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Tephrochronology of Bed II, Olduvai Gorge, Tanzania, and placement of the Oldowan–Acheulean transition

Lindsay J. McHenry [a, *], Ian G. Stanistreet [b, c]

[a] Department of Geosciences, University of Wisconsin-Milwaukee, 3209 N. Maryland Ave., Milwaukee, WI 53211, USA
[b] Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Brownlow Street, Liverpool, L69 3GP, United Kingdom
[c] Stone Age Institute, 1392 W Dittemore Road, Gosport, IN, 47433, USA

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ABSTRACT

Tuffaceous marker beds, derived from volcanic products from the Ngorongoro Volcanic Highlands, help define a stratigraphic framework for the world-renowned fossil and stone tool record exposed at Olduvai Gorge, Tanzania. However, previous efforts to constrain this tuff record, especially for Olduvai Bed II, have been limited because of erosion, contamination, reworking, and the alteration of volcanic glass under saline-alkaline conditions. This paper applies previously defined geochemical and mineralogical "fingerprints" for several major Bed II marker tuffs, based on glass (where available) and phenocrysts more resistant to alteration (feldspar, hornblende, augite, and titanomagnetite), to tuffs from stratigraphic sections in the Olduvai Junction Area, including previously and recently excavated Acheulean and Oldowan sites (HWK EE (Locality (Loc) 42), EF-HR (Loc 12a), FLK (Loc 45), and MNK (Loc 88)). The Middle Bed II Bird Print Tuff (BPT) is found to be more compositionally variable than previously reported but is still valuable as a stratigraphic marker over short distances. The confirmation of blocks of Tuff IID in conglomerate helps constrain Upper Bed II stratigraphy at sites where in-situ tuffs are absent. This paper also compiles the results of published geochronological research, providing stratigraphic context and updating previously reported dates using a consistent $^{40}Ar/^{39}Ar$ reference standard age. The results of this work support the following paleoanthropologically relevant conclusions: 1) the early Acheulean site EF-HR (Loc 12a) is situated above the level of Hay's Tuff IIC, and thus sits in Upper rather than Middle Bed II, (2) the HWK EE (Loc 42) Oldowan site is constrained between Tuff IIA and Tuff IIB, just above the boundary between Lower and Middle Bed II, and 3) the Acheulean site at FLK W most likely lies within the Middle Augitic Sandstone, above Tuff IIB, similar to the placements by Leakey and Hay for the earliest Acheulean at Olduvai.

1. Introduction and background

The stratigraphic subdivisions of the Olduvai Basin have long been defined with reference to a series of marker tuffs, in the form of both primary volcaniclastic deposits and reworked volcaniclastic sandstones with varying amounts of tephra originally sourced primarily from the nearby Ngorongoro Volcanic Highlands (NVH). These marker tuffs allow paleoanthropologists to establish temporal correlations between sites throughout Olduvai Gorge, constraining time slices necessary for landscape paleoanthropology (Stanistreet, 2012; Blumenschine et al., 2012a, b) and providing a tephrostratigraphic framework to calibrate the fossil and lithic technological record. However, tephrochemistry has demonstrated that the framework developed by Leakey (1971) and Hay (1976), based largely upon physical mapping, is incomplete or inaccurate in some areas of the gorge (e.g., Bed I to the west of paleolake Olduvai: Blumenschine et al., 2003; McHenry, 2012; and Tuffs IIC and IID in the Side Gorge: McHenry et al., 2016). This has led to an effort to systematically test previously proposed tephra correlations. Olduvai Bed II is exceptionally problematic for tephrochronology, because of (1) multiple significant disconformities at most sites (Stanistreet et al., 2018), (2) reworking of tuffaceous material and contamination with other clastic material or products of previous volcanic input, and (3) progressive alteration of volcanic glass and susceptible phenocrysts (e.g., nepheline and melilite) under saline-alkaline conditions.

* Corresponding author.
E-mail address: lmchenry@uwm.edu (L.J. McHenry).

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The saline-alkaline lacustrine and groundwater environment in the Olduvai Basin limits the preservation of volcanic glass, which alters readily to zeolites and clays (McHenry, 2009, 2010). Phenocrysts, including augite, feldspar, hornblende, and titanomagnetite, are more resistant to alteration and are often preserved under these conditions. McHenry et al. (2008, 2016) and McHenry (2005, 2012) developed geochemical and mineralogical fingerprints for Olduvai Bed I and II tephra, using the assemblages of these more resistant minerals and their major and minor element compositions, in addition to glass where available.

This paper will apply already established mineralogical and geochemical fingerprints (McHenry et al., 2016) to Middle and Upper Bed II paleoanthropological sites, with a focus on establishing tephrostratigraphic correlations between recently excavated sites that bracket the end of the Oldowan and appearance of the Acheulean lithic technologies at Olduvai (HWK EE (Locality (Loc) 42), EF-HR (Loc 12a), and FLK (Loc 45)). It will also summarize the recent literature on Bed II geochronology, providing an update to McHenry et al.'s (2007) summary and some stratigraphic context for recently published dates.

This paper will use Hay's (1976) tuff nomenclature throughout, with the understanding that the named "Tuffs" are not always primary volcaniclastic units, but are marker beds that can also contain layers mixed with non-volcanic detritus. This paper will refer to localities using both their Leakey (1971) names, which are widely used in the paleoanthropological literature, and their Hay (1976) geological locality names (abbreviated as "Loc" throughout), which are more familiar to geologists and which cover a broader geographic area. Figure 1 shows the locations of the sites referred to in this text, with their Hay (1976) geological locations.

1.1. Summary of previously determined mineralogical "fingerprints"

More comprehensive descriptions of the individual Bed II tuffs are presented in McHenry et al. (2016), where they are thoroughly characterized in the context of newly established geochemical type and reference localities within the Olduvai Junction Area. Compositional similarities between individual tuffs, either due to similar tephra compositions or to similar levels of contamination in the more reworked units, make precise fingerprinting difficult or impossible. For most units, however, general compositional zones can be identified, as was done for Bed I in the Olduvai Junction Area by McHenry et al. (2013). Figure 2 shows a composite section for the Olduvai Bed II tuffs and other major lithologic units referred to in this manuscript (the Lemuta Member, Augitic Sandstone units), including more recent published dates where available.

Lower Bed II tuffs (including Tuff IIA, and the less tuffaceous "Twiglet" marker unit of lowermost Bed II) have tephriphonolitic glass and nepheline (where preserved), with only minor feldspar covering a broad range of compositions from intermediate plagioclase to sanidine, a wide range of augite compositions trending towards high Mg compositions compared to underlying Bed I tuffs, and the near absence of hornblende (McHenry et al., 2016). In Middle Bed II, Tuff IIB rarely has a significant tuffaceous component, and when it does it often closely resembles Tuff IIA, although with locally higher abundances of biotite. McHenry et al. (2016)

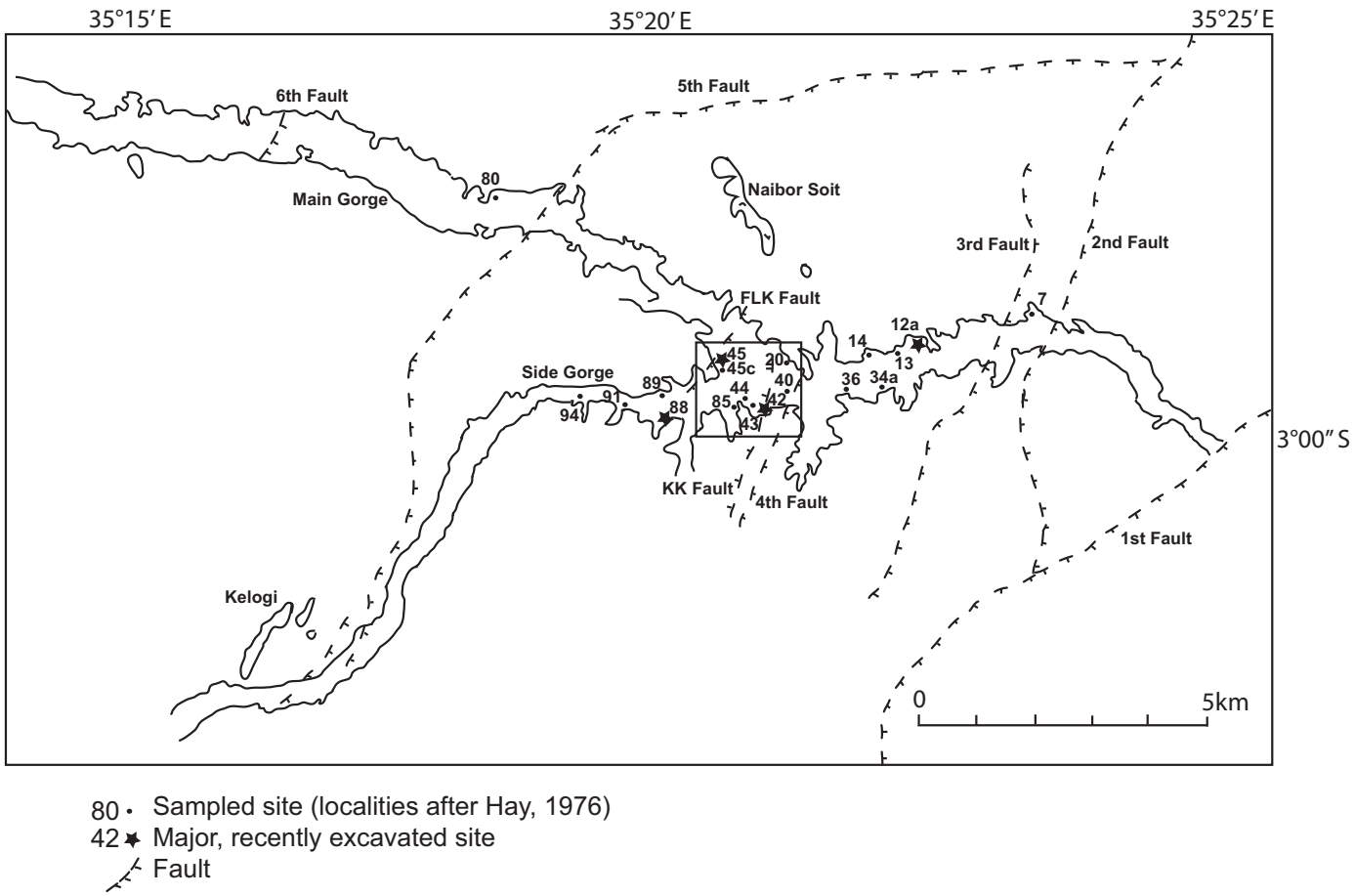

Figure 1. Map showing the locations of all Hay's (1976) geological localities referenced in this paper. The box shows the extent of the Olduvai Junction Area. Recently excavated Middle-Upper Bed II sites are indicated by stars: Loc 12a (EF-HR), Loc 42 (HWK EE), Loc 45 (FLK), and Loc 88 (MNK). Base map after Hay (1976).

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