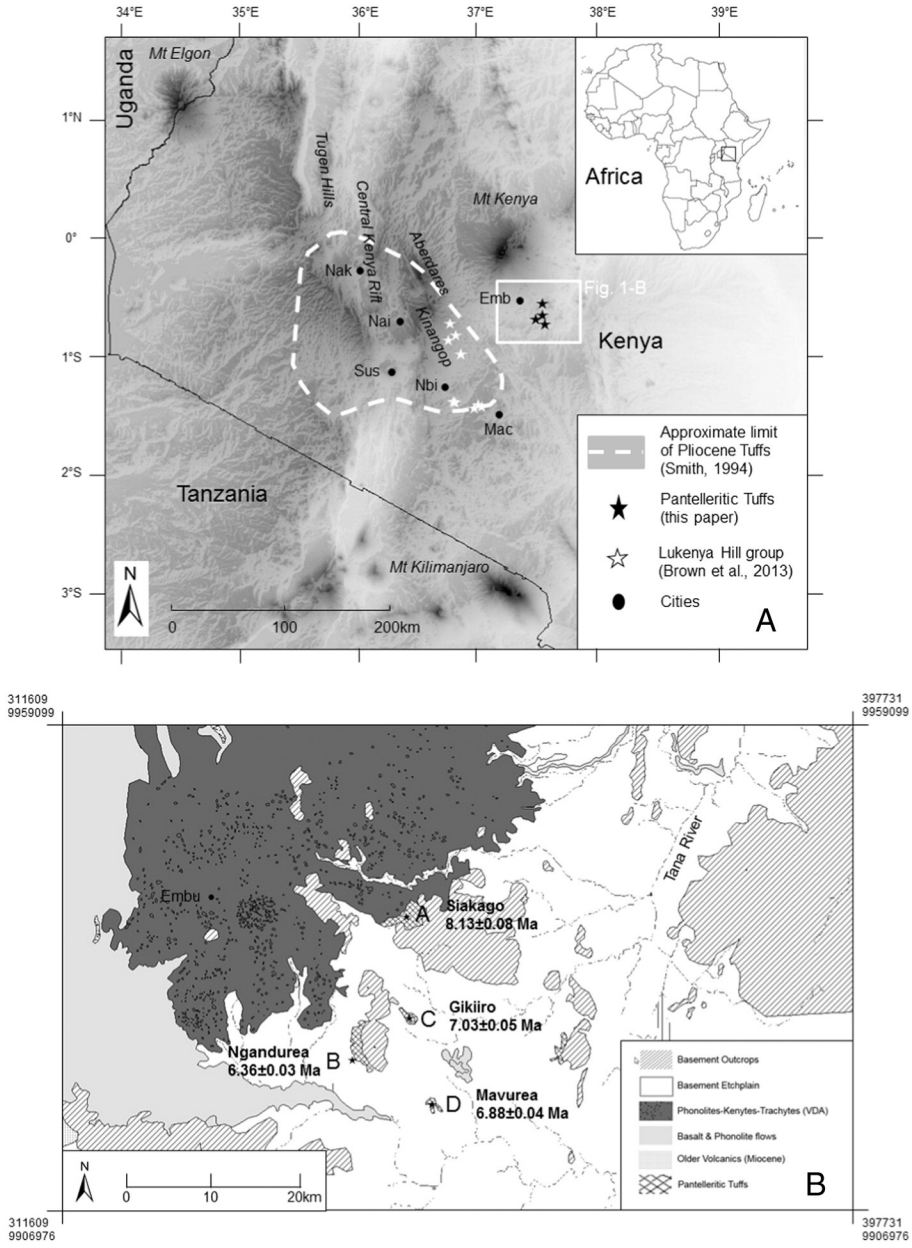

Fig. 1. Geological setting. (A) Location of study area and other localities within Kenya (Nak = Nakuru; Nai = Naivasha; Sus = Suswa; Nbi = Nairobi; Mac = Machakos; Emb = Embu). (B) Simplified regional geology map of the study area (after Bear, 1952) with the locations and ages of the tuffs. Note the depressions in the VDA deposit as mapped in Schoorl et al. (2014). Coordinates in UTM (zone 37).

($^{40}Ar/^{39}Ar$; Veldkamp et al., 2012; Schoorl et al., 2014). Somehow, these extensive tuff deposits have been ignored in Mio-Pliocene volcanic reconstructions. Given their location approximately 150 km east of the Kenya rift-axis, these tuffs can only have been deposited from large-scale, disruptive eruptions and may provide important information on distinct environmental changes and may be useful for palaeogeomorphological reconstructions of the region.

In order to resolve the origin and age of the tuffs south-east of Embu, exposures were mapped and sampled for geochemical analysis and $^{40}Ar/^{39}Ar$ dating. This paper aims to characterize the tuffs and to relate them to the Late Cenozoic geological and palaeoenvironmental history of central Kenya.

1.1. Study area

The study area is located in central Kenya and encompasses the eastern part of Embu County. Geological features in that setting include Mount Kenya volcanic deposits in the north and exposed Proterozoic metamorphic and crystalline rocks of the Mozambique Belt in the east and south (Bear, 1952; Fairburn, 1963; Veldkamp and Visser, 1992; Fig. 1-A). In the area south-east of Embu, volcanic tuffs have been found adjacent to, and below, Mount Kenya volcanic rocks (Bear, 1952; Fairburn, 1966; Fig. 1-A). These volcanic deposits have been correlated to the undated Nyeri tuffs and their origin has been preliminarily suggested in the Aberdares (Fairburn, 1966). More to the south, in the area north of Machakos and east of Thika, Fairburn (1963) mapped similar tuffs, which he referred to as the Athi tuffs. Later Baker et al., (1971, p. 199–200) correlated all these tuffs to the Plio-Pleistocene trachytic group.

Direct age estimates of the tuffs do not exist and only very tentative correlations have been explored. A palaeogeomorphological reconstruction of the Pliocene upper Tana basin raised questions about the age of the observed tuffs. It was suggested that some of the tuffs could have been related to main blocking phases of the