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Discrimination, correlation, and provenance of Bed I tephrostratigraphic markers, Olduvai Gorge, Tanzania, based on multivariate analyses of phenocryst compositions

Jörg M. Habermann [a,*], Lindsay J. McHenry [b], Harald Stollhofen [a], Raimon Tolosana-Delgado [c], Ian G. Stanistreet [d,e], Alan L. Deino [f]

[a] GeoZentrum Nordbayern, Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany
[b] Department of Geosciences, University of Wisconsin-Milwaukee, 3209 N. Maryland Ave., Milwaukee, WI 53211, USA
[c] Helmholtz Institute Freiberg for Resource Technology, Halsbrücker Str. 34, 09599 Freiberg, Germany
[d] Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Brownlow Street, Liverpool L69 3GP, UK
[e] The Stone Age Institute, Bloomington, IN 47407-5097, USA
[f] Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA

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ABSTRACT

The chronology of Pleistocene flora and fauna, including hominin remains and associated Oldowan industries in Bed I, Olduvai Gorge, Tanzania, is primarily based on $^{40}Ar/^{39}Ar$ dating of intercalated tuffs and lavas, combined with detailed tephrostratigraphic correlations within the basin. Although a high-resolution chronostratigraphic framework has been established for the eastern part of the Olduvai Basin, the western subbasin is less well known due in part to major lateral facies changes within Bed I combined with discontinuous exposure. We address these correlation difficulties using the discriminative power of the chemical composition of the major juvenile mineral phases (augite, anorthoclase, plagioclase) from tuffs, volcaniclastic sandstones, siliciclastic units, and lavas. We statistically evaluate these compositions, obtained from electron probe micro-analysis, applying principal component analysis and discriminant analysis to develop discriminant models that successfully classify most Bed I volcanic units. The correlations, resulting from integrated analyses of all target minerals, provide a basin-wide Bed I chemostratigraphic framework at high lateral and vertical resolution, consistent with the known geological context, that expands and refines the geochemical databases currently available. Correlation of proximal ignimbrites at the First Fault with medial and distal Lower Bed I successions of the western basin enables assessment of lateral facies and thickness trends that confirm Ngorongoro Volcano as the primary source for Lower Bed I, whereas Upper Bed I sediment supply is mainly from Olmoti Volcano. Compositional similarity between Tuff IA, Bed I lava, and Mafic Tuffs II and III single-grain fingerprints, together with north- and northwestward thinning of Bed I lava, suggests a common Ngorongoro source for these units. The techniques applied herein improve upon previous work by evaluating compositional affinities with statistical rigor rather than primarily relying on visual comparison of bivariate plots.

1. Introduction

Since the pioneering work of Reck (1914), Leakey (1928, 1965a, 1971), and Hay (1963, 1973), Olduvai Gorge in northern Tanzania (Fig. 1) has been renowned as one of the richest paleoanthropological sites in the world. Tuff layers are the basis for the chronostratigraphic framework (Hay, 1976; McHenry, 2005, 2012; Fig. 2) and they are used for dating (e.g., Leakey et al., 1961; Curtis and Hay, 1972; Hay, 1976, 1992; Walter et al., 1991, 1992; Manega, 1993; Blumenschine et al., 2003; Deino, 2012) and correlation of archeological finds (e.g., Leakey, 1971; Blumenschine et al., 2012a, 2012b; Clarke, 2012; Stanistreet, 2012; Stollhofen and Stanistreet, 2012; Habermann et al., 2016). It is therefore critical to accurately and uniquely identify tuff markers and their reworked equivalents across the Olduvai Basin, and to correlate them to their source volcanoes and specific activity periods (e.g., Walter et al., 1992; Mollel et al., 2008; McHenry et al., 2008; Stollhofen et al., 2008; Deino, 2012; Mollel and Swisher, 2012).

Based on consistent differences in glass and pheonocryst compositions of tuffs, McHenry (2005, 2012) broadly confirmed Hay's (1976) Bed I tephrostratigraphic framework by fingerprinting tuff markers, clarified previous miscorrelations, and established geochemical methods as an important tool to refine Olduvai tephrostratigraphy (see also McHenry et al., 2008, 2013, 2016). Feldspar and augite are significant juvenile tuff components that are commonly still preserved even within reworked or highly weathered pyroclastics, where volcanic

* Corresponding author. Tel.: +49 9131 8526066.
E-mail address: joerg.habermann@fau.de (J.M. Habermann).

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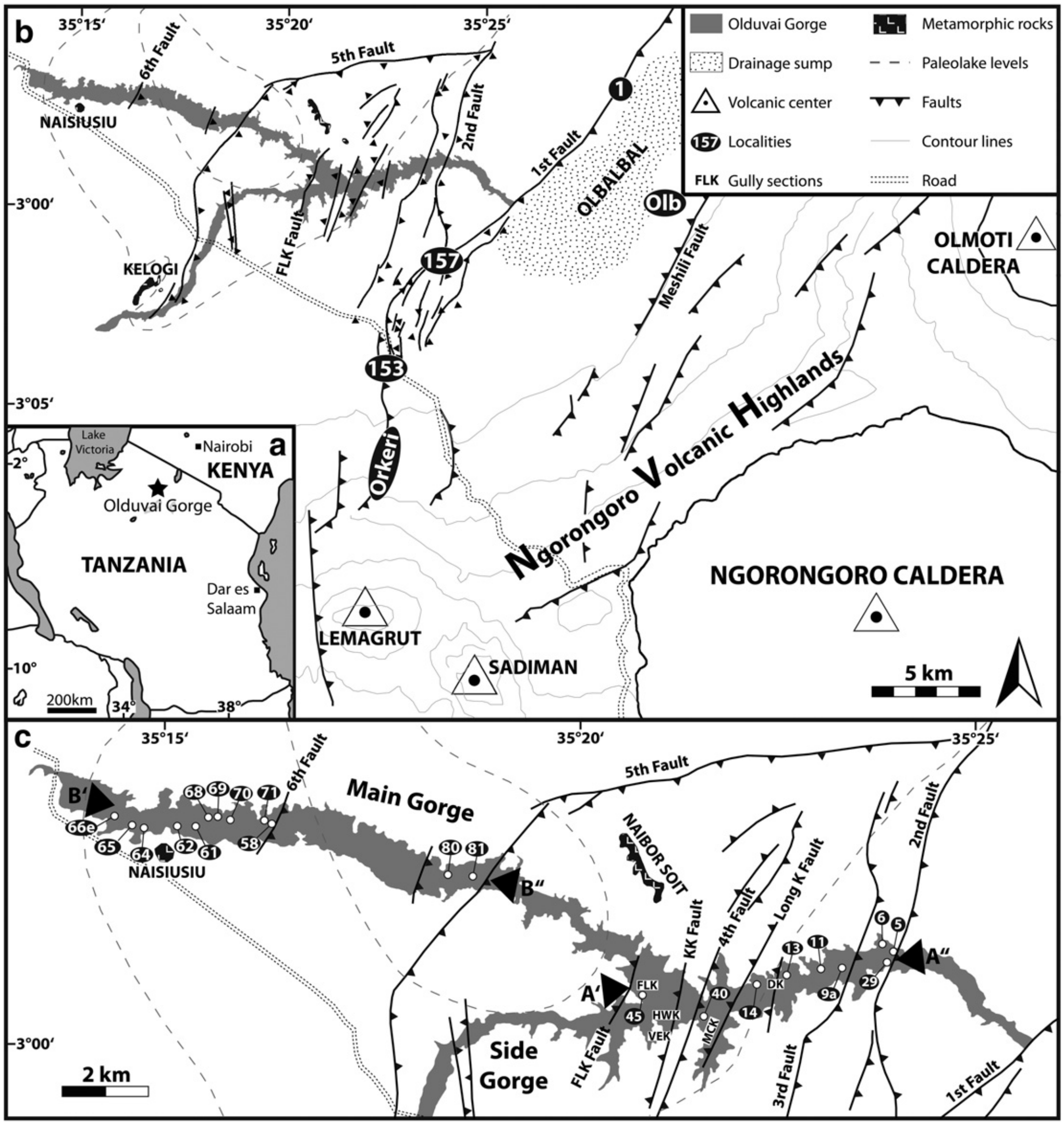

Fig. 1. (a) Location of Olduvai Gorge in northern Tanzania, (b) Olduvai Gorge map after Hay (1976) with major tectonic and volcanic features, and geological localities at the First Fault and Olbalbal, and (c) Main Gorge area with geological localities (Hay, 1976) and position of korongos (gully sections; Leakey, 1971) referred to in the text. Black triangles delimit endpoints of the profile line shown in Fig. 7 (A′ to A″) and Fig. 8 (B′ to B″).

glass is absent due to alteration. Detailed electron probe micro-analysis (EPMA) of these mineral phases is thus particularly useful for tuff fingerprinting (cf., McHenry, 2012). Until now discrimination of volcanic glass and mineral compositional data of Olduvai tuffs is primarily based on visual allocation of clusters in bivariate plots of selected major element oxides.

The Bed I tephrostratigraphic framework, and in particular the basal part of the less well explored western Olduvai Basin (Fig. 2) is the subject of investigation for this study. Here, our knowledge of stratigraphic relationships is hindered by significant faulting, lateral facies and thickness variations, and the presence of incision surfaces and stratigraphic gaps. Furthermore, the correlations of proximal ignimbrites and lavas at First Fault footwall exposures to medial and distal successions exposed within the gorge, as well as their source attributions, have remained conjectural (e.g., Hay, 1976; McHenry et al., 2008; Stollhofen and Stanistreet, 2012). To address this, the discriminative power of the chemical composition of the major juvenile mineral phases (augite, feldspar) from tuffs, volcaniclastic sandstones, siliciclastic units, and lava of Bed I are statistically evaluated using multivariate methods. Classical multivariate analyses [Principal Components Analysis (PCA), Discriminant Function Analysis (DFA)] are applied to analyze EPMA-derived mineral compositional data. These are well-established and widely used methods for a range of applications in geology (e.g., von Eynatten et al., 2003; Tolosana-Delgado, 2012; Krippner et al., 2014), particularly to discriminate and correlate tephras and tuffs over broad areas (e.g., Borchardt et al., 1971; Sarna-Wojcicki et al., 1979, 1984; Stokes and Lowe, 1988; Cronin et al., 1996; Tryon et al., 2011). These methods have advantage over conventional visual inspection of scatterplots by (a) allowing quantitative statements, (b) involving many variables, (c) easing reproducibility, and (d) providing statistical testing of results. Integrated with analysis of facies architecture, stratigraphic considerations, thin-section petrography, and whole-rock analysis, the methods applied aim to improve and refine the Bed I tephrostratigraphic framework on a basin-wide, fine-resolution scale, and to distinguish between Ngorongoro and Olmoti volcanoes in the nearby Ngorongoro Volcanic Highlands (NVH) as sources for Bed I tephrostratigraphic markers and volcaniclastic detritus.

2. Geological setting and Bed I stratigraphy

Olduvai Gorge (Fig. 1) exposes an ~100 m thick succession of the Pleistocene volcano-sedimentary Olduvai Basin-fill. The basin-fill has