1 **New high-precision $^{40}\text{Ar}/^{39}\text{Ar}$ ages on Oligocene volcanic rocks of northwestern Kenya**

2 Francis H. Brown^{1*} and Brian R. Jicha²

3 ¹ Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah, USA

4 84112-0102; phone: (801) 581-8767; e-mail: frank.brown@utah.edu

5 *Corresponding author

6 ² Department of Geoscience, University of Wisconsin-Madison 1215 W. Dayton St. Madison,

7 WI 53706 phone: (608) 265-1862; e-mail: bjicha@geology.wisc.edu

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Abstract:

New, high-precision $^{40}\text{Ar}/^{39}\text{Ar}$ ages from volcanic rocks in northwestern Kenya are provided for some areas of exposure in this remote area. We report seven $^{40}\text{Ar}/^{39}\text{Ar}$ ages generated from single crystal total fusion experiments on alkali feldspar separated from volcanic rocks in the Mogila, Songot, and Lokwanamur Ranges and the Gatome valley. A rhyolite from the lower part of the sequence in the Mogila Range yielded ages of 32.31 ± 0.06 Ma and 32.33 ± 0.07 Ma, and a rhyolite near the top of that sequence yielded 31.67 ± 0.04 Ma. A single sample from the Songot Range yielded an age of 32.49 ± 0.07 Ma, slightly older than the rocks collected from Mogila. In both ranges the early Oligocene rhyolites are underlain by basalts, as is also the case in the Labur Range. Ages of 25.95 ± 0.03 Ma, 25.91 ± 0.04 Ma, and 27.15 ± 0.03 Ma were measured on alkali feldspar from rhyolites from the Lokwanamur Range, and the nearby Gatome valley. All of these rocks are part of an episode of widespread volcanism in northwestern Kenya in the mid- to late Oligocene that is not currently known from the Ethiopian Rift Valley.

1. Introduction

Volcanic rocks resting on Pre-Paleozoic basement rocks in the Turkana Depression of northwestern Kenya have been known for over 80 years (Arambourg, 1943; Champion 1937), and were mapped by Walsh and Dodson (1969). The ages of these rocks at some localities are known from reconnaissance geochronology reported in Morley et al. (1999) and McDougall and Brown (2009), but several regions lack ages. Our objective in the present work is to provide ages for three mountain ranges for which no geochronological information has been available. Volcanic rocks in this region are amongst the oldest lavas and ash flows in Kenya, and may signal the beginning of rifting in the area (Davidson, 1983; McDougall & Brown, 2009). They are exposed in mountain ranges bounded by faults (Loima, Pelekech, Songot, Mogila, Lokwanamur (Lokwanamoru on some maps) and Lorienetom, from south to north; see Figure 1), which stand 750 to 1700 m above broad areas of low relief and low elevation (400–500 m) that separate the ranges from one another. Here, we report ages on rocks from three of these mountain ranges (Songot, Mogila, and Lokwanamur), showing that they were erupted during the Oligocene Epoch. We sought, but did not find, suitable materials for dating in the Loima Range.

Songot (Zingout on old maps; e.g., Champion, 1937) and Mogila are two prominent mountainous areas near the town of Lokichogio, which are separated from the Pelekech Range and the Lokwanamur Range by the Lotikipi plain and its southern extension (Figure 1). Rhyolitic lavas and ash flows in the Songot and Mogila ranges dip toward the east about 10°. Westcott et al. (1999) estimate that these rhyolites are ~900 m thick, underlain by 1,800 m of basaltic lavas.

The volcanic sequences at Pelekech, northward to Lokwanamur and Lorienetom are estimated to be up to 3 km thick (McDougall and Brown, 2009; see also Westcott et al., 1999). At Lokwanamur, rhyolites dipping $\sim 7^\circ$ to the west are exposed over a vertical distance of 900 m, with the high point separated from the low point perpendicular to strike by ~ 8.5 km. From this we estimate that the rhyolitic rocks exposed in the Lokwanamur range are ~ 1900 m thick. Champion (1937) described a forest of fossil trees rooted in a red rhyolitic tuff exposed along the road to Kaimothia. We obtained an age from a rhyolite flow from Lokwanamur (KEM-1; Table 1), and we also dated a sample of the tuff in which the trees are embedded along the Kaimothia road at 4.858° N, 35.373° E. Fuchs (1939) reported fossil wood in the same general region from imprecisely known locations near Naramum (a few km farther south) and near Lokitoi (a few km farther north).

The Gatome valley at ~ 600 m elevation between Lorienetom and Pelekech is floored with lavas and interbedded ash flow tuffs that dip gently ($< 10^\circ$) to the west or west-northwest, and are cut by many small faults. We determined the age of one rhyolite from these poorly exposed rocks in the Gatome valley (Gatome, Table 1). Westcott et al. (1999) described a faulted structure underlying the Gatome valley as the Gatome Basin.

2. Material and methods

Feldspar was separated from rocks collected from the Songot, Mogila, and Lokwanamur ranges (see tables for locations). After coarse crushing, the materials were sieved and the 18–28 mesh fraction was washed to remove dust. The non-magnetic component was concentrated from this fraction using a Frantz Isodynamic Separator. Feldspar phenocrysts were hand-

picked from the concentrate of each sample under a binocular microscope and cleaned in a 5% HF solution to remove clays and iron staining.

The feldspar phenocrysts and the 28.201 Ma Fish Canyon tuff sanidine (FCs) standard (Kuiper et al., 2008) were irradiated for 7 hours at the Oregon State University TRIGA reactor in the Cadmium-Lined In-Core Irradiation Tube. Single feldspar phenocrysts were fused at the University of Wisconsin-Madison Rare Gas Geochronology Laboratory using a 25 Watt CO₂ laser. Gas cleanup and analytical routine using the MAP 215-50 mass spectrometer followed the methods of Meyers et al. (2012). The age uncertainties shown in Table 1 reflect analytical contributions at the 2 σ level; the decay constants used are those Min et al. (2000). Mass discrimination was assessed by analysis of atmospheric argon prior to and following the analytical session and was calculated using a linear law relationship relative to a $^{40}\text{Ar}/^{36}\text{Ar} = 298.56 \pm 0.31$ (Lee et al., 2006). All pertinent data are provided following the guidelines for Ar/Ar data reporting in Renne et al. (2009). The time scale used is that suggested by Gradstein et al. (2012) with the Eocene-Oligocene boundary at 33.9 Ma, and the Oligocene-Miocene boundary at 23.0 Ma.

3. Results

Results of the single crystal alkali feldspar fusions generally produced $^{40}\text{Ar}/^{39}\text{Ar}$ dates with a unimodal distribution, with the exception for one sample (Gatome) where a range of older dates were generated. Analytical uncertainties on individual dates range average ~0.4%. and radiogenic ^{40}Ar averages 95.5%. Outliers were omitted from the weighted mean age calculation if they had a normalized median absolute deviation (nMAD) greater than 1.5 (Powell et al., 2002).

Alkali feldspar phenocrysts from a rhyolite in the lower part of the sequence in the Mogila range yielded ages of 32.31 ± 0.06 Ma and 32.33 ± 0.07 Ma, and those from a rhyolite near the top of that sequence yielded an age of 31.67 ± 0.04 Ma. Hence the volcanic rocks of the Mogila Range are of early Oligocene age and the sequence spans ~ 0.65 Myr. Alkali feldspar from the single sample from Songot yielded 32.49 ± 0.07 Ma, slightly older than the volcanic rocks of Mogila, yet it suggests that the rocks of Songot and Mogila erupted during part of the same early Oligocene volcanic episode.

Fifteen of twenty fusions from a sample near the fossil tree locality (K14-957) in the Lokwanamur Range south-southwest of Kaimothia give a weighted mean age of 25.95 ± 0.03 Ma. One grain yielded an age of 25.18 ± 0.09 Ma (significantly younger than the mean) whereas the other four outliers were older, ranging from 26.11 ± 0.09 to 26.50 ± 0.16 Ma. Sample KEM-1, from slightly farther south yielded an indistinguishable age of 25.91 ± 0.04 Ma.

The sample from the low exposures in the Gatome Valley (Gatome; Table 1) yielded a very precise age of 27.15 ± 0.03 Ma, ~ 1 Ma older than the rocks dated from Lokwanamur. Locations of dated samples are shown on Figure 1, and Figure 2 summarizes the ages and types of rocks present in this region and related regions.

4. Discussion and Conclusions

Our results are significant for several reasons. Volcanic rocks exposed in the Mogila and Songot Ranges (32.5-31.7 Ma) correspond better chronologically with those exposed on the west flank of the Labur Range 150 km to the east (32.3 ± 0.3 Ma; McDougall and Brown, 2009; Figures 1, 2), than they do with those exposed in the Lokwanamur (~ 26 Ma) and

Pelekech ranges (~27.0 Ma; McDougall and Brown, 2009), the latter being significantly younger and lying only 65–85 km to the east. Consequently the synformal structure that forms the Lotikipi Plain (Westcott et al., 1999; Baker et al., 1972) is a broader feature than has been previously depicted. As the volcanic rocks of the Mogila and Songot Ranges are distinctly older (by ~ 5 Ma) than those of the Pelekech, Lokwanamur, and Lorienetom Ranges, the thicknesses of these rocks in the subsurface of the Lotikipi and Gatome basins suggested by Westcott et al. (1999) are easily explained because the sequences must be stacked. We note also that volcanic rocks that dip gently to the west are present at very shallow depth over much of the Gatome Basin.

Our new high-precision ages are consistent with previous age determinations of McDougall & Brown (2009) and strengthen their observation that Oligocene and older rocks are principally confined to the northwestern part of this region (see Figure 1). No single structure appears to account for this distribution, but McDougall and Brown (2009) pointed out that the boundary effectively falls at what they termed the Kataboi Fault Zone between the Lothidok and Moruerith ranges. We have tentatively mapped rocks of the Loima Range as Oligocene because the sequences appear to be continuous with either those of the Songot Range or the Pelekech Range.

Ages >30 Ma accord well with determinations on the main volcanic sequence in adjacent southwestern Ethiopia reported by Davidson (1973), who also reported still older whole-rock K/Ar ages >45 Ma on the Akobo Basalts farther north (Figure 2). Volcanic rocks with ages between ~31 Ma and 27 Ma have not been reported in southwestern Ethiopia, or in the main Ethiopian Rift, yet volcanism was widespread in northwestern Kenya during this interval. Rhyolitic volcanism ~27 Ma ago is recorded in the Suregei region of northern Kenya

(McDougall & Watkins, 1988) as well as in the Pelekech, Moruerith and Lokwanamur Ranges, an area that spans at least 1.5° of longitude and latitude. Basalts underlie rhyolites dated at 31–32 Ma in the Labur Range (see McDougall & Brown, 2009) and also in the Songot and Mogila Ranges (Walsh & Dodson, 1969; Westcott et al., 1999), so the sequence is similar. Of the major mountainous parts of northern Turkana, only the Loima Range (Muruanasigar) remains to be dated directly.

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Table 1: Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ single crystal alkali feldspar total fusion experiments

Sample #	Location latitude, longitude	Range	K/Ca Total	N	MSWD	Weighted mean Age (Ma) $\pm 2\sigma$
K14-957	4.858°N, 35.373°E	Lokwanamur	34.8	15 of 20	0.98	25.95 $\pm$ 0.03
K14-983	4.224°N, 34.430°E	Mogila (top)	38.6	18 of 20	0.95	31.67 $\pm$ 0.04
K14-982A	4.214°N, 34.372°E	Mogila (bottom)	32.1	20 of 20	0.60	32.31 $\pm$ 0.06
K14-982B	4.214°N, 34.372°E	Mogila (bottom)	28.2	20 of 20	0.84	32.33 $\pm$ 0.07
K14-984	4.116°N, 34.453°E	Songot	37.2	24 of 24	0.84	32.49 $\pm$ 0.07
Gatome	4.145°N, 35.295°E	Gatome valley	64.6	9 of 14	0.84	27.15 $\pm$ 0.07
KEM-1	4.856°N, 35.372°E	Lokwanamur	66.5	13 of 14	0.84	25.91 $\pm$ 0.07

Fluence monitor is sanidine from the Fish Canyon Tuff; reference age 28.201 Ma from Kuiper et al. (2008). Decay constants: $\lambda_{40\text{Ar}} = 0.580 \pm 0.014 \times 10^{-10} \text{ a}^{-1}$ and $\lambda_{\text{B}} = 4.884 \pm 0.099 \times 10^{-10} \text{ a}^{-1}$ from Min et al. (2000).

Figure 1

Figure 2

Figure Captions

Figure 1. Simplified geologic map of the northern part of Turkana, Kenya (largely after Walsh & Dodson (1969) with additions from Morley et al. (1999) and from field observations. Many faults are omitted for clarity. Dated units are shown as numbers without error (again with some omitted or averaged; those in normal font are reproduced from McDougall & Brown (2009); those in bold are reported in this paper. The broad horizontally dashed line separates Eocene-Oligocene volcanic and sedimentary rocks from Miocene volcanic and sedimentary rocks, but no single structure appears to account for the boundary. Areas mapped as Cretaceous strata are proven only east of Lokitaung; others are putative. Loima is shown as belonging to the older sequence because it appears to be continuous with the sequences at Pelekech, Songot, and Mogila, but this is not yet proven. This map is not an authority on international boundaries.

Figure 2. Distribution of dated rocks in northern Turkana and southwestern Ethiopia (see McDougall and Brown (2009) for ages on rocks from more distant localities).