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A new tephrochronology for early diverse stone tool technologies and long-distance raw material transport in the Middle to Late Pleistocene Kapthurin Formation, East Africa

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A B S T R A C T

The Middle to Late Pleistocene (780–10 ka) of East Africa records evidence of significant behavioral change, early fossils of *Homo sapiens*, and the dispersals of our species across and out of Africa. Studying human evolution in this time period thus requires an extensive and precise chronology relating behavioral evidence from archaeological sequences to aspects of hominin biology and evidence of past environments from fossils and geological sequences. Tephrochronology provides the chronostratigraphic resolution to achieve this through correlation and dating of volcanic ashes. The tephrochronology of the Kapthurin Formation presented here, based on tephra correlations and $^{40}Ar/^{39}Ar$ dates, provides new ages between 395.6 ± 3.5 ka and 465.3 ± 1.0 ka for nine sites showing diverse blade and Levallois methods of core reduction. These are >110 kyr older than previously known in East Africa. New $^{40}Ar/^{39}Ar$ dates provide a refined age of 222.5 ± 0.6 ka for early evidence of long-distance (166 km) obsidian transport at the Sibilo School Road Site. A tephra correlation between the Baringo and Victoria basins also provides a new date of ~100 ka for the Middle Stone Age site of Keraswanin. By providing new and older dates for 11 sites containing several important aspects of hominin behavior and extending the chronology of the Kapthurin Formation forward by ~130,000 years, the tephrochronology presented here contributes one of the longest and most refined chronostratigraphic frameworks of Middle through Late Pleistocene East Africa. This tephrochronology thus provides the foundation to understand the process of modern human behavioral evolution as it relates to biological and paleoenvironmental circumstances.

1. Introduction

The Middle Pleistocene (780–130 ka) through the early Late Pleistocene (130–~60 ka) is an important time period for modern human evolution in East Africa. Early fossils of *Homo sapiens* in East Africa date to 195 ka (McDougall et al., 2005, 2008) and this region was important to human dispersals across and out of Africa in the Late Pleistocene (Soares et al., 2011; Rito et al., 2013). In these periods, stone tool technologies became more diverse as the Acheulean, a technology characterized by large, hand-held stone tools such as handaxes and cleavers, and which persisted for over ~1.5 million years across Africa and western Eurasia, was replaced by a variety of technologies referred to as Middle Stone Age (MSA) in Africa and Middle Paleolithic (MP) in Eurasia. These MSA and MP technologies include a wider range of tool forms such as points and a greater diversity of stone tool production methods compared to the Acheulean (Clark, 1988). The development and diversification of core preparation and reduction methods, including Levallois and blade techniques, are an important part of the process of technological evolution as these prepared core technologies were an integral part of composite tools such as hafted hunting weapons (Sisk and Shea, 2009; Wilkins et al., 2012). Recent geochemical sourcing of obsidian artifacts at the Sibilo School Road Site also shows long-distance raw material transport (~166 km) was a feature of human behavior before ~200 ka (Blegen, 2017). Long-distance raw material transport is important for determining the degree to which hominin groups interacted with one another at different times

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throughout the evolution of the human lineage (Ambrose, 2012). Until recently this behavior had not been archaeologically documented at sites younger than ~60 ka (Blegen, 2017). Understanding the timing of these hominin behavioral innovations in relationship to the biological origins of *H. sapiens* and past environments is essential for understanding circumstances and selective pressures explaining the evolution and dispersals of our species. To this end, a more chronostratigraphically complete paleoanthropological record is necessary for the Middle and Late Pleistocene of East Africa. Tephrochronology provides the means to achieve this chronostratigraphy.

East Africa provides great potential to document stratigraphic and chronometric equivalence among paleoanthropological sites. Extensional tectonics in the East African Rift System (EARS) produces abundant volcanism including tephras. Rapid sedimentation in basins of the EARS buries and preserves volcanics as well as sedimentary deposits containing paleoanthropological materials (Hay, 1986). Tectonic activity of the EARS also subsequently re-exposes these materials through continued extensional faulting (Chorowicz, 2005). The science of tephrochronology, the dating and correlation of tephras through chronology, stratigraphy and geochemistry, makes these units extremely valuable as widespread isochronous markers in the geological record (Lowe, 2011). Well-established Pliocene and Early Pleistocene tephrochronologies exists for paleoanthropological sites in Kenya, Ethiopia, Tanzania and Uganda (Feibel, 1999). Comparatively few data are available for these areas during the Middle and Late Pleistocene (Morgan and Renne, 2008; Tryon et al., 2010; Brown et al., 2012; Blegen et al., 2015, 2016; Blegen, 2017). The Kapthurin Formation has played an important role in incorporating tephrochronology into the dating of archaeological materials relevant to modern human origins (Deino and McBrearty, 2002; Tryon and McBrearty, 2006).

2. The Kapthurin Formation background and previous research

2.1. The Kapthurin Formation

The Kapthurin Formation is a series of sedimentary and volcanic deposits exposed over an area of ~150 km^2 west of Lake Baringo in the central Kenyan Rift (Fig. 1). These sediments unconformably overlie tilted and faulted sediments of the Chemeron Formation, forming the upper portion of a ~16 million year sedimentary sequence spanning the middle Miocene to the Holocene (Martyn, 1969; Hill et al., 1986). Kapthurin Formation sediments have a maximum thickness of ~125 m near the central axis of the basin around the east to west trending Kapthurin and Ndau Rivers and the majority of these exposures occur between the towns of Marigat and Kampi-ya-Samaki, within 25 km west of the modern Baringo–Nakuru road (Tallon, 1976, 1978). Kapthurin Formation sediments outcrop discontinuously as far south as the Perkerra River and as far as ~10 km north of the town of Loruk, though these deposits become thinner north of the Kasurein River (McCall, 1967; McCall et al., 1967; Tallon, 1976, 1978; Spooner et al., n.d.). The Kapthurin Formation is divided into five members. From lowest to highest stratigraphically these are: The Lower Silts and Gravels Member (K1), The Pumice Tuff Member (K2), The Middle Silts and Gravels Member (K3), The Bedded Tuff Member (K4), and The Upper Silts and Gravels Member (K5) (Table 1; Fig. 1).

Sediments in the Kapthurin Formation contain dozens of archaeological and paleontological localities. Fossil sites, including several sites preserving hominid fossils, derive from the Middle Silts and Gravels Member (K3) (Wood and Van Noten, 1986; Cornelissen et al., 1990; McBrearty et al., 1996; McBrearty, 2005; McBrearty and Jablonski, 2005). Archaeological sites are more evenly distributed throughout the section (Table 2). The diversity of Levallois as well as blade core preparation and reduction methods at archaeological sites from directly beneath the base of the Bedded Tuff Member (K4) are emphasized in Supplementary Online Material (SOM) Figs. S1–S3 and their captions. Two recently excavated MSA sites, the Sibilo School Road Site (GnJh-79) (Blegen, 2017) and Keraswanin (GnJh-78) are shown in SOM Figs. S4–S5.

2.2. Tephrochronology and paleoanthropology in the Kapthurin Formation

Early researchers used stratigraphically and lithologically distinct tuffs, such as the Pumice Tuff of the Pumice Tuff Member (K2), to distinguish strata at the member level within the Kapthurin Formation (Martyn, 1969). Correlation of the Grey Tuff in the Middle Silts and Gravels Member (K3) based on macroscopic lithology (Fig. 2) has been used to provide stratigraphic control for several fossil sites including two containing hominin fossils (Tallon, 1978; Deino and McBrearty, 2002). Tephrochronology has also been used to determine the stratigraphic positions and ages of many archaeological sites in the Kapthurin Formation (Table 2). Chemical characterization of tuffs in the Bedded Tuff Member (K4) has shown many of these tuffs belong to a continuous compositional trend. The compositional change occurs along a single trendline reflecting the chemical evolution of a magma source by fractional crystallization of foresteritic olivine and anorthitic plagioclase minerals from basaltic parent magma (McBirney, 1984). This trend results in more compositionally evolved melt with proportionally less Mg and Ca and proportionally more Fe, Ti and Cl in successive eruptions preserved in the glass phase of tuffs found stratigraphically higher in the Bedded Tuff Member (K4). The compositionally evolving magma can be visualized in a number of element oxide bivariate plots (Tryon and McBrearty, 2006). Thus, the most evolved chemical composition found in a tuff from the Bedded Tuff Member (K4) falling along the evolving magma trendline indicates the relative stratigraphic position and relative age of the tuff within this member (see Fig. 3 for schematic representation). While not without exceptions (discussed further in the 'Discussion' section), this methodology is generally useful in establishing a relative chronology for archaeological sites found at and directly below the base of the Bedded Tuff Member (K4) where the vast majority of tuffs are basaltic and conform to this compositionally evolving trendline (Tryon and McBrearty, 2006).

Previous Kapthurin Formation tephrochronologies leave three major issues unresolved:

1) The tephrochronology of the Middle Silts and Gravels Member (K3) is incomplete.

Tallon (1976) considers the Pumice Tuff and the Lebus Tuff stratigraphic and chronological equivalents (Fig. 2). However, the Pumice Tuff is exposed north of the Ndau River to the Kasurein River, whereas the Lebus Tuff is only exposed around the Lebus River (Fig. 1b). Tallon's (1976: 103–110) type section for the 'Grey Tuff' is in the Lebus River valley where his type sample of the Grey Tuff occurs above the type sample of the Lebus Tuff (Fig. 2). The stratigraphic relationships of the Pumice Tuff, the Lebus Tuff and the multiple units Tallon refers to as the Grey Tuff are problematic, as the Lebus Tuff and the Grey Tuff are not seen in the same stratigraphic succession farther north in the Kapthurin Formation where the Grey Tuff has been directly dated by the $^{40}Ar/^{39}Ar$ method and overlies multiple hominin fossil sites (Deino and McBrearty, 2002). There are several (n > 20) gray-colored, fine-grained tuffs in the Kapthurin Formation and lithology alone is insufficient to verify the chronological and stratigraphic