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Abstract

The Karonga District of northern Malawi has an extensive Stone Age archaeological record, primarily represented by stone artefacts that occur in both superficial and buried contexts. Work conducted in the 1960s provided initial documentation of this record. Some of this was presented in summary form in a small number of publications. However, most data were restricted to unpublished field notes, maps, and other static or largely inaccessible formats. GIS has been an essential tool for bringing together these diverse datasets in a digital format to facilitate integration of new research and promote re-investigation of old sites. Examples from both the regional and site scale demonstrate how old data have been combined with recent survey and excavation data to document, analyse, interpret, and archive current knowledge about the rich Stone Age record of northern Malawi. A significant result from this approach has been the suggested reinterpretation of the Mwanganda's Village Site.

1. Introduction

The Karonga District of northern Malawi boasts a rich Stone Age archaeological record, including alluvial sand and cobble deposits that contain large quantities of artefacts diagnostic of the Middle and Later Stone Ages. The majority of archaeological work on the early prehistory of Malawi was undertaken by J.D. Clark and colleagues in the 1960s and 1970s [1–6], with only occasional reports since [7–9]. Although nearly all of this work has taken place in Karonga, little remains known about the technology, chronology, or spatial

distribution of the archaeological materials. This is for two reasons. First, until recently these deposits had received no systematic investigation using modern approaches to data acquisition and analysis. Second, most data from the original work are restricted to unpublished field notes, maps, and other static or largely inaccessible formats.

In 2009 the Malawi Earlier-Middle Stone Age Project (MEMSAP) was initiated with the goal of building a long chronology of Stone Age behaviour in northern Malawi [10] and linking that record to palaeoenvironmental data from nearby lake sediment cores [11–14]. Essential components to this work are the recovery of well-dated artefact assemblages and development of a detailed understanding of landscape evolution in the study area. GIS has been an essential tool in these multiscalar investigations, but it has served an additional purpose within the specific context of the history of Stone Age research in Malawi. Namely, it has facilitated the integration of new research with published and unpublished information from sites last investigated several decades ago. The case study of the Mwanganda's Village site will illustrate this point.

2. Background

2.1. Theoretical context

Archaeologists have identified the African Middle Stone Age (MSA - from at least 285 to 30 thousand years ago) as the time when many of the defining behaviours of modern *Homo sapiens* first appeared: symbolism, social complexity, technological complexity using a variety of raw materials, and flexible foraging strategies [15–28]. Changes in demography and sociality have been argued to have been essential to the emergence of these traits [29], with models showing that cultural innovation is most likely to appear and be maintained in larger, well-connected populations [30–32]. Fluctuations in resource availability would have had one of the most immediate impacts on the demographic parameters of early human populations. Thus, understanding changes in human landscape and resource use during the MSA is important to understanding the origins of modern human behaviour.

A series of sediment cores from Lake Malawi have shown that central Africa experienced extreme fluctuations in precipitation, lake levels, salinity, and terrestrial environmental response over the course of the Late Pleistocene [11, 13, 14, 33]. During periods of "megadrought" between ca. 75–135 ka, lake surface area was reduced by as much as 95%, transforming much of the Lake Malawi

watershed into a cool semidesert and exposing human populations to episodes of significant resource stress [14]. MEMSAP was developed in response to the opportunity to pair this palaeoenvironmental record with the Stone Age archaeological record available within 5km of the modern lakeshore. This has required working at both the site and landscape scales to collect terrestrial proxy palaeoenvironmental information, develop stratigraphic and geochronologic control, and recover past evidence of Stone Age - and especially MSA - behaviour. Linking these different scales and types of analyses has demanded the amalgamation, storage, and analysis of large quantities of spatial data from disparate datasets. Thus, the practical deployment of MEMSAP has relied heavily on GIS applications.

2.2. Geologic and geographic context

The Karonga Basin comprises the hanging-wall of the Livingstone Fault, with a strip of Quaternary sediments bordering Lake Malawi along a ca. 140km stretch from the Chiweta Escarpment (south) to the Tanzania border (north) [34]. On the steep, eastern margin of the basin (within the modern political boundaries of Tanzania and Mozambique), high slope and local relief characterise the bare-bedrock, mountainous landscape. The western lakeshore landscape (within northern Malawi) is comprised of mostly gently-sloping and incised surfaces. The Middle-to-Late Pleistocene Chitimwe Beds outcrop along this stretch in areas of up to 20 km², unconformably overlying Pliocene lacustrine/near-shore sediments known as the Chiwondo Beds [35].

The Chitimwe Beds are remnants of a dissected alluvial fan originating in the western highlands [36]. They cover a sum area of approximately 83 km² and all lie within 10 km of the modern Lake Malawi shoreline (at 450 metres above sea level, or MASL). They include both sandy facies and coarser cobble facies, both of which contain stone artefacts. The immediate sediment sources for the alluvial fan system are likely an area of medium relief (no higher than 1100 MASL) that lies between 3–25 km west of the study sites, although further west the terrain can achieve altitudes of up to 2600 MASL.

Almost all of the Middle to Late Pleistocene deposits are contained within the Karonga District of northern Malawi, which encompasses a land area of 3757 km² [37]. Three large, extensive river catchments define the northern landscape. These catchments contain large quartzite cobbles of high quality for stone tool manufacture, especially in patches along the coastal plain. Other raw materials contained within the cobbles are quartz, silcrete, fossil wood, and chert. The case studies reported here derive from sites contained within the North Rukuru catchment, which is the southernmost one of these major rivers (Figure 1).

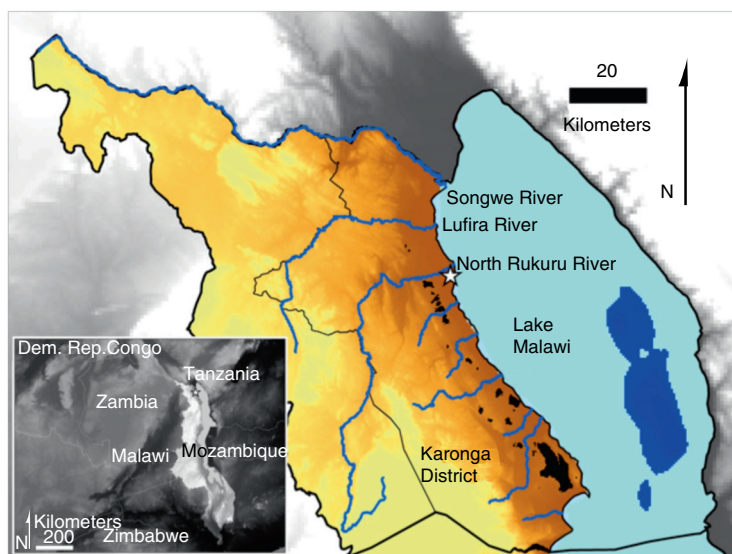
2.3. Previous research

Archaeological research in Malawi began slowly, with most work prior to the 1950s limited to antiquarian collections or anecdotal observations [38–40]. The presence of Stone Age artefacts in northernmost Malawi was first published by Dixey [41], who recovered stone tools from the Chitimwe Beds during his initial geological mapping of the area [42, 43]. However, no further investigations of these deposits were made until Clark's work in the 1960s [1, 4], when he reported the sites of Mwanganda's Village [6] and Chaminade IA [44] near the modern town of Karonga. In the 1970s Kaufulu revisited the area, and Mwanganda's Village in particular, to better understand the depositional history of the site [8, 45]. He later [9] described Stone Age artefacts found in situ in older deposits, although this has been contested [7]. Thus, until recently the majority of work on the Stone Age deposits of northernmost Malawi was conducted in the 1960s and 1970s, and has been presented in summary form in only a small number of publications.

After initial reconnaissance work in 2009, the first MEMSAP season took place in 2010 with the excavation of Karonga Airport Site, which had not previously been studied in detail [10]. Additional fieldwork in 2011, 2012, and 2013 has resulted in the major excavation of six more sites and the emplacement of test pits across an area of approximately 9 km² to the west of the modern town of Karonga and near the present-day location of the Chaminade Secondary School (Figure 2). These test pits have revealed that most artefacts are eroding from shoulders along 'islands' of remnant Chitimwe Beds.

The majority of diagnostic material is MSA in type, with younger overlying deposits normally containing undifferentiated material but

Figure 1. The study region in its geographic context (inset), showing the three major northern rivers. The Karonga District is shown with a faint black line and Karonga town is represented with a star. Lake Malawi is shown in light blue at its modern level and the dark blue shading is its location during maximum lowstands over the course of the Late Pleistocene. The 'islands' of Chitimwe Beds are solid black polygons.



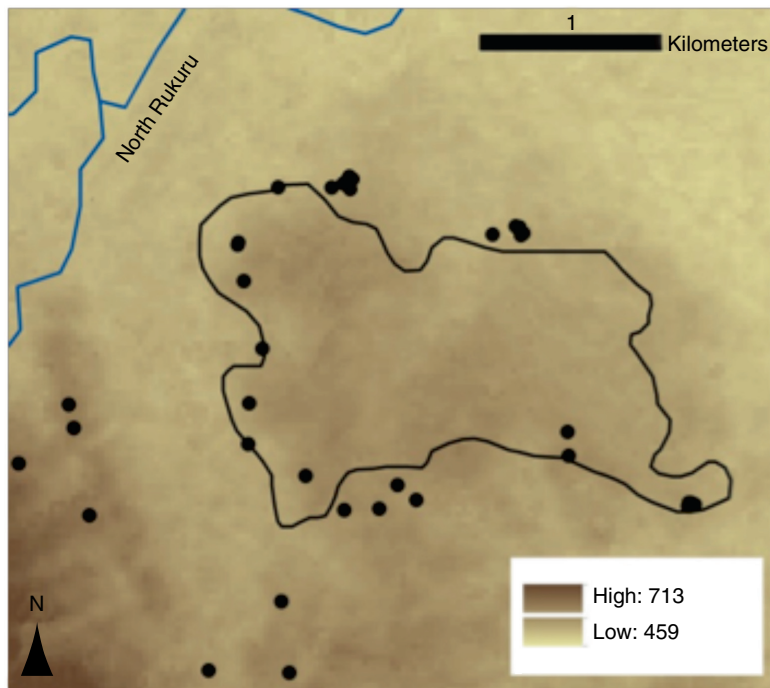


Figure 2. Distribution of MEMSAP excavations approximately 5km west of Karonga town showing how sites (black dots) are positioned along the shoulders of mapped Chitimwe Beds (black lines). Topographic data (dark brown is high, lighter colours are lower) were from ASTER GDEM, a product of METI and NASA.

occasionally diagnostic Later Stone Age (LSA) artefacts. The only material that is diagnostic of the Earlier Stone Age, including Acheulean-type handaxes, derives from Chitimwe deposits approximately 7km south of the town of Karonga, in a different exposure. This confirms Clark's original observations about the basic Chitimwe cultural sequence, including his observation that diagnostic Earlier Stone Age material is likely limited to southern Chitimwe surfaces [44]. Although artefacts occur quite commonly and away from 'islands', of Chitimwe Beds, such finds lie on top of deflated or winnowed surfaces or mixed with colluvial sheets that blanket older bedrock exposures. On the 'islands' themselves that have been the focus of MEMSAP excavations, intact alluvial deposits greater than 3m thick contain abundant buried artefacts. These valuable deposits are constantly being exposed by new housing developments and natural erosion.

3. Approach

3.1. Primary data acquisition

Survey was conducted with two main goals. The primary goal was to identify localities for further investigation. Such sites should either have evidence of buried, in situ Stone Age artefacts (to elucidate the cultural sequence), or they should be sites that sample different

depositional contexts in the study area (to elucidate the geologic sequence). A secondary goal was to search for the locations of excavations from the 1960s and 1970s. The survey method adopted was neither random nor systematic. It targeted paths that followed the contours of the landscape, or which were aimed at exploring likely regions described in written accounts [44]. Survey was conducted using a hand-held GPS, and sites identified for further investigation were revisited with an Ashtech Promark100 and later a Promark800 DGPS to obtain more precise locational data. DGPS elevations were based on a local elevation beacon to provide land survey-based MASL.

Two sites originally excavated by Clark and colleagues were subjected to renewed investigation: Chaminade IA and Mwanganda's Village. The latter site will be discussed as a case study below. Excavation proceeded using hand tools in 1m squares and by natural stratigraphy. Where natural units were thick and homogenous, excavation contexts were further subdivided into arbitrary spits. Spit thickness depended on the goals of the specific excavation and the abundance of finds. Square corners were based on UTM Zone 36L coordinates with WGS84 as the datum. All sediments were sieved through a 5mm mesh, with at minimum a 20% sample wet-sieved to provide a control sequence. A sediment sample was taken from each excavation context, and additional samples were collected from the final profiles for optically stimulated luminescence (OSL) dating, particle size analysis, and pollen and phytolith extraction.

All samples, sedimentary contexts, and artefacts identified in situ were piece-plotted with a Nikon Nivo C-series 5" total station running Survey Pro software [46]. Orientations were taken on artefacts with a long axis to determine the nature of any postdepositional movement [47]. Attributes of the points were joined to their x, y, z coordinates during data acquisition using customised drop-down menus in Survey Pro. In addition to total station point data, all context data (including sedimentary attributes, photographs, disturbances, and elevations) were recorded on standardised project forms for which there are both paper and digital copies stored in Microsoft Access.

3.2. Data manipulation and storage

Following protocols similar to those used by Marean [48], daily total station point files were checked, viewed, and uploaded into ESRI ArcGIS. Daily checking allowed the identification of incongruent data in near-real-time, so that issues could be resolved quickly and the next day's data acquisition informed by results of previous work. Visualisation in the 3D platform of ArcScene was particularly useful in identifying height errors, understanding the relationships of different excavation areas, and

moving towards a virtual site reconstruction. Detailed topographic site maps were created using points acquired by both total station and DGPS. Within excavation areas, raster layers were interpolated for the tops and bottoms of excavated sedimentary units using the kriging function in ArcGIS. These were converted into TIN surfaces, and used to create multipatch files with a polygon representing the excavation area boundaries used to define the horizontal limits. Thus, point data could be viewed and analysed in ArcScene relative to multipatches representing sedimentary volumes. All spatial and context data were stored in an Access database as well as in the GIS.

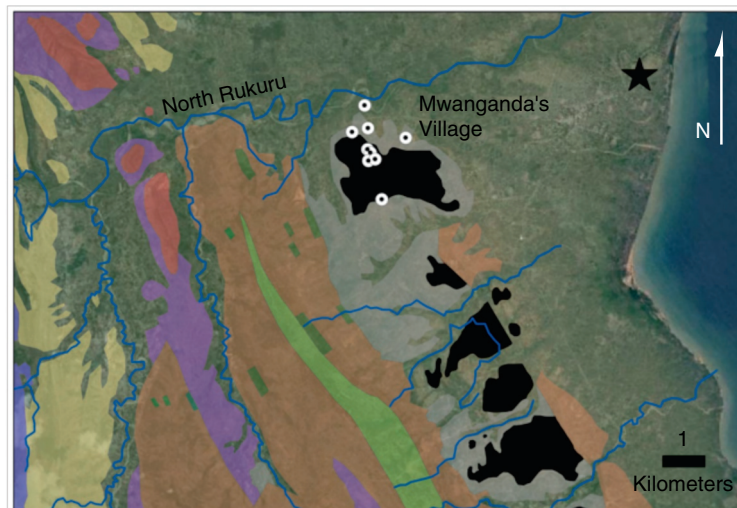
The majority of J.D. Clark's collections and notes are accessioned at the Stone Age Institute in Bloomington, Indiana. However, many of the original field notes from Malawi had been removed from that collection prior to their accessioning. Without the notes available, the specifics of Clark's excavations had to be reconstructed mainly from published accounts [6, 44]. The layout of excavations was gleaned from site descriptions, drawn profiles, and photographs of the original work. These were converted into the metric system and drawn into ArcGIS. Site plans were then clipped from the original papers, georectified into the GIS, and the positions of the artefacts and fossils digitised to examine the spatial relationship between the originally-recovered materials and those recovered during excavations by MEMSAP.

3.3. Integration of regional data from secondary sources

Spatial data acquired directly by MEMSAP were integrated into a GIS populated by secondary-source data on a regional scale. The ASTER global digital elevation map (GDEM) version 2 was used as a topographic base map. Screen shots were taken of Google Earth satellite imagery (the most recent pass of the study area was 26 October 2012) and georectified in ArcGIS, with close-ups of key sites. Geological maps from 1976 at 1:100,000 scale were obtained from the national Malawi Department of Geological Survey. These were digitised into the GIS, along with the river networks illustrated on them. The much coarser-scale maps published by Dixey [42] and Stephens [36] were also digitised.

Several original topographic maps were obtained from A. Cohen of the University of Arizona, which were hand-annotated by C.V. Haynes, the geoarchaeologist of Clark's research team. These were scanned at high resolution, georeferenced, and digitised, with sites identified on these maps entered into the GIS as point files (Figure 3). The majority of maps used either a geographic coordinate system or a UTM system based on the ARC 1950 datum, and were thus converted into the same system used by MEMSAP for excavation (e.g. UTM Zone 36L, WGS84). Other regional-scale data have also been captured and

Figure 3. The main study area near the town of Karonga (star) showing integrated regional spatial data from both modern and unpublished archive sources. Coloured polygons are different geologies with solid black being Chitimwe Beds. White circles with black dots represent a 150m buffer around sites (to compensate for coarse resolution) that were hand-annotated as being excavated by Clark in the 1960s.



included in the GIS, but are not relevant to the current paper. These include vegetation, soils, precipitation, lake bathymetry, and updated river networks and their catchments

4. Mwanganda's Village Site

4.1. Previous excavations

The Mwanganda's Village site is located on a sedimentary package grading down from south to north until being dissected by the modern-day Chirambiru Creek. Currently, much of the area is under cultivation and subject to intensive village occupation, including deep-pit latrine digging by the villagers. The site of interest was excavated by Clark and Haynes in 1965/1966 [6, 44]. They reported the recovery of a fossil elephant skeleton in association with stone artefacts, many of which had affinities with the 'Sangoan' industry. Thus, the site was determined to be an elephant butchery site dating to the earlier part of the MSA, and has been cited as evidence of early MSA megafaunal hunting dating to nearly 300 ka [49–53].

The majority of artefacts and the elephant fossils were recovered from an excavated area measuring approximately 11 × 12 m and named "Area 1". They were described as being embedded in a palaeosol formed at the contact between Chitimwe and Chiwondo Beds. A trench connected this area to a second large excavation approximately 5m to the south named "Area 2". From there a small number of additional fossils were recovered.

The Mwanganda's Village site was later re-examined by Kaufulu in the 1970s, to provide further understanding of site formation processes

[8, 45]. Description of the sedimentology of the site was based on a series of geological trenches emplaced around the elephant location and adjacent to Clark and Haynes' "Area 1". His work describes the primary focus of hominin activities as occurring near a stream that caused some local reworking of artefacts. However, overall it was interpreted that artefacts and fossils recovered from archaeological excavations were close to their primary depositional contexts [8, 45].

4.2. MEMSAP excavations

The first MEMSAP test excavations took place in 2010, with three small test pits totalling 4 m² [54]. In 2011, thirteen geological trenches approximately 1 × 2 m each were excavated across the site to document the stratigraphy [55]. In 2011 and 2012 three main areas were subjected to controlled excavation by MEMSAP. These are differentiated from the original Clark and Haynes [6] excavations by use of a roman numeral. Area I refers to a 5 × 5 m block emplaced in the deposits upslope and approximately 60m to the south of the 'elephant butchery site'; Area II was a 2 × 3 m block approximately 3 m south of Clark's own Area 2; and Area III was a 4 × 6m block in the intact deposits under and to the west of the backdirt from Kaufulu's [8] 'Trench 1' (Figure 4).

The Area I excavation revealed a terminal MSA lithic assemblage buried under approximately 1 – 1.5 m of overburden [56]. Many of the local stratigraphic units described by Clark and Haynes [6] and Kaufulu [8] were absent (including the artefact- and fossil-bearing palaeosol),

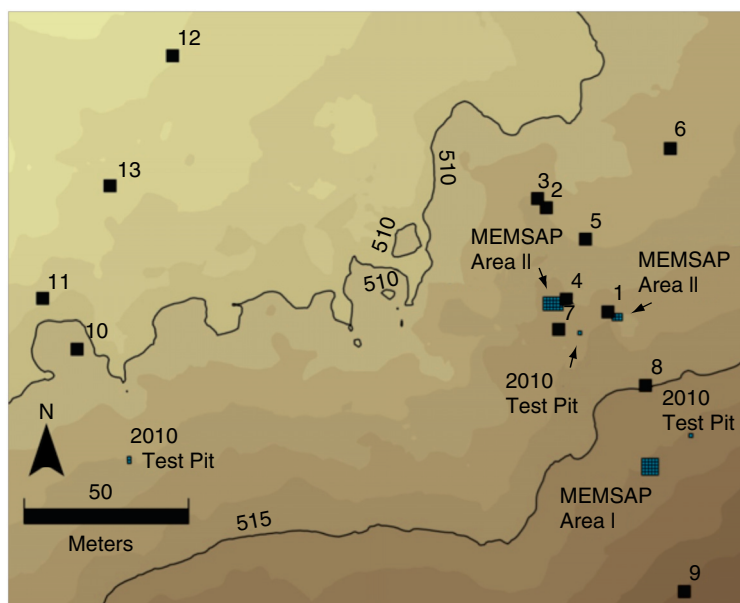


Figure 4. Map of the Mwanganda's Village site showing the basic topography and new MEMSAP excavations (blue squares). Numbered squares are MEMSAP geological trenches. Darker areas are topographically higher and contour lines are every 5m.

although the sterile basal stratigraphy described as being part of the Chiwondo Beds correlates across the 60m that separates it from Area I. At MEMSAP excavation Areas II and III, rare faunal material and lithic tools were recovered near the modern ground surface, closer to the reported elephant butchery location. These were likely associated with the originally reported archaeological finds [6].

4.3. Linking old and new data

The first challenge of linking old and new datasets lay in relocating the precise boundaries of the original excavations. We were first shown the Mwanganda's Village excavations by H. Simfukwe from the Malawi Department of Antiquities. The original excavations were not backfilled, and so today they appear on the landscape as muted depressions surrounded by low rises of backdirt. This made the exact edges of the previous excavations difficult to identify, although their bases were apparent from the exposed cracking clay typical of the lowermost stratigraphic unit (Clark and Haynes's 'Qco_{1a}' and Kaufulu's 'Unit 2 - Greenish/brownish gray sandy claystone') [6, 8]. Occasional scatters of pebbles and abraded artefacts near the edges of the depressions were interpreted as the remnants of collapsed baulks that had been capped with a lag deposit that covers much of the site today (Clark and Haynes's 'Q_k' and Kaufulu's 'Unit 8 - Stony soil).'

Detailed topographic maps using total station and DGPS data clearly showed the depressions left by the investigations from the 1960s and 1970s (Figure 5a). However, the modern surface topography did not match their published layout [8, 45]. Thus, GIS was essential in reconstructing the relationship of the old sites to new MEMSAP excavations. Kaufulu's [8] Figure 5 shows his trenches adjacent to the Clark and Haynes Area 1 and running mainly east-west, with his 'Trench 3' extending at a right angle to the south. However, our field observations and topographic data suggested that Kaufulu's trenches were rotated 90° to run north-south rather than east-west, with 'Trench 3' actually extending to the west rather than the south (Figure 5b). With the trenches (or rather, the north arrow on Kaufulu's [8] Figure 5) rotated, their configuration matches the field observations.

However, our topographic data and observations of the cracking clay in the area immediately north of Kaufulu's trenches showed that an excavation had also been conducted there. Study of the photographs and site plans from Clark and Haynes [6] allowed the approximate dimensions and layout of the original excavations to be reconstructed, including both Areas 1 and 2. This was necessary because although a plan with annotated dimensions was drawn of the elephant site itself (Clark and Haynes's Area 1), the photographs clearly showed extensions to the main excavation, as well as the

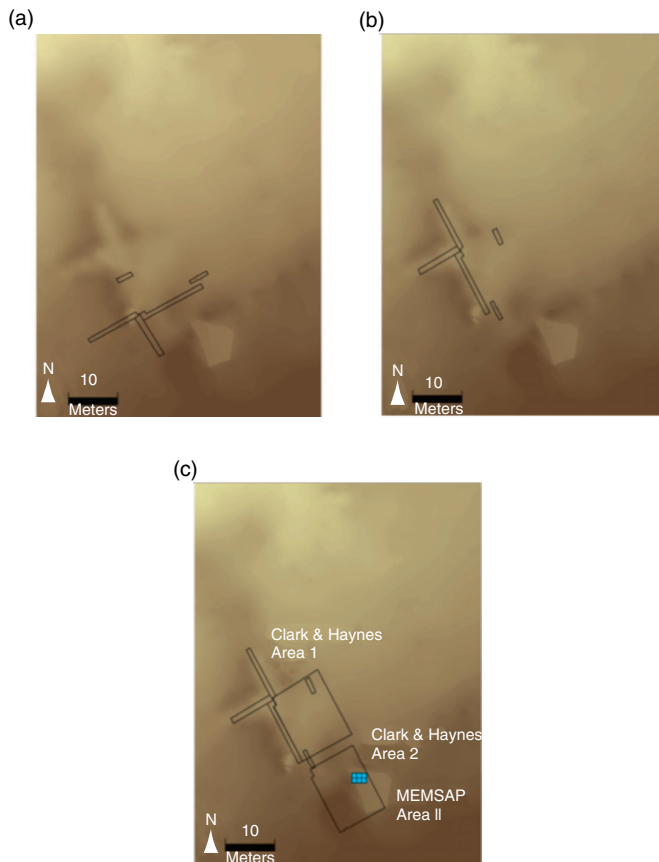


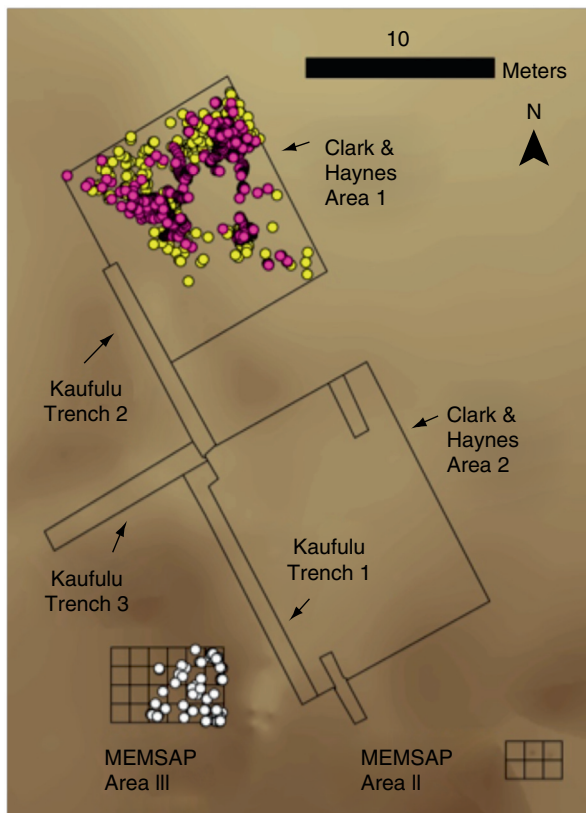
Figure 5. (a) Modern topography at and immediately around the elephant site with the published configuration of Kaufulu's trenches; (b) Superimposed plan of Kaufulu's (1983, 1990) trenches, rotated 90°; (c) Superimposed reconstruction of the Clark and Haynes (1970) excavations, with Kaufulu's trenches located at Area 1 and the MEMSAP Area II excavations indicated in blue.

trench leading to Area 2, that were not described in detail in any of the published work [6, 44].

If Kaufulu had placed his trenches adjacent to Clark and Haynes's Area 1, then the northern edge of Area 2 should lie approximately 5 m south of the southern edge of Area 1. This was tested by using GIS to superimpose the reconstructed Clark and Haynes excavation layout upon the topographic map and compare it against our own 'Area II' excavations in the same place (Figure 5c). Because our excavations had a final profile showing they had been placed within intact sediments, it would have been impossible for them to have been placed within the original 'Area 2' excavation by Clark and Haynes [6]. Therefore, all these lines of evidence - sedimentary, topographic, and subsurface - indicate that the most parsimonious interpretation for the locus of the original elephant site is as shown in Figure 6, approximately 25m northeast of where Kaufulu had identified it.

With the original elephant site location identified, a georectified site plan from Clark and Haynes [6] provided the basis for digitising the placement of the artefacts and fossils recovered during their

Figure 6. Position of the original elephant site relative to MEMSAP excavation Areas II and III. The distribution of the fossils (purple) and artefacts (yellow) was digitised from the original site plan by Clark and Haynes (1970), and the distribution of plotted finds in the MEMSAP excavations (white) represents all finds mapped using total station that were from the same stratigraphic layer as that reported for the elephant.



excavations. Data from MEMSAP's Area II and Area III provided the spatial distributions of plotted finds from new excavations. Thus, the two datasets could be linked on the horizontal plane within the GIS (Figure 6). The vertical plane was more challenging, and relied on stratigraphic correlations based on field observations of new excavations and sediment descriptions from Clark and Haynes [6] and Kaufulu [8, 45]. However, when considered together, the revised maps show only a sparse concentration of bones and artefacts near the palaeochannel reconstructed by Kaufulu and little sediment remaining near the original elephant location. The spatial data therefore suggest that the interpretation of the elephant site as being accumulated by hominins on the banks of a palaeochannel should be revisited, and perhaps reconsidered in light of current geologic data [55].

4.4. 3D GIS, sediment volumes, and plotted finds visualisation

At the scale of the single excavation block, 3D GIS was a useful tool for virtual reconstruction of sediment volumes. The MEMSAP Area I reconstruction clearly shows the relative thicknesses and slopes of the

sedimentary units, which can be made transparent in order to better display plotted artefacts (Figure 7a). 3D points within the sediment volumes can be randomly generated to represent sieved finds, which gives a greater sense of the numbers of artefacts recovered from each square. However, in thick layers with an uneven vertical distribution of finds and relatively coarse spit thicknesses - as was the case at Area I - this can be misleading because it obscures where the true concentrations of artefacts are.

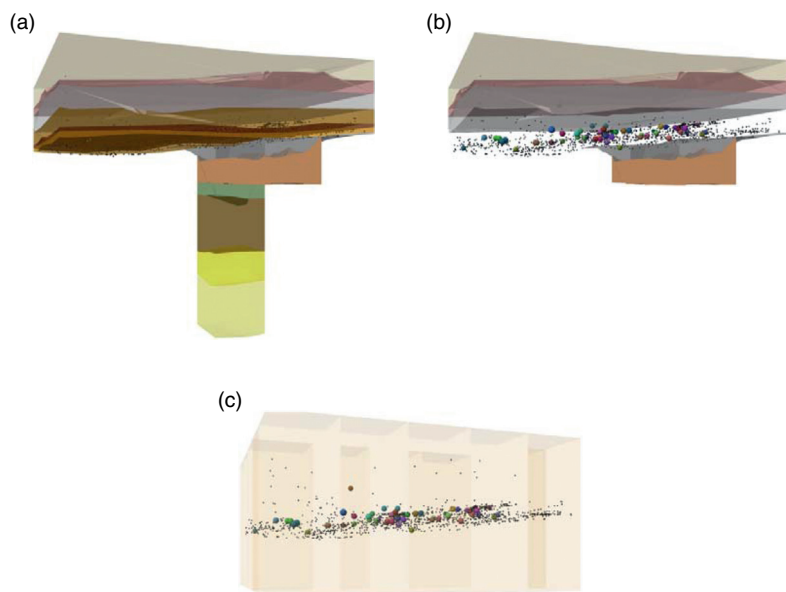
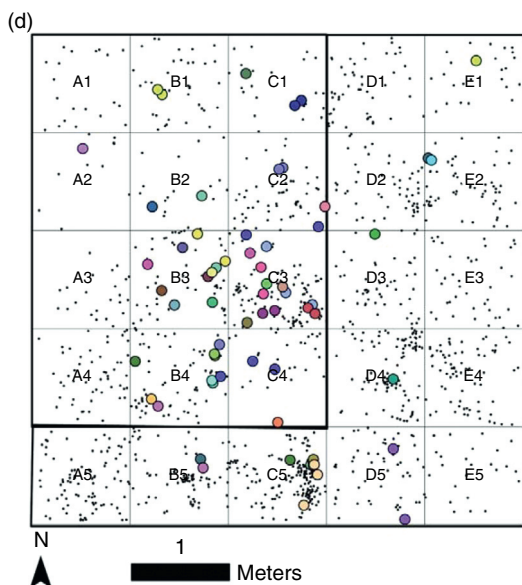


Figure 7. 3D GIS reconstruction of the stratigraphy at MEMSAP Area I using multipatch feature types, with plotted finds indicated as small black dots or as coloured spheres if they conjoin to other finds. (a) All excavated stratigraphy with 50% transparency; (b) The three main artefact-bearing stratigraphic layers turned off to better illustrate the distribution of the plotted finds; (c) Only plotted finds shown with square boundaries represented as extruded polygons; and (d) 2D plan view with the plotted finds. View in 3D images is southeast and scale is a 5 x 5m excavation.



At Area I, where most artefacts were found within approximately 10 cm of the cobble layer (the thin dark brown layer in Figure 7a), the 3D GIS was instead more useful when only plotted finds were considered. The concentration of such artefacts in the southeastern corner of the 2011 excavations (indicated as the upper left area outlined in bold in Figure 7d) guided the decision to expand the excavations in that direction during the 2012 excavations. This was highly productive, as conjoining artefacts showed that the majority of in situ spatial behaviour occurred near the centre of the excavation. In conjunction with the 3D GIS it became apparent that most conjoins occurred within a limited vertical zone, which added further support to the inference that most knapping behaviour occurred on the sediments immediately above the cobble layer, and the artefact concentrations there were not simply the result of post-depositional vertical movement. Future work at the site will exploit the flexibility of the GIS to analyse the distribution of raw materials, technological classes, artefact orientations, and artefact sizes to examine both human behaviour and post-depositional processes.

5. Conclusion

Regional-scale GIS interpretation of survey and test pit data has shown that in the area immediately around Karonga, valuable stratified and in situ sites are limited to an ever-shrinking 'island' of Chitimwe Beds. GIS also illustrates this erosion at the site scale, where the Mwanganda site is currently located in an area with increasing intensity of human occupation, and where natural- and human-induced erosion threatens the integrity of remaining intact deposits. By linking old data from the 1960s and 1970s with new data acquired over the last five years, we hope to maximise the information that can be applied from a limited number of archival and published sources. This will facilitate both research and heritage management in the area.

GIS was also used at the site scale to produce predictions about the original excavation locations and layouts. At Mwanganda's Village it was an essential part of the revision of published maps, which in turn demands revision of some key site interpretations. GIS was applied to new MEMSAP excavations to address questions about depositional processes that were used to guide new excavations in near-real-time. This case study illustrates the practical utility of GIS as an active companion to archaeological fieldwork. Within MEMSAP it has been used to bring together diverse datasets in a flexible digital format that can be interrogated recursively during field seasons and which has also been essential in post-excavation site interpretation.

Previously reported applications of GIS in central Africa have been mainly at a larger scale, for example site predictive modelling [57] or examination of settlement patterns [58]. Its most common application

remains as a simple map-making tool [59], in spite of a recommendation by McIntosh [60] in 1993 that an essential part of archaeological heritage management in Africa should include the training of African-based researchers in technologies such as GIS. Within Malawi MEMSAP is the first project to rely upon this technology in the documentation and interpretation of the country's archaeological record. This work brings new meaning to pioneering work in Karonga, integrating it into a larger picture of the range of human adaptation during the MSA of central Africa and providing a template for future research in the area.

6. Acknowledgement

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