High-resolution UAV map reveals erosional patterns and changing topography at Isimila, Tanzania

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Abstract

Isimila is a Middle Pleistocene archaeological site located in southern Tanzania. The site is known for large surface assemblages of later Acheulean lithics such as hand axes, cleavers, scrapers, and cores. While hominin remains have yet to be discovered at the site, Isimila offers a unique window into Middle Pleistocene *Homo* behavior. Although Isimila has been studied extensively, the last published map of the site and surrounding area was made available in the 1970s. Here, we present an updated high-resolution map of Isimila. Data for the map were collected during aerial survey with an uncrewed/unmanned aerial vehicle (UAV). With this map, we identify new archaeological localities, erosional patterns, newly exposed geological features, and changes in site topography. The map reveals patterns of stone tool and raw material distribution that may support previous hypotheses of raw material transport into the area by hominins. This open-access map establishes a baseline for tracking changes to site topography in the future and serves as a unique tool to enable collaboration between researchers, museum personnel, and local populations to better conserve Isimila.

Keywords: Middle Pleistocene East Africa, Acheulean/Acheulian, site topography, Uncrewed/unmanned aerial vehicle, drone map

Introduction

Isimila is located in the central highlands of southern Tanzania on the Iringa Plateau (Figure 1) and has been dated to between 330-220kya.[1] The site was first recognized for its archaeological potential by D.A. Maclennan in 1951.[2,3] Excavation and survey at Isimila have revealed large quantities of later Acheulean lithics, including large surface assemblages and *in situ* "occupation floors".[3–5] The first surface collection from Isimila comprised 26 stone tools, including hand axes, cleavers, a backed blade, and a Levallois core.[2] In 1954, F. Clark Howell conducted a survey of the IKS basin and collected at least 90 hand axes and 50 cleavers, which were described as fresh and unrolled, suggesting they had only recently eroded out of their primary context.[3] Howell[3] noted substantial variation in the "workmanship," technique, and raw materials in the lithic assemblages, which were proposed to represent both living floors and factory sites of the Late Acheulean.

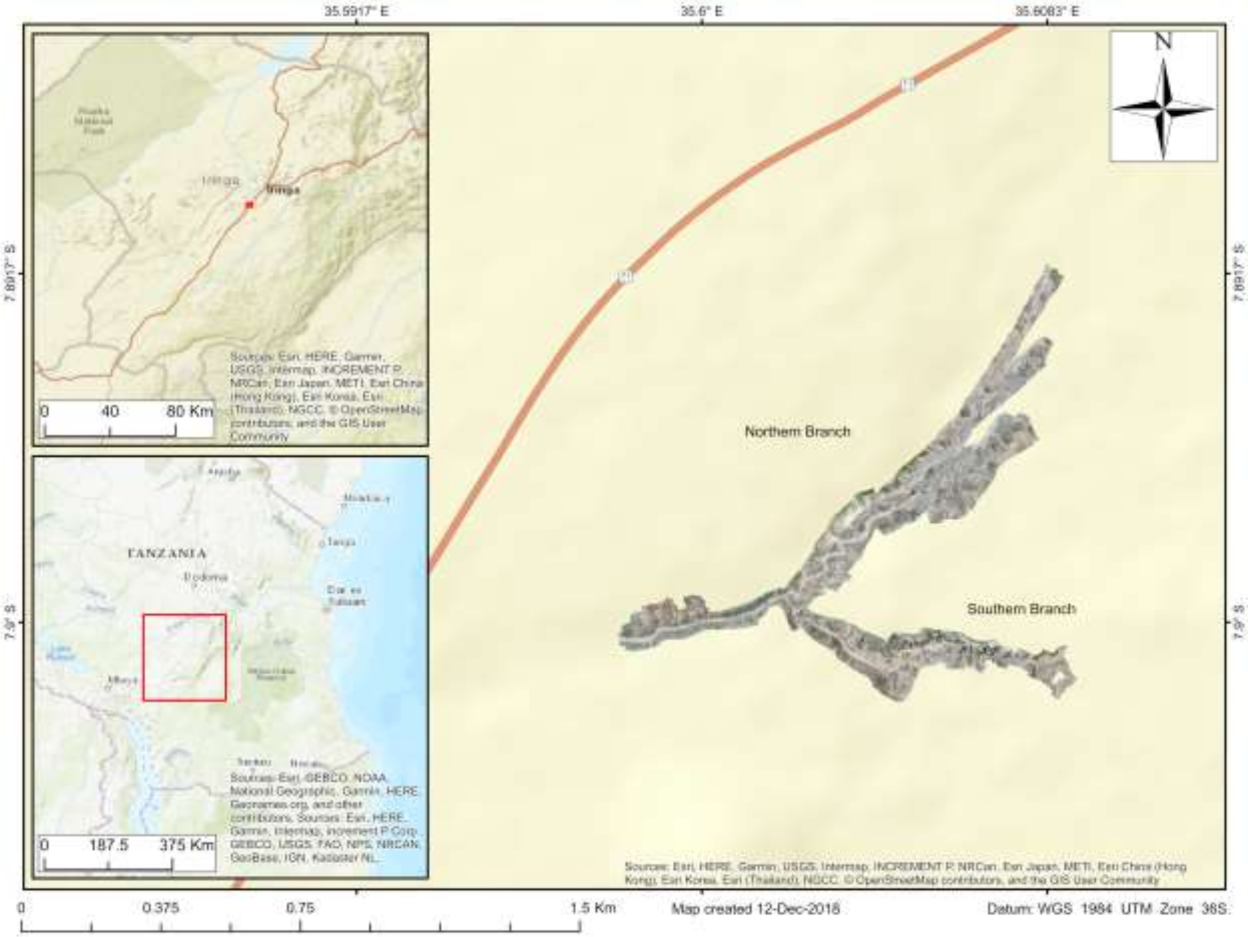
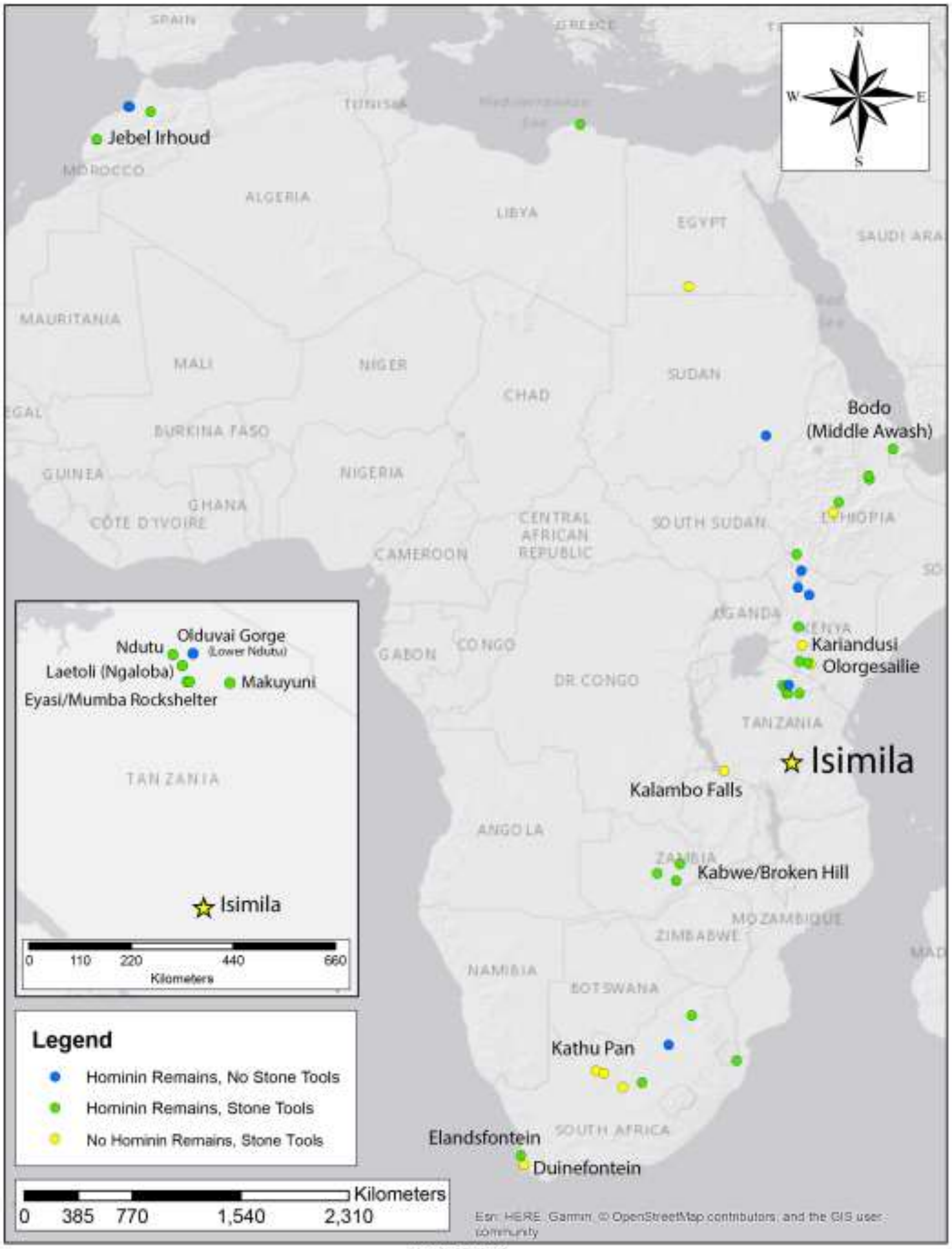


Figure 1. Map showing the location of Isimila within the Iringa plateau of southern Tanzania. The two primary sections of the korongo are labeled Northern and Southern Branch, following Howell et al.[4]

The Isimila IKS consists of northern and southern branches, with a stream running from north to south through the valley. Isimila preserves five layers of consolidated sands numbered from the top (Sands 1) to base layer (Sands 5) separated by layers of gray-green silty clay and overlying an early Pleistocene claycrete. The lower beds (Sands 3, 4, 5) are thick and largely continuous throughout the northern branch of the Korongo, while the upper beds (Sands 1 and 2) are thinner and present in only the northernmost parts of the northern branch.[4] The sediments of Isimila are thought to have been deposited during a period of drying during the Middle Pleistocene.[4] The deposition of sandy layers followed by silty clay in the Isimila Formation have been attributed to a cyclic depositional environment by various authors. However, the reconstructions of this environment have differed. The paleoenvironment of Isimila has been described as lacustrine[6], a shallow pond with some drainage out the northern end of the korongo[4], and riverine[7].

Excavations in Sands 1 revealed rich concentrations of stone tools throughout, suggesting a dense and largely continuous occupation by Middle Pleistocene *Homo*.[4] “Crudely finished” tools were interspersed with finely finished hand axes in Sands 1; this has been hypothesized to reflect behavioral flexibility in hominins in response to differing environmental conditions.[8: 351] Two occupation floors (H20 and J12 trenches) were identified in Sands 2 with a lower density of artifacts compared to Sands 1 and 3, suggesting sparse occupation by hominins.[4] Excavations in Sands 3 revealed a generalized dense occupation, including three occupation floors (trenches H15, K18, K19)(4). Excavations in Sands 4 and 5 revealed a number of small implements and the only notable fauna from the site.[4,5,9]

Based on similarities in their chronologies and lithic typologies, Isimila has been compared to Olorgesailie and Kariandusi in Kenya, as well as to Kalambo Falls in Zambia (Figure 2).[4,5,8,10] Recent discoveries at Olorgesailie have revealed the earliest known MSA artifacts in east Africa[11–13], roughly contemporaneous with the oldest age estimates for Isimila (~330kya)[1]. Isimila may provide a window into the terminal Acheulean at the Acheulean-MSA transition.[11] Within Tanzania, the lower beds of Isimila (Sands 3-5) are roughly contemporaneous with the Ngaloba Beds at Laetoli[14], which yielded Laetoli Hominid 18 (LH 18), a partial *Homo* cranium[15,16]. While no hominin remains have been found at Isimila, the region preserves an extensive archaeological sequence ranging from the Middle Pleistocene to the Iron Age.[17] As such, Isimila and the broader region provide a unique window into hominin behavior, ecology, and paleoenvironments at a critical time period in human evolution and more recent human history.



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Datum: WGS 1984. Terrain: http://www.naturalearthdata.com/downloads/10m-shaded-relief/10m-shaded-relief-basic/

Figure 2. Map of Middle Pleistocene sites in Africa that are either contemporaneous to Isimila or contain similar lithic type/distribution: Blue points indicate sites with hominin remains with no

stone tools, green points indicate sites with hominin remains and stone tools, yellow points indicate sites with stone tools with no hominin remains.[30]

Methods

A DJI Phantom 4 Pro+ quadcopter equipped with an onboard high-definition camera optimized for aerial image capture (i.e., a wide-angle, non-fisheye lens; Table 1) was used for aerial survey and data capture in July 2017. Previously published maps and preliminary pedestrian survey were used to plan flight paths (Supplemental Figure 1). Start and end points were recorded on the ground using a handheld GPS unit. The end point of each flight was used as the starting point for each subsequent flight.

Table 1: UAV Camera Specifications.

Sensor Size (mm)	**Focal Length (mm)**	**Field of View**	**Image Size (pixels)**	**Effective Pixels**
13.2 x 8mm	8.8mm / 24mm (35mm equivalent)	84º	4096 x 2160	20 Megapixels

Survey sessions were limited by UAV battery life to 15-20 minutes per flight, with an average flight velocity of 4 m/s. Flights were conducted using an altitude of 40 m to maximize the camera’s field of view without compromising detail (Table 2). Flights at lower altitudes were also conducted to capture areas of interest in more detail. In total, 12 survey sessions were conducted at two different altitudes: six sessions at 40 m, and six sessions at lower altitudes ranging from 10-20 m.

Table 2: Image Data Capture Parameters.

Flight Altitude	**Average Flight Velocity**	**Ground Sample Distance**	**Image Footprint**	**Total Surface Area**
40 m	4 m/s	1.6 cm/pixel	60 m x 31 m	1.533 km^2

The UAV was piloted manually using its native software (DJI GO 4v. 4.1.18, DJI, 2017) to set the altitude, velocity, camera positioning, capture parameters, and monitor the flight path during data capture. Live video tracking was used to capture images during flight. The video footage from the UAV was reviewed in the field and used to identify geologic features, sedimentary changes, and potential areas of interest for pedestrian survey.

Still photos were extracted from video obtained during flight sessions. GPS coordinates and altitude data tracked by the UAV were embedded in metadata for each still image. Blurry or out of focus images were manually removed. Photos were then imported into Agisoft Photoscan Pro (v 1.4.1, Agisoft, 2018) (for processing parameters and workflow, see Supplemental File 1). Initially, photos were aligned to create a sparse point cloud of tie points. A dense point cloud was then created to reconstruct the three-dimensional parameters of the coverage area (Supplemental Figure 2).

The dense point cloud (Table 3) was manually edited to remove errant points, areas of heavy noise, and unnecessary coverage outside of the basin. A digital elevation model (DEM) (Figure 2) was created from the dense point and used to create the top-down orthomosaic (Figure 3, Table 4), both of which were then imported into ArcMap (v. 10.5, ESRI, 2016), where they were cleaned, and legends were added. A color ramp was applied to better demonstrate elevation changes in the DEM. A hill shade of z-value 1 was added to enhance relief appearance in the Korongo system. An overlay map was created to compare site topography in 1962[4] and 2017 (Figure 4). The orthomosaic was digitally aligned to the hand drawn map from Howell et al.[4] using GNU Image Manipulation Program (v. 2.10.4, GIMP, 2018). Trenches and pits were cross-referenced and plotted using approximate locations.

Table 3: Photogrammetric data parameters (see Supp. Table 1 for expanded parameters)

Photo Total	**Point Cloud Total**	**Camera Pixel Size (mm)**	**RMS reprojection error**
4,493	335,168,805	0.0025	0.21 (0.095 pixels)

Table 4: Orthomosaic Summary Data (see Supp. Table 1 for expanded data)

Coverage Area	**Pixel Size**	**Full Size Dimensions (pixels)**	**Effective Resolution**

1.5 km^2	1.31 cm/pixel	100,505 x 95,235	10.9 Gigapixels

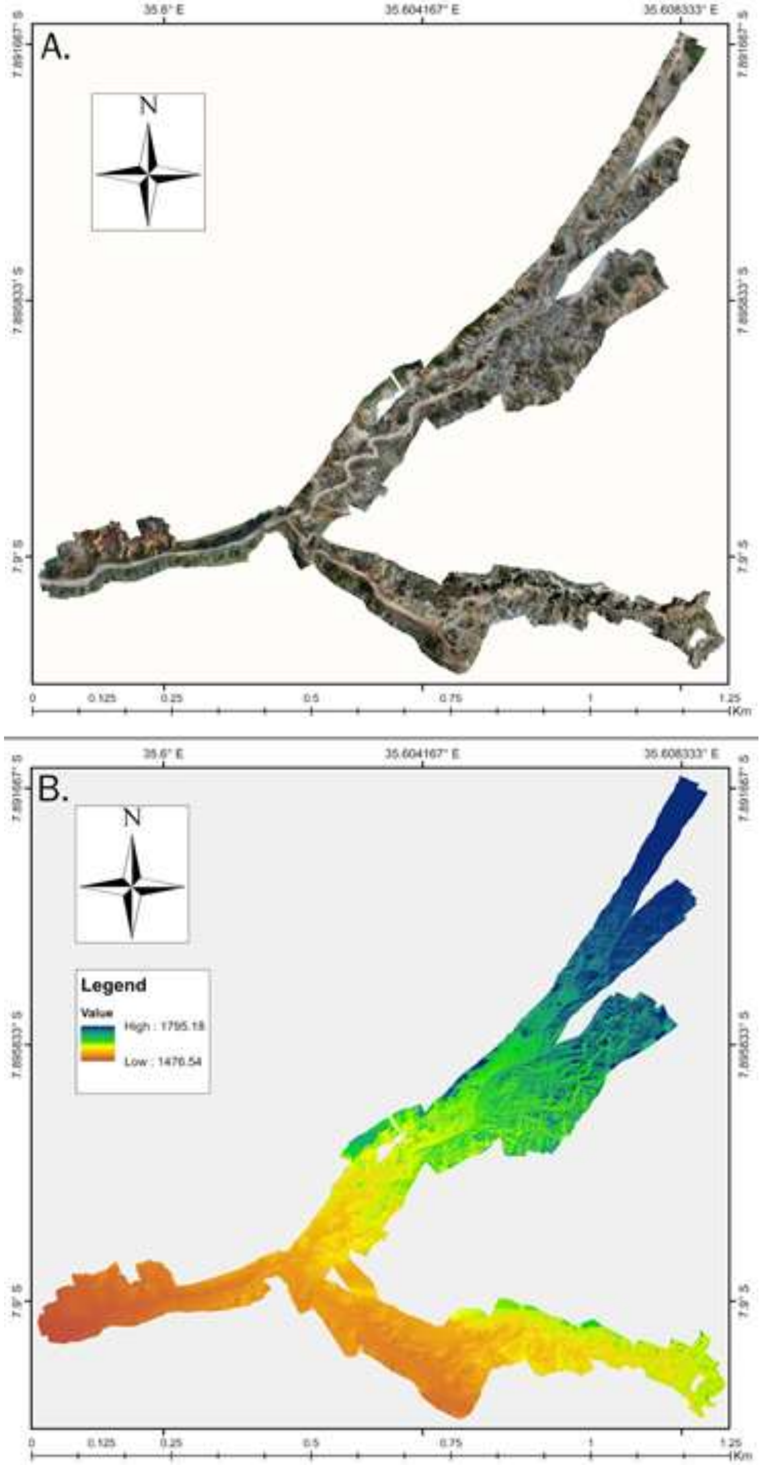

Figure 3: A) Orthomosaic of Isimila. B) DEM of Isimila.

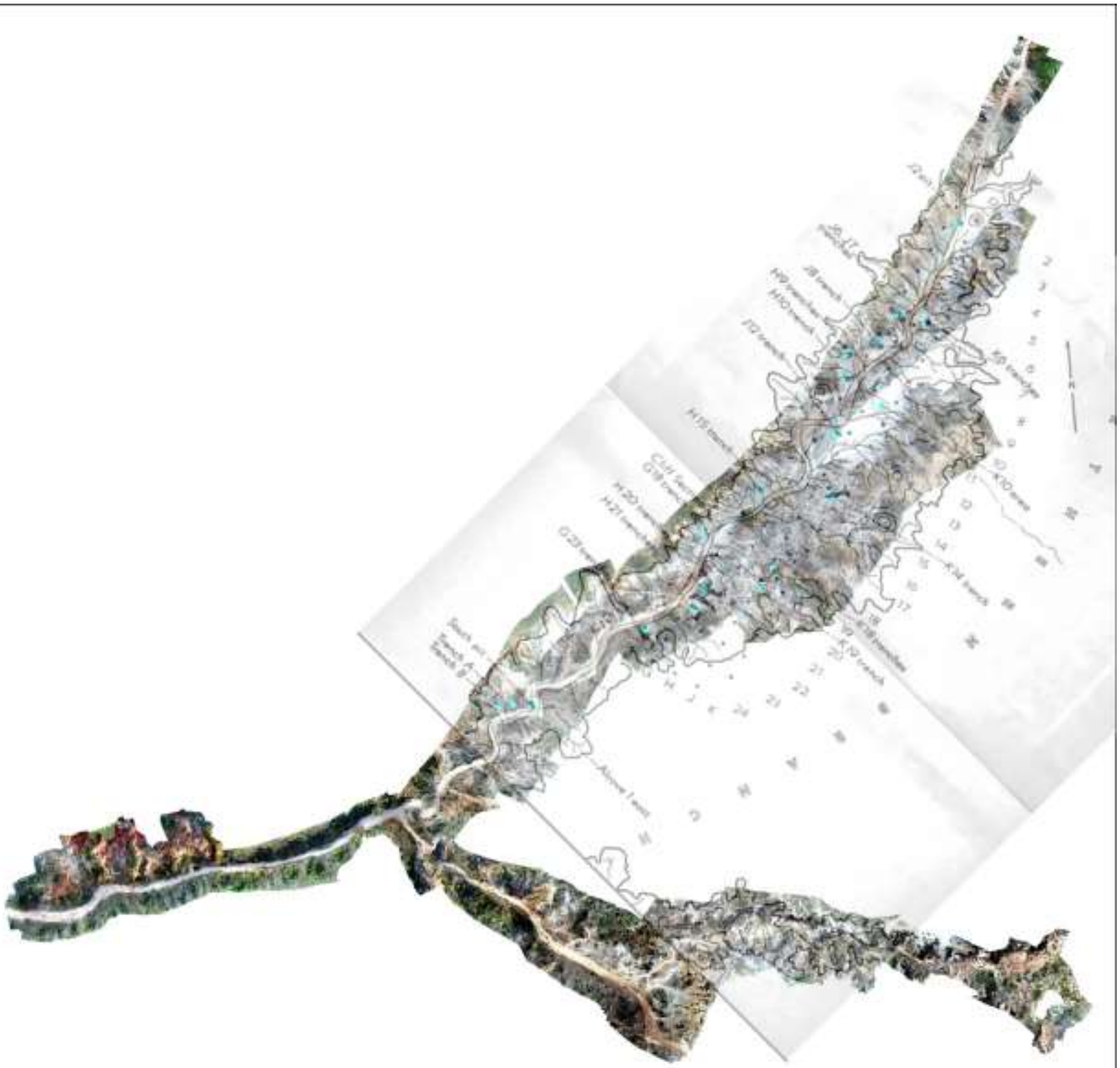

Figure 4: Orthomosaic with map from Howell et al.[4] excavation map overlay and approximate locations of previous trenches marked in blue.

Results

The overlaid excavation map (Figure 3) reveals shifts in the course of the Isimila stream. A horseshoe-shaped meander in the northern branch which appeared on the original map has been largely eroded away. The previous course of the stream now appears as a large sandy bank on the western side of the northern branch. A new meander is present to the north, cutting directly into exposed tool-bearing beds. Based on comparisons with the original excavation maps, the new meander may be washing over the location of the 1959 H10 trench (Figure 5).[4]

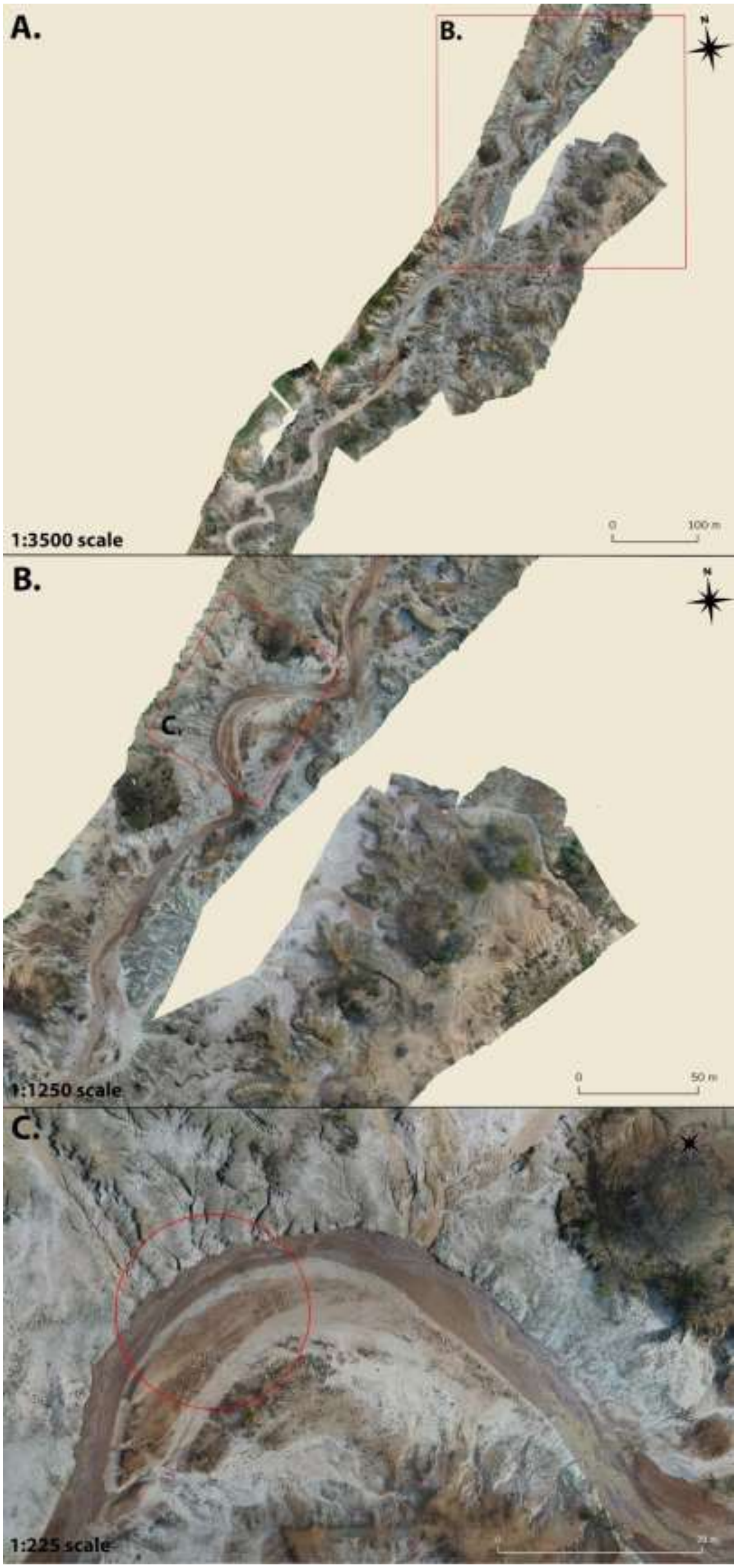
A.
B.
N
1:3500 scale
0
100 m
B.
C.
N
1:1250 scale
0
50 m
C.
1:225 scale
0
20 m

Figure 5. A) Location within northern branch of recent meander outlined in red. B) Inset of location of recent meander. C) Detail of recent meander with approximate location of H10[4] trench circled in red.

The aerial survey revealed undocumented sediment exposures and geological differences within the basin. In the northern branch, an unexcavated area of dark, ferrous sediments were found to have substantial lithic deposits (Supplemental Figure 3A, B, C). Additionally, a new region of lithic-bearing red sediments dissimilar to those in the central part of the Korongo was identified approximately 200 m south of the southernmost extent of the previous maps (Supplemental Figure 4).

The majority of stone tool surface assemblages are located in the central northern branch of the Korongo (Supplemental Figure 5). The large concentrations of lithics and debris in this area may be a result of significant erosion from the Isimila stream. While surface assemblages are present outside of this potential floodplain, they cover smaller surface areas. Most previous excavation trenches are located in areas where there are dense accumulations on the surface today. However, the areas of trenches H20 and K14 have fewer lithics on the surface today, which may be a result of artifacts from these areas being collected during previous excavations (Supplemental Figure 6).

Discussion

UAVs provide a higher resolution alternative to satellite imagery and are more versatile than traditional aerial photogrammetry or mapping.[18] As demonstrated by recent work using UAVs at Olduvai Gorge, Tanzania[19] and in the Turkana Basin, Kenya[20], UAV survey and mapping enhances research by revealing new sites and areas of geological and archaeological interest. The high-resolution UAV map of Isimila presented here enables collaborative efforts between research teams to help answer future questions about the site, including aspects of hominin behavior and its interaction with a shifting paleoenvironment. Using UAV data, we identified significant changes to surface topography at Isimila over the last half century, including shifts in the course of the Isimila stream and new perspective on the distribution of stone tools and raw materials.

Howell et al.[4] proposed the close association of stone tools to surrounding debris represented short-distance raw material transport. The orthomosaic presented here shows dense clusters of raw material and artifacts, possibly supporting the hypothesis of raw material transport into the Korongo by Middle Pleistocene *Homo*. This pattern of association is similar to those found at Olorgesailie and Kalambo Falls.[4] However, the association of artifacts and raw material in clustered surface assemblages in the heavily-eroded central portion of the northern branch may be the result of erosional processes. Additionally, new lithic-bearing deposits were identified in previously unmapped southern exposures. If the center of Isimila, located in the northern branch, was primarily a manufacturing floor next to a reliable water source, inhabited sites may be located on the periphery, possibly in the new southern exposures identified here.

Seasonal erosion and changes in the course of the Isimila stream over the last 50 years may have washed away unexcavated lithic deposits. This highlights the need for long-term repeated aerial survey and mapping. Future UAV mapping has the potential to further examine the effects of seasonal erosion and the resulting changes to site topography. Moreover, understanding the effects of natural and anthropogenic change is essential for site conservation. While Tanzania has a lengthy history of issues surrounding archaeological conservation and management[21–25], UAV mapping has yet to be used as part of a management plan. Although Isimila is a managed archaeological site, conservation risks from human activity, erosion, and archaeological excavation persist[25,26]. Annual UAV mapping and collaborative efforts with researchers and the local communities would advance research and conservation efforts in that any changes within the IKS particularly in terms of sediment starving or erosions could easily be detected and mitigated.

Conclusions

Isimila is the subject of renewed research, including excavation and extensive survey, by multiple independent research teams.[27–30] The open access orthomosaic map presented in this paper represents a unique tool for coordinating research between teams working in different parts of the site. The open access dataset presented includes a DEM, orthomosaic, previous excavation overlay map and supplemental material (https://doi.org/10.5281/zenodo.1470770). This work provides a baseline for future work and conservation efforts at Isimila. Additionally, we identify major changes to site topography, erosional effects, and new archaeological deposits. In a collaborative effort, we ask fellow researchers to submit GPS data of excavation, surface collection, and areas of geologic interest to a separate open-access orthomosaic. This map (https://doi.org/10.5281/zenodo.1470781) will be updated with new data submissions and will serve as an open access research tool.

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