
Abstract

Chapter 2 addresses correlation difficulties in Bed I that arise from major lateral facies changes combined with discontinuous exposure using the discriminative power of the chemical composition of major juvenile mineral phases (augite, anorthoclase, plagioclase) from tuffs, volcanoclastic sandstones, siliciclastic units, and lavas. These compositions, obtained from electron probe microanalysis, are statistically evaluated 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, which 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 confirm Ngorongoro Volcano as the primary source for Lower Bed I, whereas Upper Bed I sediment supply is mainly from Olmoti Volcano. Compositional similarities 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, suggest 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.

In Chapter 3, a detailed Lower Bed I facies architectural framework is established to gain a better understanding of the basin's early tectono-sedimentary evolution and to estimate the relative importance of factors (climatic vs. tectonic vs. volcanic) that influenced paleolake initiation, lake cycles, their periodicity, and paleoecology. During syn- and early inter-eruptive Naabi, CFCT, and Tuff IB phases, paleotransport patterns were triggered by voluminous sediment supply to the basin. The switch from Ngorongoro to Olmoti as the main volcanic source thus had profound impact on regional drainages and basin topography, as both volcanic sources developed separate, large-scale volcanoclastic fan aprons, prograding north- to northwestwards (Lower Bed I and Basalt Member) and westwards (Upper Bed I) into the Olduvai Basin. North- to northeastward-directed, tectono-morphologically-controlled paleotransport patterns, instead, prevailed when the rate of basin

subsidence exceeded sediment supply during less voluminous syn- and inter-eruptive periods, and imply fault activity throughout the deposition of Bed I. While the Naabi volcanic phase had profound, longer-term impact on regional landscapes and biota, the lethal effects of the subsequent CFCT volcanic phase were less severe and of restricted regional extent. The CFCT alluvial fan, fan delta, and shoreline/nearshore successions contain paleo-land surfaces that repeatedly supported ecologically productive habitats, including fully terrestrial wooded grassland, grassland/marshland, and sedgeland vegetation. Paleolake initiation in the Olduvai area around 2 Ma was fostered by the interaction between basin subsidence, reduced sediment supply, and increased moisture availability related to Earth's eccentricity and precession orbital cycles. The sedimentary record and paleoclimatic indicators provide evidence that also the Lower Bed I successions of the western basin contain records of precessional forcing during the Early Pleistocene. Alternating lacustrine, alluvial fan, and minor primary volcanic facies associations above the CFCT fan succession in the western basin record repeated shifts in prograding and retreating fan systems with time, occurring primarily in response to basin subsidence and repeated wet/dry cycle-driven lake-level fluctuations.

The discovery of ~2 Ma fossil rooted tree stumps in lowermost Lower Bed I from the western Olduvai Basin, reported in Chapter 4, provides the first direct, in situ, and to date oldest evidence of living trees at Olduvai Gorge. The tree relicts occur in an interval dominated by low-viscosity mass flow and braided fluvial sediments, deposited at the toe of a largely Ngorongoro Volcano-sourced volcanoclastic fan apron that comprised a widely spaced network of ephemeral braided streams draining northward into the Olduvai Basin. Preservation of the trees occurred through their engulfment by mass flows, post-mortem mold formation resulting from differential decay of woody tissues, and subsequent fluviially-related sediment infill, calcite precipitation, and cast formation. Rhizolith preservation was triggered by the interaction of root-induced organic and inorganic processes to form rhizcretionary calcareous root casts. Phytolith analyses imply a pronounced seasonality and indicate a wooded landscape with grasses, shrubs, and sedges growing nearby, comparable to the low, open riverine woodland (unit 4c) along the Garusi River and tributaries in the Laetoli area. Among the tree stump cluster were found outsized lithic clasts and those consisting of quartzite were identified as Oldowan stone tool artifacts. In the context of hominin activity, the identification of wooded grassland in association with nearby freshwater drainages and Oldowan artifacts significantly extends our paleoenvironmental purview on the basal parts of Lower Bed I, and highlights the hitherto underrated role of the yet poorly explored western Olduvai Gorge area as a potential ecologically attractive setting and habitat for early hominins.

Kurzfassung

In Kapitel 2 werden die durch laterale Fazieswechsel in Kombination mit diskontinuierlichen Aufschlussverhältnissen hervorgerufenen Korrelationsschwierigkeiten innerhalb des Bed I unter Zuhilfenahme der unterschiedlichen chemischen Zusammensetzung der häufigsten juvenilen Mineralphasen (Augit, Anorthoklas, Plagioklas) aus Tuffen, vulkaniklastischen Sandsteinen, siliziklastischen Einheiten und Laven untersucht. Mittels Hauptkomponenten- und Diskriminanzanalyse werden Mikrosondendaten statistisch ausgewertet, um Diskriminanzmodelle zu entwickeln, die es ermöglichen, die meisten der vulkanischen Einheiten in Bed I erfolgreich zu klassifizieren. Die unter Einbezug der Analysen aller untersuchten Minerale resultierenden Korrelationen bilden ein lateral und vertikal hochaufgelöstes, beckenweites chemostratigrafisches Gerüst, das mit dem bekannten geologischen Kontext im Einklang ist und welches die bisher verfügbaren geochemischen Datensätze erweitert und verfeinert. Die Korrelation proximaler Ignimbrite an der First Fault mit medialen und distalen Abfolgen des Lower Bed I des westlichen Beckens bestätigt Ngorongoro als vulkanische Hauptquelle für Lower Bed I. Sedimente des Upper Bed I hingegen stammen in erster Linie vom Olmoti Vulkan. Ähnlichkeiten der chemischen Fingerabdrücke von Einzelkristallen des Tuff IA, der Bed I Laven und der Mafic Tuffs II und III weisen zusammen mit den in nördlicher und nordwestlicher Richtung abnehmenden Mächtigkeiten der Laven auf Ngorongoro als gemeinsame vulkanische Quelle hin. Gegenüber visueller Vergleiche bivariater Diagramme in früheren Arbeiten stellen die in dieser Arbeit verwendeten statistischen Techniken eine Verbesserung dar, da kompositionelle Zugehörigkeiten statistisch ausgewertet werden.

In Kapitel 3 wird ein detailliertes Faziesgerüst des Lower Bed I herausgearbeitet, das zum besseren Verständnis der frühen tektono-sedimentären Entwicklung des Beckens beiträgt und es ermöglicht, die Relevanz diverser Faktoren (klimatisch vs. tektonisch vs. vulkanisch), welche die Etablierung des Paläosees, seine Seezyklen, ihre Periodizität und die Paläoökologie beeinflussten, abzuschätzen. Während Syn- und frühen Intereruptionsphasen des Naabi, CFCT und Tuff IB Intervalls wurden

Paläotransportrichtungen durch die massive Sedimentzufuhr ins Becken gesteuert. Der Liefergebietsumschwung von Ngorongoro zu Olmoti als dominante vulkanische Quelle führte zu grundlegenden Veränderungen der regionalen Drainagesysteme sowie der Beckentopografie, da beide Vulkane eigene, voneinander getrennte, großräumige vulkaniklastische Fächer bildeten, welche im Fall des Lower Bed I und des Basalt Member in nord- bis nordwestliche Richtung und während des Upper Bed I in Richtung Westen in das Olduvai Becken progradierten. Während niedrig-voluminöser Syn- und Intereruptionsphasen hingegen, in denen Beckensubsidenzraten die Raten der Sedimentzufuhr überstiegen, waren nord- bis nordöstlich gerichtete, tektono-morphologisch kontrollierte Paläotransportrichtungen vorherrschend. Die vulkanische Phase des Naabi Intervalls hatte tiefgreifende und verheerende Auswirkungen auf die Region und auf die in ihr beheimateten Lebewesen, während die Folgen der jüngeren vulkanischen Phase des CFCT Intervalls weniger gravierend ausfielen. Die alluvialen Fächer-, Delta- und Seenrand-Faziesbereiche der CFCT Abfolge brachten wiederholt ökologisch produktive Habitate hervor, in denen terrestrisch bewaldete Grasland-, Grasland-/Marschland-, sowie Schilflandvegetation dominierend waren. Die Etablierung des Paläosees im Olduvai Gebiet vor etwa 2 Ma war begünstigt durch das Zusammenspiel zwischen Beckensubsidenz, reduzierter Sedimentzufuhr und durch Exzentrizitäts- und Präzessionszyklen beeinflussten, erhöhtem Niederschlag. Sedimentologische und paläoklimatische Indikatoren deuten darauf hin, dass auch die Lower Bed I Abfolge Hinweise auf präzessionsgesteuerte Sedimentationsmuster während des frühen Pleistozäns aufweist. Wechsellagerung von lakustrinen, alluvialen und untergeordnet primär-vulkanischen Faziesassoziationen im Hangenden der CFCT Abfolge im westlichen Becken spiegeln wiederholende Wechsel in pro- und retrogradierenden Fächersystemen über die Zeit hinweg wieder, die in erster Linie in Folge von Beckensubsidenz und Seespiegelschwankungen aufgrund orbital gesteuerter Feucht-Trocken Zyklen auftraten.

Kapitel 4 behandelt die Entdeckung 2 Ma alter, fossiler Baumstümpfe im untersten Lower Bed I des westlichen Olduvai Beckens, welche die ersten direkten, in situ und bis dato ältesten Beweise für ein bewaldetes Olduvai Gebiet liefern. Die Baumrelikte treten am Fuße eines von Ngorongoro gespeisten, vulkaniklastischen Fächersystems auf, welches ein weitläufiges Netzwerk ephemerer Flüsse an seiner Oberfläche aufwies und von niedrig-viskosen Massentransport- und fluviatilen Ablagerungen verflochtener Flusssysteme dominiert ist. Zur Erhaltung der Bäume beigetragen haben deren Verschüttung durch Schlammströme, post-mortale Hohlrumbildung durch differentiellen Zerfall des organischen Materials und die darauf folgende Verfüllung des Hohlraums mit Sediment, Kalzitausfällung und Steinkernbildung. Die Erhaltung von kalkig-konkretionären Rhizolithen war

durch Wechselwirkungen zwischen wurzelspezifisch-organischen und anorganischen Prozessen gesteuert. Phytolith Analysen lassen auf deutliche Saisonalität und eine bewaldete Landschaft mit assoziierten Gräsern, Büschen und Schilf schließen, die vergleichbar mit der niedrig- und offenbewaldeten Flusslandschaft (unit 4c) entlang des Garusi Flusses und seiner Zuflüsse in der Laetoli Gegend ist. Im Umfeld der Baumstümpfe wurden unverhältnismäßig große Gesteinsbruchstücke gefunden. Diejenigen, die aus Quarzit bestehen, konnten als Steinwerkzeugartefakte der Oldowan Kultur identifiziert werden. Im Kontext mit Hominidenaktivitäten erweitert die Identifikation von bewaldeten Graslandschaften zusammen mit dem Auftreten von Süßwasserflüssen unser Verständnis der Paläoumwelt bis in die basalen Abschnitte des Lower Bed I maßgeblich und betont die bisher unterschätzte Rolle des nach wie vor schlecht untersuchten westlichen Olduvai Beckens als potentiell ökologisch attraktives Habitat für frühe Hominiden.

Statement of candidate

I certify that the work in this thesis entitled “Pleistocene volcanism of Bed I, Olduvai Gorge, Tanzania: chemostratigraphy, sedimentology, and paleoecology” has previously not been submitted for any degree nor has it been submitted as part of requirements for a degree to any other university or institution other than the Friedrich-Alexander-Universität Erlangen-Nürnberg. I also certify that the thesis is a new, original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged. Additionally, I certify that all information sources and literature used are indicated in the thesis. This thesis contains material that has been published or accepted for publication in peer-reviewed ISI-journals as follows:

Chapter 2 is based on the manuscript “**Discrimination, correlation, and provenance of Bed I tephrostratigraphic markers, Olduvai Gorge, Tanzania, based on multivariate analyses of phenocryst compositions**” that has been published in *Sedimentary Geology* in April 2016. My contribution to this publication comprised the majority of section measurements, of sampling and analytical work, data analyses and interpretation, and of writing and illustrating the text, resulting in a total contribution of about 90%. *Impact factor: 2.665 (2014/2015)*.

Chapter 4 is based on the manuscript “**In situ ~2.0 Ma trees discovered as fossil rooted stumps, lowermost Bed I, Olduvai Gorge, Tanzania**” that has been published in *Journal of Human Evolution* in January 2016. My contribution to this publication involved all the sampling and analytical work apart from macrobotanical, phytolith, and artifact analysis. I also did the sedimentological logging and interpretation, artwork, and wrote the majority of the text, resulting in a total contribution of about 70%. *Impact factor: 3.733 (2014/2015)*.

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Conference abstracts

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